Power System Operations and Control
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Module – 3
Lecture – 5
Frequency and Voltage Control

Welcome to lecture number 5 of module 3. In previous lectures, we modeled governor model turbine, model generator, model load, and we saw that is the, if you are going to load the change, in any of the system then frequency is changed and that is a steady state frequency error exists. So, we use that is the secondary ALFC control and then; we found that here we reduce the frequency errors of the system.

In whole analysis, we visualize that there is only 1 generator having, it is doping characteristic r and the damping of the system is d. That is load variation constant without change to the frequency. Let us take, if there are various generators of course, it is very much real that the power system, in one of the area there will be several generators and they will be having the different regulation characteristic. That is r and also of that system will be 1. So, if we are having various generators….

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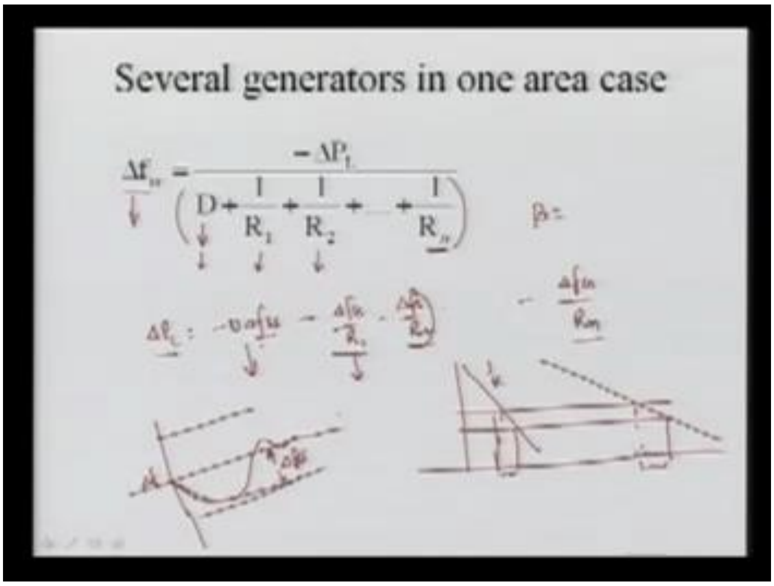

Let us suppose, we are having n number of generators in power system in that one area. Then change in the frequency error that is del FSS means; a steady state error, will be here your minus. That is change in the load, in that area divided by D. That is the coefficient which relates your frequency change, with respect to the load change and R1 and R2 are the characteristic of the individual generator. So, here now, the B of the system that is beta which, I was using now it will be.

So, the load change here this D will while we go for writing this Pl will be nothing, but, your minus D change in your FSS here, minus I can say change in your FSS upon R1 minus change in your FSS upon R2 and so on, so far minus change in your FSS upon r 2. So, this is your load release due to the frequency change, because if frequency is reduced what will happen. This is negative. Then some load will be released from the system and that load change.

That is sudden change will be and this load will be met, by this component and the remaining part you can say this generator will share the load according to this regulation constant here this R2 and this R1. Already in the previous lectures, I explained that if you are going for this and here for example, if the characteristic 1 is having lower slope and another is having this slope here. And then this is your steady state frequency that is where the system is operating and this is where the loading.

Now, if there is a sudden increase, in the loading what will happen your frequency will fall and the load sharing will be now, this much. So, the change in the loading for this and this will be different and again it depends upon this R. That is the slope of this curve that is r here 1 upon R. So, we can see which is having this slope here is lower and then we are having less generation. Here you can see r is more, what will happen. This component will be less here if R, will be less then this component will be more and they are so on, so forth.

So, here the in the power system there are various generators of different R1 R2 are there. So, we can relate the change in the frequency will be there. Then, we realized that we do not want that because, if the frequency changes here if means; if load is increased suddenly what is let us suppose, your load is increased here your frequency is a going and settling here to certain value.

We do not want this error and that is why we use some integral controller and that is we want it that this change should come here and finally, settle to the 0 means; change in your frequency must be 0 means; we must operate our power system to the normal value.

And this rated value that is your frequency that is 50 hertz in our case. Now, let us move even in the previous lectures just, I was giving the concept of the control area.

Normally the areas are connected to each other and the major region and these areas are connected with the transmission line and that is called as the tie line.

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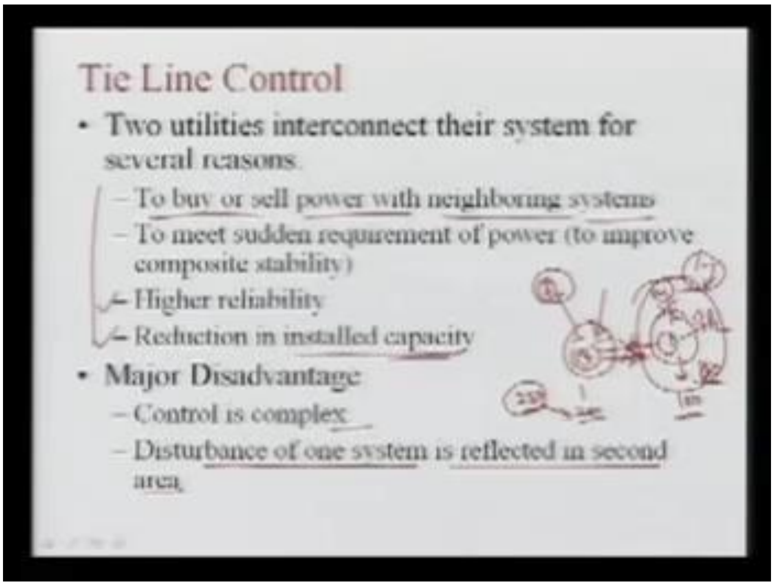

So, the tie line control is basically used and it is connected between the 2 utilities for the several regions several advantages. The first 1 is that over that tie line the utilities can buy and sell power from the nearing region. For example, let us suppose you are having 1 region here. This area is 1 and this is the tie line here. There is a possibility another region here and it has a tie line connection here so, this region 1, by the power from the area this region r area 3 over these ties lines.

So, these tie lines are used to buy or sell, it can also sell power to these areas and again through this tie lines control. So, that is why I have written here that to buy or sell power with the neighboring systems. Another advantage to have tie line control is to meet sudden requirement of power means; if there is a sudden load increase here let us suppose, change in the load here in this area; what will happen. This load will be met by the generators who are acting here, in this area as well as the generators here; they will try to supply over this tie line.

So, the to meet the sudden requirement of the power is accomplished, with help of the tie line control and overall it improves the composite stability of the system means; all the system is stable more stable than not having this tie line control. So, it also improves the reliability. For example let us suppose 1 generator has means; this generator is straight. So, there is a sudden crisis of load generation, in this area and then we can ask if generators here there are in surplus.

They can provide power and then we can meet with the reliability of the system and also it reduces the installed capacity. As we know, this is 1 of the advantages of inter connection of the system that, with the help of interconnections we can reduce this installed capacity or we can reduce the result margin to understand this. Let us suppose, we have here the capacity of total load here; let us suppose 100 mega watts. This area we are having 200 mega watts.

Now, to meet this demand you must have here installed capacity more than that and let us suppose, it is 150 mega watts. Similarly, if it is not connected here with this 1 we require here at least 250 mega watts here, as well because if there is sudden variation here and there we must able to avoid that load here. So, this is your loading and then we require here the 250 mega watt of generation. So, the required capacity or installed capacity of this 1 system here is 150.

Here is a 250 for this, but, if you are going for the inter connections then; what we can do. We can have only hundred here and the 250 here. So, what we are doing, we are reducing the reserve margin or we can say we have reduced the installed capacity of the system. That is earlier it was 150 plus 250. It was 5 neither 400. Now, it is only your 350. So, it says that if you are going for the interconnection this is tie line is nothing but, the interconnection of 2 areas and then; we can reduce the installed capacity but, it has some inherent problems.

First is the control becomes complex, because earlier we were only controlling the generators here, in this area and it was independent control but, with help of the tie line connections we have to also see the control actions of this 1. So, now the composite control action becomes complex and we have to have very good control of and also, it is not possible to have the manual. We should have the good automatic control but, the control must will be complex afterwards. Another major reason major problem, in this tie line control are the interconnection is that this disturbance occurs, in this area.

Let us suppose there is some fault, if we are not controlling this fault in the very less time what will happen. This fault will be reflected, in this system as well. If the generators keep on oscillating there is some disturbance here. This area will be also affected. For example: we can see in our Indian system, in the northern regional electricity board system that is we have the several states like: UP your Rajasthan, Punjab, Hariyana, Himachal Pradesh, Jammu and Srinagar and Uttaranchal of course, Delhi is also in that.

So, if there is a fault in 1 of the lines in any of state almost whole state this all this region are getting disturbed and sometime, you will fear and you will listen that this line causes the whole northern area in the black out. So, it is always very much true that the disturbance of 1 system is reflected in other system if it is not there. So, it will be not reflected only 1 area will be affected. So, this is 1 of the you can say major disadvantages of tie line, but, although we are having very fast and very reliable controllers they can take here if 1 line is stripping.

Then we can then; we can save our system and then we can take advantage of other interconnections here that these are the advantages.

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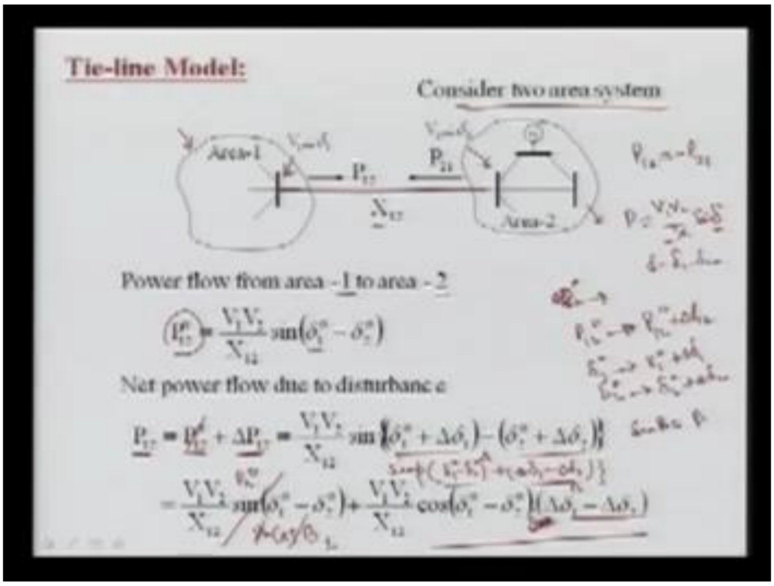

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Now, let us model because, earlier we modeled our the single area system. Now, we are going to model the 2 area system. Here I am considering only the 2 area and similarly, we can have the other areas as well. So, here this is area 1 and this is your area 2. These 2 areas are connected by a tie line here having reactance X12 and the voltage where they are connected here it is your V1 angle delta 1.This V1 is magnitude of this angle is delta with reference to some reference bus.

Here the of this bus is nothing but, it is V2 delta 2 and the power which is flowing from area 1 to 2 it is denoted as 1 2 means 1 from 2 from 1 to 2 here. Similarly, if power is flowing here then I can say it is 2 to 1. So, basically this is P12. It is nothing but, minus P21 because only the direction has changed. So, let us model this 1 using this tie line equation. So, we can write the power flow equation from area 1 to 2 when there is no disturbance in a steady state condition. So, I have written the P12 naught means; there is no disturbance.

So, power will be flowing with this equation we know it very well. This equation you must know this p is your V1 upon s sine delta. So, delta is nothing but, the angle difference between these 2 buses means; from higher bus to lower bus from angle this we are assuming this power is flowing from bus 1 to 2. So, it is your delta here. It is nothing but, your delta 1 minus delta 2. So, here we have written and V1 V2 are the voltages respective voltage x is the reactance of that line where these 2 buses are connected.

So, this is the V1 V2 upon s 1 2 sine delta 1 naught minus delta 2 naught why, I am writing naught, because we are talking about the steady state. There is no disturbance. So, this is the initial angle of these buses. Now, let us see there is some disturbance in any of the area and the power which is earlier flowing here this P12 naught now, it is changed sorry. It was P12 naught. Now, it has changed. It is your P12 naught plus some change in P12 due to the disturbance in any of the areas either 1 or 2.

So, I can write now the net power flow from area 1 to 2 it is your steady state value plus some change again; it depends this value is positive or negative it all depends that is where the disturbance where the demand is more. So, power can go this side or that side. So, this value may be negative or positive accordingly. So, we can write here what we are assuming the assumption is that volt is magnitudes of the system are a constant. So, we are assuming the V1 V2 are constants although this assumption is not very much valid, but, normally the power flow is the real power is changing flow. The voltage are constant and the angles are changing very much.

So, we have taken this V1 V2 are constant of course, the line reactance will be constant. It will be not changed. We are assuming again the frequency this x is of course, if the system frequency will be changed, this x will be also changed but, here that variation we can take the same value. Now, sine this angle here as was the delta 1 naught. Now, it is changed to basically, I can say delta 1 naught will be changed to your delta 1 naught plus some delta angle here 1 and similarly, your delta 2 naught will be changed to delta 2 naught plus change in delta 2.

So, just I have replaced these 2 angle from here and with the same condition. Now, we can simplify this means; I want to write what we can write here. This component we can write the sine. Now, here delta 1 naught minus delta 2 naught in 1 bracket plus change in delta 1 minus change in delta 2 in 1 bracket and here it is this. So, now we can expand this. This is your sine. So, I can say sine a plus b. So, what we can write we can expand this. So, V1 V2 upon X12 is the common.

So, if you are taking here the sine a into cos b. So, here the sine you can say this is your angle a this is angle your b. So, the sine a I have written here delta 1 naught minus delta 2 into here there is another term the cosine of b. Now, what will be the cosine of b you can see this is the multiplication of this term. It is nothing, but, the cos beta is change in delta 1 minus delta 2. We know that already change in the delta 1 is very small value and again we are subtracting the change in the delta 2.

So, this value is very small and you know the cosine is angel is very close to 0, we can take as unity. So, we have replaced here as unity. So, that is why that term is not reappearing and that has disappeared another term here now we can write again this V1 V2 X2 this component will be there into the cosine a here cosine a I have written delta 1 naught minus delta 2 naught multiplication of here this is your sine b and we know that again this angle is very small.

So, I can write here sine beta will be equal to beta it is value in the radian. So, this sine has disappeared with the unity and we have taken this sine. Now, what is this you can see from here this is nothing, but, it is your P12 naught. So, from this equation and this equation now, we can write the change in the power.

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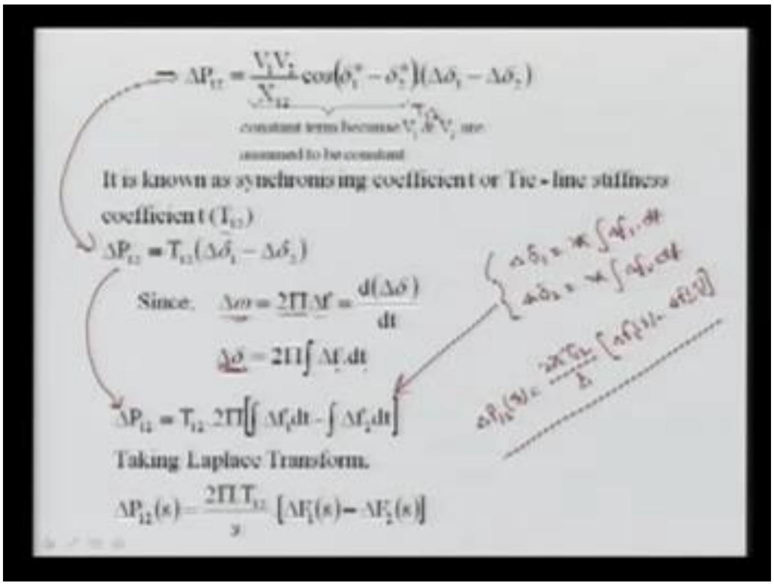

That is the P12 will be your second term you can see here. Here this is your P12 here p 1 tow naught is there P12 naught is canceled from here to here and we are getting this is equal to this component only and that is written here means; the change in power from area 1 to 2 is equal to V1 V2 upon X12 cosine of angle delta 1 naught minus angle 2 delta multiplication of the change in angle 1 means; change in angle of bus 1 in area 1 minus change in angle of bus 2 in area 2 this coefficient as you know, in a steady state delta 1 and delta 2 naught are constant V 1 and V2 are also assumed to be constant and s 1 2 of course, constant.

So, this component is completely constant and we can say we can on this is equal to your T12 and this is known as synchronizing coefficient or tie line is difference coefficient that is t 1 2. So, this equation can be written here again that is P12 is equal to T12 change in your angle 1 minus your change in angle 2 change in angle 2 here. Now, we want that angle relation, with change of the frequency, because your final term that is coming your frequency that frequency is related to you are the characteristics of your generators and also your D is related with the frequency.

So, we can write here a change in the frequency it is nothing but, your 2 pi and delta f is nothing, but, I can write here. This change in this frequency is your D upon D t change in delta. So, that this delta we can write here this is value of this delta and we can write here, this 2 pi integration of delta f into t and similarly, if you can put here 1 then it is f 1.

Here 2 is F2 means; the 2 areas if during the disturbance. They will have the different frequencies F1 and F2 then what will be the power flow of course, if they are connected in a steady state the frequency of these 2 areas will be equal.

So, without any problem we can equate the F1 change in F1 will be equal to F2 in a steady state 1 during the disturbance the frequency of this system will be different, because during the transition period for certain duration. So, I can write here your this change in delta 1 is nothing but, your 2 pi change in delta F1 into D t. Similarly, I can write the change in delta 2 is your 2 pi here change in F2 that is change in frequency of area 2 with the D t.

So, we can take Laplace transform or you can hear we had put this value here in this equation from here, we can get this 1 using these 2 equations from these 2 equations here we can get this. Now, if you were taking the Laplace transform here we can get simply this is integration. So, it will 1 upon s. So, we can get the change in here means we can get I will write. This P12 s will be equal to twice pi or T12 that is your tile line stiffness coefficient divided by s because, the s will be common here integration in both and I can write change in your F1 s minus change in your F2 s.

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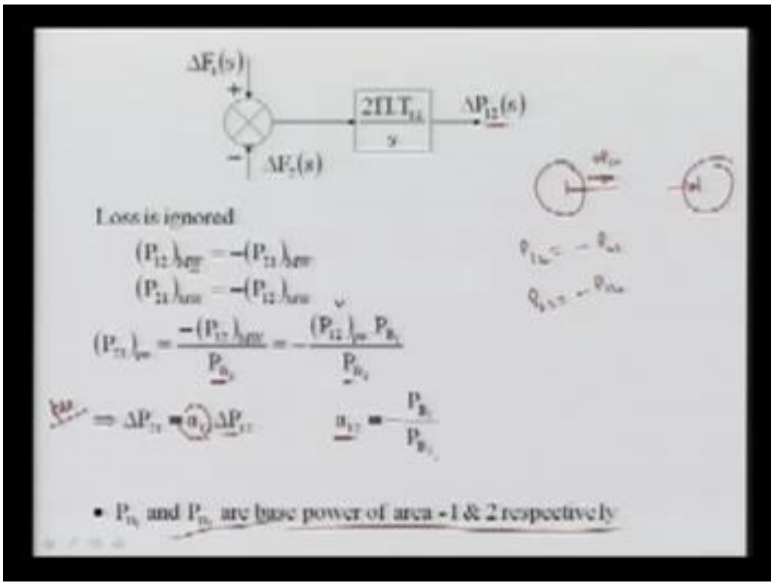

So, these are your tie line model and let us see how these are related and how we can model this again so, this whole concept this change in F1 minus F2 that is multiplied by this coefficient. If you remember 2 pi into T12 upon s that gives change in your tie line power more. Now, we know it very well that the power which is coming from area 1 here. Let us suppose, you have assumed that power is here going change in 1 to it is coming out from this.

So, this power basically in area 2 it is going to be here that that is a. So, here if it is negative here it is a negative but, these 2 areas may have the different rating different base values. So, we have to write if complete the boxes or block diagram in the per unit system let us see how we can relate it. So, we know that this P12 that is in mega watt I am talking here why I have written that is written actual value. So, the P12 that is the power flowing from 1 to 2 will be every time will be equal to the negative of area that is power flowing from 2 to 1.

So, in the notation here I can say this P12 will be equal to minus P21 we k now it very well. Here I can also write this P21 will be nothing but, your minus P12 in mega watt. Now, if you want to write this P21 per unit. So, we have to divide the base of the area too and the base of area 2 is here. Let us suppose p B2 here. So, this divided by this value we can also write in the per unit of that area that is area number 1. So, in area number 1 I can write here this value, we can represent this P12 per unit multiplied by base of that area than it is actual value divided by base of area 2. .

So, here now in per unit I can write now, this it is in p u this whole derivation p u is removed means; p u value just we are writing means change in P21 is equal to some constant here a 1 2 multiplied by change in area P12 and this a 1 2 is nothing, but, minus here that is p B1 upon p b 2. So, here it is nothing, but, this is a coefficient that is relates the base of a divided by base 2 and again with the negative sign. So, here I have written this base power of area 1 and 2.

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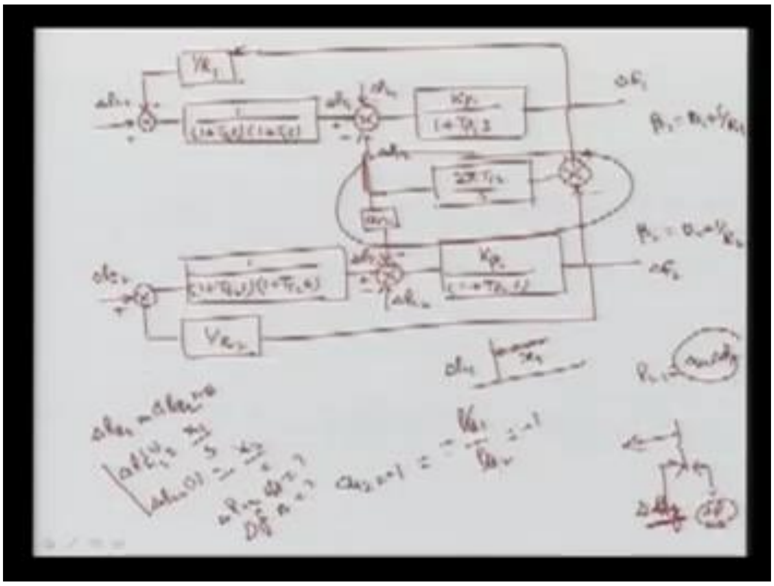

Now, let us combine this with our actual modeling that we have already done and we know that if we are having the single area. Now, I am going to write here if you remember this is your area 1. that is we had here we had this your change in p c here plus 2. Here we had the negative and this value we were getting this your 1 upon r 1. Now, why I am writing R1 because this R1 is related and I am talking this R1 is the combined effect of all the generators in that area.

Here that is going to be your governor and turbine constant that is I can write 1 over 1 plus TGS and here for the turbine 1 plus TTS here. This is giving your mechanical power. Here the gain it unity as I said the k g multiplied by k t normally set to unity. So, I have taken 1 this is coming your nothing, but, your P turbine power and this turbine power here is again that is here plus minus this Pl which is coming here. That is change in the P11 of this area 1 means we can write this is for area 1.

We are writing again this is your minus term again; this power from area 1 it is going. Then it is again here there is sum negative here while loop corresponding to your it is nothing, but, your change in P12 here all the values are in laplace. So, here it is not that the P12 is a s bracket s, but, you have to see this. All these are in the Laplace domain. This value is coming to your model of your power system and I can say here it is a power system 1 which your KPL divided by 1 plus TPL into s means all the here I can write 1 here TTL.

All the value we can write 1 here P12 of course, and here we are getting your change in the frequency of 1 and this is here going to be here. Now, again we have another area. So, similarly, we can write here that is your similar this area 1. Now, we can write for area 2 here this value is coming to your PC changing PC2. Here again I can write 1 because we are writing everything in 1. So, this is your positive this value is coming here that is your combined effect of this dope characteristic of area 2.

Now, again we are having here your governors and turbine modeling and here can, I can say 1 over the TG2; yes it is the governor time constant and here the transfer function for the turbine, I can write that TT2, yes that is coming here your change in PT2 and here I can write this. So, this value here in that area if load is changing this is plus. So, change in P12 and we know that some power is coming from area 1 here that is you can say I will come to that point here, what we are going to write and then this power system model of your area 2.

That is KP2 divided by 1 plus TP2 into s and here that is coming to your change in frequency path and this frequency here we know that of this are is related with the. Now, these 2 areas are connected with tie line and the tie line modeling we saw that F1 here that is coming to be here this is your plus this is your negative. Now, F1 minus F2 that is multiplied by you are here the tie line model that is coming here your 2 pi T12 divided by s.

So, that here is coming out to be it is going to be P12 here sorry and this here is now P21 which is going to be here of course, this is with the negative sign and we are using some coefficient a 12 if you remember. This is nothing, but, here we are again this P12 we are assuming it is going out because P21. If you remember here P21 is the direction which is coming out from the area 2. So, some load change there some generation means generation is here increased. That is your change in the PG here the load is also changed.

So, this is the generation increase this is the load change that is the mechanical power and this is going out. So, this is negative and this P12 is related. This P21 is nothing, but, a 1 2 change in P12. So, here just we have multiplied 1 coefficient. This value is if both areas having the same base what will happen. This a12 will be equal to unity. So, this a12 is here your unity means; minus 1 if you remember. It was the value was here nothing, but, minus PB1 upon PB2 means; the base of area 1 to the base of area 2 with a negative sign if both bases are related at the same base value.

So, here it will be cancelled out and you can get minus 1. So, what will happen this minus here then it is a plus. So, we can visualize here that whatever, the power which is going from area 1 it is going to area 2 and that is related here. So, this is your 2 area system and again here we are having the primary ALFC why primary ALFC. We can see again in the derivation that this case we have connected no doubt to this tie lines here, but, still there will be some frequency error. If level be changed in any 1 of the areas of the load.

So, we will see right now what will be the static performance of the system; what is the improvement what is the advantage we can see just right. Now, and then what we have to do next to reduce this error in this that is the frequency error in this load. Now, here again this value let us suppose, we are taking to 0 means here we are not changing this reference setting means; we can say this is your change in the PC1 is equal to your change in PC2. These are the reference values if they are kept 0 and let us suppose, we are changing the loads that we are changing that is you change in the P11.

It is some value let us suppose, your X1 upon s why I am writing this X1 upon s. We are taking some input response step response means; here in this area here this is your x 1. That is changed suddenly that is your change in P11. So, the P11s Laplace transform it will be X1 upon s. This X1 is. Similarly, I can write this P12s. It is your X2 upon s and then we can analyze we can see, we can say this B1 of this area here it is B1 it is nothing, but, your D1 plus 1 over R1. Here this D2 factor will be for this area it is D2 plus 1 upon R2.

Now, with these changes we are taking the chance in the both area together. So, what will be the change in the tie line power means; we want to calculate this change in P12 steady state and change, in the frequency a steady state we want to calculate. The both areas are interconnected with the some tie line. So, this is your we have included that extra tie line model here and other things here; already we modeled the first area. Then, it is second area similar to that modeling only, with the parameter for different and they are connected by 1 tie line and the tie line model are inserted.

Now, you can say you have a complete composite block. Now, again since here we are assuming that there is no secondary controller there is no secondary area load frequency control automatic load control. So, here they are we are not having any gains and these are 0.

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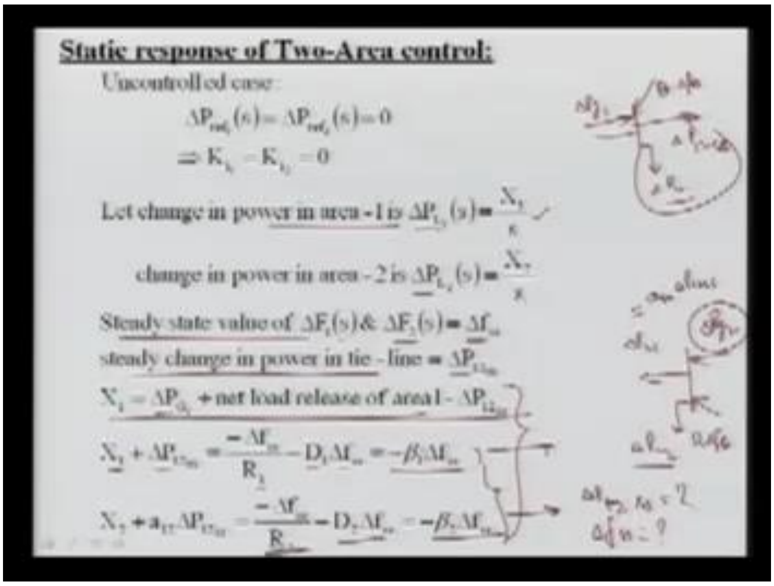

So, now we can define the steady state values and we can derive here already, I explained this means; let change in the area power in area 1 that is change in P11 s it will be X1 upon f. Similarly, for area 2 power change is your X2 upon s. We know that the steady state value of F1 and F2 will be the same; I said in the transient case only the F1 and F2 will the different and that is why there will be change in the tie line power. If the system is in a steady state the frequency of all the interconnected system, which will be the same.

So, here your change in the frequency during a steady state that is SS it is nothing but, it is your constant and that is a fixed for all the regions and also the steady state change in the tie line power will be also it will be constant to understand this 1 approach that we can use as I said the final value theorems means; we can get this change in the frequency error here using the final value theorem or we can simply another approach and here you can see that approach I have discussed here. X1 what is x 1. If X1 is changed in the load in area 1 we know if there will be any change in the load in the area 1.

That will be supplied by the governor by changing the governor action so, this is change in the real power of area 1 and since there is some frequency change. So, there will be some net load released in that area 1. So, here another component minus that is your P12 a steady state value means here from area 1 this value is going out. The value which is change here in the p generation and some load is released if there is sudden change in the p l. So, this p l will be you can say as a sum of the power here these should be plus this.

This is nothing, but, your PG1, here it is your that is the damping coefficient the change in here, I can say net load release. Here D into change in f s and this is your change in your P12 a steady state and this is your change in l. So, these 2 will be equal to the incoming means; algebraic sum of the power at any node will be 0. So, with this equation we can write this it is clear. So, it is X1 equal to your change in PG1 plus net load release of area 1 minus change in the power in a steady state flowing over the tie line; that can again simplified.

So, X1 here we are taking a change in the p 1 to a steady state this side. So, we can write X1 plus change in P12 SS that will be equal to this value. This value we know that what is the PG1; PG1 is nothing but, change in a steady state frequency error divided by R1. That is a composite R1 characteristic of that area 1 minus this D1 again the net load release coefficient into this and this is nothing but, your minus B1 into your change in frequency SS.

Similarly, we can write for area 2 in area 2 here what is happening. In the area 2 there is here, I am talking that there is some P21 which is going out. There is some change here and there is a generation here PG2 and here another component that is D 2 into FSS. So, here also what we can write this p l changes to that is x plus here P21 and this P21 is nothing but, we know that it is equal to a 1 2 into change in P12 a steady state. We know it very well.

So, this summation means X2 plus a 1 2 change in area power 1 to 2 in a steady state. That will be equal to nothing but, this 1. This change in p g 2 this value and minus this value because this change in the fall then this will be added. So, it is just reverse action and we can write here nothing but, minus beta 2 means beta 2 is the bias function of that area multiplied by change in the frequency error. Now, these 2 equations we have the 2 unknowns. That is 1 is your P12 a steady state and we have that FSS as a steady state.

We have the 2 equations they are the 2 unknowns. Then; we can solve these 2 equations and we can get the unique solution. Because the X1 X2 are the given to you how much they are going to change. These 2 are not known A 1 2 is known to you change in frequency you do not know but, the parameter R1 R2 D1 and D2 or in other words you can say B1 and B2 are known to you and then; we can solve this equation. If you are solving simply what you can do, you can multiply a 1 2 and subtract. This will be cancelled out and you can get, in change in the frequency error.

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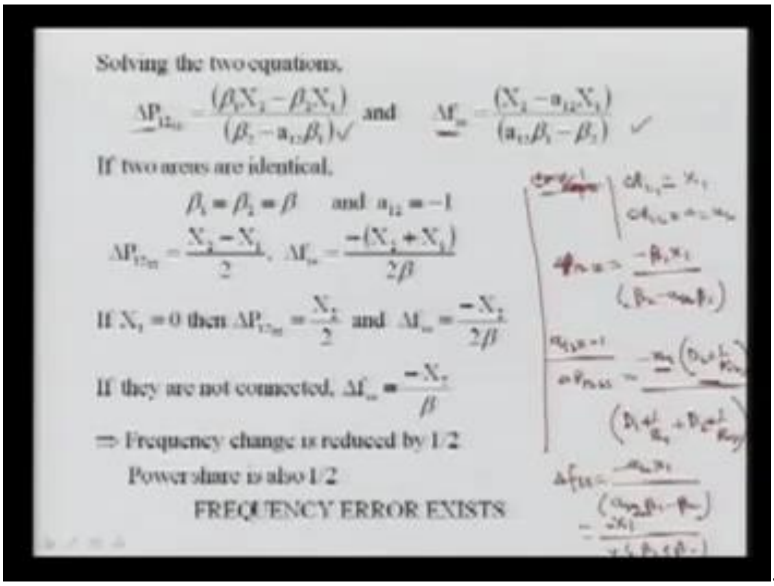

So, it will solve here, you will get that the change in this a steady state that is here that is the change in the power from tie line that is 1 to 2 in a steady state. That will be equal to here B1 X2 minus B2 X1 divided by B2 minus A1 2 B1 and your change in the frequency error. That is here change in FSS that is X2 minus a12 X1 divided by a12 B1 minus beta 2 this 1. So, we can get this expression and this equation separately. Now, let us critically analyze means; we see what we are going to achieve from these; if here I can the different conditions let us suppose, there is change in load in area 1 only.

So, here I can say X1 is there means X1 let us suppose any value means we can say here sorry, I can say this t l 1 is your X1 is there, but, the change in the area 2 will be 0 means; that is equal to your X2 means X2 is 0 means; only we are considering the change in the area 1 loading. Now, with this case, I can say it is case 1. We can go for again analyzing and then, we can get what will be your P12 SS. So, for this case; 1 the change in the power flow during the steady state that is a P12 change in P12 is steady state will be equal to here this X2 is 0.

So, I can write here simply minus beta 2 X1 over this value your beta 2 minus a12 beta 1. Now, here let us take the base value of both area 1 and area 2 are same. So, I can write here a 1 2 is equal to minus 1. So, here with this condition 1 2 in a steady state it is nothing, but, minus X1. Now, what is beta 2. We can write here it is your D2 plus 1 over R2 divided by this B2 plus now it is unity. So, it is beta 1 and beta 2. So, I can write here it is D1 plus 1 over R1 plus your this is beta 2 plus 1 over.

So, you can see the change in the tie line power flow. Here this is another factor B1 plus B2 is occurring for all the case, but, the change in that is occurring the tie line power flow from area 1 to 2. It is here the change in the loading of that area and the factor that is a bias factor that is beta 2 of another area. We can again see what will be your change in the frequency here for this case. Here as I said your X2 is 0. So, here again you can see what we are getting.

Here you will see this is nothing, but, a12 means; I can write minus a12 X1 divided by a 1 2 beta 1 minus beta 2. It will put this a12 is this value here it is 2. So, we are going to get it is nothing but, your X1 divided by minus beta 1 plus beta 2. So, in this case you can say now the values are here coming out to be half. This B1 and B2 are added together and here X1 this minus will be going up and we are getting this change in the error.

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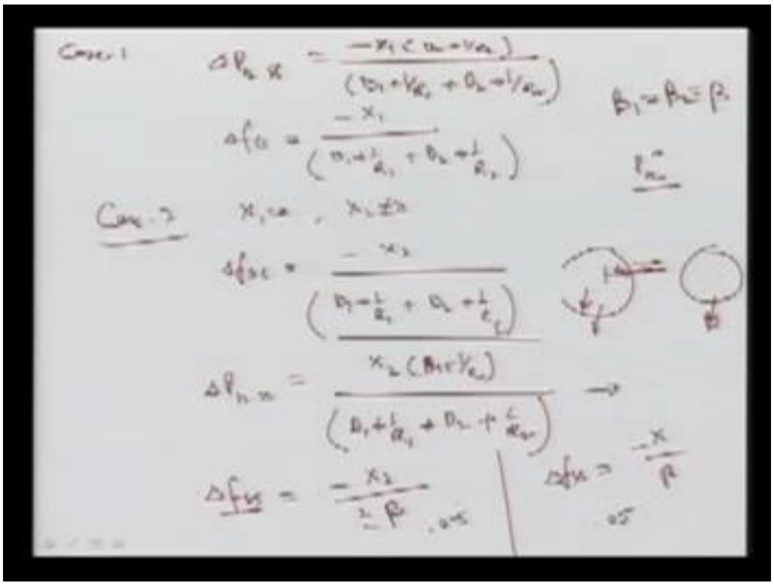

So, I can say here the change in the steady state frequency that is your change in FSS it is nothing but, your minus X1 over that is beta 1 plus beta 2 means; here it is D 1 plus 1 over your R1 plus your D2 plus 1 over your R2 here this is. Similarly, if there is change in only area 2 this will be reversed. So, here change in f means; I can say case 2 where X1 is 0 and X2 is not 0. So, I can say this is equal to minus X2 divided by your D1 plus R1 plus your D2 plus your R1; oh sorry, this is R2 and here your change in P21 SS will be now, you can see what we are going to get here from here if your X1 is 0.

So, you are getting beta 1 multiplied by this component will be as it is. So, I can simply and here now it is positive. So, we can write this here this value is your X2 into your R1 sorry, D1 over 1 upon R1 and here we are getting D1 plus 1 over R1 plus D21 over R2. Now, you can see if from this expression in the previous I can summarize that case 1 here we are getting the P12 a steady state that is it was coming here minus X1 here D2 plus 1 upon R2 here your D1 plus 1 over R1 plus your D21 over R2.

Now, whenever there was a change in the power in area 1 this component was becoming negative means; the power which was flowing earlier that is P12 naught. Now, it is going to be reduced of course that is true, because here this is area 1 this is area 2. If there load increase here in this area the power which was flowing, it will be reduced here. Similarly, if there is a change in area here load then power here will be increased. Then that will be area 1 will be supplying the power.

So, you can say this T12 steady state is the positive value X2 is positive, if it is increased then this is all the coefficients are constant. So, this will be increased and means the tie line power is increased. So, whenever there is a disturbance load increased here the power from area 1 will be supplied here. Similarly, if there will be change here then power change in here the tie line means area 2 is supplying the power. So, it is a mutual assistant means 1 area is in problem other area is assisting.

Basically, improves the reliability and the stability of the system and the frequency you can see here to see it very clearly. Let us consider that the both areas are almost equal means here I can say that is B1 let us suppose equal to B2 Then we can see how much change in the frequency that is occurring. Now, what is this. Now, we can see here that is your change in FSS it is nothing but, minus X2 divided by 2 beta.

If it is equal to beta however, in the previous case, if you remember the change in the frequency error was nothing, but, your minus x upon the beta what does it mean; it says that if the both areas are identical and they are connected with the tie line then, the change in the frequency error is reduced by 15 percent 1 over 2 here and then that is better means; here the change was let us suppose 0.54 here. Now, it is only 0.2 hertz. So, it is better off.

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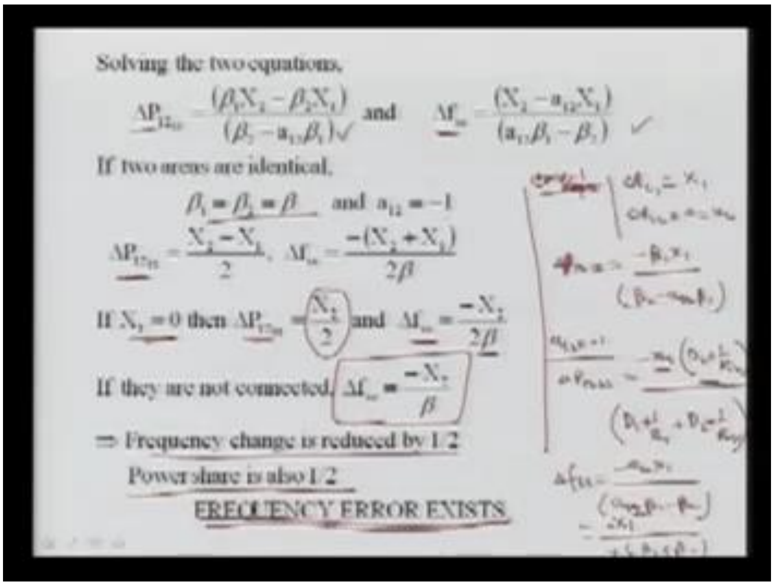

So, we can see here means; if the both areas are equal then a change in a steady state power here in the tie line that is X2 minus X1 again this value whether, it is positive to negative depends upon which 1 is higher than that if both are occurring together. So, here you can say X2 minus X1 by 2 and here X1 plus X2 that is the frequency here change X1 plus X2 by 2 beta. So, if X1 is 0 means; there is a X2 as I said here the steady state power is X2 by 2 means; the half of power of the load is supplied by the area 2 area 1 here means; power is flowing from the tie line means when there is a load.

Let us suppose, 5 mega watts is increased in area 2.5 is meeting from area 1 condition is that here if they are identical. If they are not identical then some fractional power will be flowing and the frequency error here in the X2 upon 2 beta. So, earlier if they were not connected it was the case. So, we can say the frequency change is reduced by half and the powers there is also half in both area are connected together but, in this case we can see we are observing we are getting is still the frequency error is existing which, we do not want means; in all even though both areas are connected.

If they are not having secondary controllers only the primary controllers of area 1 and area 2 we are getting the frequency error although this magnitude is reduced earlier it was higher. Now, it is reduced, but, still we do not want. So, we have to provide that secondary ALFC control for these 2 areas and let us see how they are going to be related to go for the secondary controllers.

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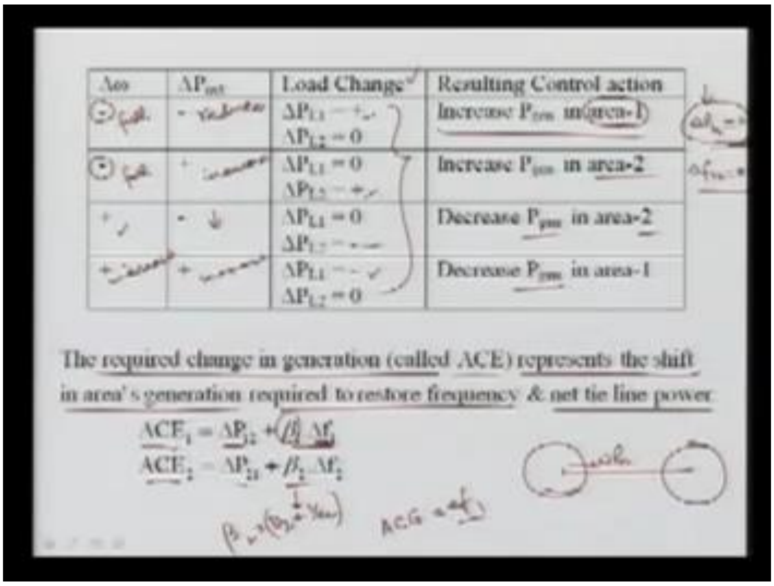

Let us think how the thing, how the scenario is changing. Now, let us take the load change means; here if you are assuming this area 1 load is increased plus means;

increased and area into load is no change that is 0. So, if here it is changing what will happen load is increased either in area 1 or area 2 frequency will fall. So, this condition shows that here it is increasing in area 2, here increasing in the area 2 then frequency is here it is falling means; frequency will reduce once. As I said load will increase frequency will fall.

So, in these both cases the frequency will fall. Now, what will be the p net; if the load here again, in the previous expression I showed you that if there is change in the load in area 1 the tie line power which was flowing from 1 to 2 that was net value was reducing. So, it will reduce or decrease you can say however if the load in the area 2 is increasing. So, it was increased. Now, what we have to take the control action. So, the resulting control action if the load in area 1 is increasing then, we have to increase the generation in that area.

Because, this tie line is always we have to restrict that what is the scheduled power that must flow during the steady state condition. So, we must generate the load generation in the area 1 to meet the load increase in that area 1. So, that there should not be change in the tie line power flow. So, the tie line flow is allowed during the emergency condition during that stabilizing mode condition and the finally, we have to change the generation. So, that again we should go that here the change in the P12 should be 0.

So, our concern here that this p net should be 0 means; we have to divide the controller that this should be 0 and also we want the frequency cases should be 0. So, we have to take the control action accordingly. So, what we have to do if the change in the P11 is increasing we have to increase the generation in area 1. Similarly, if the load is increasing in area 2 then, we have to increase the generation in area 2. So, that this value will be change in the tie line power flow should be 0.

Now, let us say that if load is decreasing. So, if the load is decreasing in area 1 here decreasing negative is decreasing. So, what will happen frequency will increase means; here increase and load is decreased here what will happen. This power from area 1 means here it is your area 1. This is your area 2 here that is your P12 net. So, if load is decreased here more power will be flowing here and that is here. It is increased. Then again to make this condition that is change in P12 in a steady state 0; we have to decrease the generation in area 1.

Similarly, if there is a decrease in the load in area 2 of course,, this frequency will increase and your p net power which, was here flowing it will reduce and to meet here this value 0 we have to take care. We have to decrease the generation in area 2. So, this is basically whenever there is 4 conditions are possible. We have to take the control actions accordingly means whatever, the amount of load is changed in that area that must be compensated by generator in that area only so, that we can have this 1.

So, the first condition to have the steady state tie line power flow 0 we have to increase the we have to increase the generation in that area and also it is not only that if there's some frequency fall that we have to try to so, that we have to operate our system on your rated frequency. So, the required change in the generation now that is called area control error ACE. In the previous case if you remember it was nothing but, you change it was change in the frequency.

For a single area here this ACE was nothing, but, your change in the frequency error and we were trying to reduce. Here that it was component if you remember to represent the shift, in the area generation required to restore frequency and the net power tie line power flow. So, here now ACE is the 2 component 1 is your change in the frequency of that area here earlier, it was there multiplied by this B1 factor because the V1 is appearing here in this your tie line power.

If you see here your this value here in this 1 you can say the B1 terms are appearing in this 1 B1 upon let us suppose, area any 1 of the area this is 0, some bias factor is appearing there. So, what we can do we can multiply here the bias and then P1 we can add together, because this p is the frequency. This is a real power; we cannot add together always you must know it. So, what we are doing here we are multiplying some of this D this factor. So, this will be the change in the power here and then we are using this tie line power it is going to be added.

So, here now for the area 2 it is your change in the power that is change in your tie line power flow from 2 to 1 plus beta 2 that is the bias factor. Here it is nothing but, this value is your D2 plus 1 over R2 already I have defined this several times multiplied by the change in that frequency of that area. So, to include this we can do.

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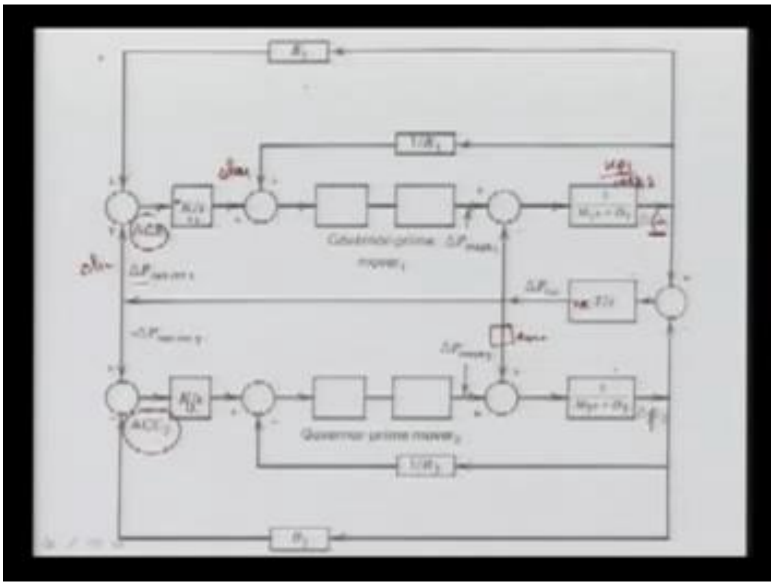

Now, we have to see we have to go for integral controller as again now what we have done here this is beta 1. This frequency here you remember this is the frequency. Now, this I have written in terms of m 1 and D1 no doubt you can represent this in terms of your KP1 and this I can write 1 upon TP1 s and others are as it is. Here I have used another factor why I have used this factor because; I have taken that is the A12. The difference is here and here, I have written 2 pi because I am writing here f.

So, there is no problem. So, this area control error here which is coming to your integrator of this area 1 here this is I2 of area 2. This is your area control error of 2 that is your that here, I can say P12 which is going from here and this is added and that is going to be integrated why it is negative. If you are adding this is a plus here this is a negative of and it will be taken care to see this. Now, we have to change the reference power. That is your reference power here that is coming here.

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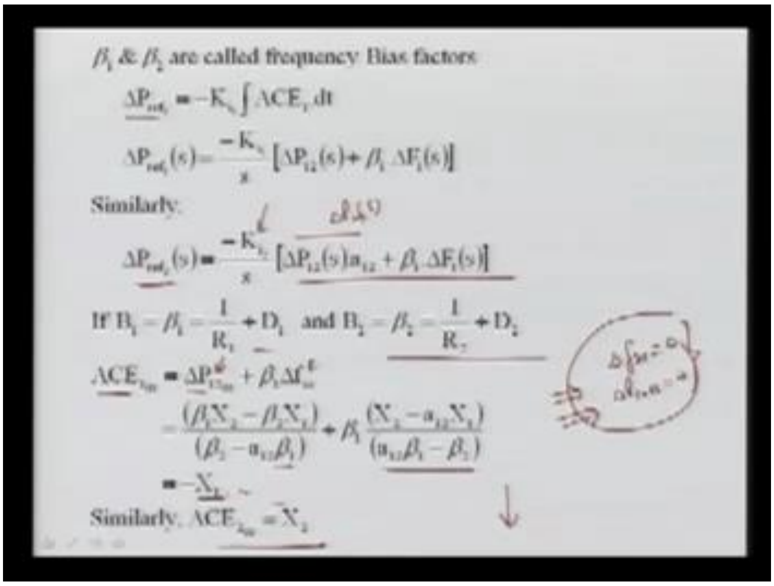

That is your PC or PC reference 1 area and we can write here this reference and minus Ki1. That is a constant of your area 1 integration constant and we are using the integration constant because we want that area residue must be 0. So, we have to use the integral controller and we have used the integration here and that is; if you are integrating that we are getting 1 upon s. So, this is a coefficient plus change in P12 s plus beta 1 in the change in Fs1.

Similarly, for area 2 we can go for another constant here Ki2 and we are having this coefficient. This value we use that is your change in P21 s here, I have replaced with a12 beta 1 is no doubt is equal to here the B1 is equal to your beta 1 and that is defined here. Similarly, this is defined here. So, now in ac1 during the steady state condition what we are going to get because our intention that we have to get this ACE 1 whenever, there is a change in the load in particular area this will be equal the load in that area.

So, that we can increase that 1 as I said in the control action whenever is a change in the loading in area 1 generation will take that loading in that area 1. So, here AC1 in during the steady state condition will be equal to your change in the tie line a steady state condition plus your beta 1 into change in your frequency steady state conditions and we can put that steady state condition which we derived earlier. So, we can put here the value that value, I have taken from here if you could remember.

This value is here as well as here and then; we can if you put this value we will get here this value and then we can simplify what is happening. This P delta P12 a steady state will be equal to beta 1 into X2 minus beta 2 into X1 divided by beta 2 minus a12 beta 1. Here you can say both are equal and then, it is divided here. So, beta 1 X2 is coming here you can say beta 1 X2 here and your this value here beta 1 X1 here and then we can get here this value.

Now, y here you can see this value is going to be cancelled here this is a reverse of this. So, we can see and this value will be simply cancelled out. So, we are getting X1. So, whenever there is a change means X1 is positive area error must be negative. So, that we can inject that generation and we can go for. Similarly, the area control error here will be also if X2 is there then it will be minus X2 and then; we can in this case we can say now, during the steady state condition here this is going to be.

The finally, here we will get the change in the frequency error as well as this error means change in your FSS will be 0 and you r change in P12 FSS. Here will be 0 for the closed loop system here we use for the open loop error other way again; we can go for similar fashion that we can use the final value theorem but, that becomes very complicated because the 2 area and several states now nine states are going to be appearing here. So, it is very complicated, but, we can here use the open loop steady states values. In the control area and now, this value is coming towards this and that is going to be increased.

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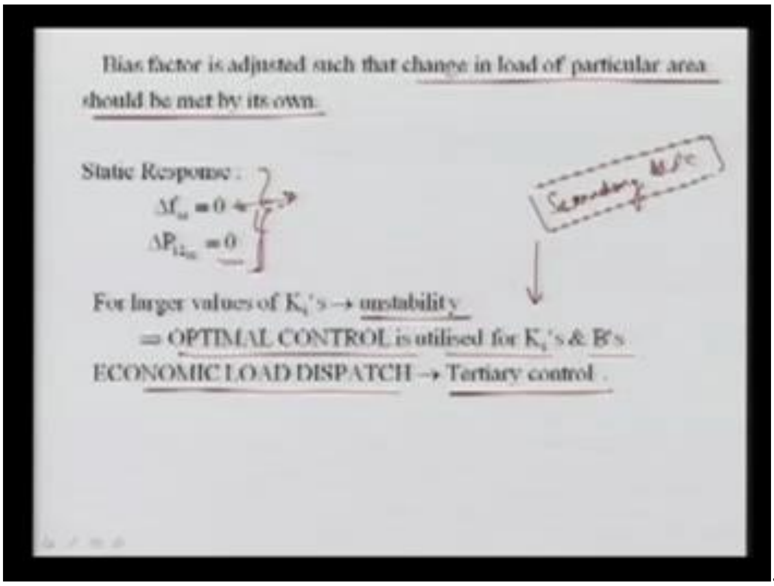

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So, your change in the frequency error as well as change in the tie line power flow will be 0. So, we saw now, this static performance now, it is 0 that is required. So, the bias factor is adjusted such that change in load of particular areas should be met by its own area. So, these factors are in such a way that we have to obtain these conditions. So, means; if there is any change. So, that area will take care. So, that this value will be 0 and at the same time we can to maintain the frequency of the system.

Another problem here, in whole system this larger value of Ki means; what will be the value of Ki. This Ki constant is very critical as you are going for adding more and more areas the choice of Ki is very critical means sometimes this Ki as I may saw in the 1 area control it was oscillating. It was giving some damping. It was under most eigen values were appearing. So, this may gives you un stability condition and therefore, we have to design an optimal control utilizing the Ki's and the B's bias factors.

Therefore, once the Ki is optimally chosen then; we can go for the combined effect, with some economic load dispatch and that is also called the tertiary control. So, this Ki inclusion is called your secondary. Secondary ALFC loop primary, we saw because there was some error. There was some error and then we added some integration controller and then; we got the secondary but, if you are going to include your economic load dispatch then; we will get here the tertiary load control and that is called tertiary ALFC loop.

So, we saw primary secondary and now it is a tertiary. So, we will see, in the next lecture we will see the optimal control how thus, we can decide to get. So, that, we can get the stable operation of the interconnected 2 area 3 area systems together. So, to in this lecture, we modeled the tie line power flow and we saw what are the various advantages and the disadvantages of your tie lines approaches. If you remember just, I will come from beginning just to recap you.

So, we model and we saw that the we model here, with this tie line here and we saw that the change, in the values here that is reduced. And finally, we say this frequency error, if the 2 areas are there then frequency error will be reduced rather than; a single area condition for the same load change and but, again the frequency error exists. So, we have to design some secondary ALFC loop and then we use this Ki. That is as, I said we have to use this area controller error and some integration constants here integral controller are used in both area.

So, that we can minimize the change that is 0 during the steady state and the frequency also here that is FSS will be 0; so, that we can have stable and the normal operation of the system. So, now as I said the gains of these values are very critical and we have to take care accordingly to stabilize this complete system. Now, we have the several states here once we are going to change there is a possibility that since, generations are changed why not we can change in a such a fashion that, we can achieve.

The economic load dispatch that is a optimal power flow solution along with change in whole system along, with that we can have the stable as well as economic load dispatch problem. So, that we will see, in the next lecture.

Thank you.