Power System Engineering
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Lecture – 54
Load frequency control (Contd.)

So, we have we have seen then this one.

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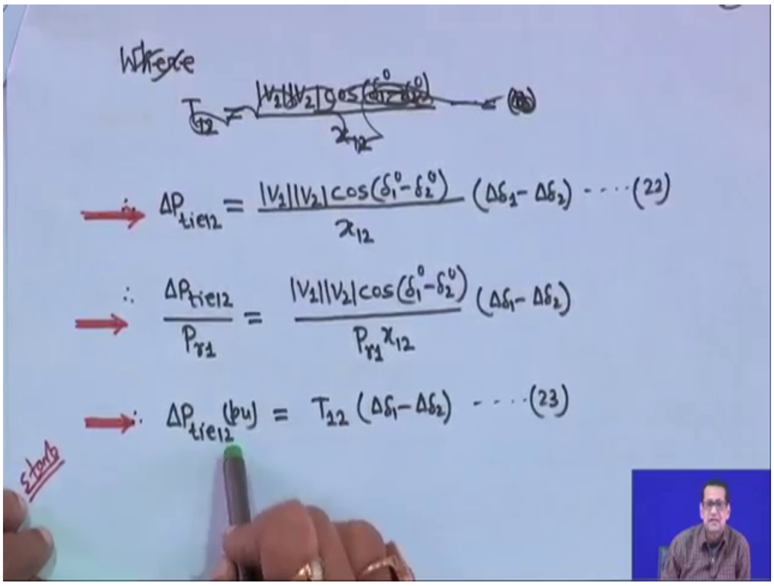

That both side we are dividing it by that your rated capacity of area-1 it is in megawatt right P r 1 is in megawatt, right. So, if you do so, then this will be in per unit. So, delta P tie 1 2 per unit is equal to T 1 2 delta delta 1 minus delta delta 2 this is equation-23.

One thing before proceeding further I would like to tell that hence onwards I mean after this equation-23 again and again we will not write per unit p u. We will simply write delta P tie 1 2, but it is understandable that all this quantities are in per unit values. So, now, T 1 2 actually is equal to magnitude V 1 magnitude V 2 cosine of delta 1 0 minus delta 2 0 divided by P r 1, x 1 2 right.

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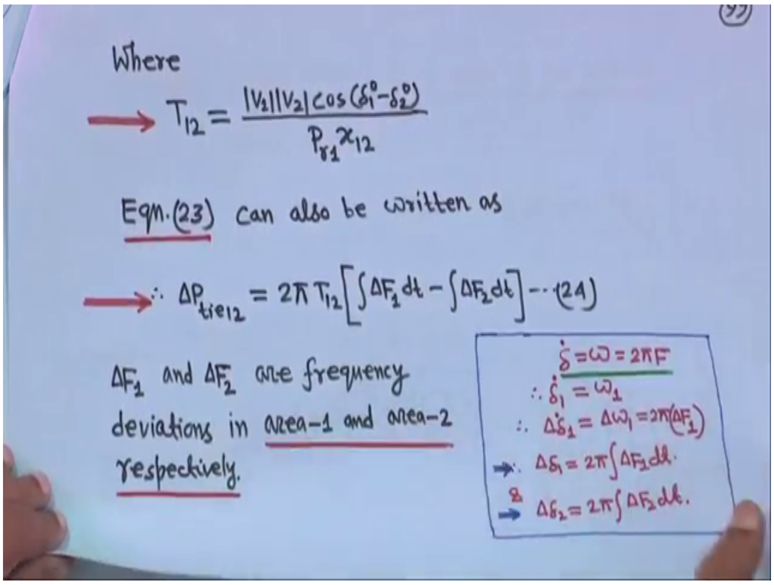

So, where T 1 2 I have written here that magnitude V 1 magnitude V 2 cosine delta 1 0 minus delta 2 0 upon P r 1 into x 1 2. Now, there equation-23 can also be written as; that means, this equation-this equation-it can be written as your delta P tie 1 2 is equal to 2 pi T 1 2 and delta delta 1 and delta delta 2 can be written as your your 2 pi then T 1 2 then integral of delta F 1 dt minus integral of delta F 2 dt, this is equation-24.

How things are coming in general you know that delta dot is equal to omega here I have done in for you is equal to 2 pi F; F is the nominal frequency 2 pi F right. Now, therefore, say this is general thing delta dot. So, for delta 1, so, delta 1 dot will be omega 1; that means, if I take small perturbation then delta delta 1 dot will be delta omega 1 is equal to 2 pi it will be your delta F 1 therefore, delta; that means, if you integrate delta delta 1 will be 2 pi integral of F delta F 1 dt.

Similarly, here delta delta 2 will be 2 pi integral of delta F 2 dt that is why in this equation-that ; that means, delta delta 1 in this equation-you substitute 2 pi integral of del F 1 dt and here you substitute 2 pi integral of del F 2 dt take 2 pi common. So, it will become 2 pi T one 2. So, delta P tie 1 2 is equal to 2 pi T 1 2 integral of del F delta F 1 dt minus delta F 2 dt this is equation-24, where delta F 1 and delta F 2 are frequency deviation in area one and area-2 respectively if there is a change in the load in either of the areas or in both the areas right.

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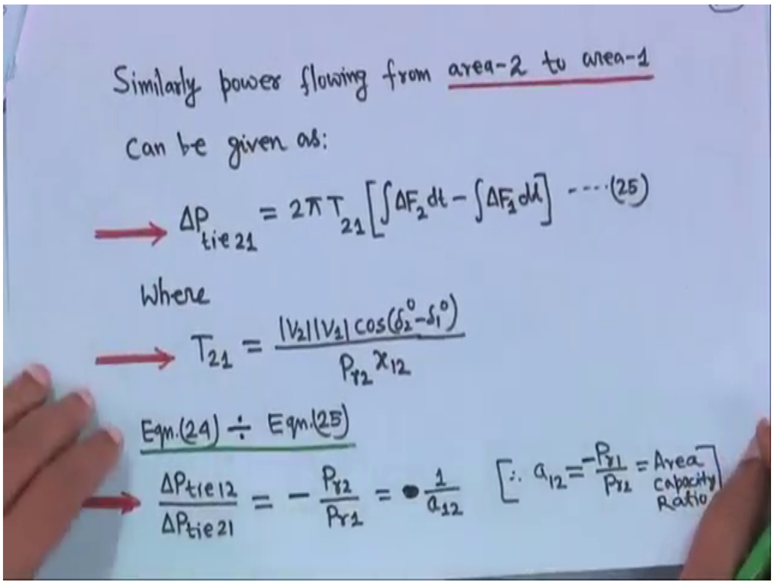

Therefore, similarly power flowing from area-2 to area-1, this is I am not doing from this inspection you can write power flowing from area-2 to area-1.

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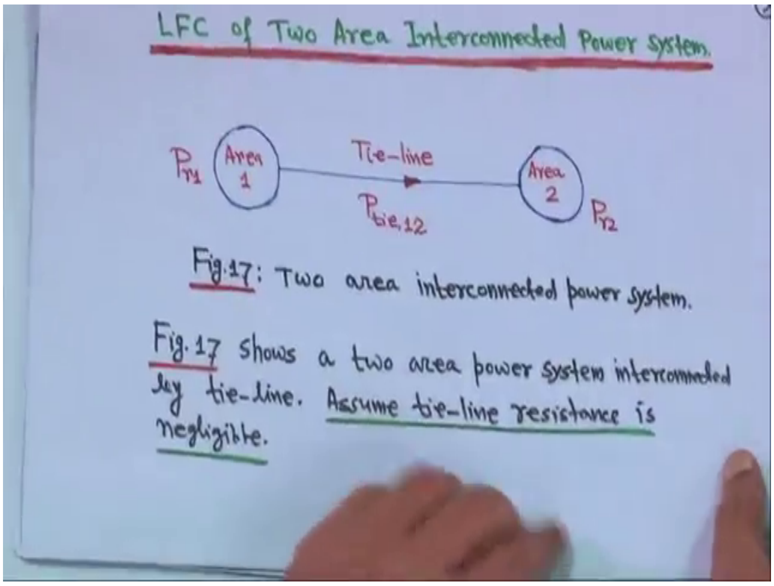

That means, from this side to that side if you take here direction is showing that 1 to 2.

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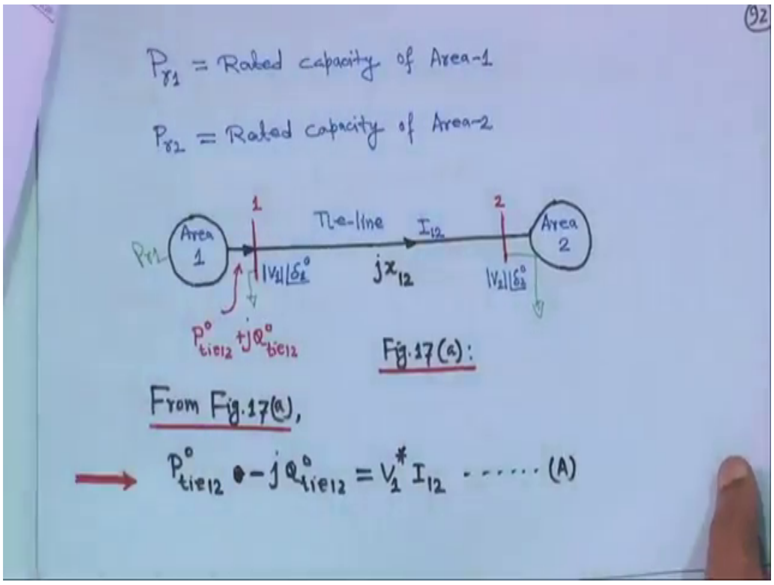

That means if power flows in this direction from 2 to 1 in this direction then you can directly write delta P tie 2 1 is equal to 2 pi T 1 2 to T 2 1 integral of del F 2 minus delta your integral of del F 1 dt right. So, in this case it is 1 2 and in this case just interchange those suffix it will be delta P tie 2 1 it will be 2 pi T 1 2 right T 2 sorry 2 pi T 2 1 and it will be become integral of del F 2 minus integral of del F 1 dt; So, just, just opposite to that.

Therefore, delta P tie 2 1 is equal to 2 pi T 2 1 integral of del F 2 dt minus integral of del F 1 dt. Basically, basically if you look in the diagram if you look into the diagram because line resistance is neglected there is. So, here if it is delta P tie 2 1, 1 2 rather and in this side if it is delta 2 1 then in real unit when it is in megawatt basically delta P tie 1 2 is equal to minus of delta P tie 2 1 because loss is neglected. So, everywhere this deviation will remain same, we are not considering the power loss right.

Therefore, this equation-similarly we can write, but in, but where delta T 2 1 this one V 2, V 1 same thing cosine earlier it was cos minus theta cos theta you know. So, earlier it was cosine delta 1 0 minus delta 2 0, now it is cosine delta 2 0 minus delta 1 0 same thing divided by x 1 2, but it is in area-2 that is why divided by the rated capacity P r 2, right. So, this is your divided by P r 2.

Previous one that it was in area one that is why it was divided by your P r 1 both side. So, that means, this is in per unit I will I told you that I will not mention again and again, but this is in per unit delta. So, T 2 1 is this one, right. Therefore, if divide equation-24 by equation-25, that means, your this is 24. So, divide equation-24 by equation-25; that means, this one; that means, this one. So, if you do. So, you will get delta P tie 1 2 upon delta P tie 2 1 you just do it know you will get it. It is nothing, but minus P r 2 upon P r 1 is equal to say we are writing one upon a 1 2, right.

That means a 1 2 is equal to minus P r 1 upon P r 2 we will call area capacity ratio, but minus sign is taken care of. If you if you do not take minus sign here then block diagram that will change with that minus a 1 2, right, otherwise if you take a 1 2 is equal to minus P r 1 upon P r 2 actually P r 1 upon P r 2 is area capacity ratio, but with this minus sign sometimes we call this is also area capacity ratio. So, this is actually it is written 1 upon a 1 2. So, once it is done that your what you call this ratio therefore, your T delta P tie 2 1 is equal to a 1 2 into delta P tie 1 2.

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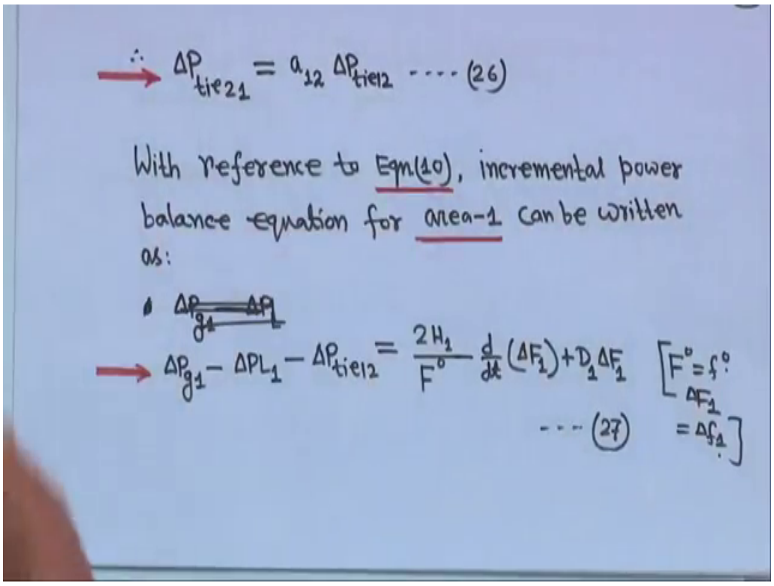

So, that is why this delta P tie 2 1 is equal to a 1 2 into delta P tie 1 2 in generally if you take a real unit I mean in megawatt forget about that that suppose it is not a it is not a per unit values. So, if it is a megawatt then if and if a 1 2 is minus 1 actually because delta P tie 2 1 will be minus of delta P tie 1 2 because loss is neglected. So, at any point of the line this power you will remain same because loss we have neglected.

So, now with reference to equation-10 incremental power balance equation-for area one can be written as we have seen earlier you know just have a look this one.

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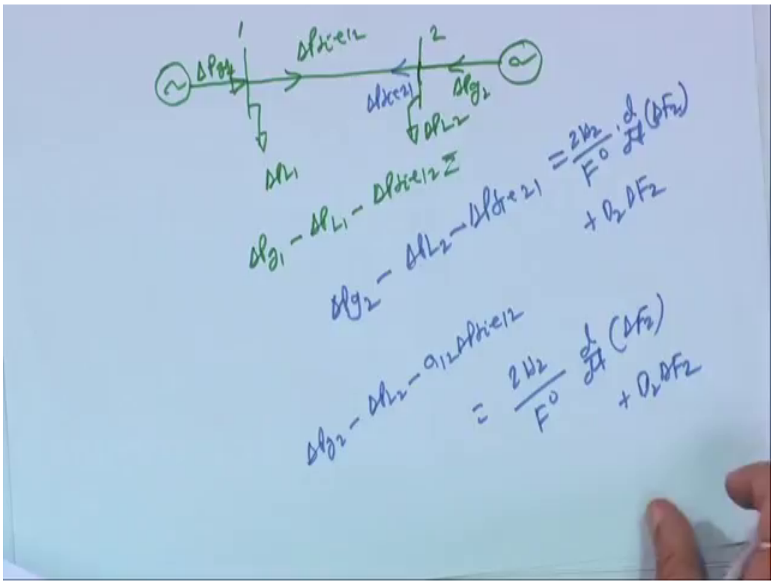

Suppose, suppose you have a generator suppose you have a generator is suppose giving power say P g 1 and this is your load say it is we are writing your delta P L 1 and generation power also change say delta P g 1 and this is the tie line connected that. So, this is your power this is 1 and this side is 2. So, this is your delta P tie 1 2 then what is the power balance equation here? delta P g 1 minus delta P L 1 minus delta P tie 1 2 is equal to during because of the load disturbance; that means, transient in balance between generational load hence that will hence the tie power also it will be affected.

So, if you if you just write down the power balance equation, so, delta P g 1 minus delta P L 1 minus delta P tie 1 2 is same as before 2 H this area-1. So, we have taken H 1 is the inertia constant 2 H 1 upon F 0 then d dt of delta F 1 plus d 1 F 1. This F capital F 0 and small f 0 superscript is this thing same. Similarly, delta F 1 capital delta delta capital F 1 and delta small f 1, they are same actually right. So, this is the equation-during transient imbalance. We will see later, but at steady state what will happen this term will vanish this term will vanish. Because, a steady state derivative is 0 only this term will exist that will see later.

So, therefore, at during transient imbalance so, delta P g 1 minus delta P L because at steady state if you write the equation-at steady state then delta P g 1 is equal to actually delta P L 1 plus delta P tie 1 2 right, but we if you take the difference this is at and this will happen during transient imbalance. So, it will be your 2 H F 0 d dt of delta F one same thing we have seen further single area system detail have been given for isolated case plus D 1 delta F 1. This is for area one that is why you are putting delta F 1 d 1 H 1; H 1 is the inertia constant. So, this is actually equation-27, right.

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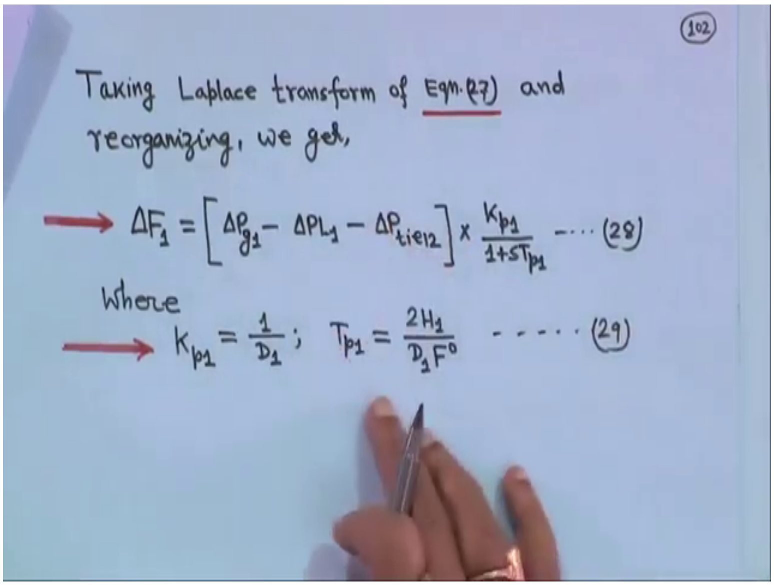

So, next is that if you take the Laplace transform on both side of this equation-this equation-again and again not putting delta P g 1 s or delta P tie 1 2, yes, it is understandable. If you take the Laplace transform same as before and just simplify, just simplify, right. So, what will get delta F 1 will get delta P g 1 minus delta P L 1 minus delta P tie 1 2 we are not putting again and again all this thing in a function of S because it is understandable into K p 1 upon 1 plus S T p 1 this is equation-28. Actually for the isolated system delta P tie was not there rest was same here also delta P tie is there, that is why minus delta P tie 1 2 into the same thing earlier for isolated case it was K p upon 1 plus S T p.

Now, it is for area-1 that is why it is into K p 1 upon one plus S T p 1, right; that means, where K p 1 is equal to 1 upon D 1 we know that K p is equal to 1 upon D for isolated case we have seen for area-1 K p 1 is equal to 1 upon D 1 similarly for isolated case we have seen 2 H upon d F 0 it is for area-1 that is why T p 1 is equal to 2 H 1 upon D 1 F 0, right. So, this is your what you call that equation- related to delta F 1 delta P g 1 delta P L 1 and delta P tie 1 2 this is equation-28 and this two we are marking as equation-29.

So, this is understandable right you take the Laplace transverse same as the isolated case only one tau added here that is because interconnection that delta P tie 1 2, right.

So, once this is done just hold on. So, once this is done then the block for this thing if you try to replace and it is your block diagram this one.

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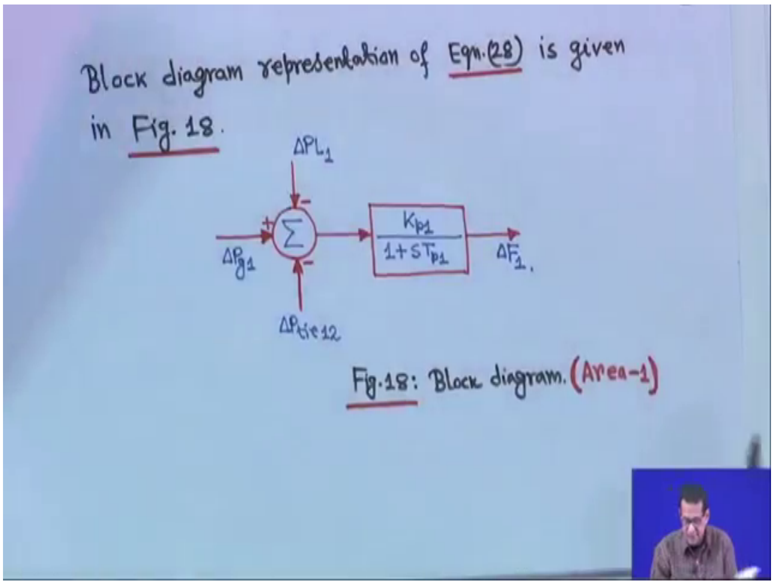

So, you can write this is delta P g 1 this is plus right delta P g 1 minus delta P L 1 minus delta P tie 1 2. So, this is minus delta P L 1 and this is say it is coming from somewhere will see later it is minus delta P tie 1 2 then into K p 1 upon 1 1 plus S T p 1 and output is that delta F 1 this is actually block diagram for area-1 this is actually only power your what you call this power system part right, power system and tie line part and later we will later and this generation also later will see from where it is coming when you will do for area-2 so, and the complete block diagram.

So, this is this equation-this equation-equation 28 actually is represented by this block diagram that is written here that block diagram representation of equation-20 is given in figure 18 this is figure 18 , right.

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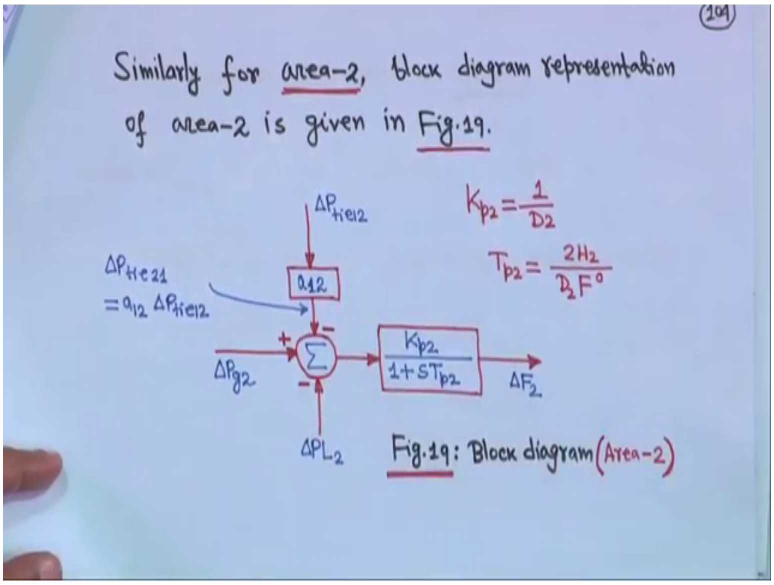

Next is next is similarly, for area-2 block diagram representation of area-2 is give given in figure 19 this 1 in the figure 2 what will happen that you know sorry in area-2 it will be K P 2 upon 1 plus s 2 delta P g 2 will be there minus delta P tie 1 2 and this is your minus a 1 2 delta P tie 1 2, how things are coming here right, this a 1 2 because this is actually delta P tie 2 1.

So, if you consider area-2 say this area if you consider here see here I am I am simply making it here only if this is your generator area-1. So, this power due to say that delta P g 2 and this is your delta P L 2 right and this side delta P tie 1 2 and this direction if you make it is delta P tie 2 1 loss is neglected; that means, power balance equation-actually same way will get delta P g 2 minus delta P L 2 minus your delta P tie 2 1 is equal to your this equation you will get that if power during power imbalance that is this 1 this 1 you can write like this that is your 2 H 2 divided by your F 0 into d dt of your delta F 2 plus D 2 into delta F 2, right.

And, and another thing is that as we have seen that delta P tie 2 1 is equal to a 1 2 delta P tie your what you call 1 2. So, here if you substitute this one then it will become delta P g 2 minus delta P L 2 minus a 1 2 then delta P tie 1 2 because delta P tie 2 1 is equal to a 1 2 delta P tie 1 2, right from equation-26 is equal to the same thing 2 H 2 upon F 0, F 0 is a nominal system frequency then d dt then delta F 2 plus D 2 delta F 2, right. So, this is for area-2 this is for area 2.

Now, if you again take the Laplace transform you will get the your what you call the same thing only the delta P tie that instead of your K p 1 T p 1 it will be your K p 2 upon T p 2 1 plus S T p 2 and this is actually delta P tie 2 1 that is actually is equal to a 1 2 into delta P tie 1 2, right, that we have seeing that is why it is coming it block diagram is made like this and a 1 2 is equal to minus P r 1 upon P r 2. So, that it is written here so, and this is delta P g 2 and this minus delta P 2.

So, this is K p 2 upon 1 plus S T p 2 that is delta F 2 this is actually figure-19 this is block diagram portion of area 2. So, this is this is power system this is tie power we will see from where it is coming and this is delta P g 2 and this is minus delta your minus delta P 2, right. So, in this case I mean in this case I mean very your what you call that next we have to complete the block diagram.

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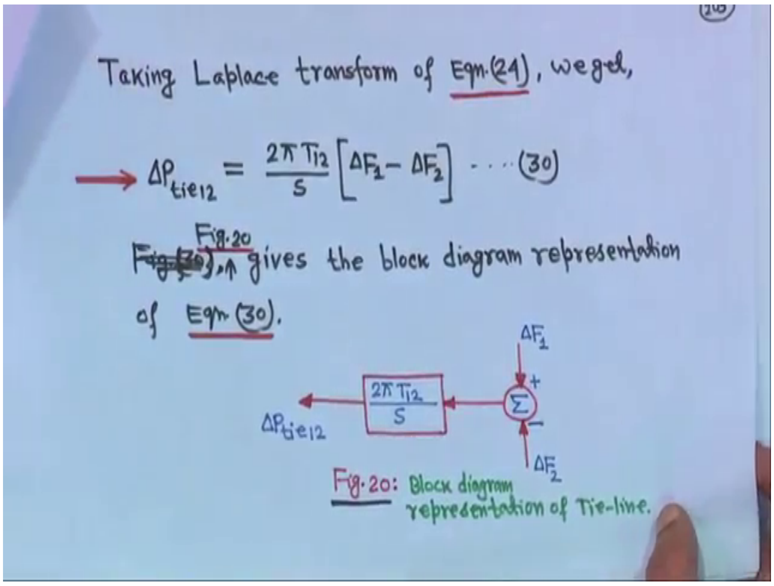

So, what will do from that your from equation 24, right from this equation-24 if you come to this right or I am writing like this that equation-24 you are written like this know rather than searching I am writing here.

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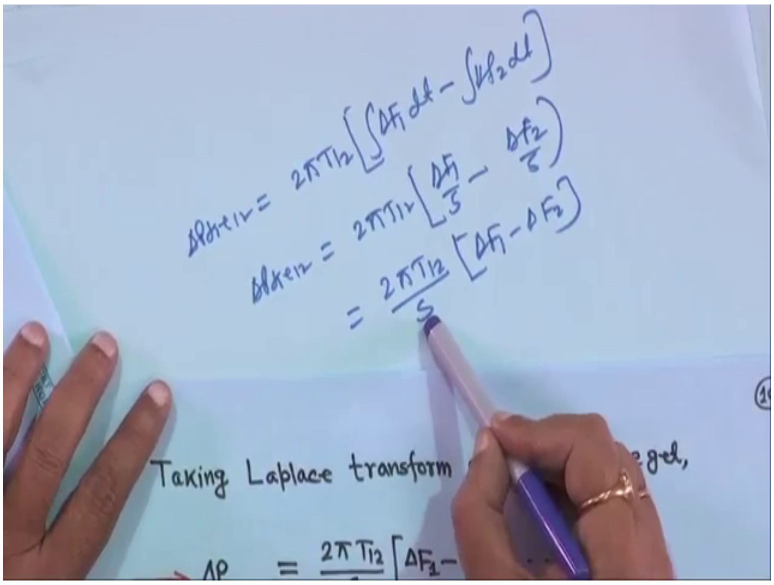

That delta P tie 1 2 is equal to 2 pi T 1 2 right in bracket it was integral of del F 1 dt minus integral of del F 2 dt right. So, if you take the Laplace transform then it will be delta P tie 1 2 yes, I am not putting in bracket it is understandable right, is equal to 2 pi T 1 2 right. So, this 1 in the bracket if you take the Laplace transform it will be del F 1 upon s minus del F 2 upon S right it is actually del F 1 function upon S del F 2 actually function upon S, but not putting. So, that mean this will be equal to 2 pi T 1 2 upon S right in bracket it will be del F 1 minus del F 2, right.

That means the tie line power equation-also can be represented in terms of Laplace transform right. So, the that is why we are writing delta P that is taking the this actually this was actually your equation-24 this was actually equation-24 just previously you have seen. So, so delta P tie 1 2 we can write 2 pi T 1 2 delta F 1 minus 2 pi T 1 2 upon S delta F 1 minus delta F 2 this is equation-thirty if for this equation-block diagram if you make then this is delta P tie 1 2 is equal to 2 pi T 1 2 upon S into delta F 1 minus delta F 2 this is the block diagram representation of the tie line; that means, the tie line also can be modelled in the S domain right.

So, this is the tie line power equation. So, now, if you if you complete the block diagram now; that means, this tie this delta P tie 1 2 whatever we have seen whatever we have seen in the previous block diagram this delta P tie 1 2 right, actually this is your delta P tie 1 2 this is delta P tie 1 2 here also delta P tie 1 2, right and this delta P tie 1 2 you have to connect from here from this equation-from this delta P tie 1 2 here. now, if you make the complete block diagram of two area system, right then it will be like this.

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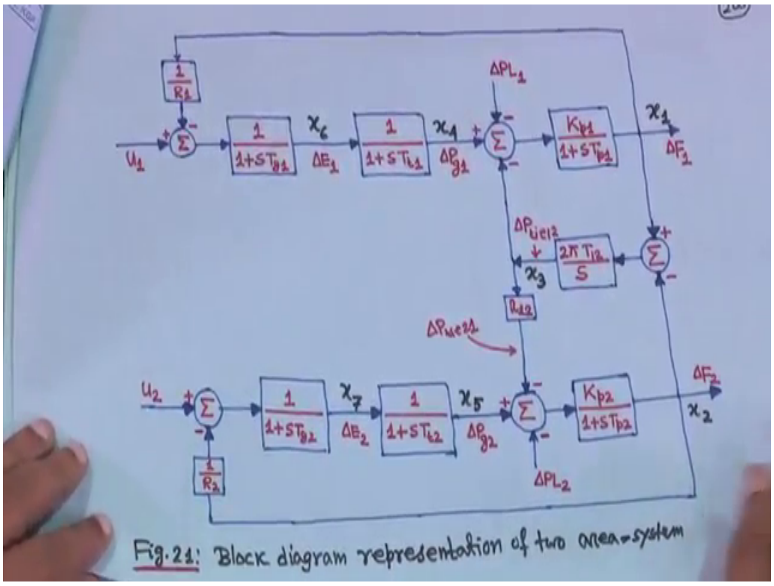

So, if you look into this then this is your area-1, this is the control signal u 1 this is for isolated system you have seen delta this delta F was coming to 1 upon r then minus feedback here, right. But, here it is area one. So, delta F 1 is coming here 1 upon r this is this is for non reheat turbine only right because if I try to put 1 more block per reheat I cannot accommodate here and this is your 1 upon 1 plus S T t 1 this is delta P g 1 and this is your disturbance 1 this is K p 1 upon 1 plus S T p 1 this is delta F 1.

Similarly, here this is u 2 the control signal this is delta F 2 it is 1 upon r 2, 1 upon 1 upon 1 plus S T g 2 1 upon 1 plus S T t 2 delta P g 2 this is disturbance minus delta P 2 and this is this is delta F 2. So, just now we have seen now delta P tie 1 2 is equal to 2 pi T 1 2 upon S delta F 1 minus delta F 2, this 1 we have seen now delta P tie 1 2 is equal to this one. So, this is the block this is the block. So, delta P tie 1 2 is equal to 2 pi T 1 2 upon S delta F 1 minus delta F 2. So, this delta we have seen now delta P g 1 minus delta P 1 minus delta P tie 1 2, right your whatever we have seen into K p 1 upon S plus T p 1 delta F 1.

Similarly, here also we have seen know this is delta P tie 1 this we have also you have seen know that previous block diagram that this one modelling actually. So, this block diagram we have seen know this one same thing we have same thing it is here only here also same thing here also. So, this is delta P tie 1 2, but delta P tie 2 1 is equal to a 1 2 delta P tie 1 2, right. So, it is minus. So, delta P g 2 minus delta and this is K p 2 upon 1 plus S T p 2 and this is your delta F 2, right.

So, this a two area interconnected system block diagram. Assuming that in each area there is one unit if you have more unit like composite modelling then you have to put. So, many; now, for the classroom purpose I think I call the classroom purpose this is ok, right. So, this is control signal later we will see that. Now, question is that we have to put then in the state variable form that is x dot is equal to a x plus b u plus gamma P.

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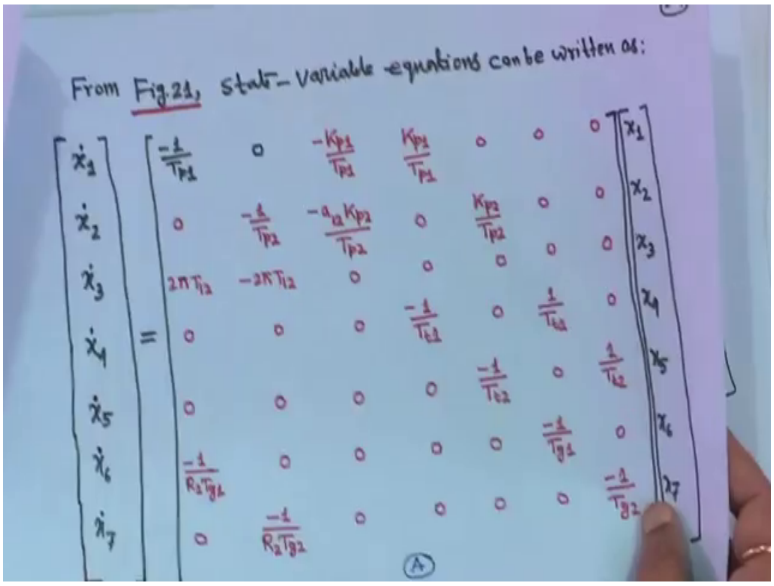

Now, I have written everything all this things for you, but let me write down all another thing is that the state variable is marked it is arbitrary. Actually whatever here you want it is arbitrary it does not matter result will remain same, but here frequency is x 1 that delta F 1 that is why we have made x 1 because our interest will be generally frequencies and tie power, right I mean generation also.

So, that is why the delta F 1 is mark as x 1 delta F 2 is given as a state variable x 2 and tie power it is given state variable x 3 this we have written generation 1 written as x 4 and generation 2 written as a x 5 and as here it is x 6 is delta E 1 and your just governor output right something and it this there is a these are the quantity not directly measurable and this is your delta E 2 is given x 7.

So, system is actually there are and if you look into that there are two disturbance your element there delta P L 1 and delta P L 2 and two control signals are there u u 1 and u 2 and there are 7 such blocks are there you representing your Laplace transform your S represent a term is; that means, this system order is 7 into a matrix will be 7 into 7 and 2 us are there u 1 and u 2, two control signals are there ; that means, b matrix will be 7 into 2 and disturbance 1 delta P L 1 and delta P L 2.

So, disturbance matrix will be 7 into 2. So, when will write this equation- just I am writing for all of you this thing first you take the x 1, right. So, if you all the everything is written here, but I will show you how we are making it.

So, if you take the x 1 first this 1 first then it will be I am making it here when will I am making from here only when will see this recording thing you will just write down on your note notebook first this one and then make one by one, right.

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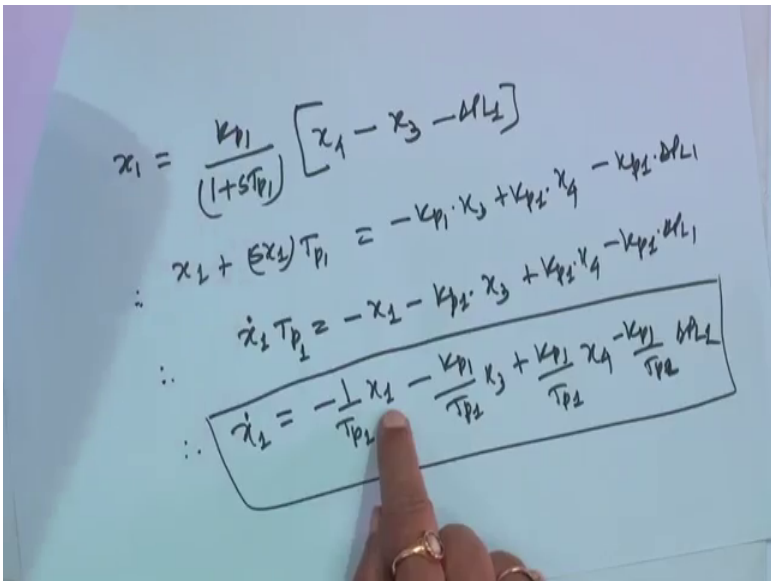

So, when we write x 1 look x 1 is equal to right it is K p 1 upon 1 plus S T p 1 right then in bracket it will be x 4 right it will be x 4. So, it is x 4 then minus this is actually x 3. So, this is also x 3.

So, minus x 3 right and this is minus delta P L 1 this is delta P L 1. So, x 4 is equal to K P 1 into 1 plus S T P 1 then your x 4 minus x 3 minus delta P L 1; that means, if you go for cross multiplication then it is x 1 plus S x 1 into T p 1 is equal to this x 3 I am writing first minus K p 1 into x 3 plus K p 1 into x 4, right minus K p 1 into delta P L 1, right. That means, this S x 1 is actually x 1 dot S mean all initial conditions are 0, x 1 dot T p this x 1 is going to the right hand side minus x 1 minus K p 1 x 3 right then your plus K p 1 into x 4 minus K p 1 into delta P L 1.

That means your x 1 dot is equal to minus 1 upon it is T p 1 1 upon T p 1 then x 1 minus your K p 1 upon T p 1 this is x 3 plus K p 1 upon T p 1 x 4 right minus K p 1 upon T p 1 delta P L 1. So, this is this is that your first equation x 1 dot is equal to. So, x 1 term is there x 3 is there x 4 is there other state variables are not there and delta P L 1 is there; that means, in this equation in this equation if you see that x 1 dot is equal to minus 1 upon T p 1 into x 1 it is minus 1 upon T p 1 into x 1 then x 2 is not there.

So, it is 0 then minus K p 1 upon T p 1 into x 3 minus K p 1 upon T p 1 into x 3, right, plus your K p 1 T p 1 into x 4 plus K p 1 T p 1 into x 4 right no other x are involve. So, all 0, 0, 0 then it is my disturbance matrix first element minus K p 1 upon your T p minus K p 1 upon T p 1 into delta P L 1 it is in the next page right u is not involve. So, u is not involved.

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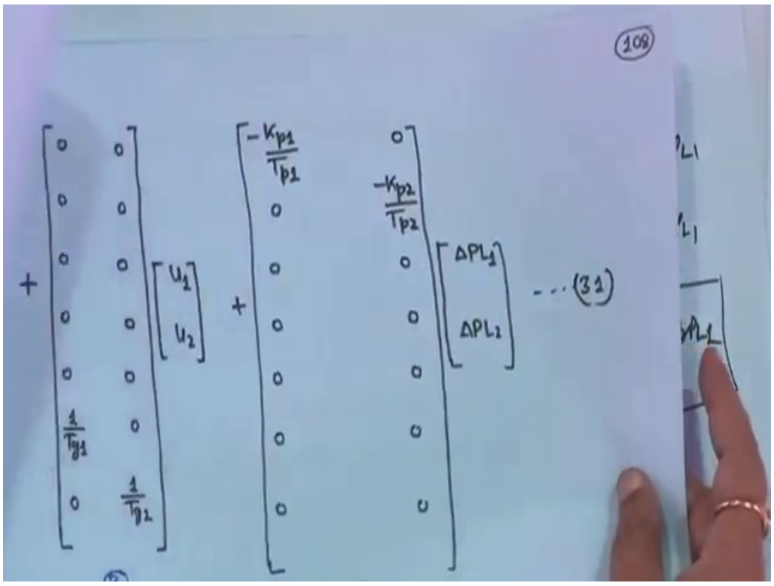

So, here first row it is 0 0 and it is first one if delta P L 1 minus K p 1 T p 1 first equation-into delta P L 1 second is not there, so, it is 0. This is first equation- right. So, similarly if you take the your what you call second one second one such that you will not be your what you call you will not be confused or anything, you can easily make it of your own.

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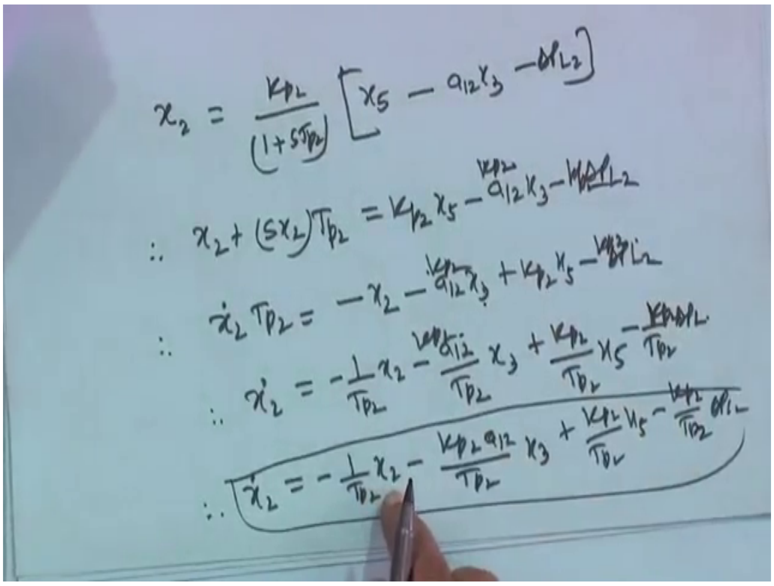

Now, second one what will do if you look into that this equation then we can write x 2 is equal to we can write x 2 is equal to K p 2 upon 1 plus S T p 2 then in bracket then it is x 5 it is x 5, right. So, this is x 5 then minus now, this is x 3. So, here delta P tie 1 2 will be actually a 1 2 into x 3 because it this is x 3 x 3 into a 1 2 here it is a 1 2 x 3 that is delta P tie 2 1.

So, minus your a 1 2 into x 3 this 1 right then disturbance is that delta P L 2 minus delta P L 2 now, if you go for cross multiplication if you go for cross multiplication it is x 2 plus S x 2 T p 2 is equal to K p 2 x 5 minus a 1 2 x 3 minus delta P L 2, right ; that means, S x 2 is x 2 dot so, x 2 dot T p 2 this x 2 taking this side minus x 2 then this is writing first x 3 a 1 2 x 3 then plus K p 2 x 5 minus delta P L 2.

That means x 2 dot is equal to minus 1 upon T p 2 x 2 minus a 1 2 upon T p 2 x 3 plus K p 2 upon T p 2 x 5 minus 1 upon T p 2 delta P 1 sorry here that multiplication of K P 2 I have missed it, here it should be K P 2, right. A multiplication here also it will be your multiplied by K p 2 here also it will be multiplied by K p 2 I have missed it; that means, here it will be K p 2 into a 1 2, right and here also it will be K p 2 your in your K p 2 into x 5 right, minus your a 1 2 K p 2 into x 3 minus here I have also missed it will be K p 2 into delta P L 2, right; So, this 1 also K p 2 into delta.

So, rewriting in a in a phase once again x 2 is equal to minus 1 upon T p 2 x 2 minus K p 2 a 1 2 upon T p 2 x 3 right, then plus K p 2 upon T p 2 x 5 minus K p 2 upon T p 2 delta P L 2, right. So, this is that this is the equation- right here actually at the time of multiplication I have missed this 1 right.

So, question is that now this is the now you check this equation equation-2 you check. So, there is no in this equation if you look into that here no x 1 is involve. So, second equation is 0. Next is minus 1 upon T p 2 x 2. So, minus 1 upon T p 2 then, x 3 if you look minus a 1 2 K p 2 upon T p 2 minus a 1 2 K p 2 upon T p 2, x 4 is not there 0, x 5 is there x 5 is this one, right K p 2 upon T p 2 right and then your this then the other state variables are not there.

So, it is 0 0 and if you go to the then no u is involve only the disturbance in area-2 is involved no u is involved here therefore, it is 0 0 and here it is 0 and it is minus K p 2 into by T p 2 into delta P L 2. So, this is the second equation.

Thank you we will be.