Power System Dynamics, Control and Monitoring
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Lecture - 37
Automatic generation control conventional scenario (Contd.)

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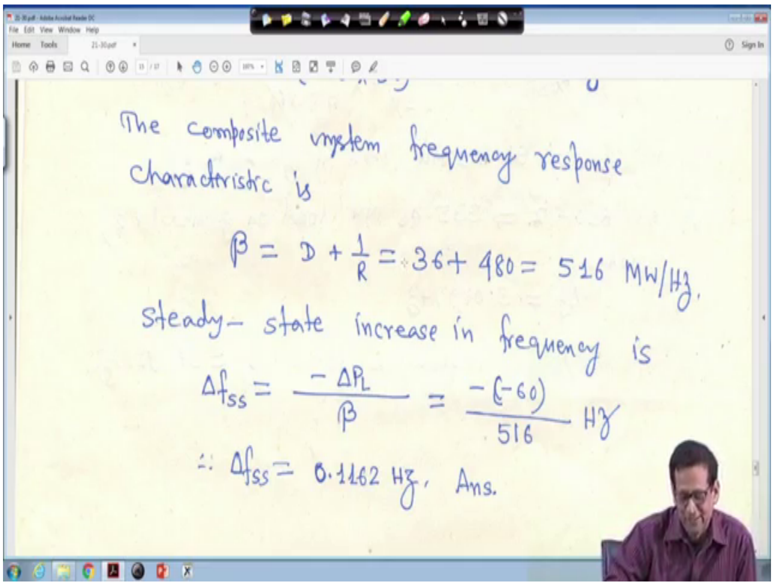

So, welcome back again. So, in the previous example we have seen that these example delta f steady state is equal to 0.1162 Hertz right.

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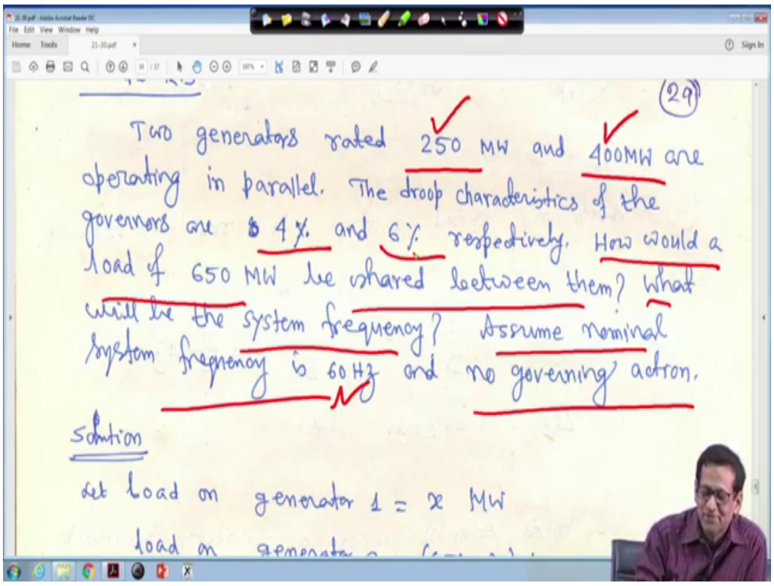

Now, next example suppose two generators rated these are typical example rated your 250 megawatt and 400 megawatt they are operating in parallel. So, droop characteristic of the governors are now you know the governor droop characteristic meaning of 4 percent or 2 percent whatsoever and 6 percent respectively.

How would a load that of 650 megawatt be shared between them? Right and what will be the system frequency? Assuming nominal system frequency is 60 Hertz which is given and no governing action. So, if you see the rated capacity of the one generator is 250, another is 400. So, total is 650 megawatt right and load also you have to match this 650 megawatt.

So, if their governors characteristic like these right droop characteristic 4 percent and 6 percent we have to find out that we generator generic how much power right. So, from this you can from your intuition you can make it something that, this is 250 and this is 400 where droop characteristics are given. So, naturally there is strong possibility one generator will be overloaded, because of a because total load is 650 megawatt right. So, how will do this?

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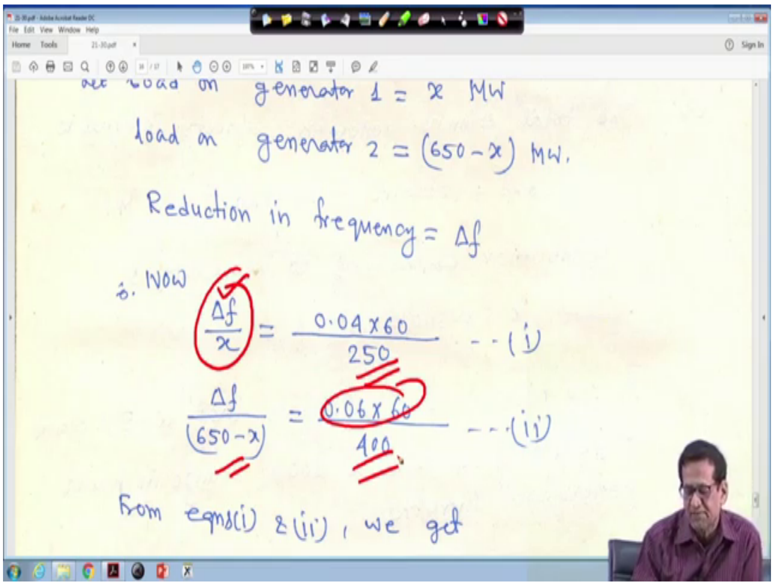

So, let load on generator 1 say x megawatt and then therefore, load on generator 2 will be 650 minus x megawatt. Because total load to be supplied by this two generators are your what you call is 650 megawatt right. So, generator 2 will be 650 minus x megawatt. Now, say due to these reduction in frequency is delta f right. Therefore, we can write for the first generator whose droop characteristic is your 4 percent. So, delta f by x is equal to 4 percent of a nominal frequency is given 50 Hertz. So, it is 4 percent of 60 right divided by its rated capacity this is one equation.

Similarly, for second generator delta f upon 650 minus x right is equal to that is 6 percent of the nominal frequency divided by its rated capacity right therefore, you solve this two equation for x.

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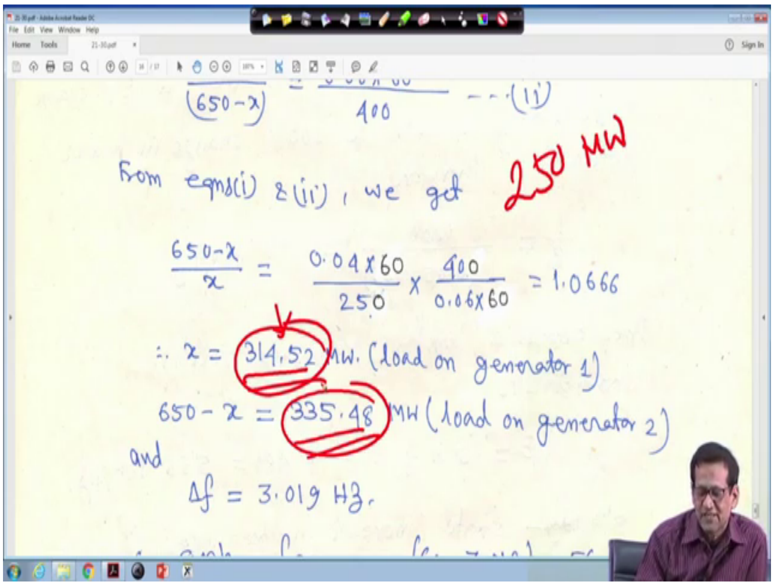

So, if you solve these two equation for x, you will get that x is equal to I mean it is what you call 314.52 megawatt right. So, this one your, so generator 1 it is 314.52 megawatt and generator 2 it is 335.48 megawatt. But, generator 1 that rated capacity is 250 megawatt.

So, if generator 1 generates your 314.52 megawatt; that means, the generator 1 is much much overloaded and I mean it is more than 20 percent overloaded right. So that means, your second generator is within that limit, because generator rating is 400 megawatt. So, it is generating 335.48 megawatt as per their your what you call the droop characteristic, so it is highly loaded right.

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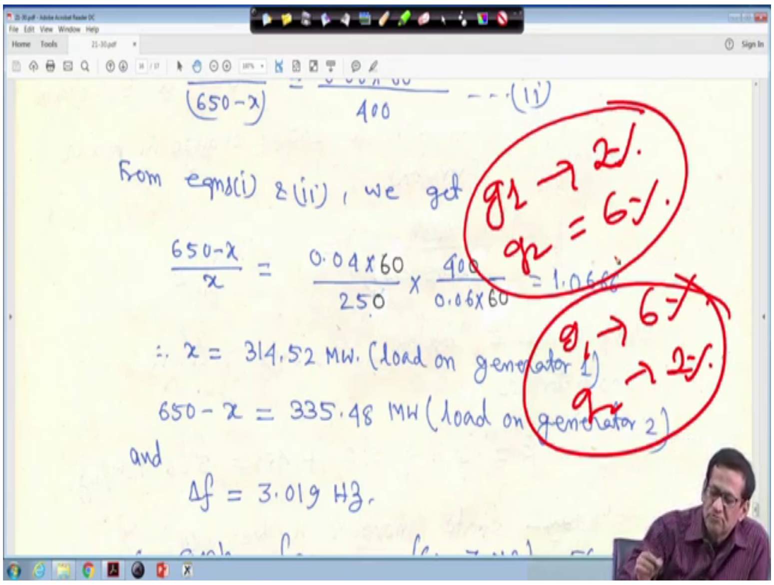

So, I will suggest that when will solve this problem you consider another one say at when droop characteristic for generator 1, say for generator 1 you take 2 percent right. Suppose, it is 2 percent and for generator 2 it is for 6 percent you solve this one right. Similarly, this is you will get one set of solution for your two generators.

Similarly, another case you take g 1 is equal to say 6 percent and g 2 is equal to 2 percent right. And you solve this one and see what is happening right. So, but that means your the generator 1 is heavily loaded. So, if we know the x then you substitute the value of x either of this equation and solve for delta f.

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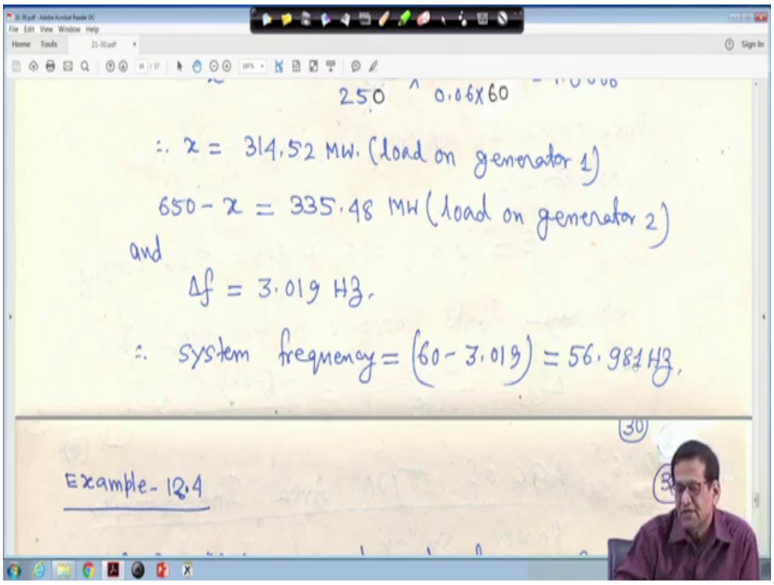

So, delta f will be 3.019 Hertz the frequency it will deviate like this. Therefore, system operating frequency will be; because 60 Hertz your nominal frequency, it will be 60 minus 3.019 so 56.981 Hertz right so this is the answer. But, one thing again that generator 1 is heavily loaded with more than 20 percent right. So, that is why I give you other two problem.

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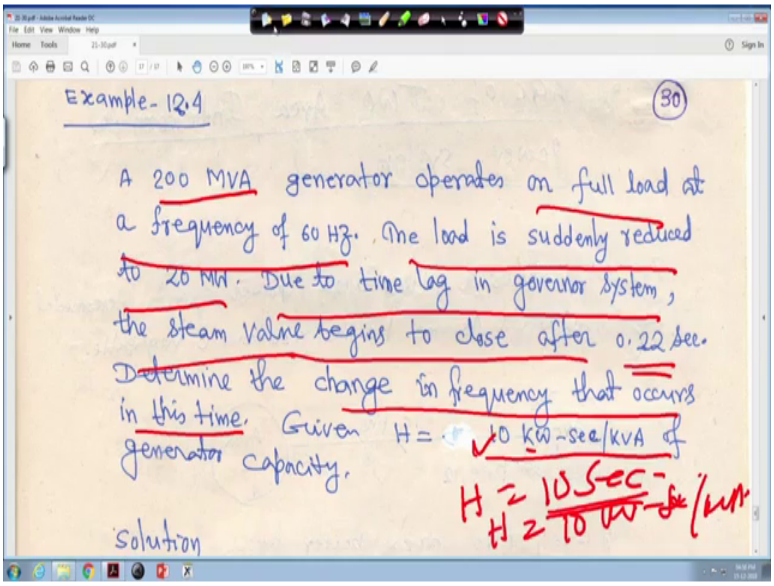

Now, another example that example 4 say a 200 MVA generator right, 200 MVA generator operates on full load at your at a frequency of 60 Hertz right. The load is suddenly reduced to 20 megawatt. The load reduction means that your frequency will increase or speed will increase right. But it will never lose synchronism due to time lag in governor system; the steam via the steam valve begins to close after 0.22 second right. So, we have to determine the change in frequency that occurs in this time given that the inertia of the generator 10 kilowatt second per KVA. This is your, what you call basically kilowatt or KVA is actually it is your dimensional crook dimensionless quantity.

So, H is equal to actually 10 second right. If given H is equal 10 second also and you can take like this that, H is equal to if it is given 10 your kilowatt upon KVA this 10 second. So, you have to you can write according to the looking into the system you can write, that is your 10 kilowatt second per KVA right. This way one can your what you call this way it is given. So, actually kilowatt by KVA is a dimensionless quantity. So, basically it is a second it is a second inertia constant right.

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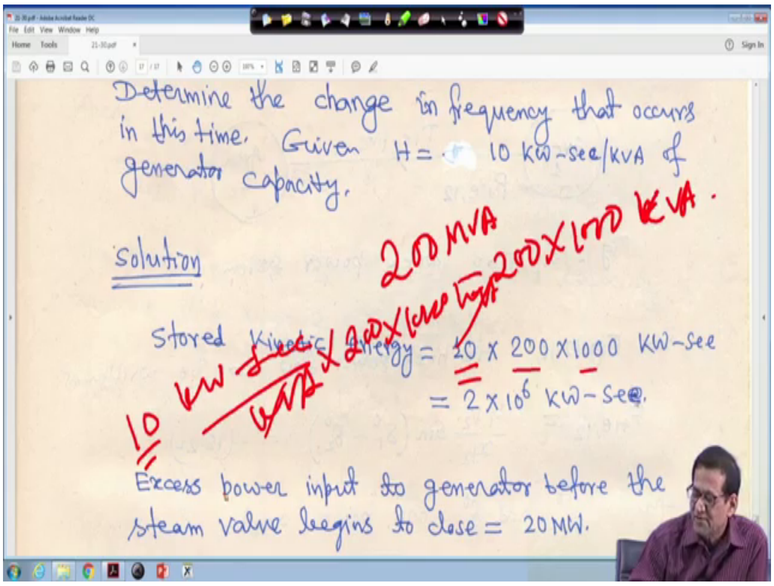

So, when will solve this problem, that is stored kinetic energy the rating your what you call the rating of the generator is 200 MVA right. So, that means it is 200 into your 1000 KVA right. So, that inertia stored kinetic energy is basically H into the rated capacity. So, it is 10 kilo what you call it is 10 kilowatt second per KVA, that is the H inertia into pr; that means, this one into 200 into 1000 right. That is what has been written at 10 into 200 into 1000 KVA. So, KVA KVA cancel actually finally, actually it is becomes your 10 into

200 this is actually KVA to mega MVA has been converted into KVA it is kilowatt second right is equal to 2 into 10 to the power 6 kilowatt second right.

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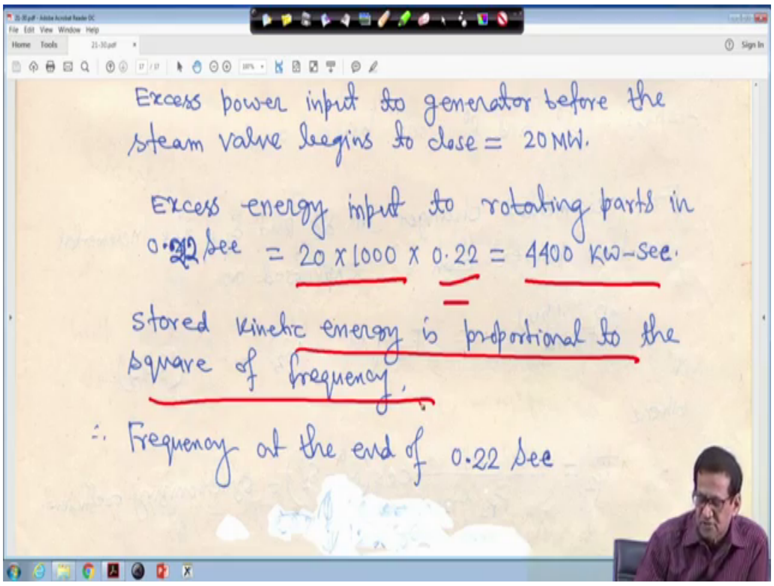

Next is, so excess power input to generator before the steam value begins to close 20 megawatt right. So, excess energy input to the rotating parts in 0.22 seconds, because if you look into the problem that the load is suddenly reduced to 20 megawatt. Due to time lack in governor system, the steam valve begin to close after 0.22 second right. Therefore, that your excess energy input to rotating parts right, in 0.22 second will be 20 megawatt convert it to kilowatt right. So, 20 megawatt multiplied by 1000 into 0.22. So, that is 4400 kilowatt second right. And now stored kinetic energy is proportional to the square of the frequency or speed we know square of the frequency.

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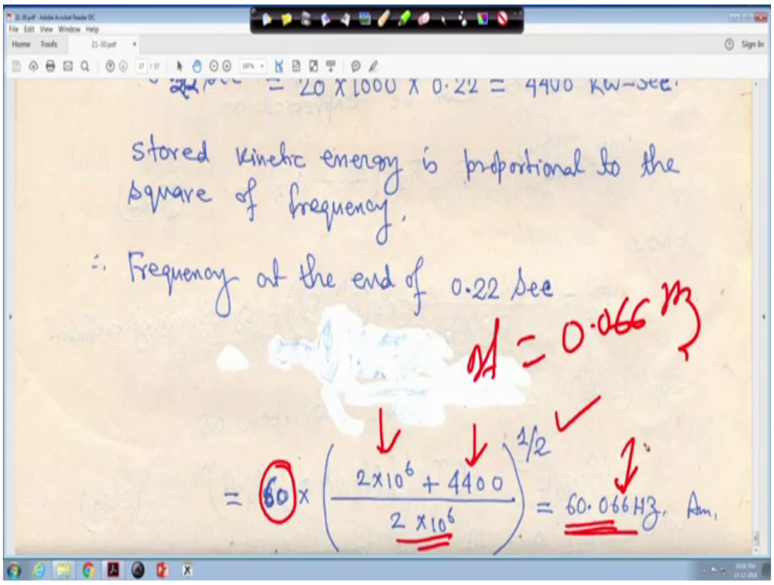

So, frequency at the end of 0.22 second directly you can make it right, using this relationship that is at the actually kinetic stored kinetic energy is proportional to the square of the speed; that means, your this is 60 into initially it was 2 into 10 to the power 6. Then, plus this your what total is 4400 divided by 2 into 10 to the power 6 to the power half right.

So, that will give you 60.066 Hertz. Because, kinetic energy is proportional to the square of the speed right. So that means, load has steep that 20 megawatt load has steep. So, frequency actually will increase that is why it is more than 60 Hertz, so see that 60.066 Hertz that means, its deviation actually 0.066 Hertz right this one right. So, this problem this two three problems we have seen now, will go to the your next one. So, AGC of two area interconnected power system.

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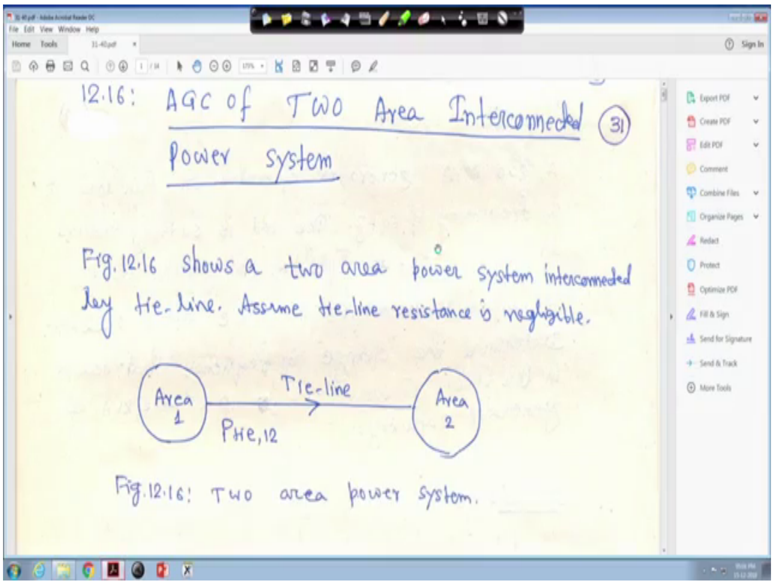

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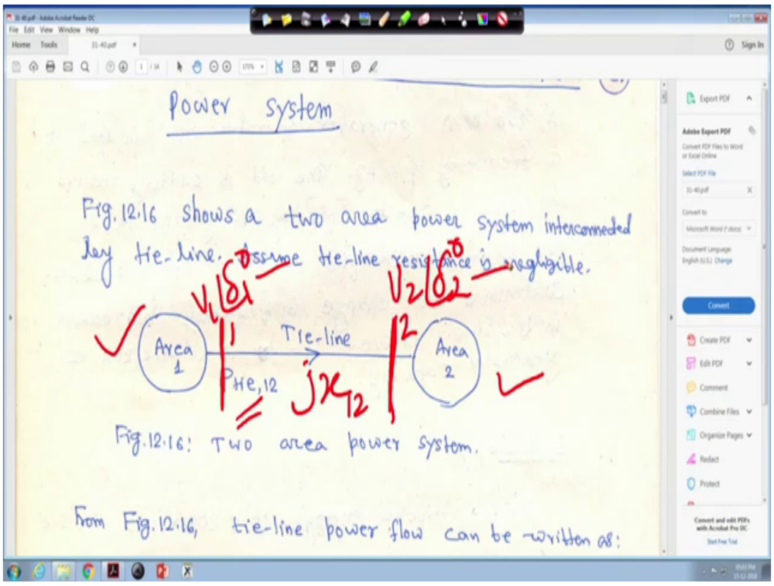

So, here it is suppose area 1 it is a power system area 2 interconnected by tie-line, I told you tie-line means three phase transmission line. And it is not so near, suppose you put to bus barrier. Voltage here is V 1 angle delta 1 0, and this voltage V 2 angle delta 2 0 right. And tie it has your tie-line has resistance and reactance, but we neglect the resistance and will consider only the reactance the x 1 2 this is bus this is 1 and this is 2 right. So, and power flowing from assuming a direction 1 to 2 that is P tie, 1 2 that is the schedule power flowing from area 1 to area 2.

So, suppose in the system there is some load disturbance. So, but we will assume we have discussed before that if real power load changes that it affects mainly the system frequency or speed hence the your voltage angle right. But leaves the bus voltage magnitudes actually unaffected therefore, if we assume some load disturbance is there for which your this delta 1 delta 2 change right, but V 1 V 2 will remain constant right. V 1 and V 2 both voltage magnitude will remain constant due to some change in the real power.

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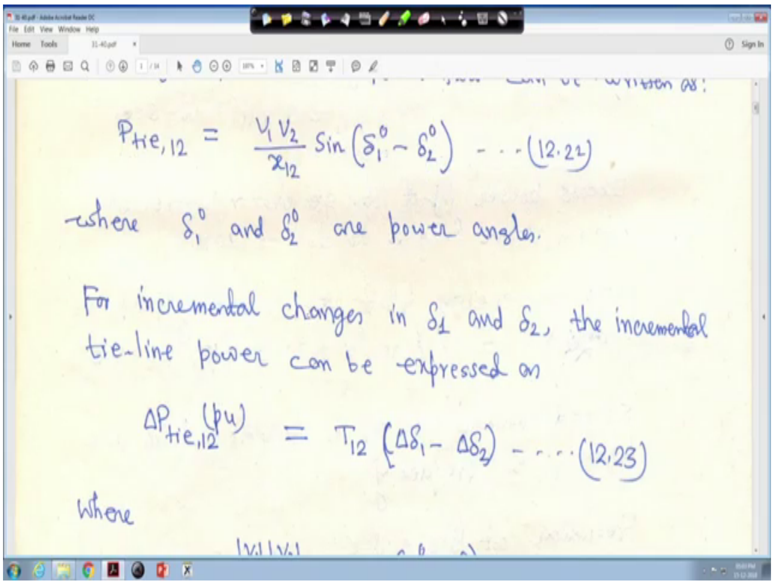

So, if it is so then we can write the tie-line power flow rather than your P tie, 1 2 I will make it suffix 0 that initially P tie, 1 2 superscript 0. So, P tie, 1 2 0 is V 1 V 2 upon x 1 2 sin, delta 1 0 minus delta 2 0 right. This you know also and x 1 2 is the reactants of the tie-line and V 1 V 2 will remain constant right. So, delta 1 0 and delta 2 0 are the power angles right.

Now, for incremental changes in delta 1 and delta 2 the incremental tie-line power can be expressed as. This is we are writing that delta P tie, 1 2 p u like this, but this one I will I will derive for you right. So, this P tie, 1 2 we actually 0 superscript I have given so it is given. Now, due to some just hold on; due to some due to some your disturbance that your things are changed.

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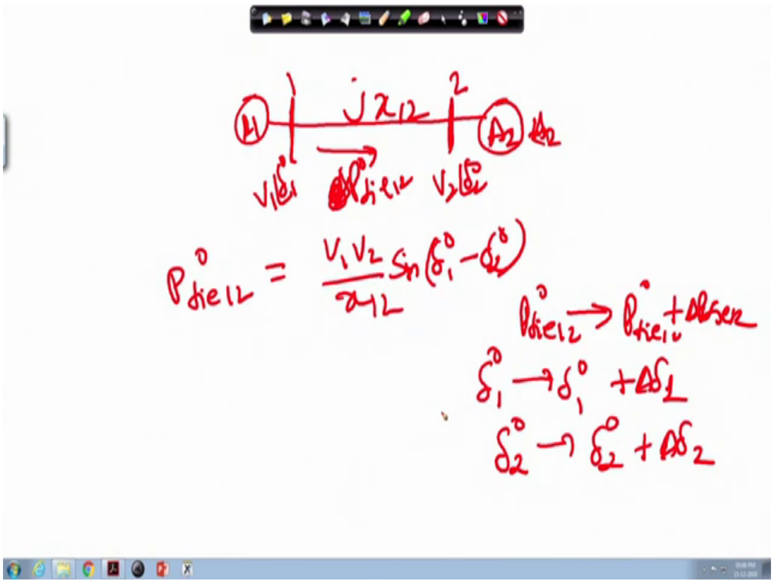

Suppose this is my area 1 right and this is my area 2 say we make A 1 and this is A 2 right, and this is your bus 1 and this is your bus 2 and voltage here is V 1 angle delta 1 0 and this is V 2 angle delta 2 0 right. Area 1 and this is my area 2 right and power is flowing through this is delta P tie initially schedule power 1 2 0 and reactants of this one is j x 1 2 right.

So, we from this we not delta P this thing P tie 1 2 0. So, we can write that your P tie 1 2 0 is equal to V 1 V 2 by x sin of delta 1 0 minus delta 2 0 this is x 1 2 right so this we know. Therefore, suppose due to some load is changing all these thing all the times. So, suppose due to some load disturbance real power load disturbance, now this delta P tie P tie 1 2 0 will change right. Because of this voltage magnitude will remain constant, but delta 1 0 and delta 2 0 also it will change.

So, for example, suppose then P tie 1 2 0 it change to your say P tie 1 2 0 plus delta P tie 1 2 right. So, similarly now delta 1 0 will be it will be changed to delta 1 0 plus delta delta 1 right. Similarly, delta 2 0 it will be changing to delta 2 0 plus delta delta 2 due to this. So, all this changes you incorporate here if you incorporate here. So, I am now I have I need lot of space. So, I am now deleting this one, but I rewrite only the let.

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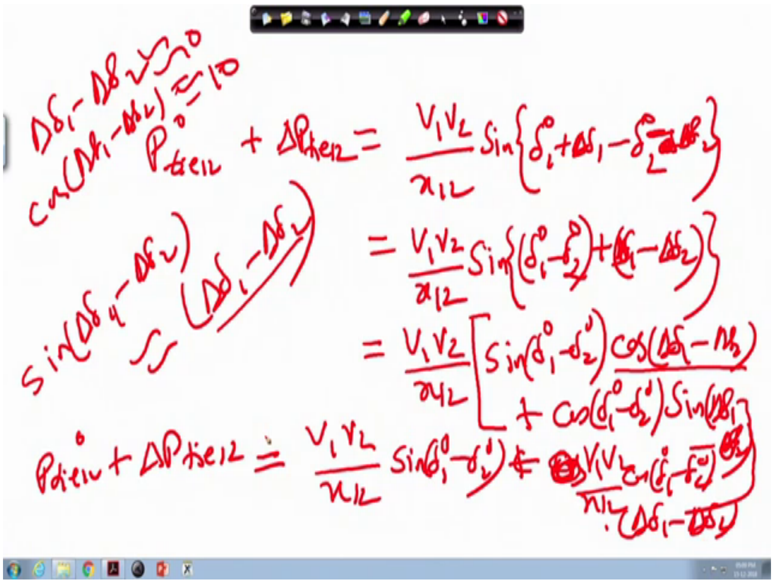

So, what you can write now that therefore, P tie 1 2 0 plus delta P tie 1 2 is equal to V 1 V 2 by x 1 2 sin of your delta 1 0 change to delta 1 0 plus delta delta 1 and delta 2 0 change to delta delta 0 minus your plus delta delta 2. So, it will be sorry it will be minus delta delta 2 right; that means, this one will be is equal to V 1 V 2 upon x 1 2 then, sin of your delta 1 0 minus delta 2 0 plus delta delta 1 minus delta delta 2 right.

Now, this one you expand this one you expand the sin a cos b plus cos a sin b. So, if you do so, it will be V 1 V 2 upon x 1 2 right. So, sin a then cos b right, then plus cos a your sin b right. So, this way you can this way you can write. Now, question is that delta delta term is very small right therefore, we can write delta delta 1 minus delta as it is very small it is approximately I mean 0 therefore, cos of delta delta 1 minus delta delta 2 it is basically 1. Similarly, as delta delta 1 minus delta delta 2 is very small; that means, sin of delta delta 1 minus approximately is equal to delta delta 1 minus delta delta 2. You know if theta is very small sin theta is equal to theta. So, therefore, sin of delta delta 1 minus delta delta 2 will be delta delta 1 minus delta delta 2 right. Therefore, this equation; that means, we can write like this that P tie 1 2 0 plus delta P tie 1 2 is equal to right so this term is 1. Therefore, it is V 1 V 2 upon x 1 2 sin of delta 1 0 minus delta 2 0 right.

Then this term actually, plus that cosine your plus V 1 V 2 upon x 1 2 cosine of delta 1 0 minus delta 2 0 into your delta delta 1 minus delta delta 2 right. Therefore, we can write I am I am just clearing this.

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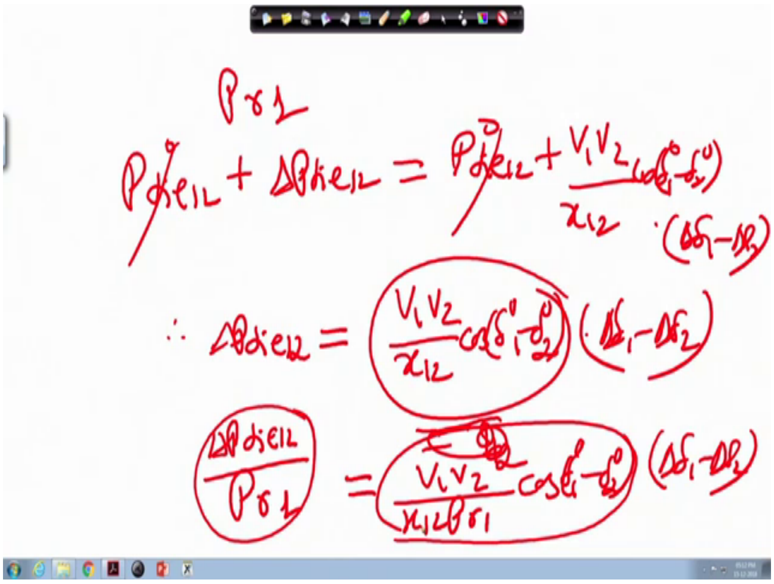

So, we can write P tie 1 2 0 plus delta P tie 1 2 right is equal to actually the first term will be of that the expression P tie 1 2 0 plus V 1 V 2 upon x 1 2 cosine of delta 1 0 minus delta 2 0 into delta delta 1 minus delta delta 2 right. So, this is actually your what you call that that your expression now left if you look into these then this one this one will be canceled right.

Therefore your delta P tie 1 2 is equal to V 1 V 2 upon x 1 2 cosine of delta 1 0 minus delta 2 0 into delta delta 1 minus delta delta 2 right. This term we define this term it is 1 to 2. So, this is equal to it we can write just hold on we will convert it to per unit right. So, this term actually we call synchronizing coefficient why it is called synchronizing coefficient that is a question to you I mean you should give the answer in the forum. So, now if the rated capacity of area 1 is say P r 1, so if you divide both side by P r 1 say rated capacity of area 1 P r 1 if you divide on both side then, delta P tie 1 2 divided by P r 1 is equal to V 1 V 2, x 1 2 P r 1 right cosine delta 1 0 minus delta 2 0 into delta delta 1 minus delta delta 2 right. That means, this is now in per unit and this synchronizing coefficient also it will be per unit because V 1 V 2 upon x 1 2 right.

So, basically it is expression of power I mean your what you call unit is power. So, this is also your what you call in per unit.

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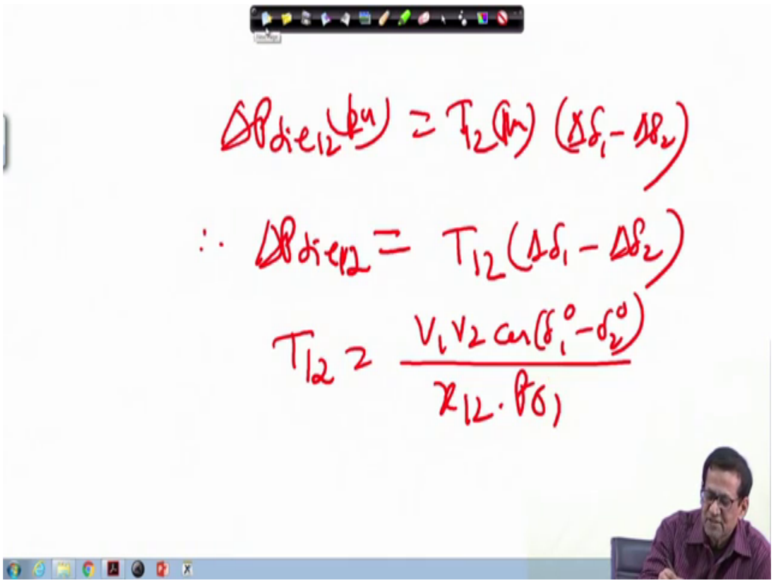

Therefore we can write, that delta P tie 1 2 it is in per unit is equal to T 1 2 of course, it is in per unit right into delta delta 1 minus delta delta 2 right. So, after that we will not use per unit again and again, but it is understandable. Therefore, in general we can write that delta P tie 1 2. So, we are not writing per unit again and again understandable T 1 2 that your delta delta 1 minus delta delta 2 right. Where T 1 2 is equal to V 1 V 2 cosine delta 1 0 minus delta 2 0 divided by x 1 2 into P r 1 right this is called synchronizing, this term is called synchronizing coefficient. So, now this is your T 1 2.

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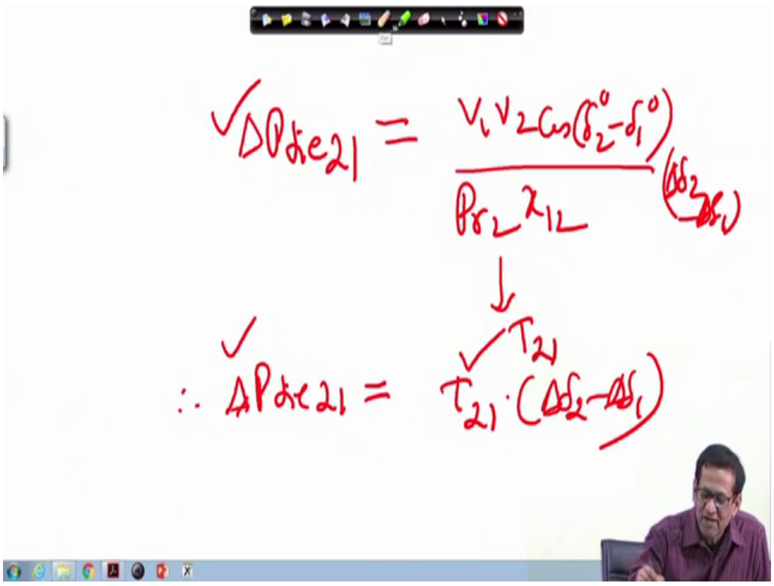

Similarly, your if we write delta P tie if you write, delta P tie 2 1 I mean 1 to 2 now 2 to 1 if you write it will be V 1 V 2 cosine delta 2 0 minus delta 1. In fact, cosine minus theta is equal to cosine theta. So, cosine delta 2 0 minus delta 1 0 or cosine delta 1 0 minus delta 2 0 it is same right. So, divided by in this case your what you call it will be P r 2 then your x 1 2 then, this side it will be delta delta 2 minus delta delta 1 because 2 to 1, that is why delta delta 2 minus delta delta 1.

So, this is actually T 2 1 right; that means, everything is in per unit this is also in per unit. Therefore, delta P tie 2 1 is equal to T 2 1 right into your delta delta 2 minus delta delta 1 right. So, this is actually your what you call your this relationship of 1 2 or 2 1 right. So, that everything is in per unit this is also per unit this is also per unit.

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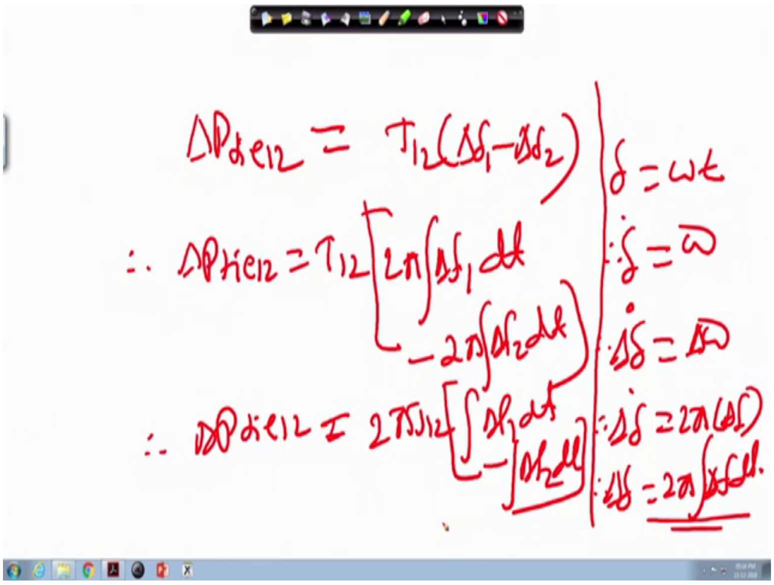

Now, that so first one when we write delta P tie 1 2 say expression when we write it is T 1 2 delta delta 1 minus delta delta 2 the first one. So, we know in general we know write generally, delta is equal to say omega T right. Therefore, delta dot is equal to omega; that means, or you can write delta delta dot is equal to delta omega or delta delta dot is equal to 2 pi into delta f right.

Therefore, delta delta is equal to 2 pi integral of delta f d t this is the general thing right. That means, that means, that delta P tie 1 2 is equal to T 1 2 then it is then delta delta 1 we will write; that means, delta delta 1 we will write that in the bracket I am putting 2 pi integral of delta f 1 d t right. Minus 2 pi integral of delta f 2 d t right. That means, delta P tie 1 2 is equal to your 2 is equal to 2 pi T 1 2 then integral of delta f 1 d t minus integral of delta f 2 d t right. So, this is the expression for delta P tie 1 2 right. Similarly, so I am cleaning this one right.

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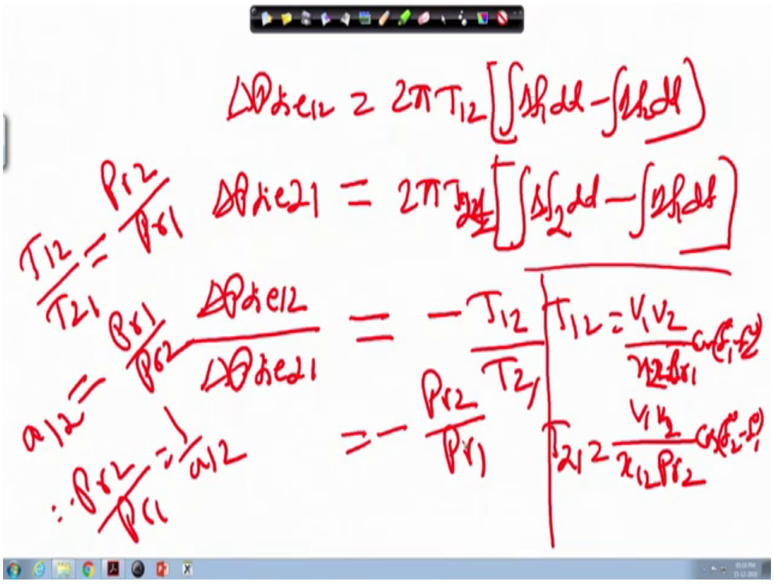

Similarly, so I write delta P tie 1 2 then is equal to 2 pi T 1 2 right and in bracket integral of del f 1 d t minus integral of del f 2 d t right. Similarly, if we right delta P tie 2 1 is equal to it will be same thing 2 pi T 1 2 by 2 2 r sorry 2 pi T 2 1, T 2 1 and here it will be it will be delta 2 delta delta 2 minus delta delta 1. So, first one will be delta f 2 d t minus integral of delta f 1 d t right.

Now, this two equation you divide one after therefore, we can write delta P tie 1 2 divided by delta P tie 2 1 is equal to right. Only if you look into that it will be minus T 1 2 divided by T 2 1. Because, 2 pi 2 pi will be cancel this will be cancel you take minus common it will be delta f 1 minus integral of delta f 1 d t minus integral of delta f 2 d t. So, it will become minus T 1 2 upon T 2 1 right. Now, we know that T 1 2 is equal to V 1 V 2 right by x 1 2 then, P r 1 and cosine delta 1 0 minus delta 2 0.

Similarly, T 2 1 is equal to V 1 V 2 it is 1 2 right. V 1 V 2 divided by your x 1 2 P r 2 then cosine delta 2 0 minus delta 1 0. Cosine delta 1 0 minus delta 2 0 is same is equal to cosine delta 2 0 minus delta 1 0 because, cos cos minus theta is equal to cos theta. Now, if you divide this T 1 2 if you divide this, T 1 2 by T 2 1 what you will get right. So, it is T T 1 2 divided by your T 2 1. So, if you divide it then it will be actually P r 2 by P r 1.

So, T 1 2 by T 2 1 is equal to P r 2 upon P r 1 right. That means, that means, this one this one it will be actually this one it will be minus of P r 2 by P r 1 right.

So, this is your what you call that your expression for ratio of this although in real unit delta P tie 1 2 delta P tie 2 1 same, but in per unit it is something different right it is coming that way. Now, you define a 1 2 that is we call area capacity ratio, a 1 2 is equal to you define P r 1 by P r 2 right. Therefore, P r 2 by P r 1 will be 1 upon a 1 2. So, here it will be actually minus 1 upon a 1 2.

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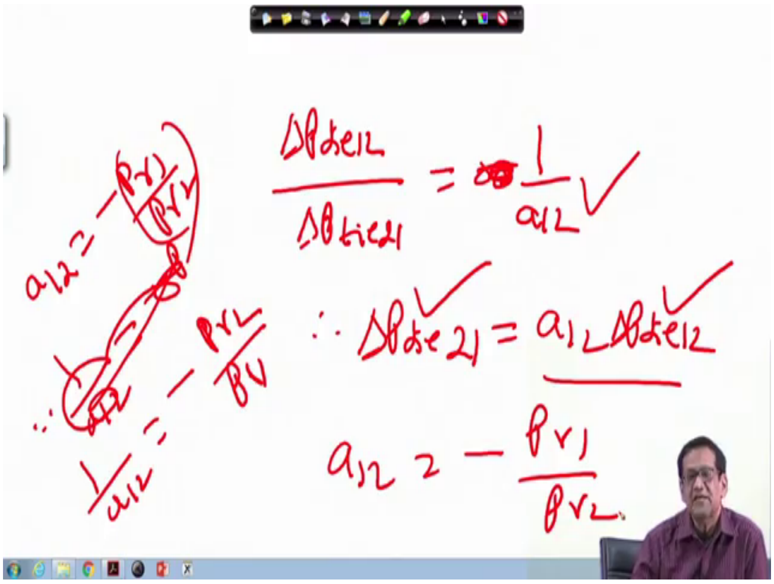

So that means, you can write that delta P tie 1 2 divided by delta P tie 2 1 is equal to minus 1 upon a 1 2 right. That means, your delta P tie 2 1 is equal to sorry it is 1 upon a 1 2. Because we have we have assumed that a 1 2 is equal to minus P r 1 by P r 2 not P r 1 by P r 2. You assume a 1 2 is equal to minus P r 1 upon P r 2. That means, 1 upon a 1 2 will be is equal to minus your what you call, that is your 1 upon a 1 2 is equal to my minus of your P r 2 upon P r 1 right.

So, that is why it is 1 upon a 1 2, but this one we define as a capacity ratio area capacity ratio, but with a minus sign right. You can take other way also no problem as long as block diagram concept is correct no problem right. Therefore, delta P tie 2 1 will be a 1 2 into delta P tie 1 2 right. But, note that it is in per unit it is in per unit, but in real unit your delta P tie 1 2 and delta P tie 2 1 they are same, but in per unit this thing has to be changed right. Because of both the areas rated capacity is same, then delta P tie 2 1 is equal to minus of delta P tie 1 2 right. Otherwise, this per unit thing this area capacity ratio you have to multiply it this one delta P tie 2 1 is equal to a 1 2 this thing. So, our a 1 2 actually minus P r 1 upon P r 2 right.

Thank you very much we will be back again.