Power System Dynamics, Control and Monitoring
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Lecture – 34
Automatic generation control conventional scenario (Contd.)

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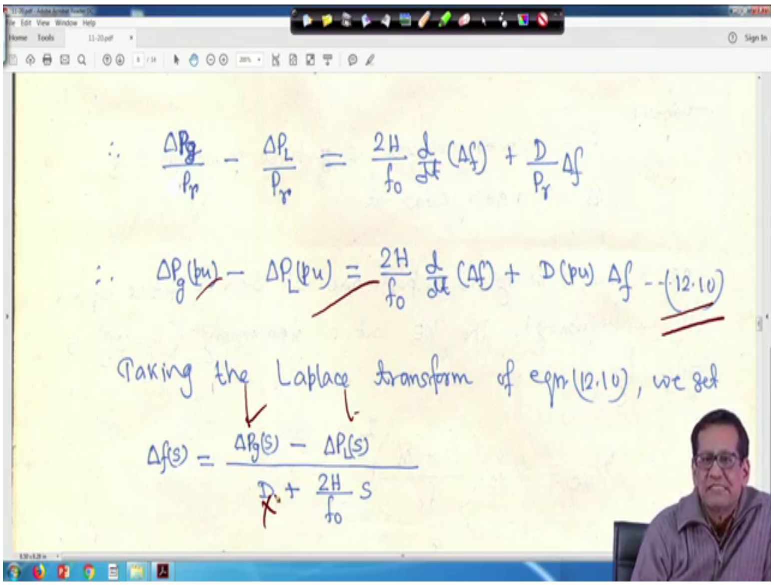

Now, we are back again. So, taking the Laplace transform on equation-10 right. If you take the Laplace transform and simplify, then you will get delta f s is equal to delta P g S minus delta P L S divided by D plus 2 H upon f 0 into S right. Later what we will do, these are all per unit, these are all per unit, so again and again here, here, so no and here will not mention the per unit again and again right, so but it is understandable. I mean from this point onwards everything is in per unit. If anything is real unit, it will be discussed, so this is your delta f.

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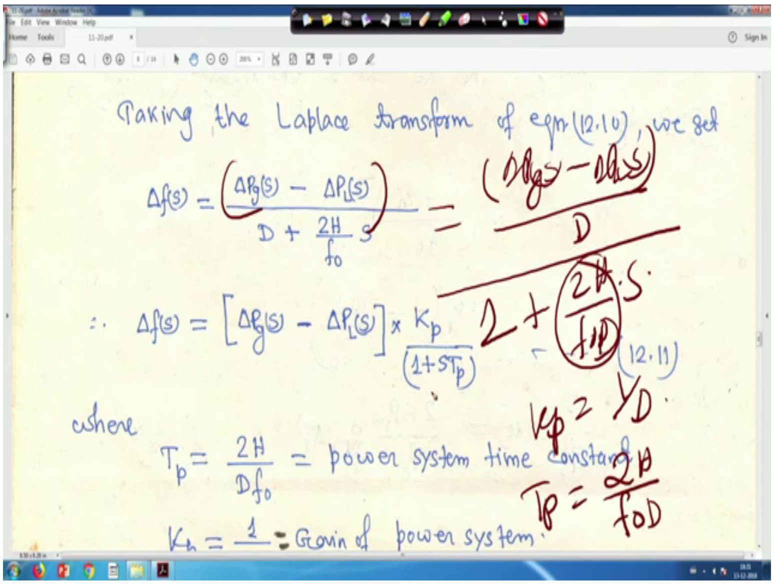

Now, this one, if you simplify, basically delta f s will be delta P g S minus delta P L S into K p upon 1 plus S T p that means, actually T p is these equation these equation right whatever it is, these equation a numerator and denominator you divide by D. So, this can be written as delta P g S is understandable put it minus delta P L S right divided by D, then divided it also [numerator/denominator] denominator also divided by D, so it will be 1 plus 2 H upon f 0 D into S right.

So, we assume K p if you assume K p is equal to 1 upon D, say let K p is equal to 1 upon D, and T p is equal to 2 H upon your f 0 into D right. This is your f 0 D, this is your T p that means, this equation can be written as delta P g S minus delta P L S into K p upon 1 plus S T p right.

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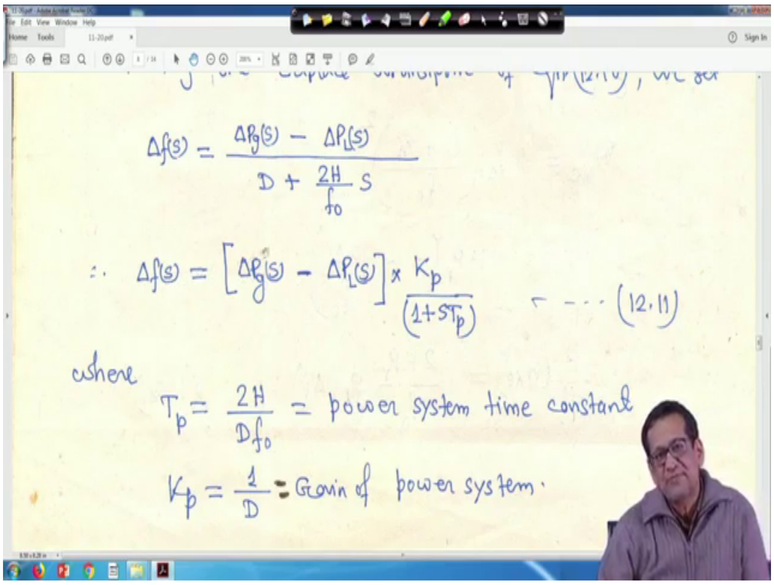

So, T p actually we call is a power system time constant, this is your this one is your power system time constant. And K p is equal to 1 by D is equal to gain of power system, this way we define this one right. So, so transfer function for that I mean generator load this relationship in between your generate generating power load, and that frequency deviation now has been completed right.

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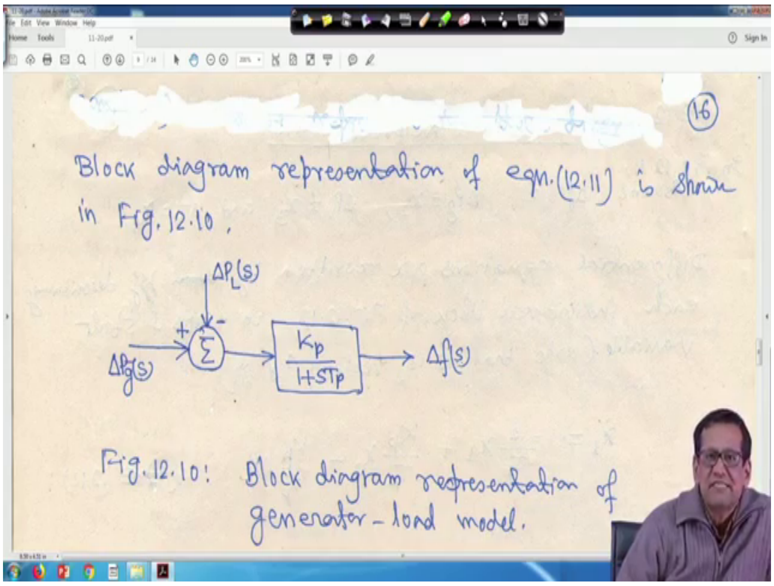

Now, that means for this portion I mean this equation that equation-11, this equation you can make it like this kind of block diagram delta P g minus delta P L into K p upon 1 plus S T p is equal to delta f. So, this way we can go for block diagram representation right.

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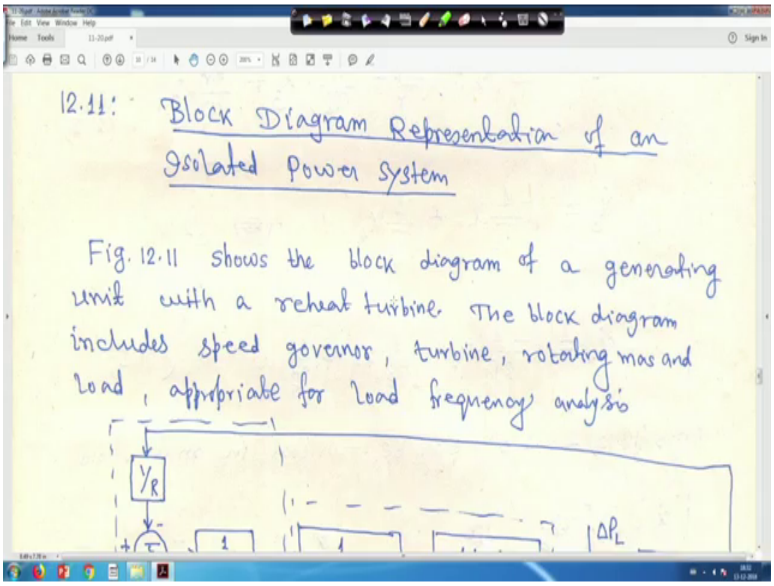

So, now so block diagram representation of an isolated power system.

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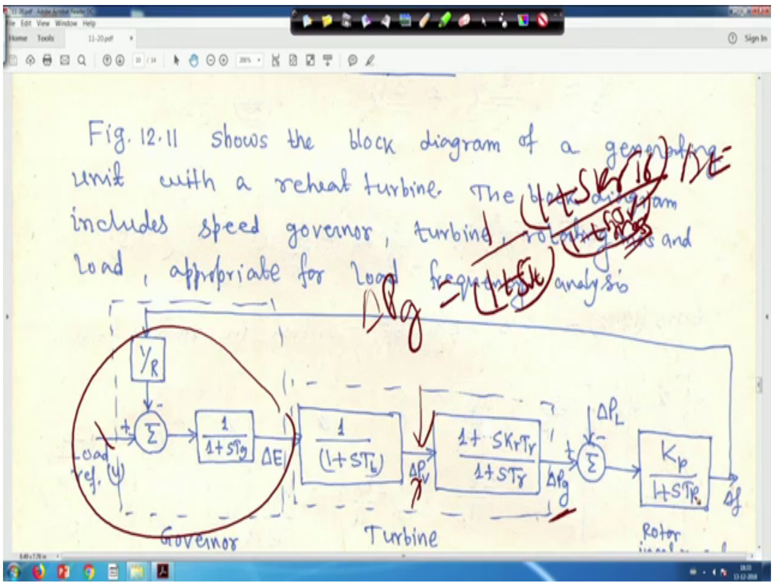

Now, what you have done the figure-11 shows the block diagram of a generating unit with a reheat turbine. The block diagram include speed governor, turbine, rotating your what to you call rotating mass right rotating mass, and your hold on is rotating mass, and load right, appropriate for load frequency analysis.

So, we have seen that how to link that modeling, it is basically modeling how to link. So, this is my governor, this is load reference set point. And we have seen also that your delta your what you call that 1 plus S T t and it is your what to you call this intermediate point, we are making your delta P V, because we have seen when we try to develop that you are what to you call reheat turbine modeling. So, we have seen that delta P g is equal to 1 upon 1 plus S T t into your 1 plus S K r T r divided by 1 plus S T r right into your delta E.

So, we have to make it in state variable form so these two blocks split it right. And in between this one state variable is taken that is delta P V. And this is delta P g is already output is there, and minus P L into K p upon 1 plus S T p right. And that is your delta f, but if this delta feedback has come here 1 upon R, this minus this is plus right. So, this part actually is a governor part right. And this part is actually turbine part, and this is actually power system part we call right.

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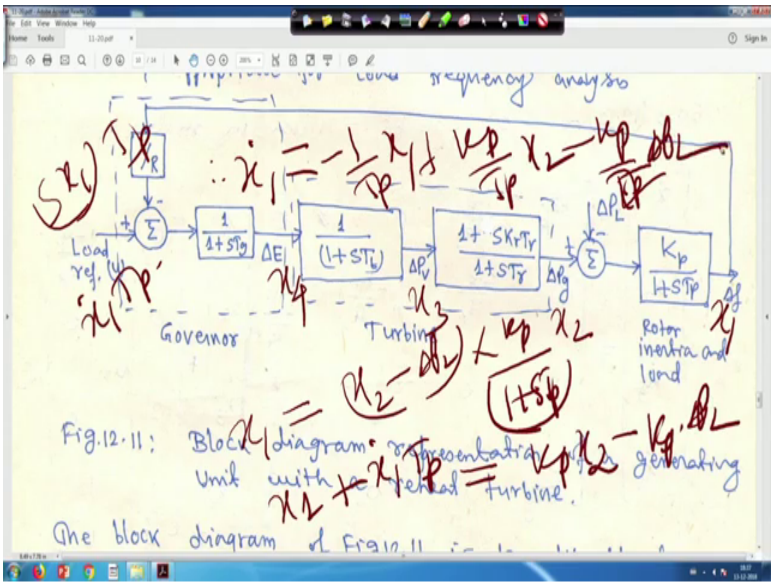

So, so this is so this is rotor inertia and load together we call this is actually power system part power system right. So, this is if you look into that if you to look into that there are four-state variable, this is one, this is one two, this is three, and this is four, there are four-state variable right.

So, we have to write down those equation in the state space form, so that mean x 1 dot, x 2 dot like this. So, if it if you just one minute, if you want to I mean just over writing on it, if you want that you are only non-reheat turbine, then this block should not be there for non this will directly we delta P g.

In that case, you will have three-state variable this one, this one, and this one. If you do not consider reheat, if you consider only non-reheat turbine, then only three you are what you call that you are three block should be there, this one, this one, and this one. And this is actually delta P g output, this should not be there right this block should not be there. So, now state variable analysis, we have to go for their right.

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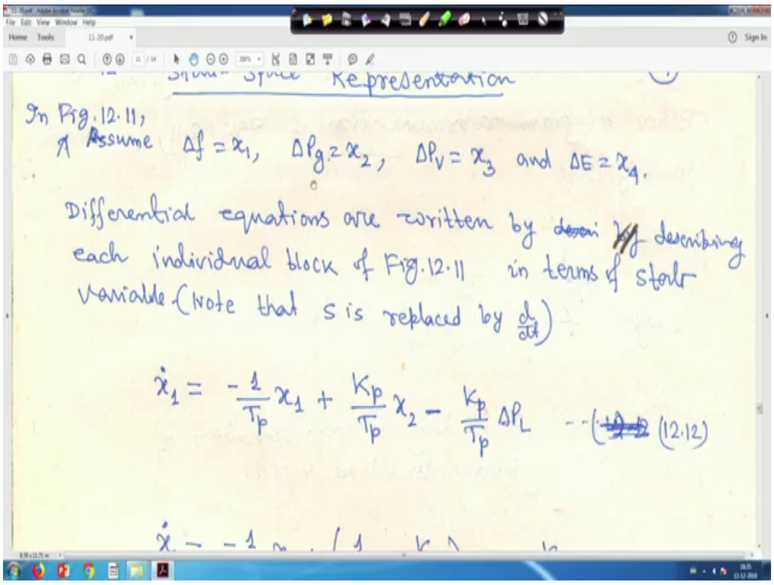

So, so delta f we have taken x 1, delta P g x 2, delta P V x 3, and delta E is equal to x 4. Now, we have taken just one I am showing, other I think you can do it. One assuming all initial conditions are 0, this is x 1, this delta f x 1, this is my x 2, this is my x 3, and this is my x 4 right this is given in the next page.

So, when you write this equation state variable equation right, so we can write and this is your load delta P L right. So, you can write I am writing here only all over writing on it, I think it you can see it x 1 is equal to this is x 2, and this is plus x 2 minus delta P L into K p upon 1 plus S T p right.

So, now if you cross multiply, so it will be x 1 it will be x 1 plus it is S x 1, here I am writing separately S x 1 into T p. But, S x 1 is nothing but x 1 dot right, so it is nothing but x 1 dot into T p right. So, S x 1, it is nothing but x 1 dot into T p right is equal to this is your what you call this is your K p x 2 minus K p into delta P L right.

Therefore, from here you can write your x 1 dot, if you write here from x 1 dot is equal to this x 1 will go to the right hand side and divide by T p, it will be minus 1 upon T p x 1 right plus K p upon T p x 2 right minus K p upon T p your delta P L. So, this way you can write, so that is why that is why you have written x 1 dot is equal to your minus 1 upon T p x 1 plus K p upon T p x 2 minus K p upon T p delta P L equation this is 12 right.

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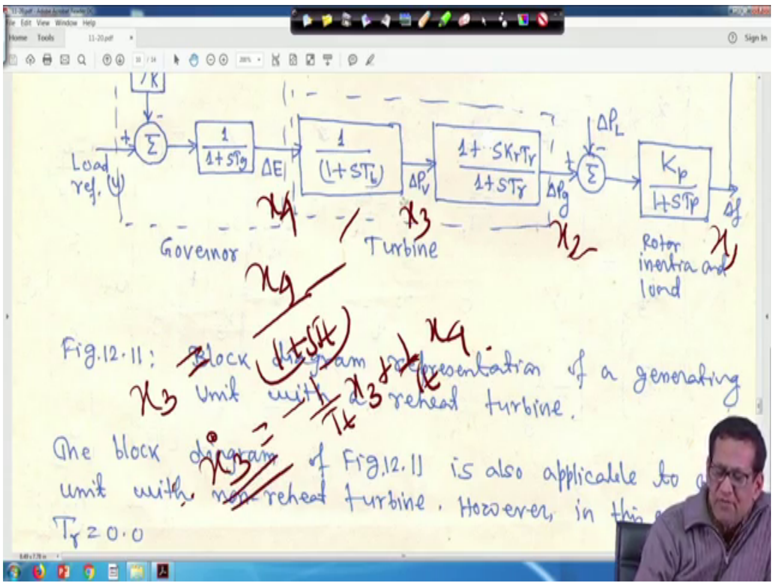

So, one more I have to show you, because one derivative term is there in the numerator in this block. So, if it is x 2 right first thing is that if it is x 2 and this is x 3, so what you have to do is for this is x 1, this is my x 2, this is x 3, and this is x 4 right.

So, in this case what you will do that x 2 is equal to your x 3 into this term, but there you need x 3 dot will come. So, first what you will do, first find out x 3 x 3 dot. So, when you write x 3 dot, so x 3 is equal to x 4 upon 1 plus S T t I mean this one this block only. If you cross multiply, then it will be x 3 dot is equal to we call S into x 3 x 3 dot, so x 3 dot will be basically minus 1 upon T t x 3 plus 1 upon T t x 4 right. So, x 3 dot can be obtained from here right.

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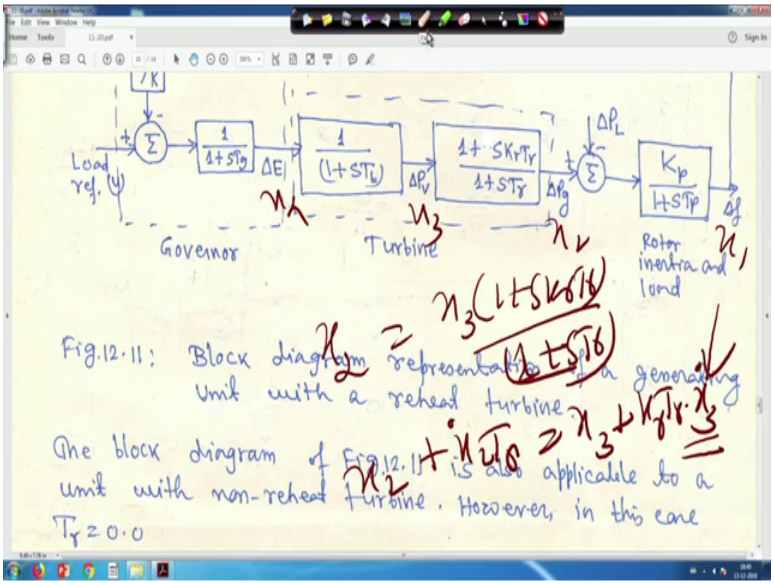

Next what will do take this equation this is my x 1, this is x 2, this is x 3, and this is x 4, so x 3 dot we have seen. Now, x 2 is equal to then, this x 3 into 1 plus S k r T r upon 1 plus S T r right.

Now, if you cross multiply, it will be x 2 it will be x 2 plus x 2 dot T r is equal to multiply this one x 3 plus S into x 3 that is x 3 dot that means, K r T r into x 3 dot right. So, to eliminate this x 3 dot, you have already got the equation of x dot is equal to minus 1 upon T t x 3 plus 1 upon T t x 4 that we will substitute here right such the right hand side will be three of any derivative term right. Then all x 1, x 2, x 3, we will get then x x 4 is equal to automatically we will get it right. So, this is for your x 1, x 2, x 3 right dot.

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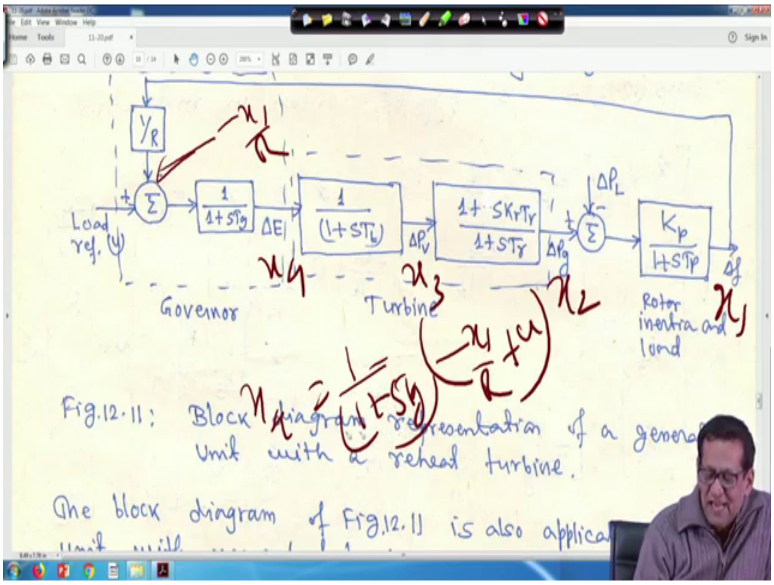

Now, x 4 is this one is your x 4, this one is your x 4, this is x 1 again I am writing x 1, then you will go to that final thing this is x 3, and this is x 4 right. So, here also x 4 is equal to you can write, this is my u.

And this x 1 is coming here, so here it is minus x 1 upon R right. So, it is basically x 4, your what you call x 4 is equal to 1 upon 1 plus S T g right into minus x 1 upon R plus u right. So, just you have to simplify, and you will get a cross multiplication and you will get the x 4 dot right.

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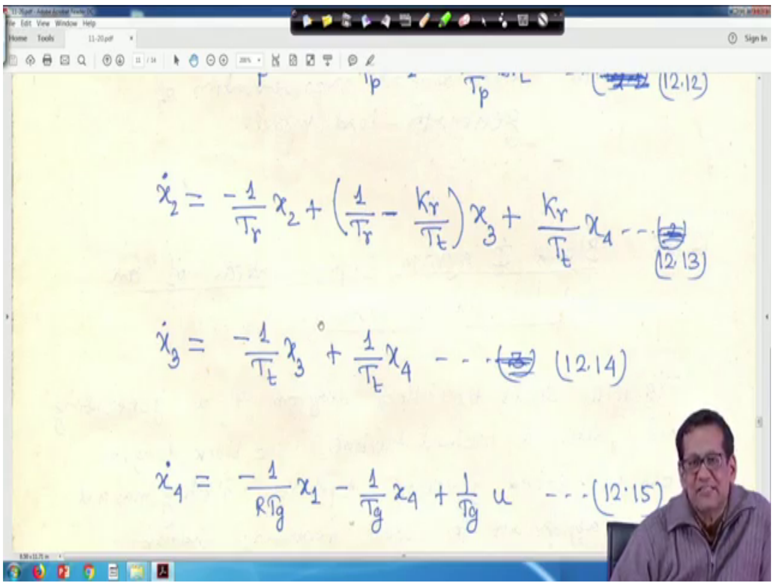

So, that is why, we have written that x 1 dot, x 2 dot, your x 3 dot, and x 4 dot. So, these all these equation 12, 13, 14, and 15 right. So, all this equations are written first you derive of your own right.

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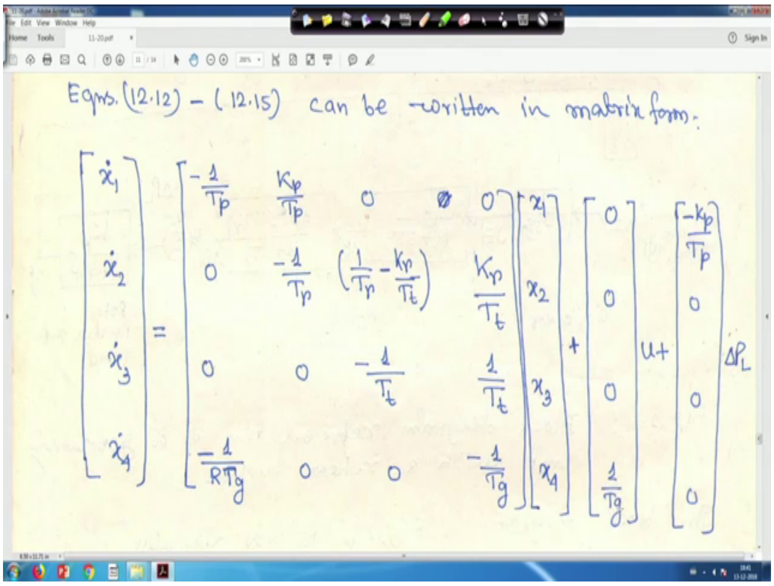

Once you get all these equations right, it can be written in the matrix form that is your x 1 dot is equal to x 2 dot, x 3 4 dot all put in this matrix form. So, this is actually 4 into 4 matrix into x 1, x 2, x 3, x 4 plus your all will be all the first three equation no u is present. So, only last one is there that is 1 upon T g u. And all the first equation the delta P L is present, all other equations it is delta P L is not there, so all 0 0 0, this is also 0 0 0, this is 1 upon T g.

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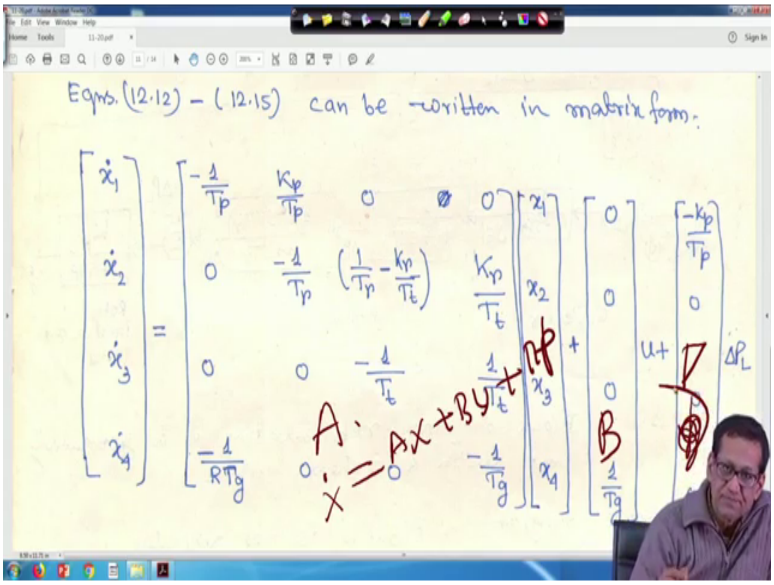

So, this matrix this matrix we call this matrix is A 1 right, and this is B right, and this is we call gamma right. So, A is a 4 into 4 matrix right, B is 4 into 1, and gamma is 4 into 1 right. So, this equation can be written in this form that x dot is equal to A X plus B U plus gamma p or this gamma rather than do using this this gamma, gamma p right. So, this is actually in the state variable form.

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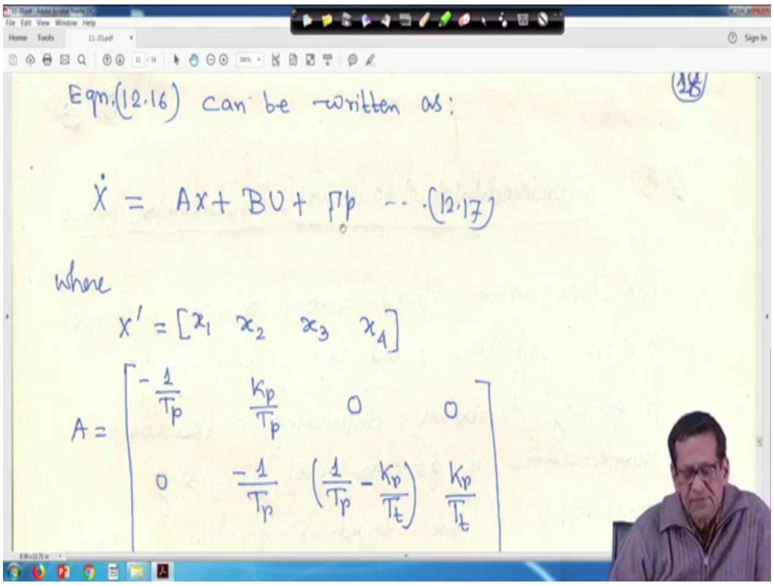

Now, we can write x dot is equal to A X plus B U plus gamma p.

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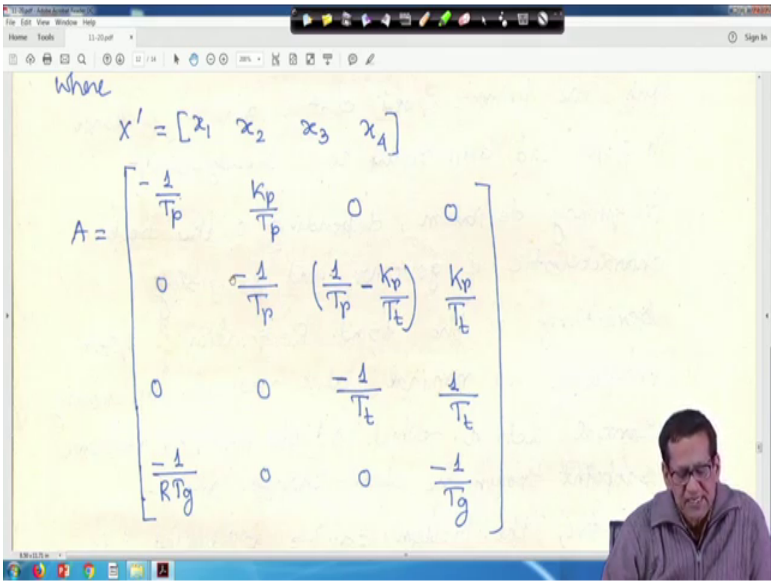

So, this is equation-17 or four-state variables are there x 1, x 2, x 3, x 4, and this is our A matrix right this is A matrix. Now, how you know that system is stable. What will do is that for A matrix, you find out the eigen values. If all the eigen values real part lying on the left top of the explain, then your system is stable right.

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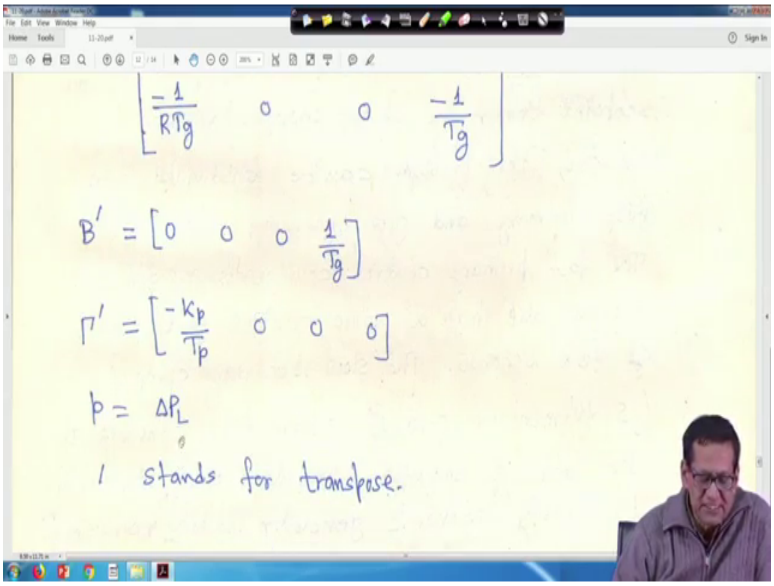

And B dash that is transpose 0 0 0 1 upon T g. And gamma dash that is transpose minus K p upon T p 0 0 0 right. And p is equal to disturbance that is delta P L. So, this equation whenever we are writing your p this p gamma p, p actually is a delta P L right.

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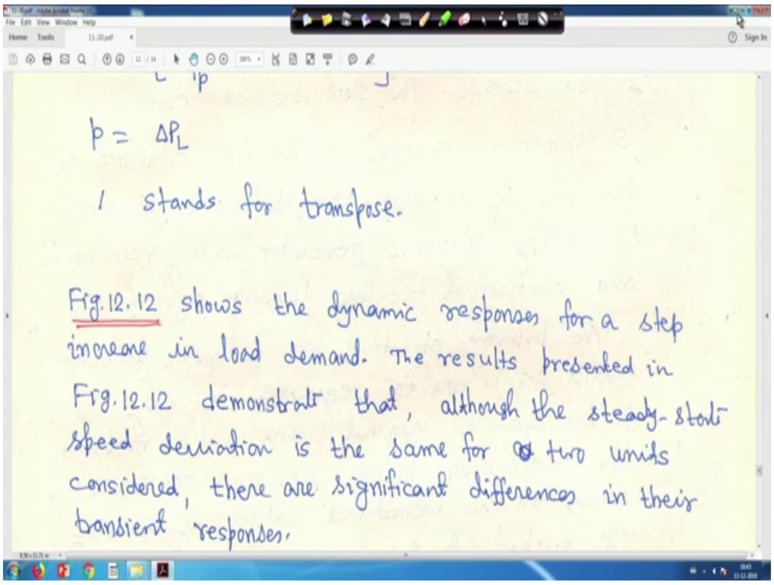

So, so figure-12 shows the dynamic responses for a step increase in load demand. So, I will show you the dynamic response is just hold on right.

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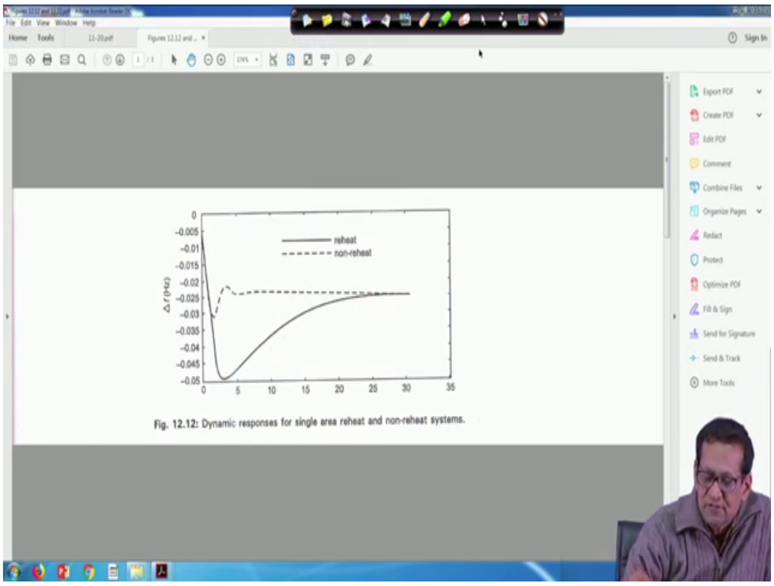

This is actually figure-12. So, this response actually for although steady state error remains same, but this continuous line this is for reheat turbine right. And when that and when the transfer function, you are what you call is drop that 3 into 3 model, this is for non-reheat turbine the dash one right. And frequency deviation for some parameter it is given right reheat and non-reheat.

Steady state value is same, but for reheat case pick deviation is more as compare to the your non-reheat one right, but there steady state value will I mean remain same right. So, this is your this is the diagram. Now, again I will go back to this one. This is our that your what you call A, B dash, and gamma. And this is so I showed you the dynamic responses also right.

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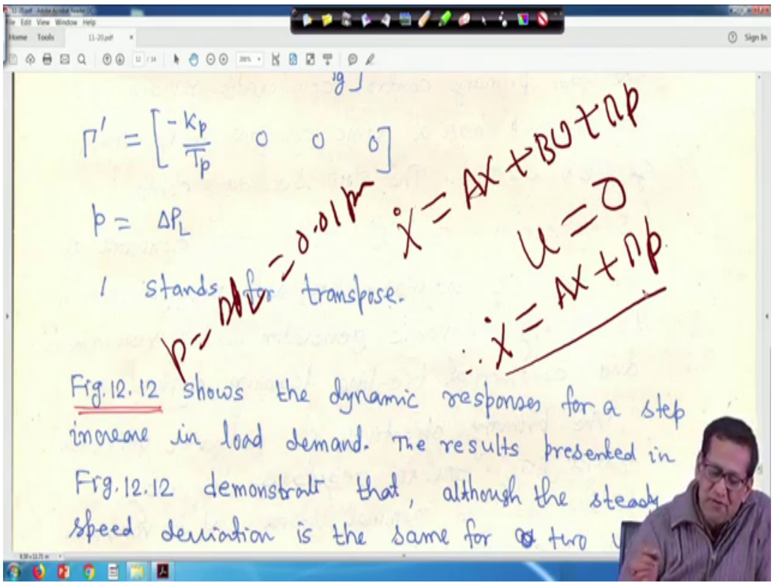

Now, another thing is that before moving to that fundamentals of automatic generation control. Another point is that that we know that x dot is equal to A X plus B U plus gamma p right. And the responses which was shown that is when u is equal to 0, there was no control signal right u is equal to 0 that means, my X dot is equal to A X plus gamma p. And the responses was shown for p is equal to delta P L, and it was taken as a 0.01 per unit 1 percent stay for change right.

Now, you from final value theorem, you can easily find out the steady state your what you call the steady state values right I have for all the state variables, but here also from this equation also when your system is uncontrol, you also you can find out the steady state values how.

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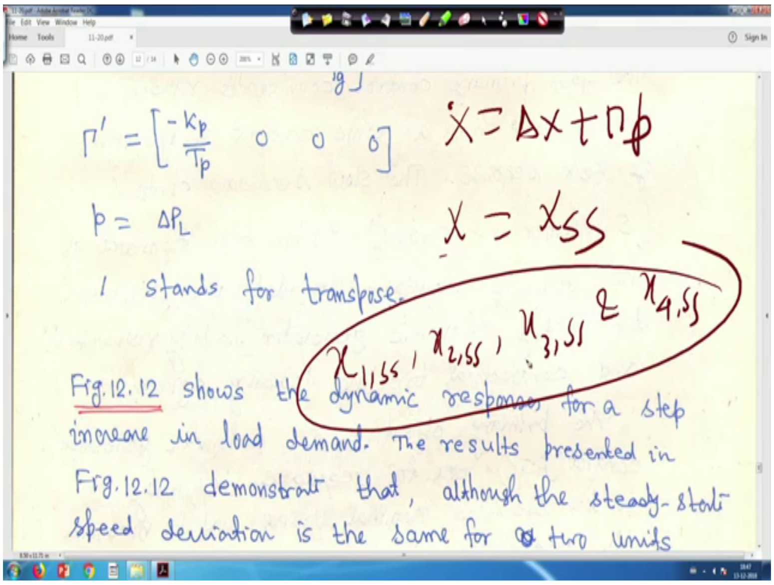

Now, at X so when U is equal to 0, X dot is equal to X plus gamma p. So, I will write here when U is equal to 0, A X plus gamma p right. Now, your X is equal to a steady state X is equal to X s s the steady state value that means X means all the state variable that means, x 1 s s, x 2 s s, x 3 s s, and x 4 s s right. So, all the study your what to call steady state value of all the state variables.

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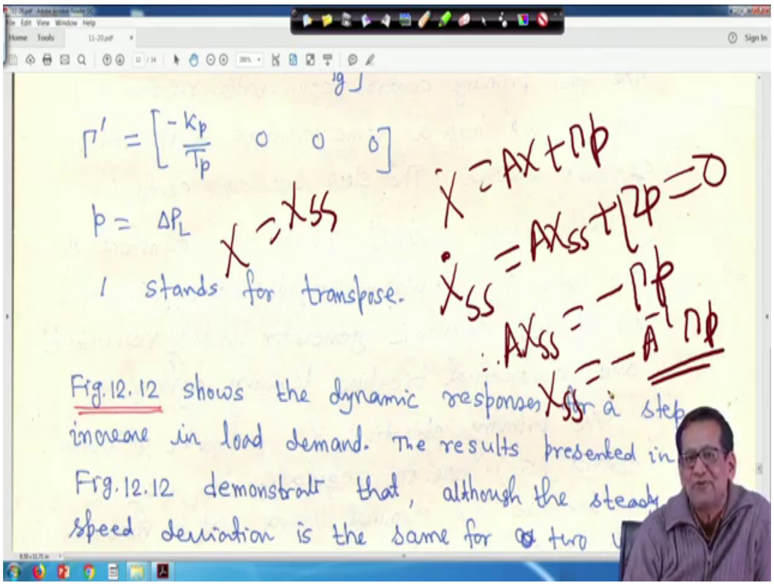

Now, when all these things reach to the steady state, so what will happen to the derivative? Derivative will be 0, when the reach to the steady state all the state variables, so that means sorry so that means so I can we can write down again that X dot is equal to A X plus gamma p, but X dot X is equal to steady state X is equal to X s s.

So, we can write here, then you substitute X s s dot is equal to A X s s plus gamma p right. But, a steady state that all the state variables are derivative will be 0 that mean this one should be is equal to 0 right that means, A X s s is equal to minus gamma p right or multiplied both side by a inverse, then X s s will be minus a inverse gamma p that means, that if A inverse exist for any system, for these all the state all the steady state value of all state variable will be known.

So, simply if you can put it in your Mat lab, and if A inverse exist for the system, then x 1, x 2, x 3, x 4, n number of state variable steady state value all will be calculate all it can be computed using this formula X s s is equal to minus A inverse gamma p right. So, this is the way how we can do it right.

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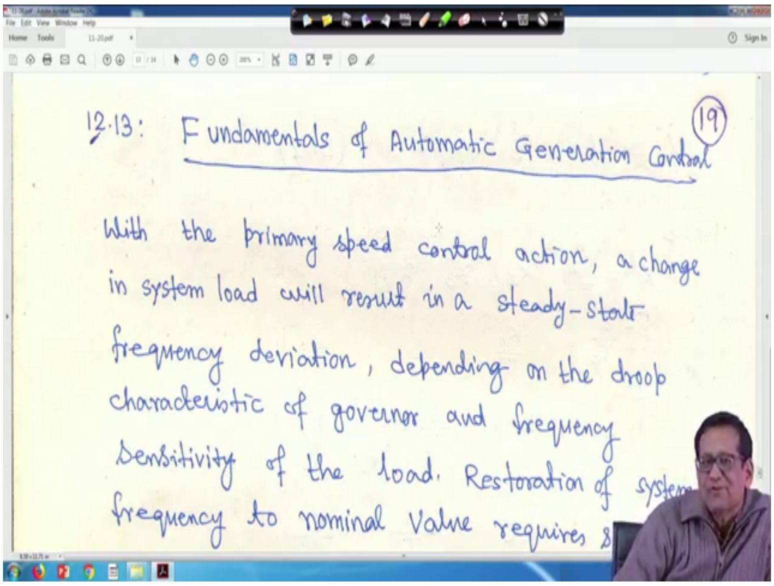

So, next is the fundamentals of automatic generation control.

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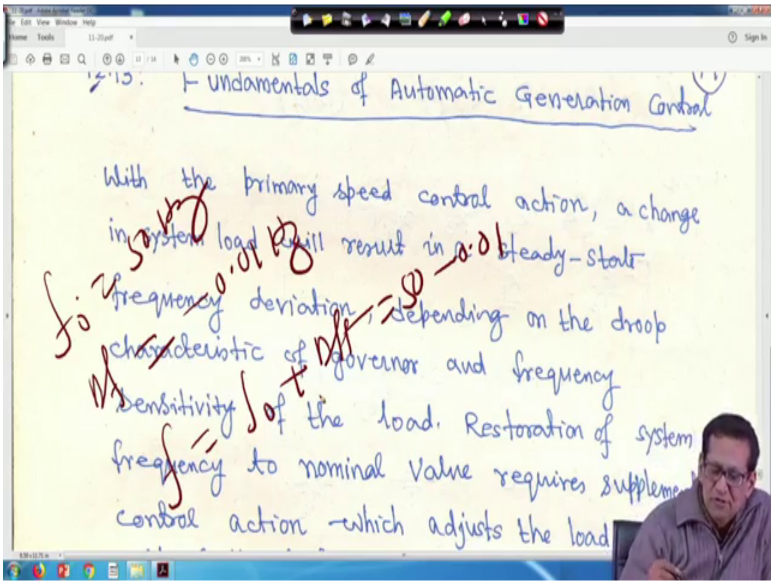

So, with the primary speed control action, actually if primary your when primary controls are later we will see later we will see primary speed control action, a change in system load will result in a steady-state frequency deviation that means, if the primary speed control is there that is governor droop parameter r, so you for a state load disturbance there will be a frequency deviation.

Frequency deviation means, suppose initially it was operating your at f 0 is equal to say 50 hertz right. So, after load disturbance, it is not making the deviation to 0 it is showing some value say some delta f is equal to say we got minus 0.01 hertz right.

So, this is delta f that means, what is the frequency as steady-state. So, frequency as steady-state will be f 0 plus delta f right that is equal to 50 minus 0.01 right. So, this is your what you call that your frequency right, but that means it is not exactly at 50 hertz, but it in less than 50 hertz for increase of the load same will happen for decrease of load of that is frequency will increase right.

So, so depending on the actually depending on that value of that you are what you call the droop characteristic of governor and frequency sensitivity of the load that is the D parameter, it depends on the R, and it depends on the D right.

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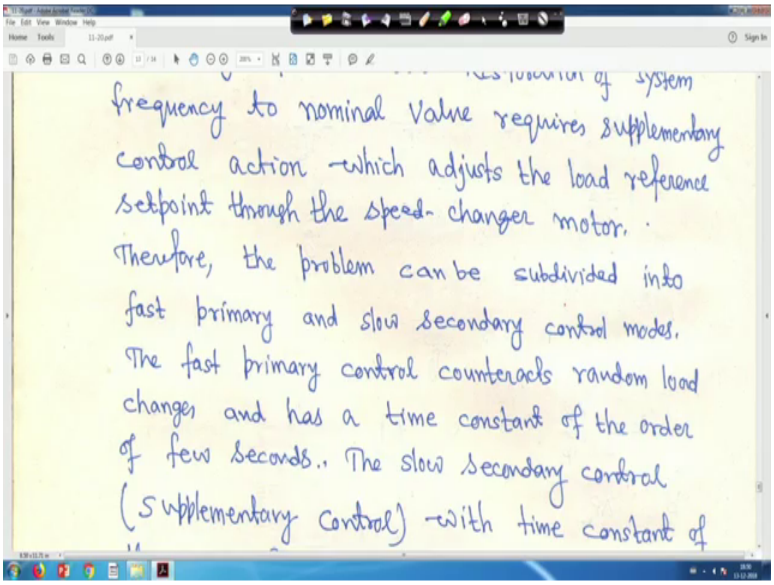

So, restoration of system frequency to nominal value require supplementary control action right, which just hold on. So, your what you call which adjust the load reference set point through the speed changer motor. Therefore, the problem can be subdivided into fast primary, and slow secondary control modes right.

The fast primary control counteracts the random load changes and has a time constant of the order of few second right. So, primary control actually your what you call your it will faster one right. And as a the slow secondary control that is a supplementary control with time constant of the order of minutes actually regulates the your what you call generation to satisfy economic generator loading requirements, contractual tie-line loading agreement that we will see later.

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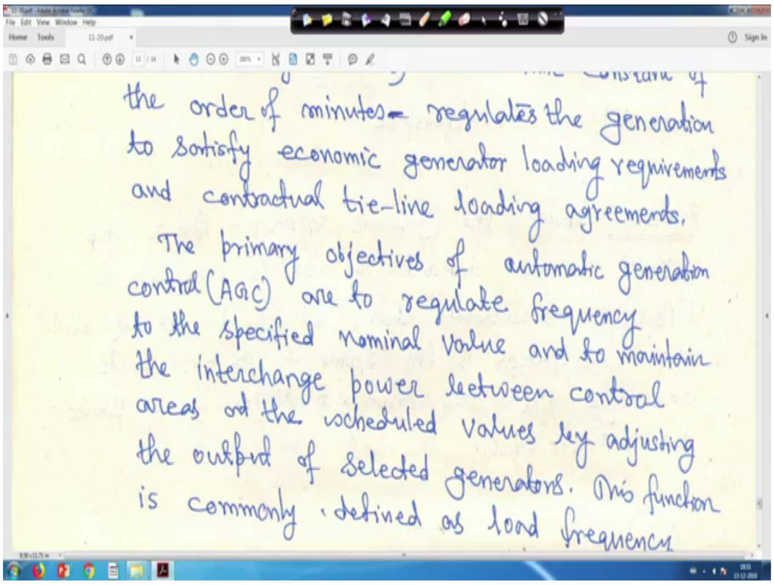

The primary objective of automatic generation control that is AGC are to regulate frequency to a specified nominal value and to maintain the interchange power between control areas that means, at the schedule value by adjusting the output of selecting selected generator that mean, many power systems are interconnected together right. And they have some schedule interchange power that is that (Refer Time: 21:36) interconnected line, so we call tie-lines right. So, this function is commonly what you call that by adjusting the output of selected generators, this function is commonly defined as load frequency control right.

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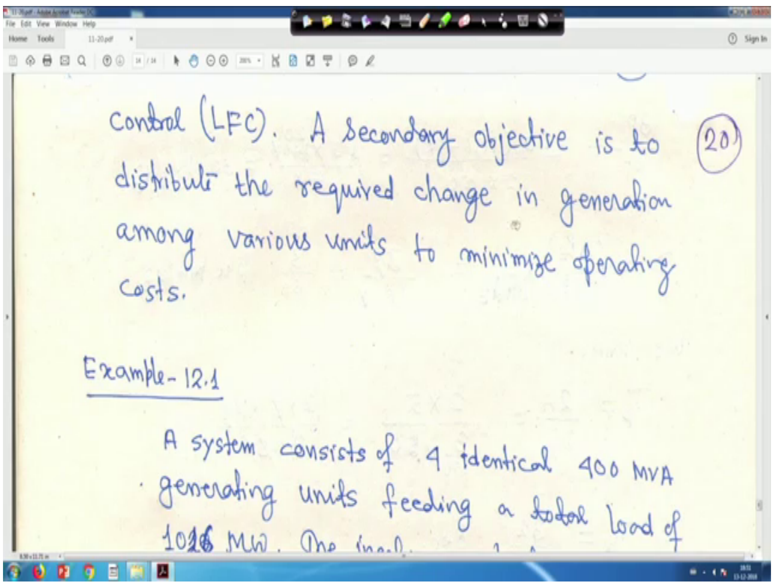

A secondary objective is to distribute the required change in generation among various units to minimize operating costs that means, idea is something like this. So, in suppose when economic load dispatch is not there, so automatic generation control is equal to load frequency control we can tell.

But, suppose you have a few control interconnected areas suppose in a particular area there is in increase of load demand say 100 megawatt. And suppose you have three or four different generating units. So, from economic load dispatch, you know that that to minimize the fuel cost that 100 megawatt you have to your optimally you have to distribute among all the generators from the economic load dispatch such that you are fuel cost is minimum.

So, if that your you are what you call that you are apart from you are your this is load frequency control plus economic load dispatch is equal to your automatic generation control. But, if economic load dispatch is not dispatch is not there, then we call it has automatic generation control is equal to load frequency control right. So, much more will come, but before that we will see simple example.

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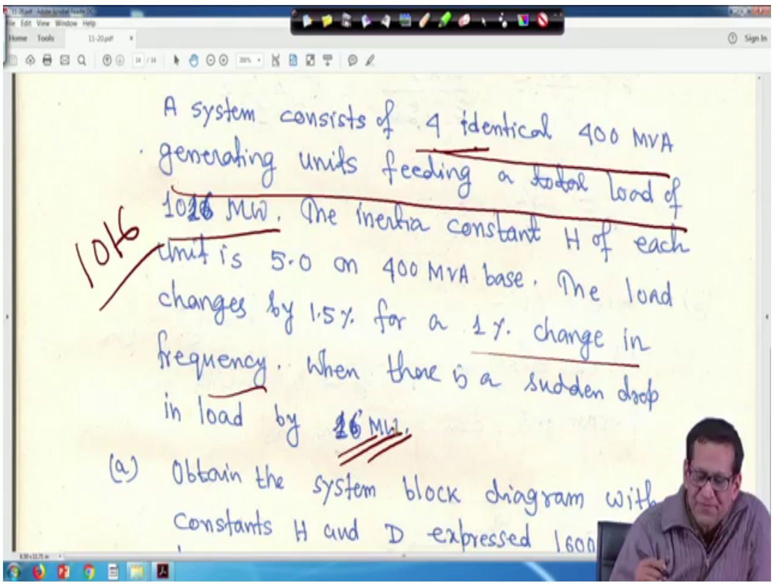

So, a system consists of 4 identical 4 identical 400 MVA generating units feeding a total load of 1016 megawatt this is 1016 megawatt right. The inertia constant H of each unit is 5 on 400 MVA base. So, we have say H means, it is in second right. The load changes by 1.5 percent for a 1 percent change in frequency. This also we have seen how to find out r.

When there is a sudden drop in load by 16 megawatt, this was 1016, this is 16 megawatt just to make that easy calculation right.

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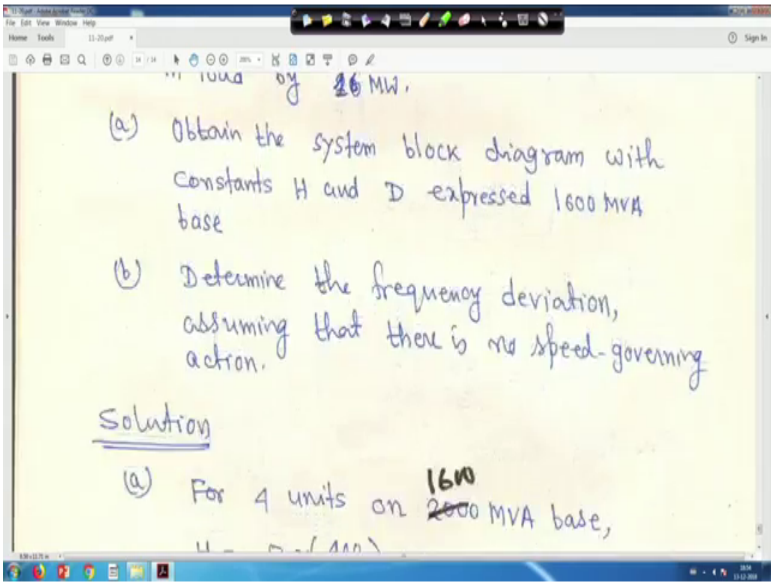

You have to obtain the system block diagram with constant H and D express that 1600 MVA base, because there are 4 units and 400 MVA. So, 4 into 400, it will be 1600 MVA base. And determine the frequency deviation assuming that there is no speed-governing action these two right.

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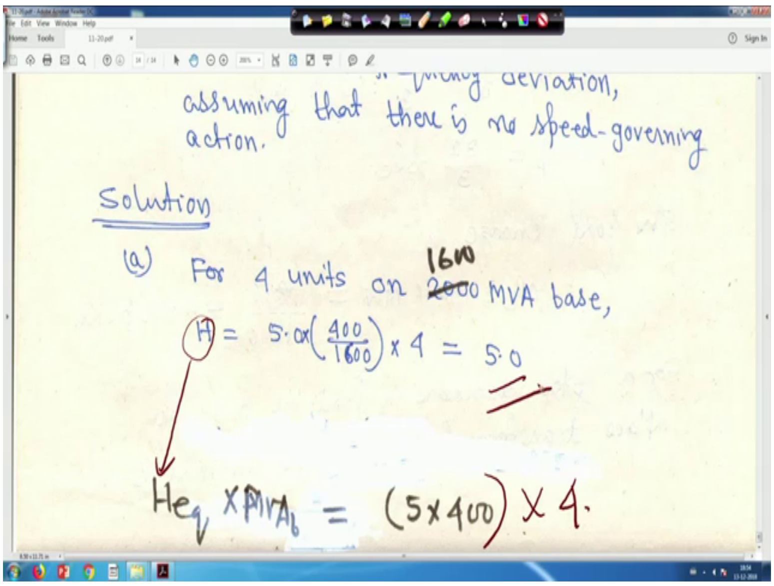

So, first part is for 4 units on 600 MVA base. So, H is equal to actually 5 into 400 divided by 1600 into 4. Actually, here I have tried to I have not completely in write up that basically this is actually H eq into MVA base is equal to 5 into 400 right into your 4 right, so that will give you actually it is 5 right. So, we will go to the next page.

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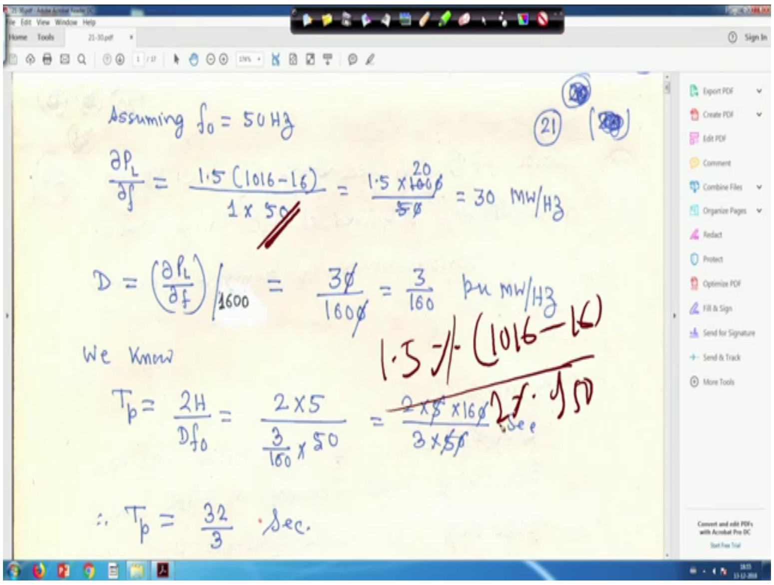

So, assuming that f 0 is equal to 50 hertz right. Therefore, delta P L upon it is given 1.5 percent change of load changing 1 percent frequency. So, 1.5 percent by 1 percent that is nothing but 1.5 by 1. So, basically this term actually 1.5 percent of this one right. I mean 1.5 percent of because load drop is 16 megawatt divided by 1 percent of 50 hertz right. So, basically percent percent canceled, so that is why written 1.5 by 1.

And this is 1016 minus 16 by 50, so that actually is coming 30 megawatt per hertz right. Therefore, D is equal to delta P L upon delta f divided by the 1600 MVA base, because is generator 400, so 1600. So, if you put this one, it will be 3 by 160 per unit megawatt hertz, because megawatt is convert into per unit that is why it represent that writing per unit megawatt per hertz right. We know T p is equal to 2 H upon D f 0. So, H is known, D computed f known, so T p is equal to 32 by 3 second right.

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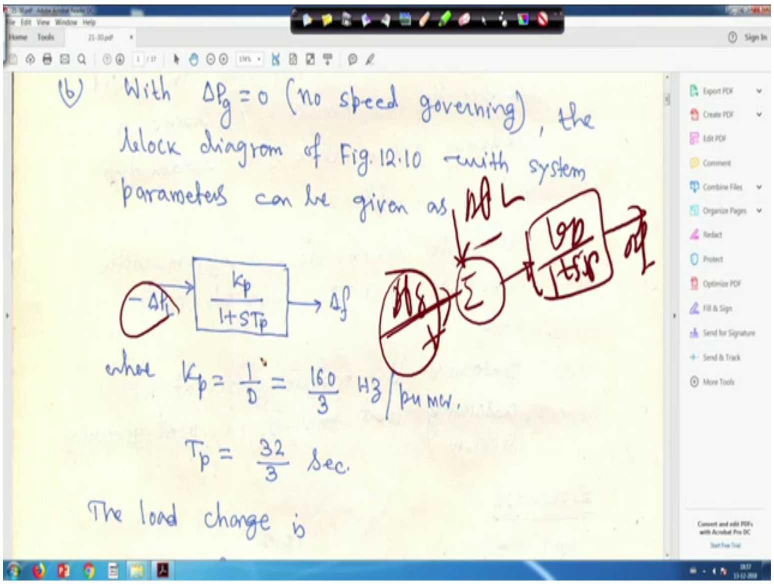

And in the second case that with delta P g 0 that no speed governing action mean delta P g is equal to 0. Therefore, block diagram will be simply delta P g 0. So, if you go back to the block diagram, it will be minus P L, because when you see the when you see the block diagram no speed governing action right, so this is plus delta P g, this is minus delta P L, and this is K p upon 1 plus S T p right, and this is our delta L.

So, from there one feedback has gone to the governor, but no governing action. So, delta P g is equal to 0, therefore this minus delta P L, they actually it is given minus delta P L K p upon 1 plus 1 upon K p upon 1 plus S T p delta f. So, K p is known 1 upon D, T p is known right.

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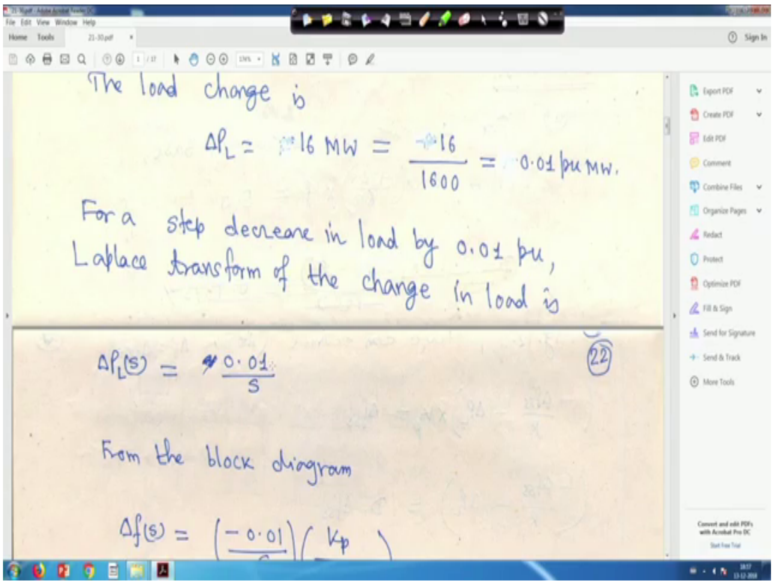

Their load change is your delta P L is 16 megawatt. So, base is 1600, so 0.01 per unit megawatt. And it is a step decrease, so delta P L will be 0.01 upon S because of step input right.

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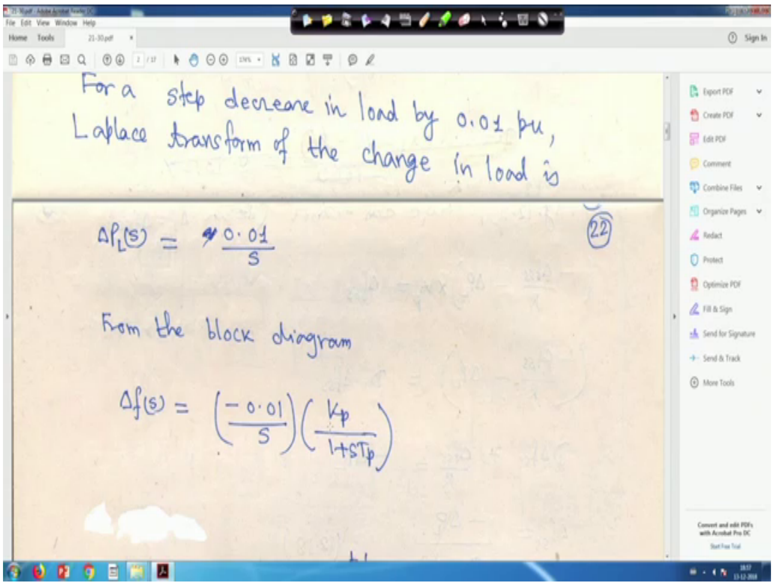

And the find the from the block diagram this one will be this one, and what you can what you can do is you take the inverse Laplace transform.

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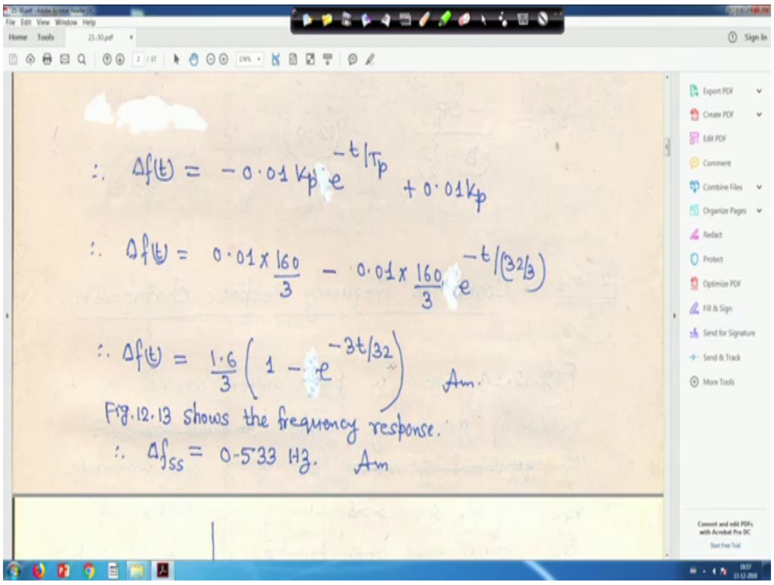

If you do so, it will become minus 0.01 K p e to the power minus t upon T p plus 0.01 K p right or delta f t is equal to put all the data, it will be 1.6 upon 3 1 minus e to the power of minus 3 t upon 32, this is the answer.

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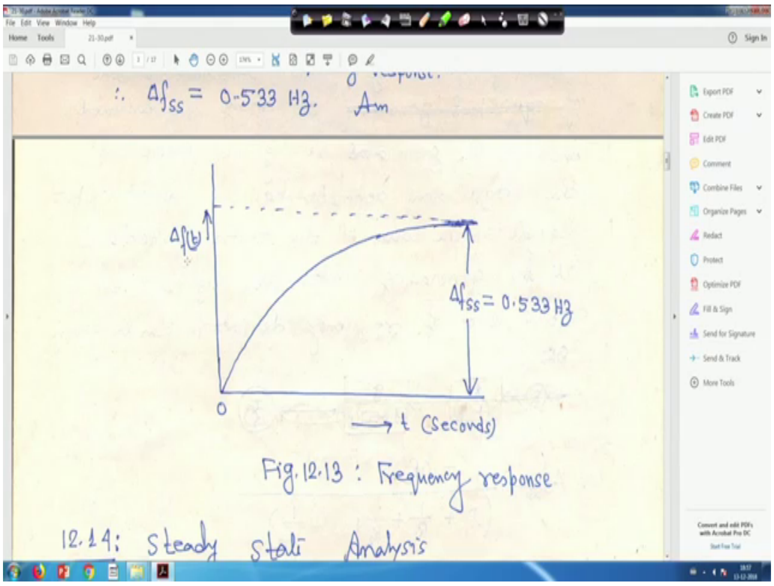

And t tends to infinity, so delta f s s will become 0.533 this is the steady-state error right. And this is your what you call delta f t verses delta f s s this is the plot right, so this is the steady-state value right. So, load increase or load decrease whatever it is that you can do it easily this is special case, this is a special case right.

So, thank you very much, we will be back again.