Power System Dynamics, Control and Monitoring
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Lecture – 33
Automatic generation control conventional scenario

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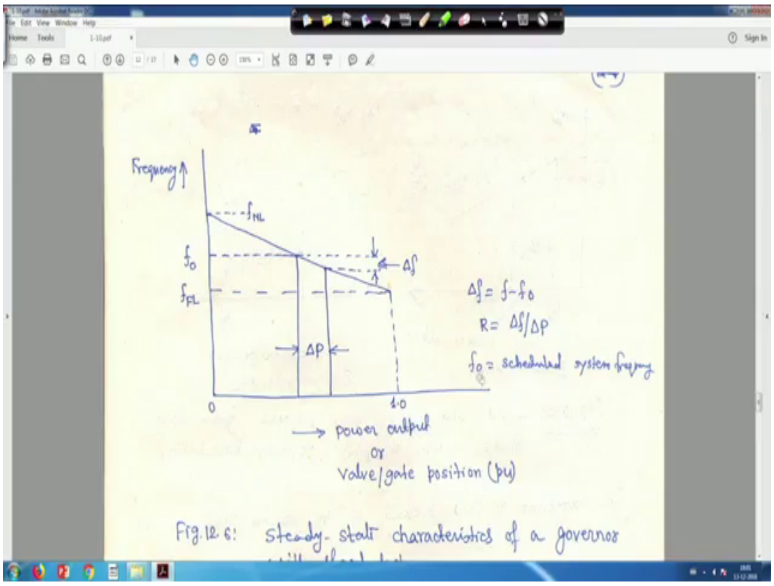

So, in the previous lecture, we have seen that you are what you call the frequency versus power output or valve or gate position right. This we have explained in the previous class.

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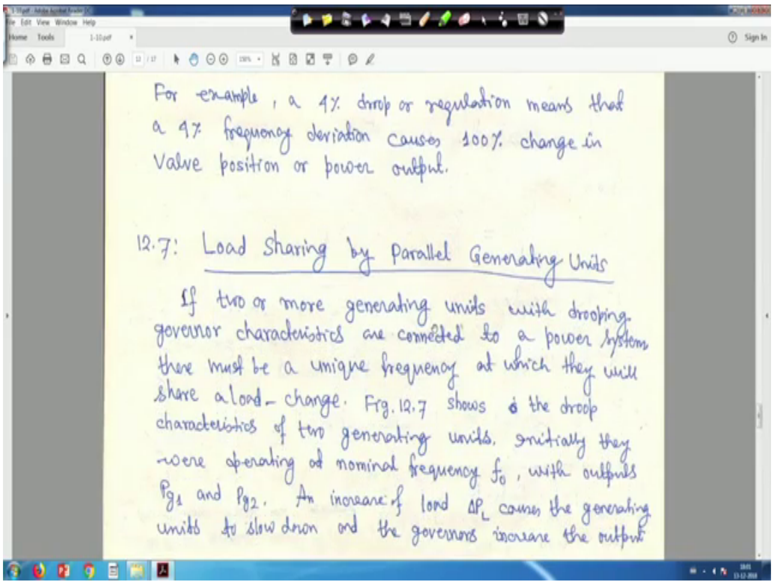

Now, your load sharing by parallel generating units, now that was for single generator. Now, if two or more generating units right with drooping governor characteristics right are connected to a power system, these must be unique frequency at which they will share a load change right.

So, figure-7 that I will show you later shows the droop characteristic of two generating units initially they were operating at nominal frequency f 0 with outputs P g 1 and P g 2. So, with diagram an increase in load delta P L causes the generating units to slow down and the governor increase your what you call output right. So, just hold on.

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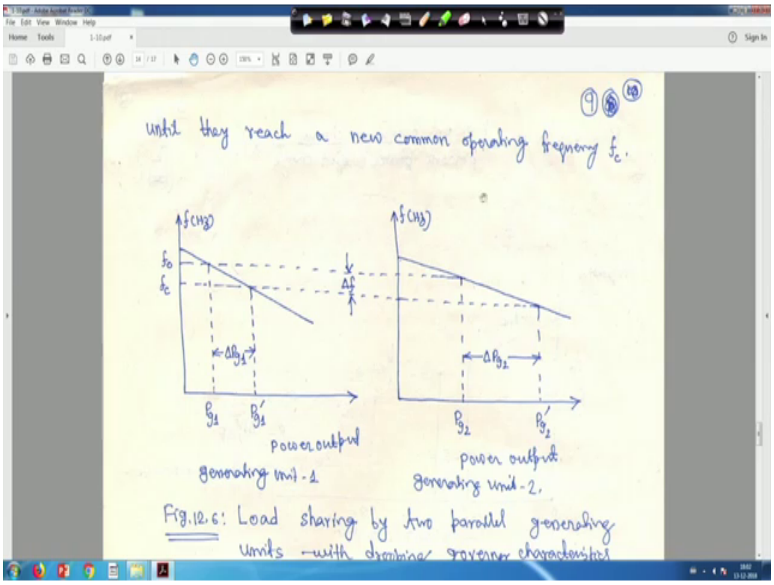

So, in this case, so until they reach a new common operating frequency there f c right f c is the common frequency. Now, this is your f c. Now, you see that two generating units are there this is a generating unit 1 and this is generating unit 2 right. So, let me increase the; you know just hold on. So, now these two generating units are there, this is your one is P g 1, another your another is P g 2 right.

So, if you look into that; that when these are the different droop characteristic this is different droop characteristic right. When they were operating at say nominal system frequency this is f 0 right, so at the time generator 1 was delivering power P g 1 right, this is P g 1. And if you do a horizontal line another one at the time was developing power generating power P g 2 right.

Now, the load has increased if load has increase so now, because of that the P g 1 as increased to your P g 1 dash, and P g 2 now it is P g 2 dash. So, power load are increased; so power also from the two generating generators there also increase. So, in that case they have to operator common frequency this is f c is the common frequency, this is the common frequency f c right.

So, if you draw an horizontal line at that time, this one is P g 1 dash and this one is P g 2 dash right. Unless and until and their droop slope that are your that is droop characteristics are different. But that but common frequency the deviation that is your delta f right, that means, I mean that means, this one this delta P g 1 and this is delta P g

2. Delta P g 1 means P g later I have given, it is P g 1 dash minus P g 1 right. Similarly, delta P g 2 this one is equal to your P g 2 dash minus P g 2 right.

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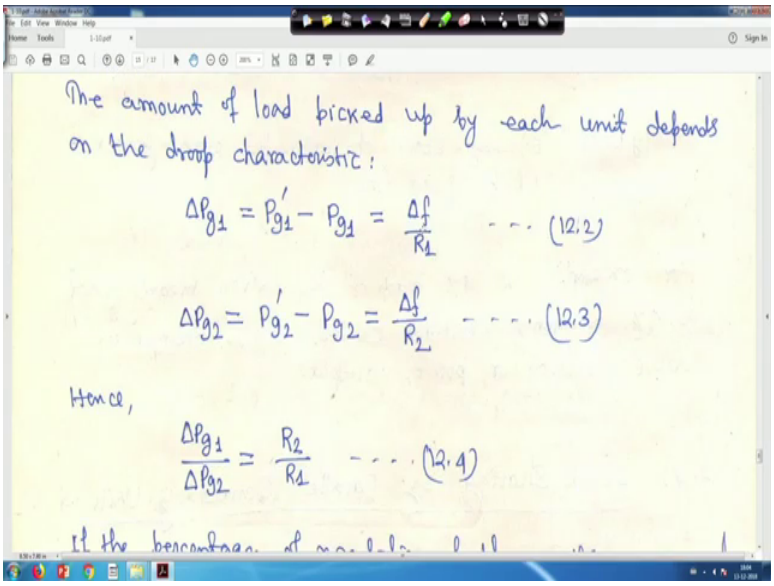

So, if we write down those delta by your what to call R is equal to that delta P g 1 I told you P g 1 dash minus p g is equal to delta f upon R 1 right because frequency deviation is common, this is equation 2. Similarly, delta P g 2 will be P g dash minus P g 2 to delta f upon R 2 right.

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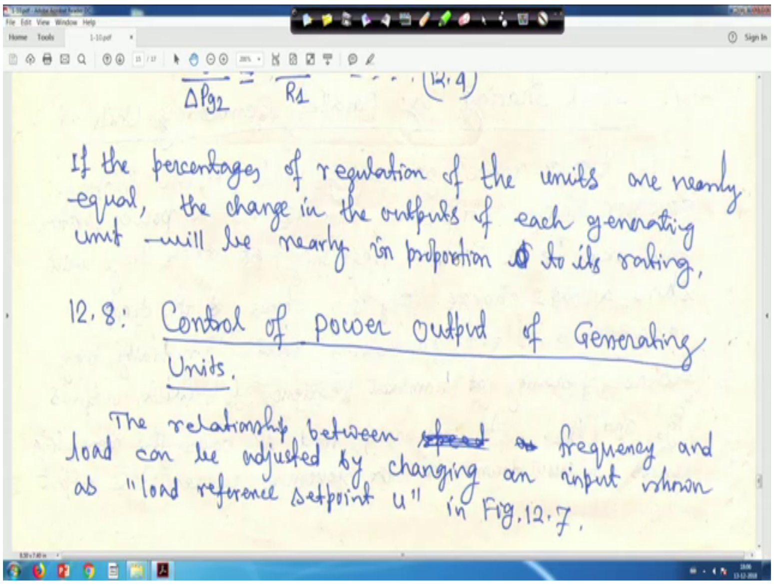

Now if you divide equation 2 by 3, then you will get delta P g 1 upon delta P g 2 is equal to R 2 by R 1 that according to this ratio the power will be say are for two generating units. But, if R 1 is equal to R 2 give there two characteristics same, then delta P g 1 will be is equal to delta P g 2 right.

So, if the percent regulation of the units are nearly equal that means, if R 1 is equal to R 2, the change in the outputs of each generating unit will be nearly in proportion to its rating right. So, it is R 1 I mean if it is R 2 is equal to R 1, then delta P g 1 will be is equal to delta P g 2 right. So, this is how that you are what you call that meaning of do characteristic that why you do need that for governor it is more or less clear to us right.

Now, control of power output of generating units. So, the relationship between frequency and load can be adjusted by changing an input shown as load reference set point that is u right. This is actually load reference set; I will come to the diagram that is figure-7 right as a load reference set point u right.

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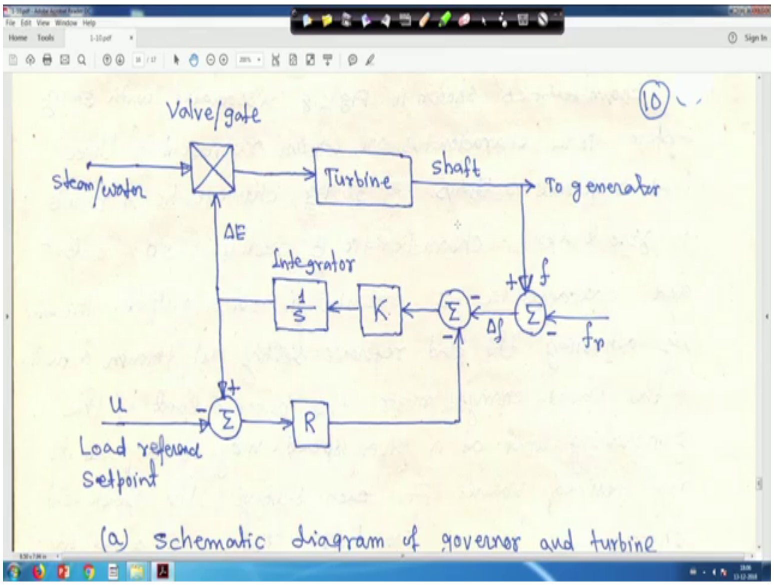

So, this is actually same block diagram same block diagram, but only that your one additional feedback is here that is called load reference set point that is called u rest to rest all the things same as before, so that is schematic diagram governor and turbine right.

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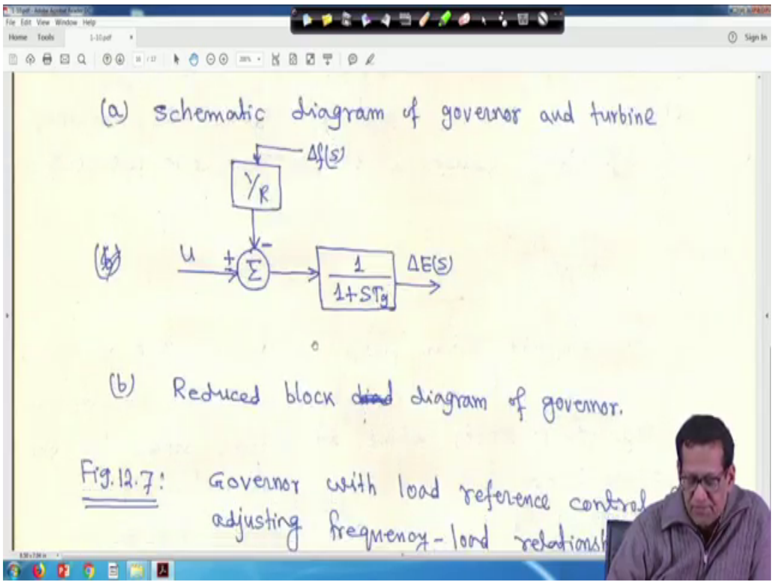

Now, if this u is there in the previous diagram, when we reduce this one, it was like this know. Now, it is u is added right in the previous diagram, it was your what you call that we make it this is your minus 1 upon R, this was delta f, and this one is one upon one plus S T g, and this is delta E S right or delta E.

Now, as this u has been added here right that is load reference set point, so this block diagram actually it is minus 1 upon R, it is this because of this minus 1 upon R this minus feedback is here, 1 upon R is here, this is delta f, and this is u right. So, if you do if you just you know what you call go for block diagram reduction, then this you will get this one only this you will be added here right, so that you feedback will be there the load reference set point. So, this is the meaning of this one actually, this is reduce block diagram for governor.

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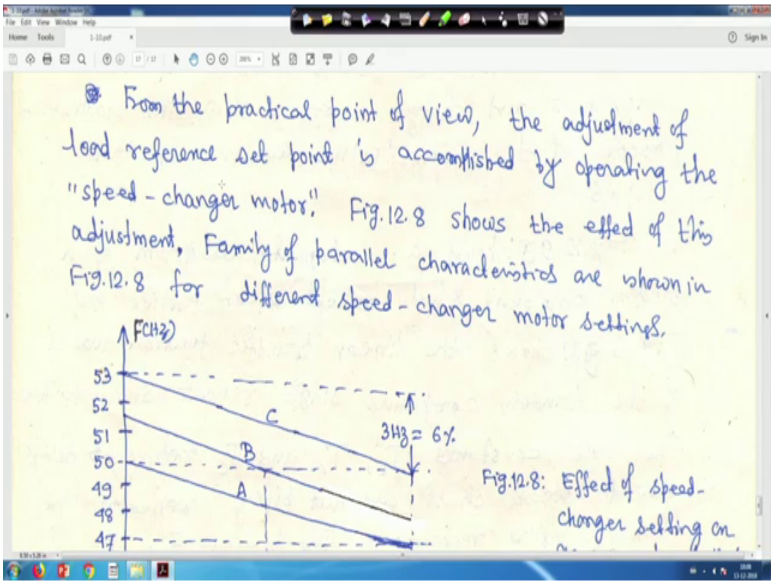

Now, so from the practical point of view adjustment of load reference set point is accomplished by opening the speed changer motor right. This speed changer motor will not see in this course, but some but this is the your what you call this is required. So, figure-8 shows the effect of this adjustment that family of characteristics are shown in figure-8, I will show you for different speed changer motor setting right.

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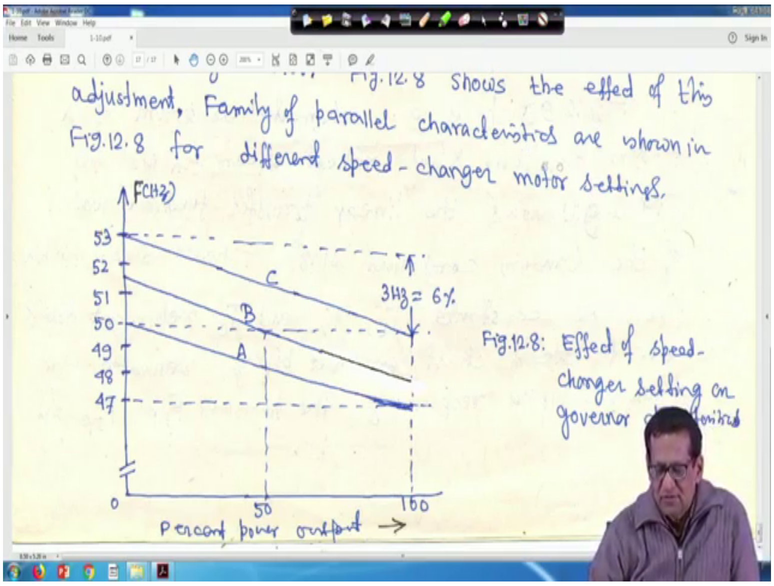

Now, if you come to this figure that there are three different characteristic, there are three just let me move it little bit of three different characteristic. So, if you look into this, that this is figure-8 effect of speed changer setting governor characteristic. Now, characteristic A, characteristic B, and characteristic C right.

Now, when it is when it is operating at nominal system frequency, say it is 50 hertz right. So, power generating at 0 for the for this one, but at the same time you are what you call if it is operating the 50 hertz, then for B it is 50 percent right, and for C it is because they look at this dash line, it is 100 percent say for a change of your 6 your what you call that 6 percent your droop valve that is your 3 6 percent changing frequency right that is your nothing but your 3 hertz, because 6 percent means 0.06 into 50 is 50 a system. So, this drop is 3 hertz, so also they have different characteristics. So, from that you can see that this is a simple you know simple example right. So, let me clear it, so will go to the next one right.

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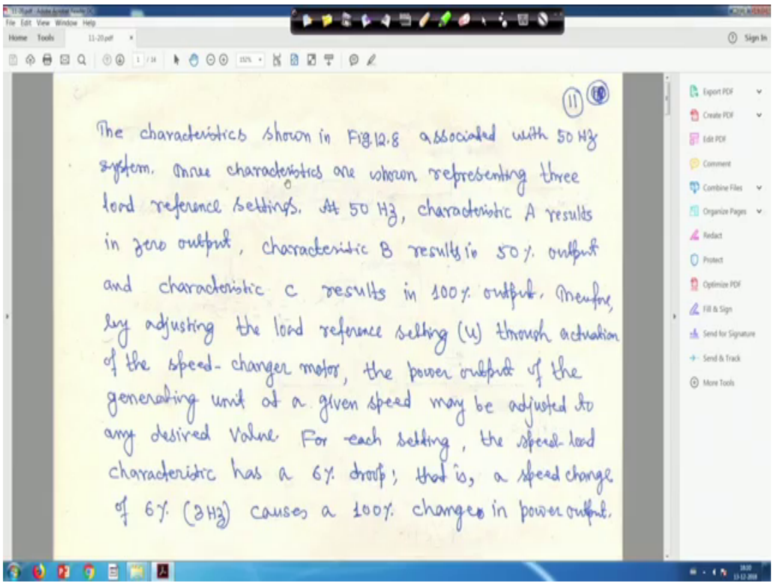

So, the characteristic whatever we have seen right, if necessary I will go to that that the characteristic as that whatever we saw that your figure-8 that three different character associated with 50 hertz. These characteristics are shown representing three load reference setting that I told you.

So, at 50 hertz characteristic A results zero output I told you, characteristic B results in 50 percent output, and characteristic C result 100 percent output. Therefore, by adjusting the load reference setting u though activation of the speed-changer motor, the power output of the generating unit of a given speed may be adjusted right.

So, later we will see little bit more about that to any desired value. For each setting, the speed load carry are what you call characteristic as a 6 percent droop right, so that is a speed change of 6 percent has a 3 hertz causes a 100 percent change in power output, this you have seen before right.

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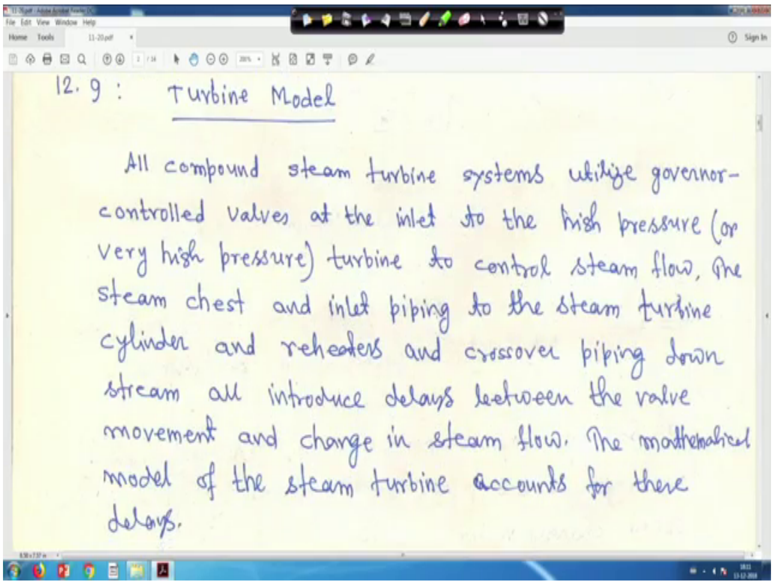

So, next is your what to call that after this so governor part more or less over. Next will go for turbine model. So, in this thing course any we will see only that steam turbine model. If time permits at the end of this course if time permits, then little bit of hydro turbine modeling I will give you very interesting it is. First, we will finish this is a steam turbine model right.

So, so all compound steam turbine system utilize governor controlled valves at the inlet to the high pressure or very high pressure right turbine, I mean just back it we are putting the turbine to control the steam flow. The steam chest and inlet piping to the steam turbine cylinder and reheaters and crossover piping down your down steam all introduce delays between the valve movement and change in steam flow that means, you have a actually in a details to cannot be covered in this course right.

So, question is that is for any say re-type turbine, it has high pressure, intermediate pressure, and low pressure cylinders are there right. So, steam chest and inlet piping and everything that when steam is flowing everything is associated with delay some time delay that will present by time constant right. The steam chest and inlet piping to the steam turbine cylinder and reheaters and crossover piping down steam all introduce delays between the valve movement and change in steam flow. The mathematical model of the steam turbine accounts for these delays right.

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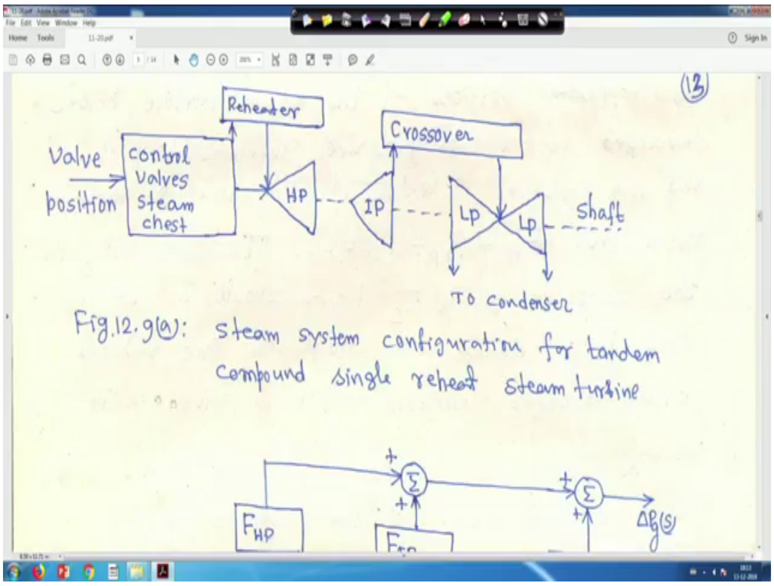

So, now figure-9 before coming to this thing, I will go to figure-9 past, then will be coming back to that right. So, when we see figure-9, that it is your tandem compound that your steam turbine turbine. So, valve position like this that control valves steam chest. So, reheater is there, then it is high pressure cylinder, then intermediate your pressure cylinder IP, and in low pressure LP right, and this is crossover, and this is the shaft that from here it is going to condenser right.

So, everywhere when steam is flowing from this part to that part, some delay is associated with that right. Now, before going to that this is steam system con tandem compound single reheat steam turbine right.

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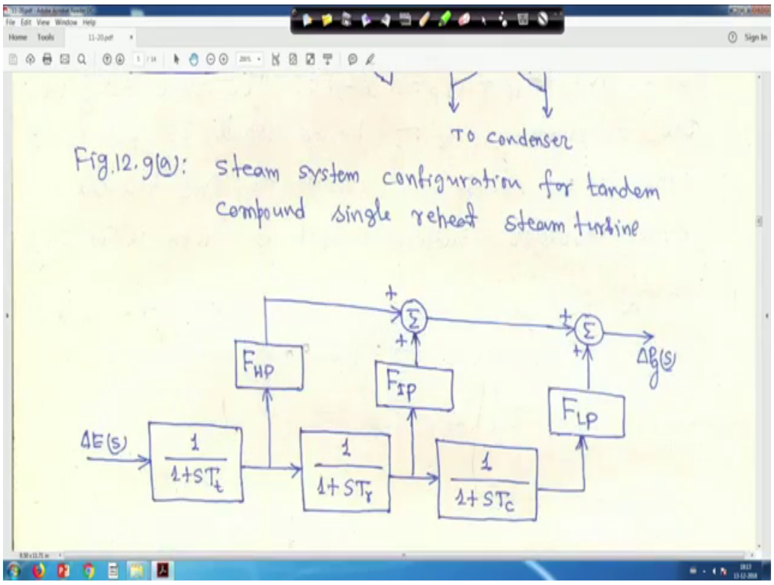

So, now everywhere when that is your delta E S that is because governor, then turbine, then you are generator all are connected together turbine generator couple together. So, input here is delta E S right. So, this is 1 upon 1 plus S T t that is steam chest time constant, then power develop in the high pressure side say F H P the fraction of power, then intermediate pressure it is F I P and low so you are what you call low pressure cylinder that is develop F L P right.

So, F H P when we put in per unit that F H P plus F I P plus F L P that is actually is equal to 1.0 right. So, these three, if you some it is 1.0. Now, or we can write that F I P plus F L P is equal to 1 minus F H P right from this equation only.

Now, this crossover this T c this at the time constant that is for your what you call it is very small right that cross over. So, this time constant is neglected. If you neglect this if this is neglected, then it will be F I P plus F L P together F I P plus and this is delta P g. Now, F I P plus F L P actually is equal to 1 minus F H P right, this is I am telling.

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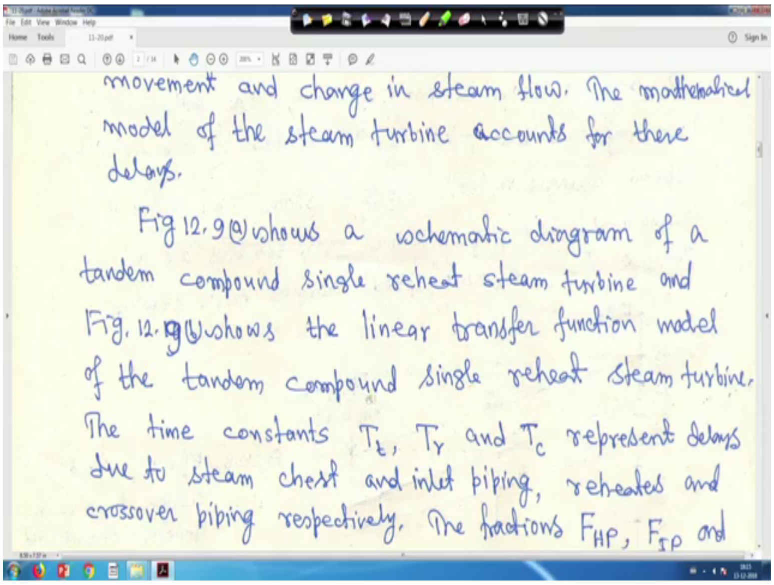

Now, we will go to the, that mathematical model development the transfer function model right. Now, if you now when will go up now so just hold on yes so figure that is figure-9 a I showed you shows a schematic diagram of a tandem compounds single reheat steam turbine, and 9 b shows the linear transfer function that also showed model of the tandem compound single reheat steam turbine.

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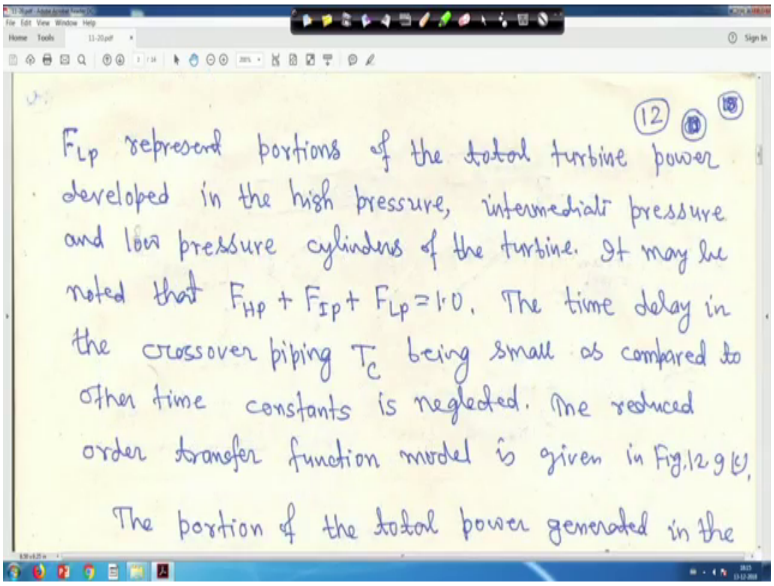

The time constant time constant T t, T r, and T c represent delays due to steam chest T t is steam chest and inlet piping time constant, T r is the we call reheat time constant, and T c we call crossover piping that is the time constant this the crossover time constant right. The fraction F H P, F I P, and your F L P right represent portions of the total turbine power developed in the high pressure, intermediate pressure, and low pressure cylinders of the turbine right.

So, it may be noted that F H P I told you plus F I P plus F L P is equal to 1.0 right. So, high pressure, low intermediate pressure, and low pressure. The time delay in the crossover piping T c I told you being very small as compared to other time constant is neglected. So, T c for this thing is neglected will not consider T c, we will simplified right.

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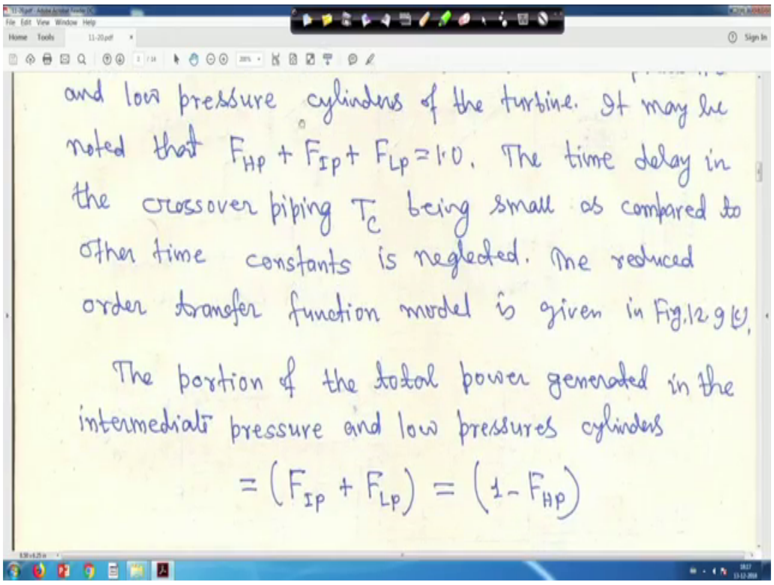

Therefore, the reduced order transfer function model is given in figure 9c. So, we will go the portion of the total power generated that is figure-9c also I showed you already just will go once again right. So, this is figure-9b or 9c the, this one T c is neglected. The figure-9c will be your this one reduced order model.

If T c is neglected, it will be 1 plus 1 upon 1 plus S T t, this is F H P 1 upon 1 plus S T r. T c is neglected, and F I P plus F L P is equal to 1 minus F H P. So, this is minus F H P, and output is delta P g right. So, this is that diagram. Now, from there will try to find out delta P g upon delta E that is your transfer function.

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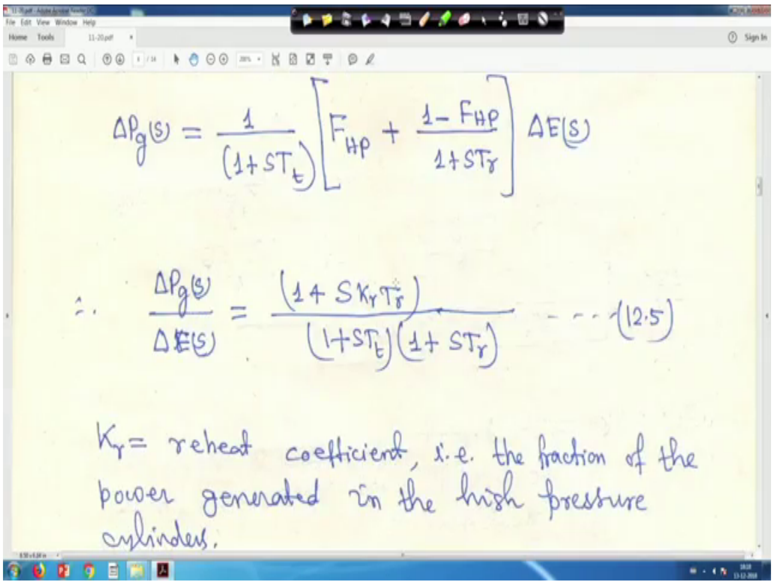

So, will go up so from figure-c right, so you can write delta P g is equal to from a figure that 9c is equal to 1 upon 1 plus S T t into F H P plus 1 minus F H P upon 1 plus S T r into delta E S. This is you go to figure-9c, and easily you can write this right or after simplification delta P g upon delta E s is Laplace your what you call operator, so is equal to one plus S K r T r upon 1 plus S T t into 1 plus S T r.

Here one small question to you that when you when you find out that you are what you call this transfer function right, so what is K r K r is equal to here what here only F H P is there. So, K r is what in terms of F H P, this is small question to you. So, K r K r we call reheat coefficient right that is, that we call K r that is so K r is reheat coefficient that is the function of the power fraction of the power generated in the high pressure cylinder.

So, basically K r is equal to what as fraction of the power generated high pressure cylinder means, K r is equal to what is small question to you right. So, but generally we call K r as a reheat coefficient, so this is equation-5. So, this is the transfer function for the your reheat you are turbine right.

And if it is a non-reheat turbine if it is a non-reheat turbine right, suppose this reheat turbine if it is a non-reheat turbine it is a non-reheat turbine right, then (Refer Time: 18:33) there will be no existence of T r. So, T r should be is equal to when 0 right if it is a non-reheat that means, in that case for non-reheat turbine the transfer function should be basically simply 1 plus S T t that is is equal to this one for non-reheat turbine right.

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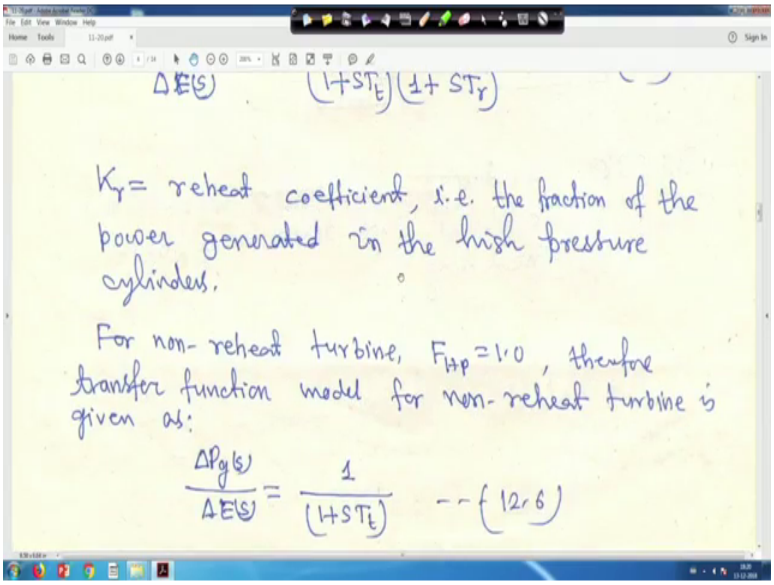

So, for a here I have written here that for non-reheat turbine the delta P g upon delta E is equal to 1 upon 1 plus S T t right. So, here actually here F H P is 1 that means, for this equation for this equation right if you take f actually K r is equal to F H P right, and that is is equal to 1, so because reheater is not present.

So, in that case if you put K r is equal to 1 that means, your 1 plus S T r 1 plus S T r will be cancel or as reheat is reheater is not there, you can simply put T r is equal to 0, then it will be 1 upon 1 the why you want right. So, this figures all this things have been told and explain right.

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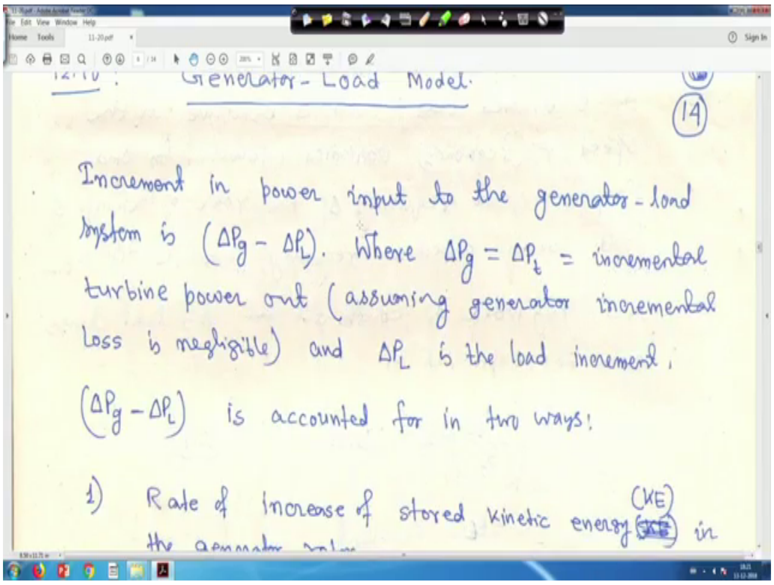

So, now we have to now complete that your next model is next one is that your generator-load model right, so this is actually generator to load model. So, increment in power input to the generator-load load generator generator-load system is delta P g minus delta P L right.

So, idea is something like this it is a lossless turbine, so we assume delta P g is equal to delta P t right. And if load there is a load changes, then there will be transient imbalance between the generation at the load. So, what will happen that whatever load changes generation will try to follow that load. If load increases, generation will try to generate the, that amount of power right. So, but as soon as you switch on the load is transient imbalance will happen right. So, it is not the steady state. First we have to we have to see the dynamic the transient imbalance is happen.

So, incremental turbine power, it is in output right. Incremental turbine power output assuming generator incremental loss is negligible, they mean in it is a lossless turbine right, and delta P L is the load increment that is small perturbation. And delta P g minus delta P L is accounted for in two different ways. So, you have to consider both.

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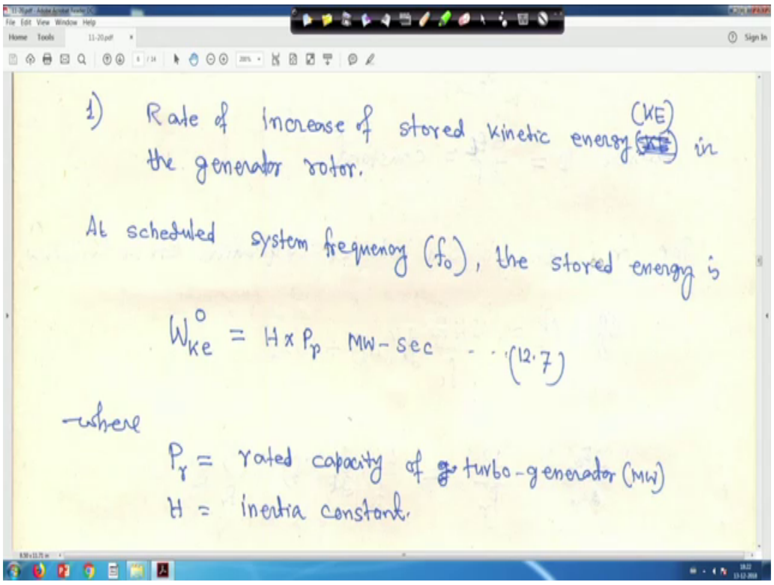

Now, that first one is the rate of increase of stored kinetic energy in the generator rotor light. So, at scheduled system frequency that is f 0, the store energy W k e 0 will be H into P r megawatt second. This you have studied for your transient stability also right, because inertia of the machine is h that is in second. And P r the rated capacity of the machine turbo generator system that is your in megawatt, so it is unit is megawatt second. So, this is equation-7 where P r is given that rated capacity of turbo-generator megawatt, and H is inertia constant that is actually in second right. So, initial your what to call stored energy that is W k e 0 is equal to H into P r.

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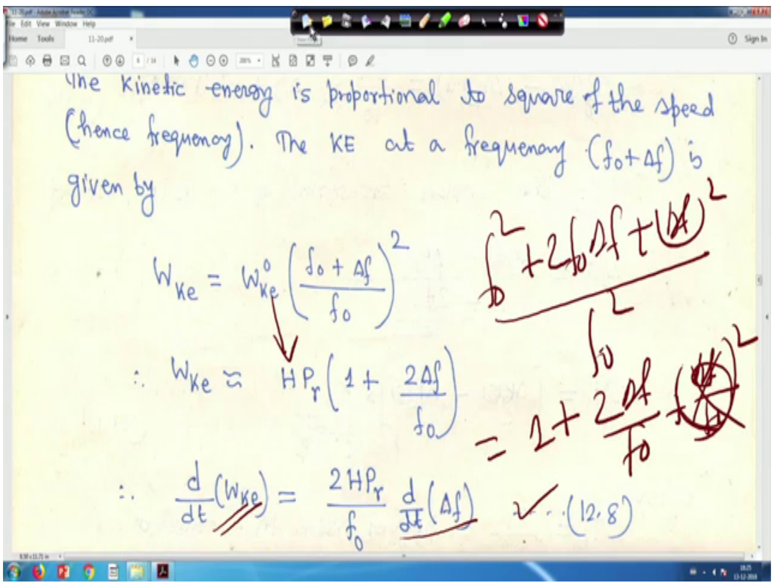

Now, the kinetic energy actually is proportional to the square of the speed. You know that W kinetic energy is proportional to a square of the speed and hence the frequency right, because you know that omega is equal to 2 pi f, so that is the kinetic energy at a frequency say f 0 plus delta f is given by, because load has change. So, initially the frequency of f 0 right. Now, suddenly load has changed, so frequency has changed instead of f 0, now it will be f 0 plus delta f, so delta f that that much change is there.

Therefore, that because of at as the kinetic energy is proportional to the square of the speed, therefore W k e is equal to W k e 0 into f 0 plus delta f upon f 0 whole square right, so directly you can write. So, then W k e 0 that you are W k e 0 is equal to H P r right that you have made it approximately.

And if you expand this one, this is actually f 0 square plus 2 f 0 delta f plus delta f square right divided by f 0 square right. This one you can write 1 plus 2 delta f upon f 0 plus delta f upon f 0 square right, but this delta f upon f 0 square is a very small quantities, so this term is drop.

Therefore, this equation is written 1 plus 2 into delta f upon f 0 right. When you are divided by this thing, so this term is dropped or and you know that rate of change of kinetic energy is power, then you take the derivative with respect to time. If you do so, it will be 2 H P r right divided by f 0 into d dt of delta f right. So, this is equation-8, so this because this is kinetic energy and you are taking your derivative. So, rate of change of kinetic energy is the power right, this is your equation-8.

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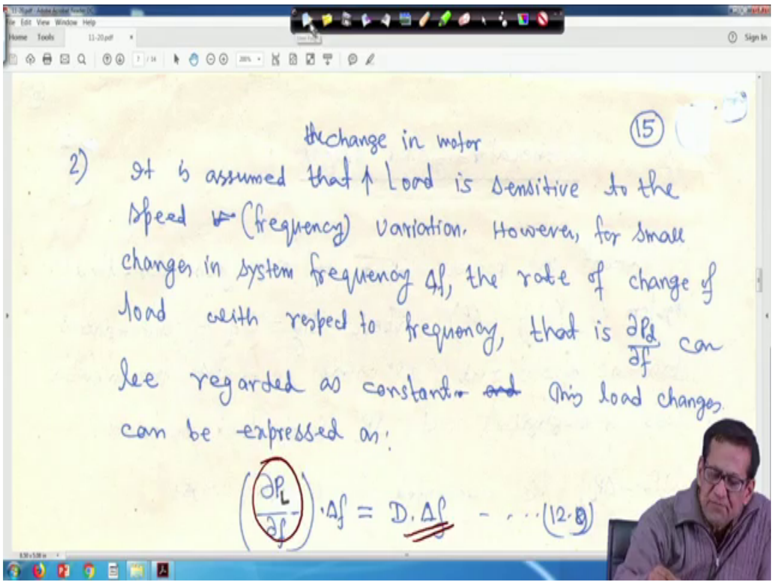

Now, next is that it is assumed it is assumed that it is assumed that the change in motor load is sensitive to the location you are what you call frequency the variation. However, for small changes in system frequency delta f, the rate of change of load with respect to frequency, that is delta P d delta f.

Sometimes, we write if load disturbance in P d, then it is delta P d delta f. If you can see load disturbance P L instead of P d, then it will be delta P L, and delta f right. So, can be regarded as constant. So, this load changes can be expressed as delta P L delta f into your delta f, but this is actually this one actually is a constant this is constant right. So, this part is a constant into delta f, because this is D into delta f right.

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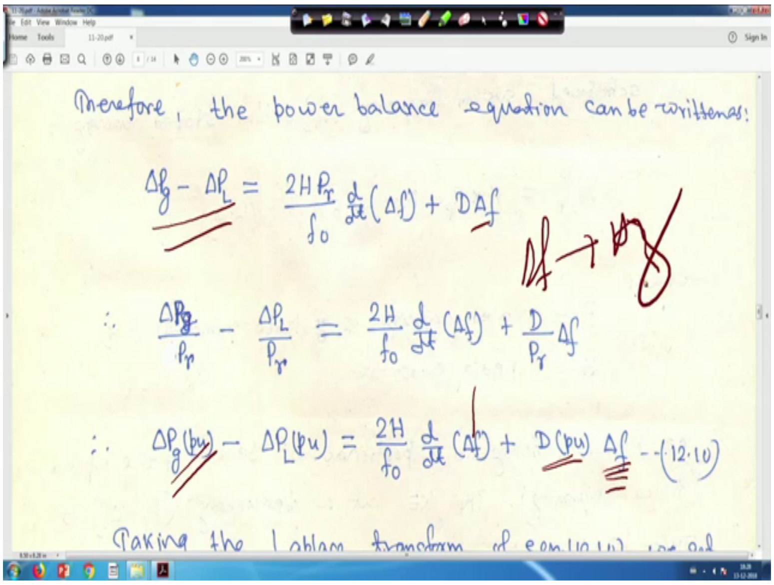

Therefore, that the power balance equation can be because transient imbalance as happened because of a change in load. So, delta P g minus delta P L can be written as now that 2 H p r upon f 0 d d t of delta f that is you are d d t of W k e right, so that is actually 2 H P r upon f 0 d d t, this we have seen plus this term D into delta f right.

Now, both side what you do, both side you divide by P r both side you divide by P r. So, this is delta P g upon P r minus delta P L upon P r is equal to 2 H upon f 0 d d t of delta f, then D upon P r into delta f that means, both sides it is divided by P r that is the rated capacity that means, this is becoming your delta P g in per unit that so in bracket it is per unit written minus delta P L per unit then 2 H upon f 0 d d t of delta f right plus D also in per unit, it will be p u because it is your delta P d upon delta f.

So, D or D also represent by your D into p u and into delta f right. But, this delta f, actually it is in hertz right. But, if you bring this f 0 inside that 2 H d d t, then of delta f upon f 0, then the in that case it may become per unit, but thins thing also you have to take care you have to you know consider that right. So, better you should not do that, but delta f everything is in per unit, but delta f is in hertz right f 0 also is in hertz.

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