Power System Engineering
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Lecture – 47
Load frequency control (Contd.)

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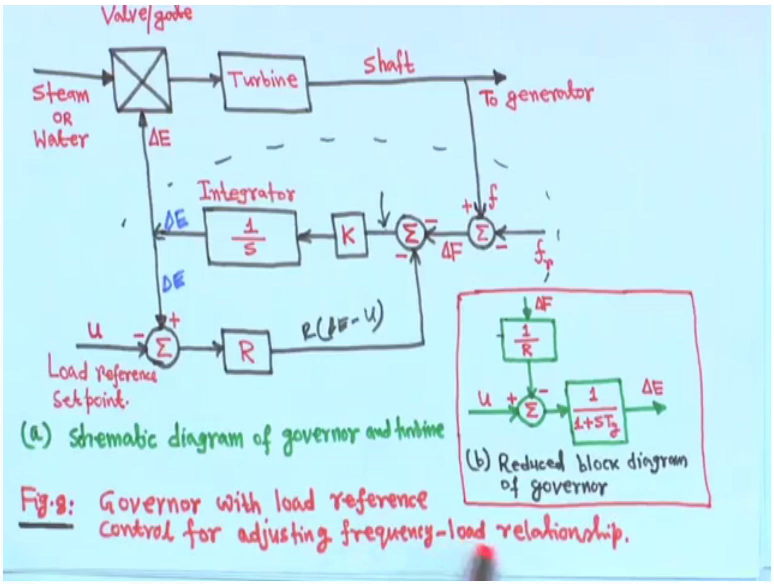

So this we have seen this is actually schematic diagram, and this is that reduced block diagram of the governor only this turbine generator, we will see later and this is figure 8 right. So, it is it is actually governor with load reference control this one for adjusting frequency load relationship right. So, ultimately u and this already I have showed you how to make it. So, once after this write up is here.

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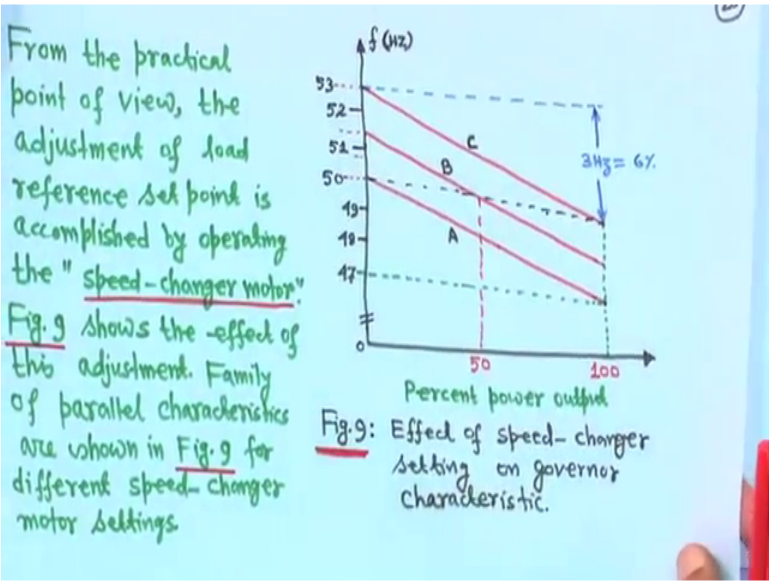

But after the suppose you have a suppose you have 3 units, right and this is something that if it is a this thing you are what you call this 50 hertz system say.

So, suppose there are your these three different duke characteristics are there right three different generating units and duke characteristics. Suppose it was operating that apart this is for A, this is another unit for B, this is another for C something like this right. So, from the practical point of view the adjustment of load different set point is accomplished by operating the speed changer motor.

Ah Figure 9 this one shows the effect of this adjustment family of parallel characteristic as shown in figure 9 for different speed changer motor settings right. Suppose this is your this side is frequency in hertz and, suppose this effect of speech changer settings on governor characteristics. Suppose when is pitch change your this thing this thing is your 50 hertz, when it is 50 hertz you look at that for a the generation is 0 right, because you draw a horizontal line horizontal line, then for it is starting from here.

So, for A it is 0, for B it is say 50 percent something some special case is taken and for C say it is 100 percent, and it is given 3 hertz is equal to 60 percent is a 50 hertz system say. So, that is why it is 1 hertz is equal to 2 pi or 2 percent right.

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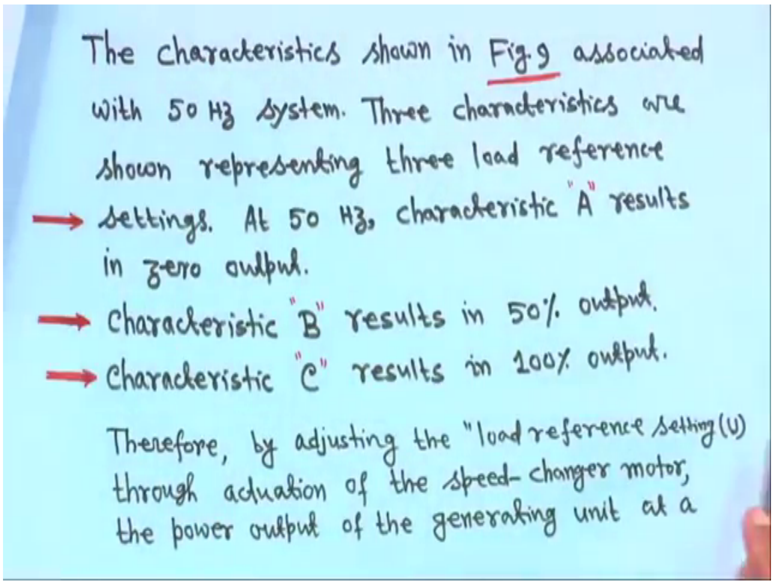

So, this is and this is the percent power output so; that means, the characteristic shown in figure 9 associated with 50 hertz system, 3 characteristic as shown representing 3 load reference settings at 50 has the characteristic a result is 0 output, because that I told you that it starting from here at 50 hertz it is resulting 0 output right, characteristic B results 50 percent output I told you and, for characteristics C there is 100 percent output.

So, therefore, by adjusting the load difference setting that U right, through actuation of the speed changer motor the power output generator unit at, it you know at a desired level I mean this thing can be changed right.

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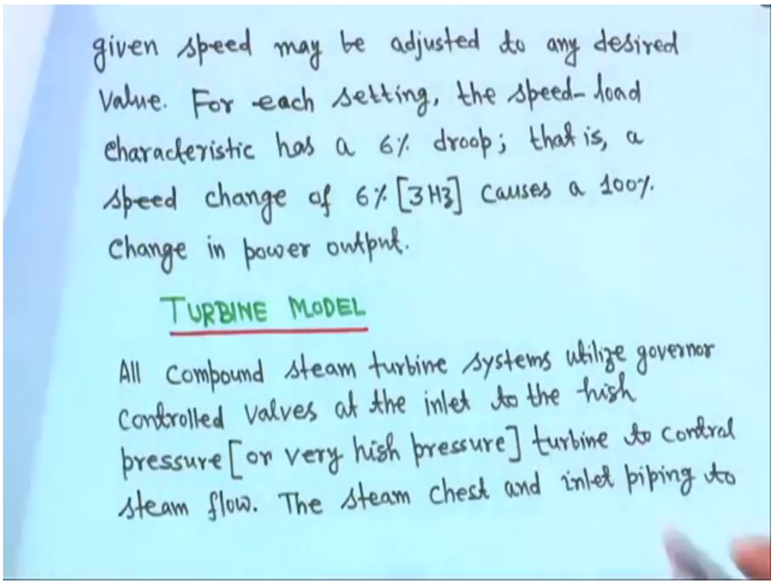

At a given speed may be adjusted to any desired value, for is setting the speed load characteristic has a 6 percent group that is a speed change of 6 percentage 3 hertz causes actually 100 percent change in power output. So, this is actually for this case suppose if it is a dupe setting is 6 percent right. So; that means, it is changing is 100 your what you call, that is your 100 percent let me know that is full load, that is the power output and if it is have 6 percent means, if it is a 50 hertz system then 6 percent full domain is 3 hertz right, if it is a 4 percent then it will be too hard and like that right.

So, that is your idea of the speed dope characteristic right, after this that is as we have to for the sake of completeness of the total block diagram representation will take turbine model. We will take as this thing your read or laundry type turbine, but you will see things are understanding, but it is only you for the sake of completeness rather than taking the block diagram I thought little bit I will tell you here.

Next is the turbine model and after the generator model right. So, all compound steam turbine systems actually utilized governor control valves, at the inlet right to the high pressure or very high pressure turbine, because turbine have different type of high pressure intermediate pressure and low pressure sections right. So, in that case so, you have to what will do we will try to represent them in the Laplace transform and black block diagram representation.

So, so the turbine in that you are and bulk mechanism for the steam turbine say do you have different sections right, but he here for the simplicity we will take the simplest model detail will not consider right, because you need this one for the you are controlling the steam flow the steam chest.

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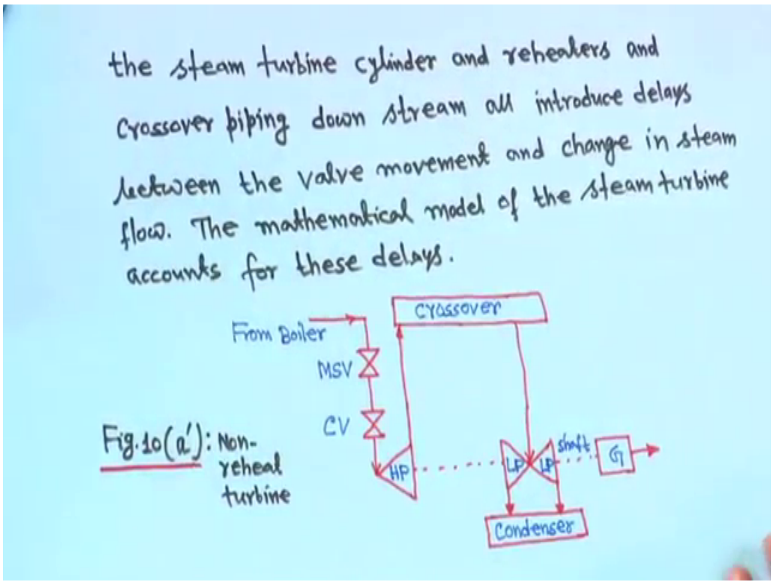

And the inlet piping to the steam turbine cylinder and reheaters right and, crossover piping down the downstream all introduced delays between valve movement and change in steam flow. Actually everything every system if you take here it is delay for example, while I am sitting here and recording this thing while I am moving this pen here or my finger here, I can observe in front of me that some fact very all the distant thing is very stay very small or negligible, but I can see some delay is there for transferring my voice, or transferring my this movement right I can sense it from sitting here.

Similarly, when suppose you take a 100 million what you call that 1 meter pipe and from 1 end you put water, another side may be with high speed does not matter, another side it will take some time because some delay will be there to these there. So, that is why that suppose for a steam turbine also, now look at this that it is you have a boiler system, boiler dynamics is very slow.

So, we will not consider that thing in load frequency control it is very slow right, then this is a non date and there will be different type of what you call bulk mechanism is they are not 1 stage 2 stage may be few more right, from the application point of view and other activities.

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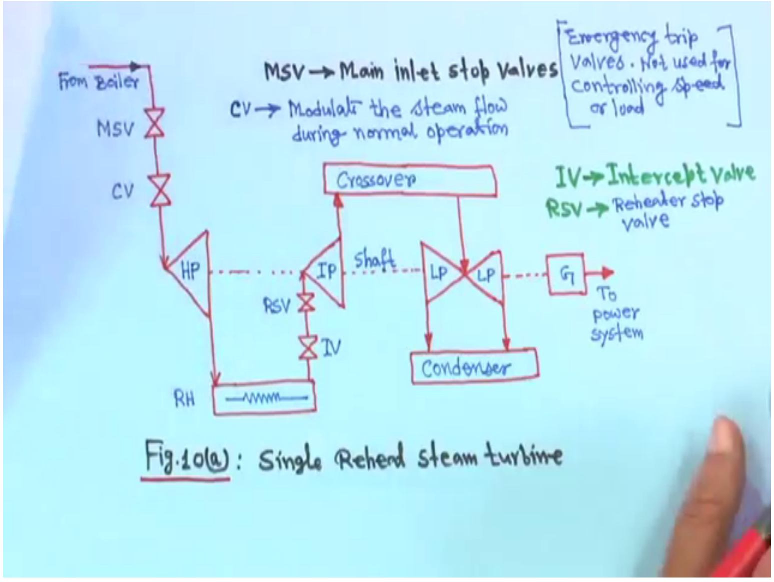

But here will show one you call MSV, another we call CV. MSV is given actually the main inlet stop valves right, this is a the MSV and CV is the modulate the steam flow during normal operation right.

So, those things here what you call that this is called control valve CV right and, MSV is main inlet stop valve that 2 things are taking MSV and CV right, why the water will steam flow will be there through this valve mechanism and your high pressure section then cross over the low pressure the if this thing, then this is the shaft and this is a generator this is a condenser right.

So, everything and some delays associated with that right from here to here, if it reaches some delay will be there; that means, you have to represent this by some time constant right; similarly crossover also. So, some sometime constant we can represent right. So, that sense when it is single rehend steam turbine when reheater is there right.

So, in that case this is a reheater if reheater is there, only in between only in between your this what you call this high pressure, then in because of reheater then inter intermediate pressure is there. So, this MSV CV all nomenclature it is there RSV also that reheater stop valve. So, here it is your and it is intercept your intercept valve IV here it is there nomenclature this is intercept valve and, this is reheater stop valve right. So, from this processor steams coming all this process some delays associated with that and according the power output right. So, from that we have to from this only, we have to make the block diagram representation our control system representation.

So, question is that if delay associated with that for whole thing and second thing is that every section high pressure intermediate pressure LP, then some packs on a power is generated and total will be say 1, will assume that it is a lossless turbine in assume that is a totally lossless right. So, this is actually single steam turbine.

So, this is high pressure side this is the intermediate side, this is shaft this dashed line is a shaft this is low pressure side, this is condenser will not come into our modeling right. And then generator will come later so, but this 1 this 1 the reheater then crossover pipe piping. So, all some things will come in the what you call in the mathematical model right, in the transfer function model.

So, how will make this? Because we have to link governor turbine generator everything such that a closed loop system is form right. So, basically it is a closed loop system.

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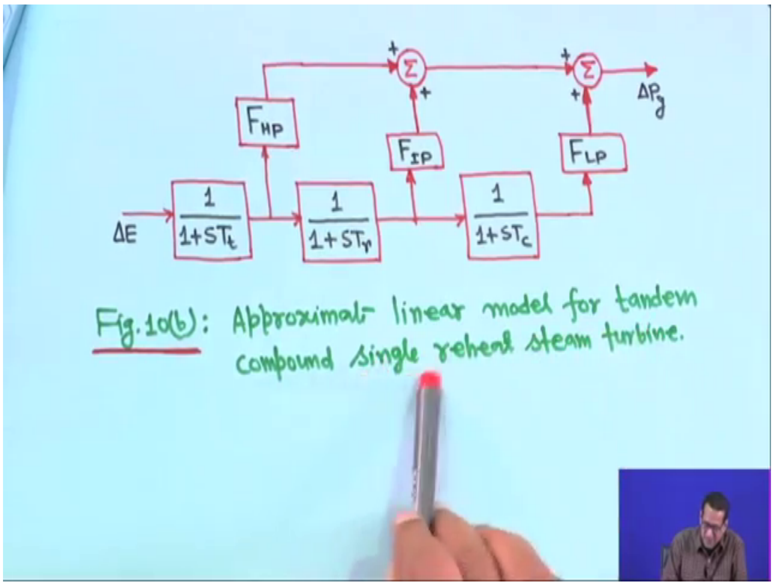

So, if you make this whole thing as a block diagram representation. It will be approximate linear model for tandem compound single reheat (Refer Time: 09:02) it is a linear model. So, from here to here when were steam is your flowing right, some delay will be associated with that, that is actually represent by this is input, because governor output whatever it was coming right, from the output of the governor it is coming to the turbine. The previously I showed you know that block diagram this delta E right.

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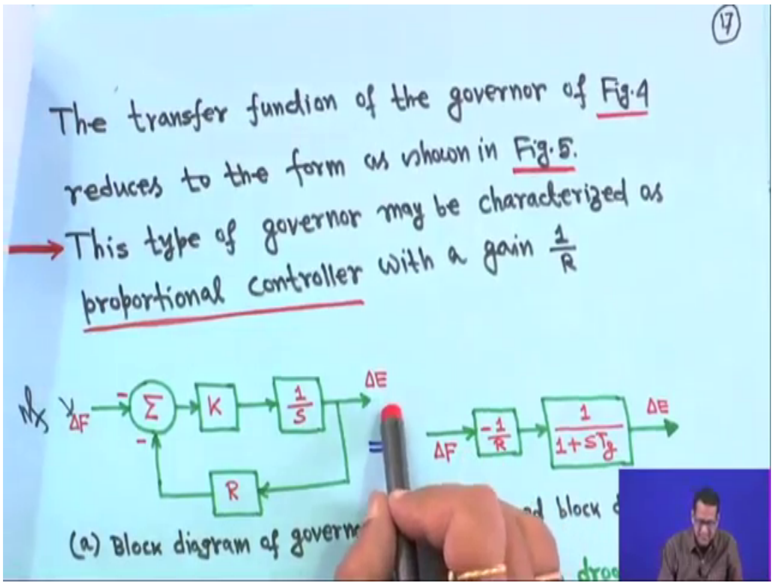

This is your what you call that that diagram, that you are here is delta E; this is the delta E this output of the governor right and, this is going to your what you call that your turbine then generator right. So, every everything is a it is a linked right. So, this is here it is output here it is delta E, but there it will be input to the turbine.

So, that is why that is why here that is why here it is the input to the turbine and this is T t the steam chest time constant, will call later I think I given this parameter this steam time constant this power will come later. After that you have a reheater, you have a reheater right here also you can represent it by some delay this is reheater. So, this is actually you can represent any delay, you can represent 1 upon 1 plus ST r, that is your reheat time constant.

And then you have this crossover right this crossover is there. So, there you can make 1 upon 1 plus ST c the 3 time constant T t T r and T c right, the 3 time constant, but T c T c is very small we neglect that and T r the reheat time constant for reheat turbine it is higher than T t, T t is some range is there in between 0.2 to 0.5 second or so, but T r it will be approximately say it is 10 second or so, right. And, this is the facts on a power generator in the high pressure side, then intermediate side and this is a low pressure and this is total delta P delta P g; that means, here in your high pressure, plus intermediate pressure, this is the high pressure side, this is the intermediate side, and this is a low pressure right section of the turbine.

So, suppose this is F HP the fraction of power generated then this is F IP from intermediate pressure because, this is your steam chest everything is coming here, some power will be generated, from intermediate pressure also it will come up because, after reheater the this section is coming after reheater this section is coming right. And therefore, it is your 1 plus ST and then it is F IP right, intermediate pressure whatever fraction of power generated. And this is your 1 upon 1 plus ST c this is cross over time constant right, and after that LP side is coming.

So, this is your F LP right. So, F HP plus a F IP plus F LP, this actually together is equal to 1 if we assume lossless right these 3 should be 1, but if you neglect this neglect this time constant T c. So, basically in that case we will find F IP plus F LP will be 1 minus F HP and that we will come right.

So, this is approximate linear model for tandem compound single reheat steam turbine. I believe this schematic thing you have understood and if reheater is not there later we will see if reheater is not there only that only that on reheat type turbine this thing, if this kind of model is there non reheat type turbine, if reheater is not there, then this term will not be there, this term also will be not will not be there, only this time constant it can be represented later we will see right. So, that means that means if you; that means, if we assume that this time constant is your what you call neglected this time constant is neglected.

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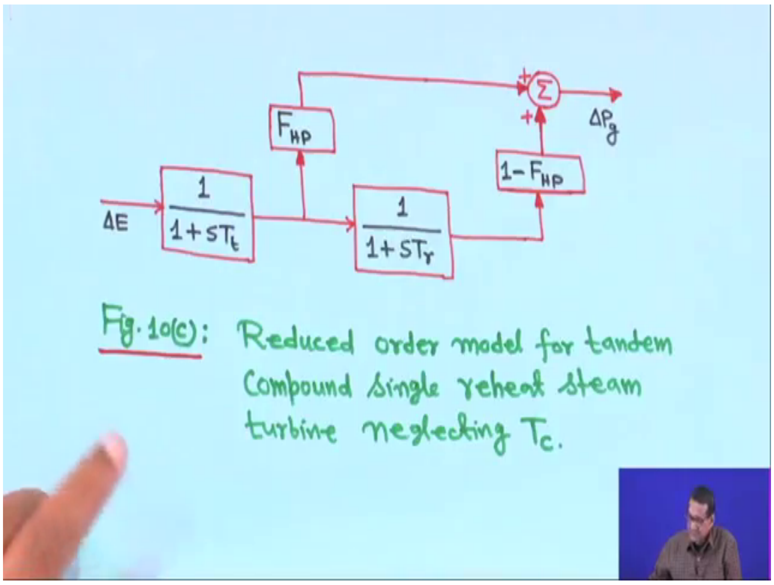

So, just hold on before showing this diagram, before showing this before showing this approximation, just have a look here right.

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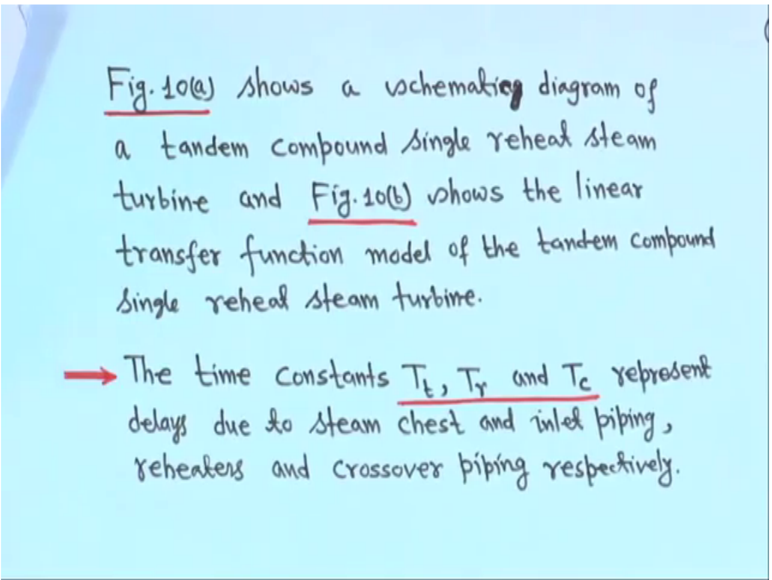

That figure 10, I shows a schematically diagram of tandem compound single reheat steam turbine and, figure this is actually figure 10 a that is the schematic 1 and this is actually your figure 10 b, figure 10 b whatever I showed.

Right and this figure 10 b actually shows the linear transfer function model of the tandem compound single reheat turbine right the time constant. T t T r and T c represent delays due to steam chest and inlet piping, I mean everything has some delays right for example, suppose you make your friend angry some of your friend will react to very quickly.

So, that is his reaction time is very fast and some of you will react in sometimes some delay will be there. So, every physical system are in real life also some delay will be associated with that right. So, the time constant T t, T r and T c represent delays, this T t you call steam chest time constant, T r or what you call your T r that is your what you call that reheat time constant and the T c crossover piping respectively.

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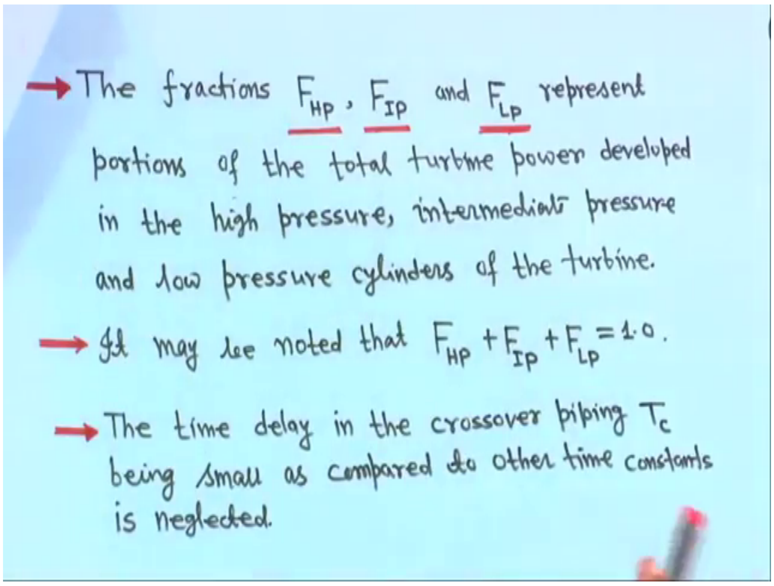

But the faction of power that F HP, F IP and F LP represent portion of the total turbine power developed in the high pressure, intermediate pressure and low pressure cylinders right see in that that I told you.

This high pressure and intermediate pressure and low pressure this power fraction of power developed, in the cylinders of the turbine. So, it may be noted that F HP plus F IP plus F LP is 1 assuming the lossless so altogether it should be 1. So, but time delaying crossover piping T c being small as compared to other time constant is neglected so, this time constant T c is very small right maybe 0.0102 something like that very small. So, this term is neglected T t range it will be in 0.2 and your what you call say point in between 0.1, 0.5 seconds T r also about 10 15 second it is very high value.

So, compared to that this 1 we can neglect, if you neglect this 1 if you neglect this T c right the time constant if you neglect right, then the reduced transfer function model is given in figure 10 c this is 10 c because F HP plus F IP plus F LP is 1 right this 1.

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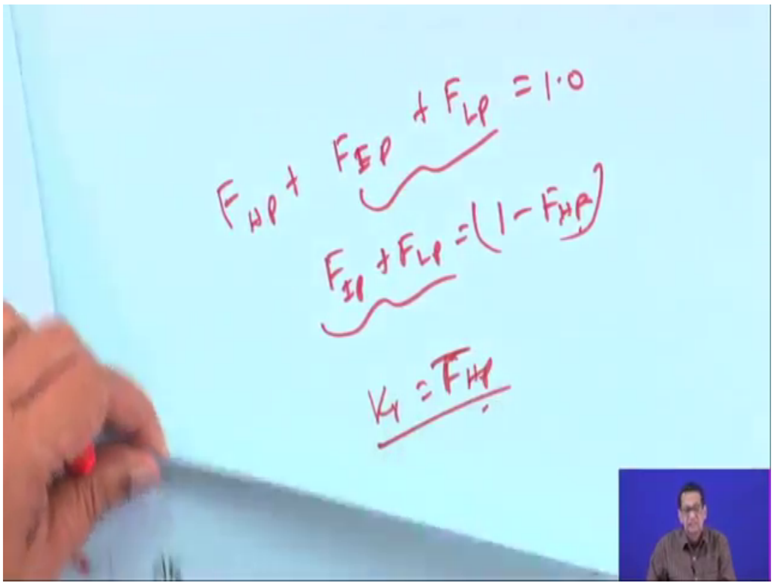

Actually F HP plus F LP that high pressure cylinder, low pressure cylinder, sorry F IP plus then F your LP is equal to 1.0 right. So, this is 1 but these 2 together your F IP plus F LP is equal to 1 minus F HP right this is the thing so; that means, intermediate pressure fractional power developed in the intermediate pressure and low pressure cylinders is equal to 1 minus the power developed in the high pressure cylinder.

Right, but we had neglect T c we are neglecting these just hold on neglecting this T c value, this time constant will be neglected, if it is neglected it will become F IP plus F LP that is nothing, but 1 minus F HP and that is why we are putting that this 1 which is F HP this is 1 plus ST r immediately after that it is 1 minus F HP r and output is P g delta P g and this is delta E right. So, this is reduced order model for tandem compound single reheat steam turbine neglecting T c that crossover piping time constant is neglected, 1 this is done once this is done right.

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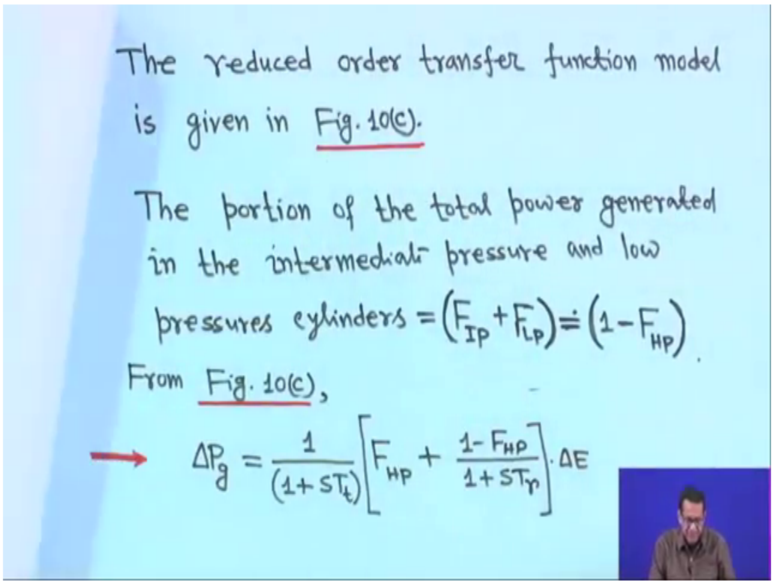

And this is I told you this is 1 minus F HP. So, from figure 10 c right from figure 10 c you make that transfer function, just make it the delta P g upon delta P will be how much right. So, delta P g this delta P g this is delta E into 1 plus ST t into F HP will go this side and here also, 1 plus ST r into 1 minus F HP that is equal to delta P g summation of this 2 this 1 plus this 1 is equal to delta P g.

So, we are writing delta P g is equal to 1 upon 1 plus ST t, it is going to here also it is multiplied here also both right. So this is keep it outside that is 1 plus ST t this is keep it kept 1 upon 1 plus ST t in bracket into this is F HP is coming here, right F HP is coming here plus 1 minus F HP in to this 1 plus 1 minus F HP into 1 upon S plus t that is 1 minus F HP upon 1 plus ST r into delta E right, because this delta E will be there because this delta this delta E is multiplied by this. So, after that this is going here and this is going here right. So, in that case this is and then you simplify and try to simplify and try to find out what is delta P g upon delta p right.

Now this is understandable from very preliminary thing of the block diagram transfer function from your third year control system right.

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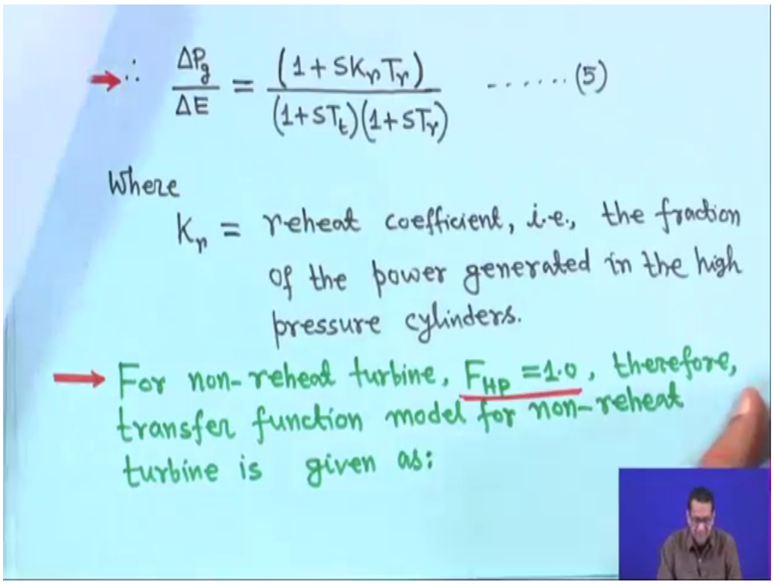

So that means, delta P g upon delta E right delta P g upon delta P g upon delta E is equal to if you simplify it will be 1 plus SK r T r upon 1 plus ST t 1 plus into 1 plus ST r right. So, K r that here K r is not mentioned, but I will put it that what is K r right, K r is reheat coefficient right it is called reheat that is the fraction of the power generated in the high pressure cylinder, that is K r is equal to actually a F HP right.

So, for non reheat turbine F HP is 1. So, K r will be 1 that actually this is the K r we represent actually it is K r nothing, but a your F HP that K r is equal to F HP right this much only. So, we represent that is for the power representation we make it that K r is reheat coefficient that is the fraction of the power generated in the high process cylinder.

So, for non reheat turbine F HP is 1, because for non reheat what to call for non reheat turbine that is your reheat was not there. So, in that case your K r K r is equal to 1, K r is equal to F HP K r is 1. If K r is 1 then this term and this term will be cancelled if K r is 1 because, it will be then 1 plus ST r 1 plus s T r in the case of non reheat turbine then it will be your 1 upon 1 plus ST t only right. So, that is this is equation 5 right.

So, that is your that is the product that; that means, for the non reheat turbine model that is given as.

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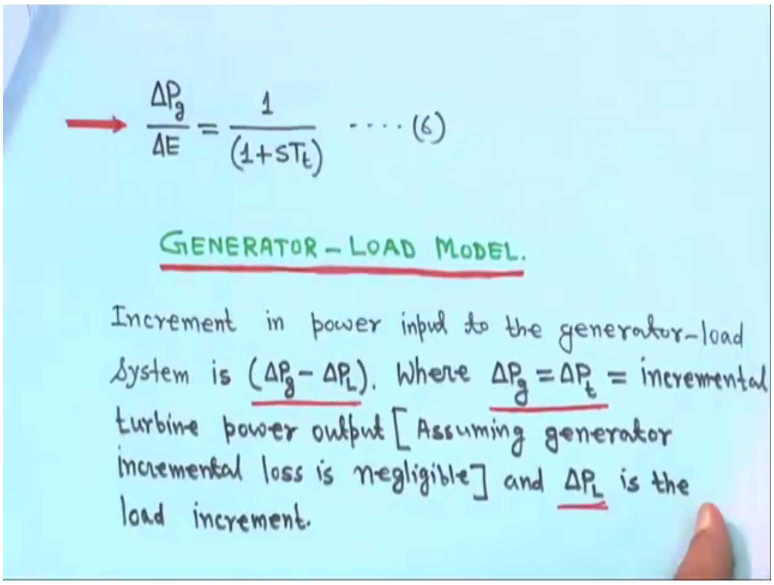

It is given as delta P g upon delta is equal to 1 upon 1 plus ST t it is equation 6 right. So, this is actually a turbine model. So, we got del that is delta p; that means, we related delta P g and delta E if it is a non reheat turbine it is 1 upon 1 1 plus ST t, if it is your what you call reheat turbine it is 1 plus SK r T r upon 1 plus ST t into 1 plus s T r K r is nothing, but the fraction of power generator in the high pressure cylinder right. So, this is your we call reheat coefficient right. So, up to this it is ok.

So, delta P g is equal to your delta E upon 1 plus ST t right; that means, delta P g is equal to delta E upon 1 plus because, we have to relate 1 section to 1 part to another part using different your this block diagram in Laplace transform, but here not putting delta P g s upon delta P s the function of s it is understandable sets like throughout this that I have tried to avoid.

Next is generate a load model. Next you have to make a generator or load also you have to model with frequency, then only your block diagram representation will be complete right. So, increment in power input to the generator load system is delta P g minus delta p l, suppose generator was generating generator was generating your 200 megawatt power in the system. Suppose load demand has increased from 200 to say 210. So, 10 megawatt increases there.

So, there is a change in load say delta P L that is this 1 is 10 megawatt so; that means, additional power generation from generator it has to be 10 megawatt such that there will be balance. So, as soon as 10 mega generated a generator, the change in generating power from 200 of course, it is delta P g minus delta P L, but instantaneously generator cannot generate the 10 megawatt it will take some time. So, if it is so there will there will be there will be transient imbalance between the generation and the load right because, this delta P g is equal to delta P L it will take some time right.

So, but this has this is already 10 megawatt and slowly and slowly it is catching up the delta P g will catch to this one, but unless or until steady reach there is a transient imbalance because, difference will be there between delta P g and minus delta P L. So, if it is if it is; that means, and we are writing delta P g to delta pt is equal to incremental your turbine power output in per unit system.

We are assuming the power generated by the generator and the turbine it is same and assuming that turbine is a lossless turbine right. So, and another thing is there that is not here, that is in power unit system that you are what you call that turbine that generator power output and torque, it is actually same in per unit, but those are beyond us those are beyond the scope, but here that delta P g is equal to delta P to have taken because, assuming the lossless turbine there is an incremental turbine power output assuming generator incremental loss is negligible, that is lossless and delta P L is the load increment.

So, in that case this delta P g and delta P t both will remain same right,. So, due to this transient imbalance what can happen the loop.

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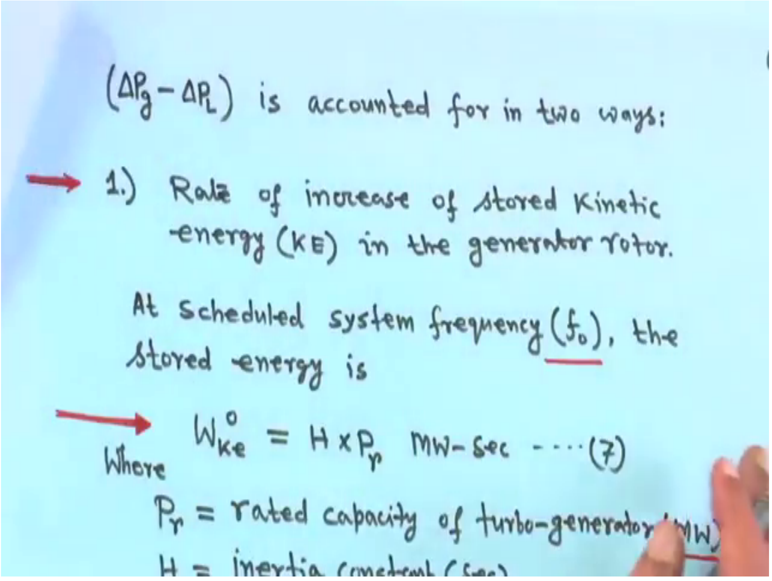

That is because of that it is only transient imbalance. So, in steady state is reached then delta p is equal to delta P L, but whatever we are discussing here the state steady state is not least it is transient imbalance is there. So, that is accumulated in 2 ways suppose first 1 is rate of increase of stored kinetic energy in the generator rotor right, that that is the at scheduled frequency f 0 the store energy is W Ke 0 is equal to h into P r that is that kinetic energy.

When you express this we have written, I think in the previous course in transient stability studies, I think we have seen this one. So, h is the inertia that we have seen and P r is the rated capacity of the machine therefore, initially that what you call at system frequency f 0 that energy stored is W Ke and this is superscript 0 is equal to H into P r that is megawatt second because, H is in second right is that your inertia, that we have studied in transient stability, in the previous course power system analysis and P r say is the rated capacity of the generator in megawatt.

So, this product is you are megawatt second that we represent this is your stored energy in the system, this is say equation 7. Where P r is the rated capacity of turbo generator that is megawatt and H is inertia constant in second right, this you write the stored kinetic energy.

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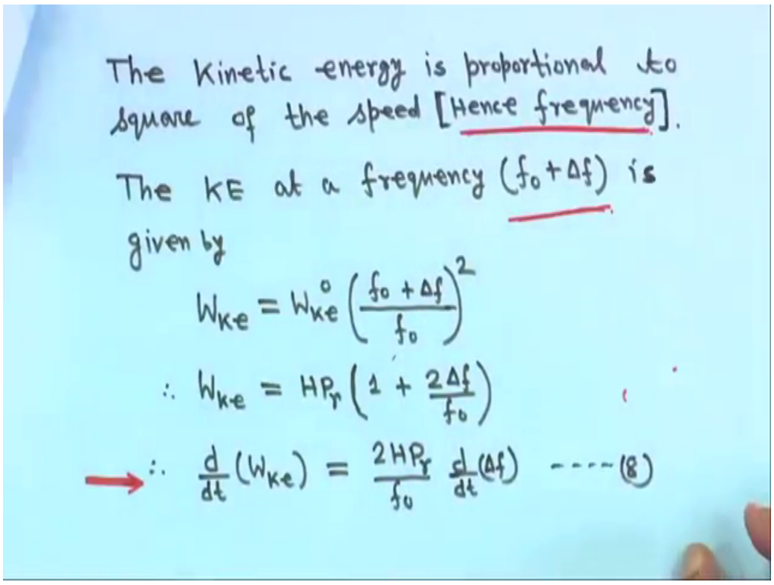

Next is that this kinetic energy is proportional to the square of the speed because, you know that K KE is proportional to the square of the speed right. So, in that case where that omega is related to your frequency omega to related to frequency therefore, kinetic energy at a frequency f 0 plus delta because, due to this change in load that due to this change in load right, the peak of speed will change although it will not lose synchronism, but some change will be there.

So, in that case the difference will be there then with frequency you will not be exactly f 0 it will deviate it will be said f 0 plus delta P L. So, that is why the kinetic energy at a frequency when that load is partner that is a load perturbation right at the time frequencies f 0 plus delta f. Now as kinetic energy is proportional to the square of the speed right. So, initially this can be written as W Ke that W Ke 0 into f 0 plus delta f square upon your f 0 square it is something like this.

Actually the kinetic energy is proportional to the speed right, then speed means that if it is omega just hold on in a separate seat, I am writing for you right.

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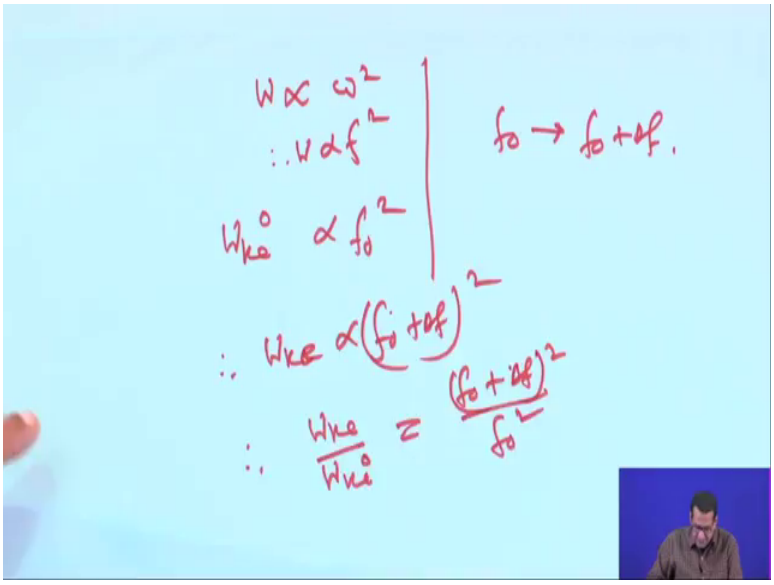

Because in general W is proportional to your omega square right w is proportional to omega square; that means, that is omega is actually proper your power 2 pi f; that means, W is actually proportional to f square. So, if kinetic energy say at nominal frequency this is proportional to f 0 square, and if load there is change in load right; that means, the frequency has changed and was f f 0.

Now f 0 has changed to f 0 plus delta f; that means, my W Ke is proportional to then your f 0 plus delta f square right; that means, that means if you make it like this W Ke by W Ki 0 is equal to you can write that f 0 plus delta f square divided by f 0 square this you can write. So, that is what I have written W Ke W Ke 0, f 0 plus delta f square upon f 0 square is whole as a written square; that means, it is the same thing whatever I have written here f 0 plus delta f 0 square.

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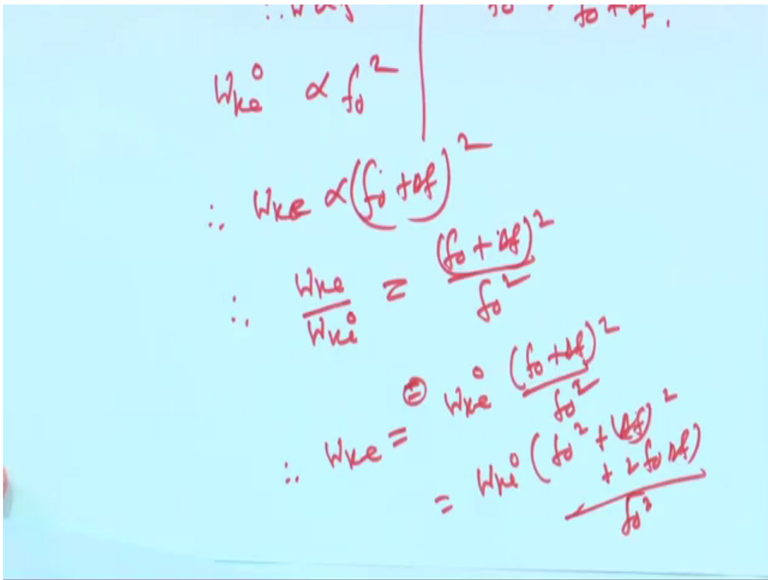

Now if you expand this if you expand this; that means, that will before expansion that is W Ke is equal to WK is 0 into f 0 plus delta f square upon f 0 square this way you can write. Now if you expand it W Ke 0 that is your f 0 square plus delta f square plus 2 f 0 delta f divided by your f 0 square this way you can write right.

Now, question is that delta f square this delta f is very small. So, square is much smaller. So, this term you drop from this equation this you drop.

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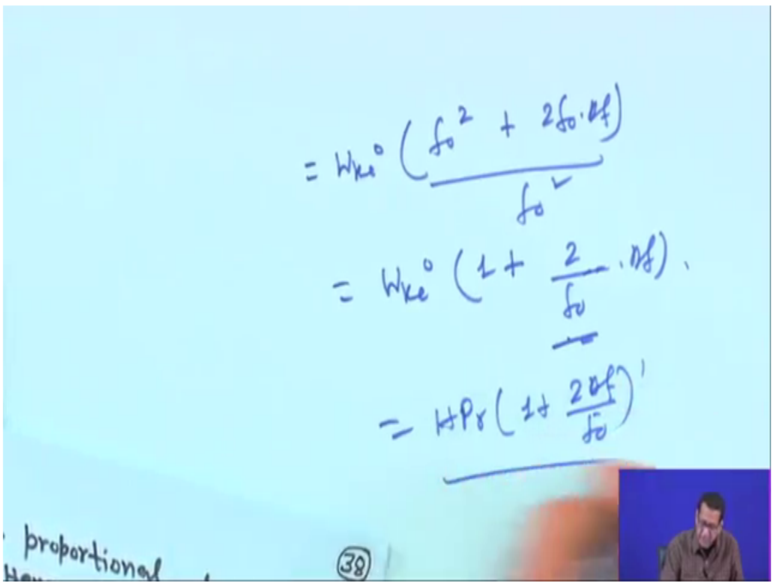

That means this one will be W Ke is 0 in bracket I can write this is your f 0 square plus 2 f 0 into delta f divided by f 0 square, this way you can write; that means, this 1 W Ke 0 divide f 0 square numerator at this thing f 0 square by f 0 square 1 plus 2 f 0 by f 0 square means 2 f 0 right into delta f right so; that means, it is your W Ke 0 1 plus 2 delta f upon f 0. So, same thing upon simplification this, we are writing W Ke 0, W Ke 0 is equal to H into P r we have seen. So, here we have written W Ke 0 you write 1 more line W Ke 0 is equal to H into P r, then 1 plus 2 delta f upon f 0 right.

So, whatever we are writing here, W Ke is equal to HP r 1 plus 2 f into delta f upon 0 right. So, now rate of change of energy is power. So, you take the derivative with respect to t of W Ke. So, d dt of W Ke is equal to if you take the derivative it will 2 HP r upon f 0 into d dt of delta f this is equation 8 right. So, H is a constant and P r is a constant f 0 is the nominal frequency on the variable is delta f. So, it is d dt of delta K is equal to 2 HP r upon f 0 d dt upon delta f.

So, this is your and this is one part, that is the variation of your what we call delta P g minus delta P L and frequency is changing and accordingly you can make this equation that del d dt upon delta k K is equal to 2 HP r upon f 0 d dt of delta f this is equation 8 right.

Thank you.