Power System Engineering
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Lecture – 49
Load Frequency Control (Contd.)

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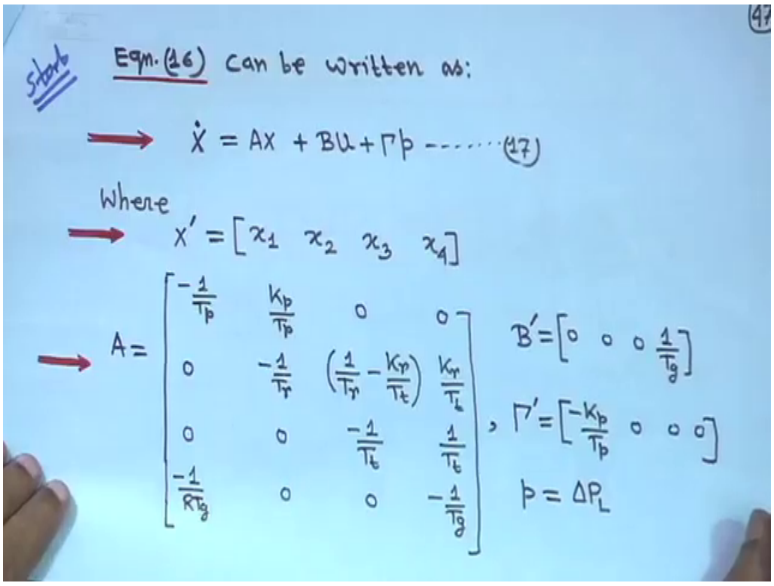

So, so whatever we have seen just now that this is a matrix and this dash for transpose, right? Such that; it can save some face that is why you have taken transpose and this is actually b transpose and this is gamma transpose and p is the disturbance, right?

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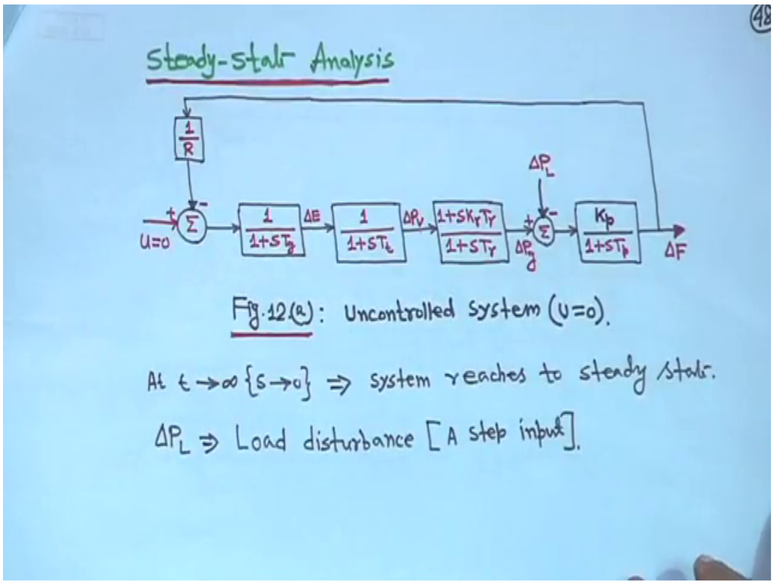

So now look steady state analysis, first part we will see the steady state analysis that suppose this is your control signal u is 0 uncontrol mode when u is 0 uncontrol mode and this is your this part is governor then turbine then generator, right? So, and as usual we will see what is the steady state value of delta f delta Pg here delta Pv delta E is not our interest, but we will see all these things and uncontrolled mode when there is no controller so u is equal to 0.

Now, you know from your control system that when t tends to infinity, I will get the steady state value; that means, S tends to 0; that means, system reaches to steady state when S tends to 0 or t tends to infinity and delta P L is a load disturbance and at it is a step input, but if S tends to 0 here there is no question of you know integral function or integral controller type of thing. So, no question of here in this block diagram Ki upon S or something, right? That, but everything is 1 plus S T g 1 plus S T t and in this form therefore, in this block diagram what you do you put that S tends to 0. So, makes is equal to 0 then your block diagram will be something like your steady state block diagram. See if we put and you will get the same answer whatever you do using final value theorem. So, in this block diagram you put S is equal to 0.

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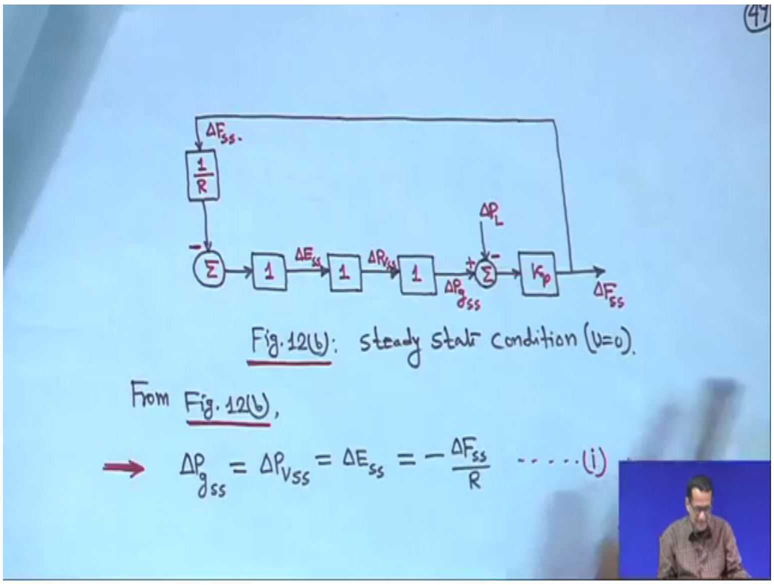

That means if we put it then this is actually steady state condition if we put S is equal to 0 this part will be 1, S is equal to 0 here this part is 1, S is equal to 0 here also this part is 1 and S is equal to 0 here this part is K p and this is delta Pg delta P L, but for S is equal to 0 means these are all steady state values that means, this block diagram for S is equal to 0 can be written as this is delta S as it is steady state value this is K p because S is equal to 0 here? S tends to 0 means t tends to infinity. Here also it will be delta Pg SS min steady state. And here it is 1, it is 1, it is 1; that means, these 3 block here it is 1 here it is 1 here it is 1 forest is equal to 0 you port.

So, in that mean easy way to get the steady state value. So, and this is your delta F S feedback is here and u is 0 I am not writing here, but here it is u 0 u is equal to your 0, right? So, that means from this figure what we will get it is 1. So, delta Pg SS will be delta P VSS and is equal to delta E SS is equal to your minus delta F SS upon R is equal to minus delta F SS upon R because anyway u is 0?

So, this is your this is your del this is one condition that delta P these 3 actually in pile at steady state all these 3 values are equal that because all are coming 1 1 1. So, this is one equation. So, this is equation 1, right? And similarly, from this block diagram you can write delta emphasis is really K into K p into delta Pg SS minus delta P L. Even it is a step input as we have already put that t tends to infinity means S is equal to 0 in this block diagram in this block diagram for a step input do not make it delta P L upon S;

because already we have put it here although it is a step input that do not put anything that we will see later when he lose final value theorem.

So, question is so this is delta Pg S is this delta minus delta F SS upon R this is one equation another one is delta F SS is equal to K p into delta Pg SS minus delta P L.

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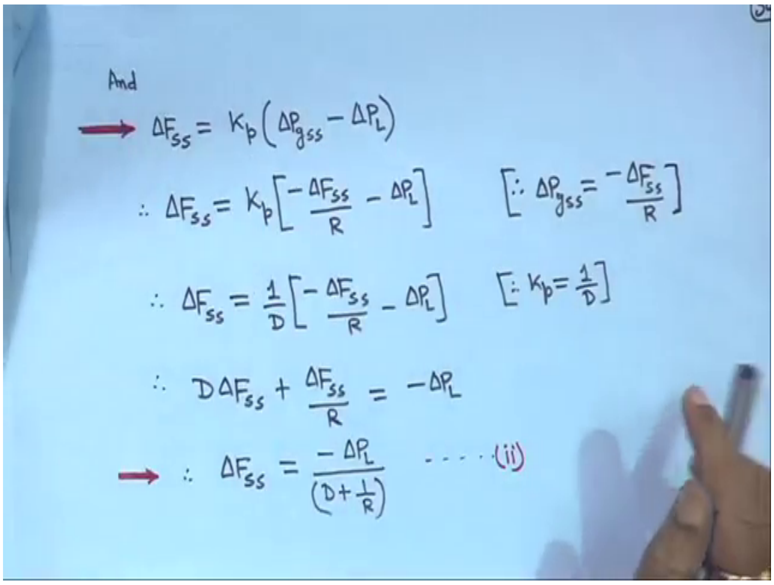

That is delta F SS is equal to K p into delta Pg S a Pg SS minus delta P L, right? Now delta F SS is equal to K p into the delta Pg SS we got this one is equal to minus delta F SS upon R say back at have delta Pg SS is equal to minus delta F SS upon R. So, you put it here, right? Minus delta P L and then K p is equal to actually we know that earlier we have seen K p is equal to 1 upon D therefore, this one you make K p is equal to 1 upon D. And you simplify if you simplify this you will get delta F SS the steady state value is equal to minus delta P L upon D plus 1 upon R this is equation 2 this is the delta F SS value, right?

Next is. So, if it is delta F SS then if you substitute your what you call this delta F SS is here in this expression delta Pg SS. The delta F SS is equal to if you put it here then you will get expression for study state expression for delta Pg SS that we will see later, right?

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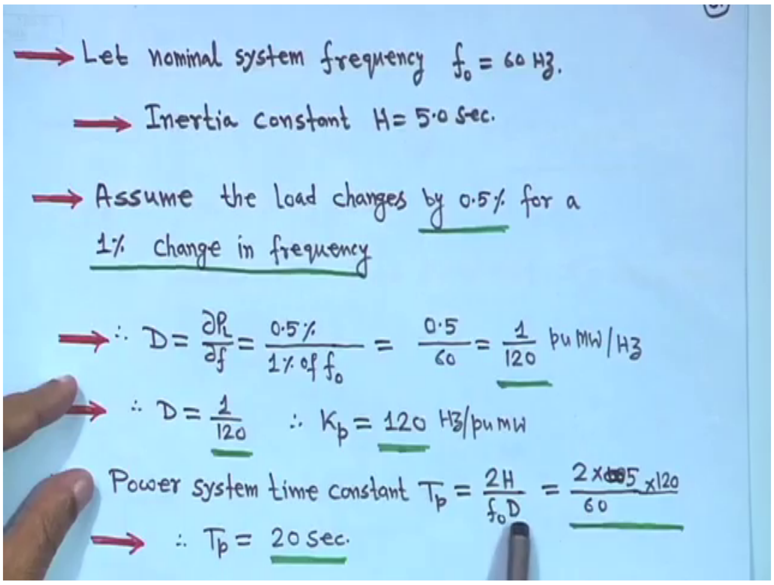

So now you as let us let your what you call then this nominal system frequency says 60 hertz, right? Suppose it is 60 hertz.

Now, inertia constants they say it is H is equal to 5 second this 18 hertz in terms of second we have seen in the transient stability analysis for power system analysis course, right? So, I assume that load changes by 0.5 percent for a 1 percent change in frequency then we know D is equal to delta P L upon delta f; so 0.5 percent upon one percent of f 0. So, is equal to 0.5 upon 60 because f 0 is 60 f 0 is 60, right? 60 hertz, right? At 0.5 percent 1 percent do not making it by 100 or 100 automatically it will be cancel. So, basically it is 0.5 and 1 percent of your what you call your f 0. So, person cancel ultimately it will become 0.5 by 60, right? So, that is equal to 1 upon 120 per unit megawatt per hertz, right? That means, D is equal to 1 upon 120. So, K p is actually reciprocal of D. So, K p is equal to 120 hertz per unit megawatt. So, K p value we got.

Now, we know that this is also we have seen power system time constant t p is equal to H upon f 0 d. So, H is 5 seconds or 2 into 5, right divided by f 0 into D. So, f 0 is 60 hertz and your D is equal to 120, right? 1 1 upon 120. So, here if you put D is equal to 1 upon 120; that means, it will go to the numerator. So, it is basically 2 into 5 into 120 upon 60; that means it is 20 second, right? It is 20 second. So, then T p we got then D value we got K p we got, right?

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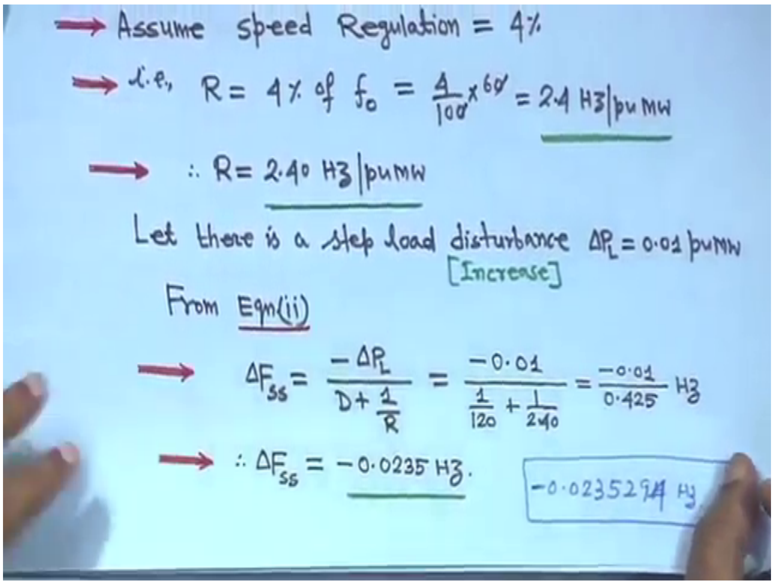

Now, assume a speed regulation is 4 percent, right? That is your R. So, R 4 percent means it is 4 percent of the nominal system frequency. So, 4 percent of f 0; that means, 4 percent of 60 that is it is for upon 100 into 60. So, 2.4 hertz per unit megawatt this is R. So, R is equal to 2.40 hertz per unit megawatt. Now let there is a step load disturbance delta P L is equal to 0.01 per unit megawatt. There is step load disturbance that is increase I have written here in the bracket an increase in the disturbance; that means, whenever increase in the disturbance delta P L you will take as a positive thing, right? Positive value. So, 0.01 per unit megawatt.

Now, from equation 2 we got this one delta F SS is equal to minus delta P L upon D plus 1 upon R. So, put all these values delta P L we have taken to 0.01. So, minus 0.01 because of this minus then D is equal to 1 upon 120 and R is equal to 2.4, so plus 1 upon 2.4.

So, is this will become actually minus 0.01 upon 0.425 hertz, but F SS is always delta F SS is always in hertz, right? That means up to 4 decimal place you take; so delta F SS will become minus 0.0235 hertz and if we make it further so minus 0.0235294 hertz, right; why I have taken this I will show you how you so many decimal places.

So that means, steady state value will come actually minus 0.0235 hertz.

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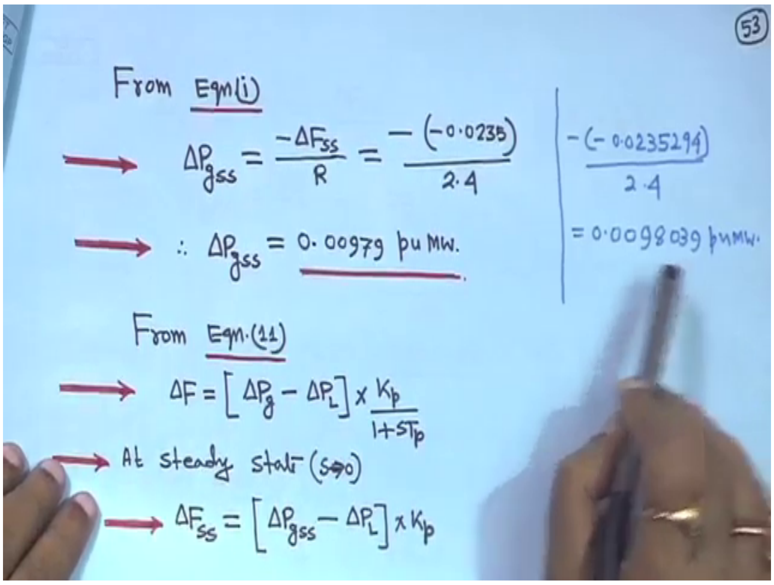

Now, we know delta Pg SS is equal to minus delta upon R this is from equation 1 this also you know. So, minus and delta F SS is minus of minus 0.0235 upon 2.4. So, delta Pg SS will come 0.00979 per unit megawatt and if you take up to 7 decimal places a bracket I made it is minus 0.0235294 upon 2.4 it actually comes 0.0098039 per unit megawatt, right? Almost same, but I have taken this one.

Now, question is there is a question is we have taken the load disturbance is 0.01 per unit megawatt, but generation at the steady state that generation should match the load. So, delta Pg SS should have become 0.0 0.01, but in this case, it is coming 0.00979 or rather oh it is 0.0098 so slightly less.

So, why this is happening? This is happening I will show you now; this is happening because of your that load is your sensitive to the changes in frequency. So, this that is why you were not getting exactly 0.01 because that is frequency that it is showing that steady state error some deviation is there that minus 0.0235 hertz that is why this is happening it is not exactly 0.01, right?

So, again from this equation or the block diagram whatever it is from this block diagram only we can make it just hold on from this block diagram we can write this steady state block diagram we can write this one, right? This one from this block diagram we can write delta F SS is equal to K p into delta Pg SS minus delta P L. This is from figure 12 b from this block diagram only we can write rather than equation 11 directly you can write that this equation from here it is coming on S tends to 0, right? So, delta F SS is equal to delta Pg SS minus delta P L into K p. This is from the step dry figure 12 b the steady state diagram, right? So, in this case now if you if you just see look at this one delta F SS.

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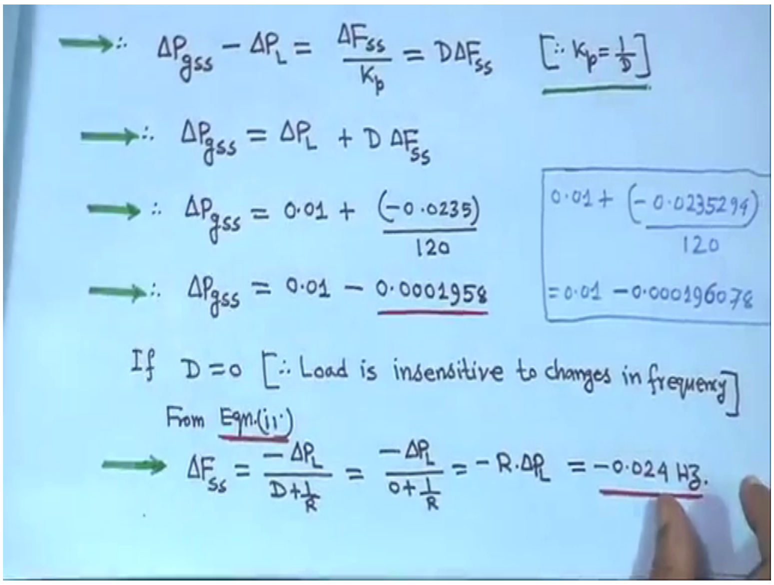

So, delta Pg SS minus delta P L is equal to delta F SS minus a divided by K p. So, this is delta Pg SS minus delta P L L P L is equal to delta F SS upon K p and K p is equal to 1 upon D. So, K p K p is equal to 1 upon D they had it written here. So, that is equal to D into delta F SS; that means, that delta Pg SS is equal to delta P L plus D into delta F SS; that means, delta P L is 0.01 plus this minus 0.0235 upon 120.

So, delta Pg SS actually coming 0.01 minus this term; that means, whatever you got 0.01 minus of this term, right? Minus of this term that means there, here it is shown that in here that it is not exactly this one it already coming this one, right? Up to 7 decimal places if you take both the same, but I have taken it these difference is there and this is this difference. And this difference is happening because of this your we call sometimes is said pause your damping term also D sometimes we call it, right? Because this frequency it is showing some steady state value it is not exactly 60 hertz, it is some deviation is there minus 0.0235.

So, frequency is not exactly at 60 hertz it will be F 60 minus 0.0235 because of this your frequency excursion that this term is a this is this is this your delta Pg SS will cannot be equal to 0.01 because the your this your this your what you call the load is sensitive to the frequency change in frequency; that is why this difference is there this is the difference.

now if D is equal to 0, say if D is equal to 0 I will load is totally insensitive to the changes is frequency D is 0; that means, your D is equal to delta P L upon a delta f if that term is 0; that means, here D is 0 say at the time delta Pg SS will become delta P L.

So, without any control or if you try to do this, if there is no controller frequency after load disturbance it will so steady state error and because of this frequency steady state error delta Pg SS cannot meet that load demand. I think it has been I think this has been your heart to call understandable to you I think you have understood this, right?

Now, from is now from equation 2 so we can write delta F SS is equal to minus delta P L upon D plus R, right? D is equal to 0 delta Pg SS is equal to delta P L. Now in this equation then what will be the steady state error of frequency? So, if D is 0 it will be basically minus delta P L upon 1 upon R that is equal to minus R into delta P L and R is equal to 2.4 therefore, and delta P L is 0.01. So, it will be coming minus 0.024 hertz then we steady state error actually is what to call it was my earlier it was minus 0.0235. Now minus 0 0.024 hertz slightly change if D is equal to 0, right?

So, from this you have from this you can understand the steady state value of your what you call this one. Similarly, similarly your other steady state values at whatever you have got that delta Pg SS we have got say 0.09 00979 or 0.0098 exact one this is the exact one; that means, steady state value for these 2 things delta Pg and delta E that delta Pg and delta E steady state value their same is equal to delta Pg SS so 0.0098.

So, not writing here because in the here I have written here delta Pg SS sorry is equal to delta P a Pg SS is equal to delta E SS. So, all these steady state 3 values are same, right? Therefore, what you call this thing that delta f S there is slight change minus 0.0 hertz. Suppose if you there is 4 percent regulation if it is a 6 percent regulation then E then it will be your 60 hertz then value this value will change, right? It will become minus 0.036 hertz.

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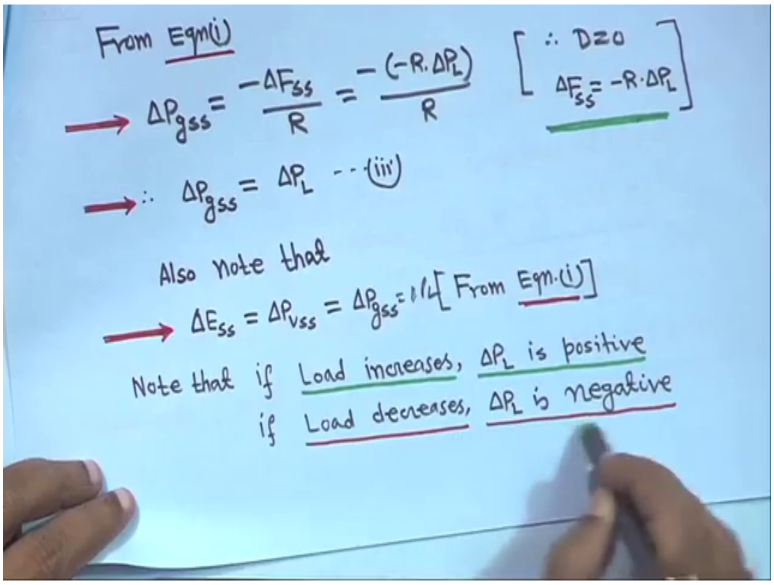

So, this and from equation one again from equation 1 you will get delta Pg SS is equal to minus delta F SS upon R. And from here you are here from here we have seen that if D is equal to 0 directly delta Pg SS is equal to delta P L you are getting. Now again from this equation that we have seen that if D is equal to 0 delta F SS is equal to minus R into delta P L and we know that delta Pg SS is equal to minus delta F SS a F SS upon R. And that means, delta F SS is equal to minus R into delta P L you substitute here you substitute here. So, R r will be cancel and minus minus it is plus so delta Pg SS is equal to delta P L, right?

So, that is the idea for this D and without D, right? So, also note I have written here delta E SS is equal to delta P VSS is equal to they all will be your equal to 0.01. If is equal to delta P L, all under this case all this case for D is equal to 0 it will be is equal to delta P L and in this case delta P L value is taken 0.01.

So, if load increases delta P L is positive this should be in your mind and if load decreases delta P L is negative, right? These 2s must be in your mind all the time.

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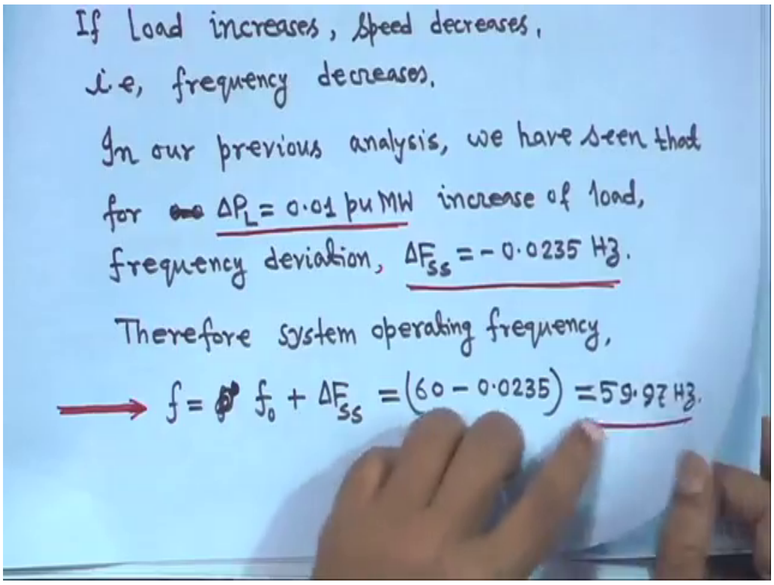

Now, that means, that if load increases if load increases I told you speed decreases speed decreases that is frequency decreases, right? So, in our previous analysis just now whatever you have seen that delta P L is 0.01 per unit megawatt it we are not telling just 0.01 per unit we are telling per unit megawatt, because this is actually related to power; that is why making it 0.01 per unit megawatt, right? Increase of load frequency deviation is this much daily basis is equal to minus 0.0235 hertz when load is sensitive to changes in frequency. Therefore, the system operating frequency will be f will be f 0 plus delta F SS f 0 is 60 hertz and delta F SS minus 0.0235 hertz. That means, system will operate at 59.97 hertz I hope you have understood this one, right?

So, that is the operate system operating frequencies things are very simple just you have to keep certain things in mind a little bit little bit we need to understand, right?

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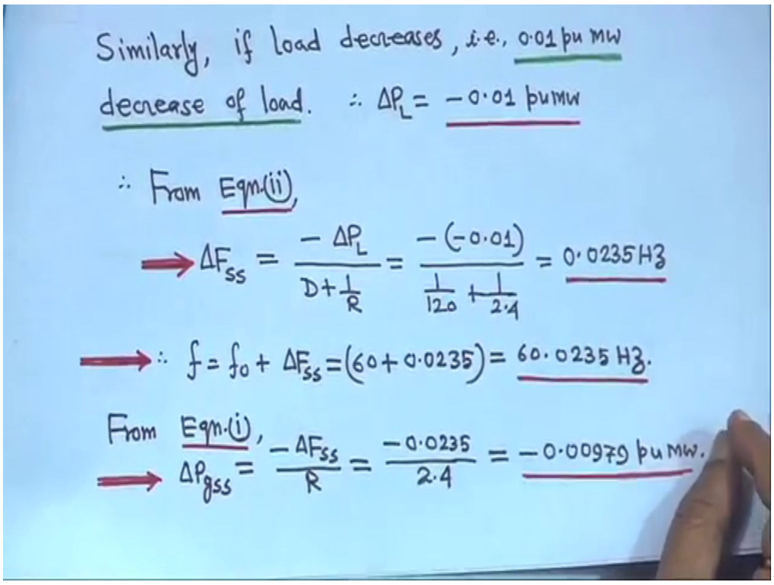

Similarly, look while load decreases when load decreases, if load decreases that is 0.01 per unit megawatt; that means, delta P L you take minus 0.01 per unit megawatt because decreases means you have to take negative sign; that means, from equation 2 delta F SS minus delta P L upon D plus 1 upon R. So, it is minus of minus 0.01 divided by 1 D is 1 upon 120 and plus R is 2.4 plus 1 upon 2.4 simplify it will become plus 0.0235 hertz, right?

So, f is equal to f 0 plus delta F SS so it will be 60 and if it is plus. So, plus 0.0235 it is 60.0235 hertz it is just slightly above the nominal operating nominal system frequency, right? And from equation 1 we know delta Pg SS will be minus delta F SS upon R. So, it is minus 0.0235 upon 2.4 because delta F SS is coming plus. So, it will be minus 0.0235 upon 2.4 so minus 0.0097 per unit megawatt. So, negative sign means that generator will decrease it is generation. Suppose it was operating at for example, say it was operating at 200 megawatts say and you say your 0.01 power units a pie suppose if you make it like this 0.01 per unit megawatt, it was there better you take 1 per unit megawatt it 1 per unit megawatt and now till load has decreased to 0.01. So, it will be 0.99 per unit megawatt.

So, that way you are what you call? That your that system will generate your 10 y or this much power this mega power unit megawatt power less, right? So; that means, generation will decrease otherwise the negative means the generation will decrease. Suppose take for example, if 10-megawatt load decreases suppose switched off; that means, generation also will decrease, right? So, negative sign means generation decrease and positive sign for frequency means positive sigh your, what you call? That frequency is increasing deviation is plus. So, frequency is increasing, right?

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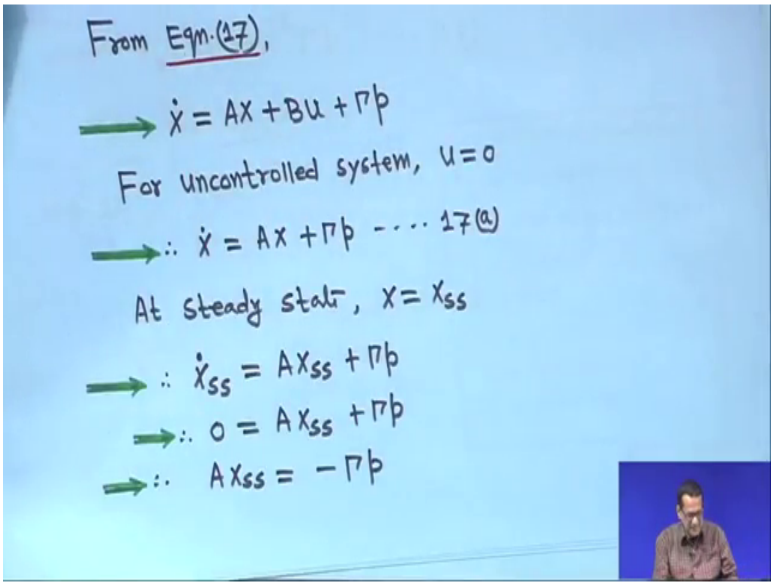

So, next is that that is one thing and now next is that X dot is equal to AX plus B u plus gamma p. We have seen this 10 have to call this state space analysis this stay all these equations we have seen A B gamma, right? And X A is as told you state transition matrix B is the control transition matrix and gamma is the disturbance transition matrix.

So, for uncontrolled system look this is all I show by how can you can obtain, but how you can obtain from this equation also because all the parameters are known assuming T p T t T R everything is known all parameters are known at the end I will give you those parameters all the parameters are known; that means, u is equal to 0. If u is equal to 0 this term will not be there. Therefore, X dot is equal to AX plus gamma p say this is equation I have marked as 17 a, right? So, at steady state X is equal to X SS, right?

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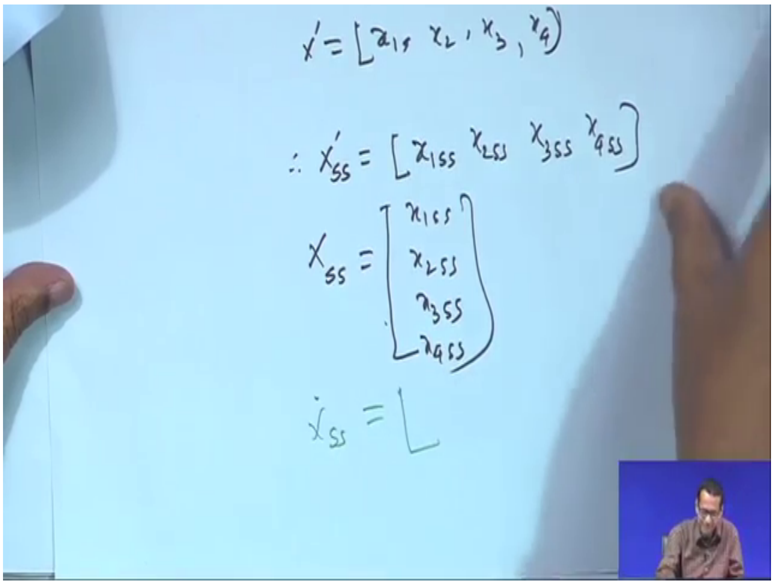

That means, all the state variable for example just for your understanding, just for your understanding we know that X is equal to X transpose is equal to say X 1 then X 2 then X 3 then X 4, right? X 4. So, if you if you make it like this; that means, my st X transpose steady state; that means, your X 1 steady state X 2 steady state X 3 steady state and X 4 steady state, right? So, this is transpose; that means, that X; that means, here if X X X equal to X S means, that is your I if X S is equal to is this one that is your X 1 steady state X 2 steady state X 3 steady state and then X 4 steady state values this is X SS, right? That is what we are taking that X.

So, at steady state X is equal to X SS, right? Steady state; that means, all the variables are reaching to the steady state value; that means, you put X is equal to X S dot here, right? X S here that mean this is a capital X of course, capital X SS dot is equal to a capital X S is plus gamma p and capital X S dot is equal to 0 because all the so, when it reaches the steady state just hold on when it reaches to the steady state suffers any debi any there are 4 state variable it does not matter.

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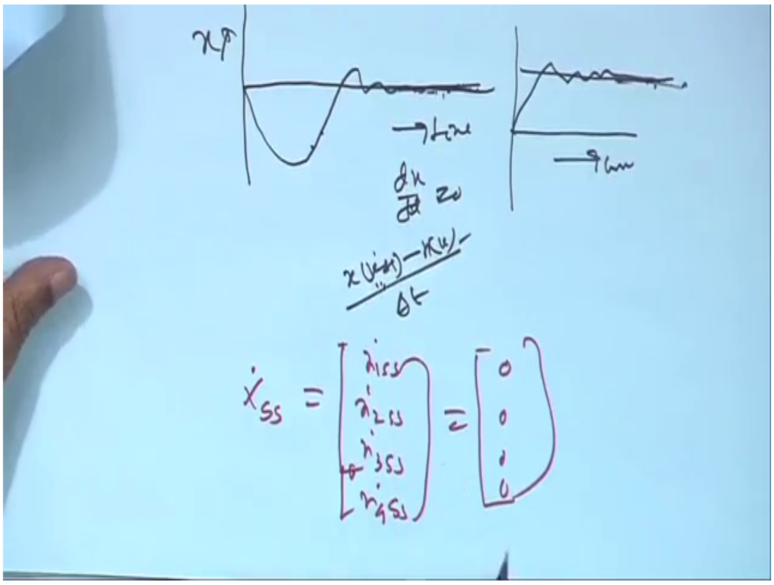

Where all of them reaches to steady state for example, take 1 for example, something is reaching like this some steady state values, right? May be another one reaching to this something the steady state values, right? When you when you are reaching to the steady state value say this is your time and this is your state variable say some X, right? This is time, right?

And when this is to a steady state; that means, there is no change in the current value and the previous dependence you take it will be 0 said means all these things it is in steady state means the derivative is 0, right? For example, if AX reaches to a steady state any point; that means, it is derivative at that point is equal to 0, but if you take somewhere here somewhere here derivative if you try to find out the derivative 1. So, approximate definition of derivative is suppose the current value minus the previous value divided by this or what you call the time span, right? So, but when it reaches to ready state current value A p B A current value and previous value they are same. So, there is derivative will be 0, right? Therefore, when it reaches all the steady state the derivatives are 0.

So, if it is so that they where there should not be any confusion because you have all the 4 state variables in this case because you have X 1 X 2 X 3 X 4 all the 4 variables all steady S all are reaching to the steady state, right? At t tends to infinity it is that is S tends to 0 it t tends to infinity. So, all these things are easy steady state that we all the derivative will become 0; that means, X SS dot will be is equal to basically just hold on ;

suppose here I am writing suppose it is X SS dot actually is equal to your X 1 SS dot, X 2 SS dot, X 3 SS dot and X 4 your SS dot and all these dot actually becoming 0 0 0 0 0 because all are reaching to the steady state.

So, that is why here X SS dot is equal to 0, right? This you proved; that means, AX SS plus gamma p is equal to 0; that means, AX SS A capital X SS is equal to minus gamma p, right?

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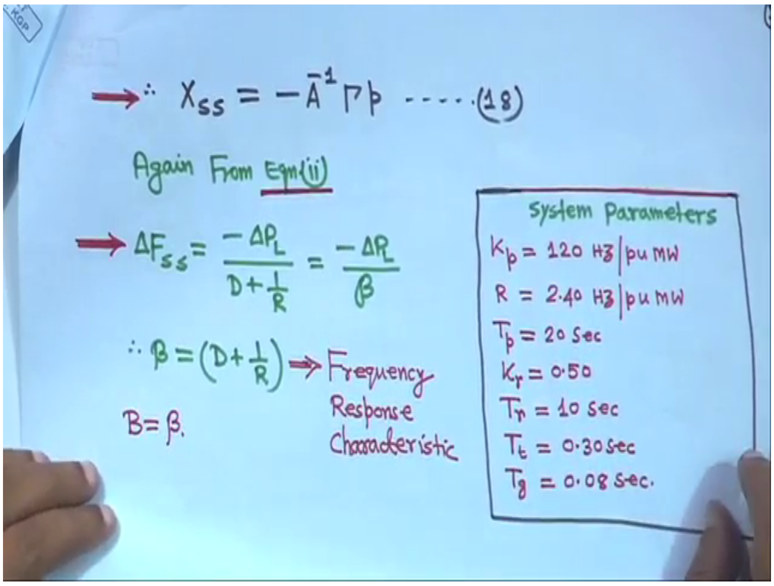

That means X S is equal to minus A inverse gamma p, right? That means, X S is equal to minus A inverse gamma p.

So; that means, this for this for our system when a re time re type turbine we have taken this a matrix actually is a you are have to call 4 into 4 matrix. And all these parameters are given here K p is equal to 120 hertz per unit megawatt some we calculated, R is equal to 2.4 0 hertz per megawatt that also 4 percent regulation on 60 hertz, T p we calculated 20 seconds say other parameters are say Kr is 0.50, Tr is 10 second say, T t is 0.30 second and governor time constant 0.08 second T g is a steam chase time constants 0.30 second and the re time constant 10 second all parameters are given.

So, A A pi in A A matrix all the parameters are known. So, you can take the A inverse only thing is that for this kind of solution that A inverse must exist, but for this problem whatever you have taken that A inverse actually exists so; that means, A inverse means it will be a 4 into 4 matrix, right? A inverse and multiply by gamma and disturbance only A single term delta P L. So, in from this X 1 SS X 2 SS X 3 SS X 4 SS all you will get it will be a column vector, right? Because this is just you multiply it will become a column vector. So, all you will get it so if you have if you if you all these parameters in MATLAB itself after writing their matrix in mat lab itself you can verify and whatever we have done you will find identical result, right?

So, this is one way to find out steady state this is one way to find out the steady state values for example, suppose here it is 4 into 4 that is why on the plane paper we can do it. Suppose this matrix is 50 into 50 or 60 into 60 and suppose A inverse exist and in that case you will not mathematical on the paper it is very difficult to find out the statistic values because you have to do a laborious task, but if A inverse exists and with all this if you write the A matrix with just a simple inversion and multiplying all these you will get all the steady state values, right?

So, that is why MATLAB you can verify this all the take these parameters take these parameters because at the steady state actually this T p all time constant T p T r T t T g K r it will have no effect actually. This all these time constant they have the effect during the dynamic your performance you would a dynamic simulation, right?

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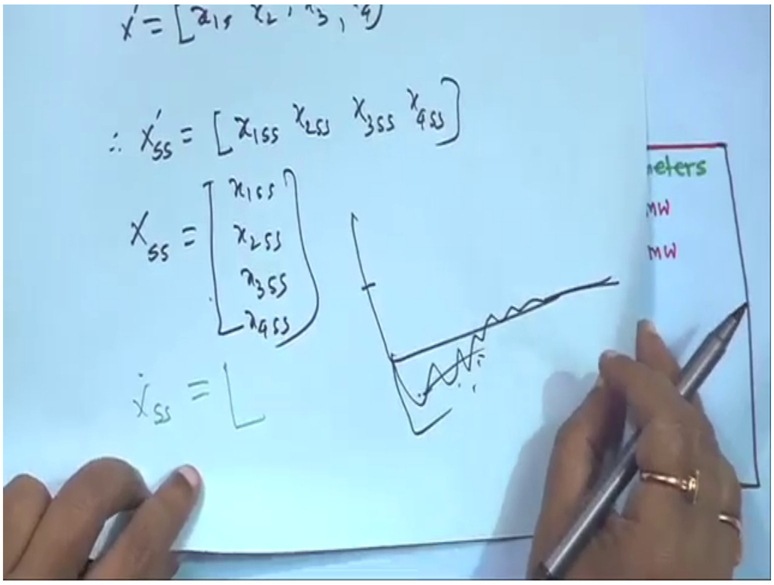

So, all this time constant when you take other thing whatever they have during the transient during the transient time, I mean when this transient is there that all these para parameters have effect, but only reaches to a steady state. So, travel time constant has no affect has this thing, right? It so; that means, whatever value you take T p Kr Tr Tt Tg ultimately it will give you the same statistic value whatever you got, but if you are K p and are changes naturally the steady-state value our function of K p and R.

So, that is why K p are changes steady state value will change, but if you take all the other parameter associated with that S the Laplace operator, right? You will find they have effect on the transient, but not have the steady state. So, I think this is understand understandable to you, right? So, this is this is your what you call steady state value. And again, try again re writing from equation 2 write delta f S is equal to minus delta P L upon D plus R, sometimes we define this as a beta because equal to D plus R and a bit how it sometimes call it is frequency response characteristic, right?

So, b is equal to generally for a g c purpose B u is taken as a beta it can cannot be never less than beta. It is a frequent sometimes we call it a frequency by setting it cannot be beta, by a less than beta those things your what to call her will take interconnected system. Certain things are beyond the scope, but why we should not be take a less than beta how it will complete this particular topic. At that time, I will put this question and ask you after explaining everything B should B is equal to beta even greater than beta no problem, but it cannot be less than beta, right?.

So, this is actually your frequency response characteristic D plus R and this is your beta. So, because this your, what you call that? Minus delta P L will beta into delta F SS, right? So, the steady state value also depends on this value D and 1 upon R if load is sensitive to changes in frequency, and speed regulation parameter R that governor speed regulation parameter plays an important role in terms of your hertz we call the frequency response.

So, this is your, what you call? These are the parameter actually I have taken from the from literature standard parameters these are the standard parameters.

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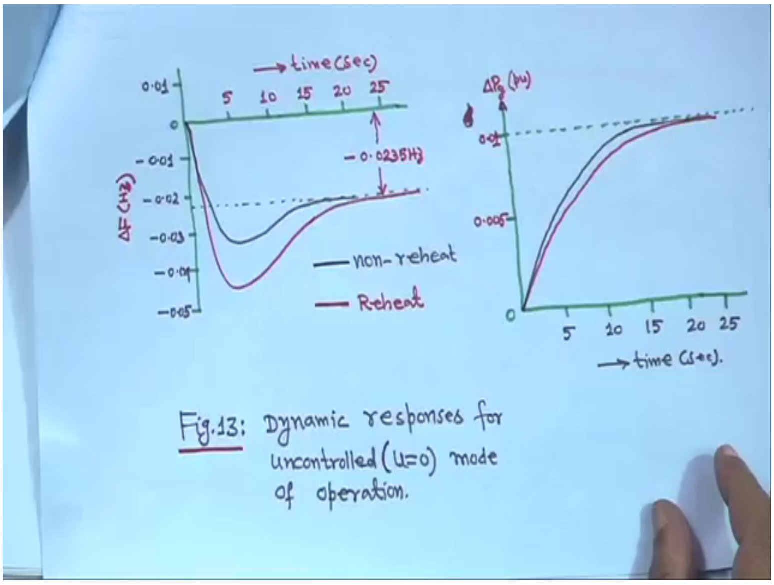

So, something like what you call some responses for uncontrol mode, right? 1 on D type model will see later, just now it is a you are what to call that your thin that k matrix is a 3 into 3 and for heat type if you suppose in MATLAB simulink if you plot this your, what you call? This frequency response and generation response you will get like this will thank you very much will be back again.