On Power System Dynamics Control and Monitoring
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Lecture - 16
Power System stability (Contd.)

We are back again.

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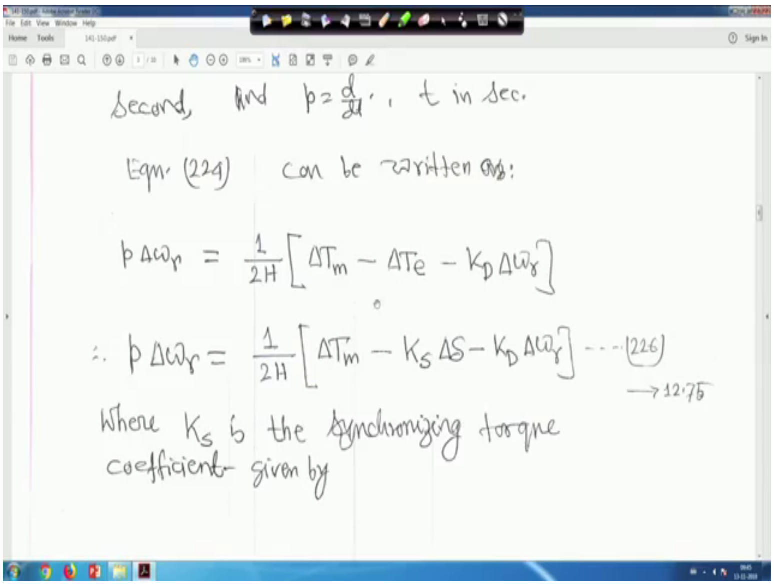

So, this is this looks like a little bit funny know what question is that is something like.

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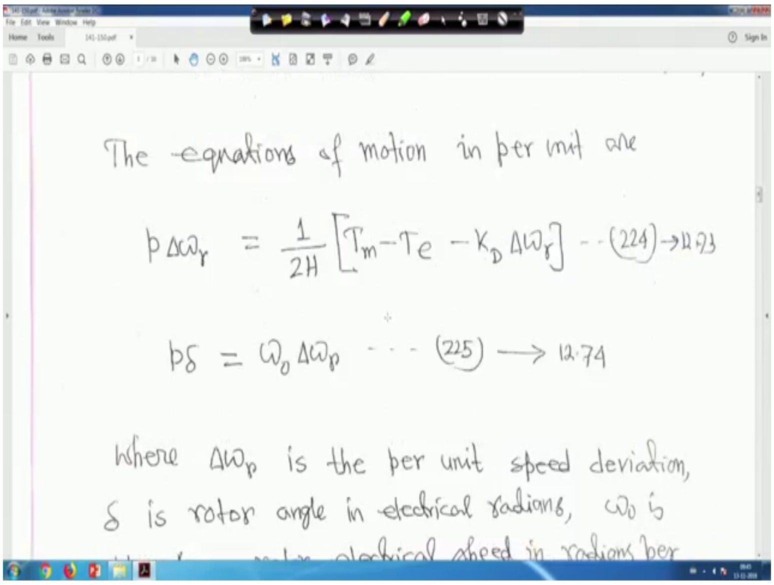

This so, actually we know that we know that your omega r delta omega r is equal to this we have seen earlier omega r minus omega 0 right this we know. So, what we do you put here that delta omega r is equal to omega r minus omega 0. So, if you do so if you do. So, it will writing over it just see that it is omega r minus omega 0 this term is equal to 1 upon 2 H right in bracket it is T m minus T e minus your KD into your omega r minus minus omega 0 right. Actually it is KD into omega r minus omega 0. Now, if you take small perturbation on both side then what will happen, then it will be p into delta omega r this is your reference p omega 0.

So, p into delta omega r is equal to it will be 1 upon 2H right and it will be delta Tm because writing over it just have a look then it will be delta Te and again it will be minus KD and it is omega r minus omega 0 it takes a small perturbation into KD delta omega r right. So, that is why this Tm and Te it is becoming delta Tm minus delta Tr other thing remains same in that equation. So, this is the your already thing is that delta omega r is equal to omega r minus omega 0 right. So, that is why this equation is written like this right similarly next page we will see, but I making it here just hold on.

Similarly, this is nothing for you similarly equation 225 it is p delta delta p delta. So, p delta is nothing, but this is omega 0 and delta omega r actually omega r minus omega 0 right. Now, if you take small perturbation so, it will be p delta delta is equal omega 0 then delta omega r. So, p delta delta will be omega 0 delta omega r because this is omega r this is nothing minus omega 0 right.

So, if you take small perturbation so, p delta delta is omega 0; that means, this equation can be written as left hand side only p delta delta right hand side remain as it is omega 0 into delta omega r right. So, there is no confusion at all from this from this mathematical relationship it is coming right absolutely no confusion right. So, this is my equation 20, 225 you know delta omega raise the per unit speed derivation delta is the angle in electrical radian per second omega reading is the base your base rotor electrical speed in radian per second and p is the defence law operator later we will replace p by s Laplace operator right and t in second.

Now, equation 224 can be written as that p it has that what I know p delta omega r is equal to 1 upon 2H delta Tm minus delta Te minus delta omega r this I have explained already. Therefore, p delta omega r is equal to 1 upon 2H minus delta Tm delta T we representing your KS delta delta; that means, these equation this equation this equation later has been explained these equation can be written as it is KS into delta delta right.

So, that is my delta Te and this KS is called synchronising torque coefficient synchronising torque coefficient why it is called synchronising torque coefficient this is question to you right. Book you may not find it, but you have to while you listen this thing you just put this answer to your forum right this term is called synchronising torque coefficient right and it is KS delta delta. So, in that equation we replace delta T by KS delta delta right. So, therefore, delta Te is KS delta delta and minus KD into delta omega r.

This is equation 226 forget about this one this is for my own reference. Where KS is the synchronising torque coefficient and this KS I told you is nothing, but E dash E upon XT cos delta 0 this is equation 227 right.

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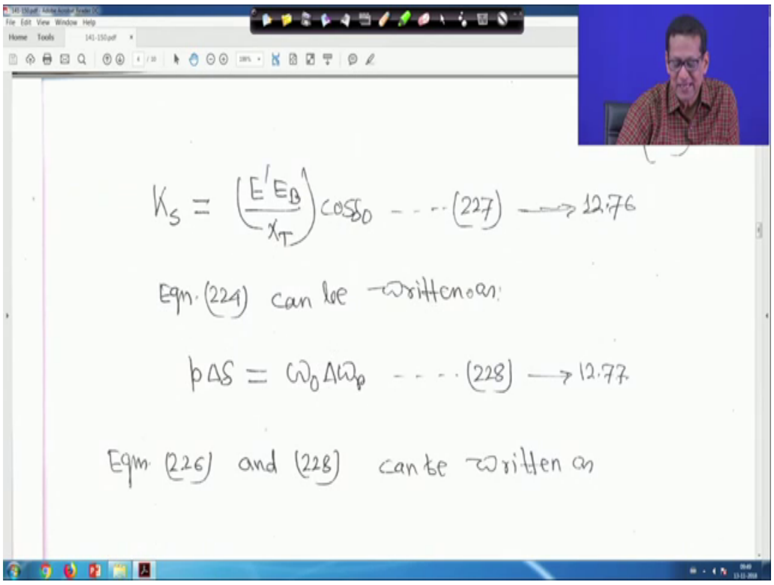

Now equation 224 I told you can be written as I told you already I told you that it was p delta is equal to omega 0 delta omega then again p delta delta also will be omega 0 delta omega r this already I have told you previous page right just previous page from that only that equation 224 how it is coming right.

Therefore equation 226 and 228 can be written in that your state variable form that is your this is there p is nothing, but d dt that is basically delta omega I mean d dt of delta omega r means delta omega dot and d dt of delta means delta delta delta means delta delta dot. You put this equation 226 and 228 in the matrix form then it will become a state variable form it will become that it is 2 into 2 matrix from slowly and un slowly dimensionally we will consider other thing.

So, dimension of the matrix will grows slowly and slowly. So, in this case it is minus KD upon 2H this is minus KS upon 2H this is omega 0 and this is 0 this is delta omega r this is delta delta plus 1 upon 2H and 0 this is delta Tm.

So, basically your d your p delta omega r is equal minus KD upon 2H delta omega r that you are seen minus KS upon 2H delta delta plus 1 upon 2H delta Tm. Similarly, delta delta is equal to omega 0 delta omega r right and this is delta omega delta delta this is delta Tm this is equation 229 right.

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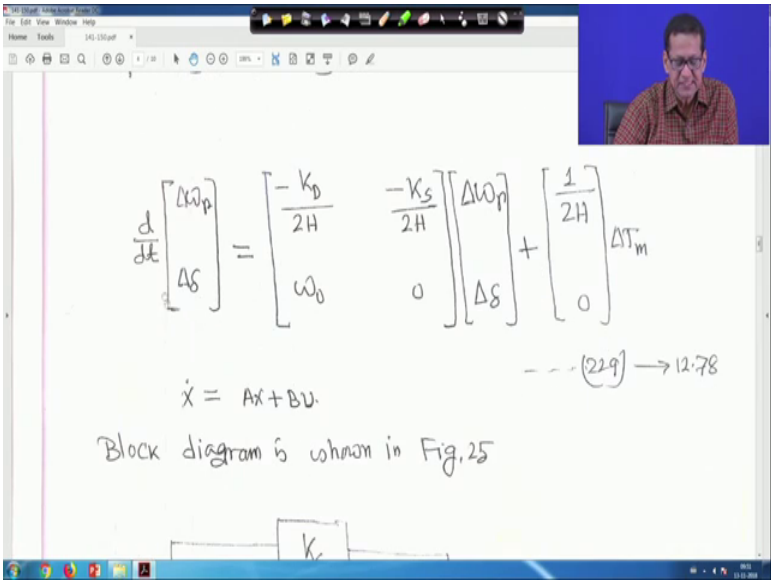

This equation can be written as x dot is equal to Ax plus Bu; that means, that means your x actually this is your a matrix right this is a matrix this is a 2 into 2 matrix right and this is your B and this is your u. So, actually u we are just we are representing like this u is equal to delta Tm right.

And this is my d matrix and this is and state variable x dot is equal to; that means, x 1 is equal to here delta omega r and x 2 will be is equal to delta delta right and this is my state variable equation.

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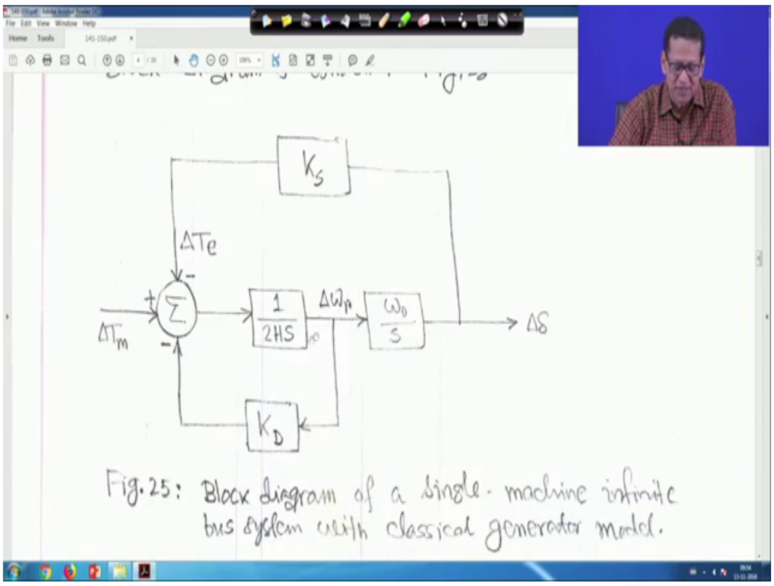

Now if you represent this in block diagram then this is my delta Tm right and if you look into just see those equation I crossed like the block diagram this is delta Tm and this is minus delta Te right. So, we have seen know and this is your delta omega r.

So, KD delta that is delta Tm minus KS delta Te minus your what you call KD delta omega r right into 1 upon 2H S is equal to delta omega r this you have seen right and this is your and that is also we have seen from the 2nd equation that is I think 226, I think this is to sorry 2 228 this is 228 it is 228 it is p delta is equal to your omega 0 delta omega r right. So, when you are put in the Laplace transform actually p is represented by S right, I mean this one this one now p actually you replace by S.

Therefore, this equation yeah instead of look instead of S delta delta S then delta omega S we are not representing it is understandable only p is replace by S. So, this is S delta delta is equal to omega 0 delta omega r right; that means, I am putting it here; that means, my delta delta this one is equal to your omega 0 by S right into delta omega r right.

So, omega 0 by S delta delta is equal to into delta omega r that is why your this one your this one your what you call it is delta delta is equal to omega 0 by S into delta omega r. Similarly, here also that your 2HS that p 1st equation, that is your equation your 220 226 right. So, this equation also you replace by you have what you call that p is equal to S let p is equal to d dt just one or two lines have write in for you it is p is equal to you replace p by S we will got to the Laplace domain right.

So; that means, this is my S and this is delta omega r is equal to 1 upon 2H in bracket delta Tm minus delta T sorry minus your KS delta delta then minus KD delta omega r right. So, what you do multiply cross multiply that is will be 2HS delta omega r bring this term to this side so, it will be plus KD delta omega r.

So, take omega r common it will be 2HS plus KD right. So, based on that only your this thing is coming right this thing is coming that your block diagram this one is coming one upon your 1 upon 2HS and this is your feedback is taken that is your KD right that this oneth coming like this. So, in this case in this case later we will see in this case your omega r this KD omega r term you did not bring to the your left hand side only simply you have taken S delta omega r, I mean it is simply like this.

Later we will bring it these two that side if you replaced p is equal to S say p is equal to S then your delta omega r is equal to 1 upon 2 HS right and in bracket it is delta Tm minus KS delta delta minus KD your delta omega r right this is taken (Refer Time: 10:37) we did not bring to the left hand side later we will see when block diagram will slowly un slowly will go and a your number your order of the equation will increase. At that time we will bring this one to this side at that time we will find it will be 2HS plus KD omega r will represent step by step right. So, this is 1 upon 2 HS and this one right.

So, that is why your that is why this one this equation this block diagram is like this right it is your 1 upon 2 HS right into your delta Tm minus your KS delta delta minus KD delta omega r right is equal to delta omega r. And this is I told you that o delta delta is equal to omega 0 upon S you know delta omega r. Now this is the block diagram of a single machine infinite bus system with classical generator model.

Now, next is from figure 25, then from this figure you just simplify this one then because if I rest I am still in have to do is delta delta is equal to omega 0 upon S delta delta is equal to omega 0 upon S into delta omega r and delta omega r is equal to 1 upon 2 S 2 HS delta omega r is equal to 1 upon 2 HS that you have seen into delta Tm minus KS delta delta minus KD delta omega r. So, that is delta delta is equal to omega 0 upon S into 1 upon 2 S minus all this things right.

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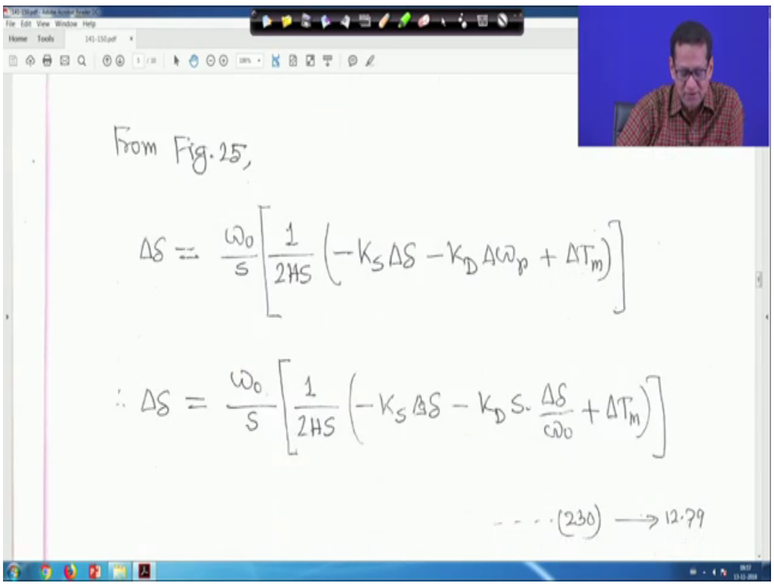

Now or delta delta it will be omega 0 upon S 1 upon 2 H S that minus K S delta and this delta omega r you replace delta omega r is equal to your S delta delta upon omega 0. Because, here from here from here your I am writing here just hold on from here that delta delta is equal to omega 0 by S into delta omega r right therefore, delta omega r is equal to S by omega 0 into delta delta right. So, this delta omega is equal to S by omega 0 delta delta is substitute. So, if you do so if you do so it is coming delta omega is equal to KD minus KDS delta delta upon omega 0 plus delta Tm right this is equation 230 this right hand side whatever is it in this for my own reference.

So, now if you simplify this one cross multiplication and simplify then it will be coming like this S square delta delta plus KD upon 2 H S into delta delta plus KS upon 2 H omega 0 delta delta is equal to omega 0 upon 2 H delta Tm right. This is simply quadratic equation and characteristic equation right that is you have start it also in your 3rd year control system engineering.

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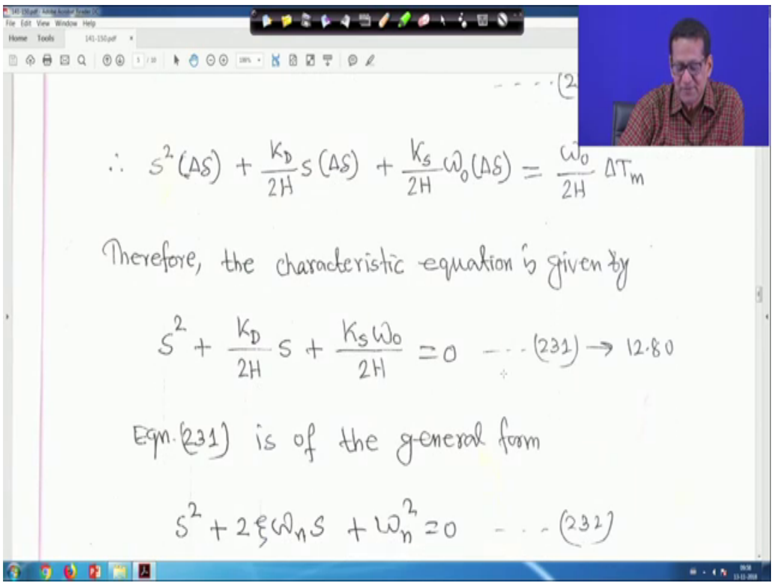

Therefore the characteristics equation is given by second order system it is S square plus KD upon 2 H into S plus KS omega 0 upon 2 H is equal to 0 this is equation 231 right. So, this is the simply second order equation like characteristics equation.

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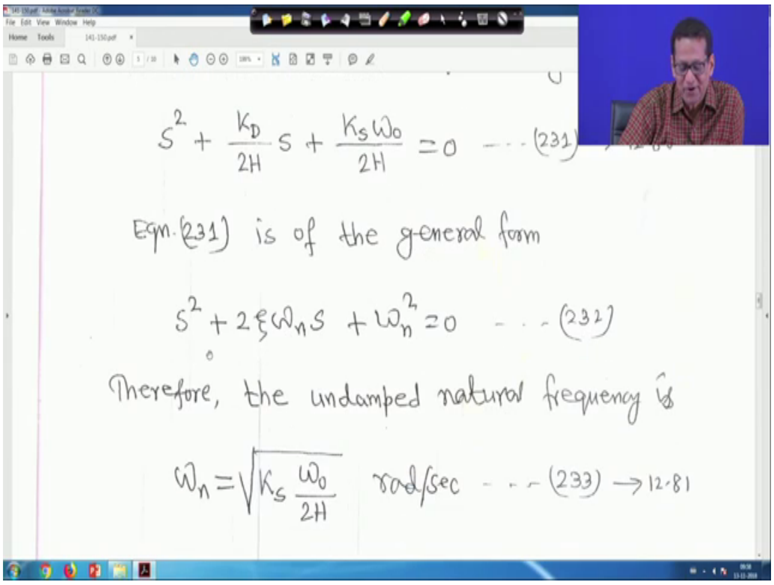

So, equation 231 is of the general form, you have studied in your 3rd year control system engineering for second order system it is S square plus 2 psi omega n S right plus omega n square is equal to 0 right. Therefore, omega n square your is equal to having this is this equation this equation and this there analogues to each other therefore, omega n square is equal to KS sorry just let me let me delete it once again.

So, these two equations are analogues to each other therefore, omega n square is equal to this one your KS omega 0 by 2 H right. Therefore, omega n is equal to root over KS omega 0 upon 2 H that is here radian per second omega n is equal to root over KS upon omega 2 H this is equation 233 this is nothing this for my own reference right. So, this is radian that is omega n right another thing is that 2 psi omega n let me clear it another thing is that this term is analogues to this term is equal to this one; that means, 2 psi omega n is equal to KD upon 2 H right. So, from which omega n is known and if you substitute omega n you will get this value of psi right that I have written in the next page.

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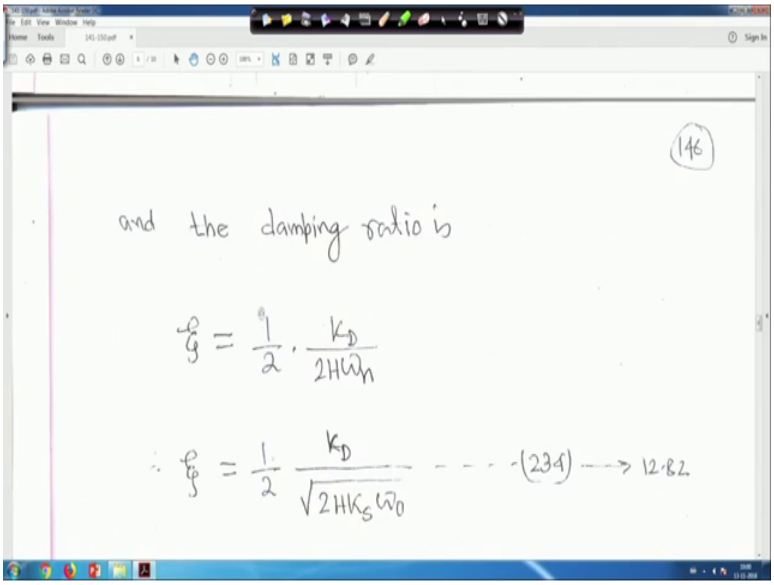

So, and the, that is and the psi is the damping ratio that is psi is equal to half into KD upon 2 H omega n right. So, therefore, the undamped natural frequency omega n is the this one right and your the damping ratio is psi is half into KD upon 2 H omega n. Now put omega n value and simplify you will get psi is equal to half KD root over 2 H KS omega 0 this is equation 234 forget about this one this is for my refer own reference.

As the synchronizing torque coefficient that is a KS increases the natural frequency increases and the damping ration decreases that as KS increases natural frequency your increases because this is this is actually omega n root over KS into omega 0 2 H. If KS increases then omega n natural frequency also increases and in the damping ratio KS KS term is root over 2 H KS omega 0 it is in the denominator. So, KS increases that psi decreases right that damping ration decreases.

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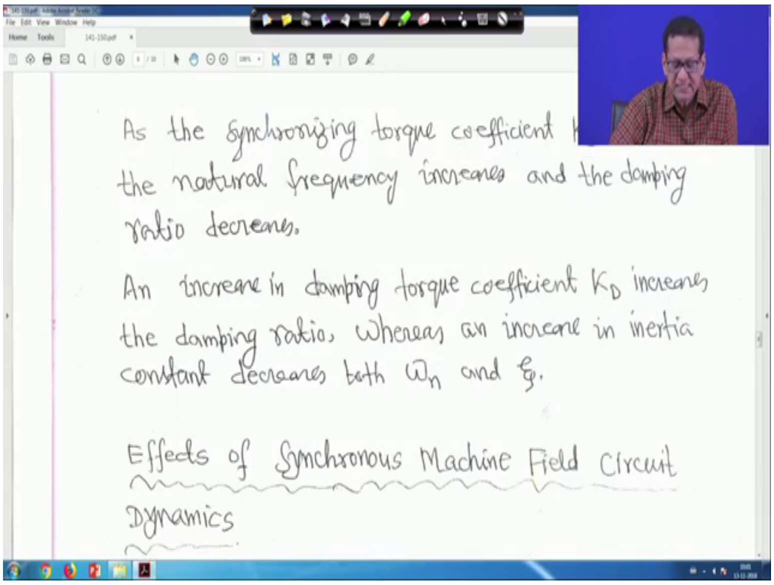

And increase in damping increasing damping torque coefficient KD increases the damping ration. Now KD is the new meritary if KD increases damping ratio increases right whereas, an increase in inertia constant decreases both omega n psi right. So, if it is in the your denominator H increases means psi will decrease right similarly here also it is in the root over KS omega 0 upon 2 H.

So, each in the in the denominator so, if H increases. So, natural frequency will decrease right. So, next is that effect of I think this block diagram is understandable to later we will take some problem later right. So, next is effect of synchronous machines field circuit dynamics. So, now consider the system performance including the effect of field flux variations now will effect of synchronous machine field circuit dynamics all this equations for field circuit everything has been developed before.

So, what I will suggest that again and again I cannot go back to those equations which I have left much before. So, whenever you will listening to this lecture just open the those a those notes because all notes every hour every week you will get those notes keep it in point of view then things will be easier. With now consider the system performance including the effect of field flux variations.

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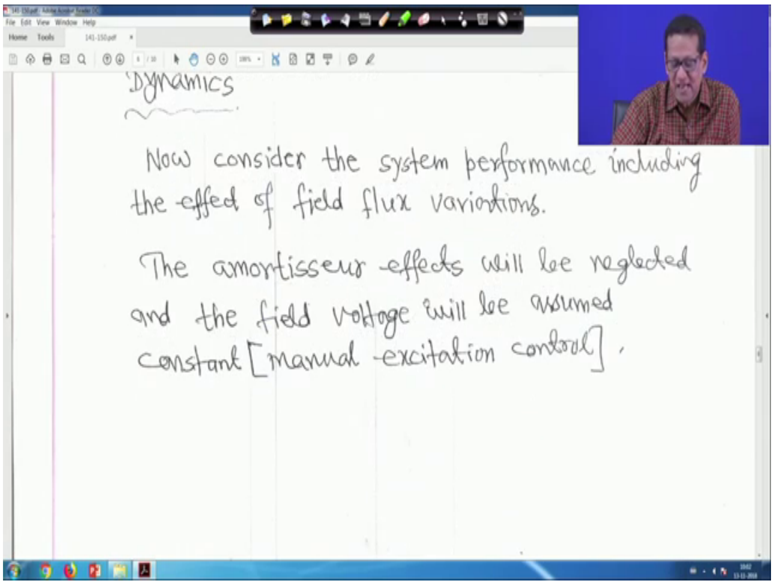

The amortisseur effects will be neglected just for the simplicity and the analysis because you will think about the classroom exercises. So, will be neglected and the field voltage will be assumed constant that is the manual excitation system you will assume the field voltage will remain constant. Regarding excitation system I told you time permits and the end I will try, but if time does not permit it will be impossible right. So, amortisseur effects will be neglected and the field voltage will assume that is constant that is EFD if it is constant; that means, your perturbation delta EFD will be 0 right.

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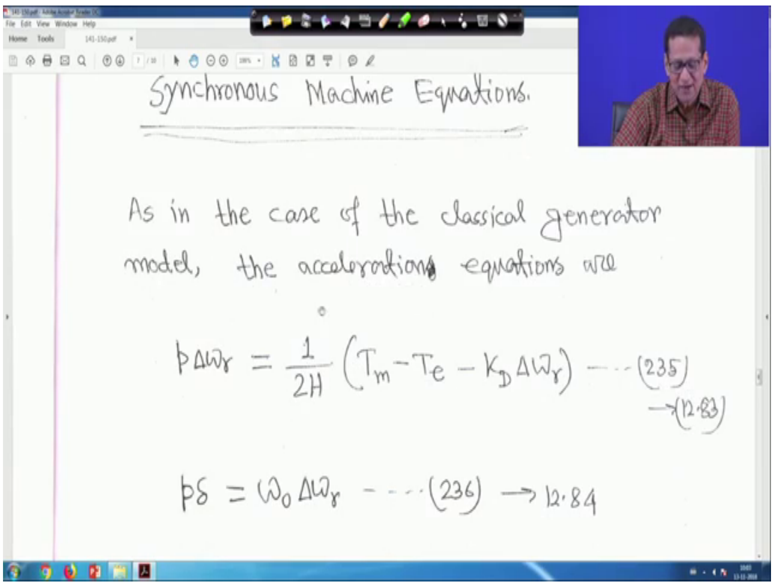

So, synchronous machine equations; this all that now and in the case of the classical generator model the accelerations equations are we have seen that p delta omega r is equal to 1 upon 2 H Tm minus Te minus KD delta omega r and p delta delta omega 0 delta omega r. Or in other ways small perturbation when you see p delta omega r upon 1 upon 2 H we have seen delta Tm minus delta Te minus KD delta omega r and p delta delta will be omega 0 delta omega r right.

Now omega 0 is equal to 2 pi f 0 electrical radian per second, that is your base feet right. Now, in this case the rotor angle delta is the angle that is electrical radian per second by the q axis lead the reference voltage EB that also we have seen right.

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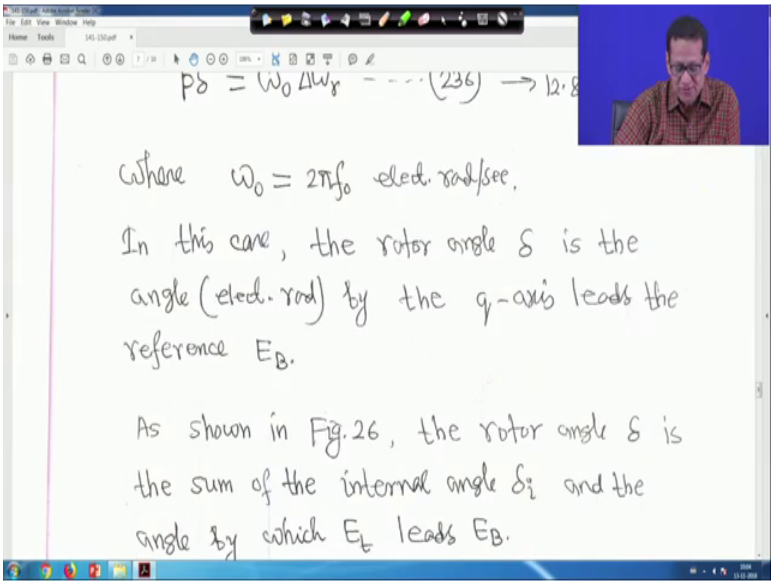

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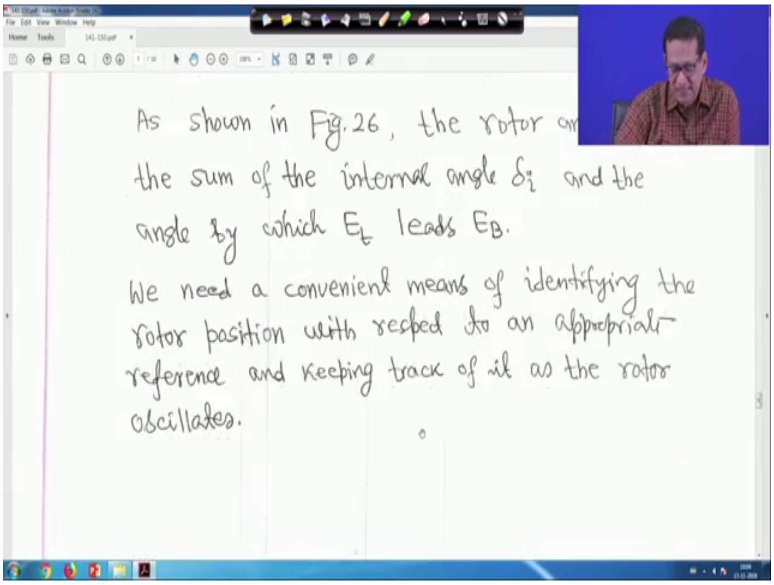

As shown in figure 26 the rotor angle delta is the sum of the internal angle delta i and the angle by which Et leads EB.

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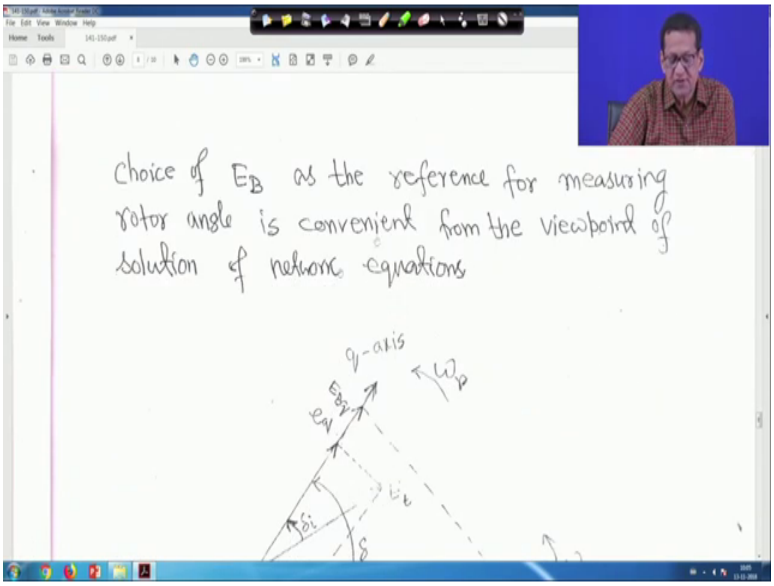

So, before going to this I will go to this figure this is figure 26 this is my EB say right this is my EB this is the reference we have taken and this is your q axis and this is d axis. So, on the q axis it will EBQ that is capital EBQ and on the d axis it will capital EBD right and this is my et that is your that is your terminal voltage et this is et hope it is readable right this is my Et and this is the pressure diagram.

And its and its your on q axis component eq and d axis component ed and Et this Et actually your lagging from this eq or capital EBQ by your this thing by an angle delta i this also you have seen earlier and this is the delta. Delta is equal to the delta i plus the angle between Et and EB and your delta is equal to delta i this angle plus the angle b 2 in et and EB right.

So, so, I will go back again. So, this is what I have told in that is figure 26 the rotor angle delta is the sum of the internal delta i just told you and the angle by which Et leads EB. Now, we need a conventional means of identifying the rotor position with respect to the appropriate reference and keeping track of it as the rotor oscillates right.

So, choice of EB as the reference for measuring the rotor angle is convenient from the viewpoint of solution of network equation. So, EB we have taken as a reference right and delta will be delta i plus the angle b 2 Et and EB right.

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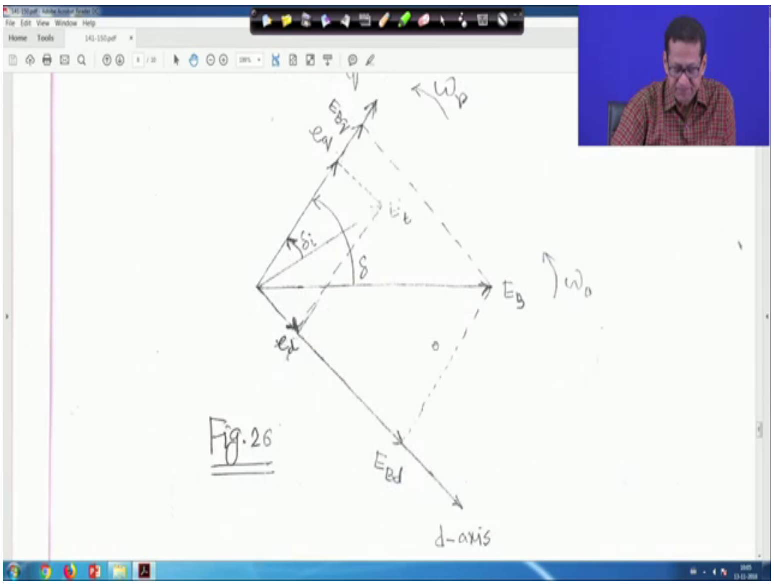

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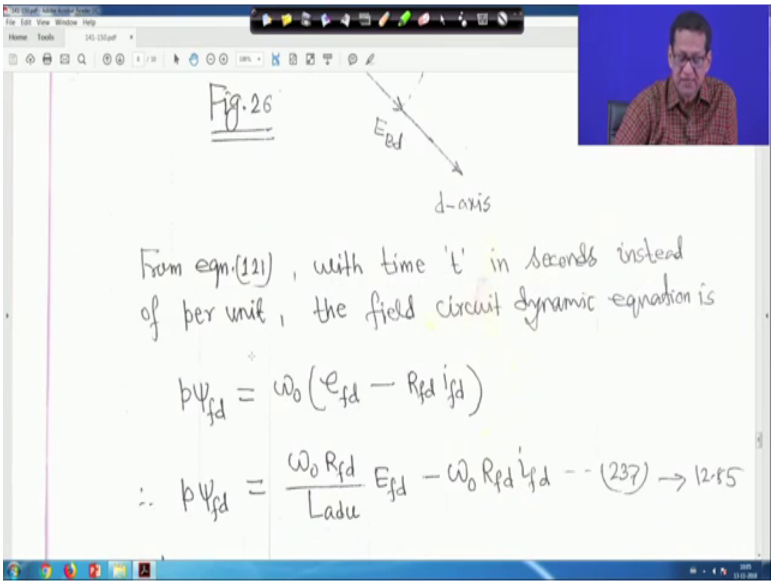

So, from equation 121 right this all these equations had been given before you go to equation 121 with time t in second instead of per unit the field circuit dynamic equation can be given as your p psi fd omega 0 efd minus Rfdifd from equation 121. I suggest that this all the lecture notes will be available to you just open it point of view because if I want to go back because of 121 much time will be lost right.

So, or this efd also we have multiply omega 0 and efd also define report you put it here right. So, it will be and when you using u and s u means Unsaturated value and s means Saturated value with the inductance or reactance when you have put it right. So, p psi fd is equal to omega 0 Rfd upon Ladu Efd minus omega 0 Rfdifd this is equation 237 right.

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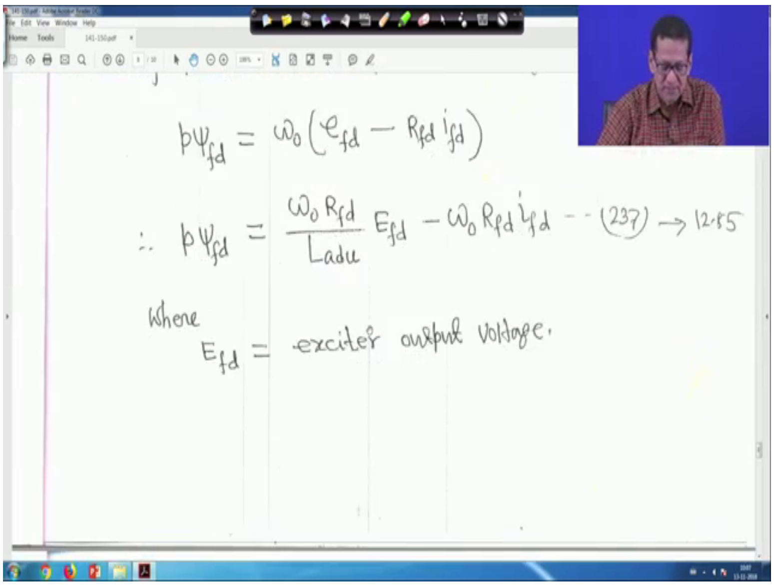

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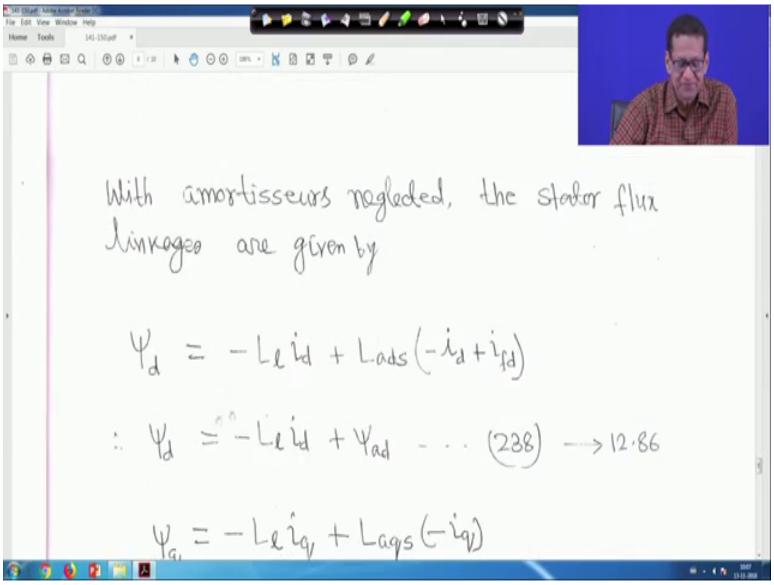

So, now, with amortisseurs neglected the stator flux linkage are given by t hat that go back to the stator circuit equation right this equation if I recall correctly go to the figure 28 right. So, from figure 28 that where analogous circuit is given flux then your inductance then your what you call that your current right. So, with amortisseurs neglected the stator flux linkage are given by this go to figure 20 which you have left out which we have left before right.

So, it will be minus Li id plus Lads in bracket minus id plus i fd right or psi d is equal to minus Llid plus psi ad. Psi d is equal to this term this go back to the figure 28 if I recall correctly please go back to figure 20 this is my psi ad right this is nothing for you this is for my reference right. So, this is psi ad psi d is equal to minus Llid plus psi ad go to figure 20 I think figure 28 right. Similarly, figure 20 b the psi q is equal to minus Lliq plus Laqs into minus iq right or it is psi q is equal to minus Lliq plus psi aq this is actually psi aq this is equation 239 you will go back to figure 20 b right.

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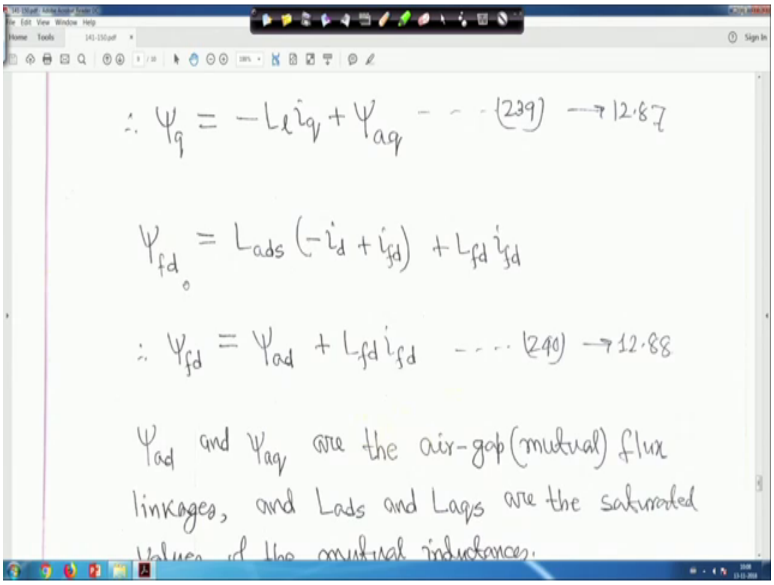

Now, therefore psi fd is equal to Lads bracket minus id plus ifd plus Lfd ifd all you back to figure 20 a or b right or psi fd is equal to psi ad plus Lfd ifd because these term psi ad that is equation 240 right. Now psi ad and psi q are the air gap that is mutual flux linkages and Lads and Laqs are the saturated values of the mutual inductances right.

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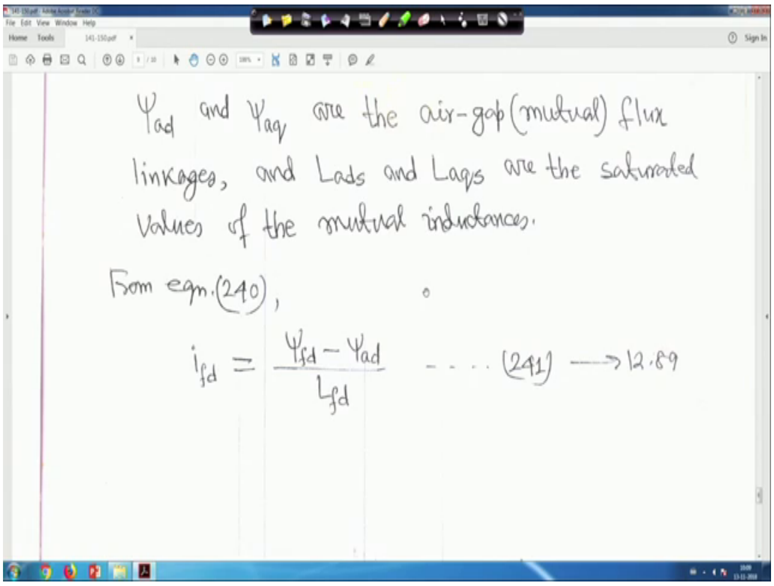

From equation 240 I mean from this equation just previous equation we can write ifd is equal to psi fd minus psi ad upon Lfd right. So, this is equation 241 this is for my own reference right. Now that d axis mutual flux linkage can be written in terms of psi fd and id.

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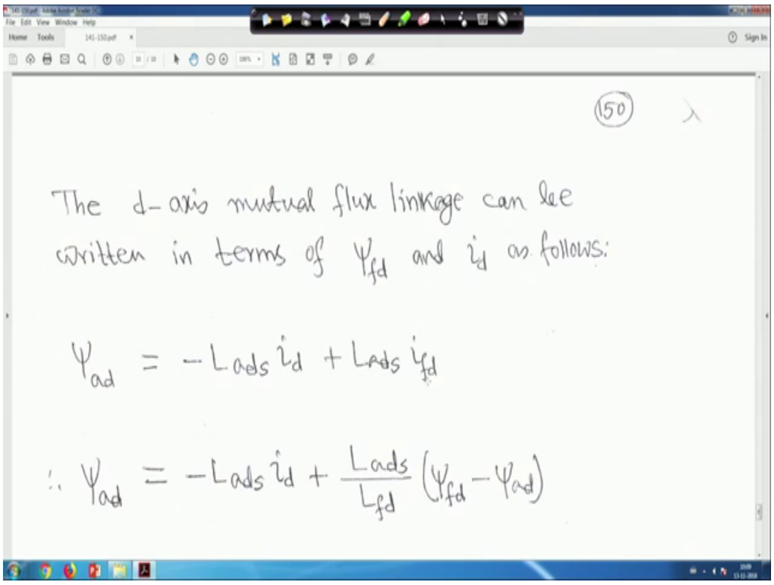

Therefore psi ad can be written as minus Lads id plus lads ifd I mean just multiply that this equation this equation just a this equation is minus Lads id plus your your Lads ifd right. I mean this is your psi ad this is actually somewhere this is actually your psi psi ad this is psi ad ifd is equal to minus Lads id plus your Lads ifd right.

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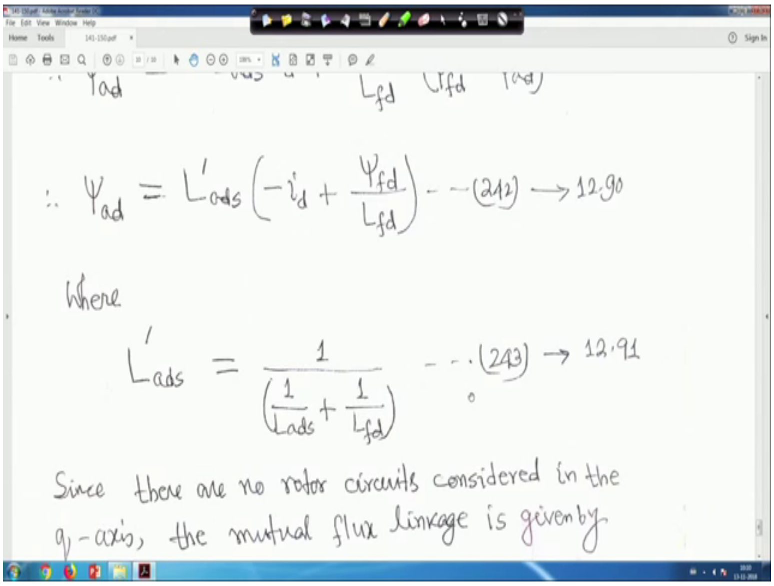

So, now, therefore, your this is minus Lads id and ifd ifd from this equation this one you substitute here you substitute here right you put it here.

So; that means, psi ad is equals to written as Lads dash into bracket minus id plus psi fd upon L fd say this is equation 242 right. Where, Lads dash is equals to 1 upon your denominator 1 upon numerator denominator will be 1 upon Lads plus 1 upon L fd this is the simplify you will get it just you simplify. Since there are no no rotor circuits considered in the q axis the mutual flux linkage is given by psi aq is equals to minus Laqs iq this we have seen this is equation 244 right.

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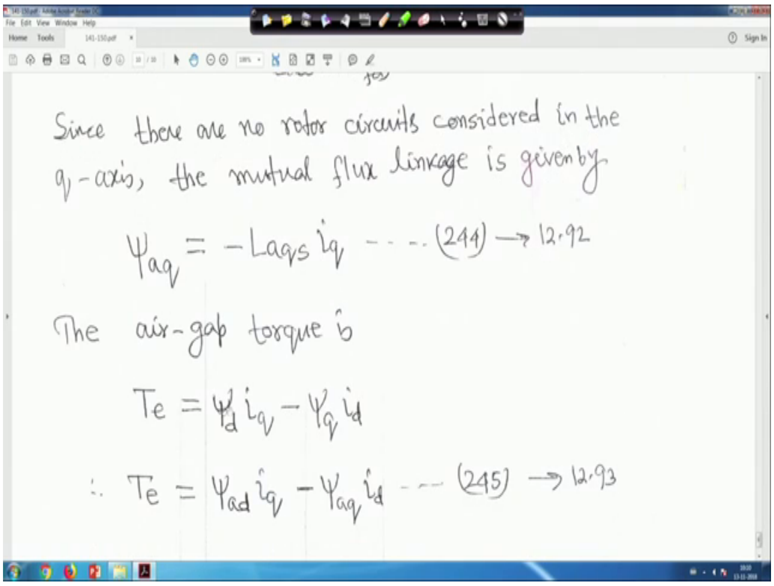

Therefore the air gap torque is we know this equation T e is equals to psi d iq minus psi q id this is the air gap torque or we can write T e is equals to psi ad iq minus psi aq id this is a small exercise for you that we are writing Te is equals to psi d iq minus psi aq id this we have seen before is equals to a writing that psi ad iq and psi aq id.

And just this is a this is a this is a small exercise for you that this one and this one right why why we are writing like. This is this is nothing for you and this also nothing for you right this is a small exercise for you put the put the answer in the forum if you cannot do it we will we will explain there right. So, 1 or 2, I am leaving upto you just all these derivations have been made before.

So, from that we are writing like this so, why we are writing like this right. So, so, just hold down we will go to the next page.

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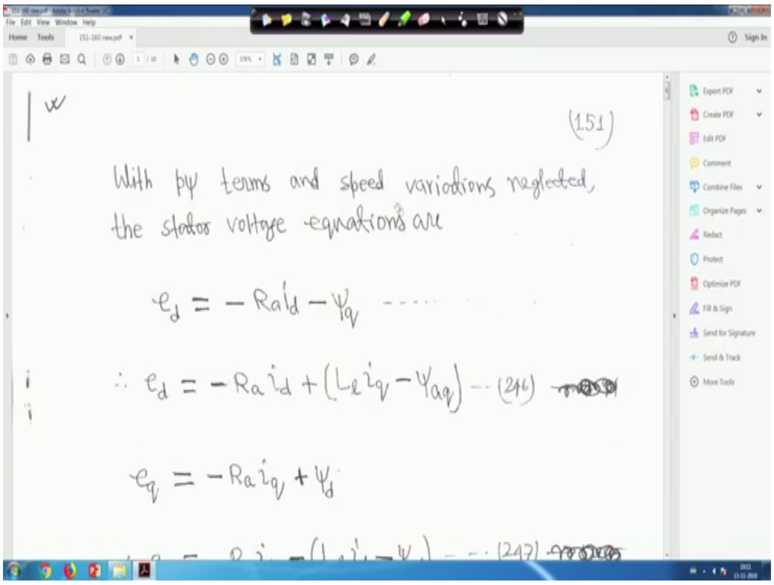

So, if the p psi terms and speed variations neglected the stator voltage equations are. So, you go back to that your stator voltage equations whatever we have derived much before right there what you do you p psi terms and speed variations you just neglect you neglect and rewrite those equation for ed and eq right.

So, you with p psi terms and speed variations you neglect and the stator voltage equations then you will find simply will be ed will be minus Ra id minus iq just you go back to the stator voltage equations and drop those terms it is simply like this.

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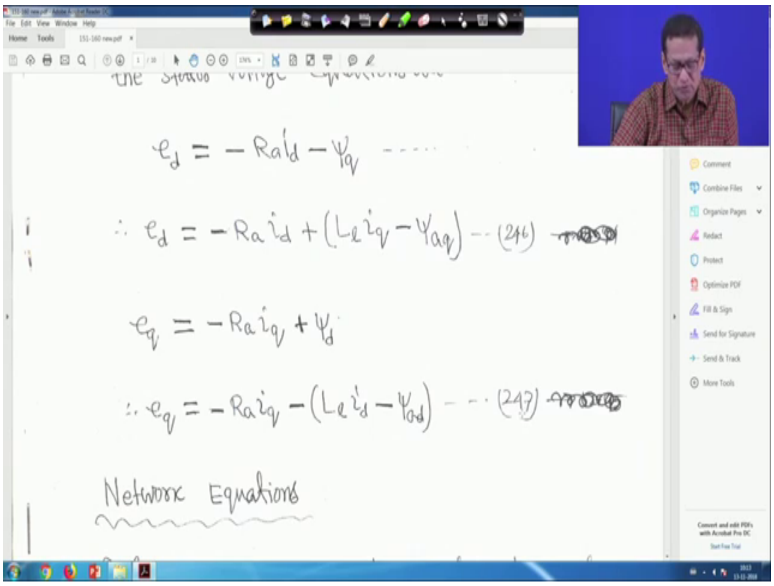

And your ed will be minus Ra id and psi q will be Lliq minus psi aq this is again it is coming from figure twenty b this psi q is equals to Lliq minus psi a q this is figure your 20 b if I recall correctly I will just see the previous equations whatever I have been made right. So, this is actually equation 246 or similarly eq is equals to minus Raiq plus id and this is again this psi d is equals to L l id minus psi ad this equation again from figure 20 a just go back to that right therefore, eq is equals to minus Raiq minus Llid minus psi ad this is equation 247 right.

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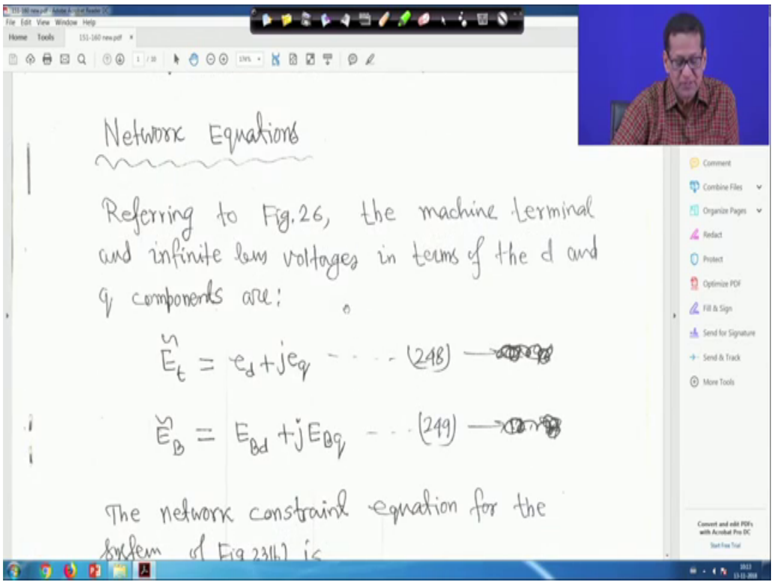

So, now with referring to figure 26 the missing terminal and infinite bass voltage in terms of that dx and qx is component r.

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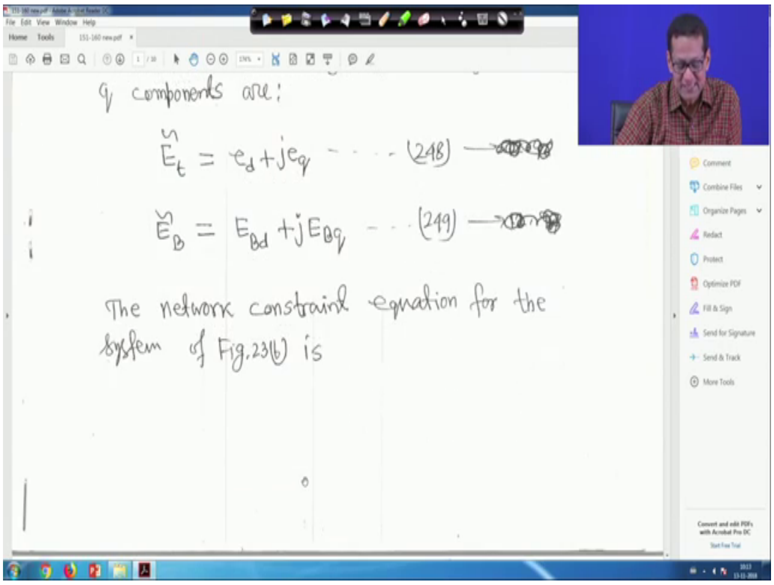

This we have seen in figure 26 Et tilde Et plus jeq this is 248 and EB that you are you are what you call they are a 2 components that they are direct axis and quadrature axis components. So, it is EBD plus j EBQ please go back to figure 26 and you can get it and you can easily see this already I have told they are need to be constant equations for the system of figure 23 b is right that is Et tilde is equals to EB plus re plus jXE it this is actually you go back to figure 23 b. Figure 23 was that your generator than a transmission system then a last system.

And thevenin equivalent was that re plus jXE and in addition to that and the infinite thevenin bass voltage that the thevenin voltage EB that is given on your figure 23 b. So, from that from that from that figure figure you can easily write Et tilde is equals to EB tilde plus RE plus j XE it tilde right or ed plus j eq E t tilde is equals to ed plus j eqeb tilde is equals to ebt plus j bq and re plus j XE it tilde is equals to id plus j xq right and this is my equation 250 right.

Now, if you multiply and you separate real and imaginary part then you will get you just multiply and simplify real and imaginary parts you will get.

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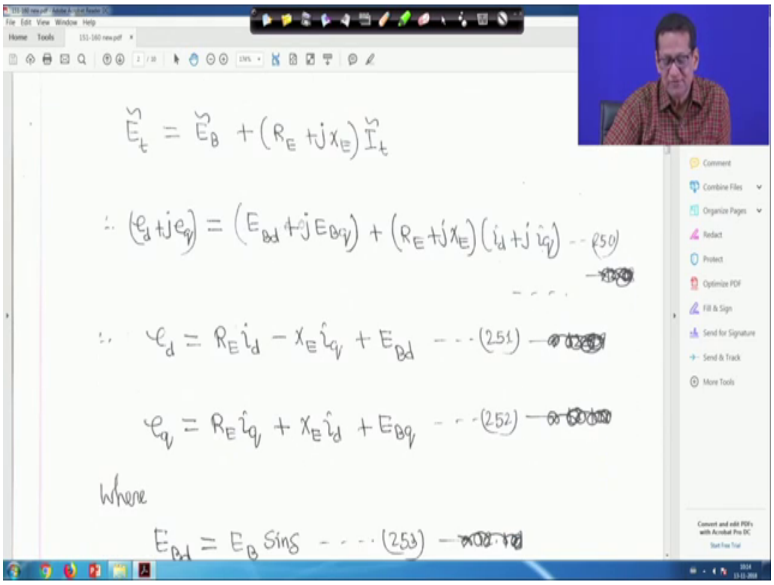

ed is equals to Re id minus XEiq plus EBd capital EBd just you put it on and eq is equals to Re iq plus Xe id plus EB q this is equation 252 right; that means, this one you put all these things you multiply this one and then separate real and imaginary parts right you will get this two equation.

Thank you very much I will be back again.