Power System Dynamics, Control and Monitoring

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Lecture – 12
Power System stability (Contd.)

So just in that previous equation right previous equation. We just solved that is your T m minus T e divided by V A base divided by omega 0 m.

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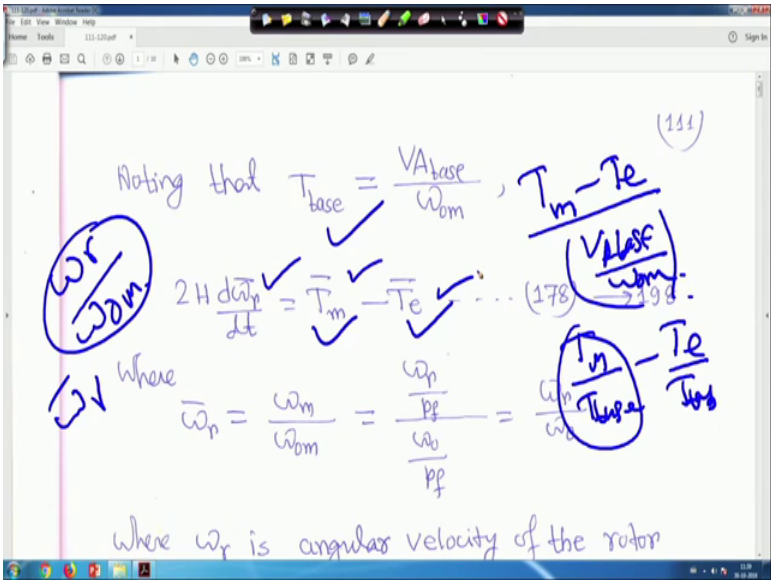

And this is basically nothing but a torque base, this is nothing but the torque base, then with this equation will become T m by torque base minus your T e by torque base right. So, this T f by T base is equal to T bar T m bar we are writing here and T by T base also T e bar right. So, in per unit this is per unit and this one omega r upon d t we are writing previous from previous equation we have written know omega r upon that omega 0 m this is actually nothing but omega r bar. So, this is 2H d omega r bar d t is equal to T m bar minus T e bar; that means, all this quantities are in per unit right.

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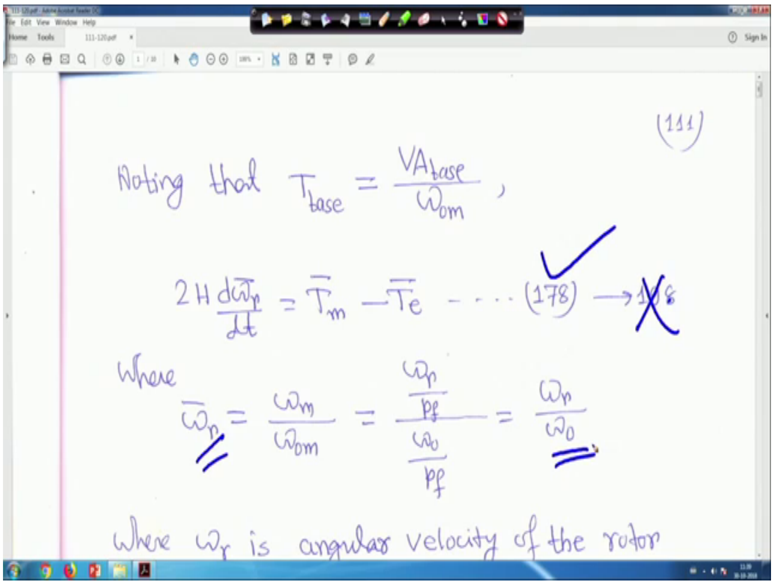

So, and this is no need to read this is equation 178. So, we have seen omega r bar is equal to omega m upon omega 0 m So, this we can write that omega r upon p f divided by omega 0 upon p f right this is basically your filed poles p f is field poles is equal to we can write omega r upon omega r bar is equal to omega r by omega 0 right.

So, actually things are simple just to we are transforming it to per unit values.

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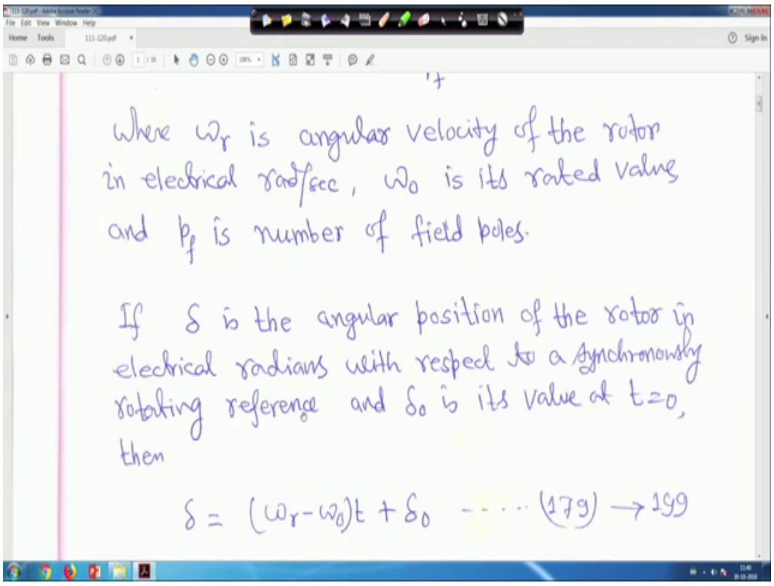

So, where omega is the angular velocity of the rotor in electrical radiant per second and omega 0 it is rotors value and p f is the number of filed poles right. So, if delta is the angular position of the rotor in electrical radiance with respect to a synchronously rotating reference and delta 0 it is initial values at t is equal to 0 then we can write delta is equal to omega r minus omega 0 into t plus delta 0. This is equation 179.

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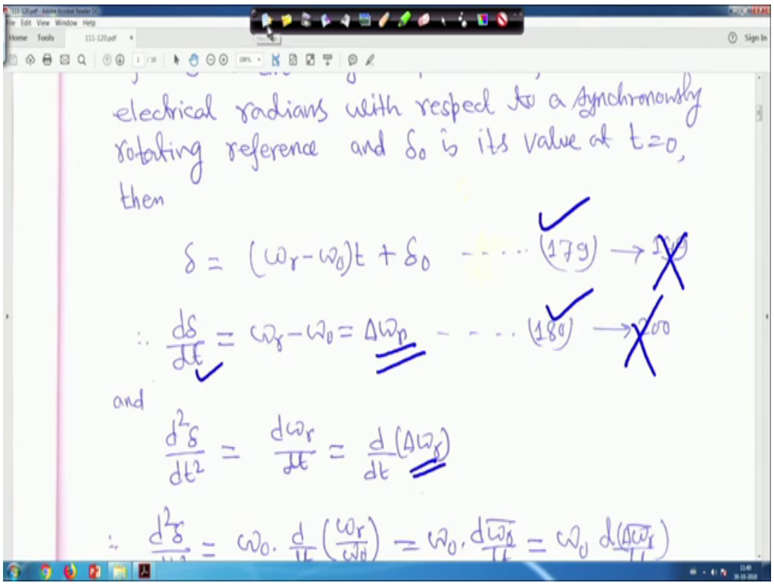

So, this is no need, only this is equation 179 and this is equation 180. That means, if you take the derivative of it so, d delta by d t will be omega r minus omega 0 and this is nothing but is equal to delta omega r right. If you take the double derivative of it and d square delta is equal to d t square is equal to d omega r by d t is equal to d d t of delta omega r right.

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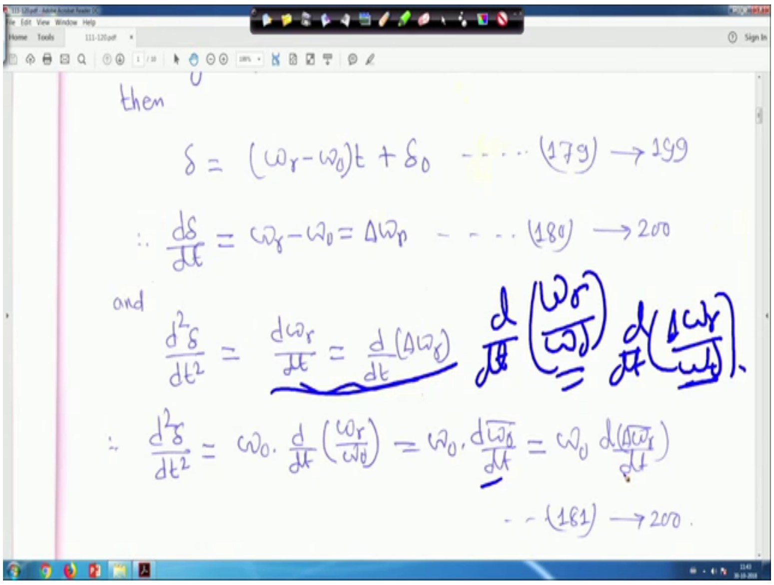

Therefore, this d square delta d t square is equal to omega 0 right into your d d t of omega i mean you numerator and denominator you multiple by omega 0. So, this equation you are writing omega 0 d d t and omega r by omega 0 we are dividing it by omega 0 and here it is omega 0 is equal to we can write omega 0. Then d omega d d t of omega r bar, because this is if now per unit values right, is equal to we can write that omega 0 d d t of delta omega r right. Because, earlier we have seen that you are here that omega r bar is equal to omega r upon omega 0 right.

And here it is your delta omega r omega r minus omega 0 is your delta omega r right therefore, this one if you take that your omega 0 into d omega r by d t this is omega r bar right. So, is equal to we can write omega 0 d of d t delta omega r. I mean this one also you can I mean this is delta omega r. So, if you take the derivative of this one it is d omega r by d t that is d d t of delta omega r.

So, that means, we can make it the d omega r by d t omega r by d t is equal to d d t delta omega r bar I mean it is something like this it is something like this. Suppose you take this, this equation you take this equation right say both side both side you divided by your what you call that 0 right is omega omega 0 is equal to d d t delta omega r by omega 0 right.

So, this will become your d omega r omega r bar d t, because omega r bar this one and d d t of delta omega r upon omega 0 this is your base value. So, this will be per unit values, so it will be delta omega r that is delta omega r bar d d t of delta omega r bar right. So, from this only from this only we are writing it that this is very this is very interesting from this we are writing omega 0 d d t of omega r bar is nothing but omega 0 d d t of delta omega bar r bar right. So, this is equation your what you call this is equation 181 and this one this is nothing, this is for my I own reference because this is my class note. So, this is actually equation 181.

So, that means, from equation 178 and 181 you will get 2 H upon omega 0 d square delta upon d t square is equal to T m bar minus T e bar all are in per unit.

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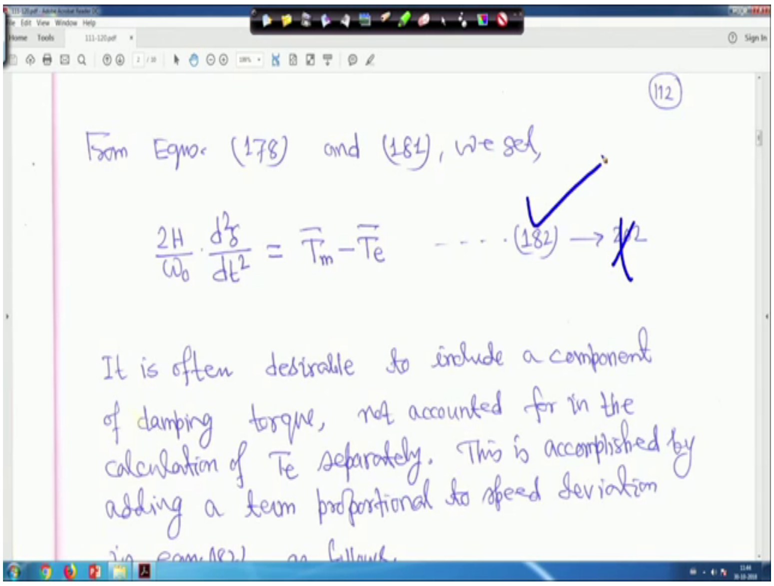

This is equation 182 this is actually nothing only this one right.

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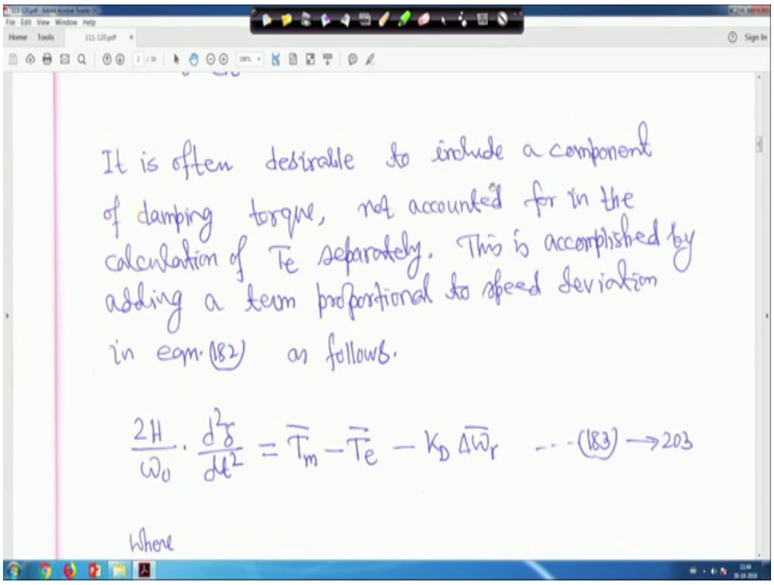

So, next it is often desirable to include a component of dampening torque right and not accounted for in the calculation of T e separately. This is accomplished by adding a term proportion to speed the speed deviation in equation 182 as follows. Therefore, we can add one dampening term that is 2H is upon omega 0 d square delta upon d t square is equal to T m bar minus T e bar minus K D into delta omega bar this is equation 183. This one you should not see, this is my again and again I am telling this is my class note, so this is for my own reference right.

So, T m bar minus T e bar minus k d into delta omega r that is equation this dampening term is added right.

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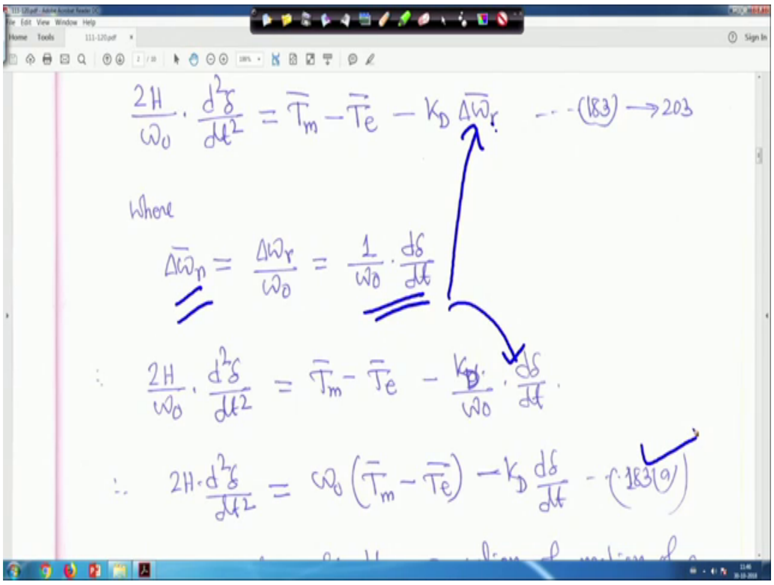

Where delta omega bar I told you earlier is equal to delta omega bar upon omega 0 right is equal to we can write 1 upon omega 0. And this is actually d delta by d t right delta omega r. Therefore, the 2H by omega 0 d square delta upon d t square is equal to T m bar minus T e bar, then these term minus KD term is there right and what we actually has been done that is delta omega r bar is equal to 1 upon omega 0 into d delta by d t this thing, this thing that your this omega bar is equal to this one has been your substituted here.

If your substitute here you will get minus KD upon omega 0 into d delta by d t right. Therefore this equation is coming it is here right. Therefore, 2H now both side you multiply by omega 0. So, it will be 2H d square delta upon d t square is equal to omega 0 in bracket T m bar minus T e bar minus KD into d delta by d t if you multiplying both side by omega 0 this omega 0 will be cancelled. So, minus KD upon a KD into delta by d t this is equation 183 a right.

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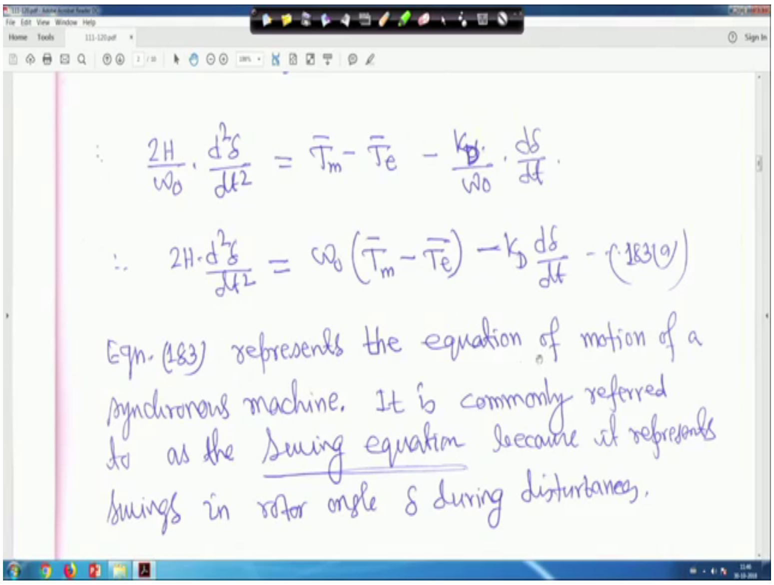

So, equation 183 represents the equation of motion of a synchronous machine right; I mean this equation, this equation 183 right. It is commonly referred to as the swing equation, because it represents swing in rotor angle delta during disturbances right. So, it is it is commonly referred to as a swing equation, because it represents swings in rotor angle delta during very disturbances.

So, next is per unit moment of inertia.

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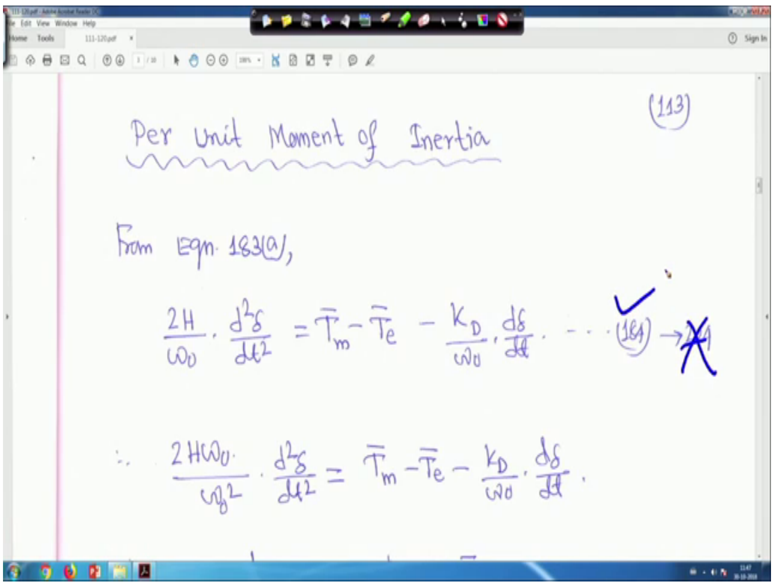

So, from equation 183 a; that means, these equation from this equation right 2H upon omega 0 d square delta d t square T m bar minus T e bar minus k d upon omega 0 into d delta upon d t. This is equation 184, this one you should not see, this one you should not see right. This is this is equation 184.

So, therefore you multiply this equation numerator and denominator by 2H omega 0, so by omega 0. So, numerator will be 2H omega 0 and denominator will be omega 0 square into d square delta upon d t square is equal to T m bar minus T e bar minus k d upon omega 0 into d delta by d t right.

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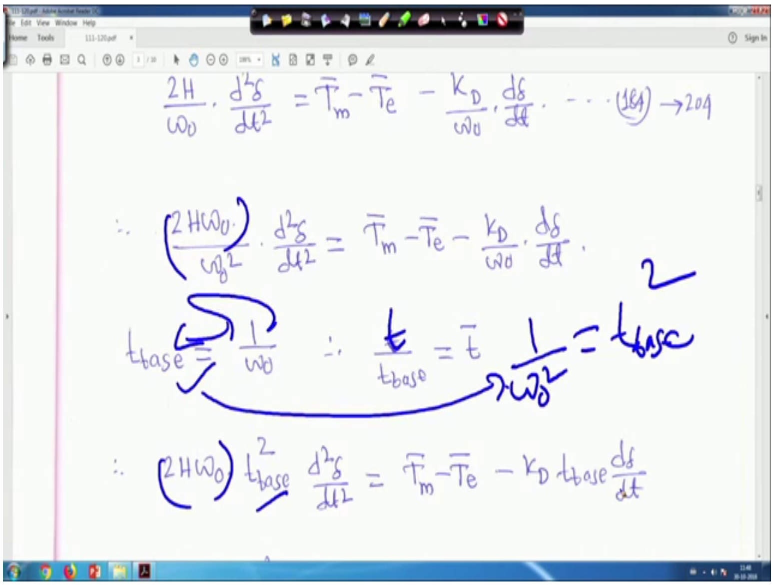

Now we know that earlier we have seen t base is nothing but 1 upon omega. So, it is 1 upon omega there is a time base right. Therefore, t by t base equal to t bar actually this is actually time it is actually t t by t base is equal to t bar right time with if you take time in per unit and t base is equal to 1 upon omega 0.

If we do so that, that means, my t base is 1. That means, my 1 upon omega 0 square will be my t base square, it is coming from here, it is coming from here right. That the 1 upon omega 0 square you can write 2H omega 0 is, if this is 2H omega 0 and one upon omega 0 square it is t base square into d square delta d t square equal to T m bar minus t T e or T e bar and 1 upon omega 0 is equal to t base, because 1 upon omega 0 is equal to your t base. So, we are multiplying minus KD into t base, because with the 1 upon omega 0 into d delta by d t this way we write right.

Next is and if we want to represent the timing per unit generally we represent in our all the quantities in per unit except time, but if we want to represent timing per unit. So what should be the technique?

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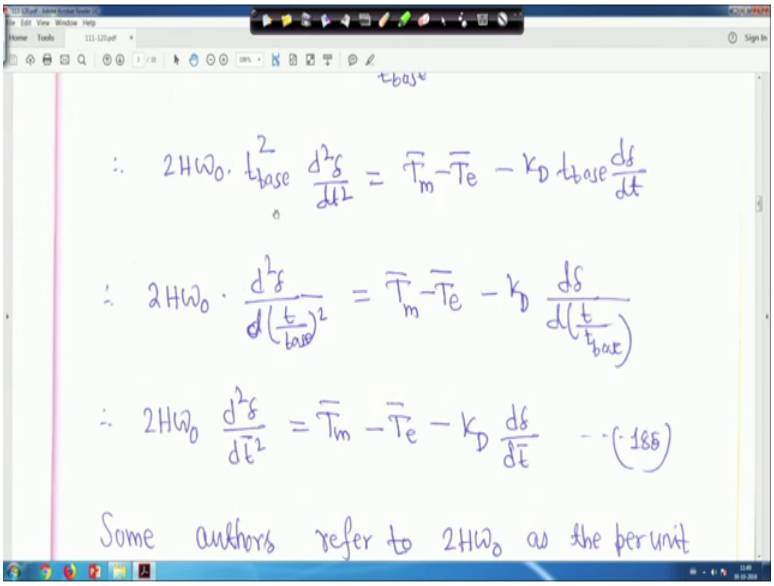

Then this 2H omega 0 is then this is d square delta d t square. So, we can write d square delta d of t upon t base square right because, this t base square has been your has a has been retained here t by t here what you call that one t is missing, that is your it is t base right it is t base right t base square. So, d square delta upon d of t by t base square, because this one has been taken here that is by this thing or what we call that a t by t base right. And similarly here also it is your minus KD d delta d upon t upon t base this has been written like this.

Therefore t by t base is nothing but t bar the timing per unit. Therefore, we can write 2H omega 0 then d square delta then d t bar square right is equal to T m bar minus t b bar minus KD d delta upon d t bar. That means, all these quantities for this equation 185 within per unit including time, if we want to represent time in per unit generally in stability studies only time we generally represent in second, but other quantities we here what we call represented per unit values right.

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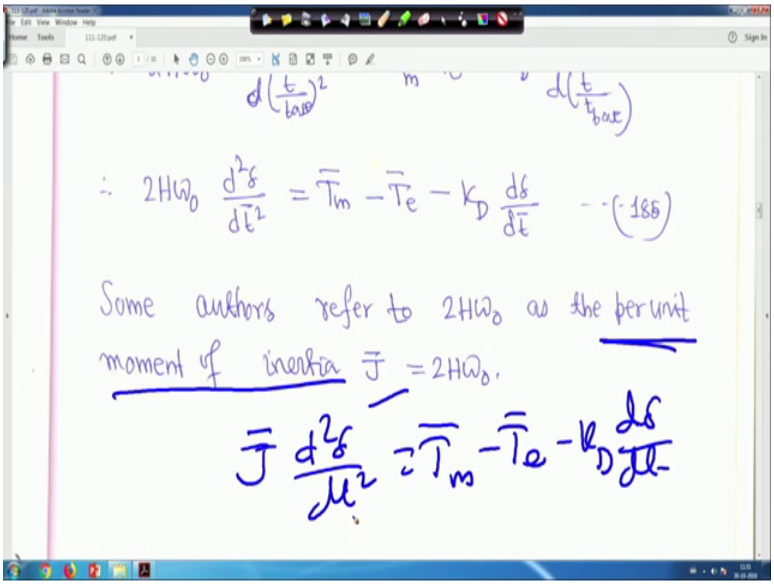

So, now some authors have written I mean many researches or authors they refer to 2H omega 0 as the per unit moment of inertia that is J bar is equal to 2H omega 0, because H you have seen from your stability studies that unit or dimension of H in second inertia is in second and omega 0 is radian per second.

So finally, 2H omega 0 will be dimension less quantity that is why some authors they refer this one as the 2H omega 0 as the per unit moment of inertia. That is why you are putting j bar. That means, everything if you see that everything will be per unit. That this equation if I write like this that j bar then d square delta d t square is equal to T m bar minus your T e bar minus KD then your d delta by d t right. So, everything is in per unit right all these quantities are in per unit.

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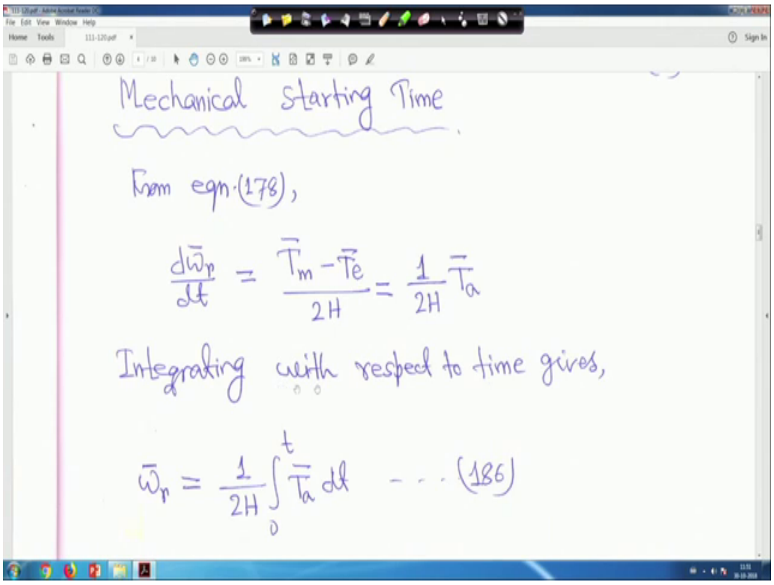

So, now next is that a mechanical starting time. Now from equation 78, 178 rather from equation 178, we can write the d d t of omega r bar is equal to T m bar minus T e bar upon 2H right is equal to we can write 1 upon 2H t a bar that is the accelerating power t a is equal to T m minus T e you know. So, t a bar will be T m bar minus T e bar, so 1 upon 2H t a bar right. Now if you integrate with respect to time then omega r will give one upon 2H 0 to t t a bar d t this is equation 186 right.

Now, this is some of calculations that your mechanical starting time.

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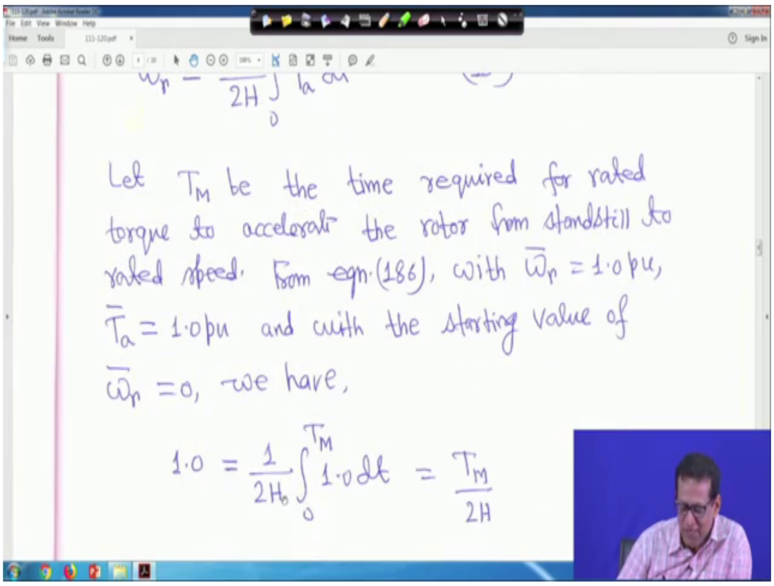

Therefore, now let T m be the time required for rated or to accelerate the router from standstills to rotor speed right. I mean if you assume the T m be the time required for rated torque to accelerate the router from standstill to rated speed. Now from equation 186 this one with omega r bar is equal to say 1 per unit and t a bar is equal to say 1.0 per unit and with the starting value of omega r bar is equal to 0, say initial value that is starting value is 0.

Then, you can see that your what you call 1 is equal to because omega r we have taken 1, 1 upon 2H 0 2 2 m here also t a bar you have taken 1 right and to d t, so it is T m upon 2H right.

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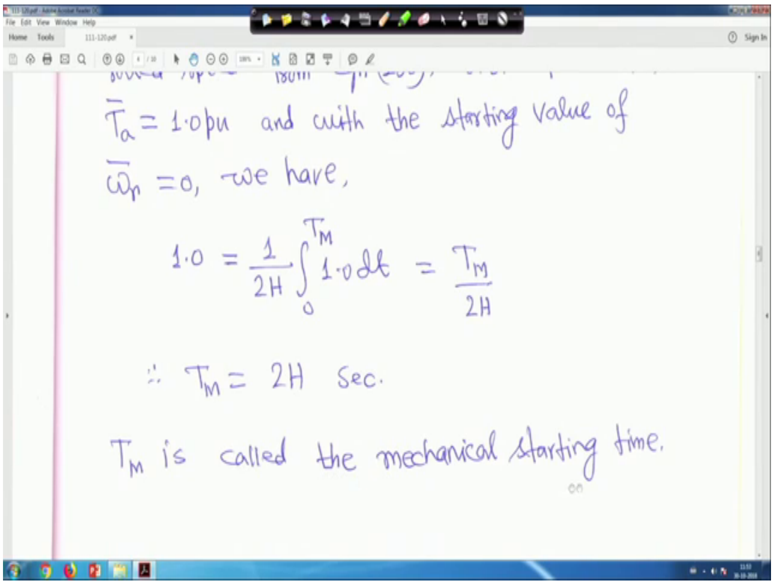

That means, we can write T m is equal to 2H second. So, T m is called the mechanical starting time. It is some rough, it is some approximate calculation. So, T m is called the mechanical starting time. So, it is 2H second because dimension are h is in second.

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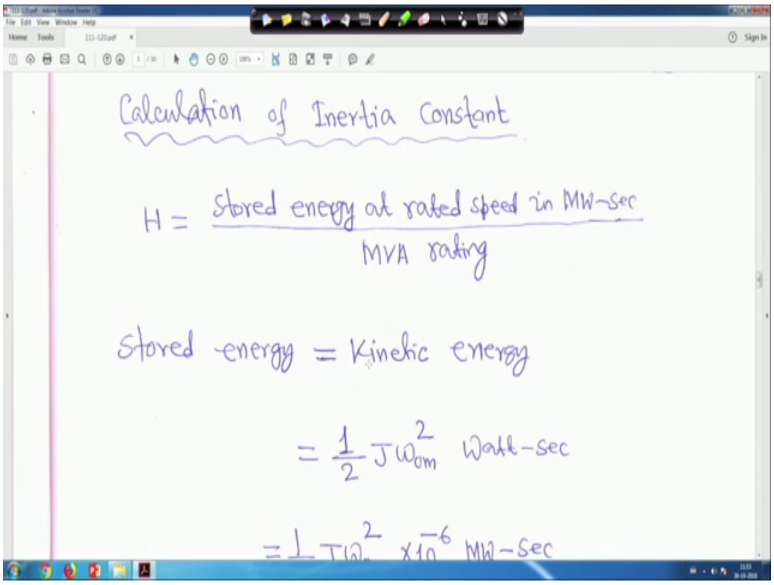

Now, calculation of inertia constant; so now we know from our power system studies, power system analysis transient stability studies are in machine that H is equal to store energy at rated speed in megawatt second divided by MVA rating right. So, its unit is second right. Therefore, stored energy is nothing but is equal to kinetic energy. So, we can write kinetic energy is equal to stored energy half J omega 0 m square that is watt second.

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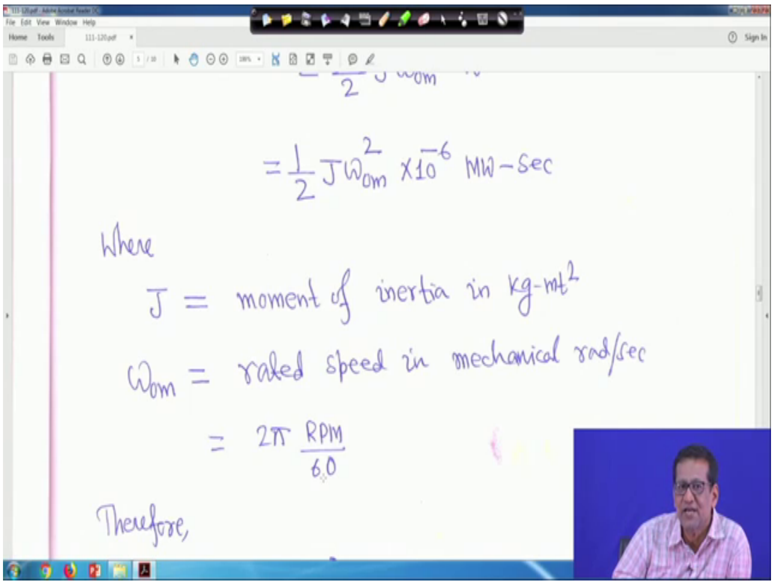

Where the energy is joule and we know joule per second is equal to watt. So, joule is equal to watt second. So, we write in watt second rather than joule right. So, we can write, now we if you convert watt into megawatt then it will be half J omega 0 m square into 10 to the power minus 6 megawatt second right because 10 to the power 6 watt is equal to 1 megawatt right.

So, that is why your half J omega 0 m square in to 10 to the power minus 6 megawatt second. Now J is equal to your moment of inertia in kg meter square, this we know. Omega 0 a means rated speed in mechanical radian per second right, is equal to 2 pi into revolution per minute RPM by 60. That is omega 0 m right, in because we are giving in radiant per second.

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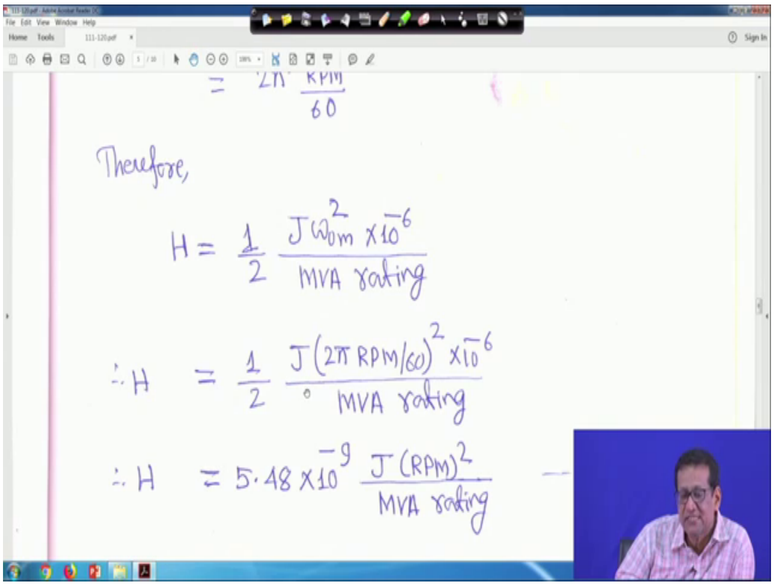

Now therefore, this H will be is equal to half J omega 0 m square in 10 to the power minus 6 divided by MVA rating right because, this is that equation, this is the equation and divided by MVVA rating. Now this is equal to H is equal to half J omega 0 m is equal to 2 pi the revolution per minute, I write RPM divided by 60 square into 10 to the power minus 6 divided by MVA rating. If you simply this one it comes actually 5.48 into 10 to the power minus 9 J RPM square divided by MVA rating; that is equation 187.

Now, this is actually value of H, this is from for the point of view of solving numerical. This you have to keep it in your mind, I mean keep it in your memory right.

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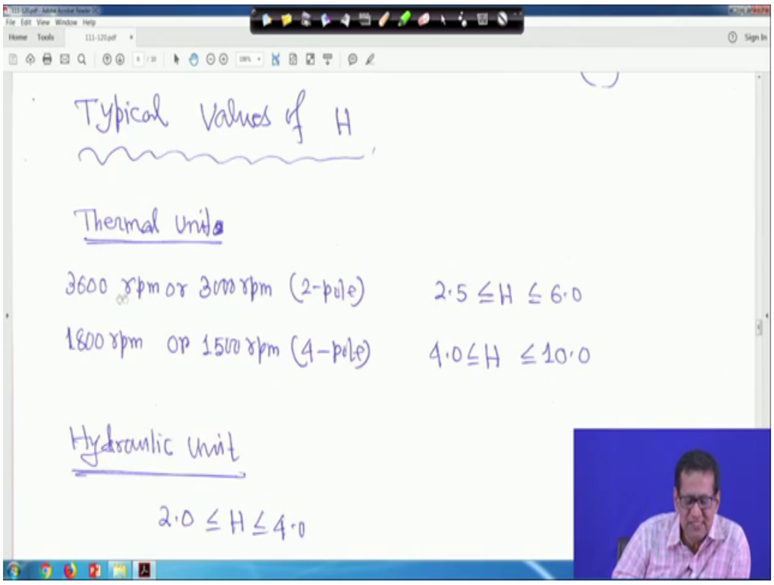

So, typical value of H; so generally for a machine that 3 6 3600 RPM or 3000 RPM right basically 2 pole machine for thermal power plant thermal unit is generally lies in between 2.5 and 6.0 second right. And if it is 1800 RPM or 1500 RPM that is 4 pole machines. So, it generally lies in between 4 and 10 second right. And similarly, for hydro unit hydraulic unit H is generally it by typical values lies in between 2 and 4 second right.

So, this is actually here what you call different values of H range or values of H for thermal or hydro power plant.

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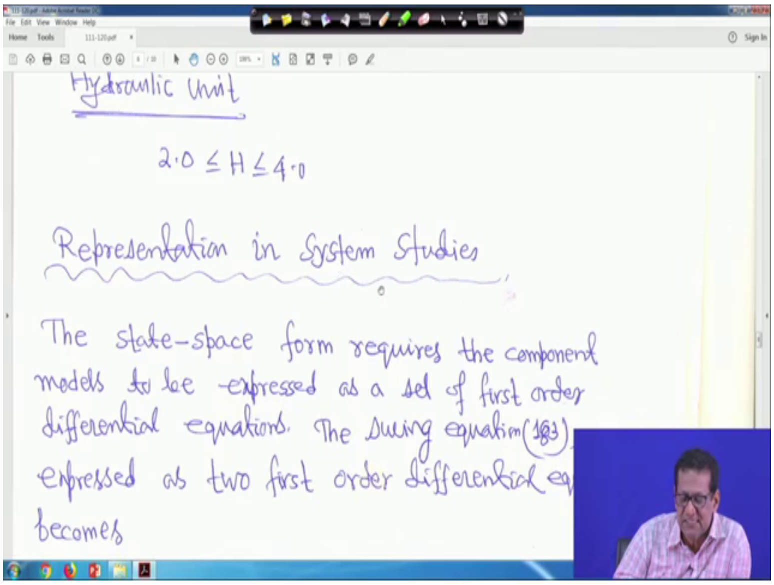

Now, represents as represent as in system studies right. The now the state space form requires that your what you call the component models to be expressed as a set of faster order differential equation because, slowly and slowly we have to go for the here, what you call development of your first order. Now here, what you call block diagram representation of the synchronous machine right.

So, the state space form requires your component models to be expressed as a set of first order differential equations.

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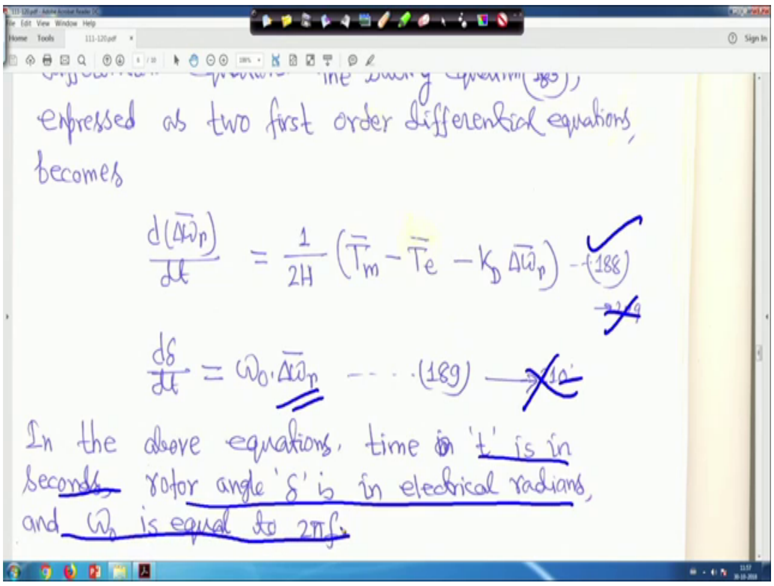

The swing equation that is 183 expressed as 2 first order differential equations it becomes actually d d t of delta omega bar is equal to 1 upon 2H T m bar minus T e bar minus KD delta omega r bar. This is equation your 188 right. So, this is 100, this is nothing, this is also nothing and d delta upon d t is equal to omega 0 delta omega r bar. This we have seen this right.

Now, in the above equation time t is in second, because here we are not using bar t bar, it is time in second at rotor angle delta is in electrical radiant and omega 0 is equal to two pi f right.

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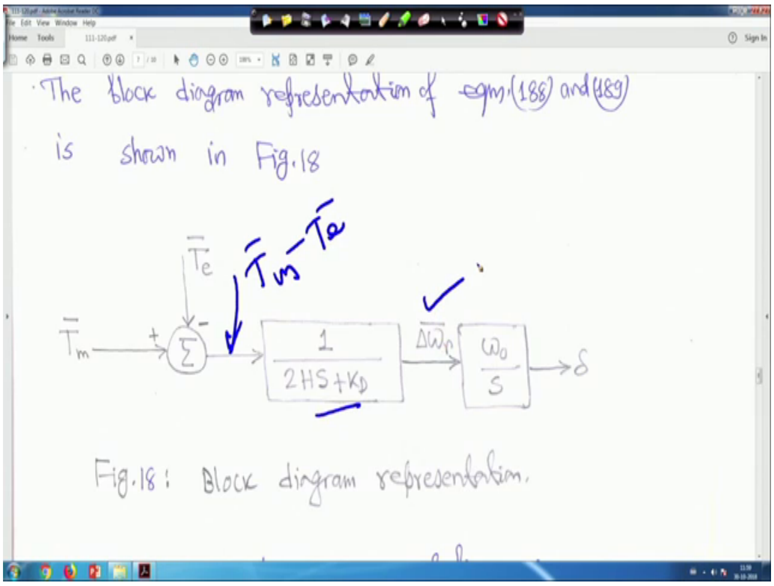

So, now the block diagram representation of equation 188. That means, this 2 equation and 189 is shown in figure 18 right.

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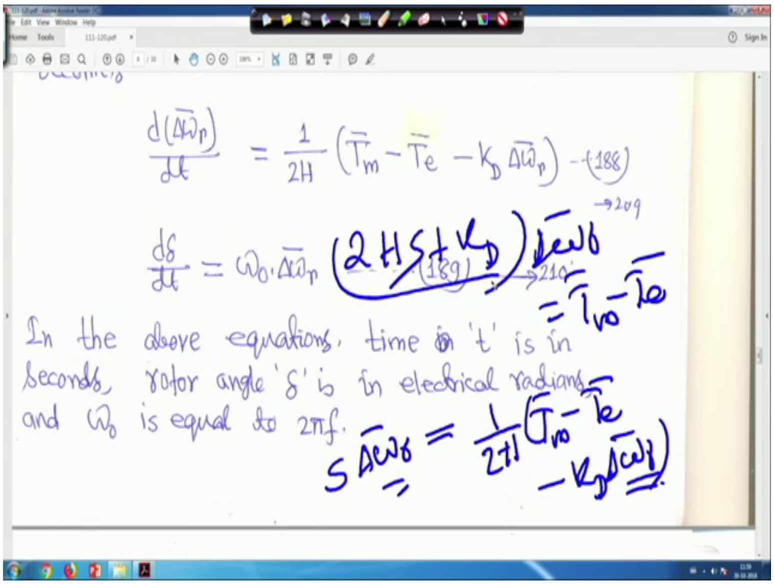

Now, question is that assuming all initial conditions are 0 if you take the Laplace transform of this one right. So it will become S into delta your delta omega bar S S will not put again and again right understandable. So, it will be s into delta omega r is equal to one upon 2H it will be T m T m bar minus T e bar minus KD delta omega r bar right. I mean if you if you look into this that if you take the Laplace transform on both side, so again and again I am not making this quantities function of S, understandable only S I will put. So, it is S right then, delta omega bar is equal to 1 upon 2H right. Then T m bar minus T e bar minus KD then your delta omega r bar right this way we can write.

Now, if you go for cross multiplication and simplify then where to write I am writing here writing here just see that then 2H S, we go for cross multiplication and after cross multiplication d KD omega r term to left hand side. So, it will be KD right into your delta omega r bar because here delta omega bar, here also delta omega bar is equal to your T m bar minus T e bar right. So, 2H S plus KD term will be there. Therefore, delta omega bar will be your T m minus T e divided by 2H S plus KD right.

So, that is why this block diagram, this block diagram if we look into that T m bar is given input here and T e bar. So, this one this output is T m bar minus T e bar into and delta omega r will be your what you call your T m bar minus T e bar divided by 2H S plus KD, that is you have seen and this output is delta omega r bar. Now again if you see this equation that your this equation if you take your what you call that your Laplace transform a again and again not putting the function of this thing just hold on, just a this thing than this one, if you take S delta is equal to omega 0 delta omega r bar right.

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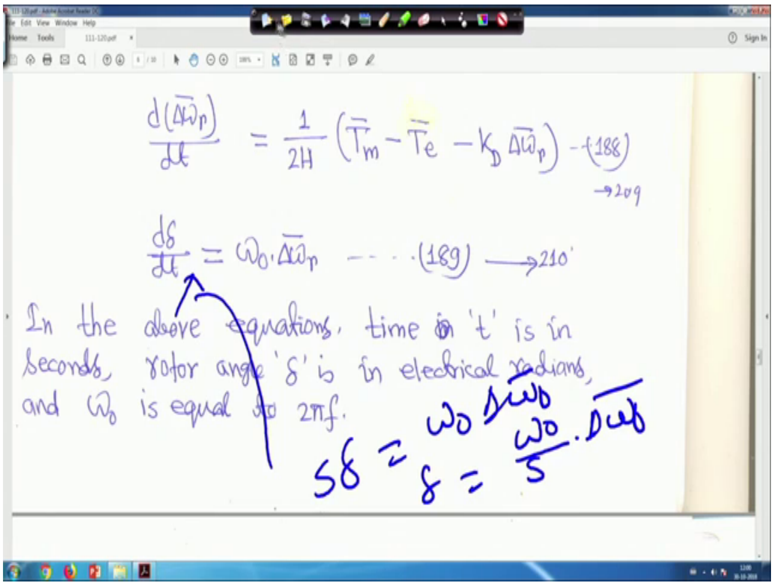

This is there, therefore delta will be is equal to omega 0 by a S into delta omega r bar right.

So, that is why here we are writing the delta is equal to omega 0 by S into delta of this is the first step, slowly and slowly it will grow right. I mean just step by step it will grow, later you will see it will make a very big model just hold on. Slow and slowly we are it will be growing that step by step right.

So, this is actually then we can write T m bar my then this is T m bar and this is minus one T e bar and this block diagram you put one upon 2H S plus KD. This output is delta omega bar and omega 0 by S into and this output is delta right. So, up to this is no problem at all it is very simple thing right.

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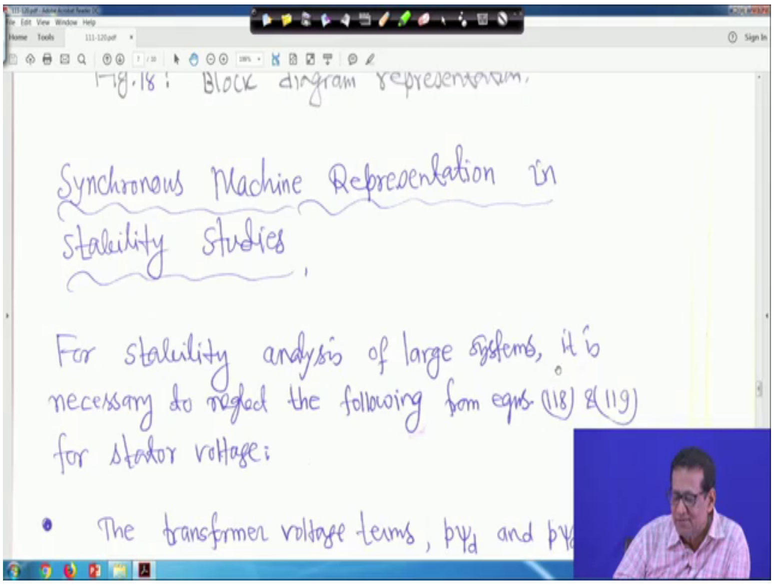

This is my figure 18; that is block diagram representation. Now synchronous machine representation in stability studies we have to make few assumptions. Now for stability analysis of large system it is necessary to neglect the following terms from equation 118 and 119 for stator voltage. So, whenever you will whenever you will listen to this course right this as all this notes will be provided to you. So, keep everything ready in front of you because if I do not want to go back again a 118 and 119 for examples many such things will come, so you will keep those things in front of you and just see this right; so that from equation 118 and 19 first stator voltage right.

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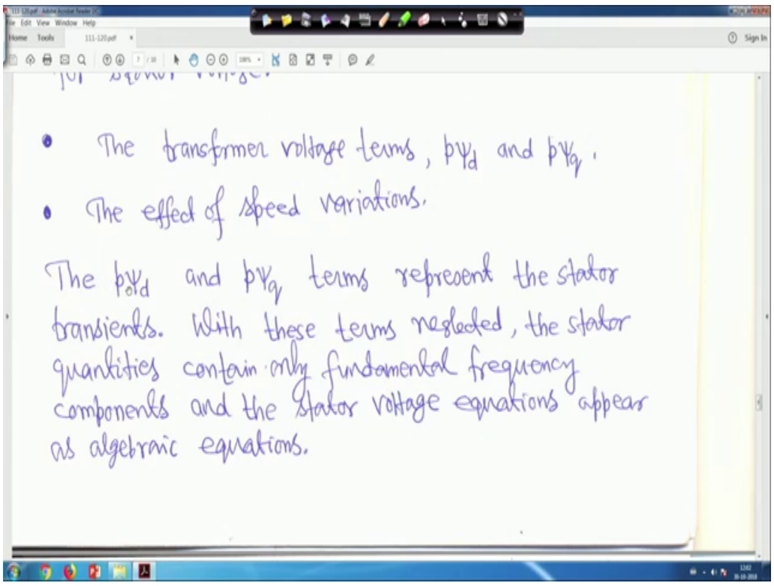

It is necessary to neglect the following terms the first is that, transformer voltage terms p psi d that is psi d dot and p psi q that is psi q dot. This will be dropped right because we are and similarly the effect of speed variation, this also will be dropped right. If it is so the p psi d and p psi q terms represent the stator transients right. With this terms neglected the stator quantities contained only fundamental frequency components and the stator voltage equations appear as algebraic equation right.

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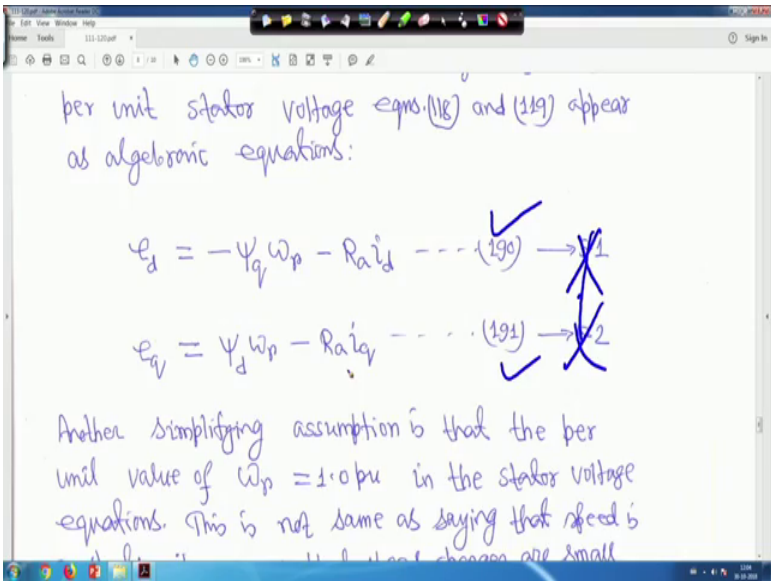

That means with the stator transients neglected the per unit stator voltage equation 118 and 119 appear as algebraic equation. So, p psi d and p psi q terms will be dropped in equation 118 and 119. I actually what I have done is this I did in big this thing, this equation number will increase right so such to maintain the continuity.

So, I perhaps a I feel that it will be very helpful for you people because when I have taught this course here they are student also find this things are quite useful right. So, that is why that equation number will continue and it will cross you can have so many equation such that there will be continuity a link right. That is why this equation number, so there nothing to be surprised looking at equation 190, 191 or 200 or more right, but it will help you a lot it because, continuity will be there and you can link 1 after another when we will have this nodes right.

So, that is why your, that means, this equation here what you call this equation, that your 118 and 119 right, so this is no need to see, this is no need to see. So, it is because of 190 and 191 right. Therefore, e d will be minus psi q omega r and minus R a i d and e q will be e e q will be psi d omega r minus R a i q after dropping p psi d and p psi q terms right.

So, another simplified assumption is we have to make many assumptions.

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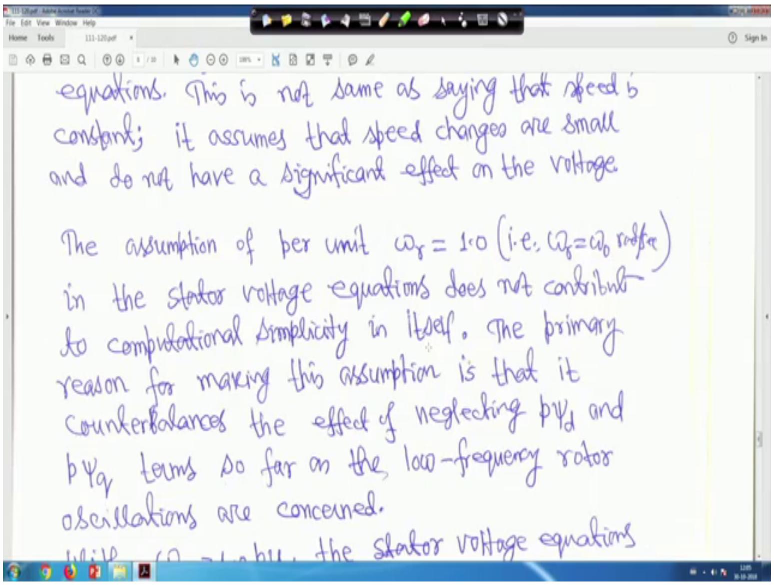

Another simplifying assumption is that the per unit value of omega r is taken 1.0 per unit in the stator voltage equation. This is not same as saying that the speed is constant. It assume that speed changes are small and do not have a significant effect on the voltage right.

So, this is this sentence is very important that in the stator voltage equations this is not same as saying that speed is constant rather it assume that speed changes are small and do not have a significant effect on the voltage right. So, the assumptions per unit omega r is equal to your 1. That is omega r is equal to omega 0 is equal to a this thing omega 0 radian per second in the stator voltage equation does not contribute to computational simplicity in itself.

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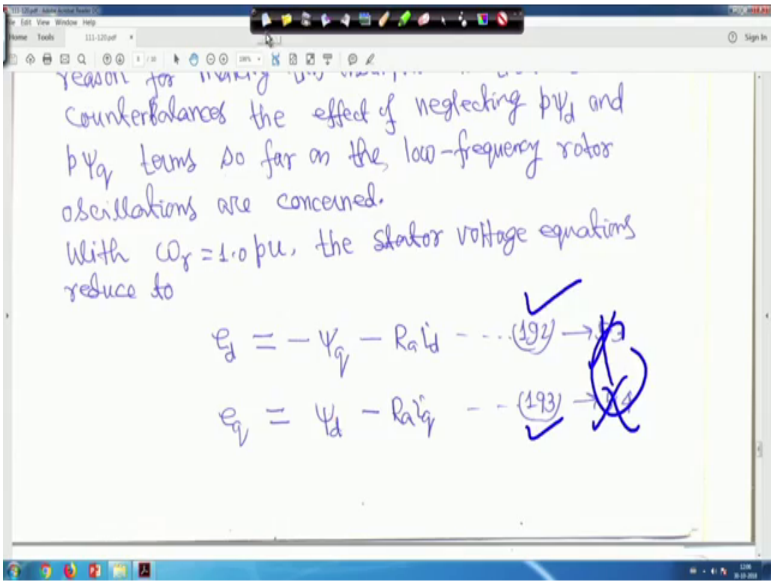

The primary reason for making it assumption is that it counter balances the effect of neglecting p psi d and p psi q terms. So, far as the low frequency rotor oscillations are concerned. We will see those things in later right much later right.

With omega r is equal to 1.0 per unit the stator voltage equations reduce to that e d will now here in this equation if omega r is equal to 1 per unit then this here what you call then e d will be is equal to this is not required right. So, this for my own reference, so e d is equal to minus psi q minus R a i d, this is equation 192 and e q will be psi d minus R a i q, this is equation 193 right. So that means we are simplifying 1 after another right. So now we will.

Thank you very much. We will be back again.