Power System Dynamics, Control and Monitoring

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Lecture - 09
Power System stability (Contd.)

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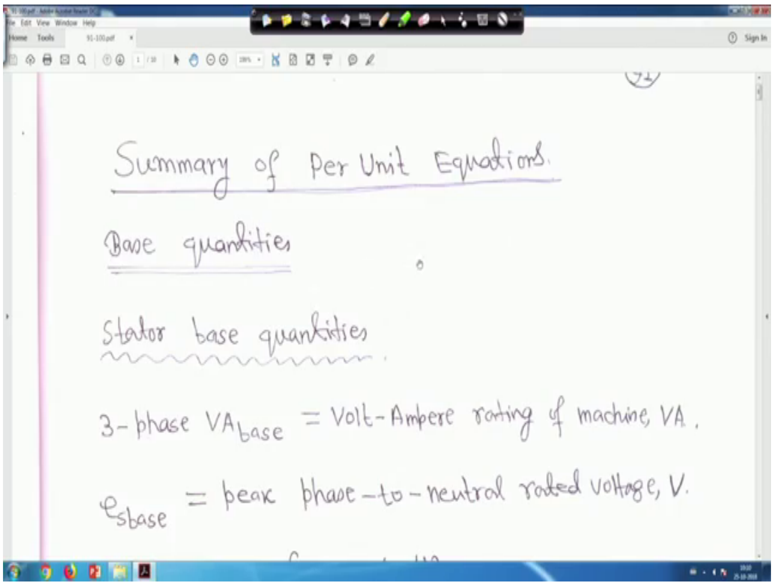

So, just in the previous lecture that is summery of your per unit equations that base quantities that all summaries.

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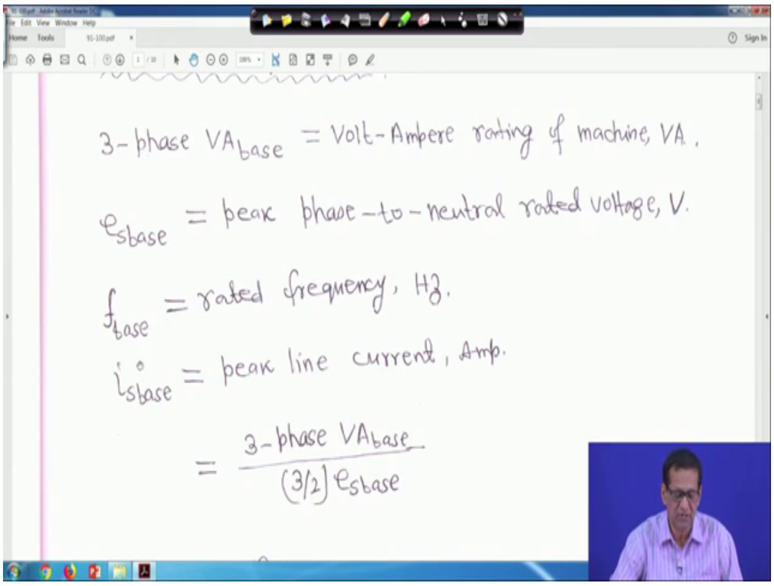

Just repeating once again that is a stator base quantities, that is 3 phase volt ampere base is equal to volt ampere rating of machine that is in volt ampere, then e s base peak value to neutral voltage your in terms of volt and rated frequency that is f base right.

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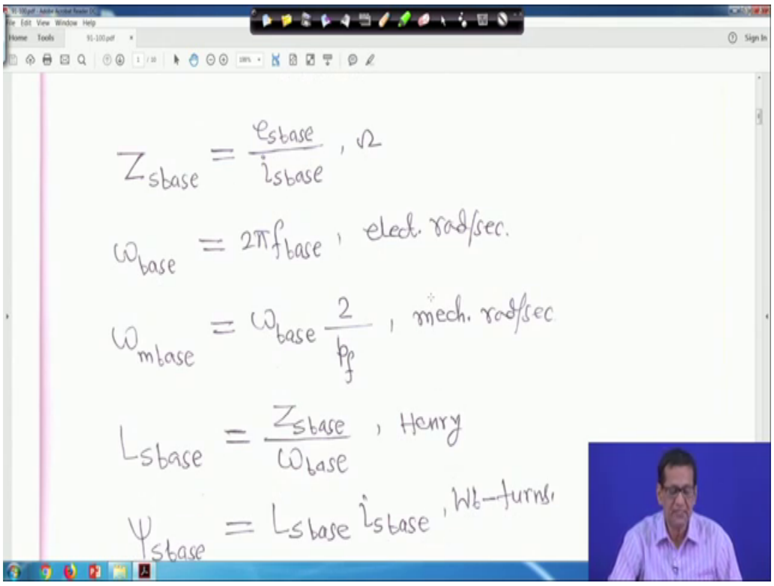

And this is i s base peak line current that is in ampere 3 phase volt ampere base divided by 3 by 2 e s base. Then Z s base is equal to e s base upon i s base this is ohm. And omega base is equal to 2 pi f base that is electrical radian per second. All these things we have seen it is just a summery right, then your omega base it is this one and omega mechanical base. So, omega base into 2 upon p f that is mechanical radian per second.

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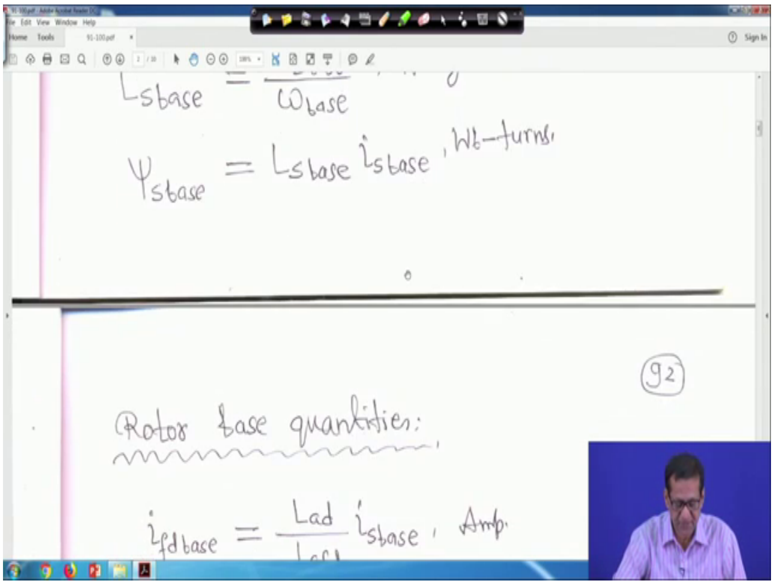

Then L s base is equal to Z s base upon omega base, this is ~~henry~~Henry and psi s base the flux linkage 1, then L s base into i s base that is wherever turns right.

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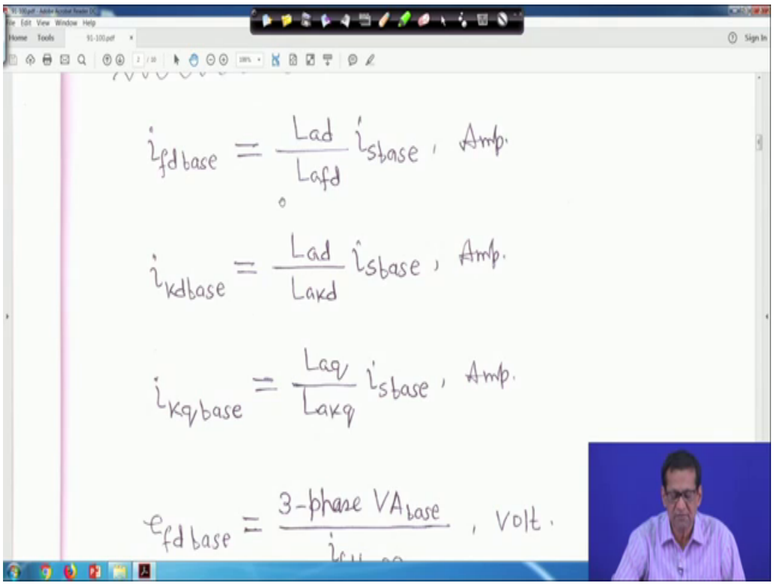

And rotor base quantities this all we have seen before right, these are all summaries and your i fd base is equal to L ad upon L ad into i s base, this is the ampere i i i kd base is equal to L ad upon L akd i s base this is in ampere i kq base is equal to L aq upon L a k q is base this is in ampere right.

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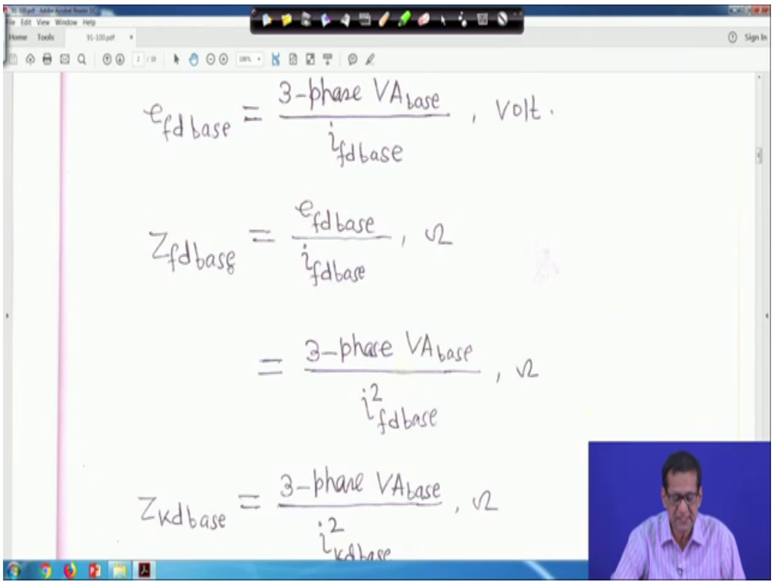

And e fd base is equal to 3 phase volt ampere base upon i fd base, this is in volt. And Z fd base e fd base upon i fd base this is in ohm is equal to 3 phase volt ampere base by your divided by i square fd base, this one numerator and denominator one can multiply by i fd right.

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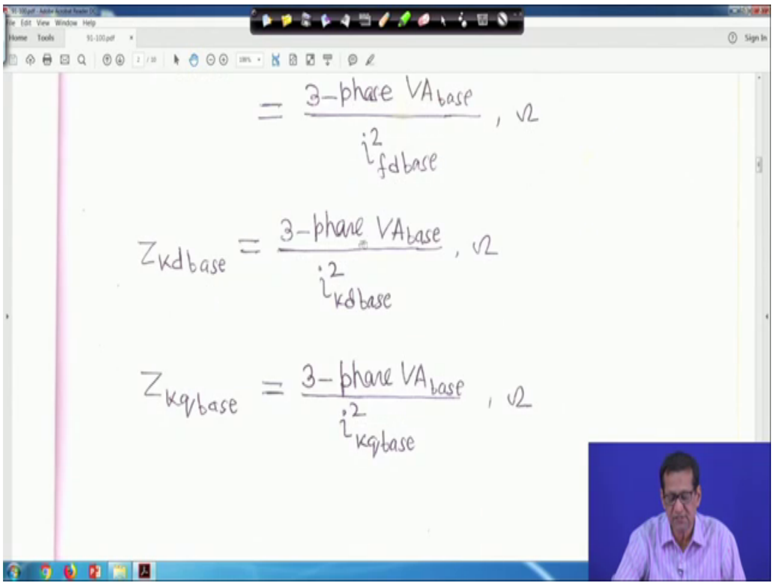

And Z kd base is equal to 3 phase volt ampere base upon i square k d base, this is ohm and Z k q base 3 phase volt ampere base upon i square k q base this is ohm right.

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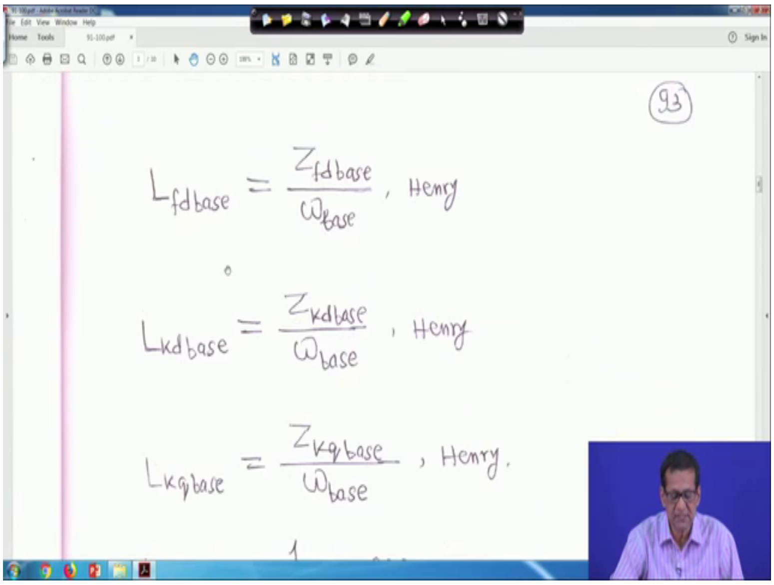

And L fd base is equal to Z fd base upon omega base this is Hhenry. And L kd base is equal to Z kd base upon omega base this is Hhenry, then L kq base Z kq base upon omega base this is Hhenry. All these thing little bit you are try to what I do while because previously everything had been derived, just try to I mean whenever you make it just try to recall all these things. So, no question of recalling also just if you have understood little bit you can do easily. And time base is equal to 1 upon omega base second right.

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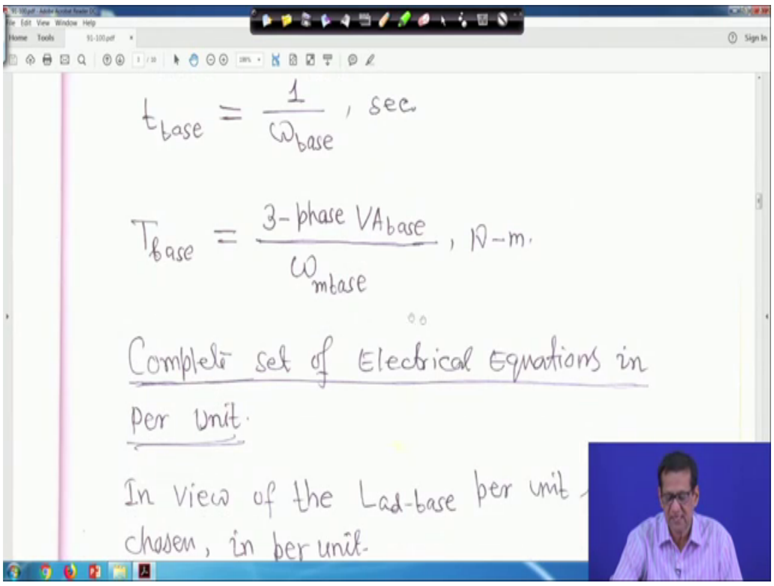

And this is your torque base 3 phase volt ampere base upon omega m base in

~~newton~~Newton meter right and complete set of equations in per unit.

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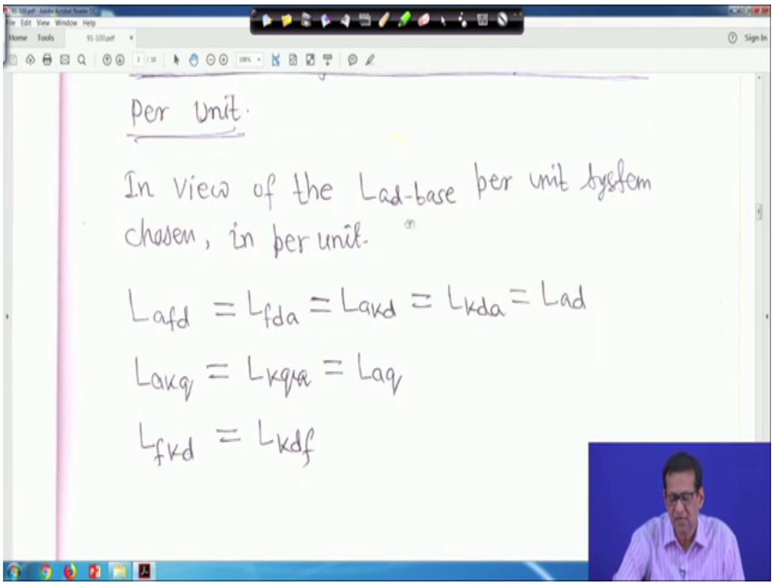

In view of the led base per unit system chosen in per unit. So, these are not we are not putting bar again again again again right so, but these are all in per unit. So, when we are initially when I started, there was no upper bar and when per unit per unit thing all the quantities are converted to per unit, at that time we will put bar, but after that we are not using bar, but these are all per unit only right. So, L afd is equal to L fda is equal to L akd is equal to L kda is equal to L ad very easy to remember all are same in per unit. Similarly, L akq is equal to Lkqa is equal to L aq right and similarly L fkd is equal to L kdf right.

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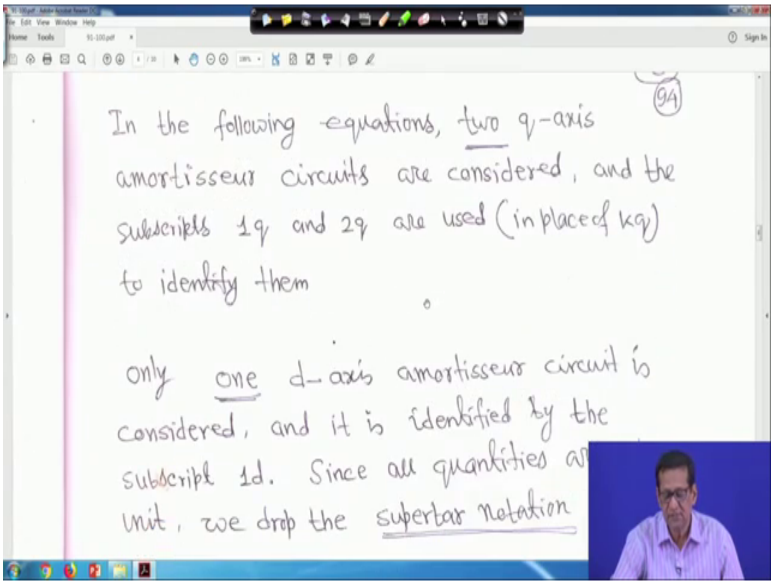

So, in the following equations two q axis amortisseurs circuits are considered. Suppose you have considered k is equal to 1 and k is equal to 2. And the subscript 1 q and 2 q are used right in place of k q to identify them right. Just for the sake of analysis right only 1 d axis amortisseurs circuit is considered in that case k is equal to 1 right. And it is identified by the subscript 1 d, because it is k d. So, k is equal to 1 similarly here it is here it was your this thing 2 k q so, k is equal to 1. So, 1 q and k is equal to 2 2 q right. So, 2 amortisseurs consider on the q axis right.

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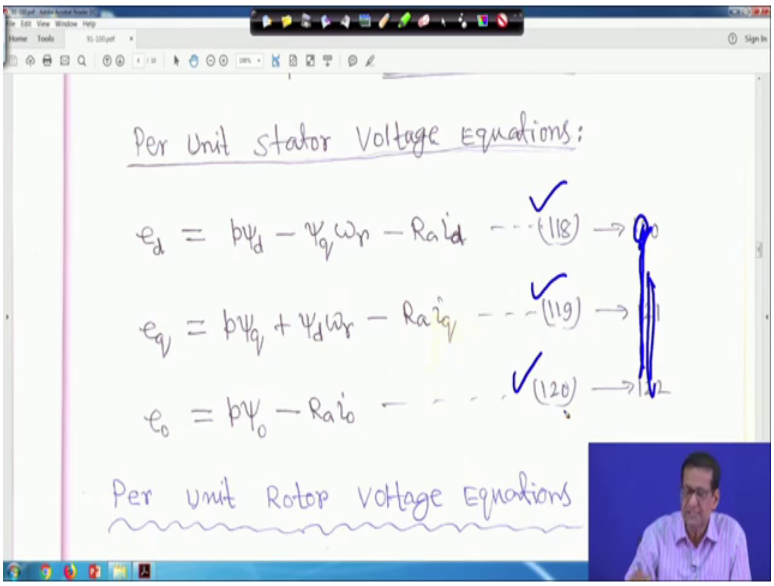

So, per unit stator voltage equations, now here we are not putting bar, but these are all per unit right again and again we will not put bar, but this is the understandable, but one thing is there that whatever ~~whatevers~~ the here equation is written here right, this should not see this you will see this one this one only this is due to something I wrote, but only you will see these equation right. So, just hold on.

So, this is your ~~your~~ what you call per unit stator voltage equation e d is equal to p psi d minus psi q omega r minus R a i d this is equation 118, e q is equal to p psi q plus psi d omega R minus R a i q this is 119~~8~~ and e 0 is equal to psi 0 minus R a i 0 this is 120 this one you should not see the right hand side.

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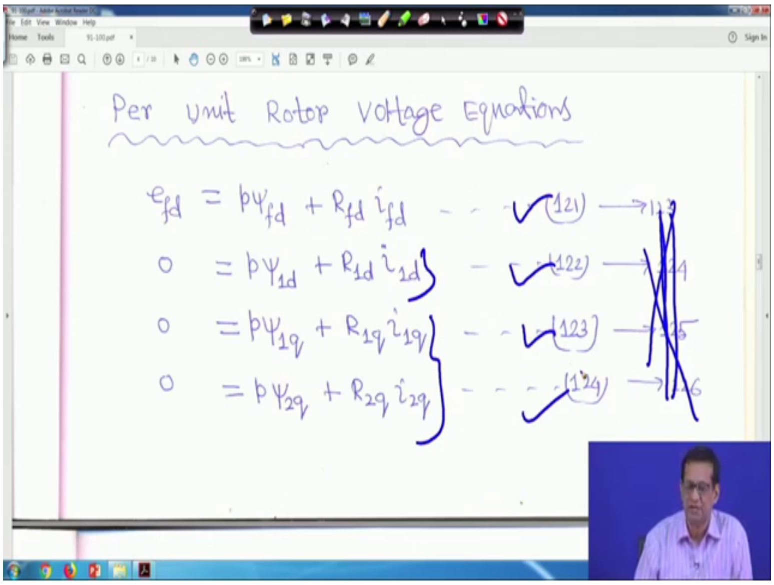

So, similarly per unit rotor voltage equation. So, in this case your e f d this one you should not see this one you should not see. So, e f d is equal to p psi f d plus R fd i fd, then ~~then~~ 0 is equal to because it is the close winding others are amortisseurs. So, p psi 1 d plus R 1 d i 1 d and we have choose 2 amortisseurs on the q axis therefore, p psi 1 q plus R 1 q i 1 q is equal to 0 that is equation 123.

And another one is p psi 2 q plus r 2 q i 2 q is equal to 0, because we have chosen 2 amortisseurs winding on the q axis, that is why these 2 equations are that is why these on the d axis only one, that is why this is 1 equation right. So, this is equation 24 this side you should not see, in the in the subsequent phases also this will come, but you skip that one only you see this equation number you follow this equation number right.

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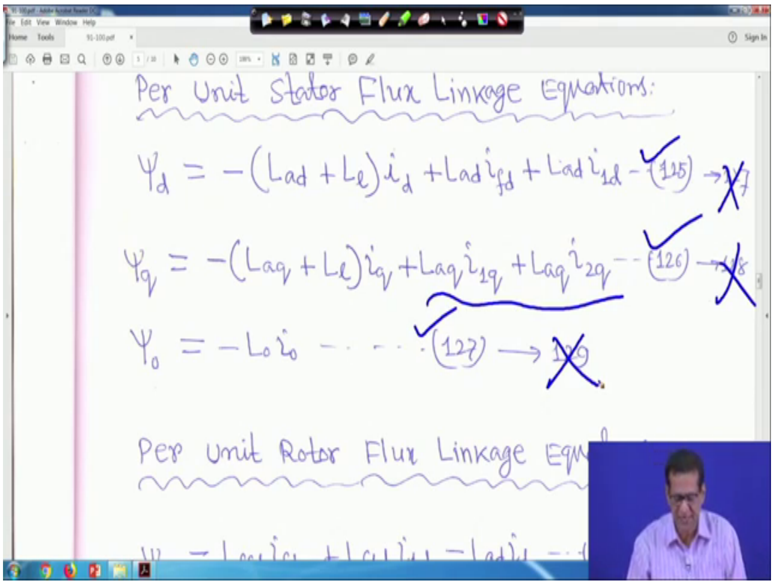

So, now per unit stator flux linkage equation, these already ~~already~~ we have been derived right, but this is your what you call this is just your just summary. So, psi d is equal to minus in bracket L ad plus L l into i d plus L ad i fd plus L ad i 1 d this is equation 125. So, this should not be same.

Similarly, psi q is equal to minus in bracket L aq plus L l iq plus L aq i 1 q plus L a q i 2 q, because this two terms are coming because in the q axis, we have chosen 2 amortisseurs this is equation 126 and psi 0 is equal to minus L 0 i 0 this is equation 127, this you should not see this equation number right.

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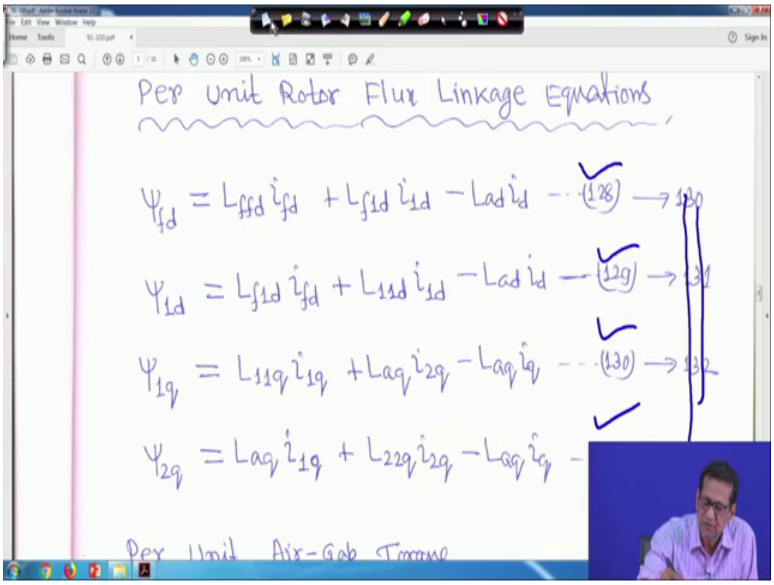

So, similarly per unit flux linkage equation. So, in ~~in in~~ this case your this one also you should not see, only you will see these equation number these equation number. So, psi fd is equal to L ffd i fd plus L f 1 d i 1 d minus L a d i d this is summery only, but everything is in per unit, but bar ~~bar~~ has been removed right and psi 1 is equal to L f 1 d i fd plus L 1 1 d i 1 d minus L a d i d right.

Similarly, psi 1 q is equal to L 1 1 q i 1 q plus L a q i 2 q minus L a q i q right. Similarly psi 2 q is equal to L a q i 1 q plus L 2 2 q your i 2 q and minus L a q i q right. So, this way your what you call, this is the per unit your rotor flux linkage equation right.

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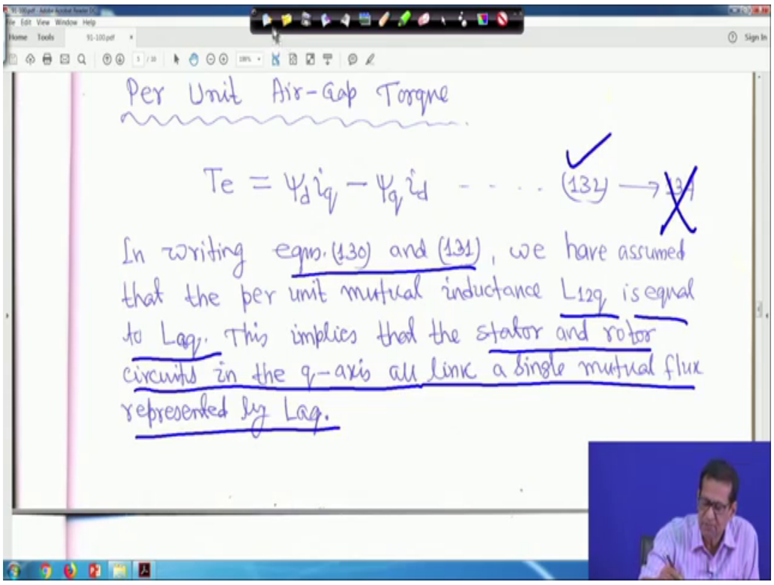

So, then ~~then~~ per unit air gap torque this we know a T e is equal to psi d i q minus psi q i d. So, this equation number you should not see this is the equation 132 right. So, in writing equation 130 and 131 right, these two we have assumed that the per unit mutual inductance that is L 1 2 q is equal to L a q right, this implies that the stator and rotor circuits in the q axis all link a single mutual flux represented by L a q right.

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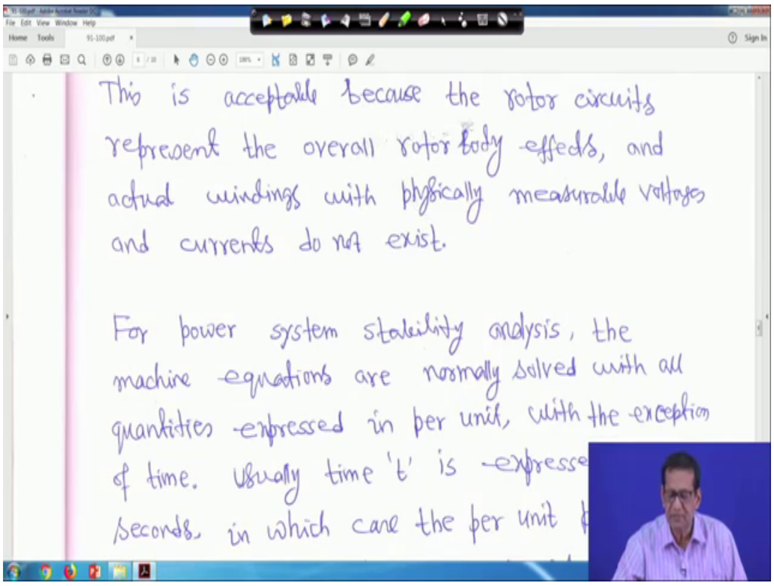

Therefore so, and this is acceptable because the rotor circuit represent the overall rotor body effects and actual winding. So, with physically measurable voltage and currents do not exist.

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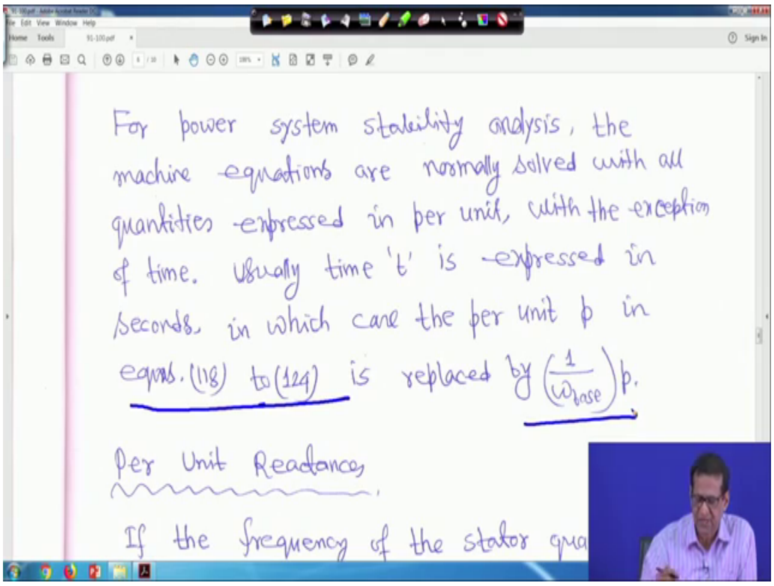

So, next is for power system stability analysis, the machine equations are normally solved with all quantities expressed in per unit, with the exception of time everything whenever we time domain simulation we do, later we will see something right. So, time will be in second, but all other quantities will be in per unit that actually makes our analysis easier and usually time t is expressed in second, in which case the per unit your p in equation your this thing 100 80 to~~2~~ 124 is replaced by your ~~one~~ 1 upon omega base e into p p you have seen that it is basically ddt by dt deferential operator right.

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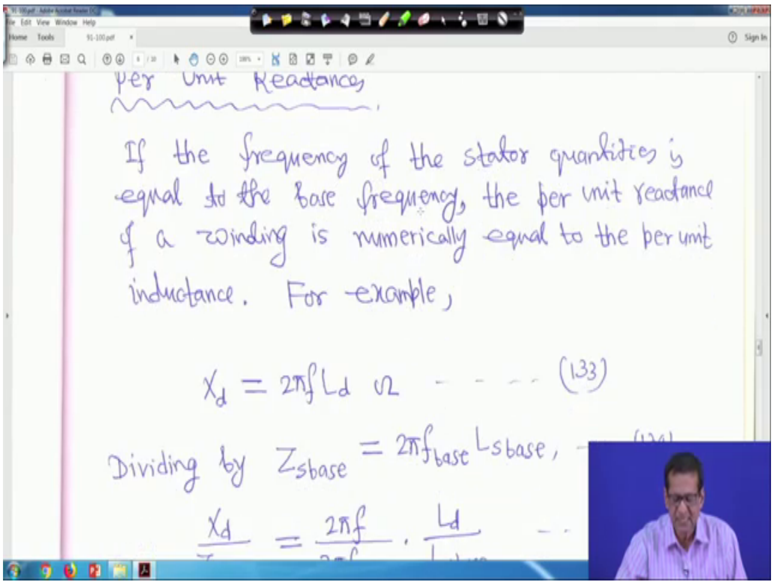

And similarly per unit reactance you have seen, but it is a summery so, just repetition once again, that if the frequency of the stator quantities is equal to the base frequency. The per unit reactance of winding is a numerically equal to the per unit inductance for example, X d is equal to we know generally in general X is equal to L omega. So, X d is equal to 2 pi f into L d ohm dividing by Z base is equal to 2 pi f base L s base on both side right.

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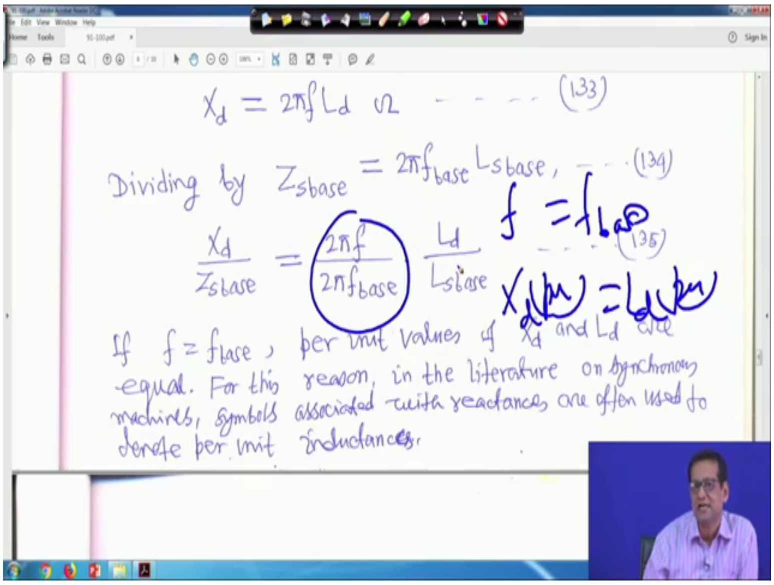

So, X d upon Z s base is equal to 2 pi f upon 2 pi f base into L d upon L s base, but f is equal to if it is f is equal to f base right, then basically X d per unit will be is equal to L d per unit.

So, per unit of X d and L d are equal because f if f is equal to f base right generally it is 2. So, in that case x d per unit is equal to L d per unit. Therefore, suppose in numerical if it is given the per unit your inductance right is given this that is nothing, but per unit reactance tool also right.

So, that is why this X d that means, this one that X d per unit right is equal to L d per unit right and here f is equal to f base you put f is equal to f base. So, this term will be unity so, it will be X d per unit is equal to L d per unit right. So, that is if suppose if this given in that sense in per unit and you will and you require reactance per unit for numericals, then in that case inductance per unit means this is per unit reactance right.

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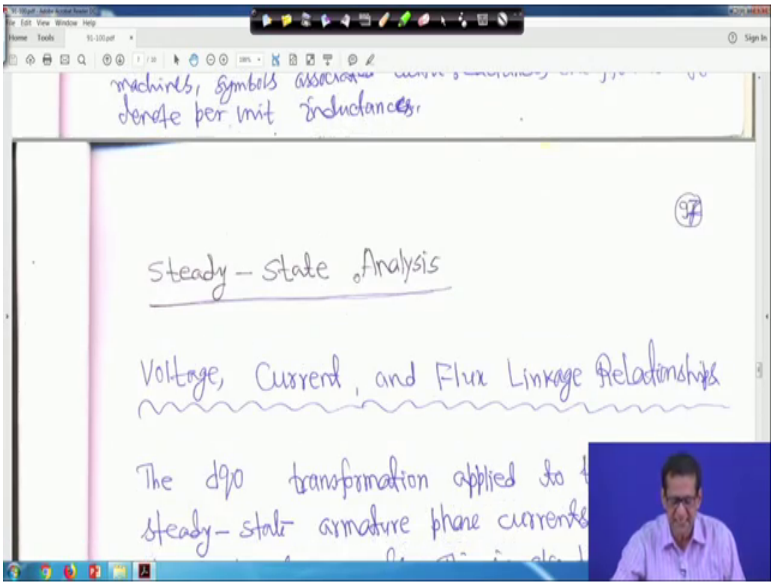

So, next is this is steady state analysis, but before that we will take one small example just hold on.

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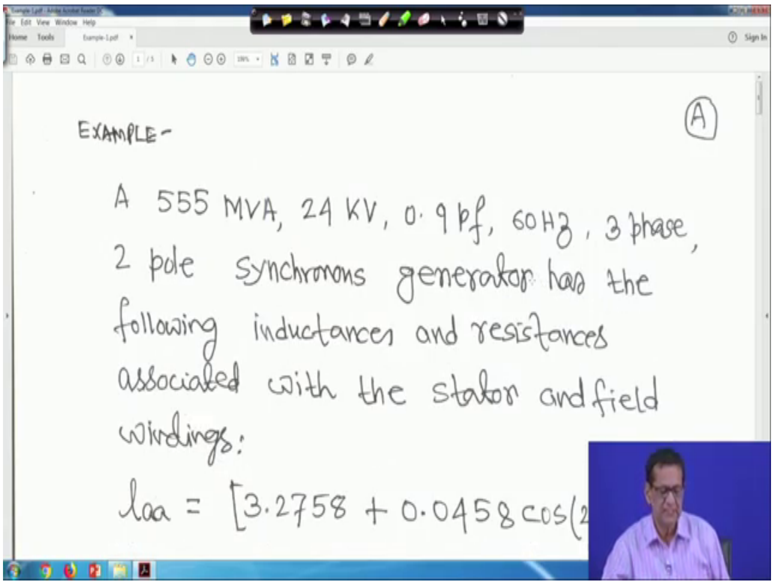

So, so this is your what you call this is your example 1. So, A 50 A sorry A 555 MVA, 24 KV 0.9 power factor 60 hertz 3 phase 2 pole synchronous generator has the following inductances and resistances associated with the stator and field windings right.

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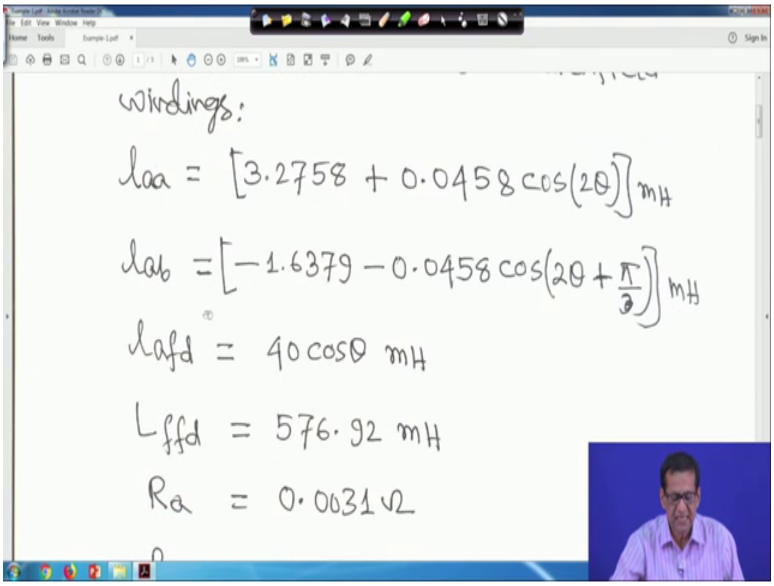

It is given small l aa is equal to 3.2758 plus 0.0458 cosine 2 theta, this is bracket close using milli Hhenry. Similarly L a b is given that minus 1.6379 minus 0.0458 cosine 2 theta plus 5 by 3 milli Hhenry, this is given L la fd is given 40 cos theta milli Hhenry L ff d is given 576.92 milli Hhenry R a is given 0.0031 ohm R fd is given 0.0715 ohm right.

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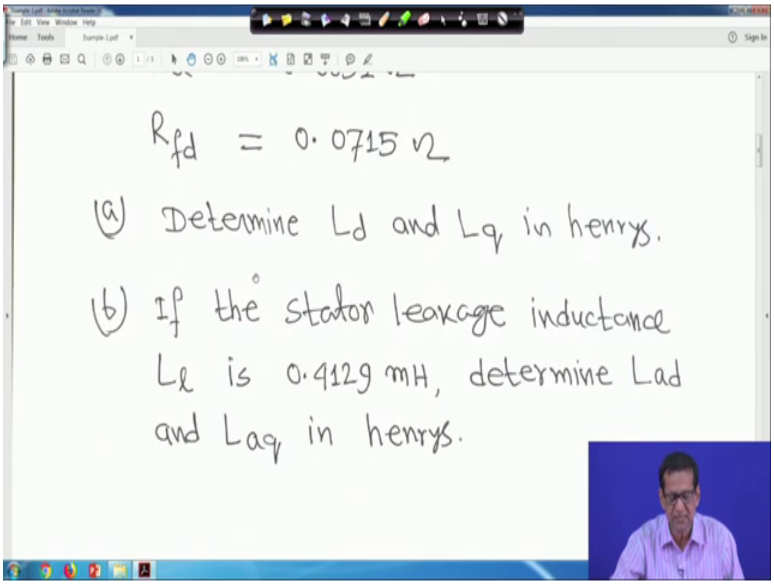

So, what we have to determine, we have to determine L d and L q in henrys, the if the stator leakage inductance L l is 0.4129 milli henry, we have to determine L ad and L aq in henrys right. So, this is the problem so, generator is 555 MVA 24 KV 0.9 power factor 60 hertz 3 phase 2 pole synchronous generator. And this and this parameters for all these things are given all right.

So, in this case we have to determine L d and L q at the same time that is L l is given you have to determine L ad and L aq in henrys right.

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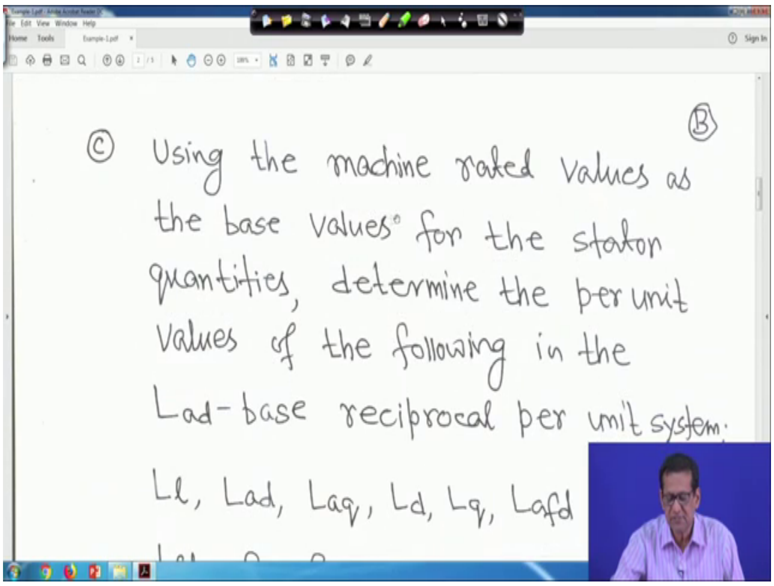

And ~~e~~ see using the machine rated values as the base values for the stator quantities, determine the per unit values of the following in the L ad base reciprocal per unit system.

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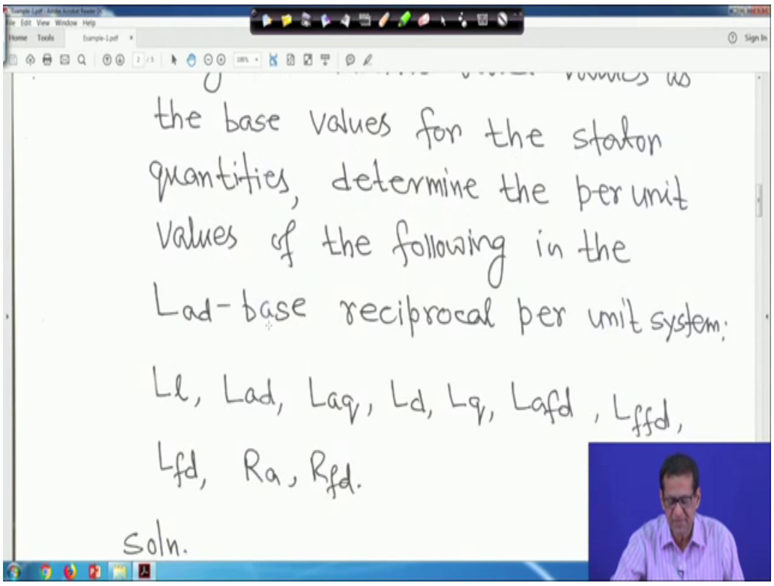

Then L l L ad L aq L d L q L afd L ffd L fd R a and R fd all these things we have to find out in per unit right. So, this is the problem.

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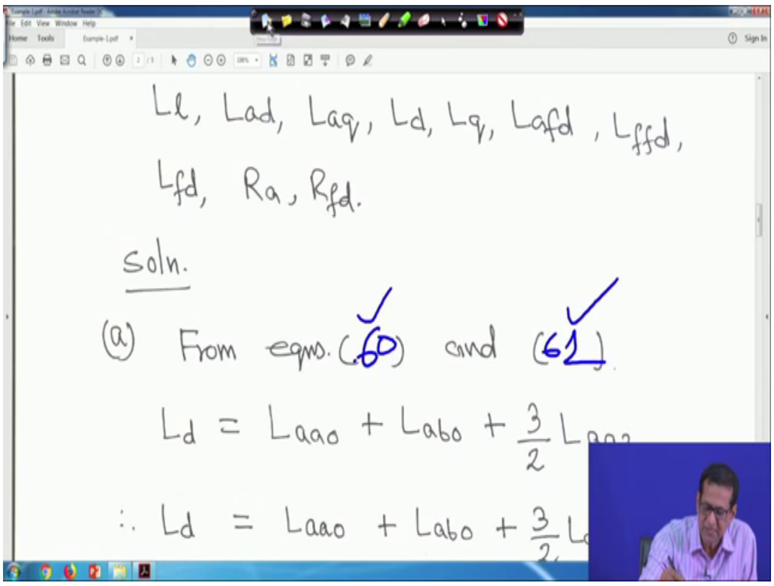

Now, solution from equation here number I forgot to write, but I am writing it from equation this will be equation 60 and this will be equation 61 right. So, this is equation 60 and this is equation 61 right. So, L d is equal to L a a 0 plus L a b 0 plus 3 by 2 L a a 2 right. So, this is actually coming from equation 60 please go effect to 60, you will get this right. So, this is equation 60 and this is equation 61. So, let me clear it. So, this blank is given this 60 and 61.

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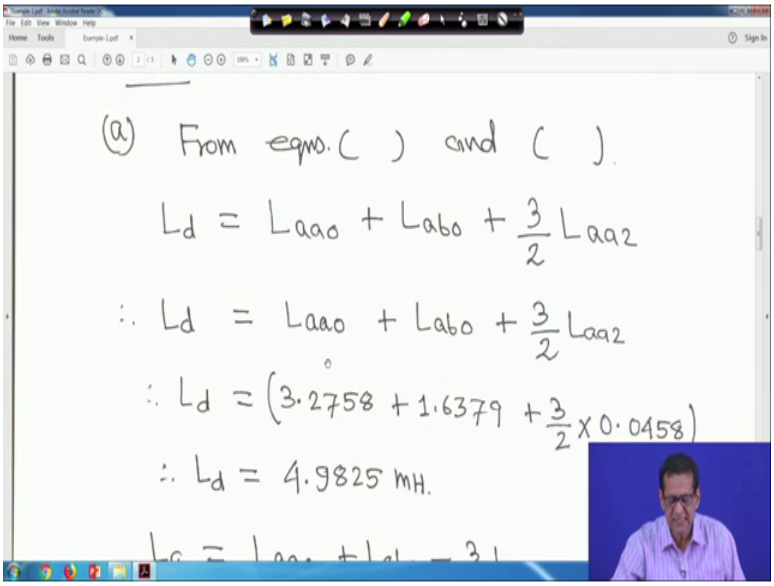

So; that means, L d is equal to L a 0 plus L a b 0 plus 3 by 2 L a 2 right. Now, ~~now~~ from this from this data from the from this from this data only just go back to that equation 60 and see the all the quantities there. So, what you will get that this one L a a 0 3.2758, then L a b 0 1.6379 and then 3 by 2, then L a a 2 0.0458. So, just directly you substitute if you do so, you will get L d is equal to 4.9825 milli H~~h~~enry right.

So, yeah I mean if you come to that yeah your what you call L a a 0, then your L a b this thing is given a b 0 all these things are given. So, from that directly you can substitute right. So, that is why we are making it that your lab this L a b 0, then plus C by 2 into 0.0458 right. So, all these parameters are given from that equation.

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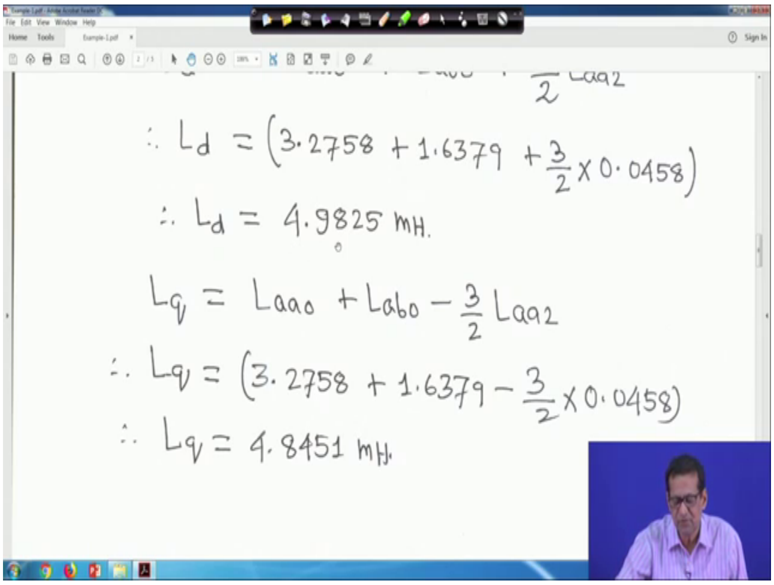

So, you will get L d is equal to 4.982 milli Henry all right. Similarly, L q is equal to L aa 0 this is from equation 61. So, L a a 0 plus L a b 0 minus 3 by 2 L a a 2, because these already we have derived right this is from equation 61 right substitute this value. So, 3.2758 plus 1.6379 minus 3 by 2 into 0.0458. So, L q is equal to 4.8451 milli Henry right. .

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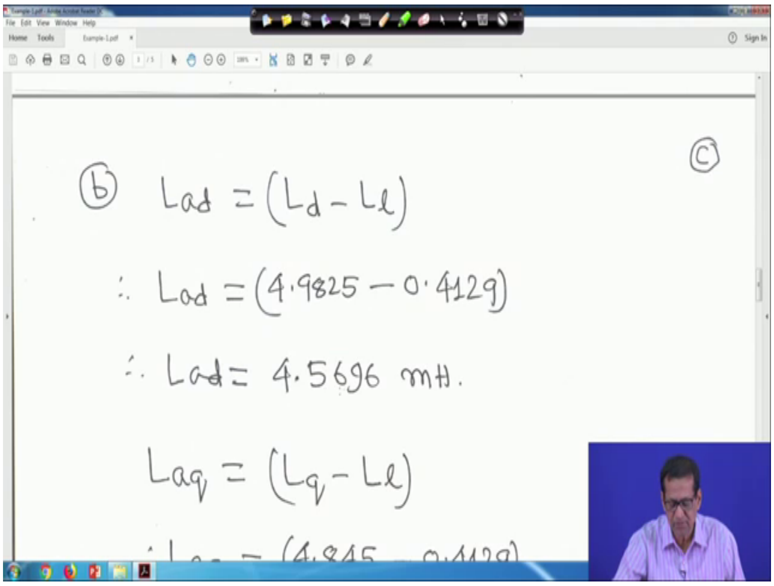

So, this is L q now, part b. Part b it has been (Refer Time: 15:53) find out your L ad and your L a q L a d is actually is equal to L d minus L l these already we have seen.

Therefore, L ad is equal to 4.9825 minus 0.4129. So, L ad is equal to 4.5696 milli Hhenry right. Similarly L aq is equal to L q minus L l.l Sso, L a q is equal to L q is 4.845 minus this L l 0.4129. So, this is L aq is equal to 4.432 milli Hhenry right, straight forward only you have to put the put put those data in the formula right.

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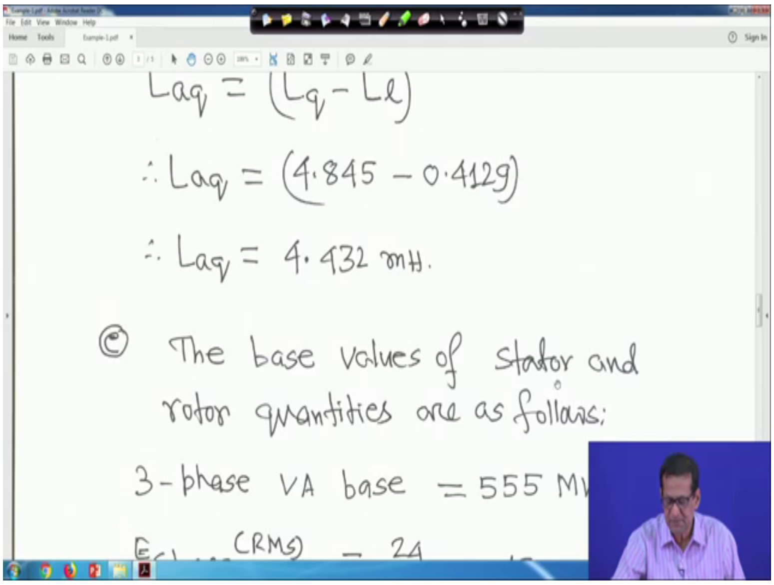

Now, the base values of stator and rotor quantities are as follows.

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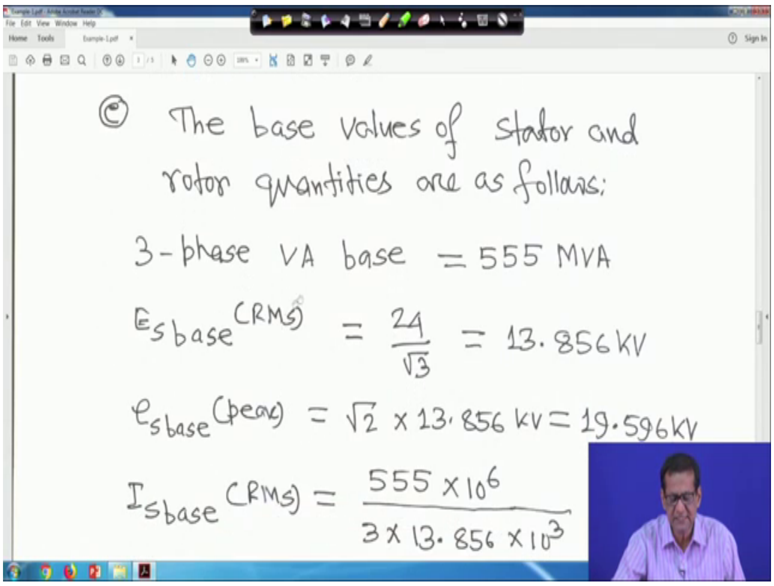

Actually it is 3 phase it is given 3 phase volt ampere base, we can take 555 MVA right. Now, E s base that is the RMS value that is your machine base voltage you have to take.

So, RMS value 24 if 24 KV it is given. So, 24 by root 3 so, it will be 13.856 KV right.

So, now e s base that is your peak ~~peak~~ 1 right. So, small e s base peak 1 the all ~~all~~ these terminology had been defined before it will be root 2 into 13.856 right. So, that is your 19.596 KV right. So, this is your e s base small e s base p.

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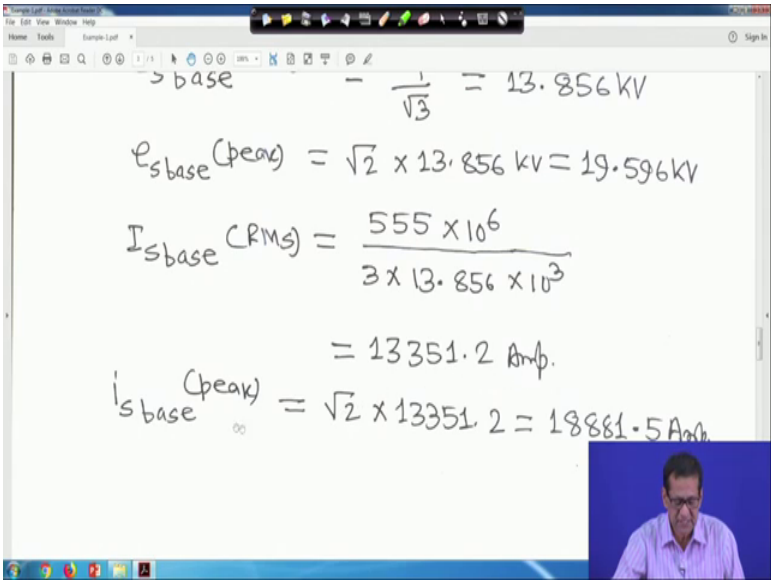

Now, i s base RMS will be this is MVA base 555 into 10 to the power 6. So, volt ampere divided by your this is your 3 into 13.856 into 10 to the power 3, because it is 3 phase 3 your 3 phase MVA. So, that is why multiplied this 1 by 3 right. So, 3 into 13.856 into 10 to the power 3. So, that is coming around 13351.2 amps right. Similarly, i s base peak will be is equal to root 2 into this value 13351.2. So, it is 18881.5 ampere right that is i s base peak.

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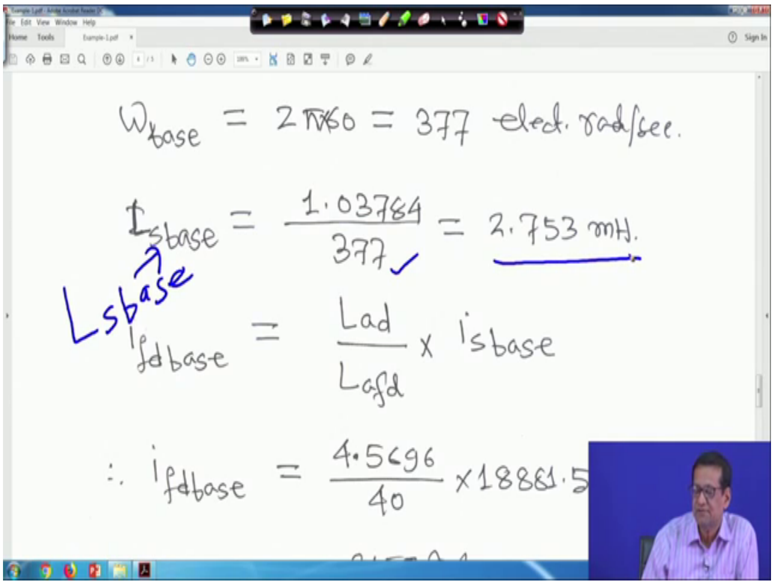

Now, therefore, Z s base Z s base will be ~~if you~~ if you look into that, the Z s base will be your this thing we got your 13.856 into 10 to the power 3 divided by your 13351.2 right. So, this is 13351.2 and this ~~e~~ E s base is 13.856 right. So, 13.856 into 10 to the power 3 upon 13351.2, it comes around your this is actually one dimension error is there. So, this is actually Z s base it is actually ohm right by mistake I put it ampere it is ohm right, because this is Z s base right so, this is your ohm.

Now, omega base is equal to 2 pi into your f base, that is this is your 60 hertz right. So, that is 377 electrical radian per second right. So, this is ohm so, therefore, ~~i~~ L s base is equal to your then 1.03784 divided by 377 right. So ~~so~~, a sorry L s this is this is L s base not i s base L s base right, because Z is equal to L s general in dimension ohm is equal to L into omega. So, this is L s base.

So, let me let me make it this is actually L s base right, this is L s base is equal to what Z s base that is 1.03784 divided by frequency base 377. So, 2.753 milli H~~h~~enry.~~;~~ N~~n~~ow from this formula we know now let me clear it. So, i fd base is equal to L ad upon L afd into i s base. So, L a d is equal to 4.5696 divided by your 40 into 18881.5 right. ~~so~~So, that is your 2158 ampere right.

Similarly, e fd base this is your base MVA your what you call pi pi pi into 10 to the power 6 volt ampere and divided by this i fd base, here it is 2158 this is actually 257.183 kilo volt that is e fd base now, Z fd base will be now e fd base upon i fd base.

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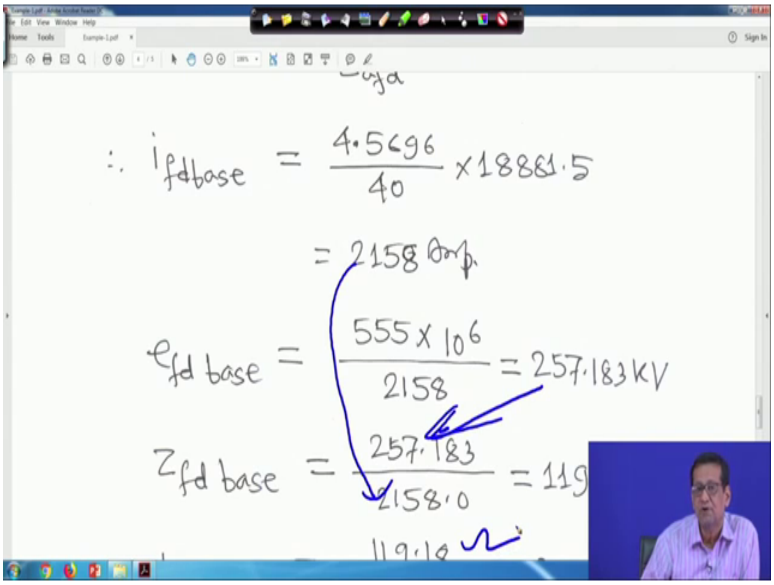

So, this is your so, e fd base is this one this is your 257.183 and i fd base is 2158.0 this is your i fd base right is equal to 119.18 ohm right. So, that is 119.8 your ohm right. So, this is Z fd base.

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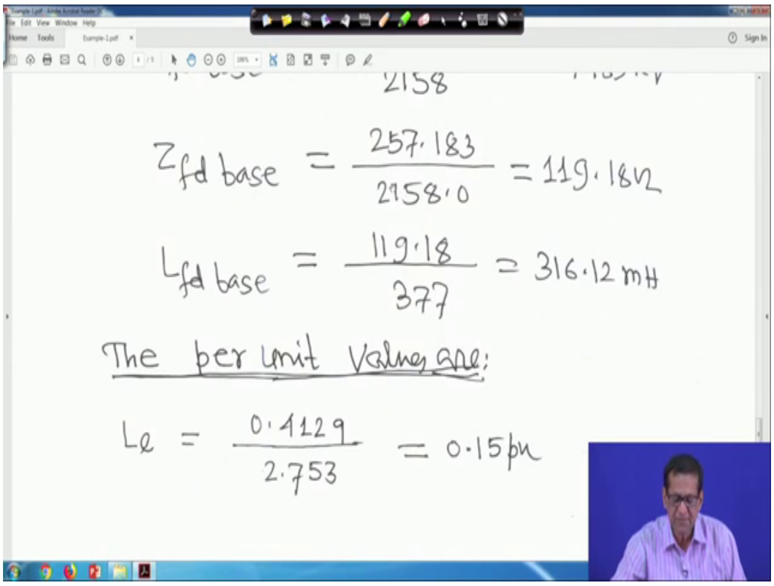

So, then L fd base will be now simple Z fd base upon omega. So, it is the 119.18 upon 377 is equal to 316.12 milli H~~h~~enry right. Now, all these base quantities now we have determined just ~~just~~ you have follow step by step, that how to determine all these things now the per unit values are therefore, L l will be is equal to 04129 divided by 2.753, because your here it is L s base is equal to 2.753 milli Hhenry.

So, therefore, your it will be 0.4129 divided by 2.753 so, 0.15 per unit right. Similarly L ad will be 4.5696 divided by 2.7, because L s base is 2.753 so, that is 1.66 per unit right.

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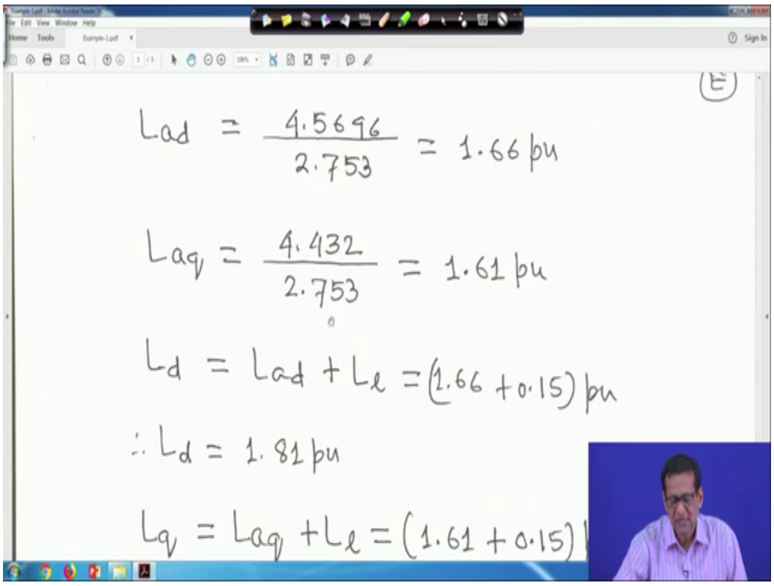

Similarly, L aq is equal to 4.432 divided by 2.753 that comes around 1.61 per unit right and we know L d is equal to L ad plus L l right. Therefore, it is 1.666 plus 1.66 plus 0.15 per unit. So, it is L d is equal to 1.81 per unit right. And L q is equal to L aq plus L l is equal to 1.61 plus 0.15 L q is equal to 1.76 per unit right.

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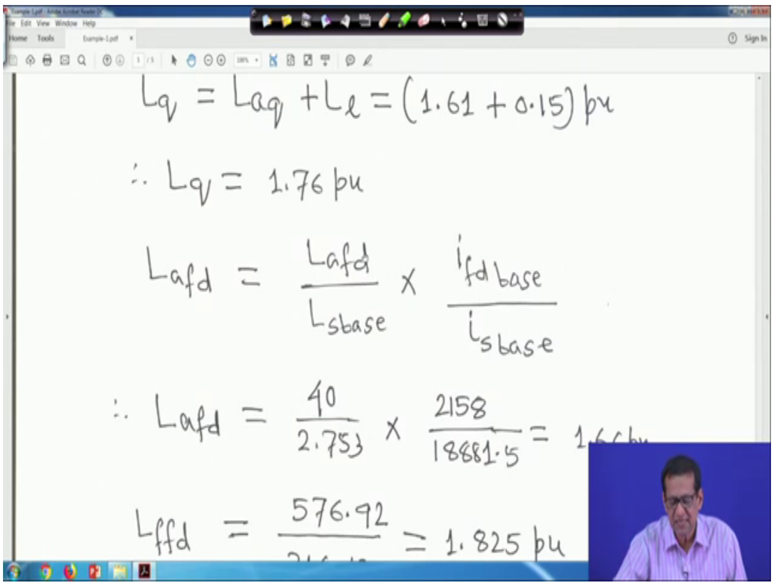

Therefore we know that L fd is equal to L afd upon L s base into i fd base upon i s base, these all these things have been derived. So, just we are just we have to put these values.

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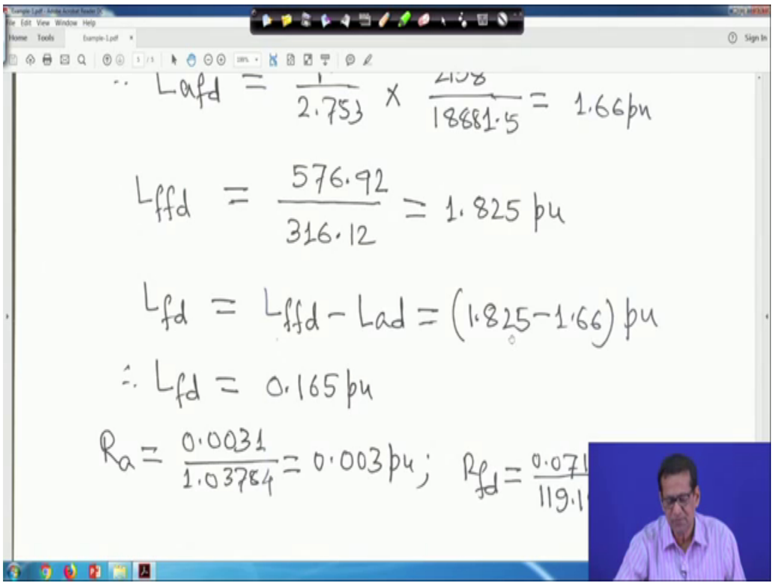

So, so 40 upon 2.753 into i fd base 2158 divided by 18881.5 is equal to 1.66 per unit right.

Similarly, L ffd is equal to 576.92 divided by 316.12 that is 1.825 right. So, directly I mean directly you can your what you call, just using this formula you can easily get all these things right. Similarly L fd is equal to L ffd minus L ad right is equal to 1.825 minus 1.66. So, L fd is comes coming around 0.165 per unit.

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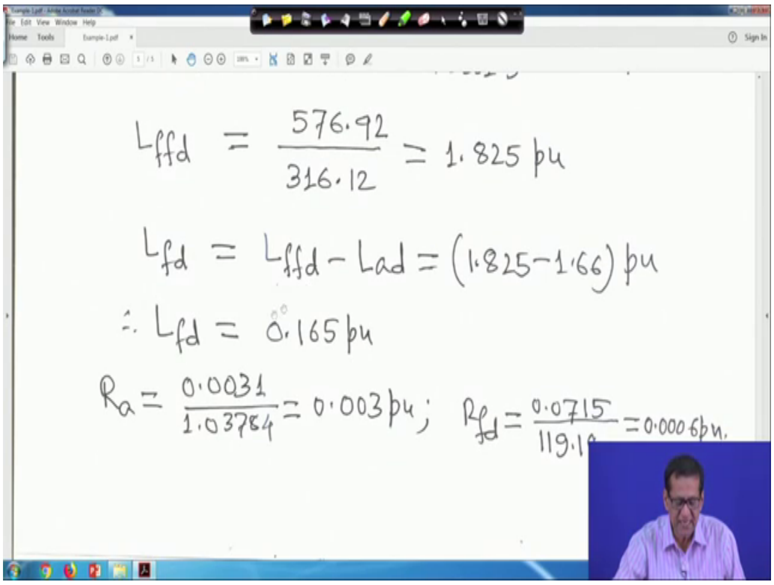

Similarly, your R a R a was given 0.0031 that is ohm and divided by the base base value that 1.03784 for it comes 0.003 per unit. And similarly R fd is equal to 0.0715 divided by 119.18 that is point triple naught 6 per unit. So, this is actually this problem had been taken just to see that how to solve that your per unit, transform the quantities to per unit value right.

So, that is why this problem has been taken although, although what you can do is read the problem very carefully. And then all these data are there just you step by step you follow that determine all these things and then you find out the base values, and then convert all these quantity to the per unit values right just hold on so, just hold on. So, now just hold on. So, all these things your what you call per just 1 minute just hold on.

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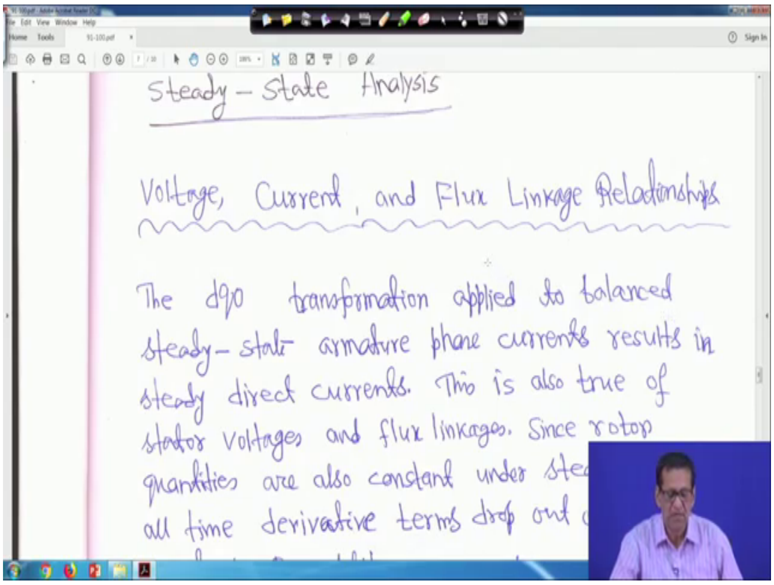

Let me go back to a steady state analysis from here we will start, steady state analysis. Now so, voltage current and flux linkage relationship, now we will come to the steady state analysis and after that we will go to the dynamic analysis, little bit your study is required first steady state analysis right.

So, voltage current and flux linkage relationship right. So, the dq 0 transformation applied to balance steady state armature phase currents result in, steady your direct current right. This is also throughout the stator voltage and flux linkages this we have seen right.

Since rotor quantities are also constant under steady state, all time derivative terms drop out of machine equation, because a steady state that any term attached with p that is d by dt that is dot right, all these things will be dropped right because a steady state goes down to 0. So, in addition in addition 0 sequence components are absent and omega r is equal to omega s is equal to 1 per unit, because steady state that your what you call synchronous speed and your omega s is equal to omega r right.

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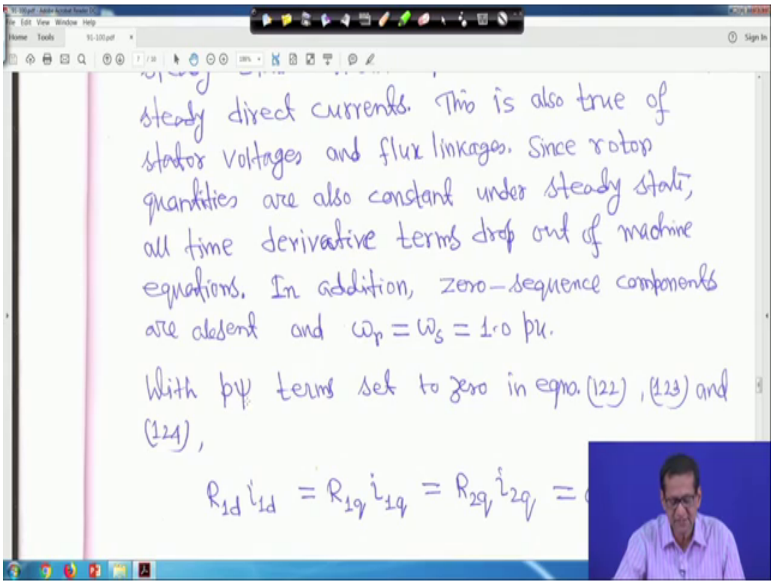

So, with p psi that is your all these dot psi dot terms right, set to 0 in equation 122, 123 and 124.

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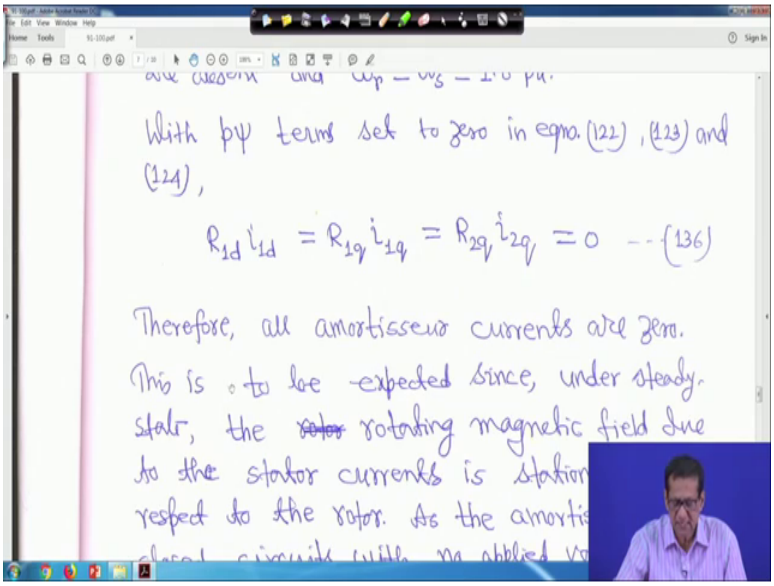

In that case if you do so, in that case all these your what you call this R 1 d i 1 d is equal to R 1 q i 1 q is equal to r 2 q i 2 q all will become 0, this is equation 136; that means, at steady state all the all the terms are dropped right. So, I mean that is dot term that is p psi terms are dropped right, that is psi dot because steady state psi dot is 0. So, therefore, all amortisseur currents are 0.

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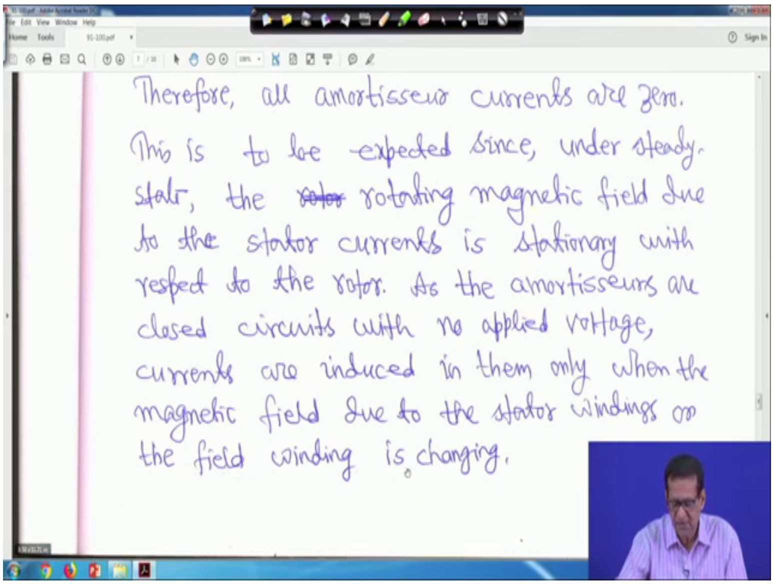

This is to be expected since under steady state, the rotating magnetic fields due to the stator, current is stationary with respect to the rotor right. So, as the amortisseurs are close circuits with no applied voltage currents are induced in them only, when the magnetic field due to the stator windings of the ~~or the~~ field winding is changing. Otherwise if it is steady state if it is not changing; that means, that those your d psi by dt term is there right. So, that is why we have written this equation these all these things becoming 0 right and we are dropping psi dot term.

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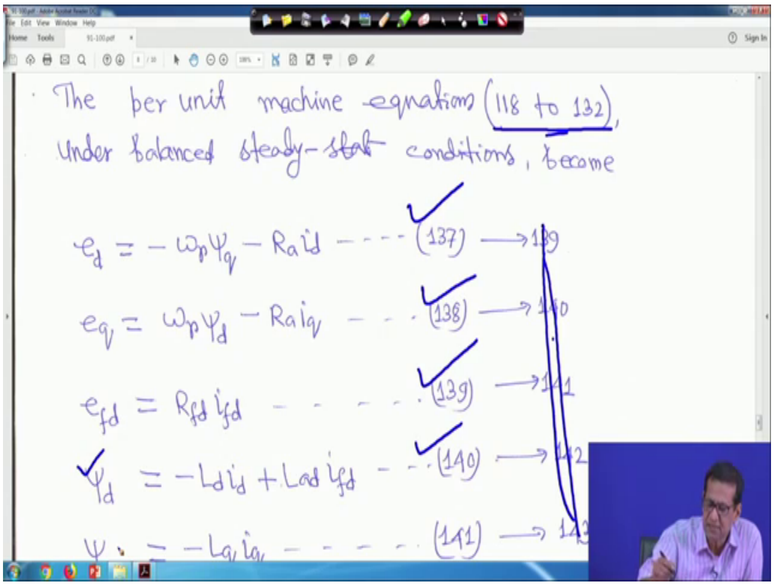

So, that means, the per unit machine equation that is from 118 to 132 under balance steady state condition it becomes like this right.

So, it is your this side you should this side you should this is from equation 118 to 132 all these case that p psi term. So, drop if you drop I rewrite those equations this should not be seen should not be seen. So, e d will become minus omega r psi q minus R aid all these things are in per unit right. So, this is equation 137.

Similarly, e q is equal to omega r psi d minus R a iq so, this is actually equation 138 right and similarly e fd is equal to R fd i fd this is equation 139 and psi d is equal to your minus L d i d in plus L ad i fd, this is equation 140 right. Similarly just one psi q is equal to just let me move it up.

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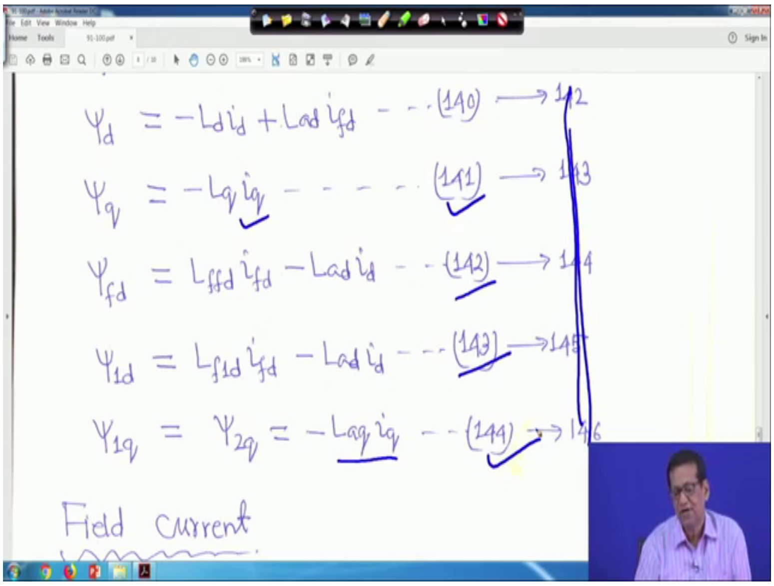

Similarly, psi q is equal to minus L q i q this is equation this should not be same this should not be same right.

Similarly, psi fd is equal to L ffd i fd minus L ad I d this is equation 142. Similarly psi 1 d is equal to L f 1 d i fd minus L ad I d this is equation 143. Similarly psi 1 q is equal to psi because we have assumed that 2 amortisseurs are there on the q axis. So, psi 1 q is equal to psi 2 q is equal to minus L a q i q this is equation 144 right. So, leave this right hand side this thing we should not see.

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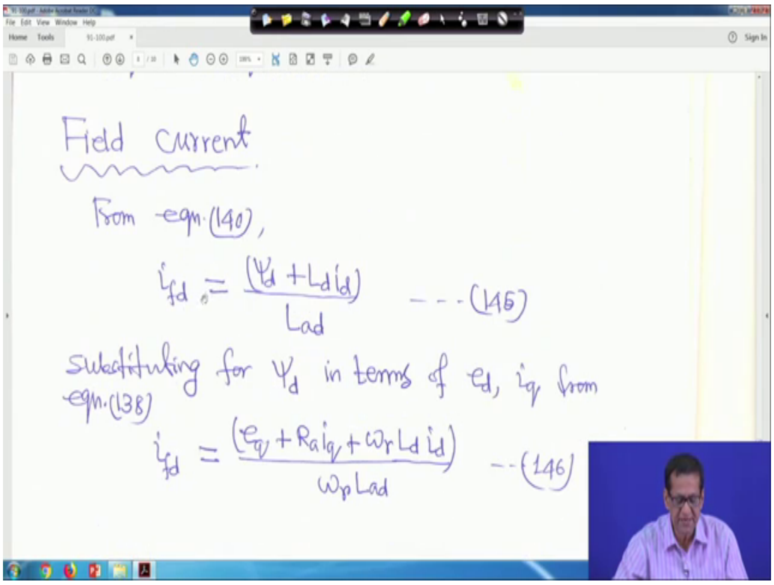

So, now, filed current from equation 140 I mean from this equation from this psi d is equal to minus L d id plus L ad i fd from this equation from equation 140 right. So, you can write that i fd is equal to your psi d plus L d id upon L ad that is the equation 145. Now, substituting for psi d in terms for e d i q from equation 138 right, if you come to your 138, whatever 37 38 e d e q whatever is given if you substitute you will get this expression of i fd that is e q plus R a i q plus omega r L d i d divided by omega r L ad, this is equation 146 right.

Thank you very much we will be back again.