Fundamentals of Electrical Engineering
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Lecture – 56
Single Phase Transformer (Contd.)

So, we are back again so, this is another example right.

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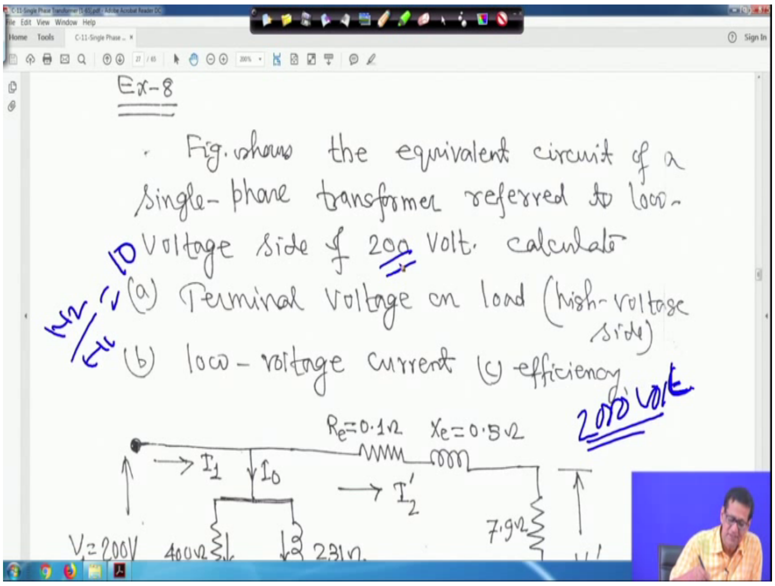

So, this figure if I actually the figure I will show you figure shows the equivalent circuit of a single - phase transformer referred to low-voltage side of 200 volt. Calculate the terminal voltage or load that is on high-voltage side, low-voltage current and the efficiency right. So, in this problem one thing actually one thing is that the low-voltage side is 200 volt. Actually high-voltage side 2000 volt right; high-voltage side is 2000 volt. So, it is not written here, I have missed it here so, high-voltage side you take 2000 volt; that means, you are; that means, you are N 2 by N 1 is equal to it will be 10 right.

So, that because N 2 by N 1 is equal to V 2 by V 1 say so, this will be your 2000 divided by 200 so, it will be your 10 right. So, based on that we will move so this is the circuit diagram that (Refer Time: 01:23) it is refer to low-voltage side.

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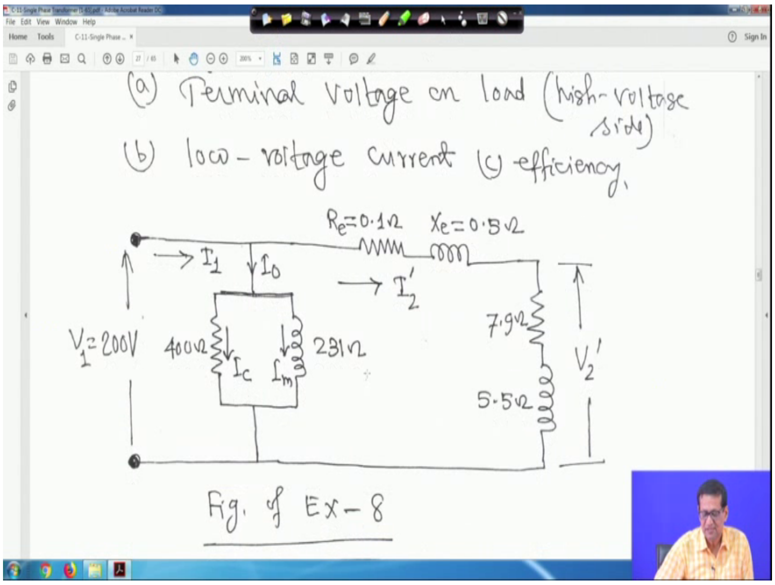

So, this equivalent circuit of this one for mathematical derivations, we have seen earlier. So, this low-voltage side voltage look at the cursor that two 200 volt. So, this core less component resistance is given 400 ohm and magnetising component it is given 231 ohm this is the current I 0. Current flowing through this is I c and through this branch is I m.

It is something like your solving apart from this transistor and other solving like a series parallel circuit, though we have done it for a single phase and this is R e 1 that is 0.1 ohm and X e is equal to 0.5 ohm and this is the current I 2 dash flowing in the your primary side and I 1 is equal to I 0 plus I 2 dash and this is that your 7.9 ohm resistance and 5.5 ohm reactance that is that your what you call inductive load, it is referred your primary side low-voltage side and voltage across the load is V 2 dash. Earlier we have seen is V 2 dash is equal to k V 2 we have already show seen it, but these are all for mathematical derivation right.

So, all these parameters are given. So, we have to find out the terminal voltage on high-voltage side that is V 2 then low-voltage low current that is I 1 and the efficiency right so, that is the that we have to find it out. So, now, I m is equal to it is a parallel circuit so, I m is equal to 200 by 32, 31 whatever it will come and I c will be your 200 by 400 right so, this is a parallel circuit.

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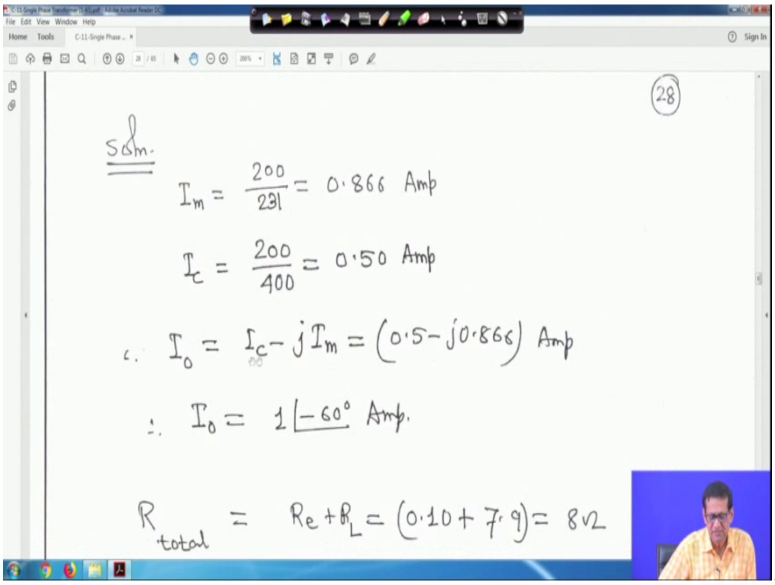

So, I m is equal to 200 by 231 so, 0.866 ampere and I c is equal to 200 by 400. So, 0.5 ampere and we know that I 0 is equal to I c minus j I m right. So, it is 0.5 minus j 0.866 ampere. So, it is actually your I 0 is equal to magnitude will be 1 and angle will be minus 60 degree ampere.

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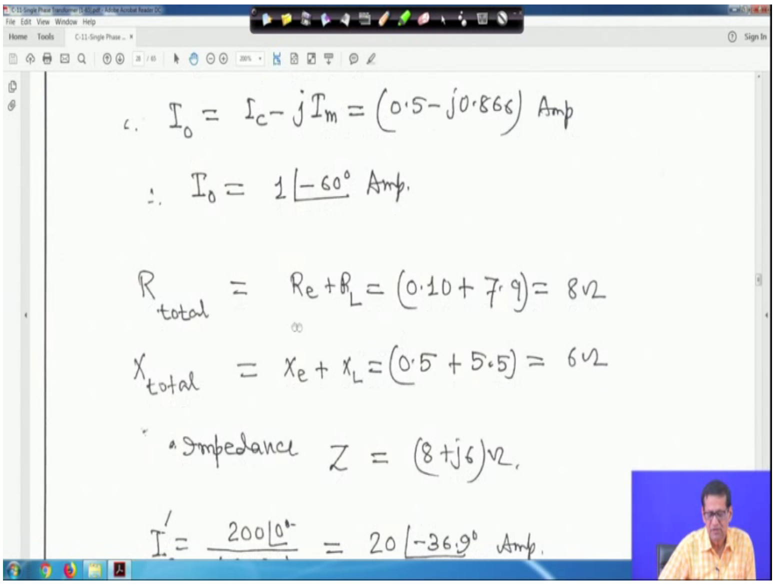

Now, total load that this side if you take that total resistance that R e is given 0.1 and X e is equal to 0.5 ohm, where here your R L dash 7.9 and X L dash 5.5 ohm. So, from the primary side that R total will be R e plus R L here I am writing R L right. So, 0.1 plus 7.98 ohm and X total will be X e plus X L just see the addition so, it will be 6 ohm.

Therefore, impedance Z will be 8 plus j 6 ohm. Therefore, I 2 dash will be that V 1 the voltage your what you call that low-voltage side, this is the reference voltage we have taken. So, 200 angle 0 degree upon 8 plus j 6 so, it will come 20 angle minus 36.9 degree ampere. Therefore, I 1 is equal to first part I 2 dash plus I 0 right here in the circuit, here you apply your KCL, I 1 is equal to I 0 plus I 2 dash right.

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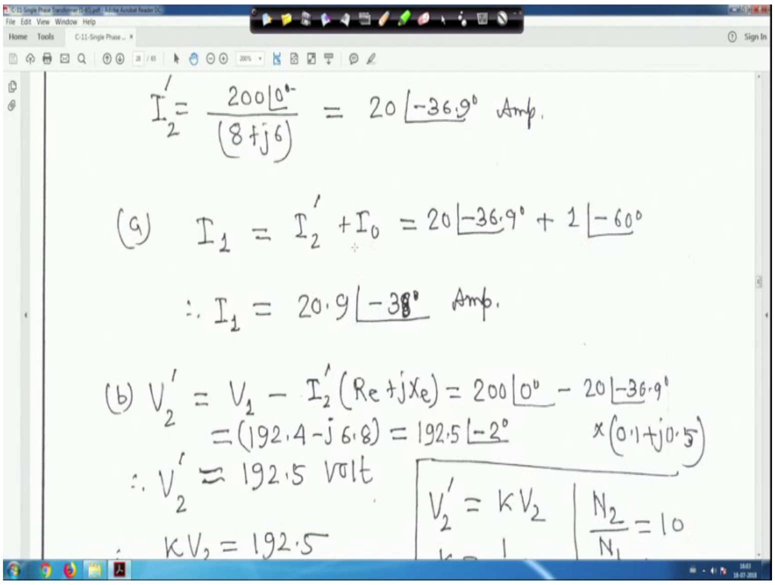

So, your if you do so, it will come I mean substitute I 2 dash and here it is I 0. So, it will become 20.9 angle minus 38 degree ampere right.

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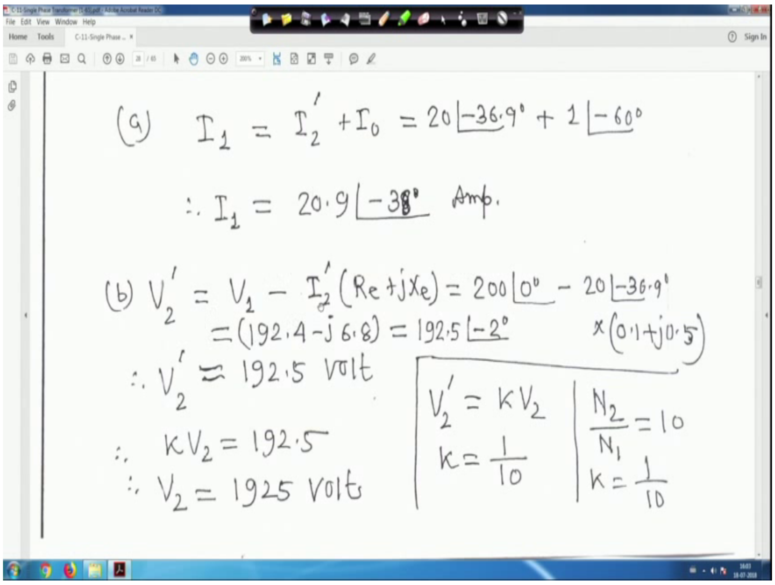

Now, V 2 dash will be V 1 minus I 2 dash R e plus j X your j into X e 1; that means, here in this circuit what you call you apply here in this circuit you apply your this thing, k or KVL right.

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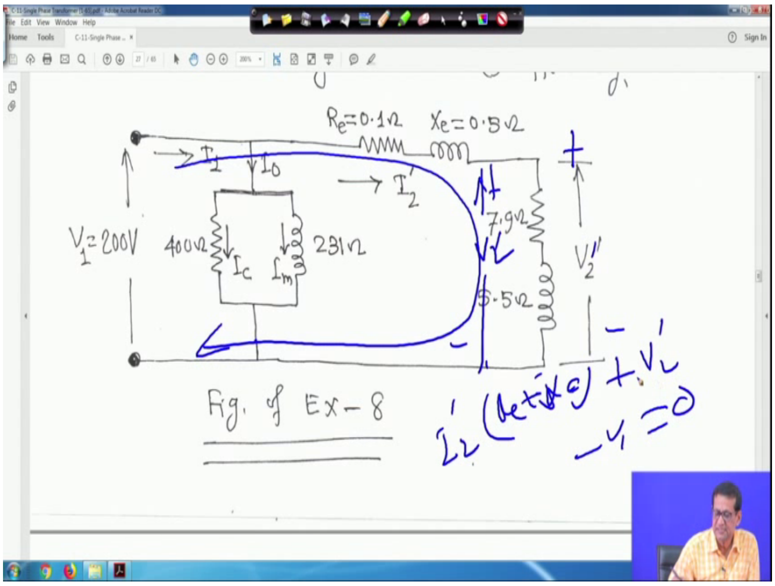

So, in this case this is the current I 2 dash; I 2 dash into your R e plus j X e and this is the voltage plus minus. So, plus V 2 I mean this is the voltage same thing this is the V 2; V 2 dash rather V 2 dash right so, this is plus minus. So, plus V 2 dash minus V 1 equal to 0 so, you apply KVL, same thing is same thing we have applied there right.

So, that means, that is V 2 dash is equal to V 1 minus your if you take I 2 dash into R e plus j X e 1 right. So, in that case it will become 200 angle 0 minus 20 angle minus 36.9 right into that your R e 1 is 0.1 plus j 0.5. If you simplify, it will become V 2, V 2 dash will become here it is 190; 190 192.5 angle minus 2 degree right and that magnitude of V 2 dash will be 1925 volt. And earlier we have seen V 2 dash is equal to k V 2 and N 2 by N 2 1 I told you this 10 because, high-voltage side voltage is 2000 volt, I miss that one it was not written there.

So, K is equal to 1 upon 10. So, K V 2 is equal to V 2 dash because V 2 dash is equal to K V 2. So, V 2 will be 1925 Volt right and your what you call that angle of V 2 dash is minus 2 degree right. So, similarly your what you this is your what you call? So, magnitude of V 2 1 1925 volt and next is the efficiency. So, when will find the efficiency right, output is V 2 dash I 2 dash cos phi by phi 2 right.

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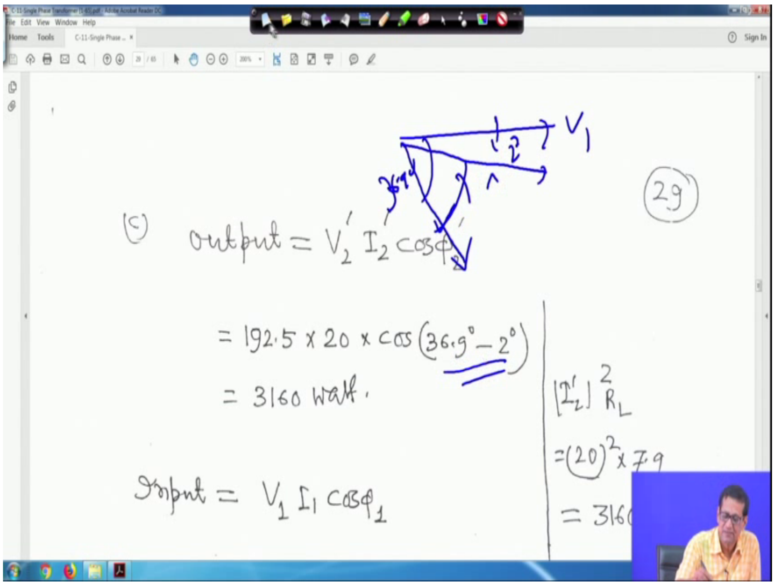

So, V 2 dash your if you look into the circuit; if you look into the circuit that cos phi 2 dash actually angle between the this voltage V 2 dash difference of the angle between the your angle of I 2 dash and your angle of your V 2 dash right. So, if you look into this that V 2 dash I 2 dash cos phi 2. So, V 2 dash is 192.5, I 2 dash 20 magnitude and cos your angle of I 2 dash 36.9 and V 2 dash was your minus 2 degree right.

Here, we are here we have your what you call V 2 dash is minus 2 degree and here it is your where is I 2 dash is minus 36.9 degree right. So, in this case, so, it will be difference only, it will be cos minus theta cos theta; both are lagging, I mean if you take the reference, this is my reference. This is my V 1 reference so, one angle is 30, this angle is 36.9 degree and another angle is this angle is 2 degree. So, this is the angle right so, it will be 36.9 minus 2 there is a power factor angle. So, that is why 36.92 minus 2 degree right.

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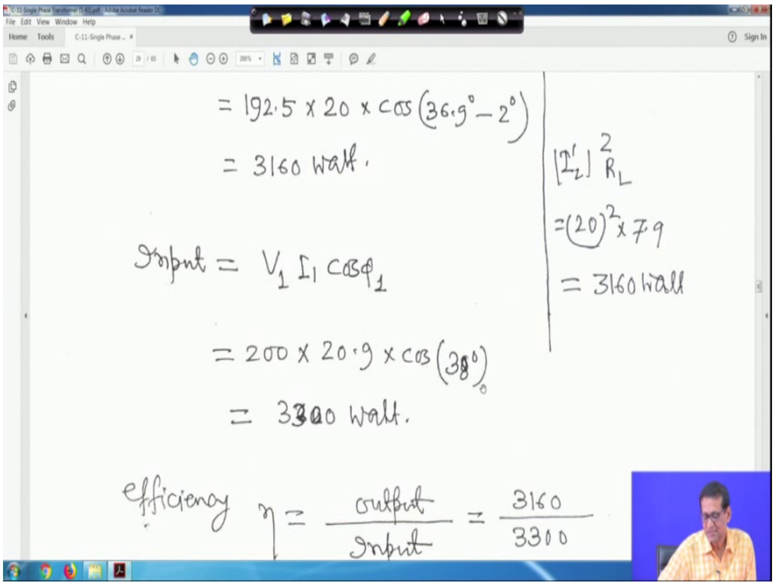

So, that is why it is coming your what you call 3160 watt right. At the same time if you see this the output, at the same time if you make I 2 dash square R L because this is a load power. This power is actually consumed by the load if you look into that 20 square into 7.9, it is 3160 watt so, your answer is correct right.

Now, input power is input that low-voltage side V 1 current is I 1 cos phi 1. So, V 1 is your low 200 volt, I 1 we compute 200 your 20.9 and phi 1 will be your 30 or your what you call that angle V 2 your I mean if you come to the angle of I 1 here minus 38 degree and V your that V 1 angle is 0, it is reference phase. So, it is cos 38 degree so, that is why it is cos 38 degree, it is 3300 watt.

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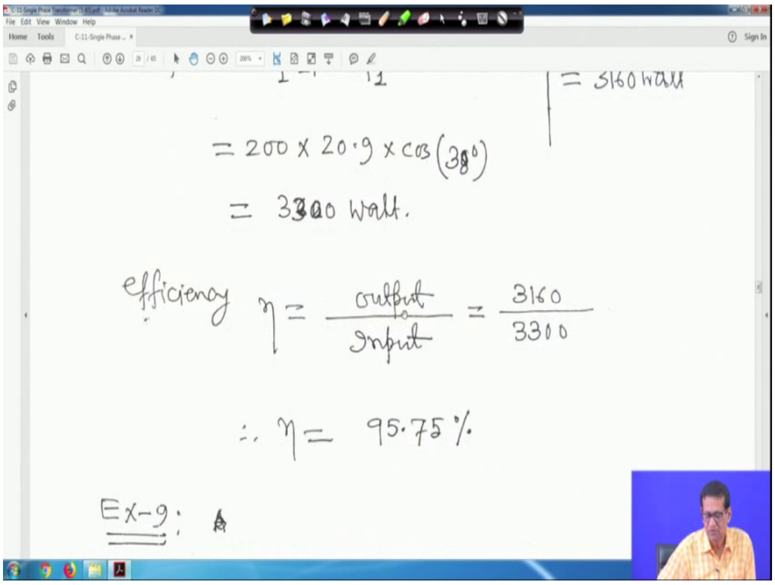

So, efficiency will be output by input so, 3160 upon 3300 so, 95.75 percent right. So, this is the efficiency of the transformer; transformer efficiency actually is very high right.

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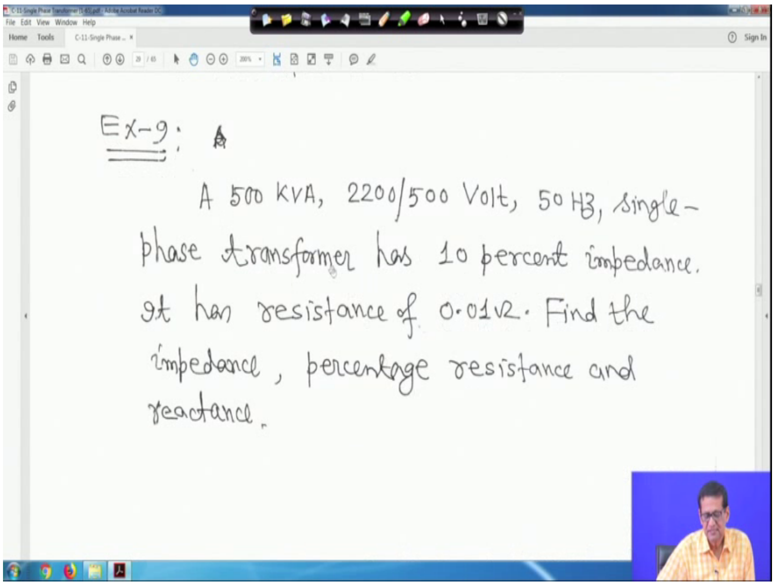

So, another one is that is 500 KVA, this is a full-load rating right 500 KVA transformer 2200 your 500 volt. So, high-voltage side 2200; low-voltage side is 500 volt, 50 hertz frequency is 50 hertz. Single phase transformer has 10 percent impedance, 10 percent means it is dimensionless; that means 0.1, I will show you how you can do it right. It has resistance is given; it is resistance is given 0.01 ohm.

You have to find out the impedance value, percentage resistance and percentage reactance. But it percentage your what you call impedance is given 0.10 so, how 0ne can do it? Just listen carefully that how you can do it. So, because similar type of problem later you will get it so, one can do it very easily right.

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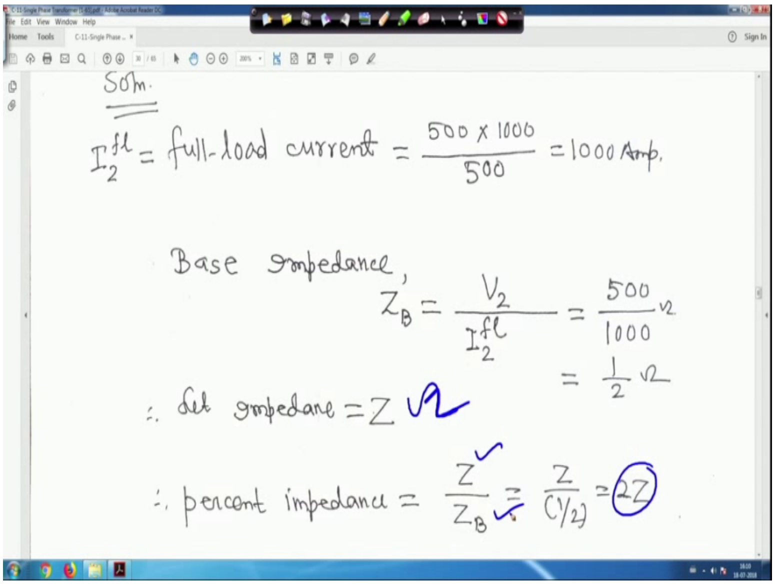

First you find out the full-load current because, this is your what you call full-load KVA 500 KVA (Refer Time: 09:42) KVA. So, this is 500 into 1000 so volt ampere and divided by 500 volt, the low-voltage side right. This is full-load current at the low-voltage side because 500 volt on the low-voltage side right. So, similarly if you want high-voltage side, you can divide by your what you call you can divide by 2200. But (Refer Time: 10:02), we are trying to find out at the low-voltage side so, it is 1000 ampere right.

Therefore, base impedance will be Z; it is called Z B when base impedance right, It will be V 2 by I 2 f l. So, low-voltage side voltage is 500; this is rated voltage and full-load current is 1000 ampere. So, this is my base impedance right, based on that percentage is determined actually; percentage resistance, percentage reactance, percentage impedance is determined. So, this is my Z B is equal to V 2 upon I 2 f l so, 500 by 1000 so, half ohm. Now, let impedance is Z right; therefore, percentage impedance will be Z upon Z B.

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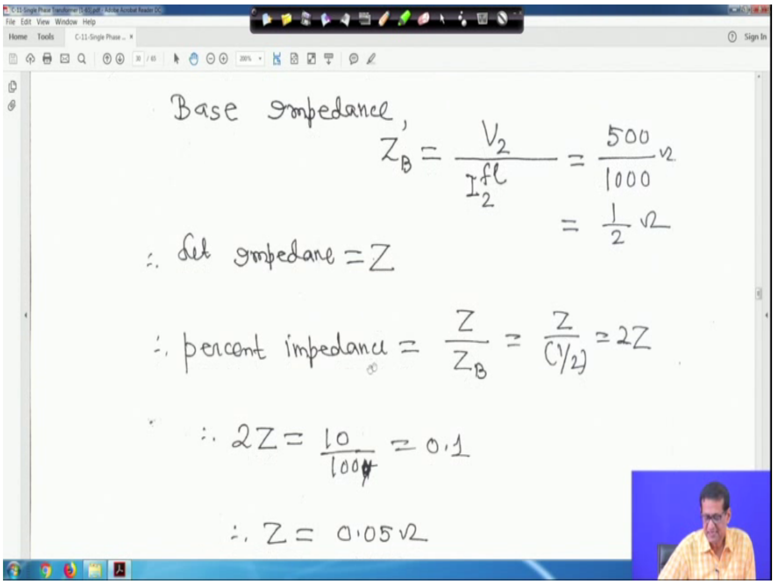

If you assume transformer impedance is Z, then Z by Z B will be your percentage impedance. It is dimensionless quantity, where this Z in ohm this Z base is also ohm. So, Z by Z B is a dimension less quantity so, it will be Z divided by Z base is half. So, 2 Z say in this case and it is given base impedance is given 0.1 that is that means, percentage impedance actually given 0.1, so, 2 Z is equal to 0.1.

Therefore, Z is equal to your what you call you find out 0.05 ohm because, here impedance is let impedance is Z right. So, this actually this is actually Z ohm, it is ohm right and this is ohm, this is ohm. So, it is a dimensionless quantity. So, 2 Z is equal to 0.1 so whatever value you will get that is Z actually in ohmic value so, 0.05 ohm.

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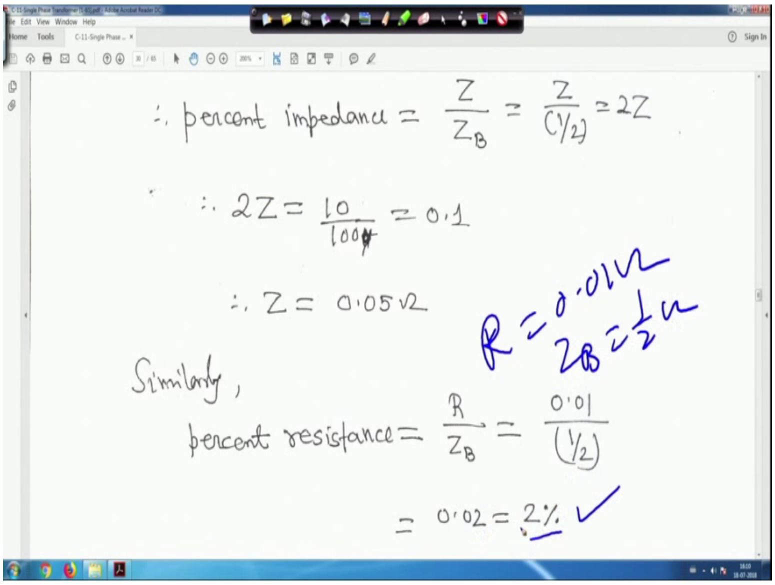

Now, percentage resistance you know that R upon Z B right. So, percentage; so, R is given 0.01 ohm right. So, because this R 1 actually this R actually it is given 0.01 ohm and Z we have got it half ohm. So, this is actually percentage resistance is 2 percent right 0.01 by half, so, 0.02 so, it is 2 percent right. And therefore, X is equal to your we know now X square just hold on.

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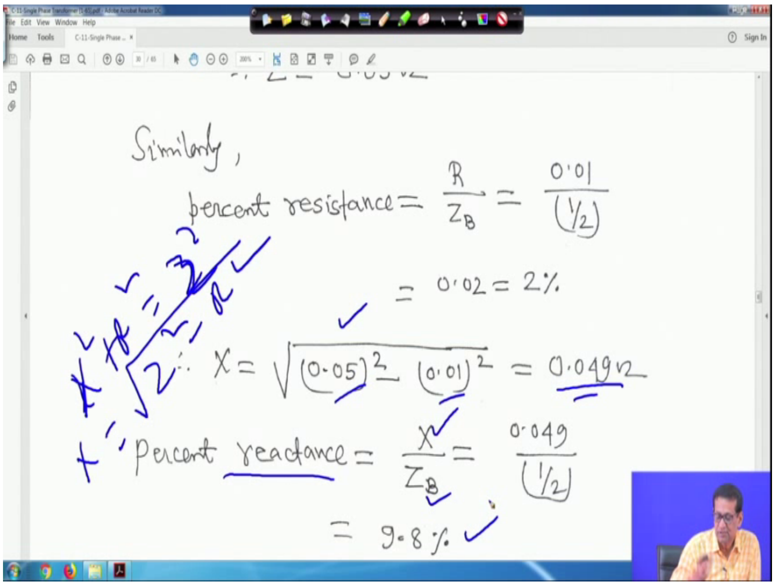

We know X square plus R square is equal to Z square right. Therefore, my X is equal to root over Z square minus R square that here it is used right. So, it is 0.05 and it is 0.01

so, you are getting 0.049 ohm that is X value and percentage reactance will be again divide by Z B because this is ohm; this is also ohm 0.049 by half so, it is 9.8 percent or 0.98 per unit right.

So, this is how one can calculate your this thing. This exercise you do it finding out your what you call that rather than low-voltage side full-load current you will find out that your what you call a high-voltage side full-load current. And base impedance and try to do it and see now what you get whether you gets identical thing or not right so, this is your this thing.

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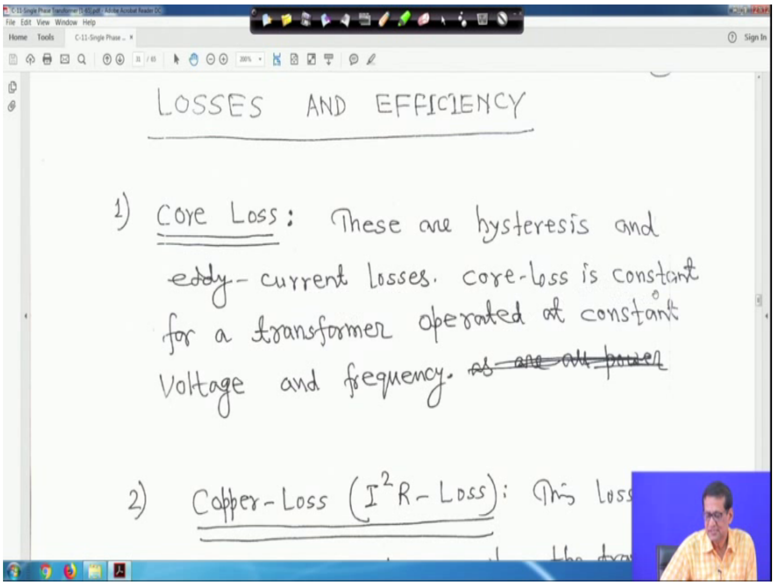

Now, Losses and Efficiency; so, in a transformer different types of losses are there, but what we will do actually we will come our main concern will be that iron loss that is core loss that is eddy current and hysteresis are together and the copper loss that is the I square R loss in the winding resistance right. So, core loss these are hysteresis and eddy current losses; core loss is constant for a transmission sorry transformer operated at constant voltage and frequency.

If voltage is constant frequency is constant so, core loss is more or less constant because we have seen eddy expression for eddy current and hysteresis loss. So, generally variation of voltage or frequency is negligible. So, we will consider that these loss is very basically constant core loss right and copper loss that is I square R loss right.

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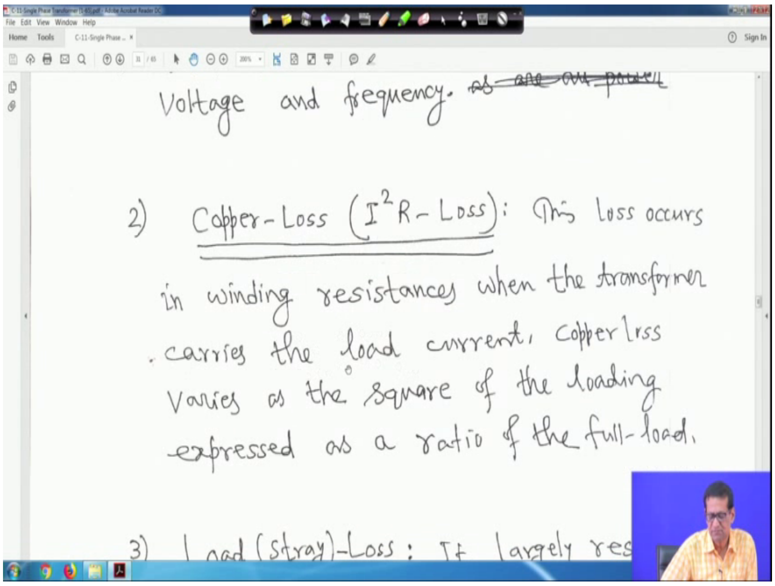

So, this loss occurs in winding resistances when the transformer carries the load current. So, actually transformer if load varies transformer current I varies, therefore, this copper loss is a variable loss right. All the time load is not constant; when the current is not constant therefore, this copper loss is a variable loss.

So, when the transformer carries the load current, copper loss varies as the square of the loading expressed as a ratio of the full-load. So, generally that your actually if I varies; therefore, your loading also varies right load also varies. So, sometimes you expressed as a square of square of the ration of the full-load rather right later we will see that.

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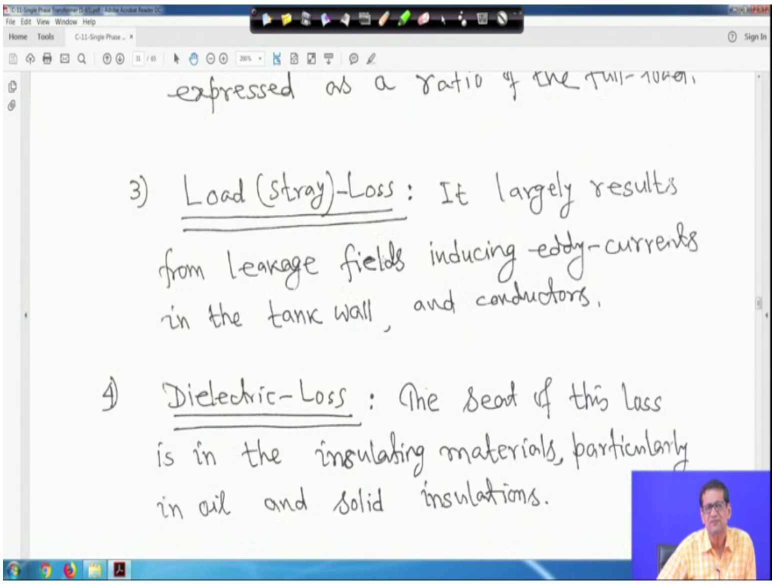

Now, other type of loss is which we will not consider in our study, but for our your general knowledge right sometime load or stray loss, we call. It largely results for your from leakage fields inducing eddy currents in the tank wall and the conductors right. Another thing is called dielectric loss; the seat of this loss actually is in the insulating materials particularly oil and solid insulators right insulations right.

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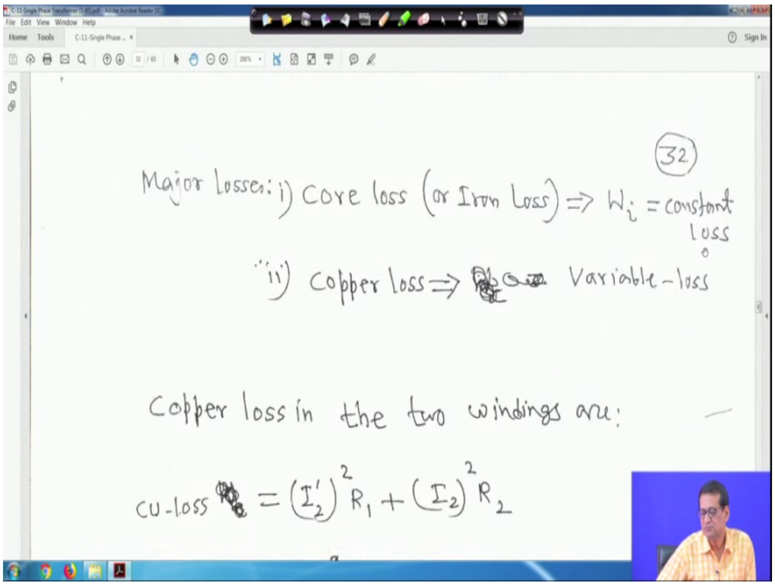

So, major losses, we will consider copper loss sorry core loss or iron loss that is W i, we will assume this is a constant loss because, we assume that voltage and frequency will remain constant.

Another is a copper loss it is a variable loss right because, if load changes, then your what you call that current changes so, it is a variable loss right. So, copper loss in the 2 winding transformer are I 2 square R 1 plus I 2 square R 2, I mean we have seen the equivalent circuit of the transformer and I am going back to 1 circuit right.

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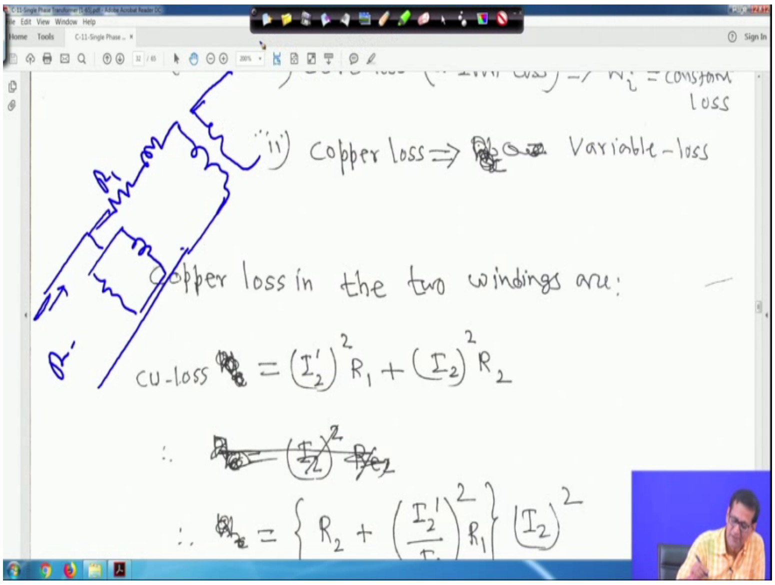

I am going back to 1 circuit that your copper loss in the transformer just hold right just hold on, we will go back to the circuit just hold on instead of drawing it, I will go back to that. Here right, not here when primary and secondary comes right here.

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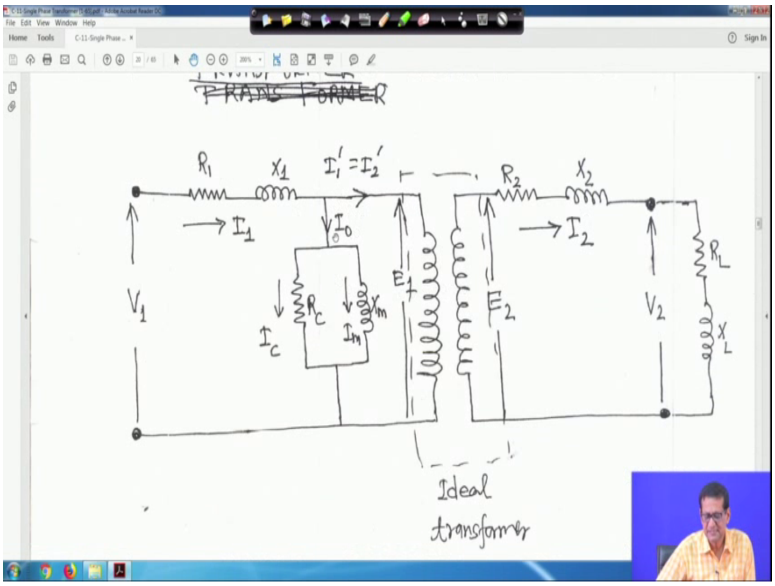

So, the this side actually this is taken to this side right I will hold on better just hold on I will draw it for you; I will draw it for you. Wait I have to search it again I will go back, I will draw it for you. Just hold on, I will draw it for you rather than searching right. So, if you draw the circuit; if you draw the circuit so, this is your what you call my this is core loss component and this is my magnetising loss component right.

And this is your primary side say and this side you have your what you call R 1 say and you have X 1 right and this is your primary side winding. And this secondary side winding right it will suppose how I can accommodate this space is just hold on. Let me clear it, I am making it here just see that whether it is your understanding or not.

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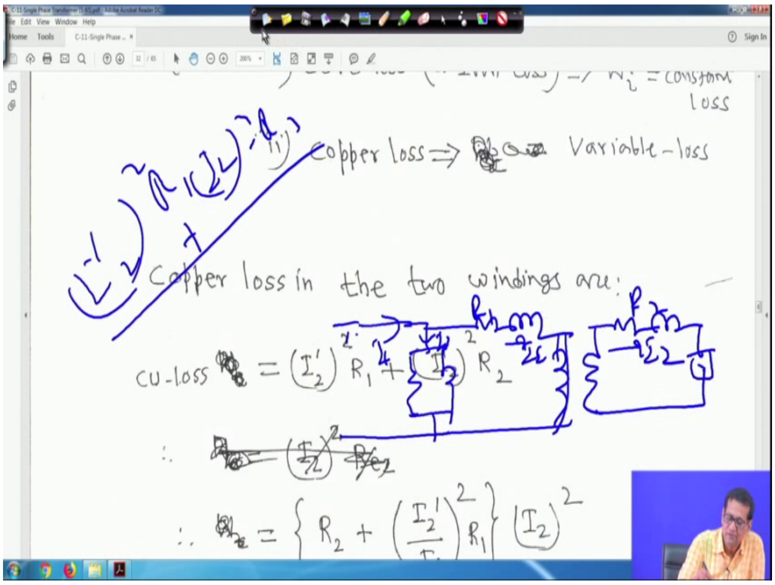

So, this is my R and because of space constraint so, this is my R and this is your this thing this side is a primary side right. So, this is the current I 1, this is the current I 0 and this side current is say we are taking I 2 dash and this is my primary winding right and this is my R 1 and my secondary winding is this one. So, this side is R 2, this is X 2 and here load is there say so, this is R 2 and current flowing through this is I 2.

So, here loss and the total loss is so, magnitude that I 2 square into R 1 plus your magnitude here I 2 magnitude into R 2, this is a total copper loss right real power loss. So, let me clear it so, this is what we are writing that your I 2 dash square R 1 right plus I 2 dash square R 2 right total copper loss. So, in this case you just take your what you call I 2 dash square common.

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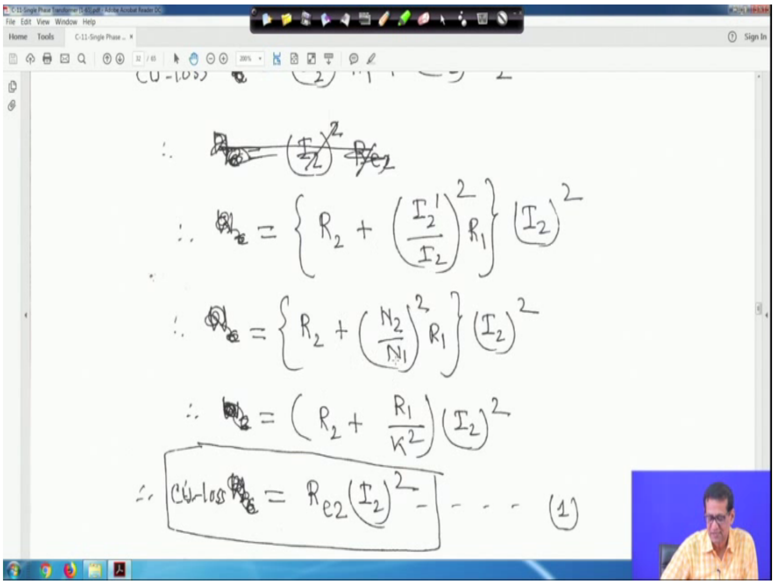

So, it will become R 2 plus I 2 dash upon I 2 square into R 1 right. So, we know that I 2 dash by I 2 is equal to N 2 by N 1, earlier we have seen it. So, you just substitute here; if you substitute that it will be R 2 and we know we have see you have taken throughout our this transformer thing K is equal to N 1 upon N 2. So, therefore, if K is equal to N upon N 1 upon N 2, it will be R 2 plus R 1 upon K square into I 2 square. Therefore, copper loss will be say R e 2 into I 2 square.

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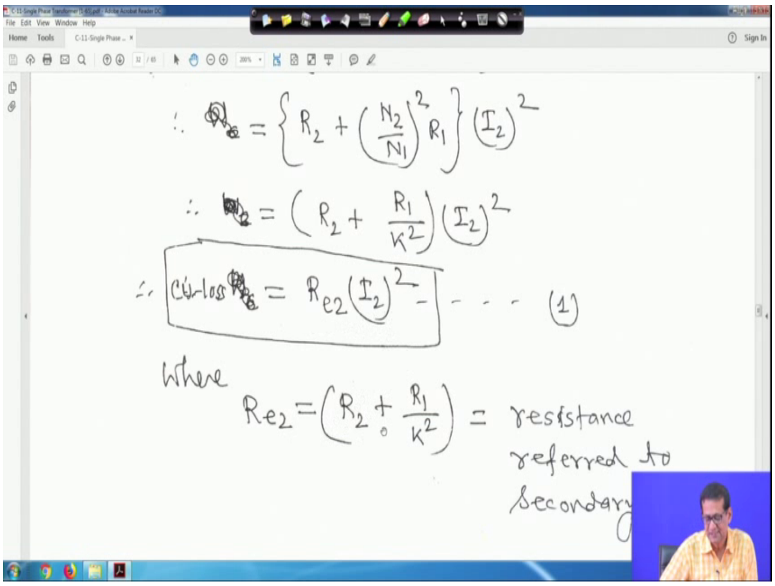

This R e 2 actually is the equivalent resistance refer to the secondary side. Resistance refer to the secondary side if you take on the primary side same thing in that case it will be R 1 plus your K square into R 2 right. But, we are made it on the refer to the secondary side, this is the copper loss right this R e 2 into I 2 square and this is R e 2.

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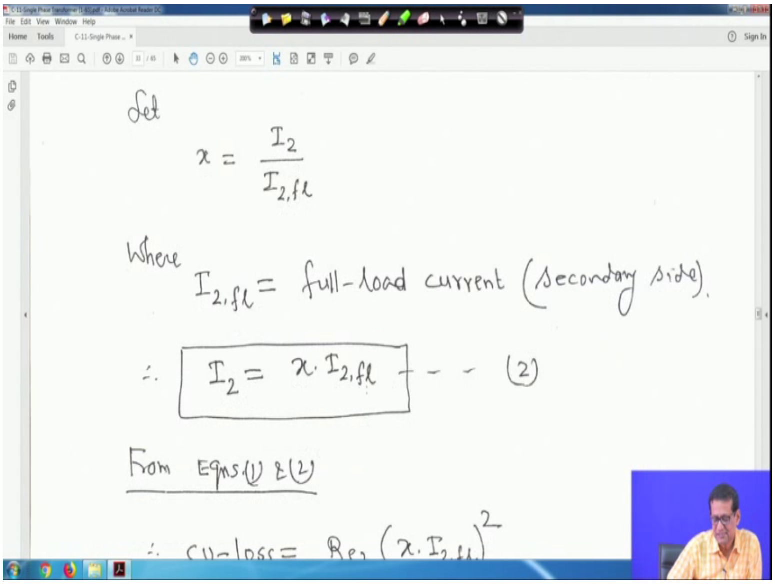

So, now let us say x is equal to I 2 upon I because, we are doing on the secondary side because reload is placed on the your secondary side right. So, say I 2 upon I 2 f l; I 2 f l is the full-load current. Just now we took 1 example to compute the full-load current on the secondary side that is 500 KVA transformer we got 1000 ampere just now we did we do 1 problem. So, same thing mathematically if you write x is equal to I 2 upon I 2 into I 2 f l where I 2 f l stands for full load.

So, I 2 f l is the full-load current that is on the secondary side right. So, I 2 is equal to therefore, form this equation I 2 is equal to x into I 2 f l right. Now, from equation 1 and 2 so, you will get copper loss is equal to R e 2 because R e 2 into I 2 square so, here we are putting I 2.

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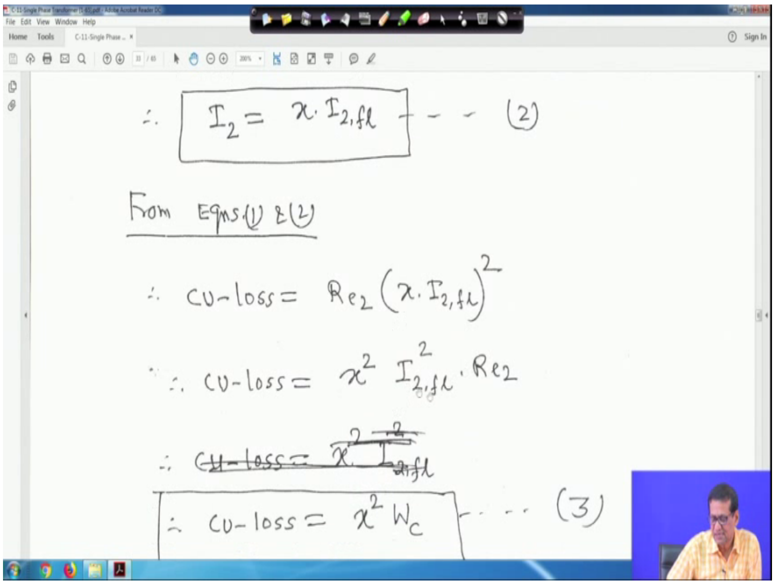

So, R e 2 into x I 2 f l square right. So, copper loss will be x square into your I 2 square f l into R e 2 this is the copper loss. Now, therefore, we can assume or we can write that copper loss is equal to x square into W c; W c is equal to I 2 square f l R e 2, it is called full-load copper loss.

So, W c is the full-load copper loss right. So, x your what you call that I 2 square f l R e 2 is W c it is called full-load copper loss. So, your copper loss when X your what you call copper loss is equal to x square into W c. Now, that is why I have written W c is equal to this much full-load copper loss.

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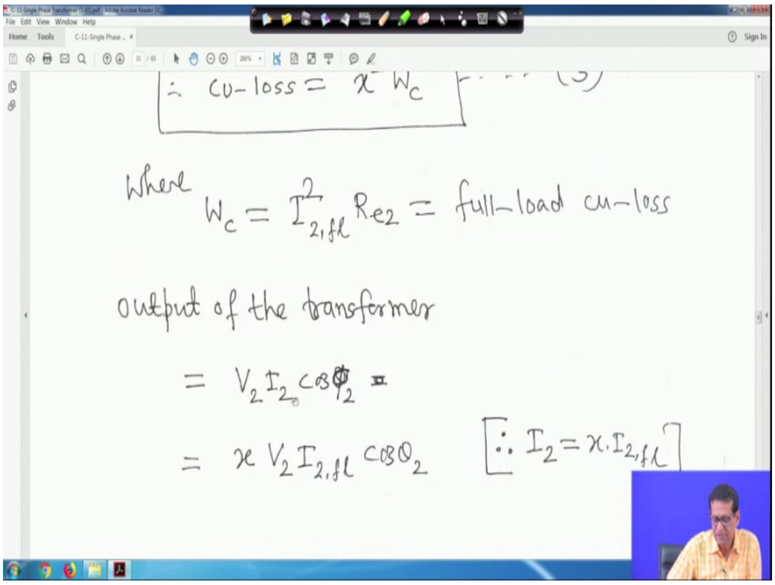

Now, output of the transformer, so it is generally V 2 I 2 cos phi 2 right. Now, your V 2 is there and I 2 is equal to x into I 2 full-load that you substitute the value of I 2 is equal to x into I 2 f l. So, x V 2 I 2 f l cos your theta 2 phi 2 right so, in this case I 2 is equal to x into I 2 f l.

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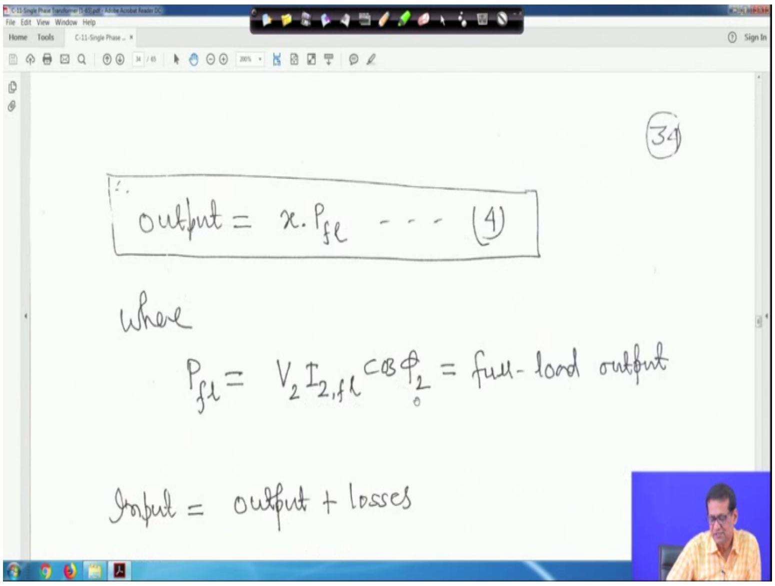

So that means, output is equal to x into your P f l so, P f l actually full-load output right. So, that is your what you call for example, for example, suppose if 500 KVA and power factor is given so, we find out P f l right. So, basically P f l will be V 2 into I 2 f l into cos phi 2 so, that is your full-load output. We also got the current now for 500 KVA transformer KVA watt given that is why, but if you want power in terms of watt.

So, V 2 I 2 f l into cos phi 2 that is the full-load output right and output is equal to X into P f l right. And if X is 1, then output is equal to your full-load output right or otherwise if your X varies, then naturally output will vary and it will and it happens for transformer because throughout the day load is changing. So, therefore, input is equal to output plus loss so, this is my output X P f l right plus losses. So, input is equal to output plus core loss plus copper loss both we have to consider.

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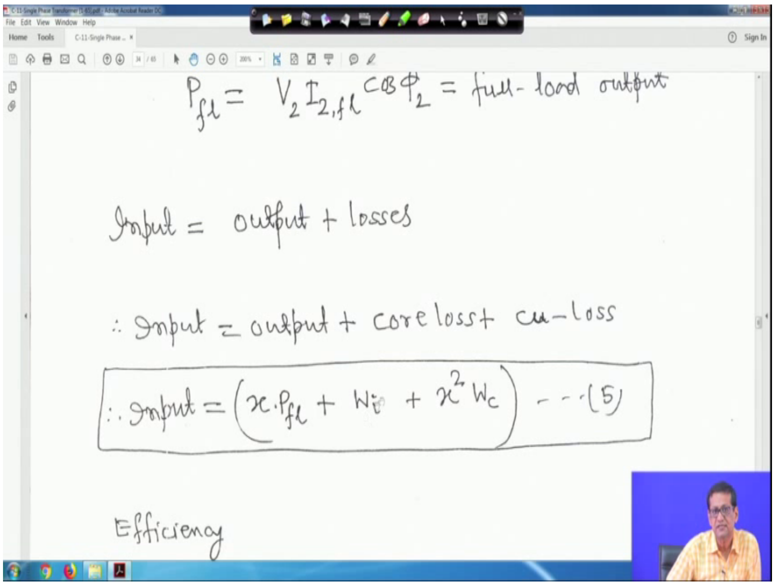

So, input is equal to then x into P f l the output plus W i the core loss or iron loss we call right, this W i you call iron loss or core loss plus x square W c so, this is equation 5.

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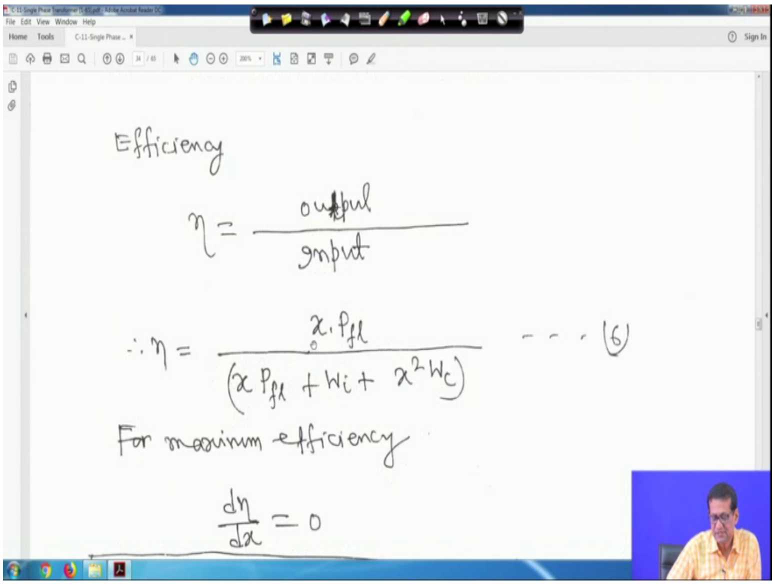

So, efficiency is output by input so, efficiency can be written as x into P f l this is the output divided by the whole term the input right. Now, for maximum efficiency, you will take d zeta upon dx is equal to 0.

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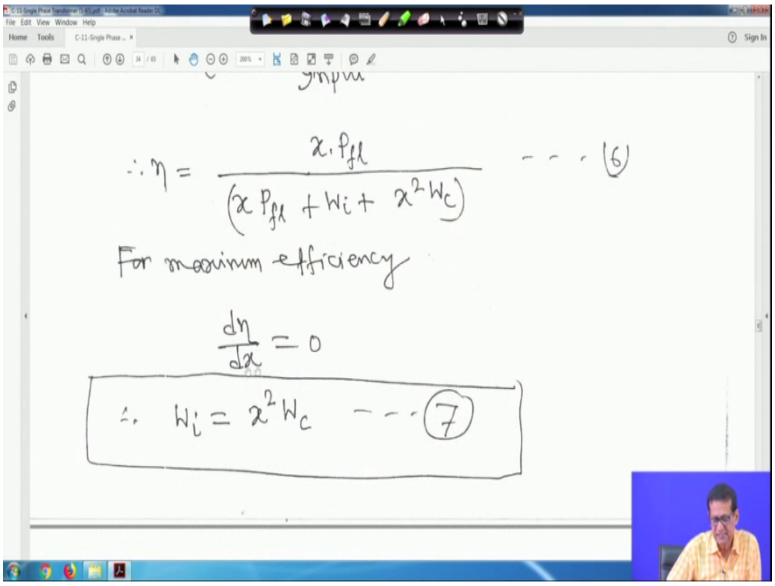

If you say d zeta upon dx is equal to 0, you will see iron loss is equal to copper loss. Therefore, for a maximum efficiency that this condition you have to keep it in your mind for solving numerical. For maximum efficiency, iron loss is equal to copper loss right, but you this derivative you please do yourself you will get this answer.

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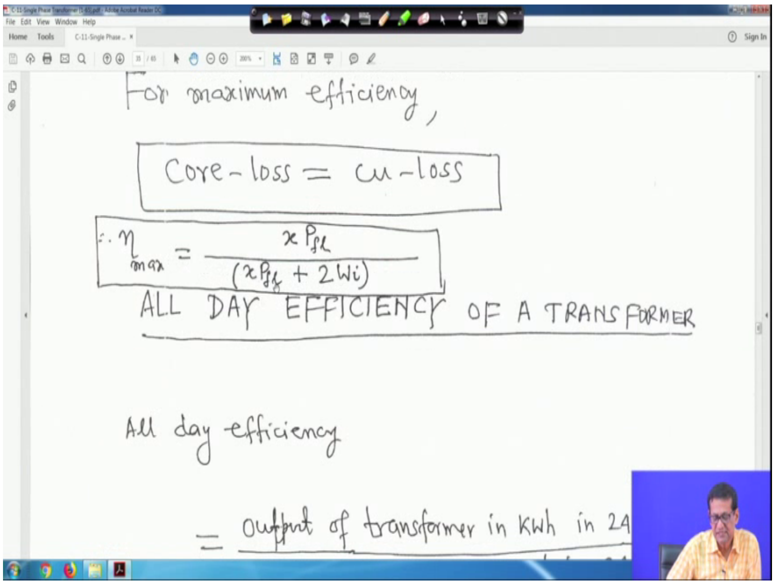

So, therefore, for maximum efficiency core loss is equal to copper loss this is the thing. Now, therefore, nu max is equal to if you put W i is equal to your x square W c right; that means, x square W c is equal to W i if you put in this expression; x square W c is equal to W i. Then it will become x P f l divided by x P f l plus W i that is what is written here then maximum efficiency x P f l upon x P f l plus 2 W i right. So, this is the all for maximum efficiency of a transformer. Now, all day efficiency of a transformer; it has formula we will take 1 numerical for that you will understand the thing.

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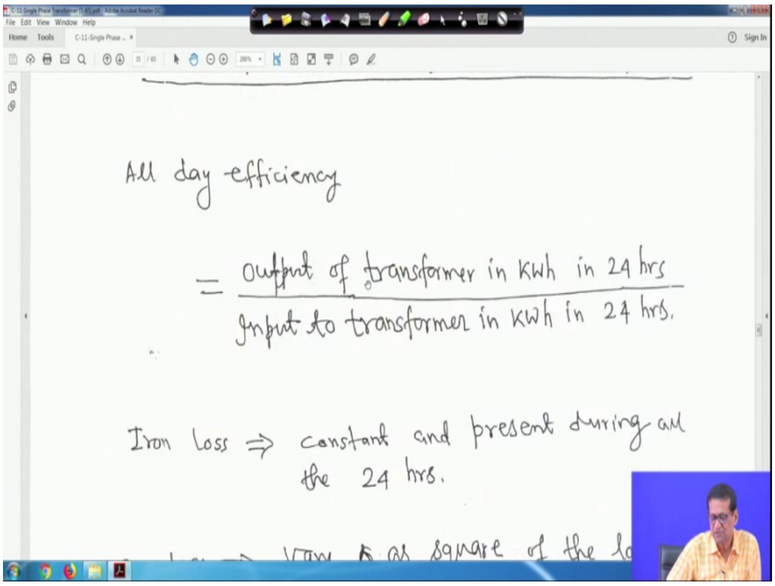

All day efficiency is equal to output of transformer in kilowatt hour in 24 hours right divided by input to transformer in kilowatt hour in 24 hours right.

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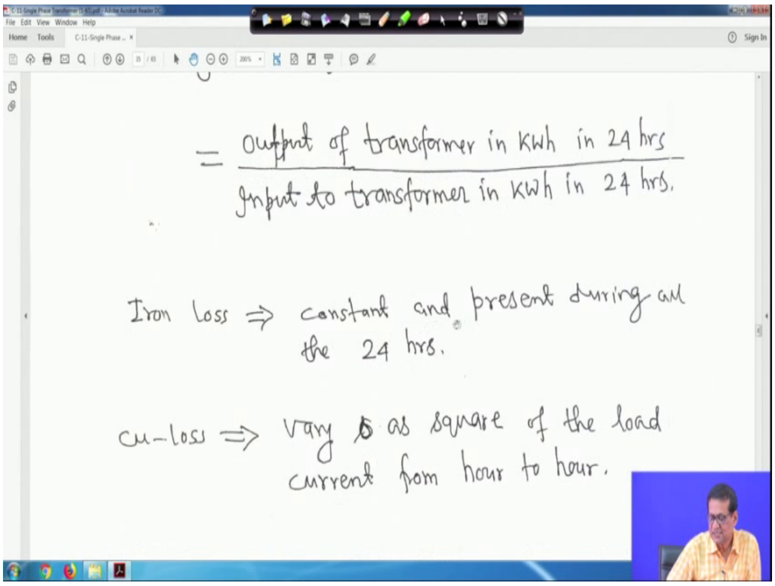

So, iron loss constant and for your constant and present during all the 24 hours. So, whatever iron loss will be there it will remain constant and 24 hours. Whatever iron loss will be there, multiply by 24 throughout the day this much of kilowatt hour your what you call in terms of kilowatt hour iron loss we will get. And copper loss vary as square of the load current from hour to hour varies right so, copper loss variable, but iron loss will remain constant we will see when we take one example right.

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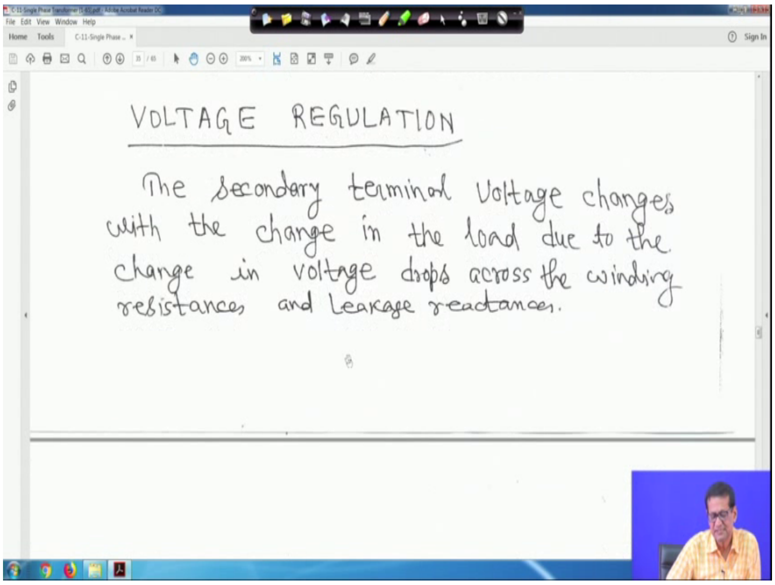

Now, another thing is the voltage regulation; this is very simple thing. The secondary terminal voltage changes right with the change in the load due to the change in the voltage drop across the winding resistance and leakage reactance because, if the load changes, then naturally voltage drop on the secondary side will change so, the right.

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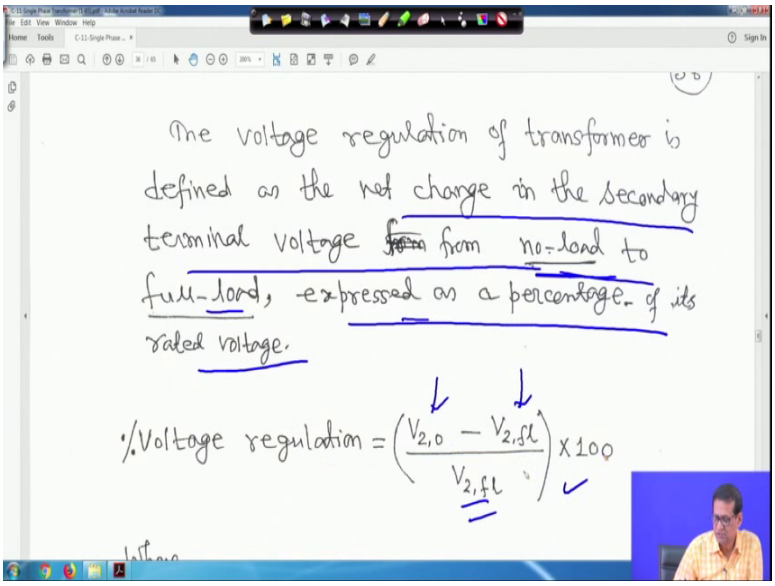

Therefore, the voltage regulation of transformer is defined as the net change in the secondary terminal voltage from no load to full-load right. So, from no load to full-load expressed as percentage of it is rated voltage right; that means, voltage regulation is this is your V 2 0 the low load and this is V 2 f l the full-load divided by V 2 f l into 100, this is the voltage regulation.

So, it is the net change in the secondary terminal voltage from no load to full-load expressed as a percentage of it is rated voltage so, this is my voltage regulation right. Now, what is V 2 0 what is V 2 f l? So, your V 2 a your V 2 0 that is the secondary voltage when load is thrown off that is V 2 0 is equal to E 2.

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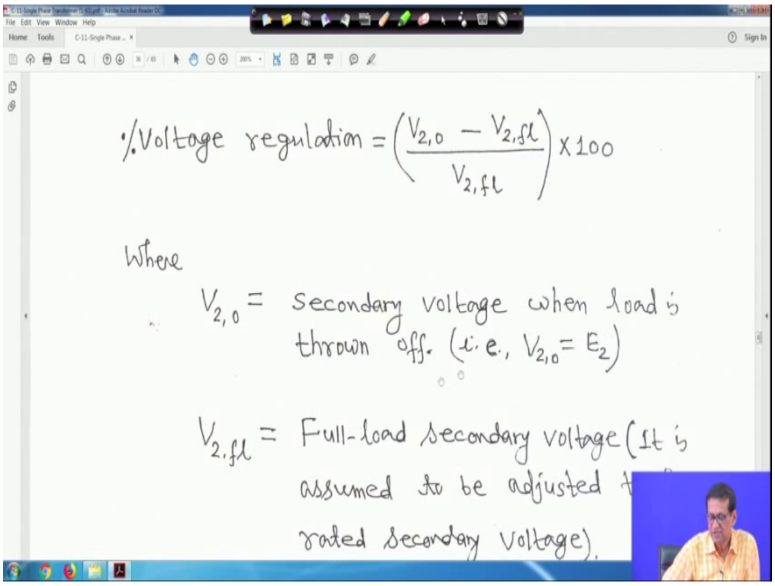

That means, when load is not there say no load condition right and V 2 f l is full-load secondary voltage, it is assumed to be adjusted to the rated secondary voltage right.

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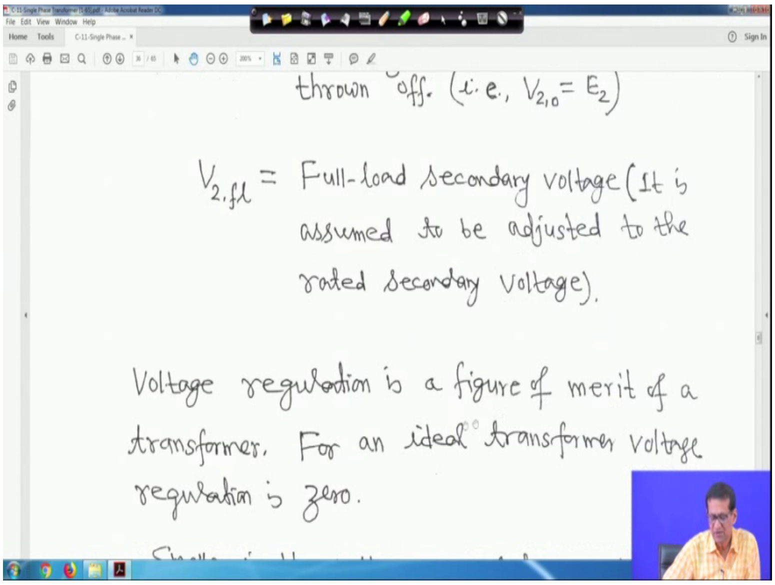

So, voltage regulation is a figure of merit of a transformer. For an ideal transformer voltage regulation is 0 because in that case your V 2 0 is equal to your V 2 f l value is same thing because for ideal transformer right. So, in that case regulation is 0 for an ideal transformer.

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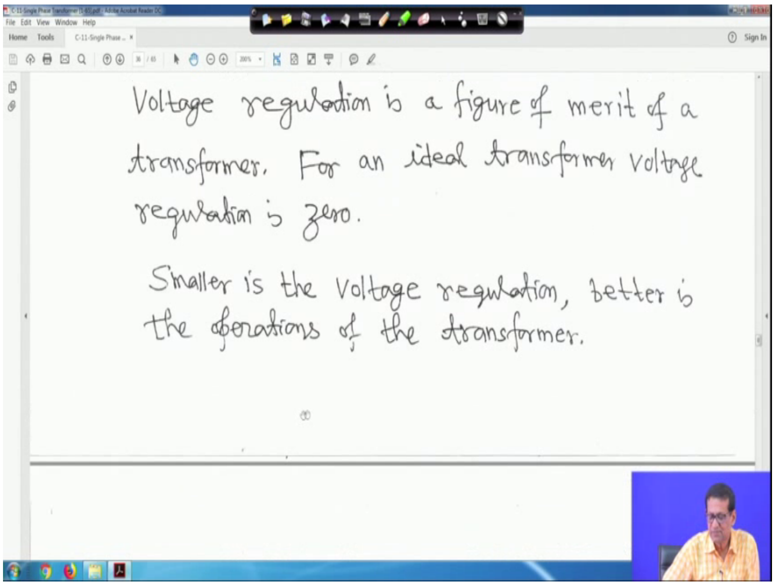

So, smaller is the voltage regulation better is the operation of the transformer right. So that means, voltage across the terminal of the load will be better right.

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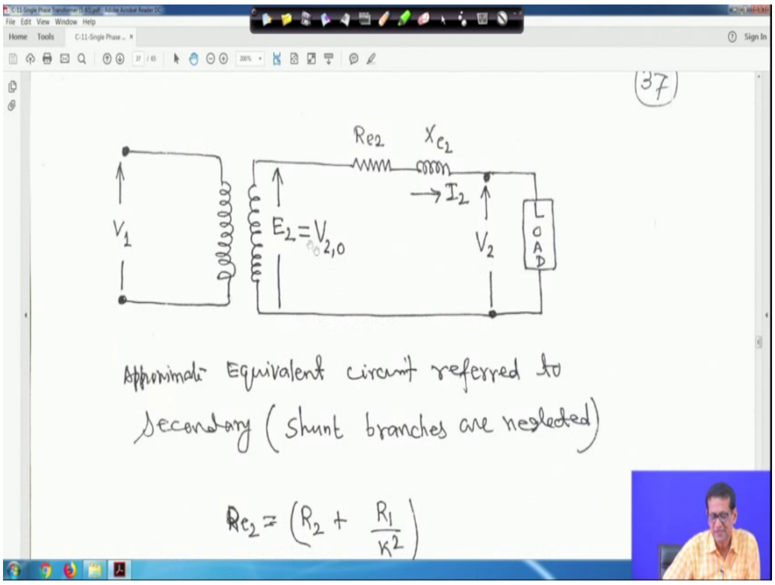

Now, if you look into the circuit like this so, this is my E 2 is equal to this is an ideal transformer as if nothing is here except winding. So, this is E 2 is equal to V 2 0 and this is R e 2 X e 2 your what you call that your secondary resistance and reactance this is the current I 2 and V 2 is the voltage across the load right. So, assume equivalent circuit, referrer to this 1 then R e 2 actually will be R 2 plus R 1 upon K square right.

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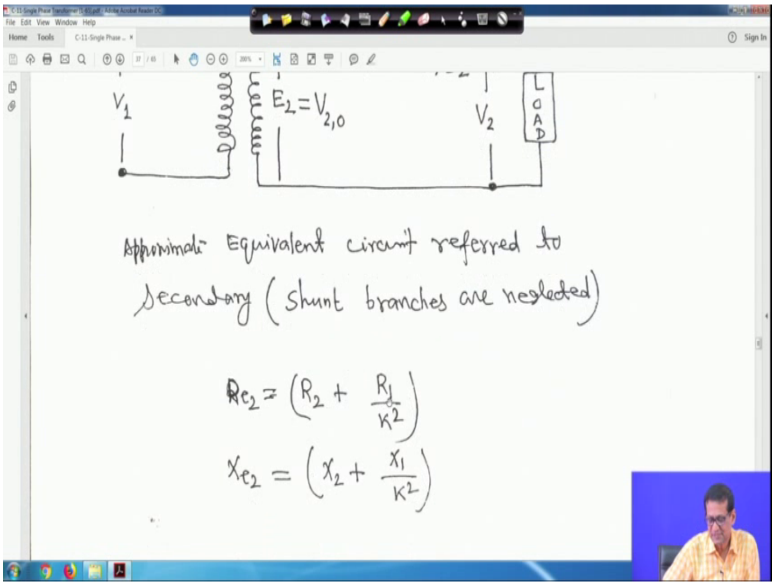

So, R 2 plus R 1 upon k square and X e 2 is X 2 plus X 1 upon K square right. So, this is your what you call the approximate equivalent circuit referred to secondary; shunt branches are negligible, I mean we are approximated this shunt branch everything is approximated it is neglected right. So, R e 2 X e 2 expression you know all this right so, this is your what you call the voltage regulation.

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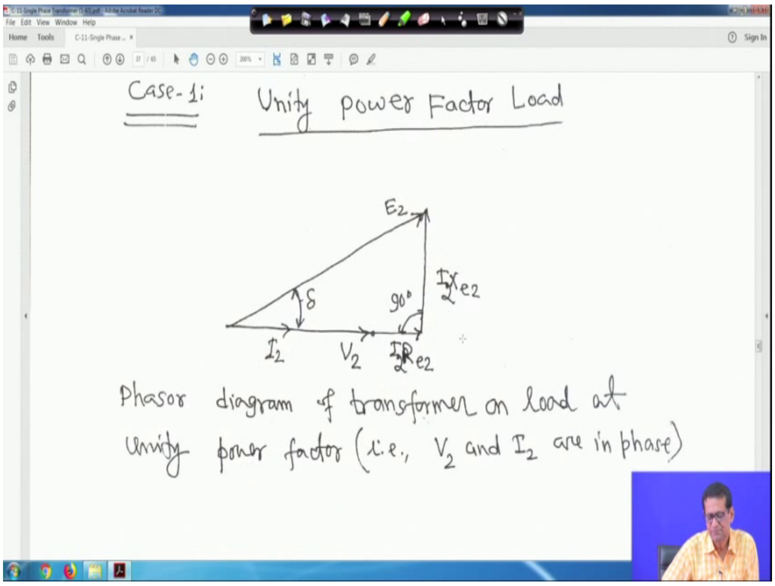

Now, then another one is now, for voltage regulation expression for different power factor say case 1 we considered unity power factor load. When load unity power factor, it is purely resistive right. If it is purely resistive, then your current I 2 and V 2 both are in phase right. If both if this 2 things if both are in phase right so, this is my voltage V 2 and this is your and voltage drop across resistance I 2 into R e 2 right.

So and as it is unity power factor load so, your that this is my I 2 and V 2 both will be in phase right and this is another thing is I 2 R e 2 drop also you add because E 2 is equal to if you just look into this that E 2 is equal to your V 2 plus I 2 R e 2 plus j I 2 X e 2 right. So, as j I 2 X e 2 means it will be 90 degree from here to here and this is my voltage E 2 and this is my delta right. So that means, that mean my E 2 your what you call E 2; E2 square will be is equal to V 2 plus I 2 R e 2 square plus I 2 X e 2 square under root right.

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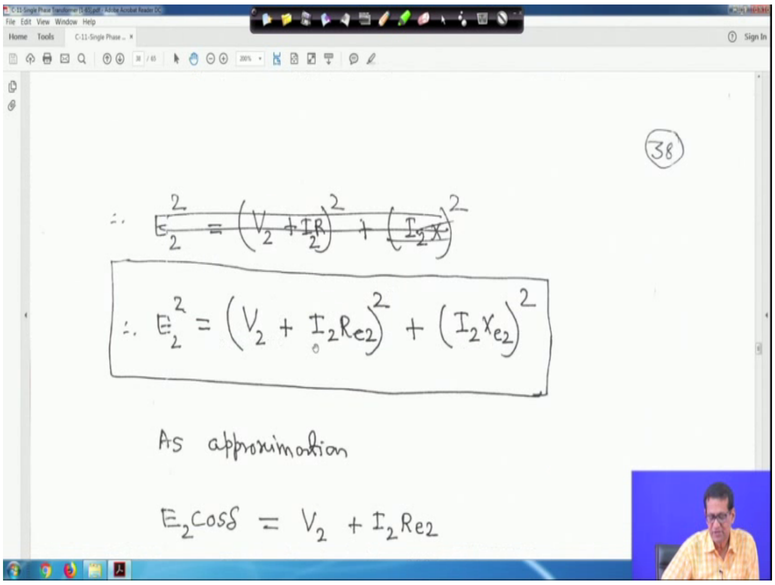

So, that is why your E 2 square is equal to V 2 plus I 2 R e 2 square plus I 2 X e 2 square; that means, your that E 2 is equal to square root of this one. Now, as an approximation you can write for the E 2 now E 2 now another thing you can write the E 2 cos delta is equal to V 2 plus I 2 R e 2 that also we can write E 2 cos delta is equal to.

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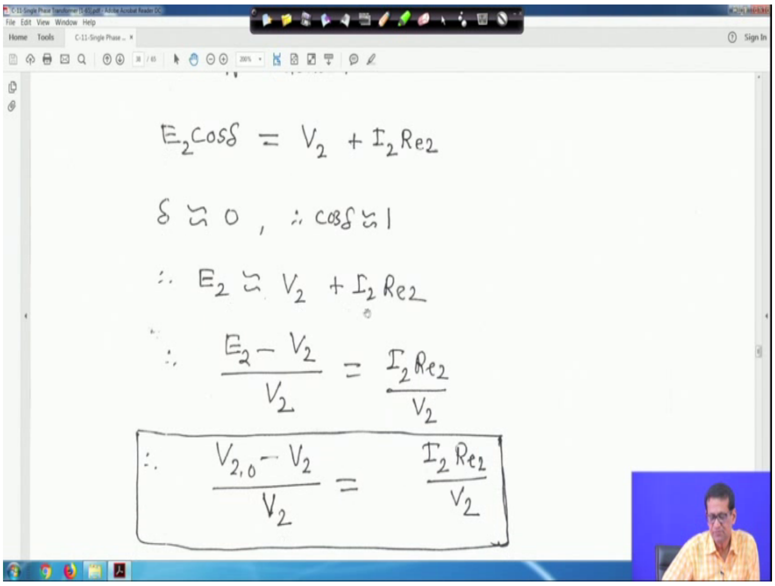

So, that is why we have written E 2 cos delta is equal to V 2 plus I 2 R e 2. Now, if delta approximately is equal to 0 say that is cos delta is 1; therefore, approximately E 2 approximately is equal to V 2 plus I 2 R e 2 or we can write E 2 minus V 2 upon V 2 right is equal to I 2 into R e 2 upon V 2 right or we can write we just seen now E 2 is equal to V 2 0; that means, V 2 0 minus V 2 upon V 2 is equal to I 2 R e 2 V 2 right. So, this is the expression of the your what you call the regulation right.

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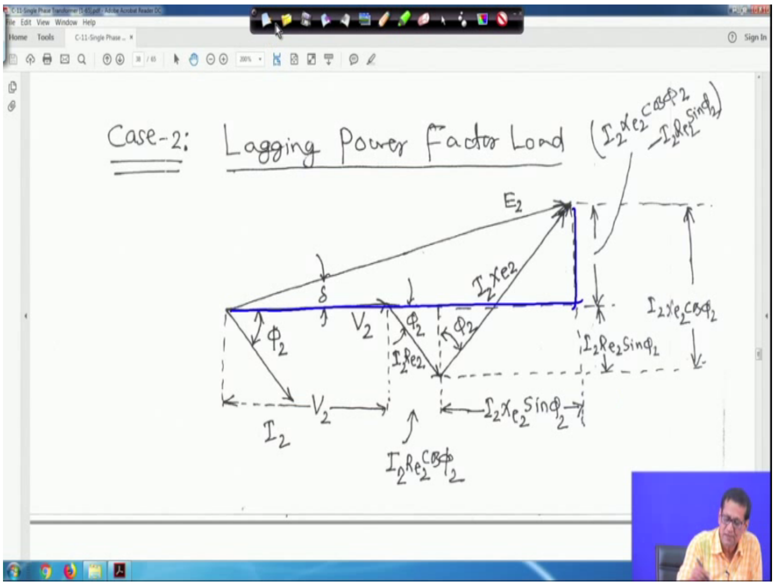

Similarly, for lagging power factor load, this is for unity power factor for lagging for lagging power factor load; that means, current lagging power factor load mean current is lagging. So, this is my current secondary current I 2, it is lagging from V 2 by an angle phi 2 right. So, in that case your what you call this is the current is lagging. So, along this at it will be drop will be I 2 R e 2 and then, I 2 X e 2 will be this 1 right and this angle is 90 degree look at that this angle is 90 degree and this is your E 2 this is your E 2 and angle between V 2 and E 2 is delta here it is delta right.

Now, you make all horizontal and vertical projection. So, this portion look at the cursor I am not marking by ink look at the cursor here will be I 2 R e 2 cos phi 2 because, this is phi 2 this angle is phi 2. Therefore, from the simple geometry this is angle is also phi 2 right. This angle will be also your what you call phi 2 right look at the cursor, this you can do it by simple geometry. Therefore, this portion is I 2 R e 2 cos phi 2 and from here to here it is I 2 X e 2 sin phi 2, look everything I have marked and this whole vertical line this angle is phi. So, it will be your phi 2 so, it will be I 2 X e 2 cos phi 2 right.

And this portion, vertically if you see that this portion I 2 R e 2 sin phi 2 right. So, this is simply your what you call is simple geometry, you can make it out all this things right.

So, not much to explain because you have seen your dingle phase AC circuit phasor diagram everything right so, with this if you make this is a. So, therefore, this triangle your what you call if you make it is a your what you call that your write this your this triangle if you consider, I mean this portion and this portion if you consider. So, E 2 square will be V 2 plus I 2 R e 2 cos phi 2 plus I 2 X e 2 sin phi 2 whole square right plus I 2 X e 2 cos phi 2 minus I 2 R e 2 sin phi 2 square right.

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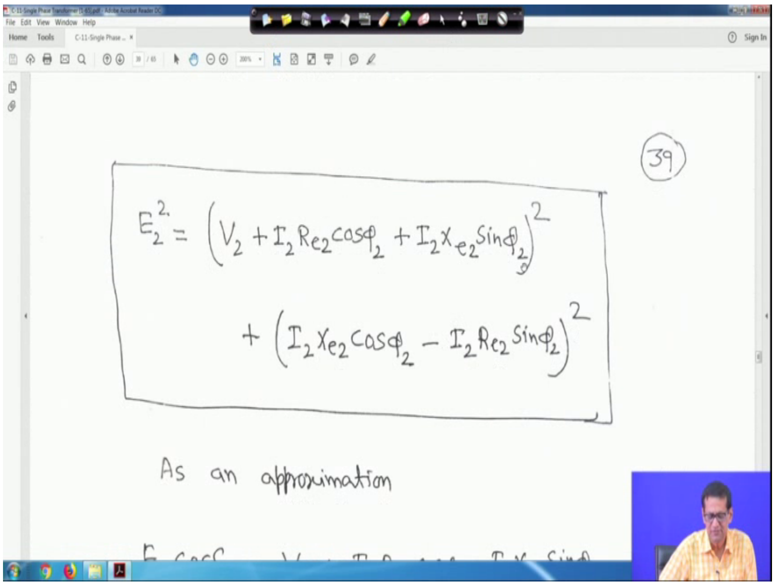

So, if you look into this that if you look into this that these has been written. This is E 2 square is equal to this one so, from which E 2 you will get? Now, as an approximation also you can write E 2 cos delta right E 2 E 2 cos delta there mean I mean I mean I mean this one. I mean E 2 E 2 cos delta I mean this portion is equal to my V 2 plus I 2 R e 2 cos phi 2 plus I 2 X e 2 sin phi 2 right. So, that is your what you have written here what we have written here right this is the equation.

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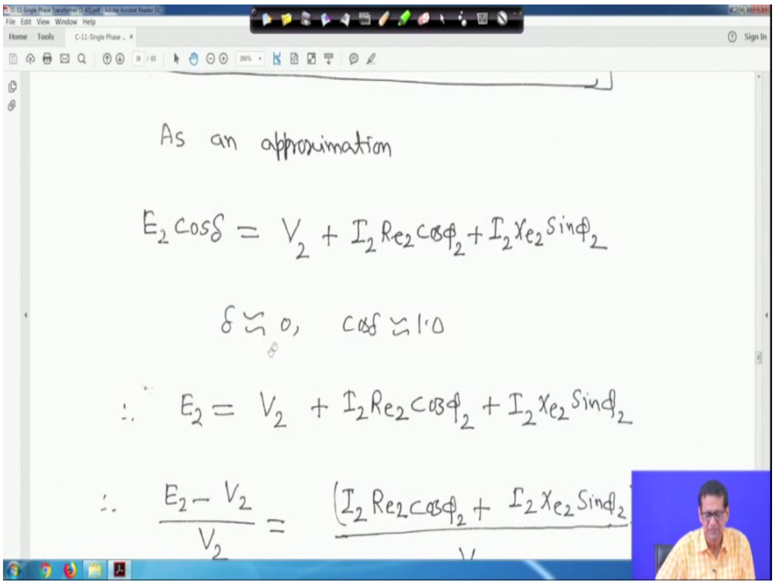

Now, assuming delta is very small equal to 0. So, cos delta is equal to 1; therefore, E 2 is equal to V 2 plus this term right or you can write E 2 minus V 2 upon V 2 is equal to this one you take I 2 common.

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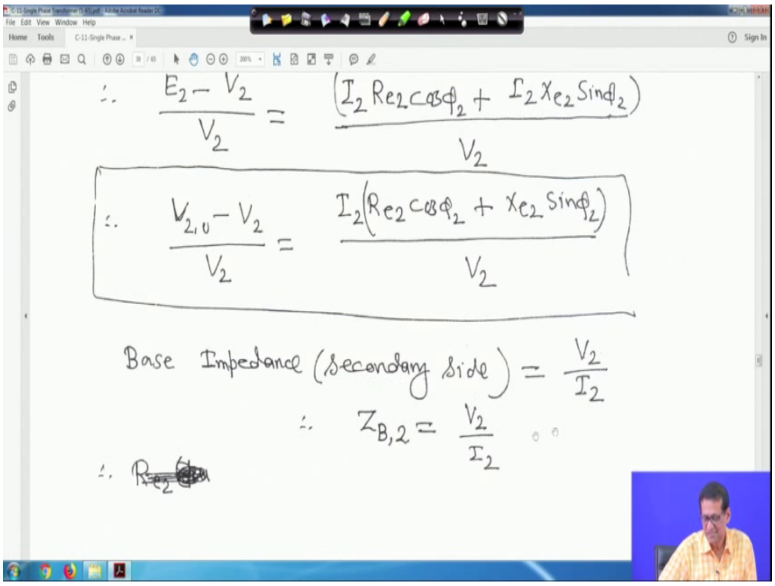

So, it will be V 2 0 minus V 2 upon V 2 is equal to I 2 R e 2 cos phi 2 plus X e 2 sin phi 2 upon V 2 right So, therefore, base impedance we have just seen base impedance secondary side, it is V 2 upon I 2 on the secondary side.

So, Z B stands for your base impedance and 2 stands for secondary side so, Z B 2 is equal to V 2 upon I 2. Therefore, this equation R e 2 cos phi 2 plus X e 2 sin phi 2 divided by V 2 upon I 2, we can write and that V 2 I 2 V 2 upon I 2 is equal to Z B 2 right. So, that is Z B 2; therefore, we can write V 2 0 minus V 2 upon V 2 R e 2 upon Z B 2 cos phi 2 plus X e 2 upon Z B 2 sin phi 2.

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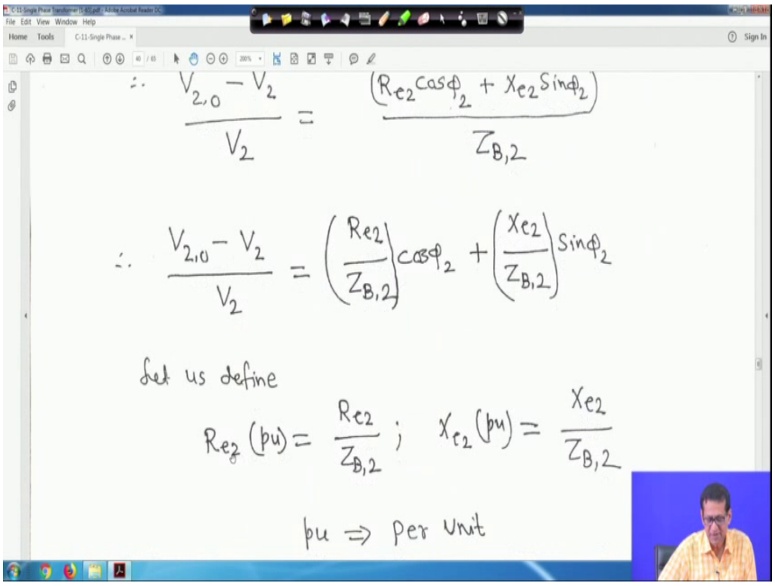

That means, let us define this is R e 2 per unit; that means dimensionless quantity, this p u means per unit right per unit. So, R e 2 upon Z B 2 and X e 2 per unit is X e 2 per unit is equal to X e 2 upon Z B 2 and as I written here it is per unit.

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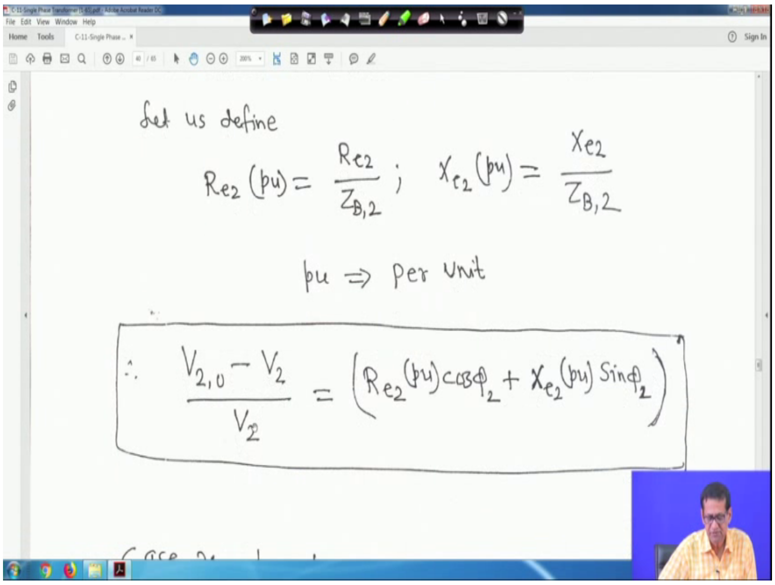

Therefore, V 2 0 minus V 2 upon V 2 the voltage regulation in terms of your percentage that is R e 2 per unit into cos phi 2 plus X e 2 per unit sin phi 2; very simple it is just little bit your practice is necessary.

Thank you very much, we will be back again.