Electrical Machines - I

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Lecture - 16
Determination of Equivalent Circuit Parameters - No Load Test

Welcome to lecture 16 and we have been discussing about the exact equivalent circuit, its phasor diagram, then approximate equivalent circuit and I will also draw its phasor diagram.

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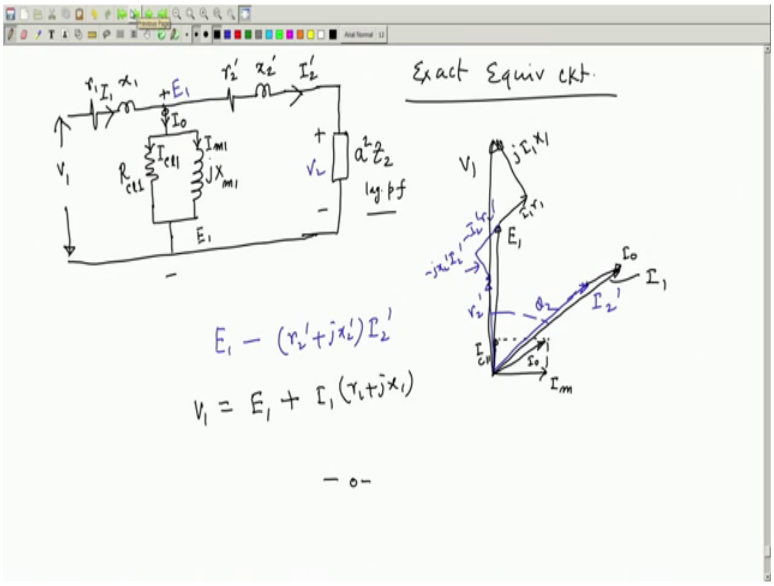

Exact Equiv ckt.

$$E_1 - (r_2' + jx_2')I_2'$$

$$V_1 = E_1 + I_1(r_1 + jx_1)$$

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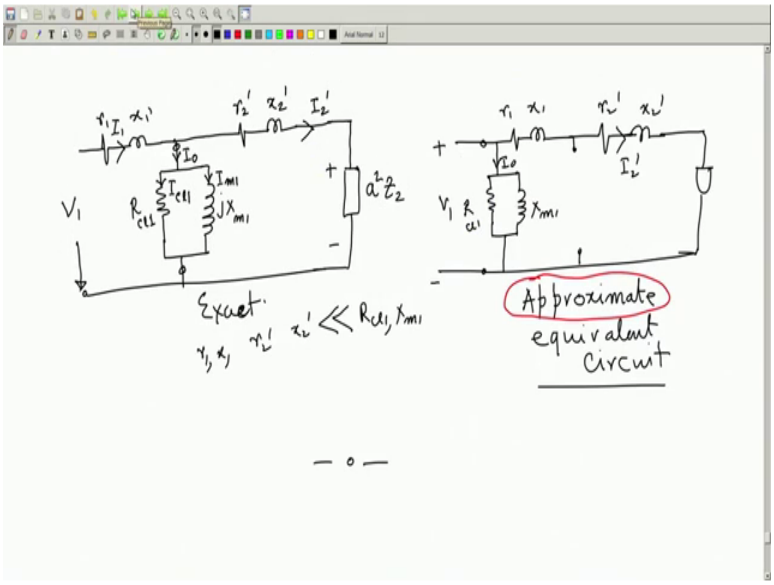

Recall that the approximate equivalent circuit was like this where this parallel branch has been brought right across the supplier. The approximation made is under no load condition as if there is no current through the winding, but nonetheless core loss will always take place. So, it was like that now if you see this r 1 x 1 and r 2 dashed x 2 dashed, they become in series ok. So, this is one of the greatest advantage of looking at the transformer equivalents circuit in terms of its approximate representation.

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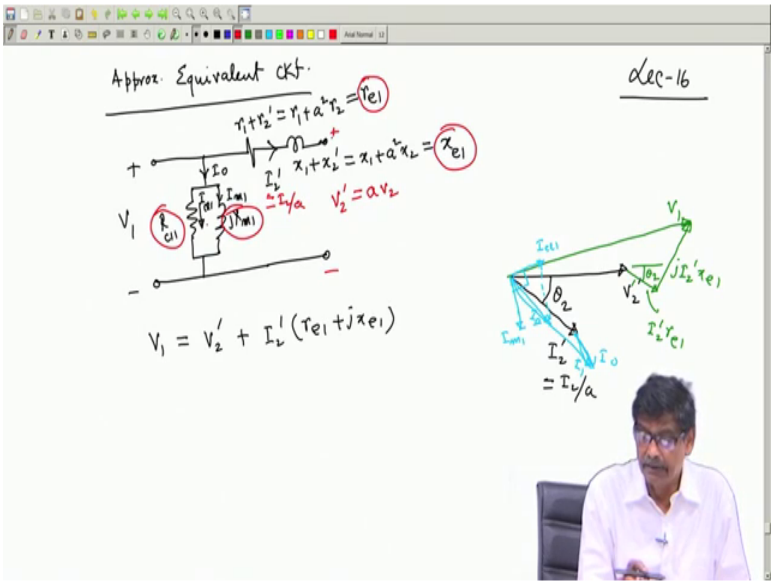

So, what will happen is this equivalent circuit, then can be further simplified. So, approximate equivalent circuit refer to primary it will then boil down to this one. These r 1 and r 2 dashed can be represented by a single resistance as r 1 r 2 dashed which is nothing, but r 1 plus a square into actual resistance of the secondary term and this can be written simply as r e 1. That is equivalent resistance in terms of primary winding; we see equivalent resistance.

Similarly, the two reactants can be grouped together and written as x 1 plus x 2 dashed and that is equal to x 1 plus a square x 2 and this is called equivalent resistance; equivalent reactants. Equivalent reactants referred to primary side x e 1 and that is all. These two are the secondary terminals where an impedance will be connected if it is connected a square z 2.

And this will be R c l 1 and this is j X m 1 and this is your V 1 and mind you this current is I 2 dashed and this is no load current and no load current comprises of two parts; core loss component c l 1 and I m 1. Then this voltage if I show it by different colours. So, that you understand, this voltage is V 2 dashed which is equal to a into V 2 actual secondary. This current I 2 dashed is equal to I 2 by a. This is how things will go, then the phasor diagram drawing becomes so simple.

Let us see; suppose we start drawing the phasor diagram with respect to V 2 dashed. Now as you can see V 1 will be equal to V 2 dashed; this voltage plus this drop plus I 2 dashed into r e 1 plus jx e 1. This will be the phasor diagram.

So, we start the phasor diagram drawing in this way. First draw V 2 dashed and then draw I 2 dashed. Suppose it is supplying, what is I 2 dashed? Actual current by a and this is then the load power factor angle mind you is the load power factor angle theta 2 whatever impedance you have connected. Then to get V 1 you add 2 V 2 dashed; this drop simply.

So, this will be V 2 dashed plus I 2 dashed r e 1 plus j I 2 dashed xe 1 and you will get V 1. No point in showing e 1 e 2 etcetera. So, as I am telling you as you go to the approximate equivalent circuit, you on the plea that the series impedances are much smaller compared to the parallel impedances of this core loss resistance and magnetizing impedance. Then it is the phasor diagram that is all and you this is the angle theta 2 and this is your V 2 dashed.

So, to V 2 dashed, you add this ok. Now where is your I 1? If this is V 1 you see this I naught will be lagging this V 1 by whatever that current is. Aare you getting? After you see after you get the V 1 to V 1, you have in this phasor in this approximate phasor diagram your I cl will be in phase with your applied voltage. So, this will be I cl 1 and your magnetizing current you show 90 degree lagging in this circuit.

So, this angle will be then 90 degree as per the approximate equivalent circuit I m is not and if you wish to calculate where your I 1 will be that is what I am doing. So, I m 1 and then add this to get your I naught to I 2 dashed you add your this I naught to get I 1 an input power factor will be angle between V 1 and I 1. I think you have got the idea, but this is the thing. Similarly the same transformer if you draw the equivalent circuit referred to I will do that because you practice them.

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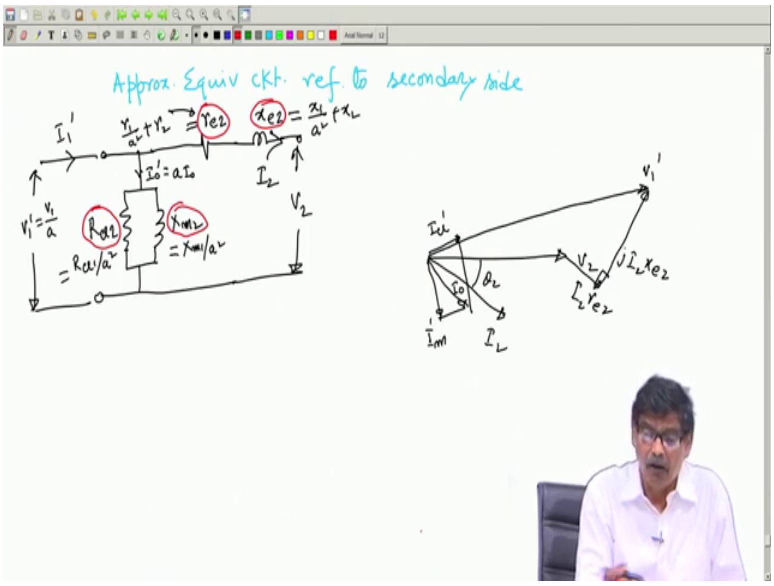

So, suppose approximate equivalent circuit referred to secondary side or load side; secondary side. I will draw it very quickly because I know what is what. So, equivalent first you draw the equivalent circuit. Equivalent circuit referred to secondary side, we have already drawn.

All parameters now it will look like same thing. Only thing this is R cl 2. This is X m 2 referred to secondary side and this R cl 2 is nothing, but R cl 1 by a square from this side to that side things are to be divided in terms of Xm 1, it will be by a square. And I will now show it and leave it to you to verify it is indeed true; I will be right here as re 2 and xe 2 where, this xe 2 will be equal to x 1 by a square plus x 2 and this re 2 will be equal to r 1 by a square plus r 2; this resistance.

And this voltage is certainly not V 1 now it is V 1 dashed which will be equal to V 1 by a and this voltage will be your V 2. And this current is actual current I 2 and this is your I naught dashed which is equal to I naught a I naught is not. This is I naught dashed; I can transform this current it is by a. So, it will be a I naught dashed is equal to a into I naught.

So, get used to this transformation multiplying any impedance transfer from this side to this side will involve a and any current transformation or voltage transformation will involve a; whether multiplication division you should be very careful. I gave you some hints also that is you just simply calculate the turns ratios and you must know that impedance values in the lb sides are lower; voltage value on the low voltage side is low definitely and so on current value in the lb side is higher.

So, all these things will you get used to it. So, this is the thing and in this case this current will be I 1 dashed and then the phasor diagram for this in the same way. Here this you start with V 2 actual secondary voltage V 2. This is suppose the current delivered by the transformer to the load which am not drawing. Henceforth I will not draw because V 2, it is supplying current means some impedance is connected.

This is the actual power factor of the load, then to V 2 you add these drop I 2 r e 2 plus this angle is 90 degree j I 2 xe 2 and this is I 2 re 2 and then you will get this V 1 dashed. You will not get V 1 mind you; V 1 dashed and then you can fix up where your I naught will be because V 1 by r cl 2 will give you magnetizing current. This will give you magnetizing current V 1 dashed divided by Xm 2 and the core loss component of current will be there I m dashed I cl dashed. These two will give you I mean same stuff; I do not want to also mix.

So, I naught so, to I naught you add I 2 to get I 1 dashed and so on; I will not continue. I have done is this I have represented a practical transformer modelled it in terms of some external parameters connected either in series or in parallel. For example, r 1 r 2 R cl core loss component of resistance magnetizing reactants to an ideal transformer and got these things and after getting the exact equivalence circuit we did another approximation not without any reason.

You cannot approximate anything just like that the argument is the winding resistance and leakage reactants are much smaller compared to the resistance representing core loss and the reactants representing the magnetizing current and that comes in parallel. So, it can be approximately pushed in this way [FL].

Now, after doing this, I will now tell you given a practical transformer how do you know this parameter values? By doing some tests it can be simple test, these parameters can be evaluated.

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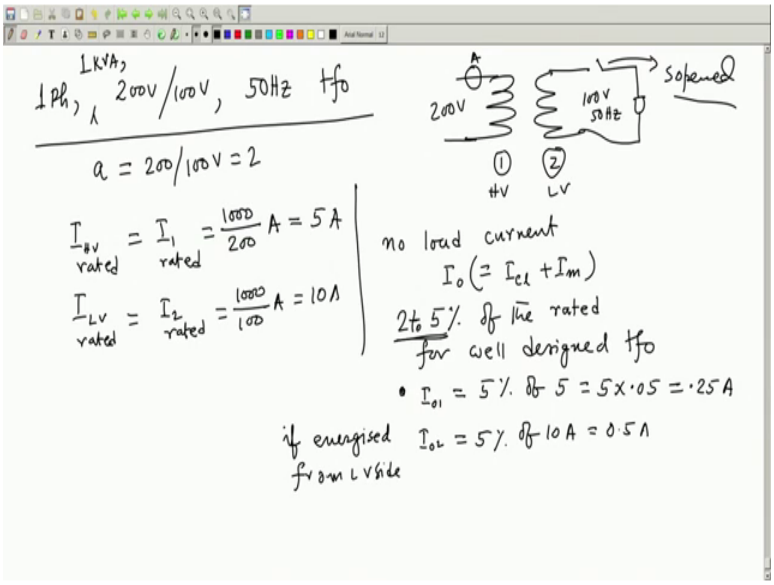

1 Ph, 1 KVA, 200V/100V, 50Hz tfo

$a = 200/100\text{V} = 2$

$I_{HV\,\text{rated}} = I_{1\,\text{rated}} = \frac{1000}{200}\text{A} = 5\text{A}$

$I_{LV\,\text{rated}} = I_{2\,\text{rated}} = \frac{1000}{100}\text{A} = 10\text{A}$

no load current

$I_0 (= I_{cl} + I_m)$

2 to 5% of the rated for well designed tfo

- $I_{01} = 5\%$ of $5 = 5 \times .05 = .25\text{A}$

if energised from LV side $I_{02} = 5\%$ of $10\text{A} = 0.5\text{A}$

But before that let us you would take some rating of a practical transformer. I took one like this say 200 volt, stroke 100 volt, single phase, 50 Hertz transformer and suppose it is practical transformer. And what I have missed KVA rating single phase. Suppose the KVA rating is 1 KVA ok; 1 KVA 200 volt, stroke 100 volt, 50 Hertz single phase transformer; tfo means transformer short way I am writing [FL]; this things given to you.

What does this mean to a practical transformer is this? This is practical transformer, I will assume this way that if you apply 200 volt 50 Hertz source here across this winding with nothing connected on the secondary side, you will get 100 volt 50 Hertz. And this will be terms ratio will be 200 by 100. This is what will happen this is the turns ratio I can get and this one. I also told you that HV side rated current which I will call side 1 and this is side 2 HV side and this is LV side that is equal to I 1 rated is equal to 1000 divided by 200.

So, much ampere these I can immediately calculate ok. So, how much it will be? 5ampere and also I know I HV I LV rated I LV side rated is equal to I 2 rated is equal to 1000 by 100. Of course, these I could in one stroke right straight away 5 into this is the rated current mind you; these things I know [FL].

So, given the transformer rating we know about this numbers or this turns ratio I can make out calculate rated current that can be allowed to flow through the HV winding and through the LV winding. KVA remain same approximately [FL]. After calculating this, I now make one very interesting point that no load current of a transformer; no load current that is I naught you recall I naught was equal to I cl plus I magnetizing ok.

No load current of a transformer is of the order of say 5 percent of the rated current 2 to 5 percent; 2 to 5 percent of the rated current. As a practicing engineer, the this idea must be there that is it must be a well designed transformer whoever has designed this transformer he must have seen that eddy current, hysteresis losses are reduced is using very good magnetic material.

So, that magnetizing current is also small and it I cl plus I m. These two together phasor sum gives you the no load current and that number, I am telling for a well designed transformer for a well designed transformer. Therefore, without knowing the equivalence circuit this that I will say that maybe for this transformer, I naught 1 no load current referred to side one will be about say 5 percent 5 percent of rated current of side one that is 5 ampere. So, it will be 5 into 0.05 that is about 0.25 ampere.

Same transformer; if you are energized from the from this side no load current LV side; it will be I naught 2. If energized from LV side, I naught 2 no load current will be 5 percent of 10 ampere. Are you getting? That is 0.5 ampere anyway exact value I do not know what I am telling given a transformer, you can guess what will be the order of the no load current.

So, no load current value is much smaller compared to the rated by maybe of the order of 5 percent of the rated current. See this transformer could be energized from the 100 volt side as well that is why LV side, I call it and your no load current can be estimated. That is if I say suppose you are energizing the transformer from the HV side with secondary no load means no impedance which is open here no load means s is opened s opened. Then I am telling suppose I want to measure this current no load current. Then how to choose the ammeter reading? It guides you from the HV side better taken ammeter which can read whose range is 0.05 ampere do not connect it 0 to 30 ampere range ammeter to record a current of 0.25 ampere. So, I can decide upon the range of the ammeter; if I know this information that is no load of this current is of the order of 0.5 percent and this 5 percent is not unique value that is given a transformer.

You expect it is it you can expect it will be close to this current, but exact current in any case I can calculate because the no load current can be about 2 to 5 percent of the rated current. You must understand that [FL]. After knowing this let us start discussing how to determine the equivalent circuit parameters.

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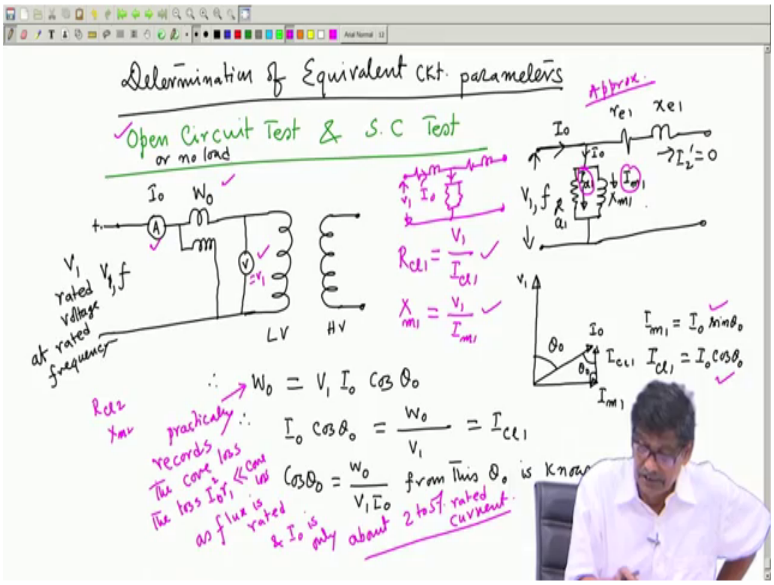

Determination of Equivalent ckt. parameters

Open Circuit Test & S.C Test
or no load

$R_{cl1} = \frac{V_1}{I_{cl1}}$

$X_{m1} = \frac{V_1}{I_{m1}}$

$I_{m1} = I_0 \sin\theta_0$

$I_{cl1} = I_0 \cos\theta_0$

$\therefore W_0 = V_1 I_0 \cos\theta_0$

$\therefore I_0 \cos\theta_0 = \frac{W_0}{V_1} = I_{cl1}$

$\cos\theta_0 = \frac{W_0}{V_1 I_0}$ from this θ_0 is known

practically records the core loss
The loss $I_0^2 r_1 \ll$ core loss as flux is rated & I_0 is only about 2 to 5% rated current.

Determination of equivalent circuit parameters. So, a transformer practical transformer is given I want to know what will be the values of re 2, what will be the value of x e 2, what will be the value of R cl 2 and what should be the value of X m 2. On any side if you know, other side can be calculated or in the previous diagram my god.

Student: (Refer Time: 24:51).

That is this is with respect to the secondary side; I drew with respect to the primary side. Similarly our goal is to calculate this one, xe 1, R cl and xn 1 that is how can I calculate it?

The answer to this is we have to do some testing and simple testing; I will do. So, determination of equivalents circuit parameters by conducting from two test; open circuit test, you conduct two test; open circuit test and short circuit test short circuit test. You conduct these two tests in the laboratory and you can get those to all the parameters ok. How do I do the test? First will take up this open circuit test, what it is all about? What is done? You take the transformer and connect an ammeter and connect an Watt meter and this is the practical transform of primary.

And generally to do the open circuit test from the LV side, this test is carried out. The reason will tell you later and suppose this is the other side HV side which is open circuit or sometimes called no load test or no load. No load means no impedance is connected across the secondary and also you connect a voltmeter across this. And here you apply the V 1 rated voltage rated voltage at rated frequency.

So, what I will do? LV side, I will energize with voltage V 1 at rated frequency f and connect an ammeter and Watt meter ok. And keep in mind this is the and approximate equivalent circuit I will be referred to what is the approximate equivalent circuit then? Here V 1 at frequency f, you have given re 1 and xe 1 are there, but these are open circuited because secondary nothing is connected in finite. So, this is that open circuit will be reflected at the open circuit in the equivalent circuit also.

So, there is I 2 dashed is 0 nothing is there because no impedance is connected. So, I 2 is not there I 2 dashed is not there and this is R cl 1 and this is Xm 1. So, under this condition this condition, you see this is I naught this is also I naught and this is I cl 1 and this is I m 1 magnetizing current. And what is the phasor diagram in this approximate equivalent circuit? Phasor diagram is very simple applied voltage V 1, your magnetizing current will be here 90 degree lagging and your core loss component of current will be in phase with the supply voltage and this will be your no load current; I naught.

So, your ammeter is going to read I naught ok. And this is called no load power factor angle. If this is theta, this is theta; theta naught, theta naught; t naught theta naught will be in an ideal transformer 90 degree, but it cannot be because it is a practical transformer having core losses ok. And this is the thing and the Watt meter suppose read W naught, then I will say that this Watt meter reading must be equal to the voltage applied across its pressure coil that is V 1 current flowing through its current coil that is I naught. Let us assume wattmeter to be ideal; I mean those losses of Watt meter neglected V 1 I naught and cosine of the angle between these two that is theta naught. This is what I will get.

And from this, I can get the value of I naught cosine theta naught to be equal to W naught by V 1 I naught and note that I naught cosine theta naught is also equal to I cl 1 from this right angled triangle. So, cosine theta naught I cl 1 is known [FL]. Then what you do follow? This point very carefully some students make very I mean big mistake. It is better you try to calculate Im also; magnetizing branch ok. Instead of trying to calculate V 1 by I naught that will give you the equivalent impedance things become complicated; it is much more easier as you see.

What do you do now? Since so, from these also I calculate cosine theta naught W naught have I done some mistake here this is not.

Student: (Refer Time: 32:42).

This will be the thing now. So, W naught by V 1 I naught cosine theta, but in any case I can also calculate the value of cosine theta naught as V 1 I naught.

So, from this theta naught is known. If theta naught is known, then from this triangle I can say I m 1 is equal to I naught which is known ammeter reading into sine theta naught. And also I cl 1 I have already written it is equal to I naught cosine theta naught. Therefore, what we have done I have got this current I cl 1 and I m 1 and my problem is to calculate R cl 1; R cl 1, then simply will become V 1 by Icl 1. This is known this is known and Xm 1 is a equal to V 1 by Im 1. So, these two values can be calculated.

Instead of trying to calculate the impedance V 1 by I naught, do not do it because that impedance will then be the series representation of R cl and Xm equivalent. And then you are gone and do not say the series part of this equivalent circuit is the core loss resistance. Then it will define the physical reasoning that is the magnetizing current requires a fixed voltage and this one.

So, you should be very careful. So, mind you then I have been able to calculate R cl 1 and Xm. So, doing this open circuit test, I can very quickly calculate by noting down the ammeter reading and wattmeter reading and these voltmeter reading that is that will read equal to V 1. I can calculate R cl 1 and Xm 1. And then am telling, if it is needed, you can then after knowing R cl 1, I can always calculate R cl 2 and X m 2.

For these, I do not have to carry out the experiment once again because I know it will be either divided or multiplied by s s square. So, correctly if I do that I will get R cl 2 as well as X m 2. So, in this equivalent circuit, I have got this one only just one point. As I told you, this is the equivalent circuit approximate equivalent circuit approximate equivalent circuit. But if you honestly look at the circuit, you will find this no load current is flowing through winding resistance as well, is not.

Because the exact equivalence circuit is what? R 1 x 1, then your this parallel branch is not suppose and then of course, these two are open circuited exact equivalence circuit. And you are doing on a that practical transformer whose exact equivalent circuit is this what we have done. Here we have applied a voltage and this current you are telling I naught fine, but then I will say look here this wattmeter reading W naught ok. We have done some approximation that I have understood, but this Watt meter reading strictly speaking, you will read the copper loss in R cl as well as copper loss in r 1.

Some of these two will be read is not, but what happens is this how to justify that why we neglect this copper loss. It is because of that in open circuit test, winding current is pretty small; maybe 2 to 5 percent of the rated current. But applied voltage is rated at rated frequency level of flux in the code is rated and it is the level of flux that decides the core loss. So, core loss will be much higher than these very small current causing a power loss in r 1.

So, we neglected the copper loss note that W 1. Practically records the core loss only; core loss. The copper loss which is also called copper loss the winding power loss the copper loss the loss I 1 square into I naught square into r 1 is much less compared to core loss, why? Because flux is rated as flux is rated and I naught is only about 2 to 5 percent of the rated current. Anyway please go through this part and try to understand each bit of it because this is the approximate equivalent circuit ok. If you forget about the exact thing from your mind it is it, then what meter this copper loss; I mean core loss only.

But that is not the case, there will be a little bit of copper loss in the winding which we are neglecting. We are attributing the wattmeter reading to be fully the core loss. We will continue with this with the SC test to determine these this parameters in the next class.

And remember that generally the reason, I have not told yet the open circuit test is carried out from LV side; from LV side means there you connect the supply HV side is kept open; anyway.

Thank you.