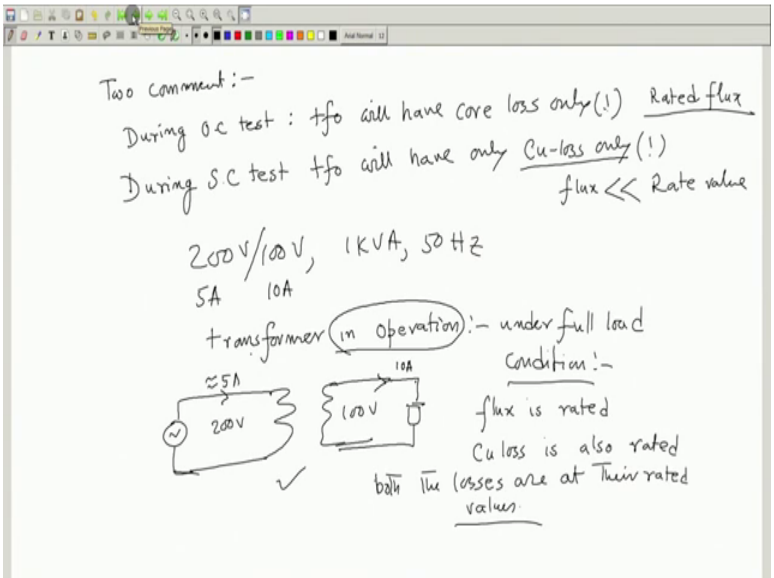
Electrical Machines - I
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Khargpur

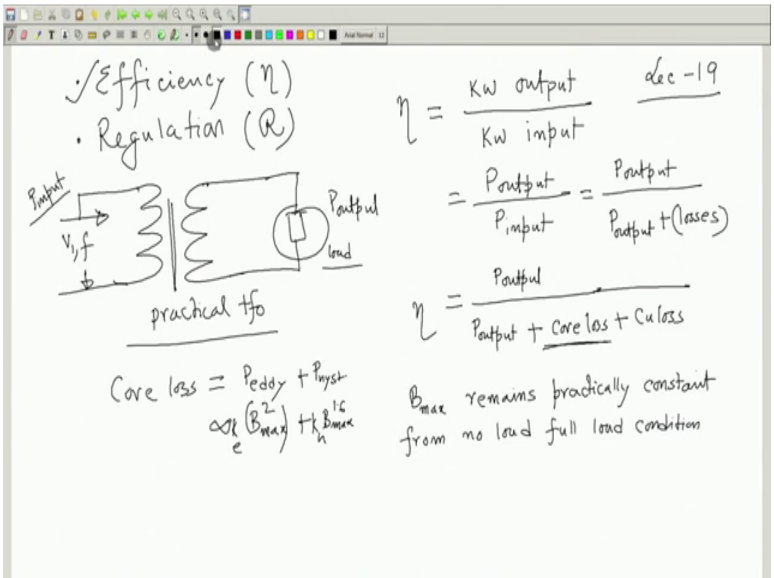
Lecture – 19
Efficiency of Transformer – Losses

(Refer Slide Time: 00:23)



Welcome to lecture number 19 and in our last lecture as you know I was telling you that when a transformer will be in operation both copper loss and core loss will be present. You cannot neglect during operation one loss with respect to another loss. Because, rated flux is there and hopefully you are efficiently using the transformer, so that rated current circulate by the coils. Our target will be to see such a condition prevail then only it will the transformer is in full operation, rated currents it is carrying, rated flux it has produced this is the way.

(Refer Slide Time: 01:13)



Now, today I will tell you, so equivalent circuit parameters I have found out. I will tell you now our next important topics will be one is called a efficiency oh, sorry (Refer Time: 01:30) the efficiency.

Student: (Refer Time: 01:33).

Efficiency no, anyway efficiency correct, efficiency of a transformer and another is called regulation this two are very important. It is usually denoted by this curly letter, these are the topics we will be discussing. Efficiency of a transformer what do I mean by it and another thing is called regulation, and I will be talking this in terms of the equivalent circuit of a transformer [FL].

But listen to me very carefully first I will take up efficiency. So, a transformer is as I told you it will be operating with load connected not under open circuit or and here you will apply rated voltage frequency during it is operation code is there, core loss practical transformer ok.

So, it is expected when the coils now to before I tell you about the efficiency, efficiency as you know who will be the kilowatt or Watt output; kilowatt output divided by kilowatt input or Watt input in whichever unit you do you always express in the same unit. This is the efficiency of a; what is kilowatt output power here; output power, so I write it P output P real power no reactive power, P output by P input.

So, what is P output, P output is here; what is P input, P input is here from the supply P input this is the overall efficiency of the transformer. These efficiency of course, if it is ideal transformer it will be 100 percent because there is neither core loss winding resistances are neglected, copper loss is also absent. So, whatever power will be drawn from the supply will be dumped to the load, so this is your load, efficiency would have been 100 percent. But in real practical transformer we have seen that when the transformer will be operating it will have both core loss and copper loss will be present [FL].

During short circuit test, so this can be written as P output this is how we will calculate divided by input is nothing, but P output plus losses is not. And this is equal to P output in kilowatt or Watt divided by P output plus core loss this I will break it up into two parts, core loss plus copper loss. This will be the expression for efficiency of a transformer [FL].

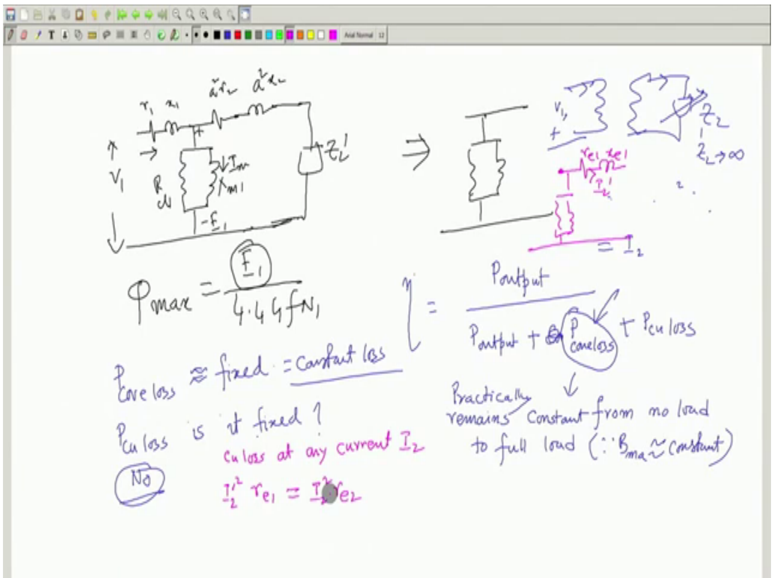
Let us first so, this losses are there therefore, efficiency will be less than 100 percent. Of course, as I told you in a very well design transformer efficiency may be as high as 99 percent so because it is a static machine, no friction loss core I mean wind age loss this things will be absent only core loss and copper loss. Windings will become hot, core will become hot, in normal operation as I told you at rated condition these things are there.

Now, first so let us see the losses first what happens to core loss? Core loss, as we know it is P eddy plus P hysteresis this two things. And it depends on B max; B max square this one this fellow and this fellow is also B max raised to the power something or in terms of area that B max it will be proportional 2.

So, core loss will be proportional to this things of course, the constant of proportionality will be different there I write k e here, k h here is not it will be proportional to; so level of b max is a crucial factor. Now, we know that B max remains practically constant this are also I pointed out earlier remains practically constant from no load to full load condition.

Is not core loss remains constant because the drop in that r 1 x 1 is little which gives you that the value of induced voltage z in the ideal transformer that may not be equal to v 1. Because recall that exact equivalent circuit of the transformer what is the exact equivalent circuit of the transformer? Let me go to next page.

(Refer Slide Time: 08:30)



Exact equivalent circuit is r 1 x 1 then your this parallel branch. Suppose refer to side one I am drawing this is a square r 2, this is a square x 2 is not, this the equivalent circuit and there is the your reflected impedance z 2 dashed. And this is R cl 1 X m 1. Magnetizing current decides B max and this voltage will decide what is the value of I m in the exact equivalent circuit here is your V 1.

Now, what do I mean by no load first, no load means secondary nothing is connected therefore, current ground will be the no load current. And when you connect load this current will now becomes earlier the current no load current was very little 2 to 5 percent this drop could be practically neglected. That is why the approximate equivalent circuit we drive earlier, but anyway what I am telling so, this voltage decides magnetizing current hence flux.

Now, what is the difference of this voltage and this voltage this is E 1 it is this drop, but r 1 x 1 are small even when rated current flows when load you have connected. There will be little drop here that will definitely decrease your phi, phi max is E by 4.4 f is not; if you go by this approximate what is phi max? Phi max is E 1 not V 1 by 4.44 strictly speaking f N 1. But this E 1 value will deviate from V 1 a little, no load condition it will be almost same as V 1 and during loaded condition a little drop here.

So, change in this phi max from no load to full load what is no load? z 2 dash is infinite it is open nothing connected, what is full load? You have connected such an impedance rated current flows. And when rated current flows there will be a drop here we agree to that drop. But r 1 x 1 is small therefore, there will be a voltage drop taking place in r 1 x 1 which will change E 1 a little, but phi max will decrease maybe by 2 percent 1 percent whatever it is.

So, the assumption that B max remains practically constant from no load to full load condition, full load condition you must have understood now when the coils will carry rated current and applied voltage is rated at rated frequency. So, flux is almost rated from no load to full load.

If that be the case then I will conclude that in the expression of the efficiency which is P output let me re write no problem P output divided by P output plus P core loss plus P copper loss of which I find that this P core loss will then remain constant;; practically remains constant from no load to full load, since B max remains constant got the point. Therefore, here is a loss which will be always taking place within the transformer. If it is primary is energized no matter whether you have connected a load on the secondary side or not, P core will be always there. So, that is why it is the loss has got two components.

So, one is a fixed loss. So, P core loss is fixed; is almost fixed will not break our heads a little change in P core loss from no load to full load no point in doing that because little change will take place. So, this loss is called the fixed or constant loss. Now, the other loss, what is this loss; P copper loss, is it fixed? The answer is no, why no? Answer is very simple.

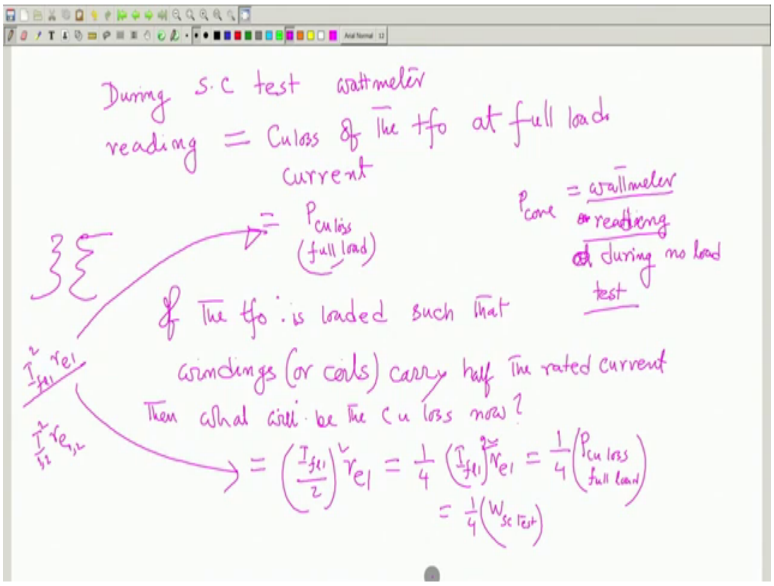
As you change the load the current I 2 and I 2 dash two will change, what do you mean by loading from no load condition z 2 is; I will draw the actual diagram z 2, z 2 you are varying to vary the load on the transformer. Here it is v 1 f 1 that is fine f, open circuit z 2 infinity switch is open. Then I will load it by decreasing this z 2 and your current will go on increasing and ratio of the currents are approximately the turns ratio.

Therefore, level of current will go on changing as you change the load on the secondary of the transformer. Then the copper loss which is in terms of primary side it will be I 1 square r e 1 which is same as I 2 square into r e 2 which is same as I mean I should write I 2 dash squared; I will write it like this. What is the total copper loss in terms of approximate equivalent circuit? It is copper loss no sorry, copper loss I will write with different colour, copper loss at any current I 2 on the secondary side will be I 2 dash squared into r e 1. Approximate equivalent circuit is this, this current is I 2 dashed here is the parallel branch.

So, I 2 dash squared r e 1 which is same as I 2 square into r e 2; I mean several ways you can write this. But the point to be noted here the magnitude of the current that you are drawing out of the transformer from the secondary side is proportional to the square of the current. So, as you change the load I 2 dash changes therefore, copper loss in the winding will be a function of current supplied.

So, copper loss cannot be a fixed loss, it depends upon what current you are extracting out of the secondary of the transformer it depends on that is that clear [FL]. After I have learned this, see there are many books to calculate the efficiency of the transformer in several ways this way, that way. I will give you a certain way a particular way of calculating efficiency which will make your life easier and also it will bring out the concept of degree of loading.

(Refer Slide Time: 18:36)



For example during short circuit test we have noted that Watt meter reading, what it was reading? It was reading the copper loss of the transformer that is winding copper loss or copper loss means winding loss of the transformer at full load current. Because during short circuit test you were windings were carrying rated current at full load current. Recall, during short circuit test, short circuit the one increase the input voltage from h b sides such that only apply that much voltage which will cause rated current flows in both the windings and whatever is the wattmeter reading I say that is the copper loss. So, that copper loss was calculated at rated full load current.

Therefore, so copper loss at full load current is this and this I call as P c u full load let me write in longhand, so that understood [FL]. After I have and P core is equal to the wattmeter reading it, so happens that wattmeter reading sorry, at during no load test is not because I have applied rated voltage rated frequency. So, flux remains same and wattmeter reading was reading only the core loss alone neglect the copper loss at that time. So, this is the thing and which is constant as you change z 2 P core will practically remain constant.

Now, the big question is this is the P copper loss at full load then what will be the copper loss when the windings will be carrying half the rated current. Because the level of the current the windings will carry depends upon what impedance we have connected on the secondary side. So, I can adjust the impedance connected such that it carries half the rated current, I will connect across the secondary of the transformer such an impedance that it carries half the rated current or 75 percent of the rated current what not got the point.

Now, I am asking you a straight question that if the windings are carrying rated current, then what will be the total copper loss? That copper loss I am telling full load copper loss when the coils carry rated current. Now, my question is if the coil, if the transformer is loaded let me write in more detail if the transformer is loaded such that windings or coils carry half the rated current. Then what will be the copper loss now; in terms of this full load copper loss how much it will be? See after all copper loss is some I square into r e. It is I 1 square r e 1 or same as I 2 square r e 2, I will not separately calculate I 1 square r 1 plus I 2 square r 2, what is the point after I have done this.

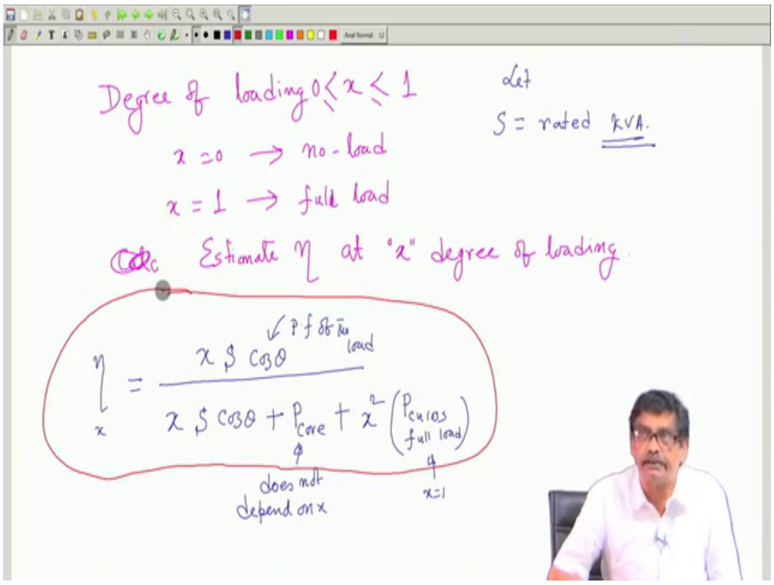
So, I will try to exploit this simple equivalent circuit no point in separating r 1 r 2. Because after all from open circuit short circuit test you cannot separate r 1 r 2 is not. It comes as r e 1 as a package r e 1 r 1 plus S square r 2 or r 2 plus r 1 by S square. See beauty is these that from the equivalent circuit when it is either 1 and 2 or it is either 1 and 2 take the corresponding values these is the copper loss.

So, at full load the copper loss is I full load suppose one side you are calculating r e 1 this will be the total copper loss and this I am telling it is this, this I have defined which I get from short circuit test. Now, I am saying that winding current is now made half. So, what will be the copper loss now? So, copper loss now should be I f l 1 by 2 whole square into r e 1 is not. If you make the currents half rated current if you have connected such an impedance on the secondary site such that the coils are carrying half the rated current r e 1 remains same.

So, I square into r e 1 will be the total copper loss that is it will become then equal to 1 4 into I f l 1 squared into r e 1 which is nothing but one-fourth into P copper loss full load. Getting the point this must be understood P c u copper loss at full load, if you know this is 100 Watt I am telling you if you are winding currents are half, then I will say the copper loss will become 100 by 4, 25 Watt.

If it is carrying three-fourth of the rated current, then copper loss would have been 9 by 16 into that rated current. And it so happens this becomes equal to 1 by 4 into wattmeter reading during short circuit test, it is not compulsory to write it like this, but this concept is important you define. Then copper loss directly depends upon the loading; degree of loading whether; now, the question is what is degree of loading? Degree of loading is I will use a number x this I must define degree of loading with respect to that rated current carrying capacity of the coil.

(Refer Slide Time: 28:05)



I will use a number x 0 to 1 and I will say x equal to 0 means no load, x equal to 1 is full load and x can have any values; x equal to 0.5 means it is 50 percent loaded the transformer is, although I told you transformer should be operated at full load condition that is why you have purchased the transformer. So, that it always operates at full load, but sometimes load varies on the secondary side then it is a nice way of telling the term degree of loading, got the point.

So, we would like to calculate try to estimate efficiency at x degree of loading. So, I will call it a like this I will write eta x, x equal to 1 corresponds to full load efficiency that way I will right. Now, this one will be the output, suppose let S is equal to rated kVA of the transformer. Then when it is degree of loading is x the output will be x into S; x equal to 1 means it is supplying rated kVA into cos theta power factor of the load, because in the definition of efficiency kilowatt I have to calculate supply to the load.

Suppose the transformer is supplying x S kVA to the load having a power factor of theta on the secondary side. So, this is the output then divided by x into S into cos theta output plus the losses of which two losses are there P core. P core remains constant it does not depend upon the degree of loading, no matter whether this is 50 percent loaded,100 percent loaded P core remain same.

Now, the question is I know P copper loss at full load; at full load means, copper loss this copper loss is at x equal to 1 when transformer is carrying rated currents. So, what will be the copper loss now at x degree of loading we have just discussed, if it is 50 percent loaded half loaded then one-fourth into these. So, x is a fraction and it must be multiplied then by x square this is the expression for efficiency of a transformer.

So, please try to assimilated this expression very clearly x is the degree of loading, cos theta is the power factor of the load and efficiency of the transformer at x degree of loading should be written x S cos theta, what is S? Rated kVA of the transformer. So, output kilowatt is how much rated kVA it is delivering at a power factor of cos theta into cos theta.

So, output divided by output plus losses got two parts; one is the fixed loss P core it does not depend on x. Let me write you know that, but still does not depend on x, and P copper loss full load I have defined at rated current copper loss is this then if it is loaded x degree of loading. Then copper loss at that degree of loading must be multiplied by x square where, x may be half three-fourth 40 percent 0.4 and so on. So, this is the most important formula, so far as efficiency is concerned and we will discuss further about this expression in my next lecture.

Thank you.