Electrical Machines - I
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Lecture - 23
Load Description and Energy Efficiency

Welcome to lecture number 23. And as you know, we were discussing about how to estimate the efficiency of transformers, power transformers and we found that the normal efficiency, we usually use power efficiency. And we found that efficiency at any degree of loading is like this; x S cos theta divided by x S cos theta plus x square P copper full load plus P core.

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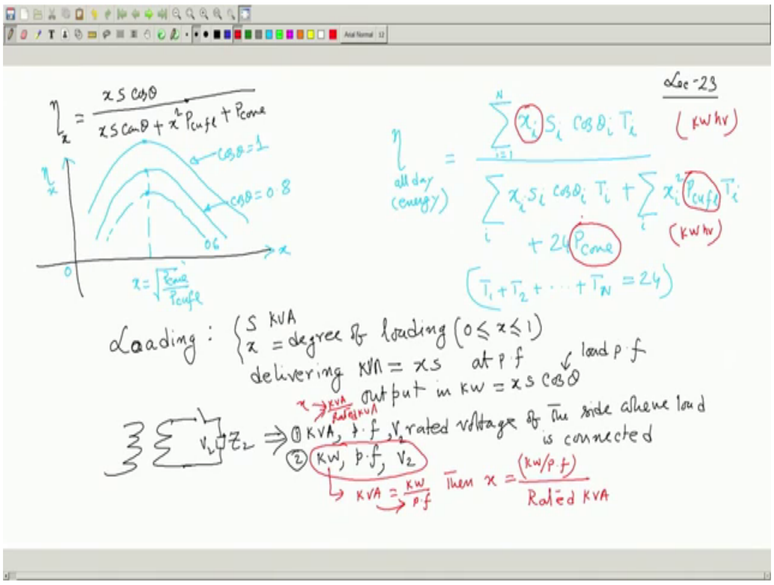

This is called power efficiency; output power in kilowatt divided by input power and we found that efficiency curve will be like this, this is some efficiency curve and I must attach to each curve the power factor, cos theta is equal to say 0.8 and I showed last time that for a given kVA this axis is x degree of loading and this is your efficiency and this is the value of x at which maximum efficiency occurs P core by P copper full load.

And if you repeat the same thing for other power factors, these curves will be some this may be power factor cos theta 1 and lower power factor it maybe 0.6 no point in attaching, leading or lagging. Efficiency will remain same and the maximum efficiency points of course, will lie always at this, this we have discussed.

And therefore, highest efficiency of a transformer will be occurring, when the secondary impedance or load connected is at unity power factor and the value of x is this number. At x into S kVA maximum efficiency will occur. Then we told you that the importance of energy efficiency, particularly with respect to distribution transformer, where the load on the secondary of the transformer will change as day progresses. For some interval of time it will be operating at degree of loading of x 1 power factor cos theta 1 for a duration of time, T 1 and we found the and that efficiency is called all day efficiency or energy efficiency.

And we found that this is, will be equal to the x i S i in a short form now, I am writing, because cos theta i, where i is equal to say 1 to N and the output so, this is into T i. So, you understand this and this one will be same thing here that is x i S i cos theta i, output energy this is energy. T i is the interval of time summed over i and plus the copper loss, which depends on the x should be equal to x i square P cu full load into T i. This is a energy loss, because of copper loss and plus 24 into P core that is all, because core loss remains constant.

So, this is summed over some in interval such that T 1 plus T 2 plus dot dot dot plus T N is equal to 24 like that. Anyway this complicated way, it can be I mean in a compact form it can be written, we have discussed all these things. Therefore, to judge whether, the transformer is good or not particularly, a distribution transformer, it is better you calculate all day or energy efficiency and see that that is quite high, that is how it is decided.

[FL] Before we proceed to discuss about regulation, only one thing I will tell see the a loading of a transformer I told you how loading is specified, loading. I told you, if the rated kVA is S kVA then x is the degree of loading degree of loading and this value is 0 to 1, 1 corresponds to full load and so on.

0 corresponds to no load therefore, transformer is delivering a kVA of I have assumed here delivering kVA is equal to x into S, if it is at power factor cos theta then I say output kilowatt, that was the essence of calculating that thing output in kilowatt. If S in kVA is a x S cos theta, cos theta is the load power factor, this we have discussed.

Now, sometimes load that is in other words what I am telling, the load on the secondary of a transformer is not, although I am drawing like this practical transformer, I was telling you to make you understand ok; there is some effective impedance connected this Z 2 maybe, because of some parallel loads. Anyway, in terms of Z 2 I told, but this load connected across the secondary therefore, is not really explicitly mentioned in terms of a complex impedance ok. If it is effectively, it will be some complex impedance.

In other words one way of a specifying this load indirectly is that you specify what is the kVA of the load and power factor as a here I have done or it could be one way of specifying load in terms of kVA and power factor, another way to specify load in terms of kilowatt and power factor, are you getting; that is load is 100 kilowatt 0.8 power factor lagging. You have fully describe the load and voltage is this voltage out of these and voltage is of course rated voltage like that of that side where you are connecting, rated voltage of this side where load is connected.

Therefore, say V 2 therefore, kVA power factor and V 2, from this I will be able to calculate what is Z 2 effective, but generally kVA power factor and the voltage at which the kVA is delivered will be specified. Similarly, it will be kilowatt power factor and V 2. So, if it is kVA power factor and V 2 for example, then this value of x why I am telling this, how to calculate the value of a degree of loading.

If you know the rated KV of the transformer and kVA it is handling at a particular interval of time, take the ratio get the value of x. However, there is a student sometimes make mistake, if the load is specified in terms of kilowatt power factor and V 2 to calculate x mind you must bring it to kVA that change we have to do. If kilowatt is given; so, kVA will be equal to kilowatt by power factor, you calculate then the corresponding x at which the transformer is operating is this kilowatt by power factor by rated kVA this kilowatt by power factor divided by rated kVA.

This is value of, this you remember and there are very nice problems given in a book which is o popular you know Parker Smith's book problems on electrical engineering very famous book and very nice problems are there.

The beauty of this book is in each problem, if you solve open circuit, short circuit test, efficiency calculations, you will learn something new. So, please solve as many problems as you can from that book apart from the fact that we will provide you some tutorial problems, whenever it will be required, but this is the thing. So, you must remember this load is not specified in terms of explicit value of Z 2.

How it will be specified? I will say a load consumed so much kVA at this much power factor at this much voltage. Therefore, from this I will be able to calculate Z 2, but I will not do that, because to calculate efficiency, I do not require Z 2 in terms of kVA and power factor and degree of loading this x is to be known. However, from kVA whatever kVA here, it is operating what is the value of x, if the load is specified? It will be simply this kVA whatever it is divided by rated kVA, that will be your x here.

For this load, if load is specified in terms of kilowatt power factor and V 2 then kVA will be kVA at which it is operating is kilowatt by power factor and then x corresponding to this load will be this, but I will insist that better do not memorize this formula, never do it. Each time if the load is totally described over the 24 hours, 41 hours, it is x 1 degree of loading T 2 hours x 2 degree of loading.

So, my target will be to calculate x 1, x 2, x 3 depending upon the load, it is handling at different intervals of time and I hope you have understood how to calculate that degree of loading and use it here, this is energy efficiency kilowatt hour on the top divided by kilowatt hour on the down. Core loss remains constant and finally, once again repeating that what is this P cu full load, when the windings will carry rated current work is the power loss that you will get it from your short circuit test.

What is P core? P core is the reading of the wattmeter under no load test. So, with that comments we conclude this part of this lecture that is the efficiency; how to calculate, estimate, this that. Now, what I will do is, I will try to calculate another important thing that is called regulation of a transformer.

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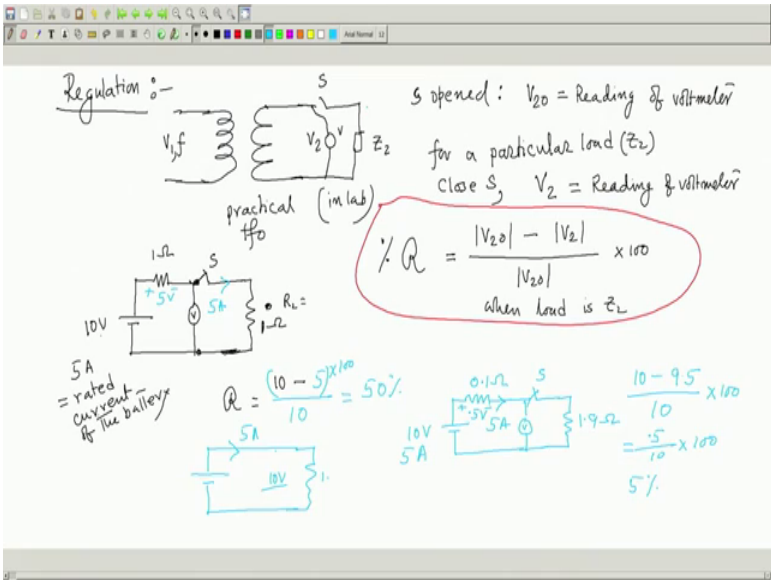

So, next topic is regulation. We know that the transformer has got internal impedance. These are practical transformer that is the winding has resistance, there will be leakage flux, R 1, x 1 magnetizing impedance all things will be there.

Now, what do I mean by regulation? Suppose, you apply the rated voltage at rated frequency, always apply rated frequency and note down this voltage with no load connected with S open suppose, I what I am telling is what is regulation of a practical transformer and suppose, I am, I want to find it out in the laboratory what does that really mean that is what I am telling.

What you do? You apply rated voltage at rated frequency in practice ok, in lab. We have energized with rated voltage and frequency with S open, S open measure this voltmeter reading, you connect a voltmeter here. With S open this voltmeter reading whatever you will get I call it V 2 0.

Note down this reading, is equal to reading of voltmeter. Note down this reading magnitude of what is this voltage voltmeter reading across the secondary here, is the voltmeter connected. Then connect a particular load; for a particular load that is Z 2 or in terms of kVA, kilowatt power factor, etcetera in whichever way it is specified connect that load close S 2 and measure once again the terminal voltage.

Reading of voltmeter I mean not S 2, close S, V 2 is the reading of voltmeter with S closed, what do you think will there be a difference in the readings of the voltmeter because I have not done any mathematics to get some expression for regulation nothing I have done, I have connected a load in the laboratory, applied a fixed voltage, rated voltage at rated frequency.

What I have done is with S open I have noted this voltmeter reading with S closed same, voltmeter reading I have noted with load connected and will there be a difference; it is expected to be, because of the fact it is a practical transformer. Therefore, there will be voltage drop in the series impedances in the model of the equivalent circuit of the transformer.

That is in r e 1 and x e 1 there will be a voltage drop and hence, it is expected there will be a change in the difference in the magnitude of this voltage. So, what you do you calculate this change and divided by the open circuit voltage, with respect to that how much voltage, the change in voltage how much it is and you get regulation, this is in per unit. So, multiply it with 100 get regulation percentage regulation, this is the thing.

So, in a practical setup, you can easily calculate regulation easily we will see, but this is what you have to do imagine at least you can do this; apply rated voltage rated frequency. Generally, regulation is to be calculated with the rated current it is handling rated kVA and load should be very clearly specified. So, I will say this is the value of the regulation at, I must add to it at the when the load is Z 2 I mean let me write like that. When load is Z 2 at a given load, because if you change Z 2 itself it might give you some other value the change in dropping voltage may give you other values, we will see that.

So, for a given load you can calculate regulation of the transformer. Regulation is best understood what exactly is means is suppose, you have a battery what I am telling you have a battery, you have its internal resistance 1 ohm and suppose a source of dc voltage. Suppose, this voltage is 10 volt and its internal resistance is 1 ohm suppose internal and these are the terminals of the battery.

And suppose, the rated current, the battery can supply is 5 ampere equal to rated current of the battery, but so, this is the rated current of the battery I know. So, I have connected the switch I will connect here a load [FL]. What should be the value of this resistance, because the battery can supply and you connect a voltmeter here. With S open the reading of the voltmeter will be 10 volt, it is open circuit.

So, regulation is this 10 volt open circuit voltage minus when you close the switch. Now, how much resistance can I connect so that current will be rated current, at rated current, because battery can supply rated current I will be always trying to draw rated current that is what I told. So, so 10 by maybe 9 ohm you connect oh no, 9 ohm another 1 ohm suppose, load resistance is 1 ohm it is a bad way. Anyway, whatever number I have taken let us stick to that.

So, what will be this resistance 1 ohm. So, when the battery will supply rated current with S closed the current in the circuit will be how much; 5 ampere, is not? 5 ampere will be the current and what will be your output voltage; 10 minus this drop that is another 5 volt here. Therefore, with S closed this voltage will be 5 and divided by 10 and I will say regulation is 50 percent, are you getting?

This is into 100 and I will say oh, this is a very bad source. You thought you will supply your load with rated voltage, is not; but at the moment you connect load the voltage drops from 10 volt to 5 volt, it is not a good source. A good source will be perhaps oh sorry, you same battery you take another battery.

Suppose, there is another battery which has got internal resistance say a 0.1 ohm are you getting and here, I will connect load, same battery can supply 5 ampere current, internal resistance is small then what will be the voltmeter reading here. With S open same 10 volt, with S closed and here how much resistance should I connect so that it will be 1.9 ohm.

If you connect, you close it. So, once again you are supplying 5 ampere to the load but the voltage drop here it will be now 0.5 volt. Therefore, output voltage available will be 10. So, with load connected this voltmeter reading will be,

Student: 9.5.

Ah?

Student: 9.5.

7?

Student: 9.5 sir.

9.5 volt. So, 9.5 volt divided by 10 and you see into 100 regulation is now quite small 0.5 by 10 into 100, it will be 5 percent, 5 or 0.05; 5, 5 percent. Therefore, you have connected you have purchased a source to supply load and whatever this your source is capable of delivering current that you will draw and you would like to see across the load almost this open circuit voltage comes.

So, this source is better than this source, are you getting? Therefore, regulation value unlike efficiency it should be as small as possible. For example, if it is an ideal battery nothing is better than that so far regulation is concerned. If it is an ideal battery no internal impedance then you can whether you connect load or not this voltage will be 10 volt always.

So, regulation is 0. We will address to this problem whether it is better to have a source having zero internal impedance or not, that is the another thing to be discussed but it looks like that from no load to full load if at all a change takes place in the magnitude of the voltage across the load that should be small. So, that it can maintain voltage there.

So, in this case of transformer it is nothing but the load sees what load will see; load will see a series impedance and there is a source of voltage here. Therefore, there will be voltage drop in equivalent resistance and leakage reactance of the transformer and therefore, the magnitude of the voltage available across the load from open circuit to that loaded condition is bound to change and that change we would expect will be less. Now, we will go to find out an approximate expression of regulation. So, we will continue with this.

Thank you.