Electrical Machines - I
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Lecture - 21
Condition for Maximum Efficiency when Load Power Factor Constant

Welcome to 21st lecture on Electrical Machines - I.

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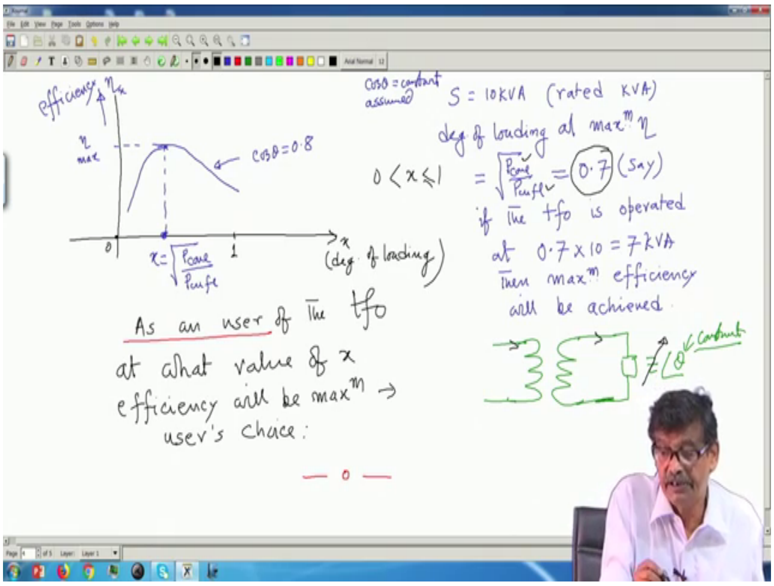

And we are discussing about how to estimate the efficiency of the transformer and if you see the previous lecture, this is the end result I have got that efficiency versus degree of loading. And we found out that efficiency will be occurring at maximum value at certain value of x; x as you know is a number between 0 to 1 equal to I mean full load condition.

Then finally, I was saying that, if you sketch an efficiency versus degree of loading curve this is degree of loading, curve, do not forget to attach at what constant power factor we have plotted this curve. Because in that derivation I kept cos theta constant maybe it would be cos theta is equal to 0.8 if this constant where is the magnitude of z? Is it not and that is very r and x of the load of this load such that x by r ratio remains constant that will ensure the power factor is constant, but anyway this is the curve we have got for a given power factor constant. Now I am asking you that while purchasing a transformer should I also tell the manufacturer that design my transformer in such a way that the value of x at which maximum efficiency occurs this is so much number that is this was the last thing.

What is my choice? User's choice should be what; user's choice. It depends I told you that how this transformer is utilized; now the things will be clearer from this.

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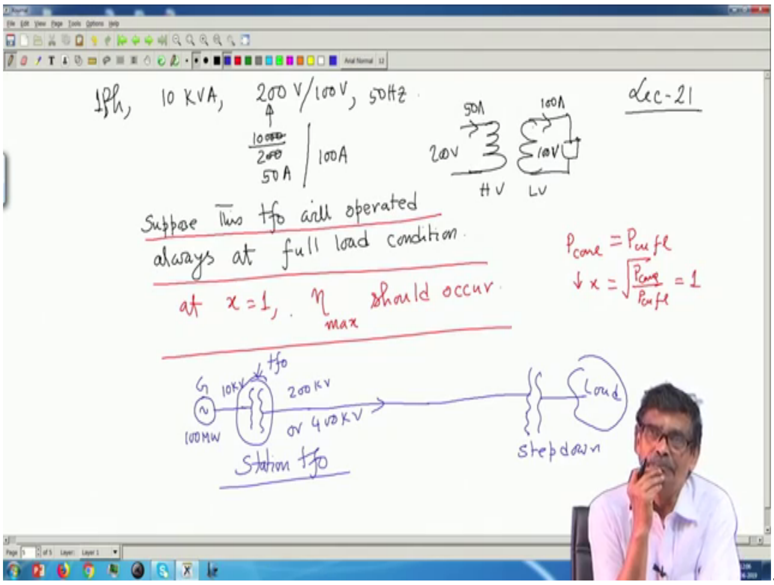

Suppose I say I have a transformer say let me take that simple example, 10 sorry I will write it as a 10 kVA. Let me take a transformer whose rating is single phase transformer; 10 kVA and say 200 volt just so that we play with the numbers to easily understand what I am meaning.

So, single phase transformer 10 kVA, 20 Hertz. I told you the moment you know you know the rated current always do that. So, 10 by 200 So, 10,000 by 200 will give you the rated current of the high voltage side 50 ampere it is and of course, the rated current of the LV side will be twice this amount 100 amperes. Suppose this is the rating of the transformer.

And I have purchased a transformer and I know this transformer I will use at full load condition for all the time 24 hours a day. Suppose this transformer I will use it, continuously at full load condition this is LV side this is HV side and this is 100 ampere and this is 50 ampere, this is the 200 volt side, this is the 100 volts. Always sketch something of this sort to understand what is happening. Suppose I say I have purchased a transformer in industry I will use it and it will be continuously operating at rated condition. Suppose this transformer will be operated always at full load condition and that is what is expected, you have purchased a 10 kVA transformer whose current ratings are 50 ampere, 100 ampere.

So, you would like to operate the transformer at full load, not that this transformer you half load it and continuously done, then you should have purchased a transformer having lesser kVA rating, but since you have purchased it looks like you will be using it always at full load condition.

So, suppose this transformer is to be operated will be operated always that full load condition, that is always it will be handling 10 kVA then the question is at what value of x I should demand that the transformer should have maximum efficiency? That is the question naturally I should ask and the answer to this is very simple. If you know which transformer will be operated continuously at full load condition, then say at x equal to 1 eta max should occur. Is not it? Therefore, a transformer which will be always operating under full load condition say in industry 24 hours it will be put to use, then while ordering this transformer say the to the manufacturer that see look you design the transformer in such a way that P core and P copper at full load they are equal so that x will then be equal to 1, is not it?

For example, you remember one of the uses of the transformer is in power system. See you have generating I will draw a single line diagram to further emphasize this point. A generator is there in a generating station then what you do that generated voltage is of the order of say 10 kVA or so 50 Hertz, here the voltage level is 10 k VA.

And suppose its rating is 100s of megawatt, you want to transmit. Generally generating stations are located at a far off place from the place where this power will be actually utilized. The distance between where this power will be utilized and the generating station may be 100s of kilometers or more. Therefore, this 100 megawatt of power should be transmitted over a long distance.

And suppose the generated voltage is the is of the order of 10 kV , but to transmit this large bulk amount of power over 100s of kilometers at voltage level of 10 kV is not economical at all, why? Because whatever currents see approximately this power divided by voltage gives you the current ok, power factor will be there in ac circuit make it assumed to be 0.8.

So, this power divided by this voltage gives you some idea of the current that will be flowing through the transmission line and transmission line over 100 kilometers of length will have some resistance. And just to transmit the power from generating station to the load center, here the load center where this power will be used there will be considerable amount of power loss in the transmission line.

And you cannot afford so it will become a very inefficient system of transmitting power bulk amount of power of this order. So, what is done? Here at the generating station itself there is a transformer first connected generator then this voltage is stepped up. I am drawing a single line diagram and this voltage is stepped up to a very high voltage may be 200 kV or even in our country we are having 400 kV level voltage.

So, there here is the transformer who does this. In transformer kVA remains same. So, current in this side will now become less and then you transmit it. But of course, at the recipient this 200 kV or 400 kV cannot be utilized directly you have to have another transformer or multiple transformer to step down the voltage, step down. at appropriate level of voltage so that that power will be utilized.

Now, therefore, this transformer if you look at these are called station transformer power station transformer. This transformer perhaps will be operating 24 hours a day almost at full load condition. Therefore, I will demand that this transformer then should have maximum efficiency occurring at x equal to 1 reasonable demand; because any device you would always like to operate it at maximum efficiency condition so that losses are minimized and so on.

Therefore, in such cases x equal to 1 will be a good choice, but also see in a some industry a transformer is used to step down the voltage to a; step down or step up a voltage to a particular level. And here in shift duty things will work and a particular transformer will be always operating at full load condition whatever the load on the secondary of the transformer is, ok.

Therefore in such cases I will say x equal to 1, but if that be the case and the argument I put forward earlier that you are purchasing a transformer and you must see that it is always operating at full load condition. But what happens is this, this is sometimes not in your hand. I will give you an example.

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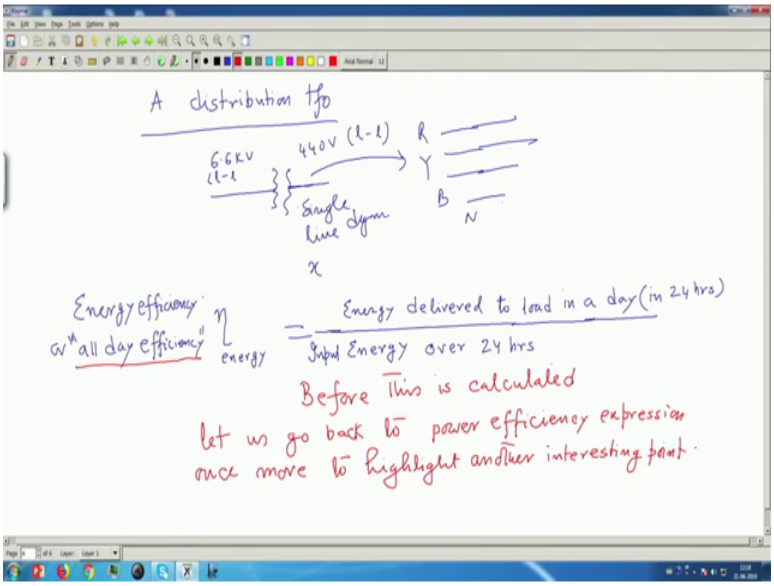

A distribution transformer for example, a distribution transformer is that transformer from the secondary of which all the households are supplied power; in your house, in my house ok.

So, what happens is this, the voltage may be at 6.6 kV of a distribution transformer and this side voltage is 440 volt line to line and this is also line to line voltage. We will discuss about the connection this at later, but let us try to understand. Now the secondary of these between R and neutral a group of houses are supplied power from Y phase and neutral another group of houses or residential buildings are supplied, offices are supplied (Refer Time: 14:42) another so that is the another job that is to see that loads are almost balanced.

So, here this thing is 3 terminals come, 4 terminals come out from this side actually. It is a single line diagram just to emphasize this point; single line diagram. Here R, Y, B and supply neutral is there. So, loads will be connected between R and N so that the supply voltage in our houses are 220 volt level, is not? Residence, all the fans, lights they are designed for 220 volt.

So, it will be there and those will become the load of the distribution transformer on the secondary side. Now if you see the nature of variation of load on the secondary of such a transformer that will change over a day I mean it will be a very large changes taking place all the time. For example, you can easily see the load on the secondary of such a transformer will be almost 0 during (Refer Time: 16:12) hours of the night that is say midnight and behind.

Because no lights loads will be there, all people will be taking rest. Maybe some AC, this that now a days will run, but compared to daytime loading or evening loading where people come back home, all electrical loads are switched on, this that. So, there will be a huge fluctuation of load from no load to some peak loads, then some medium degree of loading that is the value of x will go on changing with some time intervals.

But the point is you do not know whether in the midnight the engineers sitting in the substation will not take decision like this that in the mid time load is less. Therefore, let me put this primary side off so that no losses take place. No, you cannot do that. You have committed that you will supply power to every residential complexes at a fixed voltage and fixed frequency and at all times during emergency situation you have to switch on the loads in your house.

Therefore primary is to be kept energized all the time whether secondary of this transformer is loaded or not it is a compulsion, on the part of the company which is selling electricity to usual consumers, he cannot say that he has; he is duty-bound to keep its primary of the transformer energized all the time, although he knows that sometimes load will be very less sometimes load will be very high.

Therefore in such a scenario, that is what do I mean by load changing; x is changing and it is not in my hand, it is in the hands of the consumers. It also depends on the season ok. During winter that variation of load on the secondary of the transformer will be level of load will be much less, but nonetheless you will be prepared with primary energized thinking that some consumer may switch on load at any point of time of the day.

So, this is the thing. Now the question is in such a situation where x is in not in my hand while purchasing the transformer at what value of x should I demand that efficiency will be maximum? Certainly x equal to 1 at full load condition you should not demand that because you are fully aware that the load on the secondary of the transformer goes on changing; sometimes very light load condition almost no load, sometimes full load ok, full load will be there even in peak and so on.

But some other time it is medium degree of loading maybe x equal to 0.3, 0.4 transformer will be operating. Therefore, perhaps x equal to if we asking for efficiency to occur maximum at x equal to 1 that is at full load condition will not be a very judicious demand at the time of ordering the transformer, may be x equal to 0.6 will be a good thing.

Anyway for a distribution transformer I told this is a typical situation but for a dedicated transformer used in industry 8 hours shift duty and all the trying the transformer is on and under full load condition yes, you can very concretely say that I will buy a transformer with x equal to 1 that is its maximum efficiency must occur at x equal to 1 that is at rated condition.

But here is another extreme example where a distribution transformer secondary supplies different consumers and the degree of loading on the transformer goes on changing and goes on changing widely you do not know, but your primary is to be energized. Now to qualify a therefore, another efficiency is calculated for such transformer where load fluctuates over 24 hours with primary energized continuously and that energy that efficiency is called therefore, a distribution transformer is to be judged from not the ordinary efficiency that I have told you and there is another efficiency called energy efficiency, eta energy.

That is better judge a distribution transformer by its energy and it is defined as energy delivered, energy delivered to load in a day, because load will fluctuate that is in 24 hours divided by energy input energy over 24 hours over same 24 hours. Therefore, a distribution transformer perhaps should be energy is to be calculated, efficiency is to be calculated in a different way. We will discuss about this, this is sometimes also called energy efficiency or this is called energy efficiency or all day efficiency, clear?

We will discuss about this, what this how to calculate energy delivered to the load in 24 hours and input energy over same 24 hours of length. And from this we will try to say whether this distribution transformer is good or not, that is the idea. But before that one point about that normal efficiency if you look at this curve and this I will leave as an exercise to you ok, I will draw like this.

Before I discuss this topic, before this is calculated. Let us go back to power efficiency expression, once more to highlight another interesting point, ok.

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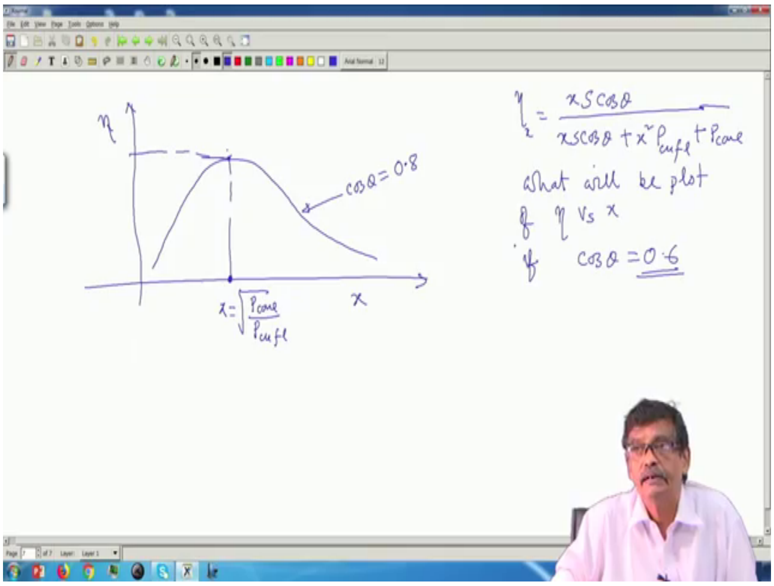

So, let us see what is this. We have seen that efficiency curve will be somewhat like this, it will have a peak and eta x as you know let me write at any degree of loading it is like this. This is the output kilowatt, plus x square P cu full load plus P core, P core constant we know that And I told you you do not forget to attach at what power factor angle this curve has been drawn may be 0.8 and this is degree of loading x and this is efficiency eta.

Now the question I will ask you ok, suppose this is the efficiency versus x curve at point power factor 0.8 gladly it does not matter. At a given power factor 0.8 this is the curve and this is the value of x, what is that? That is P core by P copper full load repeating once again do not feel bored, P core is the reading of the wattmeter from the no load test, P copper full load is the reading of the wattmeter from short circuit test.

And these two numbers you divide, take square root, get this point. This degree of loading eta max occurs, is it not; for this power factor. Now the question is suppose I vary the power factor, at cos theta equal to 0.8 suppose I do the same exercise what will be the plot? The plot of eta versus x if cos theta I change it to see 0.6.

I can do that once again repeat the exercise, keep cos theta constant, where this curve will be will it be above it, will it be below it and things like that; are you getting? Now what I am telling for a particular power factor this is the nature of the curve. First thing is this one, where it will be suppose I am not yet very clear about that but about one thing I am clear.

If you repeat the same plot with cos theta equal to 0.6, I am sure about one thing; the load at which the maximum efficiency will occur when cos theta equal to 0.6 will once again be this point only. It is at this point maximum efficiency will occur for all the power factors no matter what the power factor is. If it is 0.8, it is here. Now I am asking you what will be its value if the power factor is 0.6; you think about this and we will continue with this.

Thank you.