Electrical Machines - I

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Lecture - 05
Equivalent Circuit of Ideal Transformer

Welcome to lecture 5 on Electrical Machines - I, where we were discussing about transformers. And in fact, we were discussing about Ideal Transformer, ok, so ideal transformer.

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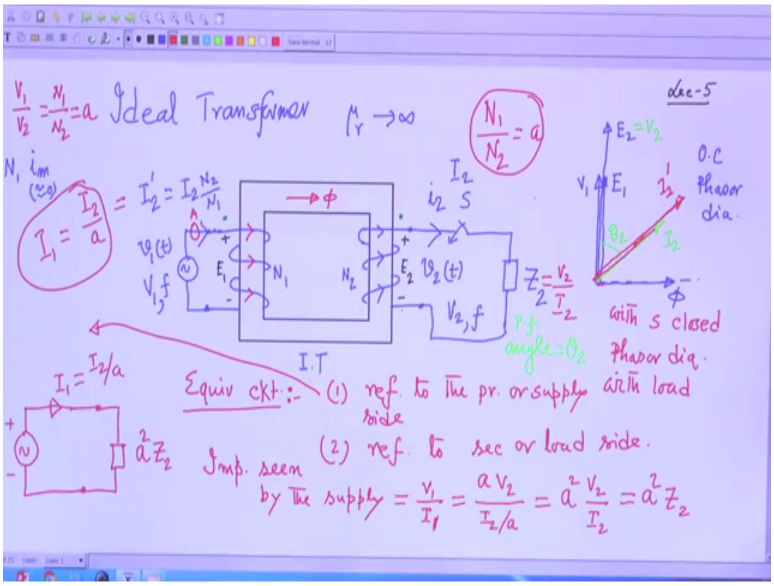

So, ideal transformer is that transformer where magnetizing current required these vanishingly small, there is no winding resistance, there is no leakage flux. And another thing I did not tell, but right now I can also add that there is no cold loss, there is no cold loss in the magnetic material in the core.

We will see what cold loss is later which comprises of ad current and distresses loss. And those losses are neglected, winding resistance neglected and magnetizing current required is very small because the permeability of the core going to change to going to be very high. So, to establish the flux you practically do not require any magnetizing current.

In my last class this was the thing I did this is the ideal transformer, ideal transformer and therefore, under no load condition the phasor diagram I drew it was like this, this is the applied voltage V 1 and this is the induced voltage in the primary which is also of same length as that of V 1 and that is E 1. Secondary induced voltage E 2 having N 2 turns and this is N 1 turns secondary induced voltage will be also in phase with this. Of course, its length will be different maybe more than V 1, maybe less than V 1 depending upon whether N 2 is greater than N 1 or not. So, this is the applied voltage.

And the magnetizing current will be lagging 90 degree, but in this case it is 0, there is no magnetizing current. And in my last class, so this is the open circuit phasor diagram, OC phasor diagram. Of course, magnetizing current is 0, but flux is here, is not. Why? Because after all purely inductive circuit whatever little magnetizing current drawn that will be 90 degree lagging the applied voltage and therefore, phi will be here, phi is finite nothing like that because you are using very best material having newer tending to infinity. So, this is the open circuit phasor diagram.

Then I told you, so to establish this flux phi mmf necessary was equal to N 1 into that i m which is vanishingly small, ok. Let it be there, but that mmf was necessary to establish this flux. Then when you close the switch here is a EMF available and there is an impedance here Z 2 therefore, there will be current in the circuit, instantaneous current is i 2 or phasor representation is capital I 2. This current will be delivered to the load.

But the moment some current is drawn from the secondary primary cannot remain silent cannot see it idle. The moment it does, so primary will also draw an extra current whose value will be I 2 into N 2 by N 1. This current it will draw and the direction of the current are like this. Therefore, two extra a mmfs come in to play in this magnetic circuit. What is the mmf of this coil? N 2 I 2. In which direction? Anti-clockwise direction. And what is the mmf produced by this coil? It is also N 2 I 2, but in this direction. Therefore, these two mmfs cannot result into flux and primary original that vanishingly magnetizing current will produce that necessary flux, is that clear.

Therefore, secondary if you load primary will draw extra current and this is called reflected current drawn from the supply. Mind you, all the EMFs this dot conventions also we discussed like polarity we fact in instant this is plus this would be plus. So, through the potential of this point with respect to this; I will define potential of this point with respect to this. And secondary current I will think it is living the dot that is the convention I have adopted, and if the current lives through the dot it must invite current from the source into the dot on the primary side, so that these two mmfs balance off. Therefore, this was the open circuit phasor diagram with S opened

Now, with S closed the phasor diagram will be the currents I have to draw. So, current will be, first I draw the secondary current. Secondary current will be lagging this V 2 voltage E 2 is equal to V 2 mind you, by the power factor of the load current this will be your I 2, ok. So, this I 2 will lag V 2 by the power factor angle of the impedance which is theta Z. So, this will be I 2. And what will be the primary current? Primary current will be let me use other colour, it will be in same phase with that of I 2, but its length will be different because it is multiplied with the ratio N 2 by N 1.

So, if a N 2 is greater than N 1, it will be like this will be your I 2 dashed, but with respect to time they are co-phasor. The mmf produced by because it has to be, because that all times it has to balance of these two mmfs. So, that the flux does not change. Therefore, whether the switch is opened or closed flux in the core remain same, same flux. And this flux to create this flux you require a vanishingly small magnetizing current into N 1 that is the mmf necessary. So, everything is now in place.

So, this is the phasor diagram with this red things with S opened, S closed or we say phasor diagram of the ideal transformer phasor diagram with load, with load on secondary side. Load only can be connected on the secondary side that is the thing. So, so this in simple terms is the phasor diagram of an ideal transformer under no load and loaded condition.

Now, after we have learned these what I will do I will tell you one very interesting thing. Therefore, in this ideal transformer when S will be opened what will be the ammeter rate suppose somebody has connected an ammeter? With S opened what will be the ammeter rate? 0, because ideal transformer no magnetizing current is necessary. When you close the switch what will be the ammeter reading? It will be I 2 dashed that is decided by the secondary current I 2. Now, also we define one thing N 1 by N 2 henceforth I will call that is called the trans ratio I will denote it by this small letter a, ok. Therefore, this I 2 dashed is nothing, but I 2 by a, ok. So, this is the thing.

Now, I will tell you about one very important thing that is what is the equivalent circuit of this ideal transformer. So, equivalent circuit I will now tell. Now, equivalent circuit generally we say with respect to the referred to the primary side one is referred to the primary side primary or supply side. And secondly, also equivalent circuit referred to the secondary side secondary or load side. I will tell you what does all this means.

See, here is a supply and then you have connected a transformer then on the secondary of the transformer there is Z 2 and this two coils are not electrically connected. They are magnetically coupled, so energy is transferred from the source to the load side via this flux, flux communicates with the second coil time varying flux and you get voltage and power in this secondary side. Now, if you look from the supply end supply side supply does not know whether you have connected a transformer and then across this secondary side you have connected a load.

What it only knows is that here is a supply and I am supplying a current I 2 dashed when S is closed and this I 2 dashed I will call it I 1 in this case, primary current. So, I 1 is equal to I 2 by a and if I 2 is 0 with S opened I 1 also vanishes. So, supply will always, supply is totally unaware of the fact that there is a transformer and the load connected across the secondary. It will interpret that as if across the supply V 1 you have connected a load and it is delivering a current I 1 that is all.

Therefore, from the supply side that is this one I will I i can draw it like this, here is a V 1 AC rms voltage it is supplying a current I 1 when S is closed. Therefore, it will interpret that you have connected an impedance, impedance seen by the supply, impedance seen by the supply is equal to V 1 by I 1. He will say oh, somebody has connected across me a an impedance and that is why I am delivering a current I 1, that is all V 1 by I 1, ok, but V 1 by I 1.

Now, what I can do is this I know that let me be on this page only let it be a bit dirty, but we are following logically. So, it will be easier for me to establish this important relationship V 1 by I 1. But I know that V 1 by V 2 is equal to N 1 by N 2 is equal to a, this I know. Therefore, I can say that V 1 is equal to a V 2 I can write (Refer Time: 16:03) divided by I 1. Similarly, I can express I 1 in terms of I 2 because I 1 is equal to I 2 by a.

So, I will write it as a I 2 by a. And this then becomes equal to a square into V 2 by I 2. But it is V 2 by I 2 which is Z 2, is not, this Z 2 is equal to V 2 by I 2. So, this is very interesting. Therefore, in this transformer if you connect a load across the secondary of magnitude Z 2 that load will appear to be different impedance across the source V 1.

What is the value of that impedance? A square into Z 2, suppose we have connected 10 ohm impedance, trans ratio is say 10, small a is 10 then a square means 100, so 100 into 10 it will appear to be an 1 kilo ohm resistance across the supply.

So, the equivalent circuit referred to the supply side it means that across the supply what is the effective impedance that has been connected a square Z 2. In other words, what I am telling is that, this supply you make a circuit like this your supply will not be able to distinguish between this simple circuit and this whole circuit. So, for as supply side is concerned, because here also V 1 applied voltage current supplied by t psi 1 then transformer then load V 2, then Z 2 etcetera, but in simple terms it is as if you have connected an impedance across the source whose impedance value is a square by Z 2 and this I 1 is equal to I 2 by a.

So, this is called the equivalent circuit of the ideal transformer your actual circuit is these, but you can to simplify matter. So, coupling circuit drawing this that to find out the currents in the circuit. You draw the equivalent circuit referred to the source side primary side, if you have connected an impedance Z 2 here, solve this simple circuit where it is a square Z 2, get the current I 1 and we have solved the problem. You may only ask that, but my actual circuit was this, so I have solved for I 1. But you have solved for I 1 you can easily calculate I 2 simply by multiplying these I 1 with this small a, that is the duty of this particular method of analyzing the circuit.

So, to analyze this circuit you can live with the actual circuit and go by this physical argument I 2 by a mmf balance solve this things you do get the current here, get the current there, and power also you can calculate if you like all the things you can do. But here is a nicer way of solving the circuit. What is that? Broadly equivalent circuit referred to primary if there is Z 2 any impedance on the secondary side multiply with a square. What is a? a is N 1 by N 2 trans ratio.

And then solve this simple circuit V 1 by a square Z 2, you will get I 1. Then you ask yourself, I have to solve these circuit currents in every parts of this circuit then what you do. I 1 is known you can easily say what this I 2 will be because there is a definite ratio V 2 in I 1 and I 2. So, it is useful to draw the equivalent circuit and solve big networks problems which are using transformers, ok.

After you have done this then you may also think. So, this is the equivalent circuit referred to the supply side. Similarly, one can see from the load point of view if you sit on this impedance you know you have been supplied with a voltage V 2 before that there is a transformer it is not going to change the current in the circuit.

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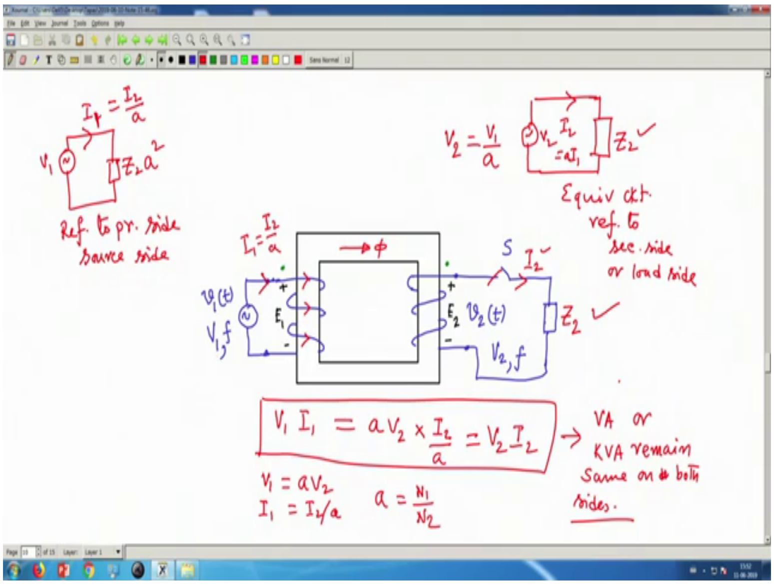

Therefore in the next page if I go, come to the next page. So, I will now tell you what is the equivalent circuit referred to the load side. So, this was by Z 2, this was this switch is closed, this is I 2 and recall this current is I 1 which is equal to I 2 by a, this we have done right now and this is the situation. So, with respect to the supply the equivalent circuit we have just got V 1, and an impedance Z 2, and this is your I 2. So, this is referred to primary side.

Similarly, I can think that impedance from the load side here is an impedance Z 2 and it is supplied with AC voltage who bothers about transformer before that I am not concerned. My current here is decided by this voltage V 2. Then solve this circuit, but how to solve this circuit? Z 2 is known, but V 2 I know this V 2. What is known to me? V 1; so, V 1 by N 1 into N 2 is your V 2, is it not. So, V 1 by a I will do and get V 2 and then I will solve this simple circuit. Because mind you V 1 V 2, E 1 E 2 they are all in time phase. Therefore, I will there is suppose take the voltage on reference phasor. So, all are magnitude and angle. So, this divided by Z 2 you do, you will get I 2 then he will ask oh that is fine, but I have to solve for currents this is the actual thing. So, we have solved for I 2. The moment we have solved for I 2 your I 1 is I 2 by a that is all, are you getting.

So, you can either draw the, so this is equivalent circuit referred to secondary side, secondary side or to load side, load side and this is the equivalent circuit referred to primary side or source side, source side.

So, rule is very clear. Any impedance you bring from the secondary side to the source side, you multiply it with a square Z 2, it should not be Z 2, a square into Z 2. And this current is I 1. And how it is related with this I 2 by a? And any current actual current on this secondary side should be divided by a. And any impedance from the secondary to this side is a square.

V 1 is already here. So, no transformation is necessary for V 1. On the load side when I draw the equivalent circuit, I am in the secondary circuit, so I should not disturb Z 2, Z 2 is Z 2, here is I 2, here is V 2, but the primary applied voltage V 1 gets modified transformed to V 1 by a, and your this is I 2, and I 2 is equal to a into I 1. Therefore, a transformer when you connect it will make some given impedance to appear as impedance of different values. Of course, phase angle of the impedance does not change that is there. Therefore, this is the important thing and phasor diagram also I have seen already.

Now, one another important thing I will derive from this two is that V 1, I 1, suppose you multiply V 1 into I 1 and express V 1 and I 1 in terms of I 2 what this product becomes. So, V 1 is equal to a V 2. And what is I 1? I 1 is equal to I 2 by a is equal to V 2 into I 2. This is one very interesting results. Therefore, volt ampere that is KVA or volt ampere product of voltage and current on the primary side is same as product of volt ampere on the secondary side. So, so this is called volt ampere or KVA remain same on both sides, on both sides. And current and voltages are related by this that V 1 is equal to a V 2 and I 1 is equal to I 2 by a. And what is a?

Do not forget, a is N 1 by N 2. What is N 1? Number of trans on the source side and number of trans on the load side. So, KVA of the transformer remain same, and current and voltages are related of the both sides like this and because of this relations exist the impedance whatever you have connected across this secondary appears somewhat differently on the primary side.

A lot of simple problems to illustrate this idea can be solved now. I will do in the next class. But try to understand the meaning of equivalent circuit. It means that ok, it is a complicated I mean apparently so many things we have to draw in the actual circuit, it is true you have to find out current, voltages in all the parts of the circuit.

But after knowing this relations exist you can either choose this equivalent circuit from which you can only get I 1, and if you wish you can always find out I 2, then go back to the actual circuit and say this is I 1, this is I 2 and so on. Or you can consider this simple circuit which is much simpler than this apparently complicated circuit here just a source and then impedance solve for the current I 2 then you come back to I 1 etcetera by noting the transformation ratio. And lastly, I told you that KVA remain same on the primary and the secondary side. So, we will continue with this in the next class.

Thank you.