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

Lecture - 07
Transformer with Multiple Coils

A welcome to this Machine - I course. We are discussing about an ideal transformer, and in my last lecture I told you how to solve a circuit symbol being several ideal transformers in the circuit because ideal transformer is so simple. But the problems are interesting. Actually, what impedance you connect, at the end of the across the secondary coil that values get transferred and we know how to do it.

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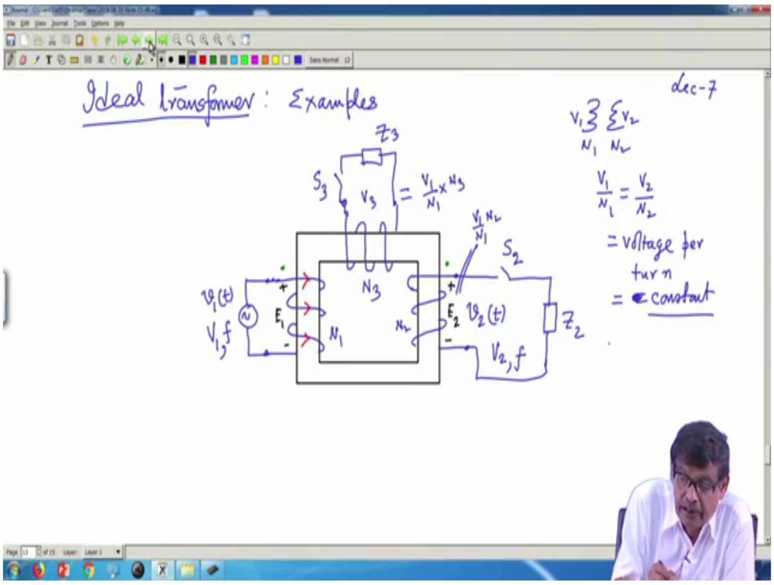

Another interesting problem, I will discuss so that you become really conversant with ideal transformer. For example, consider this is the code first I will draw, this is necessary to explain what is happening. Suppose you have this transformer with a, so far two coils I have considered, ok. What we will do is I connect another third coil, another third coil and perhaps here also I will connect a one switch and load one.

Another switch this is S 1 say S 2, this is a S 3, there is no S 1, S 1 may be there. So, this is suppose Z 2 and this is suppose Z 3. See, what I am telling I am slightly greedy, that is I will energize this with a voltage V 1 frequency f and I want to generate a two levels of voltage because same flux will be linking this coil to therefore, the induced voltage here will be also V 1 by N 1 into N 3 here the voltage will be, here the voltage will be V 1 by N 1 into V 2.

[FL] one thing I will tell you in the primary and secondary voltages are different, currents are different KVA are same, that is all fine. But also try to understand this one that is suppose you have a transformer, of turns N 1 and N 2 it is very useful while solving problems and other things. What happens is this V 2 by V 1 is N 2 by N 1 that is good, but it is also true that V 1 by N 1 is equal to V 2 by N 2. This equation is very useful, at least I find it is tells you that in a several coupled coils what remains constant is voltage per turns. What is V 1 by N 1? Voltage per turn is constant V 1 by N 1 by V 2 by N 2 it has to be.

Therefore, what you do to calculate voltage induced here, you simply calculate voltage per turn then multiply with respective turns to get the voltages here and there. So, you can have more than one secondary coils. For example, here so, what is voltage per turn here if it is N 1? V 1 by N 1 that will remain constant. What will be the voltage available here? V 1 by N 1 into N 3, multiply with actual number of turns.

Here also this voltage will be V 3 say, V 3 will be equal to voltage per turn that what where from I get from the supplied voltage and its number of turns into N 3; voltage per turn here, what will be this voltage? It will be V 1 by N 1 voltage per turn it gets fixed by this one into N 2 you know. Therefore, you can have two sources available to you of different voltage level and you can supply two different loads that is what I am trying to tell. Let us take a numerical numbers, so that things become much more easier.

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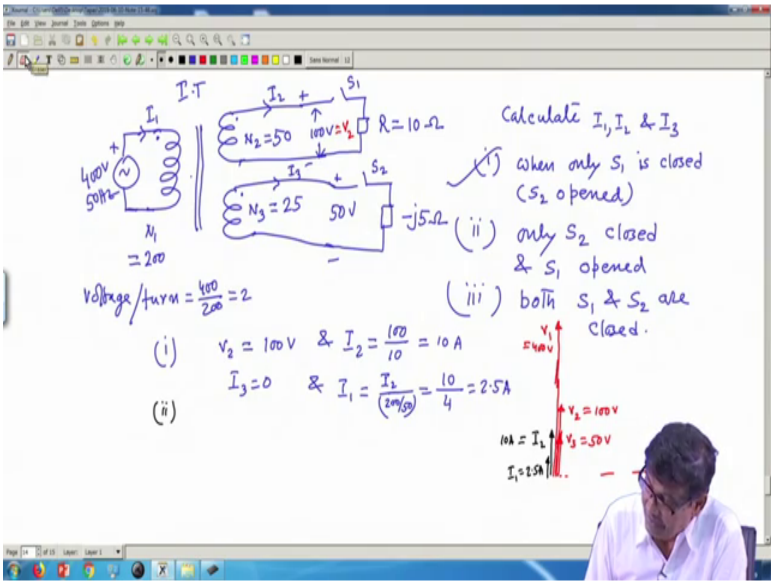

And this sort of thing I can then draw it like this. Suppose, you have a transformer, I will draw now simplified diagrams, and you have two separate secondary coils and there is a common magnetic circuit. This is how I can represent. And suppose the dots are here, this is dot, this is dot, this is dot. Suppose, I say this number of turns N 1 is equal to say 200 and here you apply an AC voltage of 400 volt then what I am telling, immediately you know voltage per turn is equal to 400 by 200 is equal to 2, 2 volt per turn.

Now, suppose I say this one is N 2 is equal to 50 turns and this one I say N 3 is equal to say 25 turns then I will immediate say this voltage will be voltage per turn 2 into 50 you will get here 100 volt. And 2 into 25 you will get here 50 volt. Are you with me? Then this is the how. So, voltage per turn is a very useful concept in transformers that remains same in several coupled coils.

Therefore, suppose the problem is like this is 200 volt, N 1 400 volt is the applied voltage 50 Hertz, these are the dots and if the secondary terminals are open circuited. So, I can now supply two loads, one load demanding 50 volts I will supply, another load demanding 100 volt I will supply. The question is that, when you supply loads how the primary currents how do I calculate? Ok. It is slightly not that easy problem, ok.

Let me a put me in this way suppose you have a switch here and you have connected a resistive load here of say 10 ohm, and also I have a switch here and here I will connect a 50, 50 by 5 a capacitive load minus j 5 ohm. I have planned to connect these two loads.

So, my problem is find out currents in all the windings and this switch is suppose S 1 this which is S 2. Calculate I will indicate the currents as I 2, this is as I 3, and this is as I 1. Calculate I 1, I 2 and I 3. Part 1, when only S 1 is closed S 2 opened. Part 2, only S 2 closed and S 1 opened. And finally, both S 1 and S 2 are closed. I to have this find out. And let this transformer be ideal. What does it mean? If you close the switch and with both the switches are open no current is drawn magnetizing current necessary is 0. So, that is the problem [FL].

First part of the problem is pretty simple; this one S 1 is close. So, it is like primary secondary. This fellow although you will get voltage here, but no current no complications; so, first part of the problem will be voltage pattern is this. So, here you will get V 2 will be 100 volt and I 2 will be equal to 100 by 10 that is 10 ampere and I 3 of course will be 0 I 3 is 0 S 2 is open. And what will be I 1? I 1 will be I 2 by a, I 2 by, a means here for this 200 is to 50. 200 by 50 this is a for this. So, it will be how much 10 by 4 2.5 ampere.

And let us also draw the phasor diagram under this ideal transformer. What is the phasor diagram? Phasor diagram will be like this. This is your V 1, 400 volt, this will be your V 2 100 volt. All the induced voltage will be in phase. V 2 is equal to 100 volt and to a slightly practical I will this is one-forth [FL], so it will be much higher this length. This is V 1 and this is equal to 400 volt.

All voltages are in phase V 1, V 2, e 1 e 2, there is no distinction between e 1, e 2, e 3, e 4. And what will be e 3 will be there, e 3 is how much? 50 volt so, e 3 V 3 will be there. V 3 is equal to 50 volt these will be the voltages. Where is your flux? Flux is along this line. Magnetizing current is also along this line, but that is 0 that is the thing.

Now, if S 1 is close there will be I 2, and this I 2 will be in phase with that of a because it is resistive load. So, the current I 2 will be I have calculated it 10 ampere it will be in some another scale, I 2 will be like this. This I 2 will try to upset them in a balance therefore, primary has to draw extra current. And that value is I 2 dashed I 2 dashed that is equal to I 2 by a.

So, what will be the primary current? And this is the H V side. So, H V side current will be less, ratio is 400 is to 100, 4, so it should be divided by 4. So, this is equal to 10 ampere. So, primary current I 1 will be equal to 2.5 ampere. I 3 nothing is there, your problem is over. If you wish you can calculate the equivalent impedance in by the source and you can verify it is equal to a square into 10 etcetera. This part is very simple.

Second part; in the second part this current I 3, S 1 is opened only S 2 is closed. So, everything remains same. So, I will better not to re-draw here only thing what I will do part 2, I am solving. So, voltages will be as it is induced, but the only thing is now I 2 is not there although V 2 will be there open circuited and I 3 is present. How much is I 3? I 3 will be 50 by 5 that is 10 ampere, but this current will lead V 3 this is your V 3; is not.

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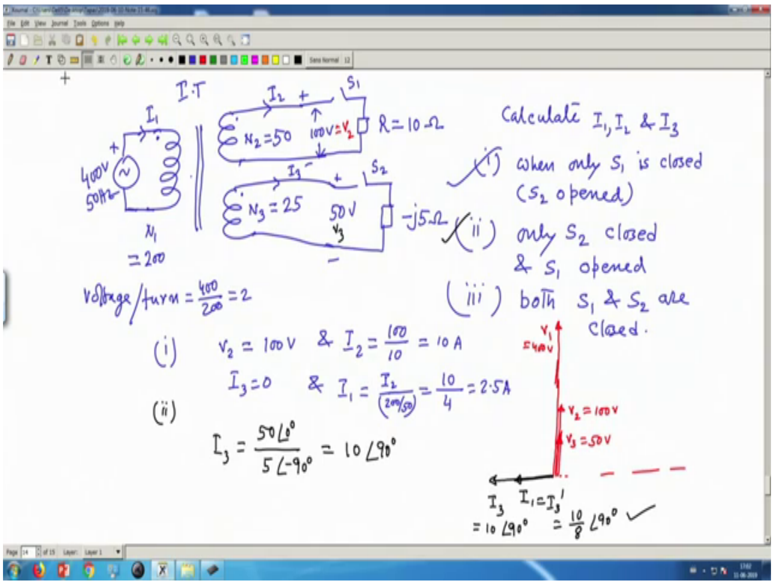

It will lead V 3 by.

Student: 90 degree.

90 degree. And what is the magnitude of this current? So, second part I 3 voltages remain same it will be suppose I take voltage on reference 50, 0 degree divided by 5 minus 90 degree. So, this will be equal to 10, 90 degree leading. Therefore, I 3 will be here, I 3 will be there. The moment I 3 flows then will be I 3 dashed and that will be equal to your I 1 and this is LV side this is HV side, so current will be less. What is the ratio of turns here? 200 by 25 means.

Student: 8 is to 1, 8 is to 1.

8. So, it will be reduced by a factor of.

Student: 8.

8. So, your I 1 and they will be in phase why because they have to balance of the mmfs. So, I 1 which is equal to I 3 dashed will be equal to 10 by 8 into 90 degree. Please try to follow me.

So, far I was in the previous examples just telling impedance values to tell you about the rated current. But now I am in a position to go slightly in advance stage that, impedance may be complex and how to calculate the currents. Had it been r l circuit the phase angle of the impedance, I could also take into account. But where ever is your secondary current the reflected current because of that must be there. So, this is the thing [FL].

Now, the last part which is slightly tricky [FL] for this what I will do is this. I will copy this, so that it is easier to talk.

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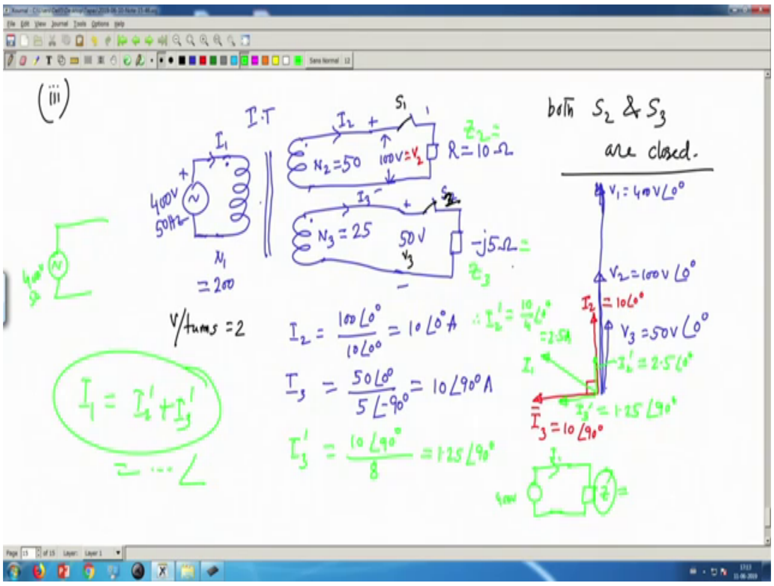

So, now copy go to the next page, paste it. And this one may be deleted. [FL] This part you just try to see how it is to be done. I am sorry for taking some time, they will be edit it is it oh [FL] [FL] delete [FL], ok.

Now, listen carefully what I am telling. So, this is the thing now. Now, both the coils switches are closed what do I do, that is the part 3. Both S 2 S 2 and S 3 are closed. Therefore, what is going to happen? Thing is that the clue to this problem, once again is that fundamental thing. What is that fundamental thing? No, matter what is the positions of the switch either closed or open flux is the core of the transformer cannot change. It has to remain same. Why? Because k V l is to be satisfied on the primary side either S 2 is closed, S 3 is closed or both of them are closed it does not matter this is S 3 actually and this is or S 1 S 2 I told it whatever it is, both the switches are closed.

Then once again what I will do is this first a I will calculating voltage per turn, voltage per turn which is equal 2 which I have already calculated and this voltage 100 open circuit voltage has got. And then I will draw the phasor diagram. Phasor diagram is this one. This is the 400 volt, V 1 400 volt; then your 100 volt and 50 volt. So, this is suppose 100 volt V 2. Scale you forget and this is your 50 volt, V 3 is equal to 50 volt. All are in phase. And suppose this I take as reference phasor all voltages are magnitude angle 0 degree, 0 degree, 0 degree and so on.

Now, you see that this is resistive now both I 2 and I 3 exist, I 2 will be equal to this 100 0 degree divided by 10 0 degree which is equal to 10 ampere, 10 0 degree ampere. I 3 is equal to 50 angle 0 degree divided by 5 minus 90 degree, correct, is equal to 10 angle 90 degree ampere, both I 2 and I 3 are present, ok. First, I will draw I 2 and I 3. So, I 2 will be in phase with V 2 because it is resistive load. Suppose this is I 2 phasor and I 3 will be leading V 2 by 90 degree, so of same magnitude mind you I have taken the numbers such that they become, so it will be 90 degree this is 90.

Now, the big question is what is I 1. Two ways we can, I will 10 you much simpler method, but I will go by the basic rule. Basic rule is because these two coils carry current extra mmf is introduced into the transformer that is namely N 2 I 2 in this direction N 3 I 3. Therefore, these extra current drawn from the supply should be such that we it will nullify both these mmfs. It has to; because applied voltage is fixed here k V l is to be satisfied. Therefore, what I will do? I will calculate I 2 dashed, because of this there will be an I 2 dashed, because of this there will be an I 3 dashed and then these I 2 dashed and I 3 dashed I will add vectorially phasor by phasor sum.

So, what is this is I 2, I 2 is how much? I 2 is 10, 0 degree. I 3 is 10, 90 degree. On the H V side, I am calculating current. So, I 2 dashed will be lesser current, I 2 dashed. It will be how much? I 2 by a therefore, I 2 dashed is equal to a is how much for this to 8, 10 by 8 oh no.

Student: (Refer Time: 27:51).

200 by 50, 4; so, 10 by 4, is it, 10 by 4, 0 degree is equal to 2.5 ampere. So, I 2 dashed is 2.5 angle 0 degree. Similarly, this is I 3 therefore, I 3 dashed will be 10 90 degree, but its turns ratio is different 400 by 25 that is 8. So, this divided by 8 reflected current. And this will be?

Student: 1.25. 1.25.

1.25, 90 degree; so, this is I 2 dashed and this is I 3 dashed which is equal to 1.25, 90 degree. And then I will say I 2 dashed plus I 3 dashed is your I 1 therefore, I 1 will be equal to I 2 dashed plus I 3 dashed.

This is one complete this problem you must go through very carefully what are the steps are because there may be situations you from the same source you want to get on the same core, you connect a several coils like this 2 coils, may be 3 coils another coil is connected, get different level of voltages. Of course, in a two winding transformer only two windings will be present. But if you do this exercise it will further strengthen your understanding of reflected current. For this there will be reflected current here. This current divided by this turns ratio. For this current there will be reflected current here. What will be the reflected current? These actual current divided by turns ratio between these two and so on.

Now, this I will not do, but I will request you to think, ok. These you have found out, I 1 dashed you will find out. Once you find out I 1 therefore, mathematically you will say equivalent circuit of all these things across the supply will be this 400 volt supply and it is delivering this I 1 therefore, impedance seen by the transformer Z dashed will be simply this voltage by this current, are you getting. I 1 you have to calculate it will have some magnitude and some angle.

This voltage divided by this current will then give you the impedance seen by the transformer. I will request you to think about it that, this is suppose in general Z 2, this is in general Z 3, are you getting. That ok, supply sees what impedance what should be equivalent circuit, I have to draw with respect to the supply side. How this R will appear here, how this Z will appear here that you think in the next class. Of course, I will discuss about that that is also very interesting.

So, I hope you have understood that if it is ideal transformer magnetizing current is 0 and everything is so simple. If any coil secondary coil carriers current, primary coil will immediately draw reflected current corresponding to that winding current what will be that reflected current. If it is I 2 on the secondary coil it will be I 2 dashed. And we have also seen that how to take any general impedance into account. So, I 2 dashed will be I 2 by a. What is a? a is N 1 by N 2.

Similarly, if there is another coil supplying another load wound on the same magnetic core, if you know I 3 there will be I 3 dashed here, such that the flux remains same. And how to calculate I 3 dashed? It will be I 3 by turns ratio between the primary coil and this new another coil that is whatever it is N 1 by N 3 now. So, these things if you take in to account and coupled with this phasor diagram; the comfort zone is all the voltages are in safe phase.

So, you have you can take them on reference. And then first calculate the secondary coil currents, and then calculate reflected currents for each of these components add them up to get the current which will be draw from the primary side. And then the equivalent impedance seen by the source can then be calculated easily without because V 1 by I 1 I will do and say that, these big circuit to the supply is nothing, but this 400 volt supply across which you have connected an impedance of V 1 by I 1.

But what I am asking you to do, in terms of Z 2 and Z 3 find out that equivalent impedance. It will be some a square Z 2 a square this turns ratio square into Z 2, this turns ratio square into Z 3 and so on. You think about it. We will discuss it in the next class.

Thank you.