Electrical Machines - I

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Lecture - 24
Regulation: Its Expression

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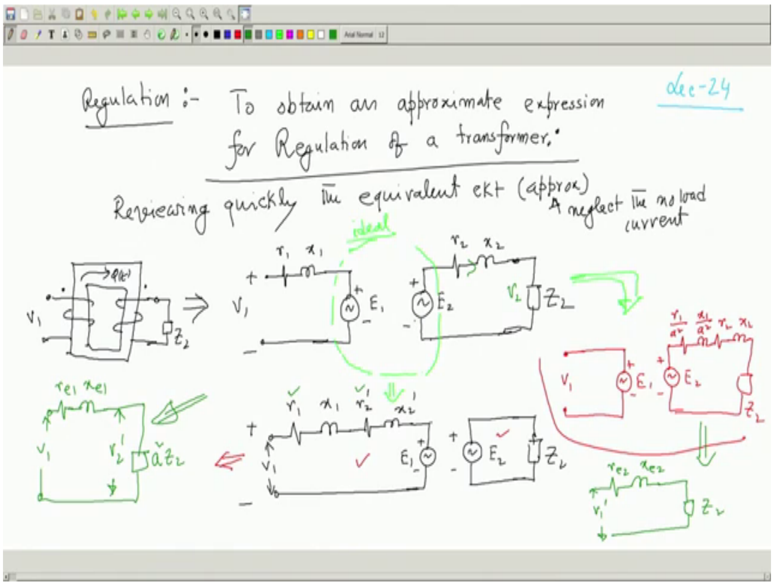

Welcome to lecture 24 and we were discussing about Regulation and goal of this lecture will be to obtain an approximate expression for regulation of a transformer.

I will do this [FL] before that it is now timed as slightly I will review the equivalent circuit, how we are drawing this way that way with respect to primary side, secondary side. So, it is like this; reviewing quickly, I mean no, quickly the equivalent circuit and approximate equivalent circuit. See this was my transformer, here were my coils primary, secondary; this is the practical transformer, these are the terminals available to me.

Then and here will be some impedance connected across the secondary Z 2. Now this can be taught in various ways one way is here is your V 1 some deeper look into this equivalent circuit, so that it will enhance your understanding I hope. So, what I told there will be r 1 x 1 I can show it like this and then here there will be end E 1.

Because this ideal transformer part is this one and parallel branch is here, that I am not drawing as you can easily see that parallel branch will not come in the expression of the regulation. In other words what I am telling why it is approximate we will neglect the no load current. Because no load current which comprises of core loss component of current and magnetizing current is only about 5 percent of the rated current and drop because of that in r 1 x 1 or r 2 x 2 they are very small.

So, this is the thing and this is E 1 a source of EMF this becomes a source of EMF as there is a time varying flux polarity I know this is my V 1. And secondary side it is like this, there is it becomes a source of EMF this is plus minus that is the dot so fine. And here was your r 2 x 2 and here is your load. This is the ideal transformer primary this is the ideal transformer secondary, no load and magnetizing I have neglected so, this is like this.

Now interesting thing is this one because this portion is ideal; you can view it, I will better tell you one of them only you adopt. [FL] What I am trying to tell, this is same as this thing oh sorry this is load, that is if you wish you show no impedance on the secondary side this you punch here. I mean push it here on the primary side this plus minus and this circuit and this circuit will be identical no problem if you solve it this is equivalent to this.

Or this thing can be also thought of although space is less, but I will draw it here this way you can also think it; you show V 1 here. It means that you are assuming secondary coils have no leakage flux and resistance all resistance and leakage fluxes are there on the primary side many ways of looking at things. This one could also be drawn like this, you can show all the impedance on the other side that is here it is V 1 here only you show E 1 you pretend this is your E 1 this part your ideal. And here is another source E 2 plus minus and here you do not neglect r 1, x 1 but push it here.

It will be r 1 by a square x 1 by a square and then r 2 and x 2 do not disturb and then Z 2 this is also correct and finally, this thing if you have drawn referred to this side, I think you have got this idea this is one block also this Z 2 can be this circuit this is the circuit we will look at. This circuit can be shown to be let me use different color and I will show it V 1. And here r e 1 this r 1 plus r 2 dashed then sorry x e 1 and here I will forget about this ideal part and connect a square Z 2.

In fact, I could draw it straight away because we have come up to this only thing magnetizing branch, I am as we will see it can be because so this is the equivalent circuit finally, I will be using one of them you use always use this one. I will I am just requesting you it does not mean that you cannot have other options either this or that. Similarly this one means what? And you will show here it is V 2 dashed. Here similarly this part will be shown as this can be here I have shown it can be shown as r e 2 x e 2; r e 2 if I am writing no dashed, it means r 2 plus r 1 by a square x e 2 is x 2 plus x 1 by a square.

And then you say that ok, this is the thing and here you say Z 2 but here you write E 1 by E 2 is N 1 by N 2 that is strictly. So, it is V 1 dashed, so this is the equivalent circuit referred to load side, secondary side and it is the equivalent circuit refer to primary side ok. So, either of this or you can leave with these, but this is somewhat complicated because complicated in the sense computationally it is difficult. You first know, this is your V 2 this is whatever current it is delivering things like that anyway you know how to handle it.

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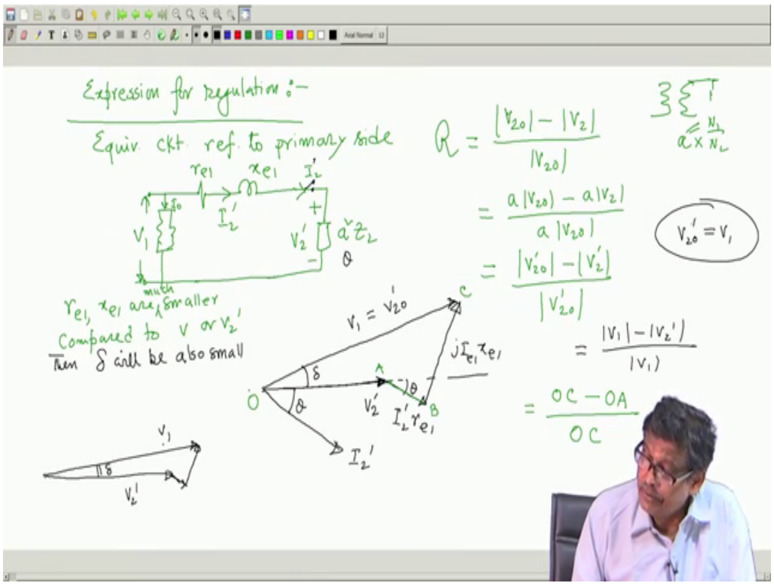

So, now, coming to the expression for regulation. So, I will refer to equivalent refer to primary side ok, refer equivalent circuit refer to primary side is this one. Primary side this will be simply this r e 2 x e 2. And here is your load reflected load, a square Z 2 and here is your V 1 and the voltage here I must write V 2 dashed is not and we have defined the regulation as magnitude of secondary voltage that is where I wrote, V 2 0 magnitude of V 2 0 minus V 2.

So, magnitude of V 2 0 minus, V 2 divided by magnitude of V 2 0; is not? That was the regulation and all quantities here were with respect to the secondary side what was this? Here was the transformer here I am measuring all the voltages.

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Oh sorry that is it will be r e 1 and x e 1, thank you. So, this will be r e 1 and x e 1 this is referred to primary side. Now come to this, this is the load side, now what I do; I multiply both the sides numerator and denominator by turns ratio a multiplied a is equal to N 1 by N 2. If you do it will be a magnitude of V 2 0 minus a V 2 divided by a V 2 0; is not? a V 2 0 will be nothing but V 2 dashed 0 with no load connected, minus a V 2 is V 2 divided by V dash 2 0.

This will be the thing with load disconnected; with load disconnected this is open. So, what will be this voltage whatever will come here this voltage with nothing connected is V 2 0; that voltage will be simply this voltage reflected.

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This will be the thing got the point, where V 2 dashed is the reflected terminal voltage when it supply some load current I 2 dashed. Some people will also draw the approximate equivalent circuit means this it is there.

But this drop as you can see it only depends on I 2 dashed. So, a I naught I can be neglected in this approximate equivalent circuit. So, this is the thing you have to calculate. Now how can I calculate? I will first draw the phasor diagram of this circuit. So, the phasor diagram is very simple, I will start from here, the terminal voltage across the load is V 2 dashed. I will draw, then I will draw the current suppose it is supplying some current I 2 dashed, load power factor angle is theta, load power factor angle does not change if you multiply Z 2 with a square; a is a scalar number.

So, it is like this; then you can easily see V 2 dash 0 is what? V 2 dash 0; that means, with this switch open in this equivalent circuit also when this is open V 2 dash 0 will be nothing but V 1 this voltage will come here as there will be no current. I think this point must be understood. So, V 2 dashed 0 is nothing but V 1 itself magnitude of this supply voltage. So, V 2 dashed to this V 2 dashed if I add these two drops, which I am drawing on a larger scale so that we understand what we are doing into r e 1 plus j I e 1 x e 1 and you must understand it is not drawn to scale if this is V 2 dashed how this can be, but there will be some geometrical thing I have to show that is why I am drawing in a larger scale.

So, and this will be how much? This is V 1 and this V 1 is nothing but V dash 2 0 you must understand this point. So, this angle is theta therefore, this regulation means magnitude of V 1 next I continue with this knowledge V 1 minus V 2 dashed divided by the open circuit voltage V 1 equivalent open circuit voltage.

Therefore I will say suppose I name these various points like this is suppose O; let this point be A this point will be B very simple calculation C; it is like this ok. Then magnitude of V 1 means length OC, this length minus V 2 dashed OA divided by OC. Now I am writing length this length minus OA divided by OC this will be regulation; clear?

So, it will be like this ok, in this page let me let it be a bit dirty but you will be continuing without any disruption that these I have to find out. Now the argument you listen. The argument is this drops this and this both these drops are much smaller compared to these lengths; you must understand. Because it is a well designed transformer r e x e 1 are smaller much smaller compared to whom? Compared to these voltages, compared to V 1 or V 2 dashed; do not forget to attach these.

These are quite small although I have drawn very large here so that some geometrical concept I will apply. That is, in other words what I am telling it will be something like this if I draw it to this scale maybe it will look like if this is your V 2 dashed, it will be like this; are you getting? This is where I am making this. So, these lengths are really small compared to these lengths. So, you have got the idea it will be like this.

Now rest of the thing is pretty simple therefore, if these two lengths are small this angle, suppose I call this angle to be delta compared to V or V 2 then delta will be also small. That is, as I was telling it is V 2 dashed I wipe that out but it is like this. If this be the case then this delta will be pretty small because we have added only small small thing here and there. So, delta is small. So, keeping this in mind is it possible then to get the difference between OC and OA; OC and OA this difference. So, I will now go to next page and start with this phasor diagram rather neatly it requires like this.

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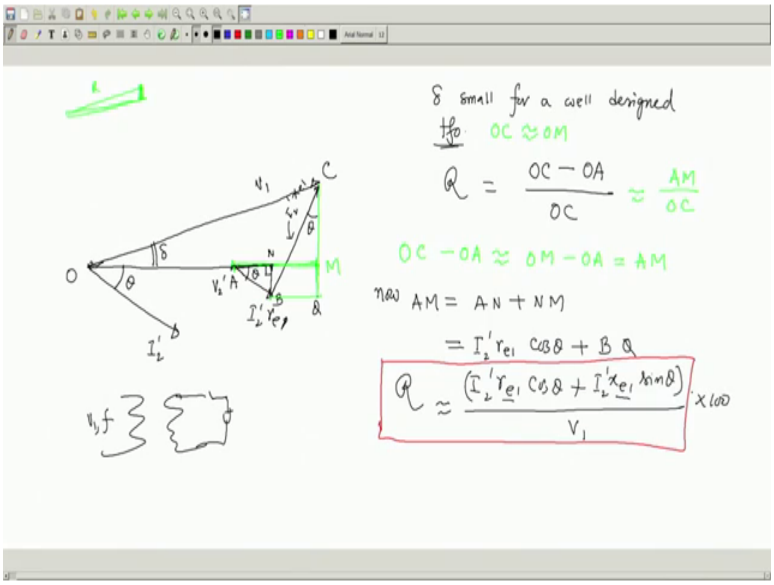

So, what you do? This is your V 2 dashed, this is your suppose it is supplying a lagging power factor load I 2 dashed, this is theta load power factor and the here are once again I will draw larger, so that, so this is suppose I 2 dashed r e 2 r e 1 and then 90 degree here and this is suppose I 2 dashed x e 1; and this length is your V 1 and this angle is delta and I named it as if I remember correctly OC, OA, B. So, OC this guy called OC, OA where is B; this point like this [FL].

Now knowing fully well, that delta will be small delta small for a well designed transformer. Then and this one I have caught OC minus OA by OC. Now by using geometry I will try to find out this length minus this length.

Now, since delta is small, if you drop a perpendicular these are the extra thing I am doing now you drop a perpendicular on this extended line here, drop a perpendicular say you. And also drop a perpendicular from this side to this side ok. Suppose this I call point M since delta is small, then I can say that OC is approximately equal to OM; is not? This length will be approximately equal to this length because delta is small. You know, if the angle is small this arc is this one if it is a radius of a these two lengths are almost equal R d theta is equal to d s this length.

Therefore, I can say that OC minus OA is approximately equal to OM minus OA and OM minus OA is nothing but AM this length.

So, numerator is this length, so this one is approximately equal to AM by OC. Now the question is what will be the value of M? Pretty simple, you know this angle is theta, this angle is theta because theta I 2 r e 2; angle between two straight lines is same as angle between their perpendiculars. This line is perpendicular to this and this line is perpendicular to this, so these two will be theta.

Therefore, if you drop a perpendicular from point B to N then, now AM can be written as AN plus of NM and AN is this length, so in the small right angle triangles. So, it will be simply I 2 dashed r e 1 cos theta plus NM, NM will be same as this length B say Q; NM is same as BQ it is a rectangle. Therefore, this will be BQ and I 2 dashed r e 1 cos theta plus BQ from this right angle triangle is this one is I 2 dashed x e 1 this drop sin theta.

So, this will be I 2 dashed x e 1 sin theta and divided by OC and OC is V 1 ok. Now I have converted it to once again voltage thing, so V 1 I can now invoke upon. So, regulation is now approximately equal to why I am telling approximate? Because I have used this approximation delta is small and so on. So, regulation is approximately equal to this.

And this is the expression we are looking for now what is the use of this expression? Because regulation is so simple otherwise when even without doing mathematics as I was telling just energize it with rated voltage frequency in the lab and then connect the load, measured with this switch open what is the voltmeter reading close this switch with this load present, take the difference of these two voltmeter readings divided by the open circuit voltage will give you regulation.

Then why I have found out an expression; this is because of the fact the rating of the transformer maybe very large maybe 100 kVA transformer whose current rating is maybe 100 amperes. So, 100 kVA load you will be requiring in the lab to find out the regulation at full load that is a 0.8 power factor that is not available for example, a distribution transformer which is 200 kVA and it caters power to various consumers I mean totaling 200 kVA can you imagine that load in your lab, no.

Therefore, you do simple test open; circuit short circuit test, get these values and on pen and paper you calculate this. You ask that oh what load you have connected; it is delivering rated current at what power factor, 0.8 power factor lagging. Then on pen and paper calculate regulation into 100 if you want to get percentage regulation.

So, you are predicting a regulation without actually loading the transformer that must be understood ok; because open circuit short circuit test are very simple test; I will carry them out, find out these values then tell me any load current the transformer is delivering of course, up to rated current and at what power factor you give me these two information and I will be able to give you the value of regulation how much voltage will drop; we will continue with this.

Thank you.