Electrical Machines - I
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Lecture - 53
Output Equation of 3 Phase Transformer

Welcome to 53rd lecture and we have been discussing some general topics on transformer, not so much mathematical. So, we started with telling that for large and large transformers, by large transformers I mean very large KVA transformers. Air natural cooling is not sufficient, and you must have at least in distribution transformer 100 of KVA's may be 250 KVA, 500 KVA these are the fittings you will expect

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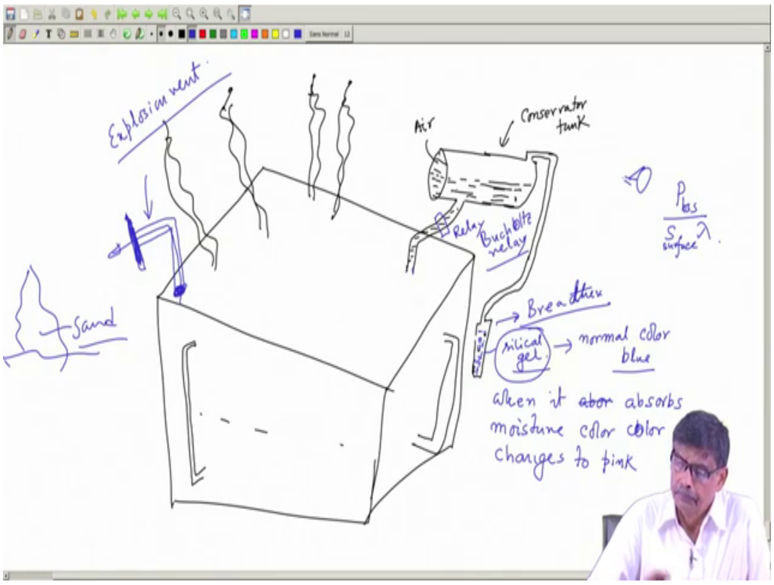

Of course, this is for single phase transformer I have drawn; it could be for 3 phase transformer as well and these are the usual fittings, cooling tubes will be there. And mind you the maximum temperature rise is decided by P loss by surface through which roughly this is the thing into emissivity, this is called emissivity which is constant of the material sum.

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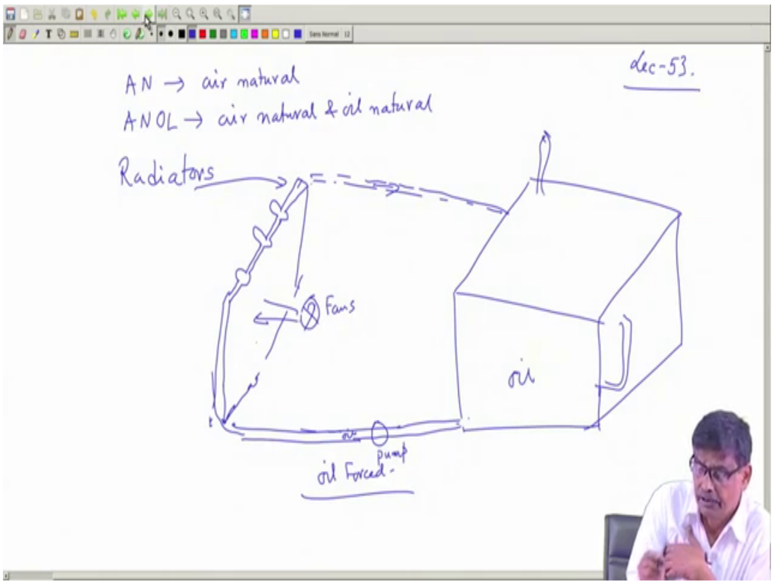

So, the cooling's are classified on the name plate of transformer, it may be written like A N it means air natural cooling; air natural or very small transformer, no extra elaborate arrangement is necessary. There may be A N O L cooling, air natural and oil natural. There are lot of things combinations of this. Now there may be very big transformers ok, then cooling tubes is also not sufficient; for example, transformers of ratings of 100 MVA which are used in power stations, very large transformers 3 phase.

In that case what you will find, it will be there are several like oil forced, air natural this kind of thing, but you go through books you can easily make out what do they mean. But what I am telling, suppose this is your transformer this is the main transformer tank bushings, etcetera all things are there and to increase the surface area the cooling tubes are also not sufficient, what they then connect is called radiators.

Radiators are nothing but iron plates with tubes like this. Just I am drawing one, it is iron plates and several things and these are rectangular type looking; iron, steel and this oil here is connected to the radiator tubes. So, these are radiators instead of cooling tubes radiator, large surface area and at this is connected here like this; there will be inlet air, oil it is connected. So, oil this is filled with oil inside, this oil is connected here, oil; and oil will fill up this plates also, these are the open space.

So, and then oil will be pumped in and it will once again come out to this connected here to the tank. So, oil will go through this radiating tubes all along and will come here. Now oil on it is own will may not go, for large transformer what they will connect a pump, oil pump; oil will be forced to go there, go up and then return to the main tank. So, these are. So, artificially you increase the surface area and this radiators may be at a, for a place I mean quite at some distance the radiator plates are there.

Then it is called oil forced cooling, oil forced. So, idea is very clear, if you want to use very large transformers you must do extra to cool the transformer, so the temperature rise of the transformer is within the limit. Because whether it is very small or large transformers the value of B max magnetic loading is approximately same may be 1 point 2 weber per meter square; if you are using copper almost delta is same may be 3 ampere per millimetre square, those are fixed generally.

Therefore you since you have gone for higher KVA rating, the size of the transformer has increased and you must have elaborate arrangement. Artificially increase the surface area of cooling and heat will be radiated not only from the usual tanks here, may be tubes also connected natural circulation of the oil here; but also force the oil to move through the radiators to make a closed path and the oil will be circulating. Sometimes air is also forced for big transformer, you keep fans here; fans which will also cool the surface area of the radiators; forced air then say.

So, these are terminologies which you will easily understand, but the basic understanding of the whole process is that for large transformer, you have to have some elaborate cooling arrangement for the transformer; for distribution transformer simple oil, for large transformer it will be like this, may be 100 of MVA transformer which is housed in power stations ok. So, this in nutshell about the cooling; only one thing I will leave it as an exercise to you, the what about the output equation of a transformer?

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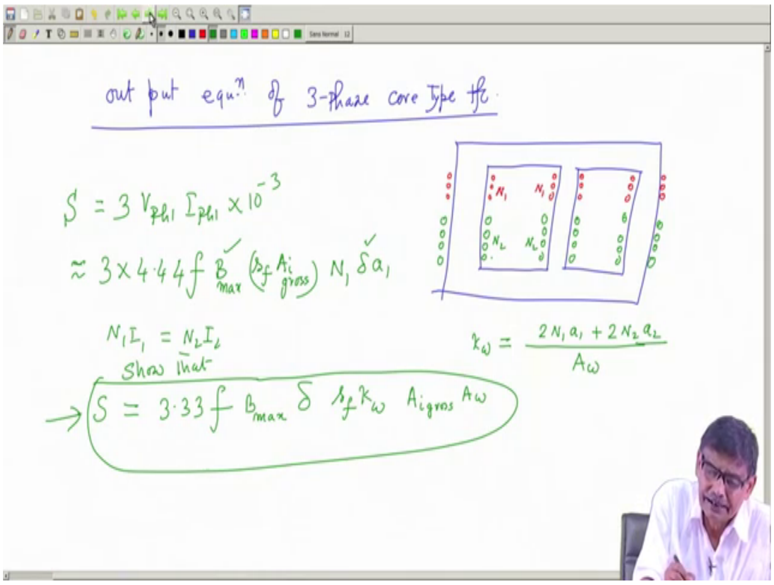

Output equation of a 3 phase transformer; 3 phase core type transformer in the same way it can be found out; I leave it to you to find it out. That is you remember I leave it as an exercise to you this is the thing. In 3 phase transformer there will be two windows like that, there will be say LV winding on each limb and for each phase A phase B phase LV winding and C phase LV winding; and HV winding will be here got the point. So, LV windings LV windings, there are two windows and this two windows are equal dimensions because old design.

So, here only thing, so you start with this thing that is KVA rating of the transformer is 3, voltage into current in terms of say primary. So, 3 V phase I phase into 10 to the power of minus 3 this is the KVA rating. And then you write this is nothing, but 3 into 4.44 f phi max you write B max as usual into a I net which becomes equal to s f into A i gross; 3, 4.44, f B max and this thing is phi max into N 1, N 1 you write and then I phase is, suppose primary side I am writing. So, N 1 into I phase 1; I 1 that is equal to delta into a 1, you know this is how it will look like. So, delta is the electric loading, B max is the magnetic loading. Now in this case, this once again N 1 I 1 is equal to N 2 I 2 per phase mmf balance will take place, then I 1 you write A 1 delta I 2 A 2 delta. So, N 1 a 1 is equal to N 1 a 2, I am telling verbally what you have to do, only thing is window space factor.

Window space factor is go to any window area covered by copper. So, suppose I say that, it has got N 1 turns and this has got N 2 turns secondary so; obviously, you can see there are two sections unlike. So, it will be what; area covered by copper 2 N 1 a 1 plus 2 into a 2 this cross sectional area. So, 2 N 2 a 2 divided by the total area available and then N 1 a 1 is equal to N 2 a 2 you substitute and for N 1 a 1 you put it there. What you will get it is this, the total KVA will be 3.33 f show that 3.33 f B max magnetic loading; this loading then this two factors s f k w is not, what else will be there 3.33 f B max delta s f k w.

Oh that is N 1 you just see that, same factors all other factors will come same way and that is this one, s f k w f then physical dimension A i gross and A w that is all. Then physical dimensions A i gross and A window like that; note that for single phase transformer it came as 2.22, but in 3 phase it is fine, 3 phase 3.33 f B max N 1.

So, other reasoning remaining same, same if dimensions are increased by factor of x losses will increase, by factor of xs cube and so on, area will increase by factor of xs 4, KVA rating will increase by factor of x to the power of 4 and so on, so this is the thing.

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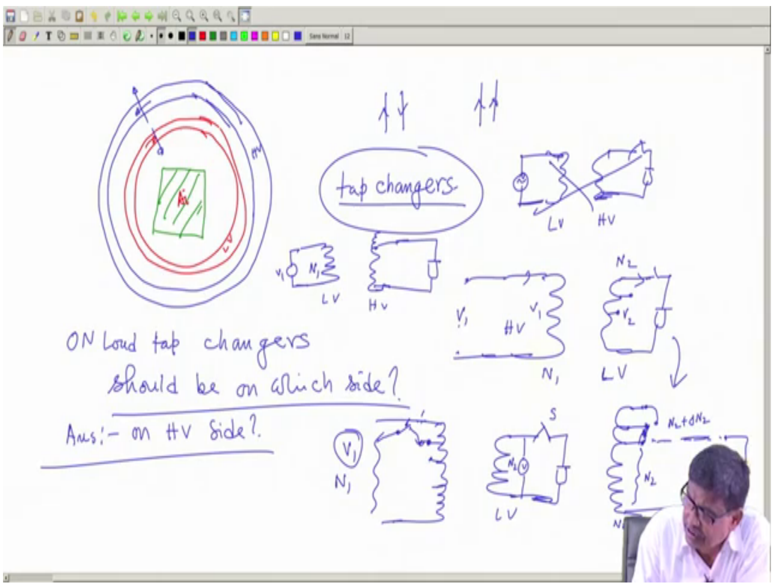

Another tit bits of this transformers in terms of single phase I will just tell you, is that if you see a leaned crossed section like this, this is the iron cross section your LV winding will be around it; this is the LV winding and then your HV winding.

Oh I am; so sorry, badly drawn and this is your, this blue is your HV winding, HV and this is say LV; because nearer to the core LV winding is present mind you, is not. And this is the top sectional view of the transformer, you now understand this is A i, this is A i hide on area; first LV winding you wound then HV winding and so on.

Now you note one thing when the transformer will be operating at any given point of time, we have seen that if LV winding is carrying current in this direction what will be the direction of current in the HV winding; it will be just opposite are you getting. That is how mmf will be balanced any, forget about that no load current, no load current is small 5 percent, when secondary load is not there this current is absent only this current will circulate that is 5 percent. But the moment you load it I 2 then I 2 dash 2 will appear, that is if HV side is your secondary I 2 opposite current; then only this 2 mmf will balance each other and your original flux will be restored and decided by the magnetizing current, that is what we are telling. This will be read like this.

If this is the situation do you expect that there will be some mechanical forces acting between these two coils? Yes, we know that if two conductors you keep side by side, they will experience mechanical forces. What will be the nature of the forces? It is just opposite to magnetism; in opposite current meant attractive not like that. It will be repulsive; that means, this LV coil, now this LV coil just cannot stay alone there will be some bobbing sort of thing over which this LV winding is put. So, when normal load current flows, but none the less there will be force of repulsion, acting that is what will be this direction of the force this way.

That is LV winding will be squeezed towards the core and this will try to go away. So, you have to take proper fixing up of the coil. So, that they can withstand that mechanical forces at rated currents at least. But what happens is this you do not know there might be short circuit taking place and very large current is flowing, then this force will become enormous and HV windings will become loosened, come out and this one.

That is why protection of transformer is so important, you cannot allow a very large short circuiting current to flow apart from the fact the winding may be spoiled. But you know to make a winding burn that large current must be there for sufficiently long time; it is not I square R; it is I square R into T that decides how long that large current is flowing. But the mechanical forces too will be very large, the short circuiting current may be high and transformer will not only be ruined by if the fault is not clear; ruined by windings will be spoiled, mechanically also it will be a disaster. LV winding will tries to push upon on all directions and it will try to go out HV winding. This is just I am mentioning, you keep now after learning these things those things can be very nicely explained. And current in the windings will be always in opposition and this is instantaneous current deduction I am showing, when it will be these ways, that will that way; but the deduction of force will be always like that.

Another last point I will comment I will make, sometimes what happens in transformers, what if you load the transformer you know because of regulation voltage decreases. See you load the transformer; connect the load we have seen that this is suppose LV side, this is suppose HV side; you load the transformer or I will draw other way to introduce the problem. So, this is suppose HV, this is LV side it does not matter in any way this is load, you load the transformer; then what happens under no load condition whatever was the voltage when you load it voltage will fall. If the load is inductive RL type and that is usually the case is only for capacitive load may be it will increase a bit; but for RL type of load is which is generally the case, the terminal voltage magnitude will fall.

So, compare to open circuit voltage, the moment you start drawing current because of the internal drop inside the transformer in the equivalent resistance and leakage reactance, this voltage will fall magnitude. And suppose you want to restore back the voltage, you cannot do anything here; two ways you can do, one thing is you increase the supply voltage a bit; the supply voltage whatever is coming that voltage you increase. So, that it will may compensate that, but that is not a option left to you supply voltage whatever is coming, coming you cannot do anything. So, what can be done is some transformers are provided with tap changers.

Suppose primary number of turns N 1 secondary turns is N 2; idea is very nice and simple. So, what I am telling, you suppose say that I will there will be some tapings provided here 1 2 3 4 turns tapings are you getting, LV I am drawing elaborately; there are this is the normal secondary terminal, then you are provided with extra tapings with a switch, this is the secondary terminals.

Now a transformer with some extra turns here on the LV side and a switch connected, you can increase the number of turns. So, what is the point here V 1 number of turns is N

1 and N 2 number of turns is not fixed, a little change I will be able to do. In a transformer what I told, voltage per turn remains constant. So, what is voltage per turn V 1 by N 1, you are simply and this is N 2 and this is N 2 plus delta N 2 some few turns you increase, then your voltage will increase on the load side, getting.

But the turns ratio that thing will not be affected too much, is not if you increase these by few turns what N 1 by N 2 practically remain N 1 by N 2 plus delta N 2, got the idea. So, transformers are provided with tap changers, have I written. And tap changers I have shown here in this example listen to me carefully, on the LV side I have made an arrangement to increase the turn, what should I do? Applied voltage is fixed; when there was no load this switch was open, this voltage was fine this is my actual secondary. But when you connect a load here this voltage falls a bit, you want to compensate you cannot do anything with this supply voltage here. Therefore, you simply increase few turns voltage per turn is decided by V 1 by N 1 and increase 1 2 turns you get more voltage. So, regulation problem can be addressed a bit by this method.

But now the question is listen to me, should I put the tap changer on the LV side or HV side. See the condition is this tap changer I will be operating under load condition that is I will put, it was supplying the load. So, you find all across the load people are complaining, voltage is small, there is a switch and those will be also oil immersed I hope and you put it there, ok. So, that is another interesting thing how tap changers work.

But the idea I am telling, you will move it here and these are called on load tap changers. There may be off load tap changers, what you can do, you switch off the supply first; then bring this switch from this point to this point and once again energized, but that is not a very good idea. So, only load tap changers are much common, I mean useful; you put it here increase the turns a bit, increase the turns a bit in order to restore the voltage desired voltage.

But the question I am putting, should were the tap changers should be tap changers on load tap changers should be on which side; should I connect HV side or LV side. For example, here while explaining the things I have shown it is on the LV side I have connected, is it a good idea? No; because LV side current is more. So, whenever you will be moving this switch from this point to this point, you are trying to break the current and quickly there it will be short circuited this turn a bit. So, tap changers will be much more stressed; therefore, tap changers should be always on the HV side. Tap changers better connect, because you have to make and break current which is large, load is already connected you cannot do anything. Particularly with on load tap changer, hundreds of current is flowing you suddenly want to move this one from this two, increase the voltage a bit.

Can I then do the same thing, if I connect the tap changers on the HV side; answer is on HV side. I will not connect tap changers on the LV side, whether it is load or not that is different issue, you must understand. But since I have drawn the load on this side, connect switch; here, what will happen is this, this is the normal N 1 turns I connected this whole thing is N 1 turns, V 1 is the supply voltage, voltage per turn is V 1 by N 1 and this is the switch, under no load I was getting a voltage here. But when I connect load I find because of the regulation voltage drops which is not desirable; then I plan I will play with number of turns on the HV side, not with LV side because current is more.

So, what should I do, because this supply voltage is fixed I cannot do anything what should I do? What should I do with N 1, should N 1 be increased or decreased; voltage per turn should be increased, then only secondary voltage. Secondary voltage I am not touching it is N 2 therefore, taping should be here; this is N 1 then lesser number of turns. So, your switch should be connected from here to there, you reduce the number of turns of the HV side same applied voltage; therefore, voltage per turn increases and it is the voltage turn which remains constant in primary and secondary side. So, secondary voltage will increase, N 2 I will not touch, got the idea.

Therefore it is interesting, you I will leave it to you to analyze this. So, N 1 must be decreased and you see it is nicely matching with the construction of the transformer. This is the core LV winding, then comes your HV winding and HV windings tapings you want to take and it is on the outer side; you easily take the taping, it is difficult nah to take tapings from LV side from in between. So, these are very small, but very interesting thing, you we have done mathematics we know how to calculate regulation efficiency.

But I think whatever I have told you it will give you a practical flavour of the way you look at transformers ok; mathematics is there, but these are small, but important things. So, there should be transformers are provided with on load tap changers also. And mind you the number of turns you will change a little bit not more. I have not told great things about design, but that is the first starting point you must have a broader idea and when you look at a transformer you may find a big transformer may be provided may not be provided with a tap changing arrangement.

On load tap changing arrangement means that; tap changers must be on the HV side as current is less and also it is easily accessible, taping is to be taken from the this HV. And then it is not that you always increase the number of turns to increase the voltage, if this side is your supply side you have to reduce the numbers of turns to increase the voltage on the LV side. Suppose I say that this is LV side and on HV side is your load, this is N 1 where you are applying a voltage V 1; voltage per turn is V 1 by N 1, LV side I am not going to connect any tap changers. So, nothing is changing here voltage per turn is fixed; I have connected load and find that voltage has fallen compared to the open circuit case. Then I want to increase voltage and I am certain I have to connect the tap changer on the HV side.

In that case what should I do with N 2, I must increase it, is not. So, taping will be this way. So, depending upon the situation you have to reduce the number of turns or increase the number of turns. On the load side if the HV side is there, so provision for increasing and decreasing both should be present; you do not know which side will be primary, secondary like that. So, these is a nutshell what I want to tell about transformers; we will have a discussion session, there will lot of problems given and I have I am going to upload several notes whatever I have told in these lectures and we will see that so.

Thank you.