Electrical Machines - I
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Lecture - 52
Cooling of Transformer & Fillings of Transformer

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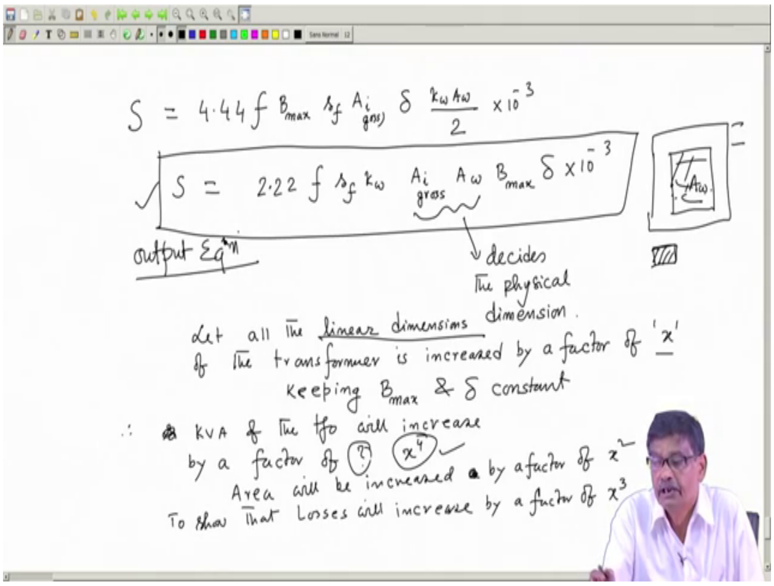

Welcome to Electrical Machine – I course and we will have been discussing about some general topics of transformer like what is it is output equation and what are the implications of increasing the physical dimensions of the machines.

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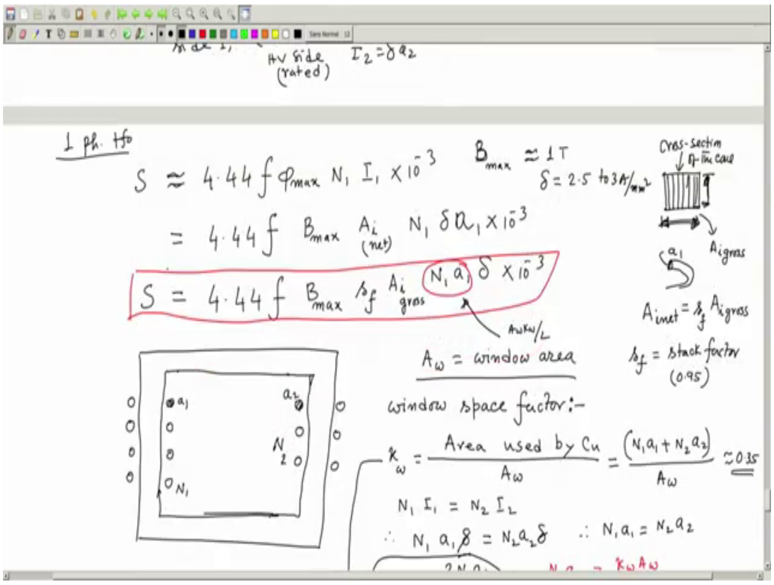

So, what we did is this we started very quick review is necessary. So, that you understand that in a transformer have starting from the KVA equation we define two things one is the specific magnetic loading and current loading. So, same volt ampere product that is the KVA can be expressed in terms of what is called delta and B max and do we define two factors one is called stacking factor which is A i gross if you multiply with this stacking factor which will be over 90 percent and above because of laminations that is the A i gross and delta is the current density of the conducting material used say for copper.

So, delta remains fixed in primary and secondary because in both the windings we are using copper, then what our aim was to show that the KVA rating of the transformer is proportional to the physical dimension of the transformer. Physical dimension who decides? The core area and the window area; over all dimension gets a determined by A i gross and B max.

And this two factors stacking factor and window space factors window space factors is about 30 – 35 percent like that because all these space in the window cannot be covered with copper because there must be space for circulation of conducting oil I mean which will take away heat from the windings ok. There will be also space required by the insulation which will be covering the conductors and so on. So, about 35 percent of the space window physical area will be occupied by copper. So, in terms of that for a core type transformer we got this KVA rating. Note down this factor 2.22 ok.

Now, see if you have a transformer in your lab may be 1 KVA, 3 KVA transformer you will find no extra cooling arrangement is necessary because of the fact the natural cooling by air comes in contact with the coils everything is open windings you can see only terminals come out from the LV, HV winding and heat generated in the coil and the core will be dissipated in the air. And I told you the rate at which heat will be dissipated and the rate at which heat will be generated, when this two will be equal transformer will attain a constant operating temperature ok.

So, it is the temperature rise which is important ok. If temperature rise should not exceed the desired level of temperature rise. For example, I say that materials used is such that temperature rise above ambient should not be more than say 75 degree Celsius ok. So, maximum temperature rise is fixed decided. Therefore and no extra cooling arrangement will be necessary for very low KVA transformer.

However, what I was trying to tell here this equation is called output equation, mind you. This is output equation of a transformer this one. Now, you imagine that this is the physical dimensions A i, A w etcetera that along with this specific magnetic loading and electric loading decides the KVA. Now, imagine I will increase all the linear dimensions by factor of x; x is suppose greater than 1 then what will happen is this the areas KVA of the transformer will increase by a factor of x square.

I will keep same B max and delta because core material same I will be using, same copper I will be using therefore, B max and delta are same stack factor and window space factor will be same and therefore, if you increase all the linear dimensions by factor of x area terms will increase by a factor of x square. So, x square into x square will become x to the power 4 therefore, KVA rating of the transformer will increase by a factor of x to the power 4 if all linear dimensions are increased.

So, this I must have written somewhere KVA of the transformer increased by a factor of. Now and area surface area overall surface area through which heat is dissipated into the atmosphere that will also increase by a factor of x square. Then, I stopped here we went up to this point we can easily show that losses in the transformer for this bigger transformer whose KVA rating is now x to the power 4 into S if S was the original KVA rating the losses will increase by a factor of x cube. Why?

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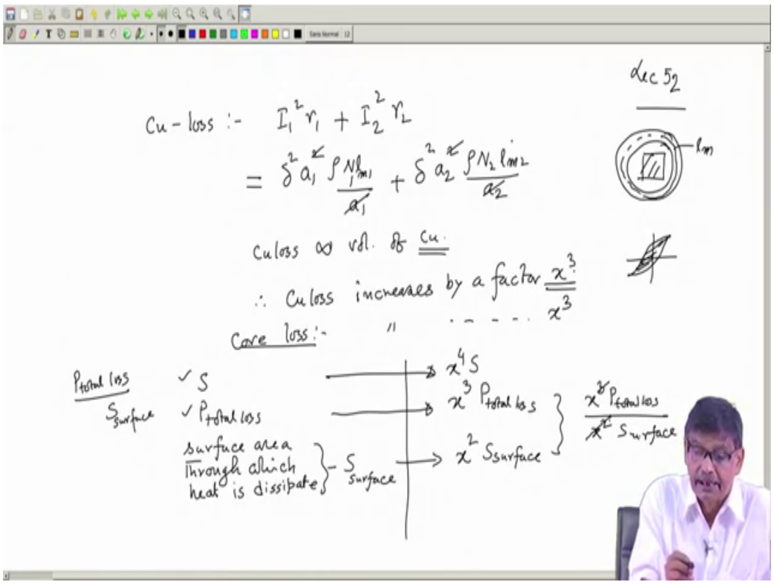

It is simply because of this see the total copper loss just to show total copper loss is equal to I 1 square into r 1 primary to copper loss I 2 square into r 2 this is the total copper loss. Now, this copper loss can be simply written as delta square into a 1 square for current in the primary side, r 1 is the resistivity of copper, rho into length of the copper. Length of the copper will be proportional to the number of turns and that is number of turns and average length mean length of the turns because you know this is the core suppose turns will be like this, several turns like this.

So, mean length of one turn you take that is l m and multiply with it is number of turns n 1 l m that will give you the estimate of the length of the copper conductor in the primary side. So, rho l by area a 1 you remember cross sectional area of the conductor therefore, this is the thing. Similarly, on the secondary side it will be del square a 2 square rho N 2 l m 2 mean length of the conductor divided by a 2 this is the thing. Now, you see one this a is goes here. So, on the top what you have physical dimension wise length into area, is not? Here also length into area. So, copper loss is proportional to the volume of copper; volume of copper.

So, copper loss will increase by a factor of x cube, is not? Volume means 3 lengths multiplied and we are increasing each linear dimension by a factor of x. So, copper loss increases by a factor of by a factor of x cube. Similarly, core loss for core loss it is much more simpler because we have already seen the core loss comprises of eddy current loss and hysteresis loss and eddy current loss is proportional to B max square x square tau square, where tau is the thickness of the each lamination and that is per unit volume or kg of copper.

Similarly, hysteresis loss the area this area it gives you hysteresis loss a measure of hysteresis loss it is also per unit volume per unit cycle. Therefore, core loss will also increase by a factor of x cube increases. Therefore, total so, to summarize if this was your original KVA rating this is the total loss and this is the surface area through which heat is dissipated say we write this. So, S P total loss and this thing let me write S surface some effective surface through which heat is dissipated.

Now, if you increase the dimension by linear dimensions by x times KVA rating will become x to the power 4 into S total loss will become x cube into P total loss, where P total loss when the KVA rating was this P total loss and your surface area this will increase by a factor of x square; x square S surface, got the idea? So, if you imagine linear dimensions I have increase same magnetic loading same electric loading this is the thing. Then you can easily see the loss increases by a factor of x cube. So, here in this case P total loss divided by S this ratio and here the same ratios that is S surface is like this P total loss by x square S surface, got the point? And this becomes x.

Therefore, what we note it here is that losses increases by factor of x cube, but the surface through which it heat will be dissipated is only increased by factor of x cube. Therefore, temperature rise will become more now, because available area through which heat will be dissipated out to the atmosphere is become less loss increases by a factor of x cube. If your surface area would have been increased by the same factor x cube then the available surface to dissipate a certain amount of loss will be same if it was x cube x cube, but it is now more because x is the number greater than 1 you have to dissipate more power loss through a lesser surface that is what I want to say.

If I say that in the original transformer with this specification temperature rise was within the limited that is say 70 degree centigrade temperature rise. In this case you will find temperature rise will become more, same materials you are using. Therefore, you know extra cooling arrangement is now necessary to keep the temperature rise within the same limit compared to this transformer.

So, this is why a transformer needs extra cooling arrangement for large transformers. For small transformer suppose you say for 5 with KVA transformer temperature rise is 70 degree centigrade or what if I reduce the dimensions linear dimensions by factor of say x equal to half say smaller size or you do not require any transformer because more surface area will be available and your total loss will be reduced if x is less than 1. We are discussing about x greater than 1 for large sized transformer what happens.

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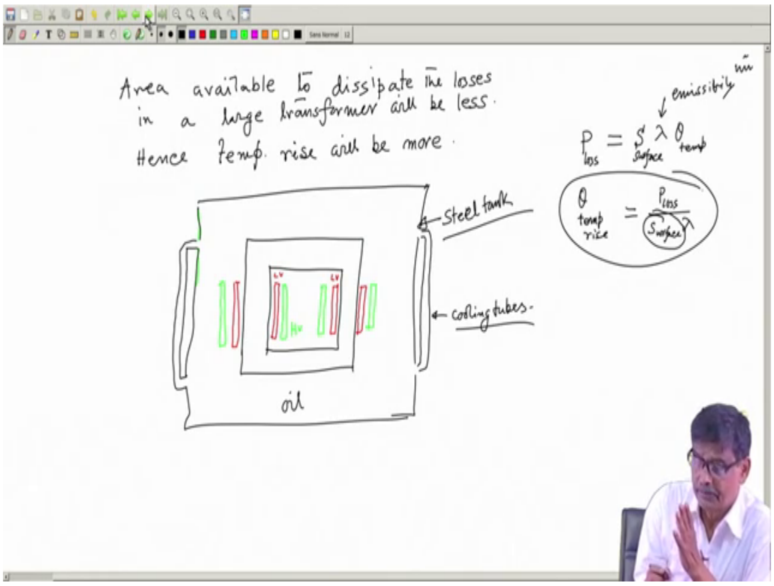

Therefore, extra cooling arrangement is a must extra area available to dissipate area available to dissipate the losses in a large transformer will be less. Hence temperature rise will be more; will be more got the point always it will be. So, if temperature rise allowable temperature rise is a known to you then will say that if the transformer is higher ratings I must adapt some other means there.

That is why what is done is this transformer core transformer core for single phase I am telling, where your windings will be here LV winding red colors are LV windings and suppose these are HV winding. Similarly, on this side because LV windings are also distributed in the two limbs in a practical transformer not that LV is wound on the same limb and this is your HV coils these are all circular around these this way. So, this is LV, half of the LV turns there and then this is HV green one is HV, got the point?

Now, this is the transformer and this whole thing can be air natural cooling earlier it was just air natural cooling, but here you will say that maybe I will immerse these this transformer in a tank filled with oil mineral oil refined mineral oil. Everything will be immersed in that and so, this is steel tank and it will be immersed in oil and then the terminals will be brought out from the top surface of this transformer.

So, here is no space you understand in my last lecture I showed you some diagram very roughly sketched not. So, well a diagram, but none the less this is the it is tank inside this transformer and terminals will be brought out through bushings through the conductors LV side, HV side. You can easily make out which one is HV if the insulation level is more that is HV and this is the LV side LV side thicker conductors anyway. So, it is immersed in oil and it will go.

So, this is called the oil natural cooled here. So, filled with oil. So, oil when it comes in contact with the core and the windings they will be heated up it will go up and it will circulate and they will carry the heat to the surfaces through which heat will be dissipated. I told you mind you that the final temperature rise can be easily expressed in some very easy way.

For example, the loss in the transformer is P rate at which heat is generated is P ok. And this should be equal to surface area into emissivity into the final temperature rise temperature is not the rate at which heat is generated must be equal to S lamda theta. What is lamda? Emissivity that is how much power it is dissipating. So, this is called emissivity and this is surface, mind you not KVA. When this two are constant then only final temperature will be attend. If loss is taking place at a much faster rate than the rate at which it is being dissipated out to the atmosphere, temperature will go on raising like an RL circuit it can be shown, but we will not go to that extent.

What I am telling theta temperature rise becomes equal to total loss P loss by S surface into lamda, that is why I was telling if your surface area available is less temperature rise will be more can be easily seen from this also ok. In any case oil will take the heat, it will come to the tank, it will dissipate like that sometimes you may require to do something extra. For example, you can to make the surface area more what you do you connect some tubes like this tubes here a series of tubes cooling tubes they are called and so on the surfaces.

So, oil will go up and it will have also natural convective currents it will improve the cooling. So, heat will be coming to the cooling tubes mind you, it is not only one it is just one I am seeing behind this along all the surfaces you can connect. On the top surface and bottom surface of course, no heat is assumed to be dissipated because so many fittings will be there on the top. So, these are cooling tubes cooling tubes.

So, effectively you have to increase the surface area because you go to higher and higher rating of transformers, your P loss increases, but surface area through which heat will be dissipated should be increased then only temperature rise you can keep to a desired limit. Now, this is one thing for example, say any distribution transformer if you look at when you are walking along the street pole mounted transformers you will find they will be good enough cooling tubes are there and it is there.

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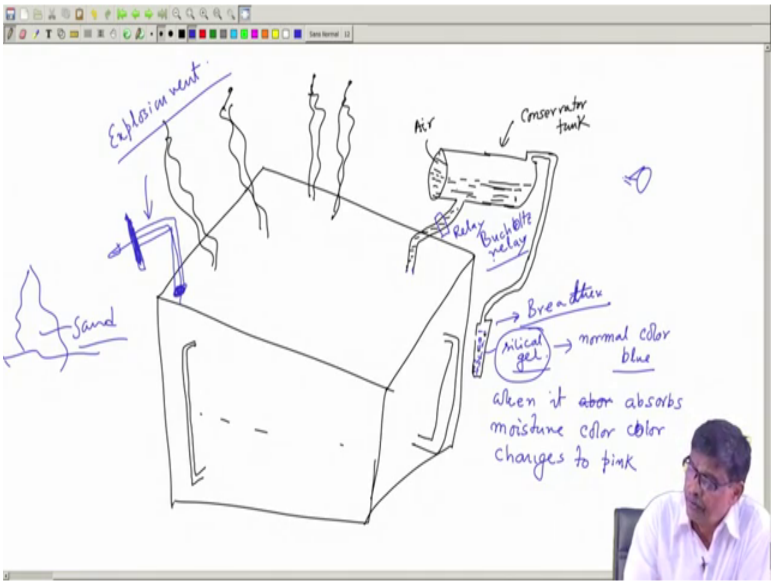

Now, another thing I will tell these are tit bits, but it is better you know that this is therefore, the tank here, is not? What are the fittings you will expect for distribution transformer say. So, there will be cooling tubes here all along effectively increasing the surface area through which heat will be I am not drawing dot dot dot series of cooling tubes. On the tops there will be bushings as I told you for HV and LV to bring out the terminals, that is also fine.

So, LV and HV terminals are brought out and these are the conductors leads from the windings. Apart from that you will find there is another fittings here which is called conservator tank a cylindrical tank and it is connected to the through a piping here. And this tank is filled with oil and through this piping it is also connected. When we when you fill up fill it up with oil will also raise here it will fill the tank then it will go up here because there is a connection through piping and then this is called conservator tank very interesting conservator tank.

And so, up to a certain level this oil will be filled up and above this oil there will be air. This is the oil-air interface. Now, what happens is this oil it is a very good dielectric property also may be 27 – 28 kV per centimeter or millimeter I have forgotten you just see the books the dielectric strength. So, it will insulate the it will provide very good insulation between the coils and the tank; tank is you know steel tank. So, it provides insulation also among the turns as you go from one turn to the on another there is voltage differences, there exist voltage per turn.

Therefore, a good insulating material you have provided. Air is also good insulator, but this oil will be much better. So, oil does two things; it helps cooling, it carries the heat from the core and winding of the transformer to the surface area heat is dissipated through cooling tubes other things, but the quality of the oil when it comes with moisture it deteriorates that is why it is filled with oil and interface with air takes place here.

Now, let us try to understand what will happen suppose the temperature is operating under I transformer is operating under no load condition, loss is very less. Temperature rise will be very less, is not? Now, you imagine and every all oil levels are here like this now you imagine that you have connected load on the transformer only core loss was taking place when the transformer was under no load condition.

Now, through the secondaries you have connected it is delivering full load, full KVA in that case copper loss comes in. So, more heat will be generated and temperature will rise if temperature rises oil is a liquid it will expand and this level of oil will go up pushing the air whatever it was above it will be pushed up, is not? And if you do not bother go on overloading level of oil will go up and down. So, there must be some interface between air it should not be sealed at the top. So, what is done another interesting fitting is connected.

Here from the say top you take out another piping here ok. These are very interesting thing and this pipe is also filled with air. Level of oil will change as degree of loading will change and here is a sort of small vertical vessel like a bottle; here there will be perforations and this thing will be filled up with a material called silica gel, a chemical material silica gel. I do not know spelling you check silica gel and there will be perforations. So, this transformer oil is in touch with the atmosphere via this tank air, this air this is filled with air and this air through silica gel through this air.

Now, why this silica gel is poured? Suppose, you have not put silica gel, it is just like this then what will happen? As degree of loading changes the air will be pushed out. Suppose, you are increasing load, level of oil will increase air will come out and when the transformer is operating a very light load condition oil will drops air, air will be sucked in, is not? That is the transformer is also breathing as human being breathes depending upon the degree of loading.

And this atmospheric air if it contains moisture that moisture will be sucked in and it will get in touch with the oil and therefore, oil property will drastically deteriorate. It will form sludge, thicker it will become and its dielectric property will also decrease. So, the this particular thing is called breather, h is not their breath.

Student: T h e.

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T t h breather it is called that is as human being breathes similarly transformer breathes. It takes air; it also pushes out air through this device. Now, what is this silica gel? Silica gel is a protection. It make sure that water vapor present in the atmosphere does not come here in the conservator tank. Why? Silica gel, the normal color of silica gel color is blue; it is in granules you know some granules, blue. Whenever air will be sucked in the color, the moisture will be absorbed by silica gel and its color will change to pink. When it absorbs moisture color changes to changes to pink and of course, so no moisture is allowed here it will go up ok.

So, this is how silica gel will prevent entry of moisture into the transformer tank and come in contact with oil try to deteriorate it, but during rainy season and all this will soon become, see it will be a very important job for supervisors whoever is watching this transformer to inspect the this breather all the time whether color has become totally pink; that means, it has become saturated with moisture. Moisture will be then going here; therefore, he will replace this silica gel with new silica gel and once again that pink colored silica gel you dry a bit it will become blue. It can be reused, but these are the things I wanted to tell ok.

So, transformer has got a breather and this is the air-oil interface and another fittings will be there on the tank of the transformer that is called explosion vent. I must tell this because. I am showing it here it will be properly positioned, but you will see another structure like this and this is also a sort of vertical pipe bent like that.

And it is not open to air there will be some diaphragm connected here and on the tank surface it is fitted. But, this tank as I told you it is made of steel, here also a not strong steel material is used a rather little sheet of iron or steel is used while fixing it, got the idea? The steel thickness of the tank is high I mean thick quite, but it is only little thickness ok. Therefore, no oil neither air is allowed to be coming in because here also it is fixed. This end is also fixed by a plate.

Therefore, no question of oil communicating with air through this then what purpose it is given? It is called explosion vent it is like a safety valve in your pressure cooker. What happens is this if suppose the transformer becomes overloaded some fault has occurred, high short circuit current is flowing, heavy losses are taking place, oil is going up here, but this place is a rather weak in it is mechanical strength. So, oil will oil pressure inside the transformer builds and it will break this and this oil will gush out from this place.

And the direction of this explosion vent is made in a particular angle where you will keep sand etcetera, so that fire does not breakout because the that will be very hot oil and it causes fire got the point. Therefore, explosion so, this plate diaphragm is also weak, this is also weak if no protection mechanism works oil will break this thing because of its own pressure heat generated and oil will gush out and you provide a directed path on the floor you keep some sand etcetera so that oil will be coming here. You must have read in newspaper sometimes in some locality transformer has exploded because of overloading or some protection mechanism did not work and it caused fire.

So, anyway this is explosion vent which acts like a safety valve and only last point I must tell you that what happens is this between this conservator tank and this tube here a relay is connected relay which is called Buchholz relay ok. When oil will be heated oil will push out, density will fall, there will be some floats inside, they will move through that mechanism you can initiate some operation or it can give you some alarm. So, that things are not good for the transformer, oil is almost vaporized here. You know float like your toilet float in the this one.

So, it will go up because density has fallen and that movement is used. So, we are not discussing that, but I will just mention only there is a place in this connecting tubes there will be a Buchholz relay connected and it will be operating and give you alarm or if necessary it will disconnect the transformer you will read those things in power system protection. So, this in nutshell will be the general fittings one is the conservator tank bushings.

In case of three-phase transformer three-bushings will come out and on the name plate there will be a plate KVA ratings this that will be written and there is a breather here silica gel which is through which air will be coming in when transformer inhales because during no load condition oil will become cooler, its level will fall air will come in and here is a gate which will not allow moisture to enter. And the color of silica gel will change from blue to pink and it will arrests the moisture air, but regular inspection is necessary to see that silica gel color has become all pink, then you take out this sack in which silica gel which are granules dry it up. So, we will continue with this next time.

Thank you.