**Electrical Machines**
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**Lecture 9**
**Auto-Transformers**

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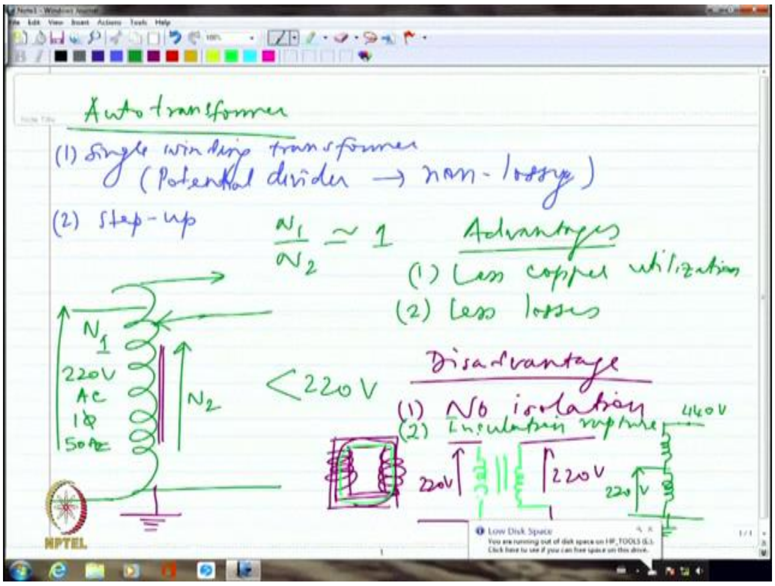


We had been discussing efficiency and voltage regulation, we derived the condition for maximum efficiency of a transformer, this essentially allowed us to differentiate between distribution transformer and power transformer, just to reiterate the power transformer normally has maximum efficiency at 100 percent load condition or rated load condition under that condition, we will have basically the copper loss equal to constant loss, which means the constant loss if we say that is 100 watts, the same 100 watts is going to be the loss under copper loss condition under full load, when the transformer is carrying its rated current.

So that is the characteristic of a power transformer or a transformer which is connected to a generator in the power station. Whereas distribution transformer normally has maximum efficiency corresponding to whatever is the prevalent load for the maximum portion of the daytime or in a particular 24 hours period, whatever is the maximum amount of load that is being present for more amount of time corresponding to that we will choose a distribution transformer which will have the maximum efficiency corresponding to that particular load condition, We will try to work out probably one problem for a transformer but that I will do after discussing auto-transformer, So, the next topic we are going to discuss is auto-transformer. In the auto-transformer what is the major difference between an auto-transformer and the normal two winding transformer. Auto-transformer actually is a single winding transformer, so I am not going to have two windings in this transformer, it will be a single winding transformer which actually is very similar to a rheostat, but it is an non lossy rheostat or potential divider. So it is really similar to a potential divider, but this is non-lossy there is no loss, that means there is no resistance loss in this particular apparatus.

So what were actually looking at is, maybe to step up or step down the voltage or obtain an output voltage which is slightly different from the input voltage, most of the times what we use the auto-transformer for is if I am applying 220 V. I may require a voltage as 230 or I may require a voltage as 200 at the output, and I want to make sure that very close to the input I am going to obtain the output, but I will be able to make the fine adjustments by actually moving the jockey point.

So let us say this is my auto-transformer which is a single winding transformer and let us say I am applying 220 V AC single phase here, What I want is probably 210 V, then I may leave out only a few turns on the primary side, the secondary side will consist of, a little fewer turns as compared to the primary side, so if I may call this complete number of turns as $N_1$ and I may have this as $N_2$ the number of turns as $N_2$.

So what I get as the output will be less than 220 V, slightly less than 220 V, so I would be able to adjust the output voltage anywhere close to 220 volts, this is one of the major applications of auto-transformer, it works like a potential divider, most of the time if I try to look at $\frac{N_1}{N_2}$ it will be close to unity, most of the times that is the way it will be, if I try to look at what is $\frac{N_1}{N_2}$ it will be close to unity, but rather than using single winding, rather two winding transformers which are having a turn's ratios of 1:1. I am trying to use only one single transformer.

The major advantage is the amount of copper used is minimize to drastically, if had been using two windings I would be spending same amount of copper on either of the windings, whereas here, one single winding I am utilising so obviously I am not really spending twice the amount of copper like what I would have done in the case of a two winding transformer. So the major advantage is saving on copper and if I am having saving on copper, obviously if

I am looking at the resistance of the primary winding and resistance of the secondary winding I would have twice the $I^2R$ losses in a two winding transformer as compared to what I would get in an auto-transformer.

So, I would say step up action is done quite easily that is one thing and advantages if I try to look at it we can say less copper utilization, and another thing is less losses.

Student: (())(6:42)

Professor: It can be step up or step down, if I am applying the voltage until here and if I try to take the voltage from here it will be step up. So, it can be step up or step down depending upon to how many turns I am actually applying the voltage and out of this whether I am taking the same number of turns as the input at the output or more number of turns or less number of turns. So, it can be step up or step down or just the transformation ratio being unity, either any one of the options can be chosen.

So, the advantages we said already, definitely that should be disadvantages otherwise we will not be using two winding transformers. So, the major disadvantage of an auto-transformer is no isolation, there is no isolation at all between the primary and secondary, I am going to have essentially, electrically both of them are connected or I would say if I call this as ground, the ground is common to both the primary side and secondary side, it is true in any transformer which has only one single winding, it is as good as an inductance.

Student: (())(8:20)

Professor: So, I should probably show two lines here, so it is a single core on which one single winding is vowed, so if you look at it, the leakage will be really, really limited, there is no question of leakage in fact, because whatever links the primary has to link the secondary, Because you are going to have the same winding acting like a primary as well as secondary.

Student: (())(8:52)

Professor: You are going to have essentially a core like this, even when we were talking about this we said that we are not going to wind the primary on one side and secondary on the other side, instead what you are going to do is, you are going to wind the whole thing and these two are going to be connected.

So, the magnetic circuit is very much complete because the core is in totality if you look at it, it is a closed core. So, you are going to have essentially the entire magnetic field line passing like this, through this, it will just pass through this like this, through the core. So, I am looking at a core type here, in core type construction, I am going to have the same winding wound on both the lengths and they will be connected in series, because they are connected in series very clearly all the voltages across all the turns add up together, it is series addition.

So the total voltage will be the addition of all the voltages across each of the turns,  So no isolation is one of the major problems of auto-transformer, but one more problem I can say is, let us say I have a two winding transformer which is $\frac{220}{220}$, let say I take a two winding transformer which is having 220 V and this is also 220 V, I can connect these two in series and make it like an auto-transformer to give me an output of 440 V. I may apply only 220 V, but I can connect the two windings in series addition, then I will be getting 440 V as the output, maybe I need it for some particular application.

Now it is as good as connecting to two transformers like this, so this is 220 V, this is another 220 V, I am applying the supply here, and I am taking the output here. This is what is the equivalent. Now if I say that is this is my ground point with respect to this the potential at this point will be 440 V. When I design the transformer I might have anticipated that I am going to apply a maximum of 220 V nothing like, higher than that, whether I look at the primary or secondary, both of them would have been rated for 220 V only.

Or $220\sqrt{2}$ at the most because peak of the voltage is $\sqrt{2}\times 220$ but in this particular case what is happening is the voltage at this point happens to be at 440 V, so the insulation can rapture if I continue to use it for too longer period, because it is facing the brunt of that $440\sqrt{2}$, that is the voltage that it is facing on a continuous basis.

So I have to necessarily design the secondary if I know apriori that I am going to use this as an auto-transformer, then I should design the insulation of the secondary in such a way that it would be able to withstand 440 V, although originally when I conceived and I made the transformer I was thinking it is going to be 220 V, so unless I strengthen the insulation of the winding which is actually connected in series and away from the ground, please note that this is away from the ground. So if I am connecting two windings in series and one of the winding is away from the ground, it is definitely going to bear the brunt of higher voltages.

So, I have to make sure that the insulation is strengthened. So, I should say clearly the second problem that I may face is insulation rupture can happen, so I can have may be insulation rupture as a potential problem in an auto-transformer if I am trying to connect a two-winding transformer as an auto-transformer.

Student: (())(13:33)

Professor: Let us try to look at it, that is what I am going to come next, So let us try to probably look at one simple example of an auto-transformer connection and see what kind of kVA rating I am going to get, what kind of efficiency, I am going to get and what kind of losses I am going to incur in this particular case.

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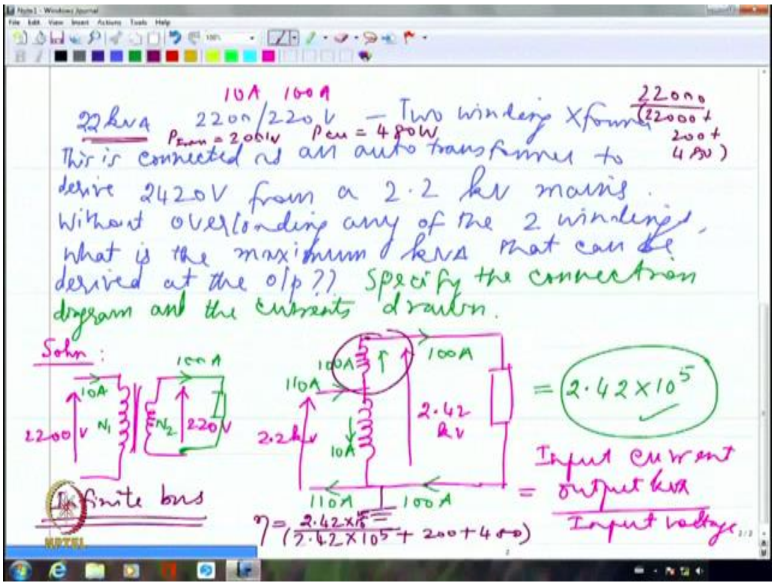


Let me take may be a little higher rated transformer which is 22 kVA transformer, let me take may be $2200/220$V transformer, This is a two winding transformer but this is connected as an auto-transformer to derive, let me add these two voltages how much is it $2200+220=2420$V from a 2.2 KV supply or mains, So I am trying to connect this using this auto-transformer, rather two winding transformer I am trying to connect as an auto-transformer to drive this voltage,

Now the question that is being asked is without overloading any of the windings or any of the two windings, what is the maximum kVA that can be derived at the output, And one more thing may be that we will have to specify is, how much is the current flowing in each of the branches during the maximum kVA output specify the connection diagram and the currents drawn, that is another thing, specify the connection diagram and the currents drawn. So, let us try to take a look at this as to how this works, hopefully this will clarify the concept about the kVA rating.

So to start with, I am having 2200 V on one side and on the other side, it is 220 V, Now if I am connecting full load that means according to the kVA rating this will have a current of 10 A and this will have a current of 100 A that is what it is saying, So, let me specify those currents as well, so this is going to be 10 A and if I connect a load here, whatever is the load value and I can calculate definitely, this is going to be 100 A and let's say maybe this is having $N_1$ turns and this is N2 turns, 10:1,

Now what is being asked is, I have to connect two of them in series, this is the 2200 V winding and that is the 220 V winding, I am applying 2200 V here, so this is 2.2 KV and what I am getting here is 2.42 KV, and I can't overload any of the winding, so I know for sure that this particular winding that is the 220 V winding can carry a current of 100 A without getting overloaded. So, I assume that it can carry up to 100 A, I will have to see how I am going to do the whole thing, so if this is carrying 100 A, this will essentially follow Kirchhoff's current law, so I will have 100 A.

So, this will be returning again 100 A, Kirchhoff current law, and just showing KCL that is it. What I am getting across the load is 2.42 KV, undercurrent I have is shown is 100 A, so how much is the total kVA, It is $2.42\times10^{3}\times100$. So, I am going to have the kVA rating to be $2.42\times10^{5}$. what I was having originally was 22 kVA, now what I am having is 242 kVA,

It is such a large value that I am getting, this is because that turn's ratio of the primary to secondary has become 1:10, so the voltage has become way too large on the secondary side because the primary and secondary voltages I have added, I have summed up the voltage and I am assuming that the load is going to get the entire thing and after all, I am not overloading the secondary.

So the secondary is able to supply 100 A of the current, same current but the voltage has become $1_1$ times whatever was the original voltage, what the transformer is meant to carry, Now if this is 100 A, but I don't want the primary to carry beyond 10 A, it cannot carry more than 10 A. So, let us say this is carrying some 10 A.

Let us try to take a look, so the total current here is going to be 110 A, so clearly this will also be 110 A, rather than supplying 10 A from the source, now I have ended up getting 110 A from the source, because if I am saying that the output kVA is $2.42\times10^5$, it cannot come out of nowhere, it has to come from the source only, nothing else. So, I have got the output kVA rating, I know the input voltage I should be able to definitely get what is the input kVA that I have to supply, input kVA has to be equal to output kVA by a large, except for whatever are the copper losses and constant losses.

So input kVA and output kVA have to be equal to each other, output kVA I have designed first, I have derived first. So input kVA has to be an exactly same as this, so I should say input current if I have to derive, input current has to be actually whatever is the output kVA divided by input voltage because I am assuming input kVA equal to output kVA, So output kVA is $\frac{2.42\times10^5}{2200}$ will automatically give me what should have been the input current, if I want this as my output kVA which is same as input kVA.

So, this gives me 110 A directly, I am supplying from the source, mind you, the primary winding is still handling only $2.2\text{kVA}\times10\text{A}$, nothing over than that. So, it is handling only 22 kVA, similarly the output winding, the secondary winding is again handling only $2.2\text{kVA}\times100\text{A}$ = 22 kVA. So, individually if you look at the input and output windings both of them are handling only 22 kVA each, so we are not overloading them, only thing is certainly how come you are having so much of increasing in the kVA.

That is because they are conductively connected together. It is working now as a potential divider. So, what you have done is essentially added the two voltages, so you have connected them in series, so if you look at the electromagnetic induction that is taking place, that is still pending for only 22 kVA, but if you look at actually what is happening in terms of the conductive coupling, one is electromagnetic induction coupling, the other one is or magnetic coupling, the other one is conductivity how they are connected, they have been connected in such a way that you are essentially making the 220 V look like it is put on the top of 2200 V.

So $2200\text{V}+220\text{V}$ together is supplying the load and together it is giving you basically, $2420\,\text{V}$ at 100 A, So I won't be able to definitely multiply the capacity by a very large factor, in the case of an auto-transformer, if I have primary to secondary turn's ratio in the two winding transformer to be large, no doubt, but if I had designed this winding only to have 220 V, it will not withstand say 2.2 kV, completely the insulation will rupture in no time because we are trying to subject that to more than 2.4 KV. So, you are going to see that specially the top portion of the winding will rupture right away. So auto-transformer connections are extremely useful when I want to may be slightly adjust the voltage.

If I try to connect it somewhat like this, I am going to end up spoiling the transformer, this is theoretical. This was only design for 220 V, but this is my ground now, the ground is somewhere here. So with respect to ground, if I look at the voltage here that is 2.4 KV, more than 2.4 KV, so then I actually design my insulation, I will design it only for 220 V but now I am applying 2.4 KV, so it may not be able to withstand it unless I had strengthened or reinforced the insulation, knowing that I am going to use it like this. So, this will result in rupture.

Now, yeah.

Student: (())(26:12)

Professor: Between the two windings, that is the two ends of the winding but that is not going to matter, Because overall what is the stress it is facing, it has to look at that, the overall stress it is facing is whatever is the voltage here with respect to the surrounding air or whatever, there is surrounding air, you are not going to do anything about it, So around that all of them essentially work at ground potential, hardly any potential, so you would see that, the insulation is not able to withstand such a large voltage stress.

Student: (())(27:04)

Professor: From the source.

Student: (())(27:09)

Professor: See we are generally looking at the power grid as an ocean, normally we say our power grid is an ocean that is the reason if you are generating only 1 MW or 2 MW you say that you are putting a drop in the ocean, so that is the reason we normally call the power source generally as infinite bus, we generally call this as infinite bus, a bus bar or a junction point, from the junction point, you probably derive so many load connections.

So we call this as the infinite bus because we assume that its capacity is infinitely large, which is not really, clearly but compare to 210 GW, which is the overall generation capacity of our grid, 1 MW is less than a drop, So it is really an ocean so you generally think definitely this is not the case with respect to our lab and when we design our lab we say normal capacity what we require is maybe 30 A, 50 A, maybe if I have 20 tables like what we have in our electrical machines lab, we say every particular table requires, maybe 3 or 4, 5 A plug point we give, so 20, 30 A, so 20x30, so we say this is what is the total ampere is I require in this lab, it is not infinite.

But we normally think that when we talk about a source, we talk about normally the power grid, the source from the power grid, which have infinite capacity. So the inherent assumption is 2.2 kV source will be able to supply 110 A that goal without fail, if definitely it is only rated for 10 A if I try to draw 110 A whole thing will burn no doubt, So we normally go with the assumption of infinite bus.

Now if this is 22 kVA and let us say the losses for this transformer, if I write $P_{iron}$ was maybe 200 W and may be $P_{CU}$ was 480 W, for example I am just arbitrarily taking same values again, I can definitely calculate the efficiency under unity power factor load condition under rated kVA then it is operating as a two winding transformer. It will be essentially $\frac{22,000}{22,000+200+480}$ this will be the total efficiency that I would get for the two winding transformer connection. When I am looking at the same thing as an auto-transformer connection, the losses will not change. We are still applying 2200 W for the primary and I am having only 50 Hz, so the flux established is the same and I am still drawing only 100 A of current from the secondary and 10 A I am supplying to the primary.

So the copper losses will not change, but the output power has multiplied by a huge factor, Because of which I am essentially going to see that if I calculate the efficiency now it will be, whatever is this $\frac{2.42\times10^{5}}{2.42\times10^{5}+200+480}$, obviously the efficiency will be much better at unity power factor.

So no wonder we say auto-transformers have much less losses, much better efficiency, So auto-transformers definitely are very good when I have strengthened the insulation to a sufficient extent, if I have not done that the transformer will be burnt, it will be very difficult for you to make the transformer withstand, the summation of both the voltages, that will not be possible, So to summarise auto-transformers are good, especially when I want to regulate the voltages by a small fraction of the total voltage that I am applying.

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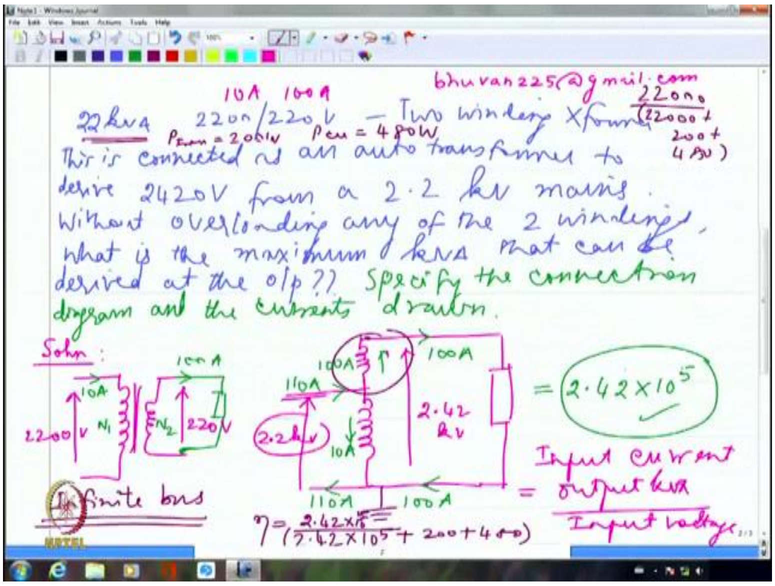


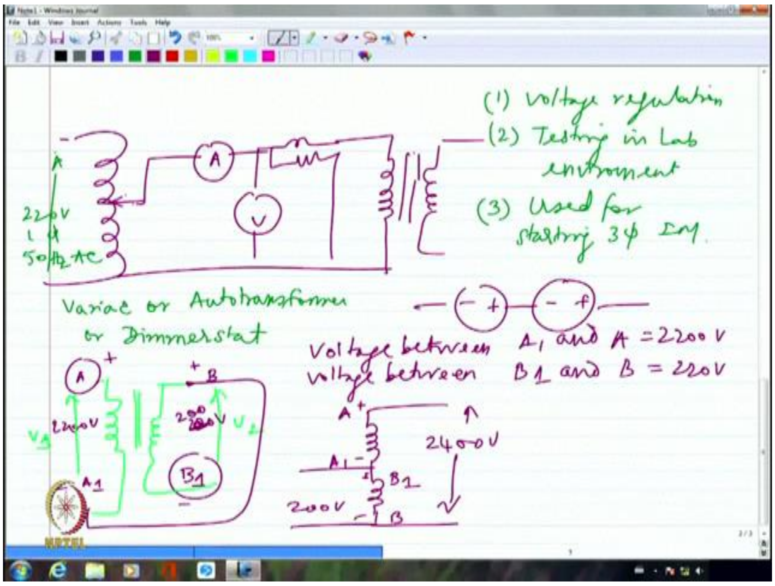


Typically it is used in laboratory conditions very commonly for conducting test on transformer which you had done, open circuit test and short-circuit test, you guys had done and I showed you also that in the front-end you always connect an auto-transformer. So normally open circuit test or short-circuit test what you are going to do is to have an auto-transformer and from here, you are going to connect, maybe an ammeter, a voltmeter, a wattmeter and then this will go to the transformer under test, this is how it is going to be, If it is open circuit test you will leave it open, if it is short-circuit test, you are going to connect essentially, the two terminals and short-circuit it basically.

So this is the auto-transformer or variac, this also has another name called variac or auto-transformer and for some reason the industry people always say dimmer stat, so probably because the voltage can be decreased and lamps intensity can be reduced, dimmed, so maybe they use the word dimmer stat, so it is called dimmer stat as well and here I will apply 220 V single phase 50 hertz AC,

So the major applications of auto-transformers are one is voltage regulation, so I will be able to regulate the voltage to a particular value but connecting maybe a few turns extra, a few turns lower whatever it is I should be able to regulate the voltage, the second thing is it is used for testing or conducting test in laboratories, lab environment, the third one is generally the three-phase auto-transformers are very commonly used to start induction motors, which will we revisit when we are going to discuss induction motors. So, these are used for starting three-phase induction motors. So, these are some of the applications of auto-transformer.

I would like you to do a little bit of self-study in this, how much of copper will be saved in an auto-transformer, Compared to a two winding transformer of similar rating, this, you guys will study yourself. How much of copper saving happens in an auto-transformer as compared to a two winding transformer of similar rating, so instead of using two windings I am going to use a single winding,

So how much of copper saving will happen when we have comparable ratings in both the cases.

Student: How to determine the direction of current in autotransformer winding?

Professor: You are talking about how to find whether 10 A is in this direction, the question was, so how do you find the current direction, 10 A how do whether it is going from up to down or down to up, basically we had calculated the kVA, once you calculated the kVA at the output, what is the input current from the voltage that is given, you have the voltage here, so because you have the voltage from the voltage you should be able to get what is the kind of current you are anticipating, so the current what I am getting is 110 A, if this is 110 A and if 100 A is going in this direction, very clearly 10 A has to come downward. So that is a way, you generally determine the direction, okay. Now will try to work out one problem, so let me take my pet rating.

Student: How can be known whether primary and secondary are addictive or subtractive pushed Mark

Professor: See it is very clearly given in the problem I had given that, we wanted to derive 2420 V from 2200 V, this can happen only if I add both the voltages, so this is series addition connection, you can also have, you could have had some 2200 V, I want to get only 2000 V or less whatever in which case you could have just taken it from here itself what, if you don’t have the tab you can only have it in such a way that in this case we had gotten this is, if I say this is minus, this is plus, this is minus, this is plus, so they are all in series addition, this all AC, I am talking about at this instant. So, they are coming in series addition, if I wanted less value than 2200 I could have actually, let us say the second winding is of 200 V value for example, in which case 2200 V-200 V=2000 V.

So I could have connected it in such a way that, if is actually plus and this is minus because I would have the polarity of the transformer clearly marked or I have to mark that leaves us to polarity test, let me tell you that also, polarity test, let me try to tell you little bit.

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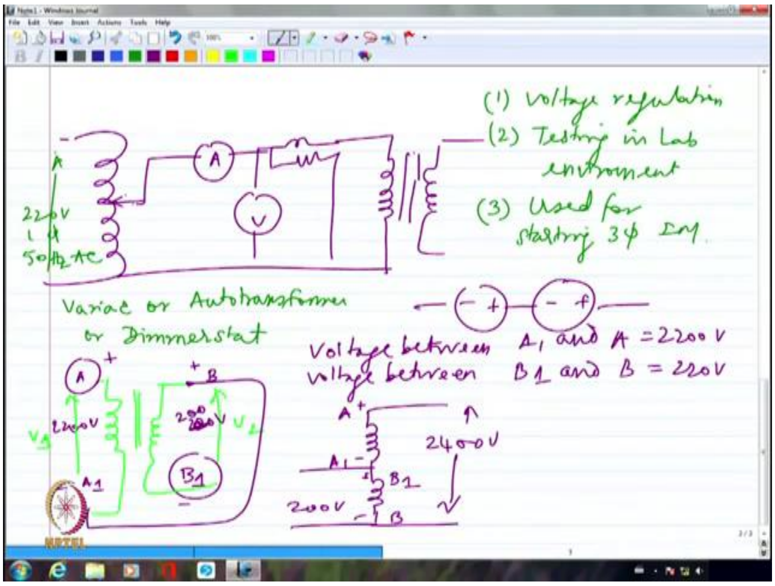


So, let say I have a transformer like this, I am applying $V_1$ here, When I connect the voltmeter, I would measure whatever is the voltage $V_1$ I am applying, And if I try to connect a voltmeter here directly I would have gotten $V_2$.

Let us say, now I connect these two in series, I have connected them together, two terminals I have connected together and if I measure the voltage between these two points, between A and B, if I get the overall voltage as $V_1+V_2$ that means I have connected them in series addition, if I get rather $V_1-V_2$ or $V_2-V_1$ whichever is higher, that means I have connected them in series opposition. I am connecting two sinusoids, with the two sinusoids can be adding or they can be opposite, so whether I am connecting them in series addition or series subtraction depends upon when I measure the voltage after connecting these two terminals together, so let me say this is probably $A_1$ and let me call this is $B_1$.

I have connected, $A_1$ and $B_1$ together and if I am getting the voltage to be $V_1+V_2$ I know that $A_1$ and $B_1$, when I connect together they are in series addition and if I had wanted 2420 V in the previous problem what we discussed I should have connected $A_1$ and $B_1$ together, then I will get 2420 V, instead, if I had wanted 2200-220 I should not connect $A_1$ and $B_1$ together, I should rather connect $A_1$ to B and I should have taken voltage across A and $B_1$, then I would had it a series opposition which will actually give me 2200-220, I did not give you that can be series addition and series subtraction, this brought out at least the series subtraction part.

So, I would be able to get by auto-transformer connection either $V_1$ or $V_2$ alone or I would be able to get $V_1+V_2$ or $V_1-V_2$. So, I would be able to get all of them by having auto-transformer connection.

Student: How to connect two wind transformer as an auto-transformer?

Professor: See in a two winding transformer being connected as an auto-transformer we are telling this, so if it is a two winding transformer, I have four terminals, which two terminals I want to connect together, that is what we were talking about, two winding transformer being converted into auto-transformer, when I do that, which two terminals I have to connect, if I want series addition, which two terminals I have to connect if I wants series opposition. So finally, when I connect the two terminals together, I have only two terminals coming out, only A and B are coming out or I will have A and $B_1$ coming out finally, I will not have more than that.

In the auto-transformer here itself, let me say that maybe this is 2200 V, maybe this was 220 V, let me take this as 200 V. When I measure the voltage between $A_1$ and A, this was 2200 V, whereas voltage between $V_1$ and V at the same instant, I am talking about the same instant, if I am measuring, I am getting this as 220 V. Now if I connect this is A, and along with $A_1$, I am going to connect $V_1$ and V, So maybe I am applying the voltage here as 200 V and if I try to look at the voltage here, this will be 2400 V together, this is series addition, this is added because I am showing that $V_1$ and $A_1$ directly have the same kind of polarity and when I am trying to connect them together, I am getting the total series addition, so when I am actually measuring, I am getting 2400 V, if I had want to 2000 V.

Student: (()) (44:46)

Professor: At a particular instant, but later on during a negative half cycle you will have the same thing reversed.

Student: (()) (44:57)

Professor: See B is at a higher potential that $V_1$, so if I call these as plus, this is minus I should also call these as minus and this is plus, only if I connect plus to minus, I going to have minus to plus, I am going to have basically series addition. See I am essentially looking at this as minus, this as plus and this as minus and this as plus, So if I am looking at it, this is actually I am starting of it, this as minus, this as plus and this as plus and this as minus, unless

I connect this two together, they will not be additive, that is plus and minus, opposite polarities have to be connected together, only then they will be in series addition.

If I connect the same polarities together it will be series subtraction, all of you guys know this I suppose, If you have two battery, if I have plus, minus and plus, minus, if I connect it like this, it is series addition, Have you marked the terminals differently, maybe I should have said this is plus and minus are connected together, So I have shown you differently that is the problem, I just realized that, so this has to be erased and I have to show you as though this is connected entire winding is gone, so this entire winding is gone.

So, I should show it as though this is connected here. That is where problem lied now if I want series subtraction all I should have done is B, I should put it here and $B_1$. I should put it here that is all, that can be a series opposition. So, series addition and series opposition I have just invert.

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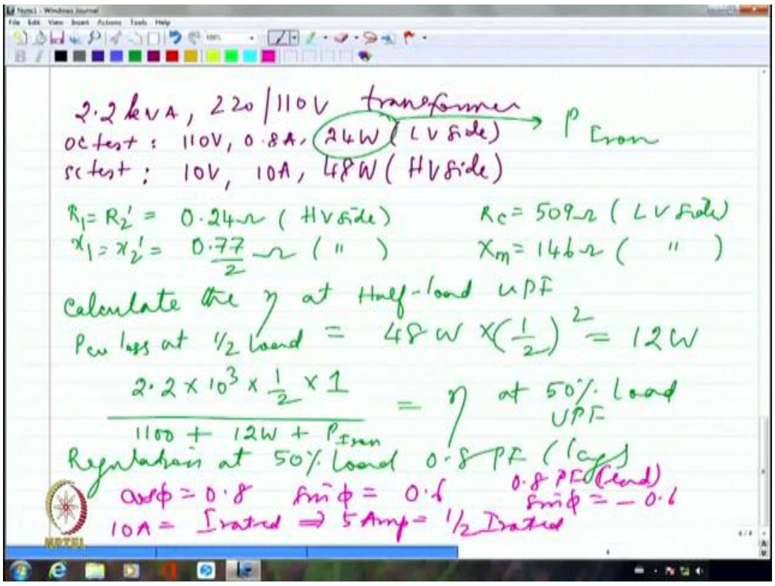


So, I am going to take my pet rating which is 2.2 kVA, 2.2 kVA, $\frac{220V}{110V}$ transformer. Now let me take maybe a open circuit test data and short-circuit test data, I had done something because I did not want you guys to calculate everything here, so open circuit test data I have taken this to be 110 V, 0.8 A and 24 watts, And short-circuit data I have got 10 V, 10 A and 48 W and this was done on the LV side and this was done on the HV side. So, you would be able to calculate for this very clearly, $R_C$, $X_M$, $R_1$, $R_2^{'}$, $X_1$, $X_2^{'}$.

Assuming that $\frac{R_{eq}}{2} = R_1$ and $\frac{R_{eq}}{2} = R_2^{'}$ also. Similarly, we will not be able to individually calculate for primary and secondary, so what we calculate as $\frac{R_{eq}}{2} = R_1$ and $R_2^{'}$ respectively. So I think I will not calculate this, you guys will be able to calculate, I will only write the values $R_1 = R_2^{'}$ =0.24 Ω, And this is probably from the HV side, And $X_1$= $X_2^{'}$= $\frac{0.77}{2}$, approximately, this also from HV side and I am getting $R_C$ to be 509 Ω, this is from LV side.

So, if we are asking you to draw the equivalent circuit, you better transport everything to one side, either LV side or HV side, And $X_m$ is coming out to be 146 Ω, this is also from LV side. Now the next question that is being asked is calculate the efficiency at half load and unity power factor, So that you should be able to calculate as if I am saying that the copper loss at half load will be 48 W $(\frac{1}{2})^2$, Because it is $(\frac{1}{2}X)^2 \times \text{Full}-\text{load}\, P_{CU}$, so that will be essentially 12 W. So, if it is unity power factor, I should be able to say this will be 2.2 kVA multiplied by half that is what is the output multiplied by unity power factor, this is the power factor.

If the power factor had been 0.8, I should have put this 1 as, instead of that 0.8, so divided by again I should say (1100 +12) W is the copper loss and $P_{Iron}$. It is already given as 24 watts, so this is what is $P_{Iron}$. So, this will give me efficiency at 50 percent load unity power factor. If I asked you to calculate, for example the regulation at 50 percent load 0.8 pf, for example, so regulation at 50 percent load 0.8 pf lag for example, so if it is lagging power factor, I can say $\cos\phi$=0.8 and $\sin\phi$ corresponding will be 0.6 because $\sqrt{0.8^2 + 0.6^2} = 1$.

If it had been 0.8 pf lead, then I should say $\sin\phi_L$ will be -0.6 because essentially the current direction would be not below voltage it will be above voltage, if it is leading. So correspondingly sin and cos, you are going to have cos will be still positive, sin will be in opposite sign of what you got for the other one, So using this, you should be able to say that current is only, this is HV side, so I am going to have 10 A as the $I_{rated}$, so I will have 5 A as half $I_{rated}$.

So I should be able to write $5(R_{eq}\cos\phi + X_{eq}\sin\phi)$, that will be the voltage drop, that you have to divided it by rated voltage, rated voltage is 220 V, if I am taking everything from high-voltage side, you should be able to calculate the regulation as well.