Fundamentals of Electrical Engineering
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Lecture – 54
Single Phase Transformer

So, now, we will study that single Phase Transformer of the headline it is a transformers.

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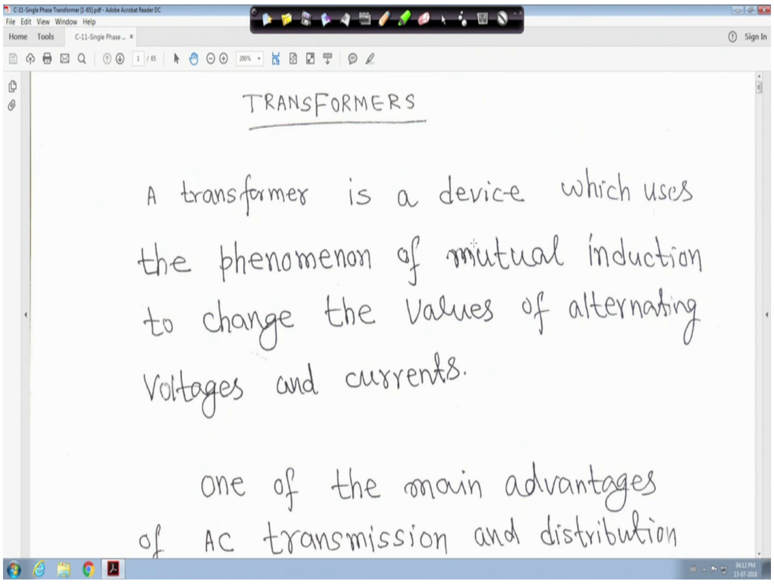

That we will study single phase transformers only and after this we will see that your 3 phase induction machine only in brief and then the DC machine will the DC motors right. So, generally if you look at the this thing a transformer is a device which uses the phenomenon of mutual induction to change the values of alternating voltages and current right. So, basically in a transformer that one of the main advantages is that that it can transmit the voltage level that is it can increase the voltage level or it can you what you call decrease the voltage level. So, this is actually what you have the transformer right.

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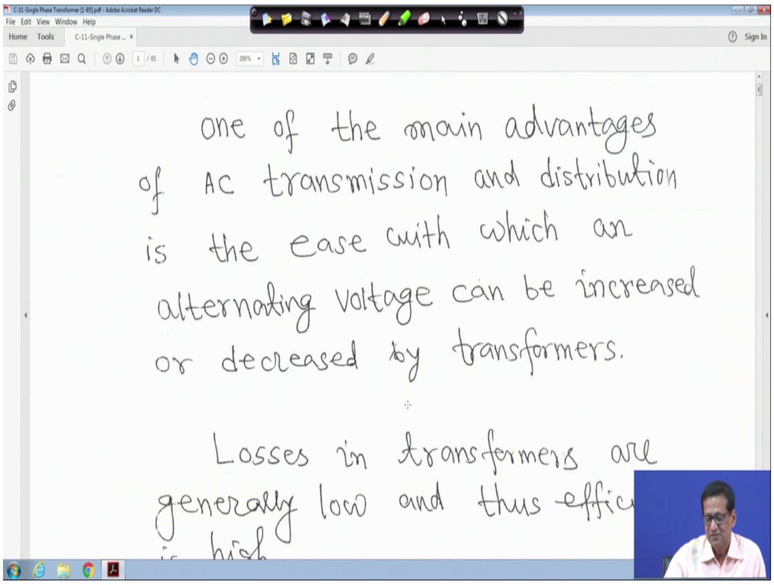

So, it can your what you call for example, many when you look at the your power station, transmission line, distribution line, there are different voltage level and those voltage steps are or step up or step down only by using your what you call the transformers right. So, that means, therefore, the transformer is a device which uses the phenomenon of mutual inductance mutual induction to change the values of alternating voltage and current right.

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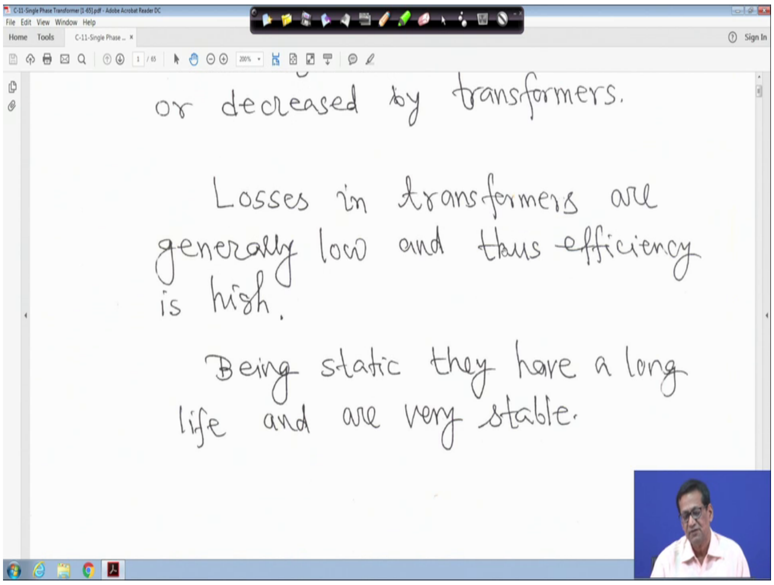

So, losses in transformers are your generally low and therefore, efficiency of the transformer is very high, losses we will see later. So, being static they have a long life and are very stable so, the transformer get static device.

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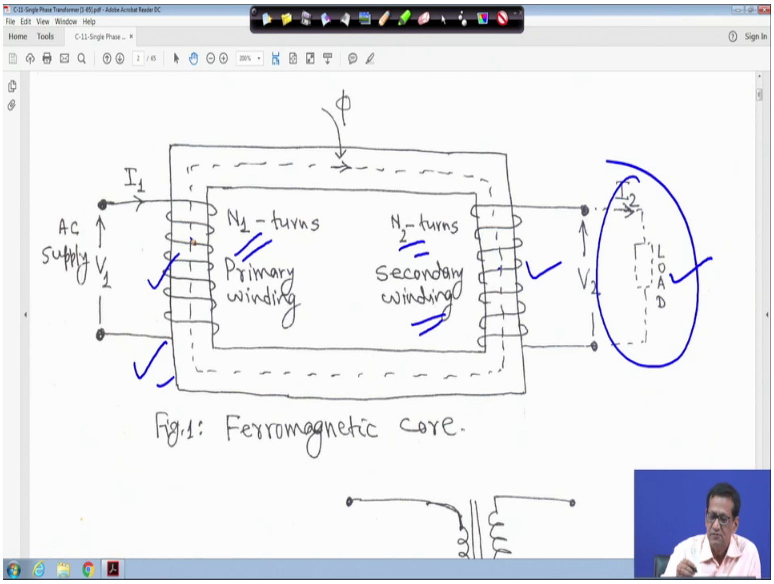

So, now, for example, suppose, if you consider your what you call a ferromagnetic core and you have your primary this side we call primary side say you have N 1 number of turns here, it is N 1 number of turns and you have the secondary you have N 2 number of turns. And in the secondary load is also connected, but shown in dash line; that means, load is not connected.

Now, an alternating supply voltage it is a V 1 is given right. So, when load is actually not connected so, what will happen is very small current right will flow through this your what you call through this primary side of the winding. And we and the flux we will link actually both the primary as well as the secondary winding when this side is your what you call open circuited right that means load is not connected.

So, no current is flowing through the your what you call secondary, but primary side you have applied your small voltage right. So, small current called exciting current will be responsible actually for you are producing the flux. And direction of the flux you will get the magnetic circuit the right hand rule I told you in the direction of the current you graph the your what you call coil and your thumb will put the your what you call the direction of the flux right. So, let me clear it so, this is actually ferromagnetic core and this is your the your circuit symbol of a transformer.

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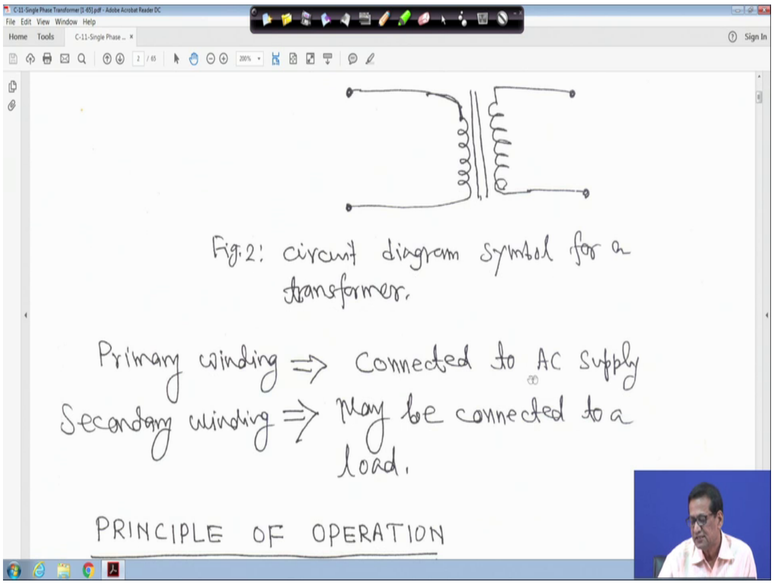

So, primary winding is connected to AC supply I told you and secondary winding may be connected to a load.

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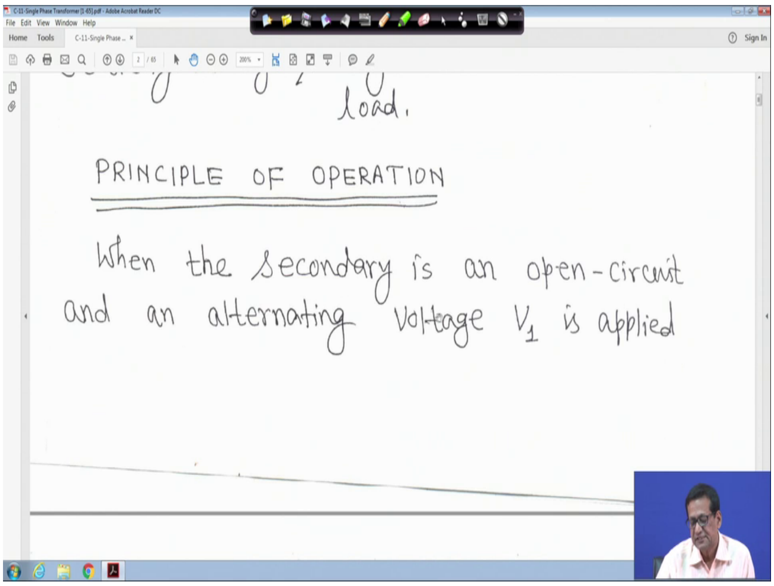

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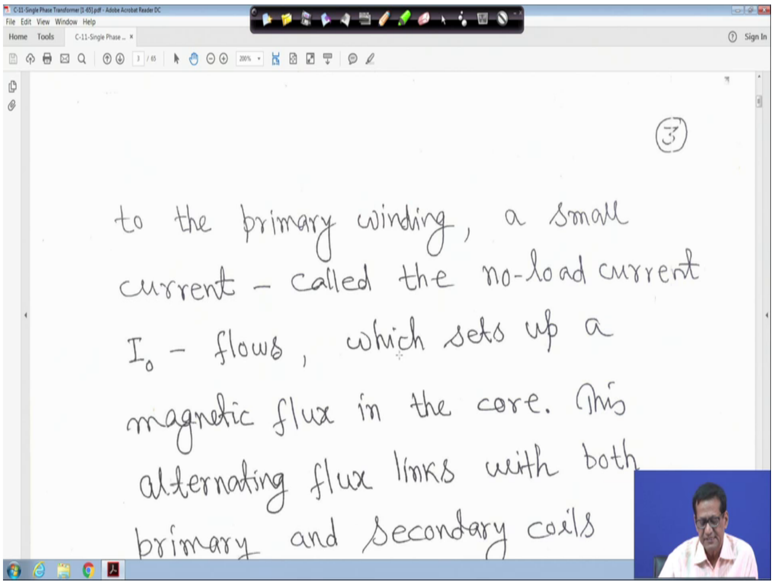

Now, principles of a principle of operation, when the secondary is an open circuit and an alternating voltage V 1 is applied I told you to the primary winding, a small current called no load that is I 0 flows right, which sets up a magnetic flux in the core. That means, here it will sets up the magnitude suppose a small current here it is showing the I 1 because it is primary side you are putting V 1 voltage I 1 current whenever it is I 0 current when it is at no load right and that time I 1 is equal to say I 0.

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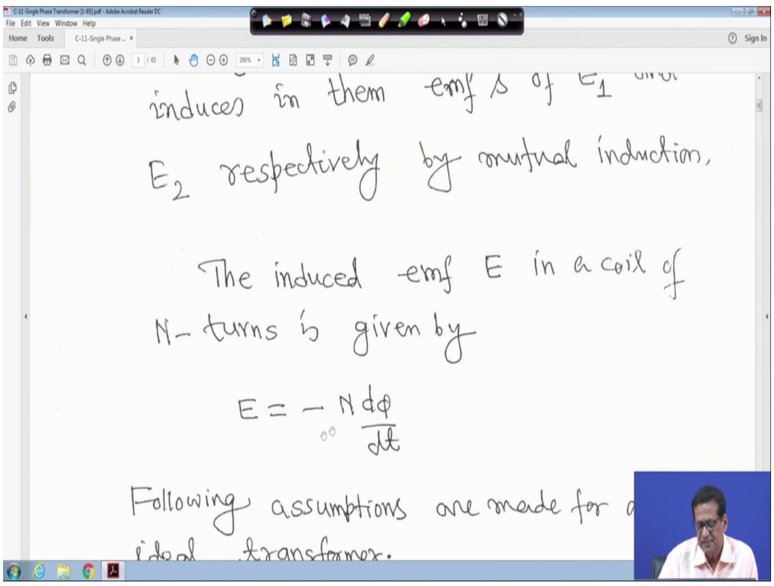

And your which sets up in magnetic flux in the core. This alternating flux links with both primary and the secondary coils right that I told you and induces in them an emf's of E 1 and E 2 respectively by mutual induction. That means, here a actually here a volt this is supply voltage anyway for the ideal transformer a voltage will be induced.

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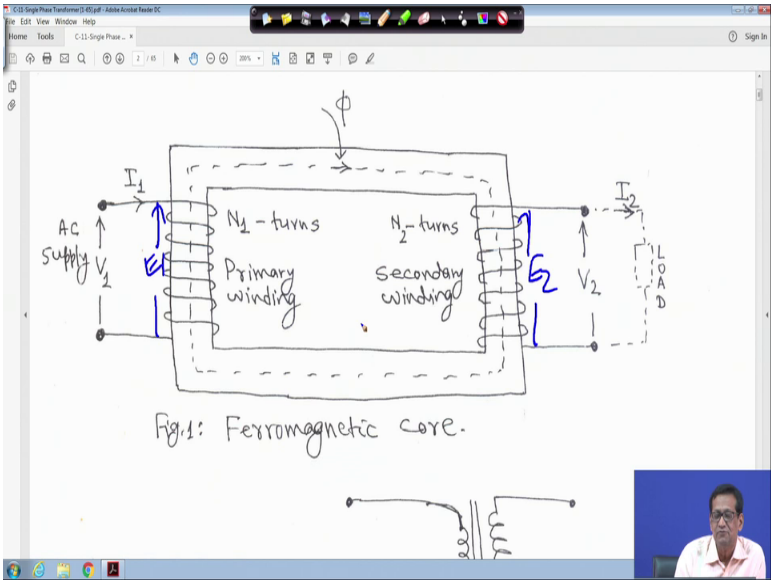

So, if I make it like this it is E 1 right, but at that time you have to see you know different way that this is the winding also has your resistance as well as that your what you call reactance right. So, we will see later so, let me clear it. So, in that case your that your E 1 and E 2 respectively by mutual inductions. So, the induced emf E in a coil if you have N turns is given by E is equal to minus N d phi by dt. So, from the Faradays law the voltage induced thing is N d phi by dt and Lenz d I or what you call Lenz's law will give you the your direction of the emf so, that is why minus sign is here. So, following assumptions are made for an ideal transformer.

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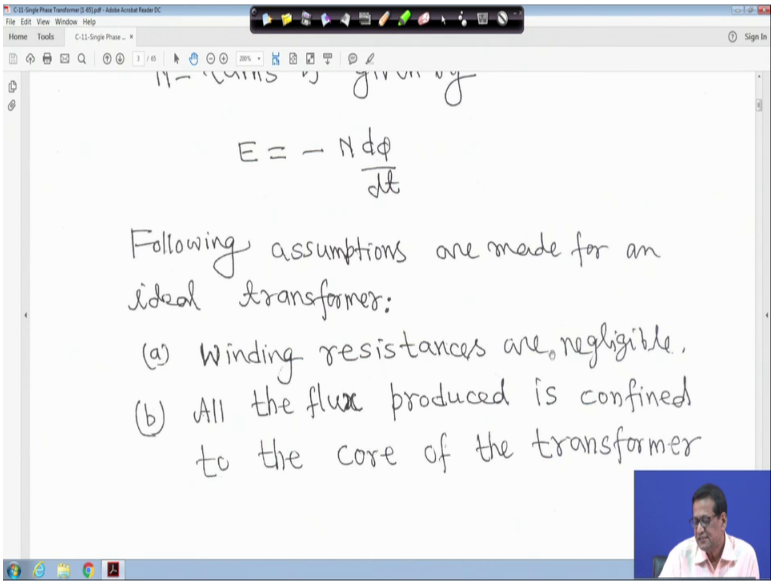

Winding resistance say are negligible, say there is no winding resistance. All the flux produced is confined to the core of the transformer.

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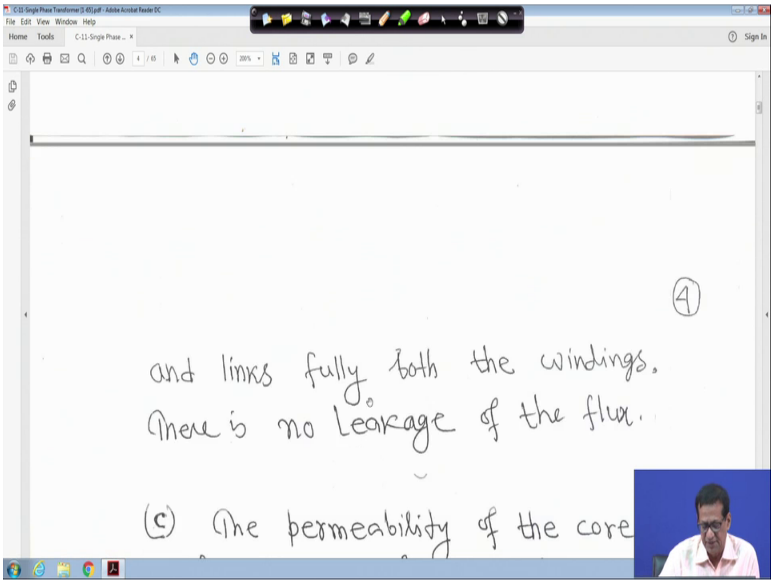

And links fully both the windings there is no leakage of the flux, you are assuming there is no leakage and the flux links both the windings fully.

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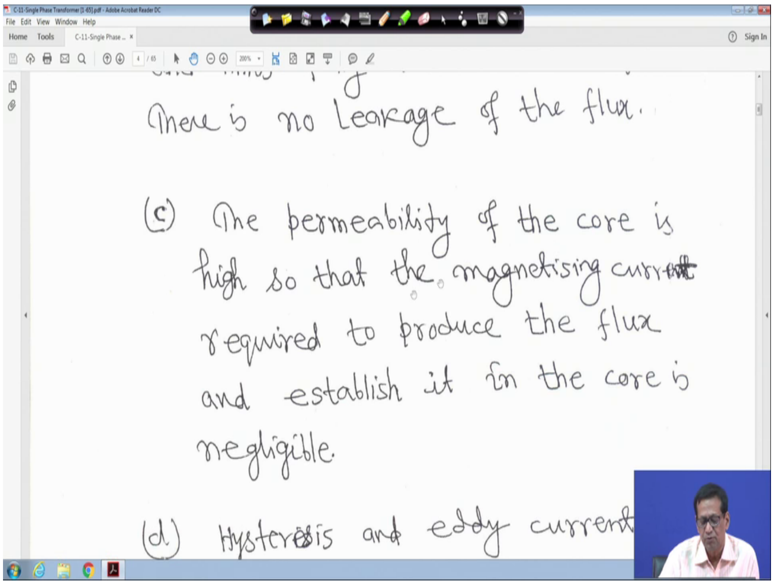

Now number 3, the permeability of the core is very high right so, that the magnetizing current required to produce the flux and establish it in the core is negligible right.

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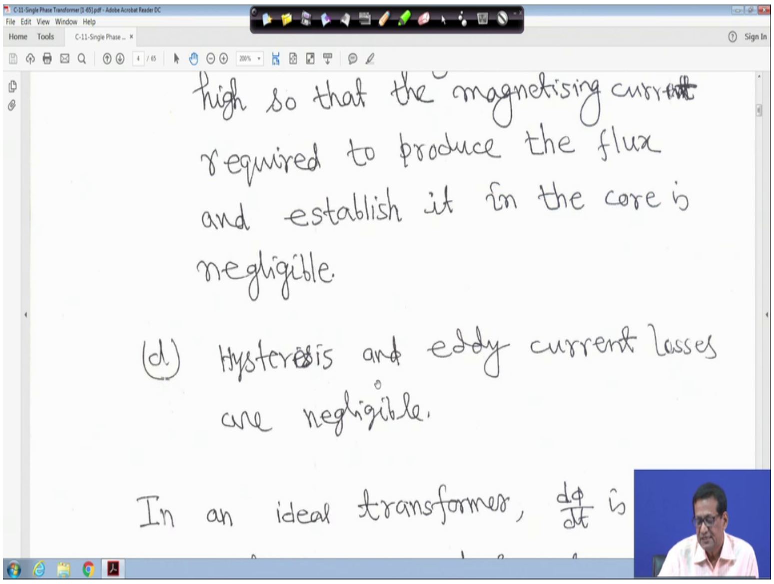

And number 4 that is d part hysteresis and eddy current losses are negligible, these are the 4 assumptions you have made right. So, these are the 4 assumptions you have made for an ideal transformer.

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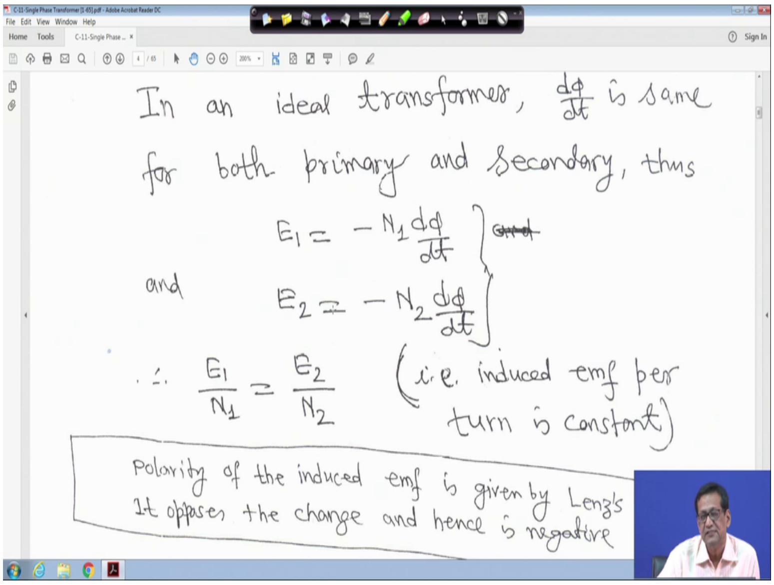

Now, in an ideal transformer d phi d psi by dt is same for both primary and secondary winding because the flux phi linking both primary and secondary winding. So, E 1 is equal to you can write minus N 1 d phi by d t that is the induced voltage in the winding, similarly E 2 is equal to minus N 2 d phi by dt and you are resist you are neglecting your what you call it is the ideal transformer your resistance is neglected.

Now, therefore, if you divide E 1 by E 2 you will get N 1 by N 2 therefore, if you divide these 2 equations E 1 by E 2 you will get N 1 by N 2 therefore, E 1 upon N 1 is equal to E 2 by N 2 that is induced emf per turns is constant that is E 1 by N 1 is equal to E 2 by N 2. Now, polarity of the induced emf is given by Lenz's law actually it opposes the change. Hence it is actually negative right from your higher secondary physics you have gone all through this right.

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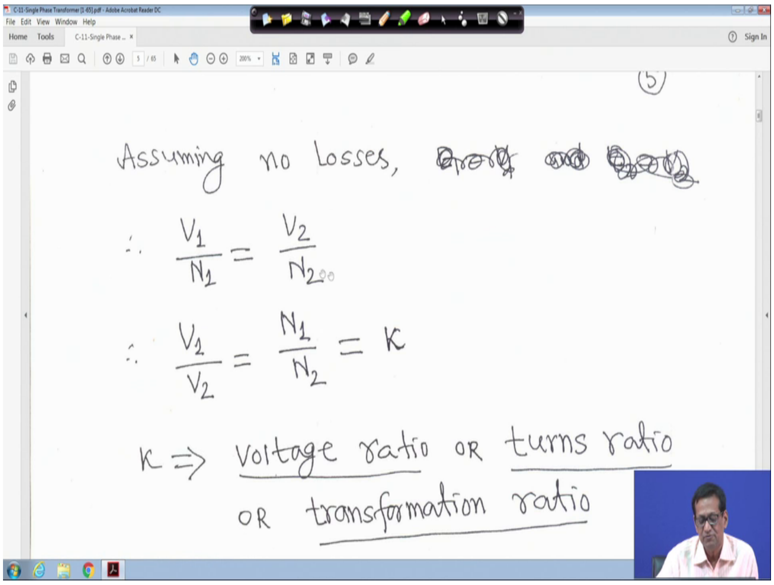

So, assuming that no losses therefore, we can make V 1 by N 1 is equal to V 2 by N 2. So, in that case if we assume that there is no loss then we can make V 1 upon V 1 by V 2 is equal to your N 1 upon N 2 here it is E 1 upon E 2 is equal to N 1 upon N 2 right. And if there is no loss we assume there is no loss then we can write that your turn supplied voltage that is V 1, V 1 by N 1 is equal to V 2 by N 2 this is primary side voltage and V 2 is the secondary side voltage. Therefore, we can make V 1 by V 2 is equal to N 1 by N 2 is equal to K that is called turns ratio therefore, K is the voltage ratio or turns ratio or transformation ratio.

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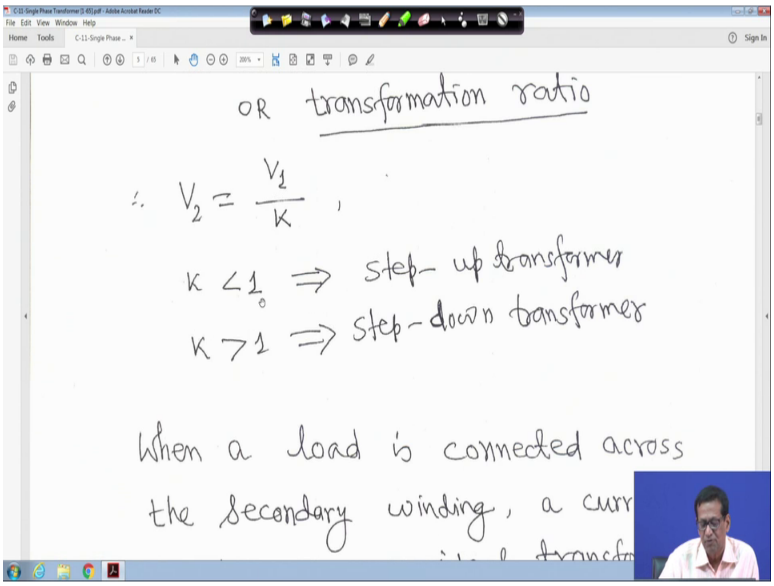

Therefore, V 2 is equal to V 1 upon K, if K less than 1 then this call step - up transformer and if K your greater than one it is called step - down transformer. So, let us go back to that your circuit again here let us go back to the circuit again. So, we are assuming there is no loss right so, and this side is voltage V 1 this side is voltage V 2; that means, this is if it is marked that this is my E 1 and here also it is my E 2 we are assuming there is no loss.

Therefore, your V 1 by your V 1 by your E 1 by E 2 is equal to N 1 by N 2 so, is equal to your V 1 by V 2 is equal N 1 by N 2. Later we will see the relationship between V 1 and E 1 similarly here. So, will be the here only right so, if K less than 1 that is step- up transformer if K greater than 1 that is step - down transformer.

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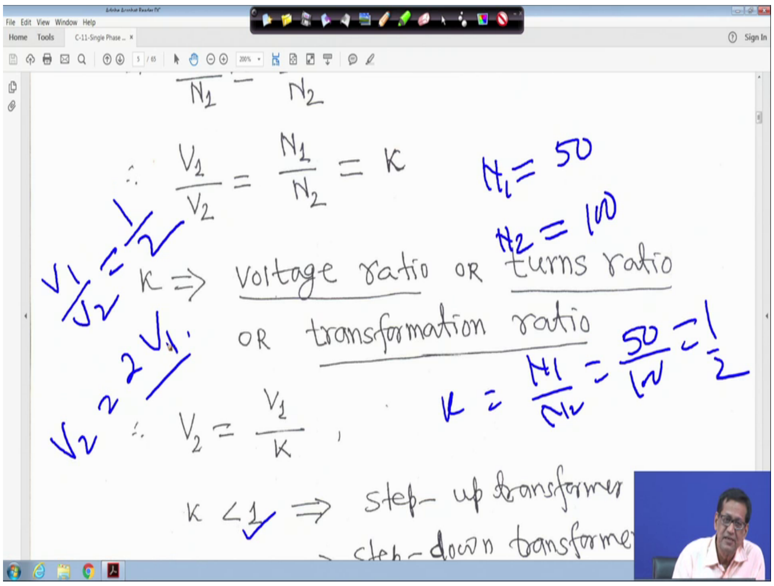

For example, suppose say N 1 is equal to say 50 right and N 2 is equal to say your 100 right, 50 turns and 100 turns. Then K is equal to N 1 by N 2 is equal to 50 by 100 is equal to half; that means, K less than 1 that is your K less than 1 because it is half; that means, it is step- up transformer.

Why it is step - up transformer; that means, here then V 1 upon V 2 is equal to K is equal to half right; that means, V 2 is equal to 2 into V 1 right; that means, it is step-up transformer because primary side voltage if it is V 1 secondary side it is becoming 2 into V 1. For example, primary side if it is 100 KB then secondary side it is 200 KB so, it is a step - up transformer if K less than 1. Similarly, for if K greater than 1 then it will be step - down transformer right. So, that is K greater than 1 for step- down transformer.

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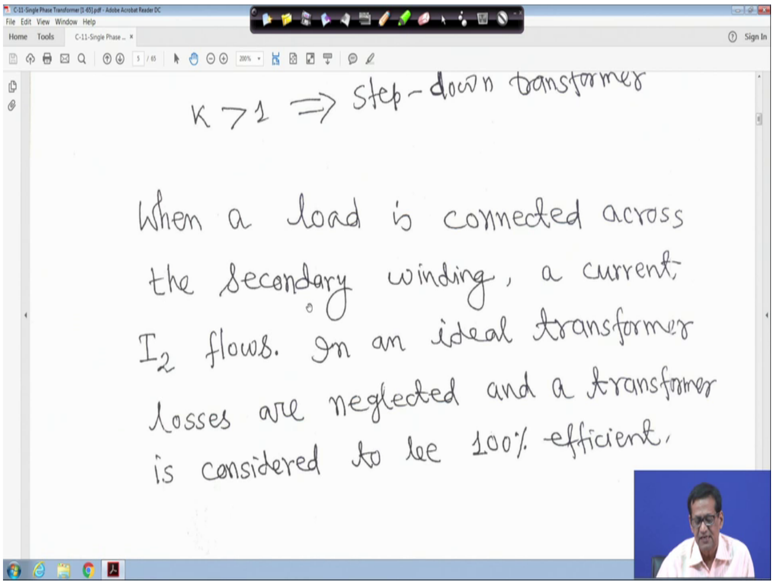

Now, when a load is connected across the secondary winding a current I 2 flows right. So, in an ideal transformer loss of whenever I am telling this first you draw the circuit diagram in the beginning right the ferromagnetic material the core the winding first you draw it.

Then you see, this when a load is connected across the secondary winding a current I 2 flows in an ideal transformer losses are neglected and a transformer is considered to be 100 percent efficient right, although the reality ideal transformer is not possible, but for the sake of our clarification.

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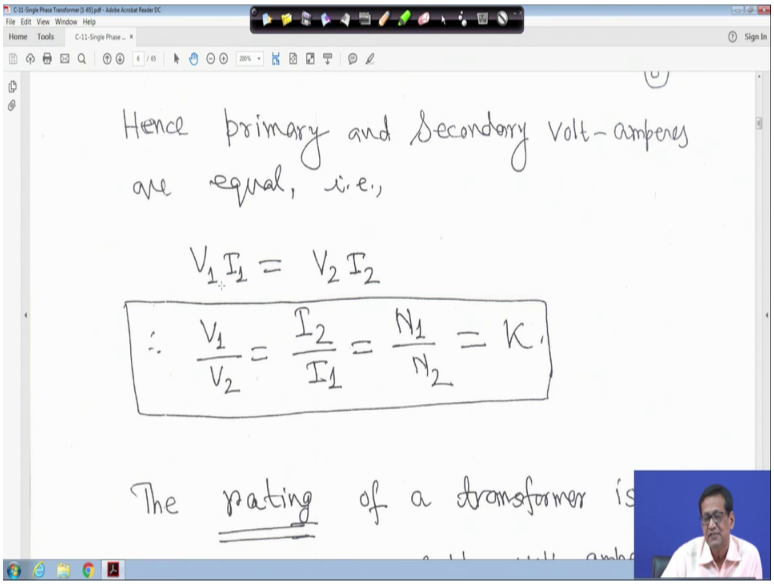

Now, hence the primary and secondary volt amperes will be equal that is V 1 into I 1 must be equal to V 2 into I 2, that is V 1 actually is your primary side voltage and I 1 is the primary side current and V 2 is a secondary side voltage and I 2 is the secondary side current. Therefore, the volt ampere must be same, if V 1 I 1 is equal to V 2 I 2 therefore, V 1 by V 2 is equal to I 2 by I 1.

So, V 1 by V 2 is now N 1 by N 2 is equal to I 2 by I 1 is equal to N 1 by N 2 is equal to K. Therefore, either you can write V 1 by V 2 is equal to N 1 by N 2 or in the case of current it will be I 2 by I 1 is equal to N 1 by N 2 that is N 1 I 1 is equal to N 2 I 2 right. So, that means, emf on the I mean if you later we will see it will be a different way.

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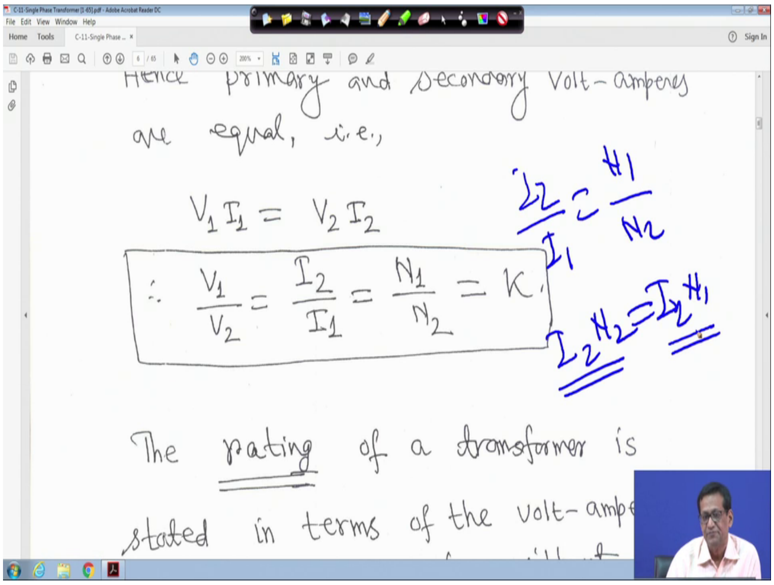

Suppose, if it is I 2 by I 1 is equal to your N 1 by N 2 go for a cross multiplication therefore, I 2 N 2 is equal to your I 1 N 1 right therefore, emf on the secondary side must be equal to the emf on the primary side right.

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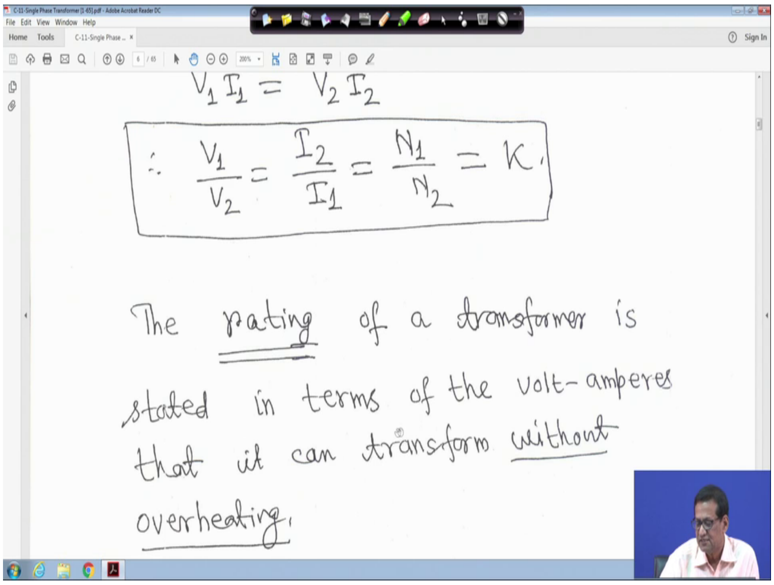

So, the rating of a transformer is stated in terms of the volt ampere that it can transform without overheating so, this way we make it then volt ampere.

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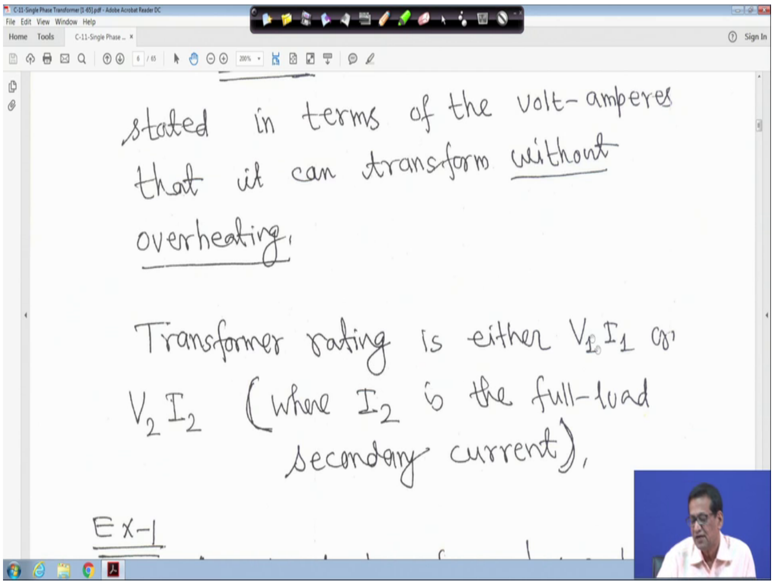

Now, transformer rating is either V 1 I 1 or V 2 I 2 when I 2 is the full load say secondary current. So, this is actually transformer rating generally on the transformer nameplate you will find it is K V a rating will be given right, this frequency will be given for unit impedance will be given all this things will be given. So, just to whatever little bit you have studied we will come to phasor diagram other thing later you take a small example.

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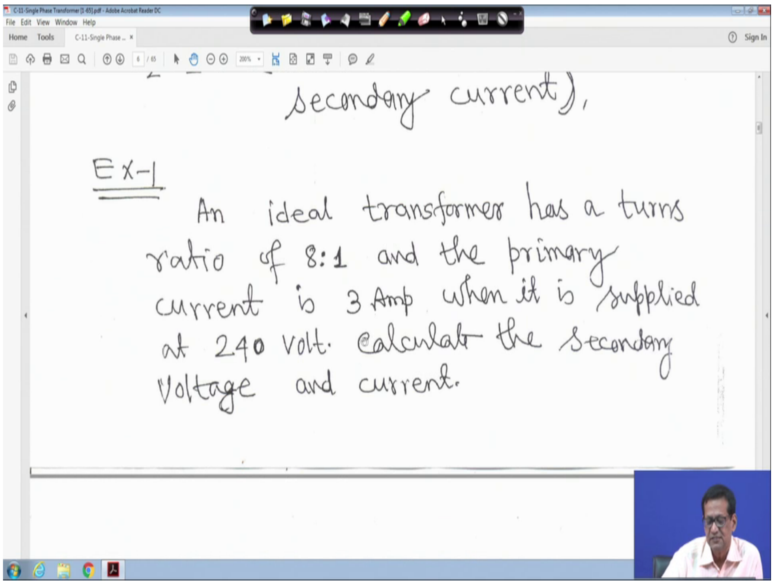

An ideal transformer it is turns ratio of 8 is to 1 and the primary current is 3 ampere it is given when it is supplied at 240 volt calculate the secondary voltage and the current right.

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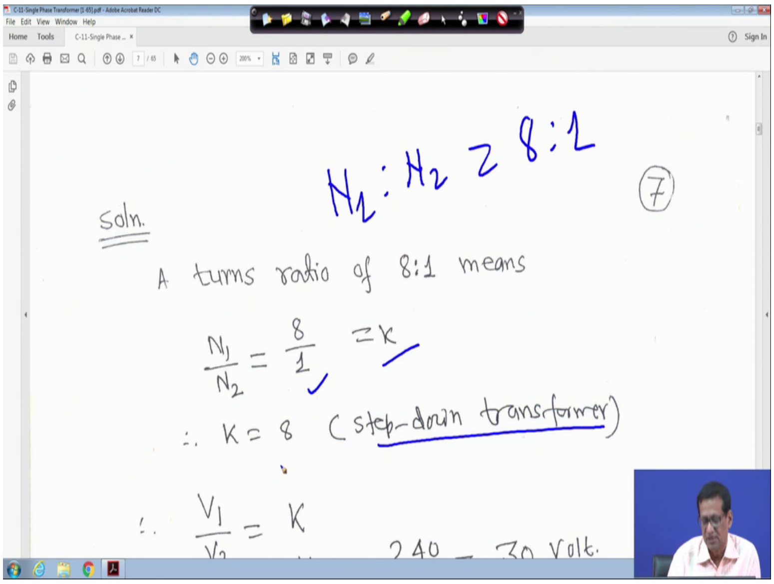

So, now turns ratio is given 8 is to 1 means it is N 1 is to N 2 I mean whenever it is given that 8 is to 1; that means, it is N 1 is to N 2 is equal to 8 is to 1. So, N 1 by N 2 is equal to 8 by 1 is equal to K. So, K is equal to 8; that means, it is a step down transformer because K greater than 1 right.

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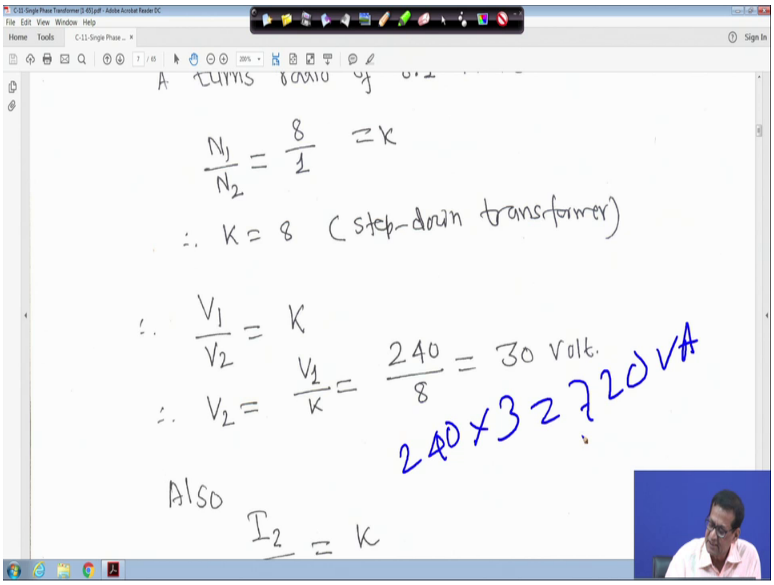

So, that means V 1 by V 2 is equal to K therefore, V 2 is equal to V 1 upon K so, 240 by 8 so, V 2 will be 30 volt. So, primary side is 240 volt secondary side is 30 volts also we know that I 2 by I 1 is equal to K. So, I 2 is equal to K into I 1 it is given I 1 is equal to 3 ampere. So, I 2 is equal to 24 ampere.

So, interestingly if you see this side it is your 30 volt right full load voltage has low, but at the same time if current has increased because volt ampere has to remain your same. So, if you see the volt ampere primary side 240 volt into 3 ampere current so, 720 volt ampere right. Similarly, for the your secondary side if you look into your second side, the secondary side also has to be 72.

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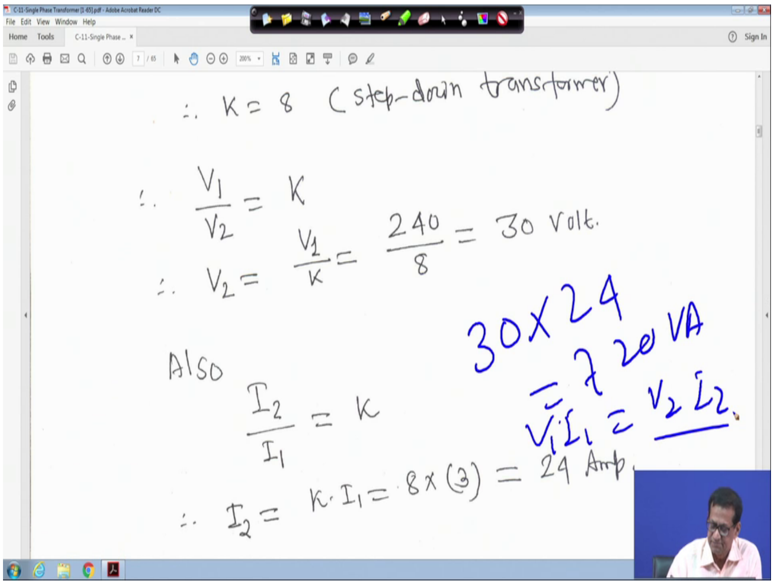

So, if you see this voltage is your V 2 is 30 volt and this is 24 ampere so, that is also 720 volt ampere right. So, that means, V 1 I 1 it has to be equal to V 2 I 2 right.

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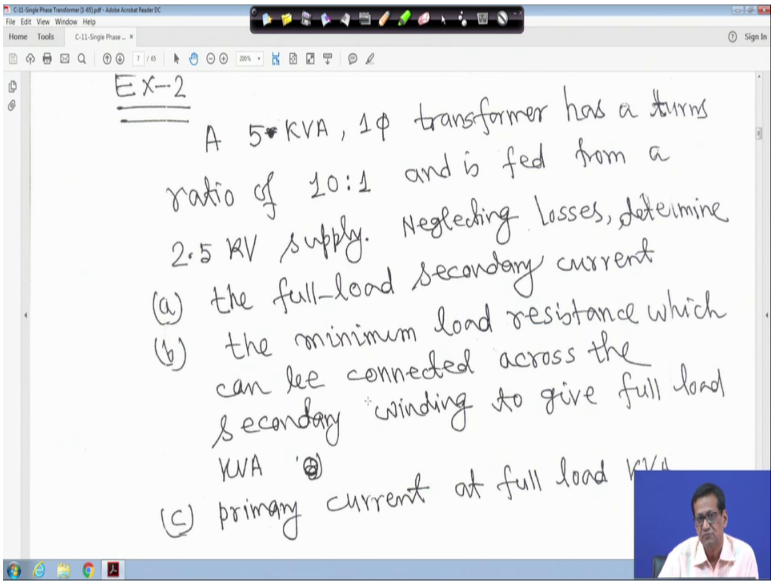

Now, another small example so, if 5 KVA, single phase it is 1 phi. So, that will be single phase single phase transformer has a turns ratio 10 is to 1 that is N 1 is to N 2 is equal to 10 is to 1 and is fed from a 2.5 KV supply 2.5 kilovolt right. So, neglecting losses determine, a the full load secondary current, b, the minimum load resistance which can be connected across the secondary winding to give full load KVA and c, is the primary current at full load KVA. So, these are the thing have been asked to and you have to do it.

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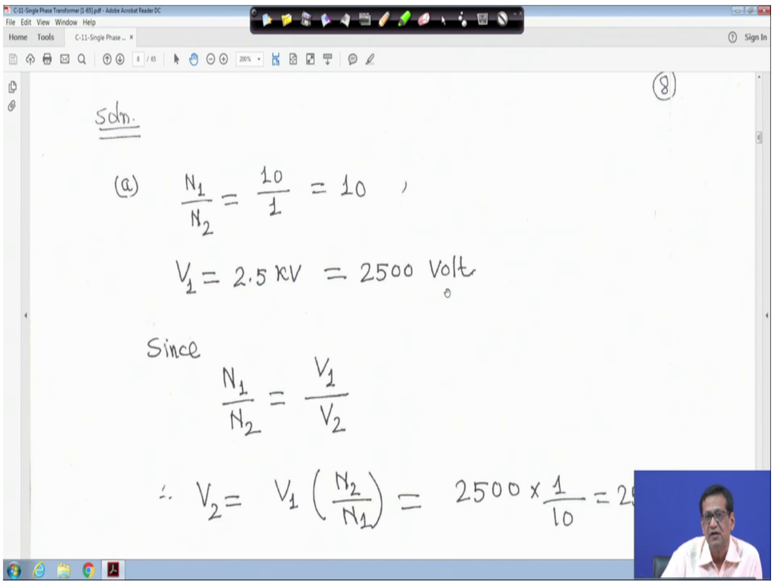

So, first thing is that N 1 by N 2 is equal to 10 is to 1, 10 by 1 is equal to 10. Now, V 1 is given 2.5 KV. So, 2500 volt multiplied by 1000.

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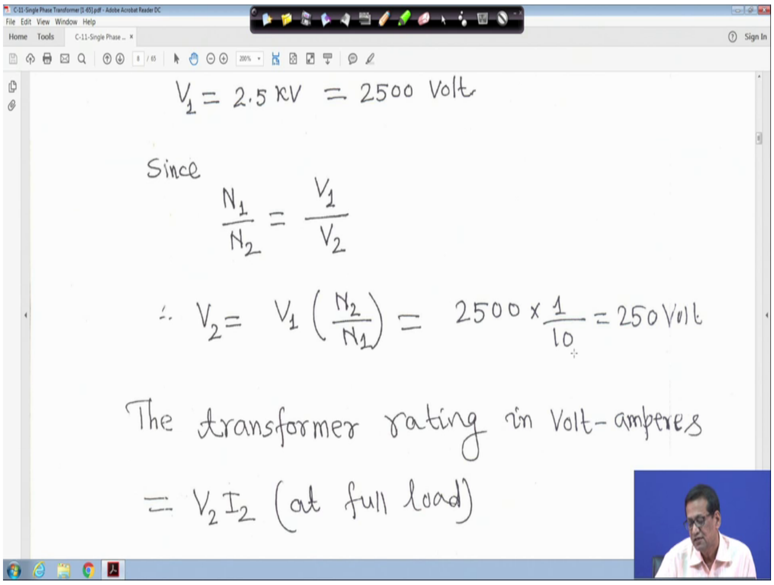

We know if since N 1 by N 2 is equal to V 1 by V 2 therefore, V 2 is equal to V 1 into N 2 upon N 1 right is equal to V 1 is given 2500 and N 2 by N 1 is 1 upon 10. So, it is 250 volts right so, V 2 is the 250 volt.

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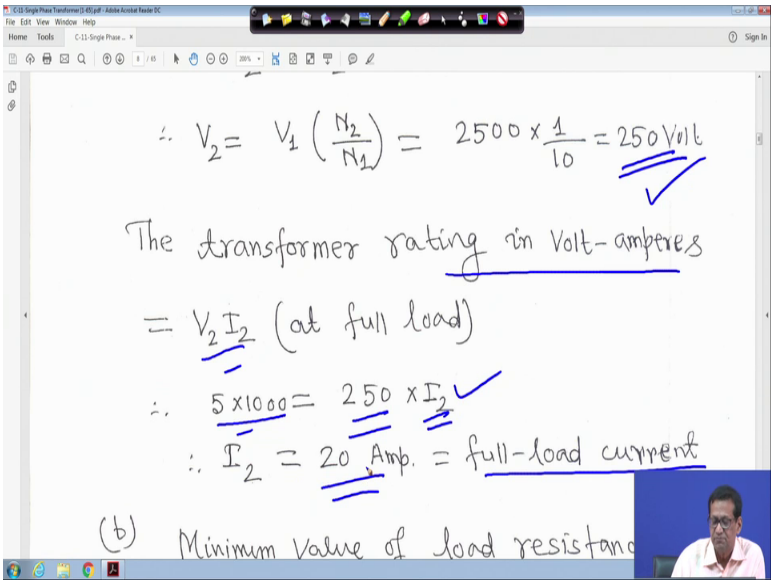

The transformer rating in volt ampere will be V 2 I 2 at full load right. So, it is V 2 is your is equal to your V 2 I 2 is that is KVA is given 5000 I mean this is something like this. So, transformer rating at in volt ampere is equal to V 2 I 2.

So, this 5 KVA is given so, 5 into 1000 ampere is equal to V 2 is to 250 volt we got V 2 is equal to 250 volt into I 2 prominence if you solve you will get I 2 is equal to 20 ampere the full - load current. So, KVA it is given in the problem it is given 5 KVA; that means, 5000 volt ampere is equal to voltage is 250 volt here and current you have to determine. So, from which you will get the I 2 is equal to 20 ampere.

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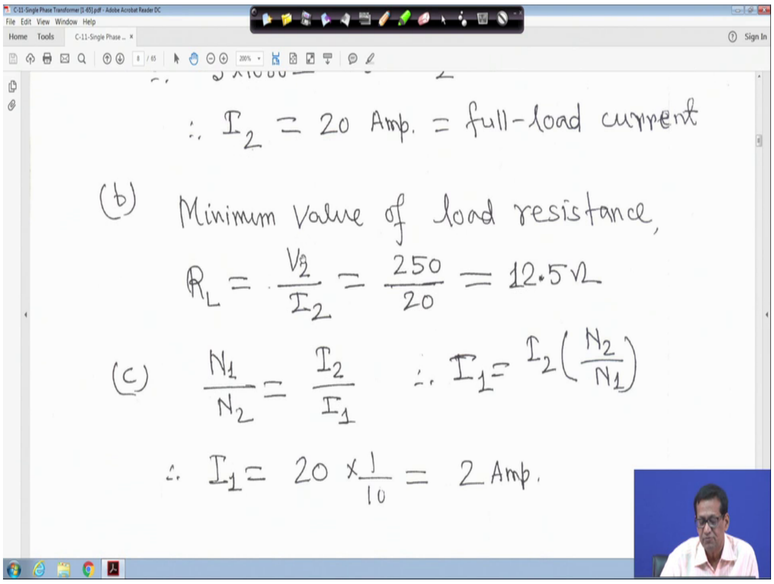

Now, b, minimum value of load resistance so, R L is equal to just V 2 by I 2. So, V 2 is given 250 we will got 250 and I 2 got 20 so, it is 12.5 ohm. See, N 1 by N 2 is equal to I 2 by I 1 we know that therefore, I 1 is equal to I 2 in to N 2 by N 1. So, I 2 we got 20 ampere and N 2 by N 1 is 1 upon 10. So, it is actually 2 ampere right so, very simple.

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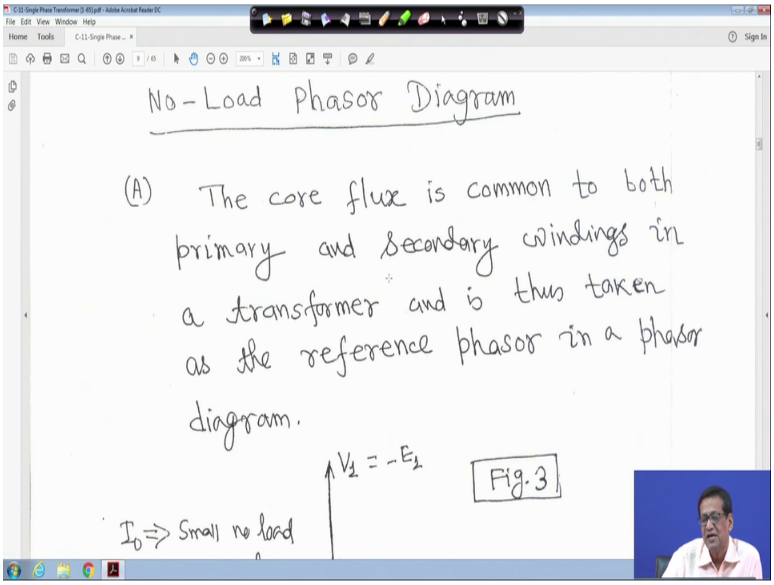

Now next is no - load phasor diagram. Now, the core flux actually no load Phasor diagram, the core flux is common to both primary and secondary windings in a transformer that I showed you in the beginning and is thus taken as the reference Phasor in a phasor diagram.

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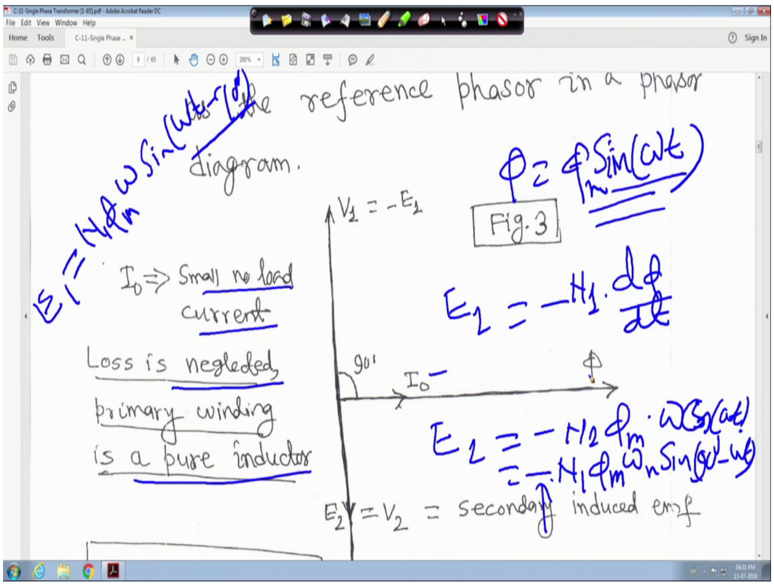

For example, in a Phasor diagram, this is the flux right, we will assume that phi is equal to so, sinusoidal variation phi M sin omega t right, this is your phi M sin omega t, this is the flux and we are taking the your phi as a reference. Now, I 0 is equally small no load current and loss is neglected right. So, primary winding then will be a pure inductor because we are giving alternating supply to the primary winding. So, if it our loss is neglected it will act like your what you call that is pure inductor.

So, in that case what will happen that, whenever you say that as per your, what you call as per Lenz's law right we know that E 1 is equal to minus for the primary winding it is N 1 right. So, into d phi by dt right, this minus sign comes because of the Lenz's law right. So, this is E 1 is equal to minus N 1 d phi by dt. Now, we know phi is equal to phi max sin omega t. So, if you just take the derivative of that then you will get E 1 is equal to minus N 1, then phi m, then omega then your cosine omega t right that much that we will get.

So, this one you can write that your minus N 1 phi m say omega this is cosine omega t. So, we can write sin 90 degree minus omega t and this minus sign is here this minus sign is here you take minus sign inside that then what we will get that E 1 is equal to your N 1 then phi m then omega right then you can write sin omega t minus 90 degree.

So, sin omega t minus 90 that is E 1 right; that means, if phi is equal to the reference that is your sin omega t right and it is a loss is neglected. Therefore, that no load current I 0 also will be is in phase with your what you call in your what you call with the flux right and I 0 actually will lagging from your V 1 by your 90 degree if loss is neglected if it is loss is completely neglected right.

So, in that case I 0 will be in phase with phi and your as it is as resistance is neglected. So, generally that your therefore, the I 0 is lagging from the voltage V 1 by 90 degree, it is because that primary winding is acting as a pure inductor right. And if you take the magnetizing m call magnetizing reactance right x m then you will see that I 0 is purely I mean loss is neglected then this I 0 and phi both are in phase and lagging from V 1 by 90 degree. So, in this case that E 1 is equal to is coming omega t minus 90 degree and; that means, phi is equal to phi m sin omega t and here it is sin omega t minus 90 degree that means so, I am clearing it right.

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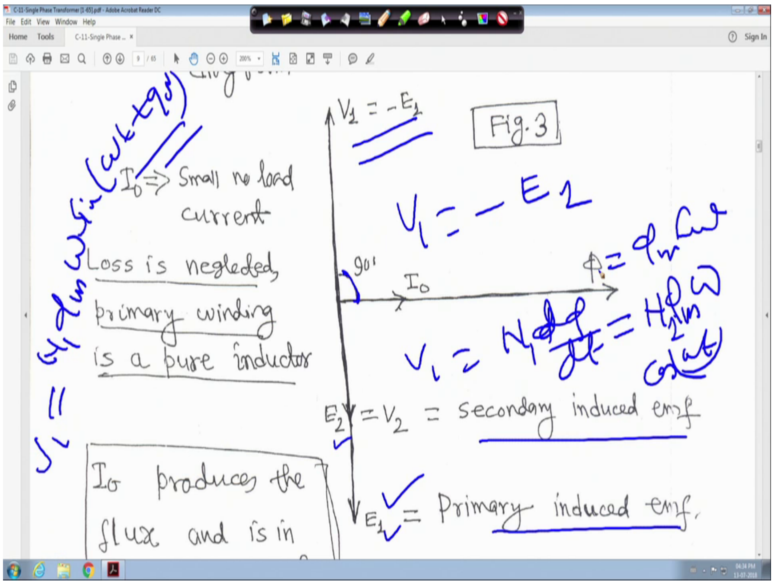

So, that means, my V 1 will be your what you call lagging from phi by 90 degree therefore, this is my E 1 this is my E 1 the primary induced emf. Similarly, E 2 also will be the same way E 2 also will be lagging and E 2 is equal to V 2 because loss your what you call we are we have considering an ideal transformer right. So, this is your secondary induced both will be like this. Now, therefore, the supply voltage from the Lenz's laws it opposes the change right.

So, Lenz's law, Lenz law it is actually V 1 is equal to minus E 1 right. So, an E 1 is equal to minus and d psi by dt; that means, my V 1 will be N at in general N 1 your what you call d psi by dt because E 1 is equal to minus N 1 d psi by dt so, minus plus it will be N d psi by d t.

Therefore, my V 1 will be is equal to N 1, phi is equal to phi m your what you call the sin omega t if you take the derivative it will be N 1, then phi m, then omega right, then cos omega t right. So, that is that will be your what you call V 1. So, if you your what you call this cos omega t if you write like this for you just misunderstanding if you write like this some where I am writing hope you will be able to read it that your V 1 is equal to your N 1 then phi m.

Then omega and this is cos omega t usually you can write one is sin 90 degree minus omega t another is your sin 90 degree plus omega t; that means, we can write sin your omega t plus 90 degree right that is by V 1. That means, this is my phi, phi is equal to phi m sin omega t; that means, this V 1 actually leading this phi by 90 degree then V 1 is equal to minus E 1.

So, this is my your E 2 this is E 1 and this is your V 1 is equal to minus E 1. So, that then E 1 is the primary induced emf and E 2 is the see your E 2 equal to V 2 is equal to secondary induced emf. So, this is actually V 1 is equal to minus E 1. So, basically your I 0 will be in phase now loss is neglected with the your in phase with your what you call is the flux phi, phi is the taken as a reference right therefore, let me clear it.

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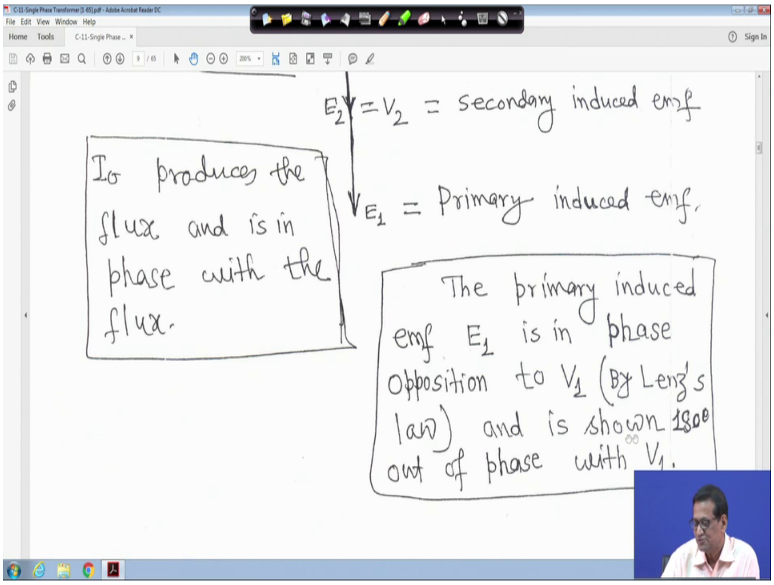

Therefore, I 0 produces the flux and in the phase with the flux. Now the primary induced emf E 1 is in phase opposition to V 1 by Lenz’s law and is shown 180 degree out of phase with V 1. So, this is V 1 and this is V 1 is equal to minus E 1 so, 180 degree out of phase. So, this is Lenz’s law and this Faradays all these things we have studied in your higher secondary physics right. So, this is how that your when we are not considering the losses so, this is the Phasor diagram.

Now, generally what happened in a transformer that heating of the core happens because of your what you call that energy losses due to your hysteresis and eddy currents right shows in the core. So, because of that some loss component will be there, if you consider the loss component then I 0 actually is not exactly lagging 90 degree from V 1 or not exactly is in phase with phi 1 there will be some lagging angle of I 0. So, that is why your whenever you have such thing right that core in this in this case what will happen.

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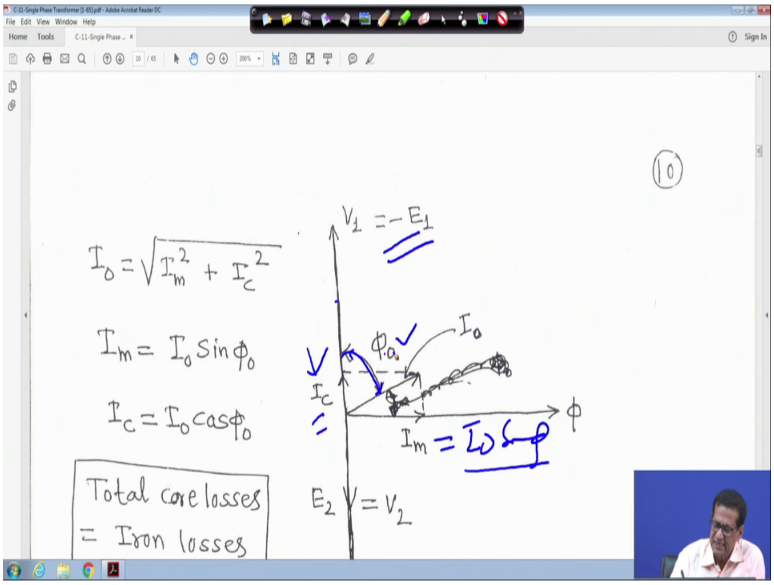

That you are this I 0 actually not exactly in phase in phase with I write because it has some core loss that is iron loss that is eddy current and hysteresis loss. So, because of that your this is V 1 is equal to minus E 1 is ok, but this I 0 actually lagging by an angle phi 0 from V 1.

So, this angle is phi 0 and it is your what your call component along phi is I m is equal to your I 0 sin phi, this component is responsible for producing that your no load flux because this is phi0. So, it is cos 90 your what you call that I 0 is your I m is equal to I 0 right it will be cos 90 minus phi0. So, it is I 0 sin phi and this I c will be I 0 cos phi 0 right.

So, this component actually basically it will give your core loss or iron loss and the no load condition right. So, total core losses is equal to basically iron loss is this is the hysteresis and eddy current losses. So, that is why I 0 is not exactly is in phase with phi but this angle actually this angle I phi 0 actually quite large so, that is total core loss.

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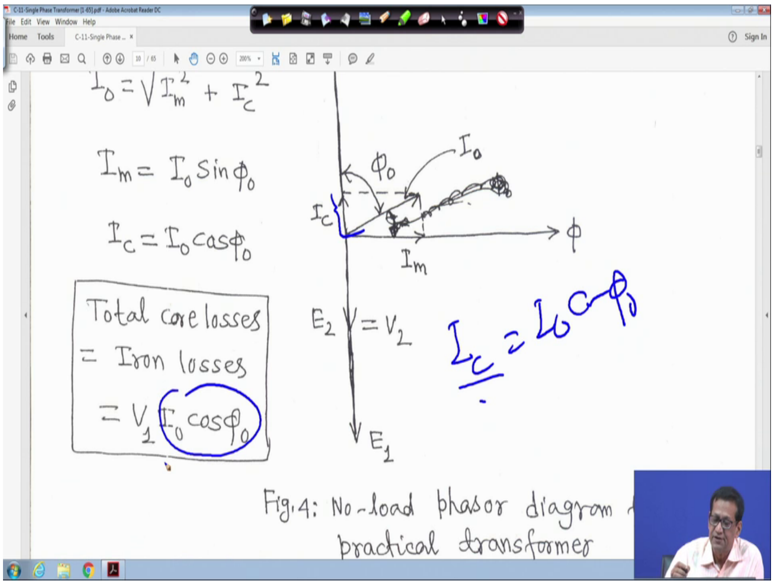

Is equal to iron loss is equal to V 1 I 0 cos phi 0 right and this and the I told you this I 0 cos phi 0 that is I c actually is equal to I 0 cos phi 0; that means, this component; that means, the I 0 cos phi 0 actually is equal to your I c; that means, V 1 into I c that is your total core loss or iron loss right. So, this is the no- load phasor diagram for a practical transformer.

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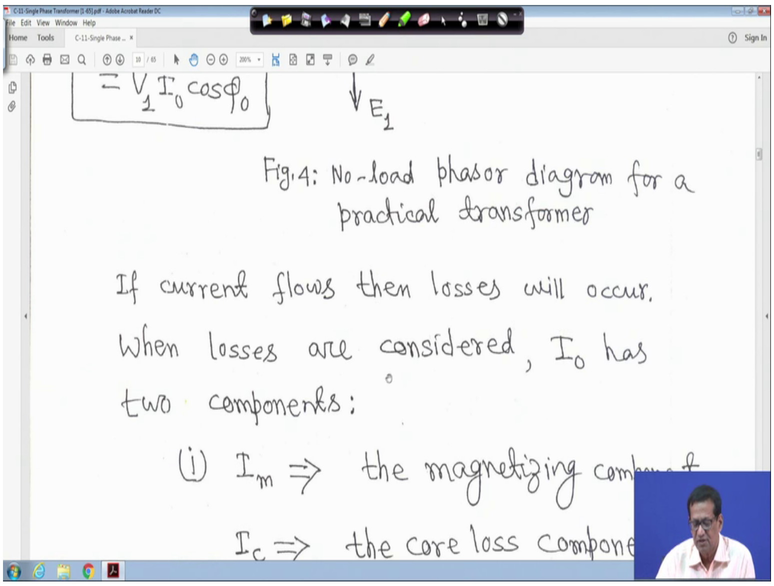

Now, if current flows then losses will occur when losses are considered I 0 has to 2 components I told you everything.

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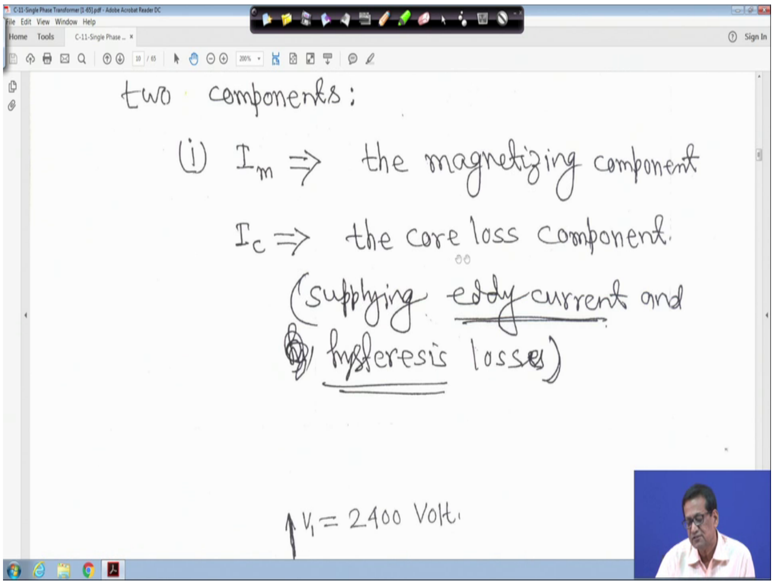

I m we call the magnetizing component and I c the core loss components this magnetizing component at no load is responsible for producing the flux. So, eddy current loss that is core loss component basically is supplying eddy current and hysteresis losses. This eddy current and hysteresis in the magnetic circuit I have given you those formulas right so, this is nothing, later will come right.

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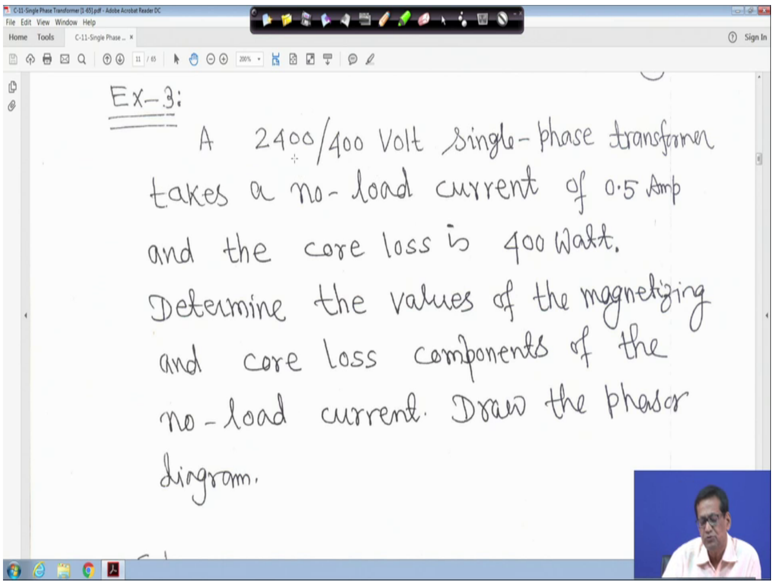

So, now, this is for this numerical a 2400 by 400 volt is a step down transformer because this is primary side 2400 and secondary side 400 volts. So, this is a step down transformer right so, N 1 by N 2 actually is equal to 6 we call V 1 by V 2. Single phase transformer takes a no load current of 0.5 ampere and the core loss is 400 watt that is core loss is given that is V 1 your I 0 cos phi 0 that is your core loss 400 watt is given. Determine the value of the magnetizing and core loss component of the no load current and draw the phasor diagram.

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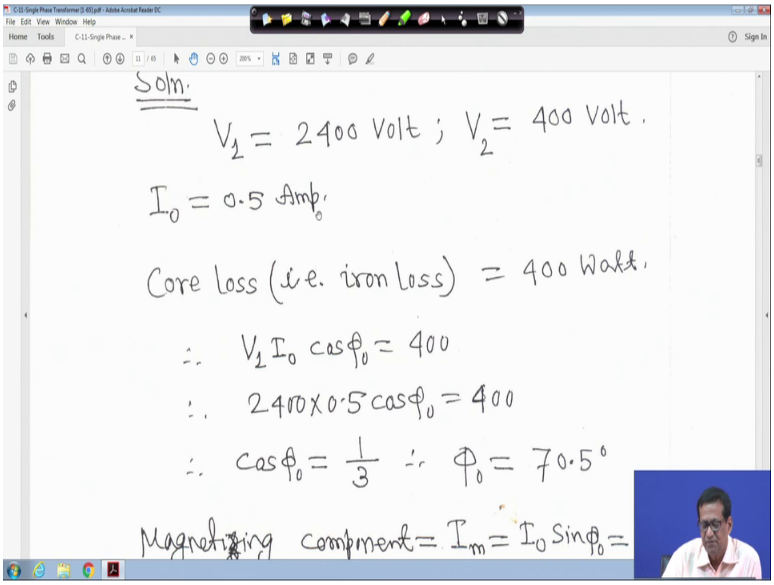

So, it is given V 1 is equal to 2400 volt V 2 is given 400 volt I 0 is given 0.5 Ampere. So, core loss that is iron loss is equal to also given 400 watt, therefore, V 1 I 0 cos phi 0 is equal to 400 so, that is 2400 into 0.5 cos phi 0 is equal to 400.

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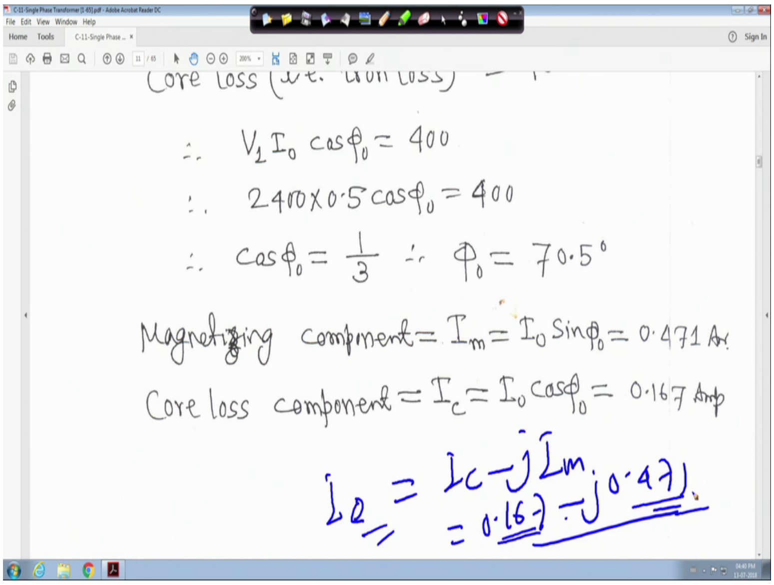

Therefore, we will get cos phi 0 is equal to one third therefore, phi 0 is equal to 70.5 degree. Now, magnetizing current I m will be 0 point and I 0 sin phi 0. So, 0.471 Ampere because phi 0 is equal to 70.5 degree and core loss component I c I o will be 0.167 ampere right. And as this current is lagging if you write in your phasor thing that your I 0 will be is equal to actually I c minus j I m right. So, I c is equal to 0.167 and minus your j 0.471 right.

If you take your V 1 as a reference so, this current actually lagging from your what you call the voltage. So, it will be minus sign right this is your real part and this is your imaginary part this is core loss component current and this is your imaginary sorry magnetizing your called the imaginary part in the magnetizing component of the current.

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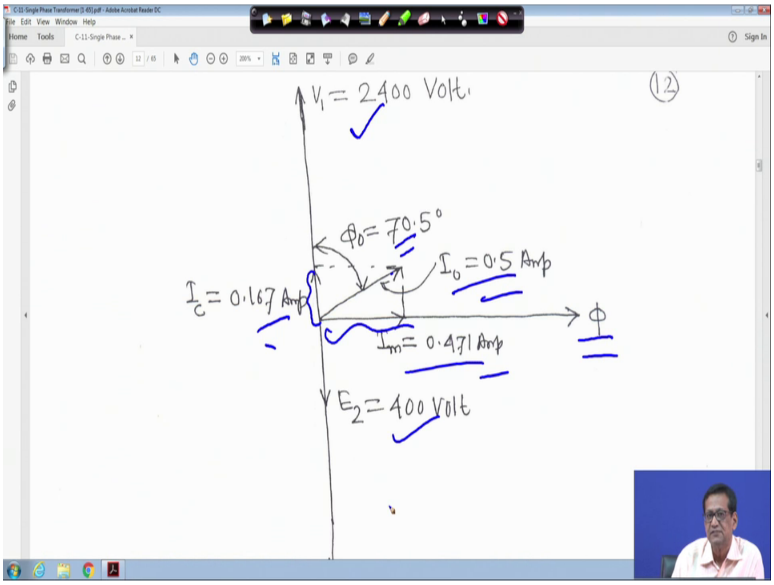

So, now this is the phasor diagram, this is your V 1 and this is your E 2 is equal to 400 volts, E 1 is also here and this angle is 70.5 degree and this is your this part is I c and this part is your I m and this is the resultant current I 0 right. So, this is simply and this is the phi the reference phasor right and E 1 is given here.

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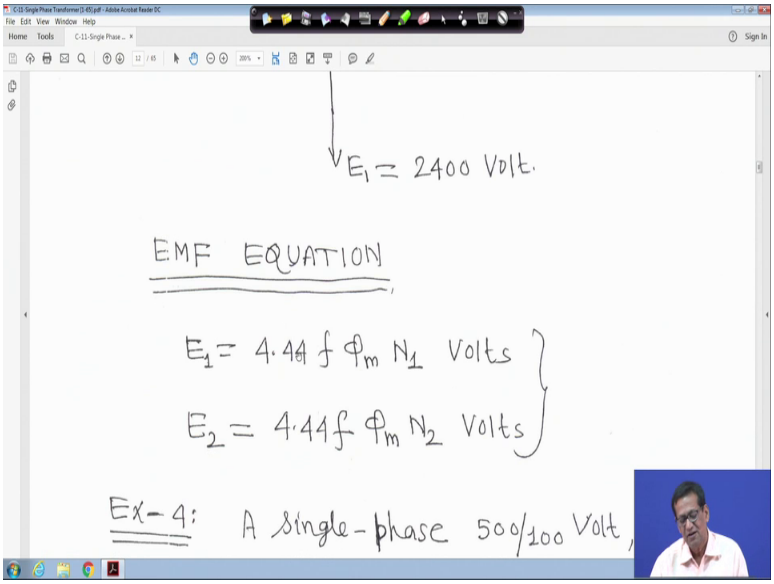

E 1 is given here 2400 because it has to be balance ideal case it has to be balanced right so, it is 2400 volt here also it is showing 2400 volts right. Now, EMF equation these 2 equations also in the magnetic circuit in general I have given, E 1 is equal to 4.44 f phi m N 1 volt and the secondary side also 4.44 f phi m N 2 volts right. So, N 1 N 2 only trance difference or different, but equations are same right.

So, this emf equation is given actually in that magnetic circuit I have given. And if you take the rmf value we have to divide it what you call that your in the that your what you call in that magnetic circuit the divided by root 2 everything has been done there right.

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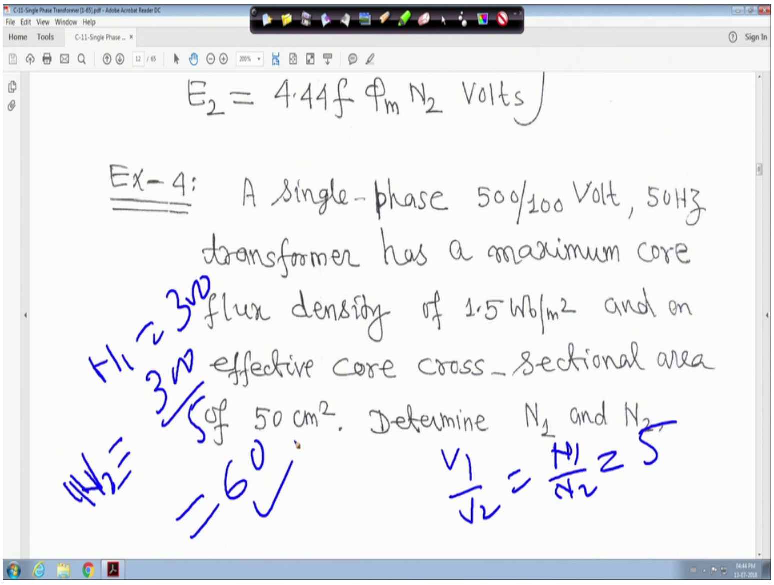

So, now if you take this example single phase 500 by 1000 volt 50 hertz then it will also a step down transformer because voltage is getting reduced on the secondary side has a maximum core flux density is 1.5 Weber per meter square and on effective core your cross sectional area of 50 centimeter square. Determine N 1 and N 2, a very simple one.

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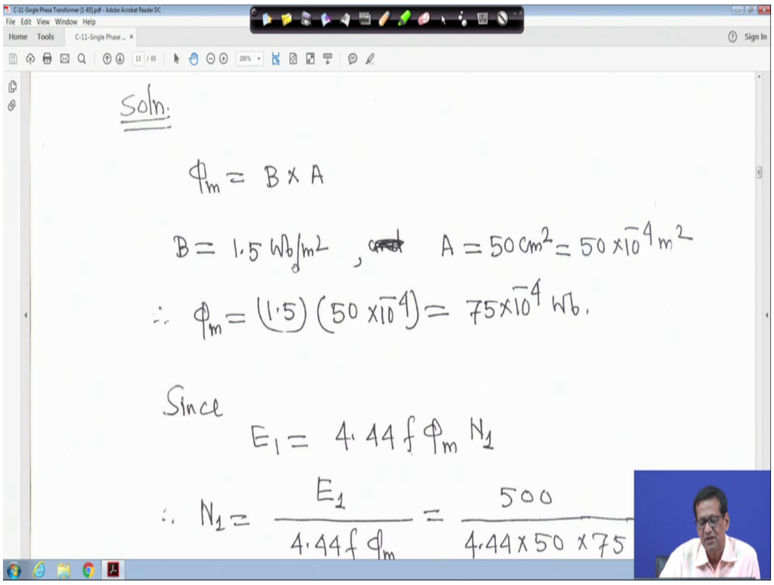

You know flux is equal to B into A you have seen in a magnetic circuit this is B is the flux density and A is the cross sectional area. So, B is given 1.5 Weber per meter square and A is 50 centimeter square so, 50 into 10 to the power minus 4 meter square. Therefore, phi m is equal to 1.5 in to this your area is equal to 75 into 10 to the power minus 4 Weber. Since, E 1 is equal to 4.44 phi m N 1 you know that therefore, N 1 will be E 1 upon 4.44 f phi m that will be 500 divided by you substitute and the if even it is not mentioned; even if it is not mentioned right.

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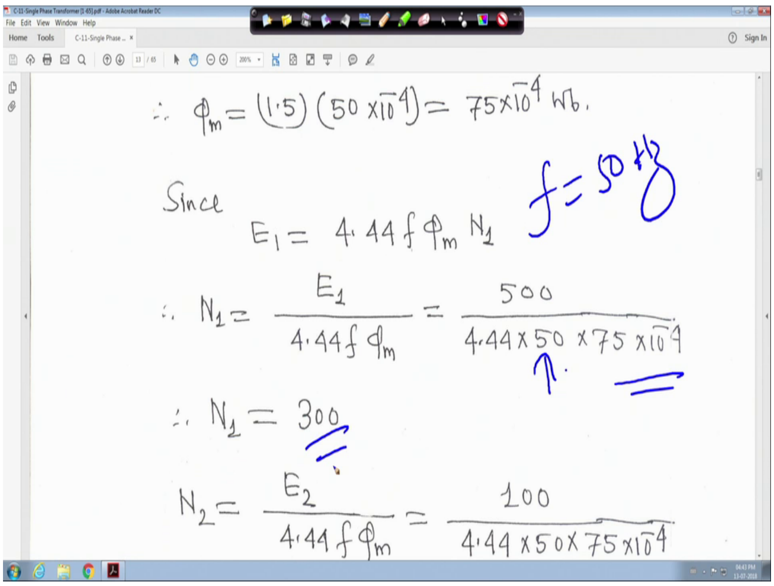

Generally, you take it is a 50 hertz system f it is equal to 50 hertz. So, that is f is equal to 50 hertz is taken and this is the phi m right you will get N 1 is equal to 300. Similarly, N 2 is equal to E 2 upon 4.44 f phi m that is 100 upon 4.44 50 hertz f is 50 hertz and this one you will get 60.

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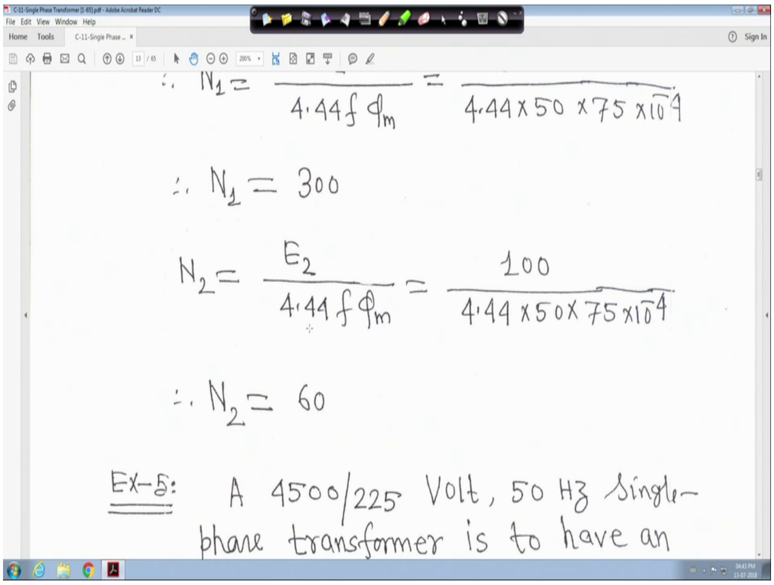

So, basically you will get N 1 is equal to 300 and N 2 is equal to 60 in your what you call even without using this the voltage ratio is given your what you call V 1 upon V 2 is given your this is your V 1 upon V 2 is equal to say N 1 upon N 2 right and N and this is given actually 500 by 100 actually will 5. So, we have got N 1 we got is 300 therefore, N 2 is equal to your 300 by 5 here from here also we can get it N 2 is equal to 60 right. So, this is your N 2 is equal to 60.

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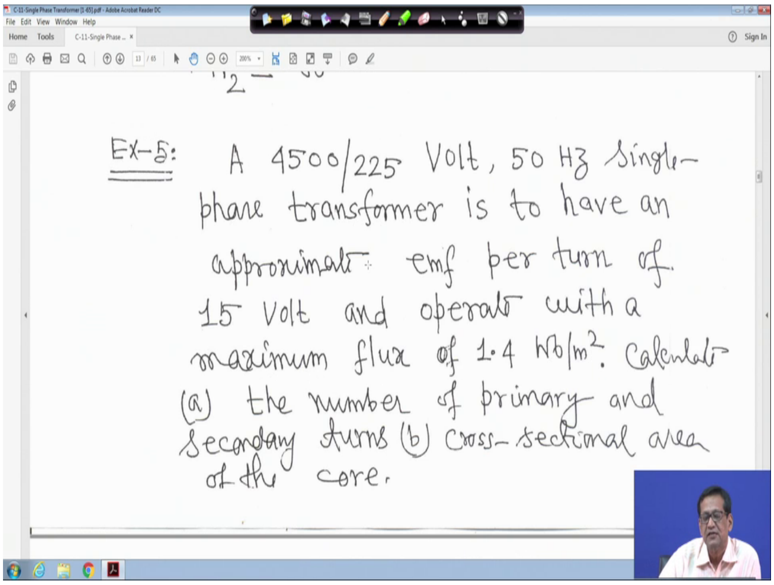

So, thank you very much we will be back again.