Fundamentals of Power Electronics
Prof. L. Umanand
Department of Electronics Systems Engineering
Indian Institute of Science, Bengaluru

Lecture - 69
Transformer example

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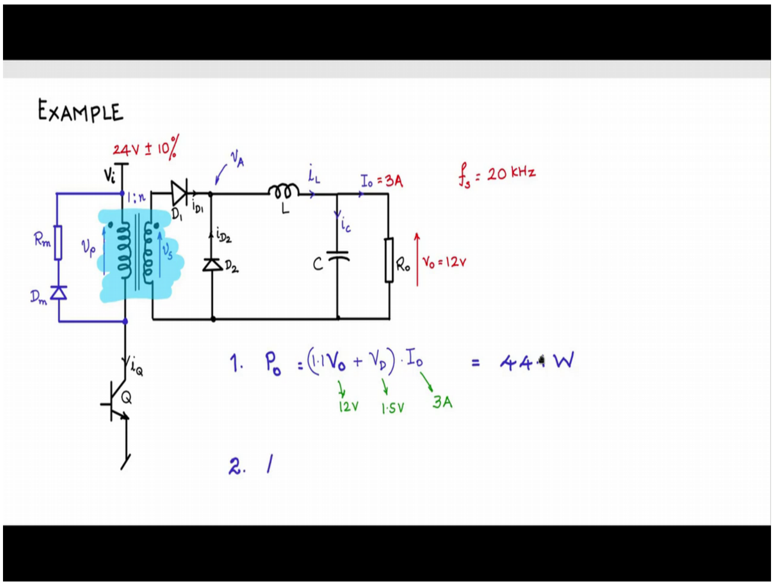

EXAMPLE

1. $P_o = (1.1 V_o + V_D) \cdot I_o$ = 44[illegible] W

2. /

Let us now take an example and design a transformer for a DC-DC converter. I have taken here an example of a forward converter where we have discussed this operation and we know how it works. So, let us say we have an output the spec output voltage spec of 12 Volts, output load current as 3 amps, switching frequency of 20 kilo hertz, input V i as 24 Volts plus or minus 10 percent and then we need to design this transformer.

So, let us see how we go about doing that. So, step 1, we need to find what is the output power. Output power is V naught I naught, but we need to find what is the power of the secondary here. So, if you see the secondary because P naught here refers to when you are talking of design of the transformer, all the power right at the point of the secondary terminals.

So, you see this is the power here V naught into I naught and in principle the components are not ideal, there will be a diode drop especially at higher powers the diode drop here will be around 1.2 to 1.5 Volts into I naught that will come in here and then there will be resistance winding resistance and there will be some drop in the winding resistance. So, put all that together you can increase V naught by 10 percent and add the V D drop.

So, what we can do is we can say 1.1 V naught plus V D will be the voltage that will be needed here to take care of a output V naught of 12 Volts. So, this will give us and slightly higher voltage at the secondary so that all these drops are taken care of into I naught will be the power at these terminals of the secondary. So, apply V naught 12 Volts, V D of 1.5 volts and 3 amps you will get around 44.1 Watts.

So, for this secondary output power we need to design the transformer.

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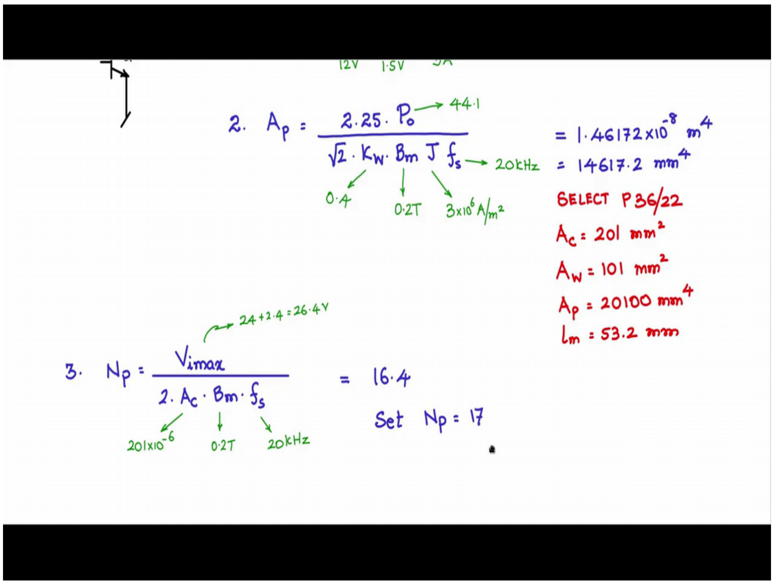

12V 1.5V

$$2.\quad A_p = \frac{2.25 \cdot P_o \rightarrow 44.1}{\sqrt{2}\cdot \underset{0.4}{K_w}\cdot \underset{0.2T}{B_m}\, \underset{3\times10^6 A/m^2}{J}\, f_s \rightarrow 20\text{kHz}} = 1.46172\times10^{-8}\ m^4 = 14617.2\ mm^4$$

SELECT P36/22

$A_c = 201\ mm^2$

$A_w = 101\ mm^2$

$A_p = 20100\ mm^4$

$l_m = 53.2\ mm$

$$3.\quad N_p = \frac{\overset{24+2.4=26.4V}{V_{imax}}}{2\cdot \underset{201\times10^{-6}}{A_c}\cdot \underset{0.2T}{B_m}\cdot \underset{20kHz}{f_s}} = 16.4$$

Set $N_p = 17$

Next step is find the area product. So, the area product for a forward converter we have derived 2.25 P naught by root 2 K w B m J f s. P naught is what we have calculated here 44.1 Watts, K w we will take it as 0.4 a conservative value, actually an the 0.4 is actually a value where the winder is quite experienced and skilful. B m for transformers we reduce the B m for inductors we used to take 0.25 Tesla, but for transformers. Do not swing beyond 0.2 Tesla because we want to limit the magnetising current and also to keep the swing within the well within the linear region of the BH curve.

Then J same as before as you used for inductors 3 into 10 to the power of 6 amp per meter square or 3 amp per mm square. Frequency switching frequency 20 kilo hertz as given as a spec. Now, if you apply all these and calculate you get 1.46172 into 10 power minus 8 meter to the power 4 multiply this by 10 to the power of 12 you will get it in mm to the power of 4, 14617.2 mm to the power of 4.

Go to the wire table as before and then search for a core which has a higher A P than this. In our case here we cancel again select P 36 bar 22 pot core which has an area product of around 20000 mm to the power of 4; A c upto 201 mm square, A w of 101 mm square, A p area product of 20100 meter to the mm to the power of 4, mean magnetic path length 53.2 mm. So, these are the characters of the core that we have selected pot core P 36 bar 22.

Next, we go to the turns primary number of turns N p is given by V i max divided by 2 A c B m f s V i max is 24 plus 10 percent which is 26.4 Volts; A c we have found out 201 into 10 power minus 6 meter square, B m 0.2 Tesla and 20 kilohertz on calculation you will land up with 16.4 set N p as 17 turns.

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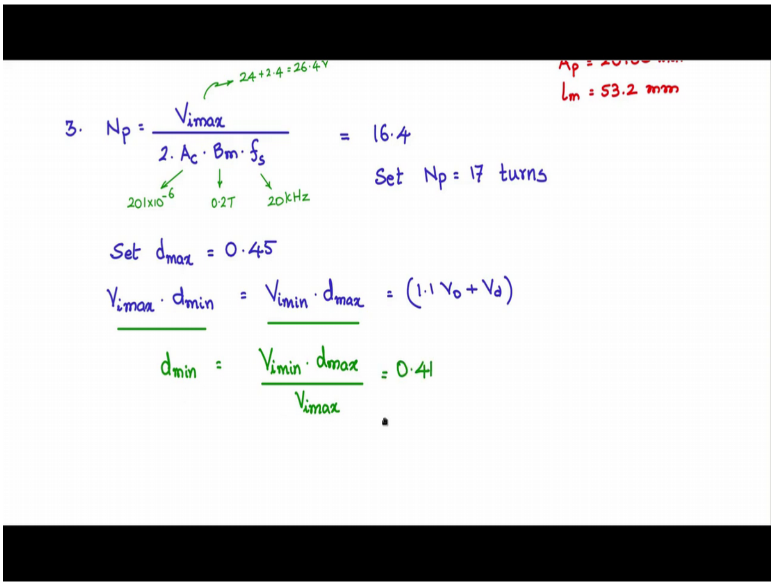

$A_p =$

$l_m = 53.2$ mm

$$3.\quad N_p = \frac{\overset{24+2.4=26.4V}{V_{imax}}}{2 \cdot \underset{201\times10^{-6}}{A_c} \cdot \underset{0.2T}{B_m} \cdot \underset{20kHz}{f_s}} = 16.4$$

Set $N_p = 17$ turns

Set $d_{max} = 0.45$

$$\underline{V_{imax} \cdot d_{min}} = \underline{V_{imin} \cdot d_{max}} = (1.1\, V_o + V_d)$$

$$d_{min} = \frac{V_{imin} \cdot d_{max}}{V_{imax}} = 0.41$$

Next let us try to find out what is the turns ratio. Set d max has 0.45. Remember that this is a forward converter you cannot have a duty cycle more than 0.5. Therefore, set d max has 0.45 to be on the safer side and V i max d min should be equal to V i min, d max should be equal to whatever the output voltage; here the upgraded output voltage 1.1 V naught plus V D.

Now, using these two you can find d min because d max is set. So, d min is equal to V i min d max by V i max; you know V i min 24 minus 2.4 d max 0.45, V i max is 26.4 you can find out d min which is 0.41 duty cycle.

Now, this 1.1 V naught plus V D should be equal to our forward converter input output relationship n into V i max into d min and here n is the only unknown 1.1 V naught V d divided by V i max and d min root apply the values at 1.35.

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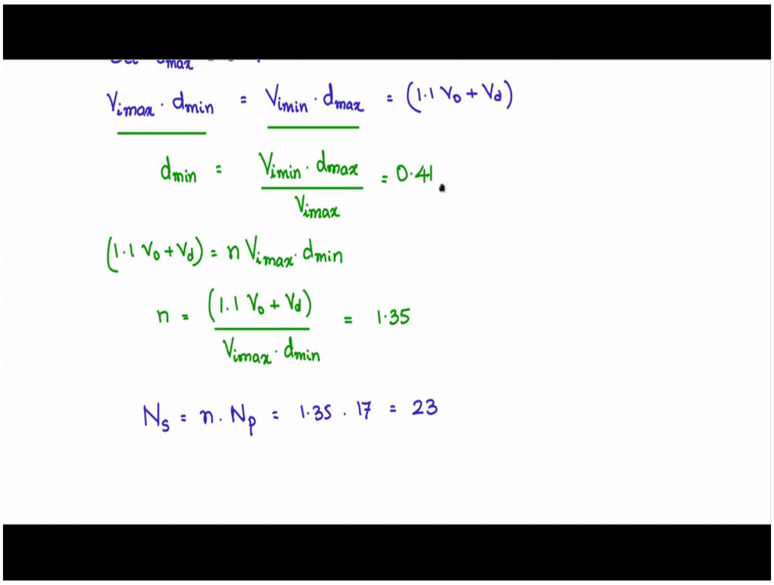

$$\underline{V_{imax} \cdot d_{min}} = \underline{V_{imin} \cdot d_{max}} = (1.1 V_o + V_d)$$

$$d_{min} = \frac{V_{imin} \cdot d_{max}}{V_{imax}} = 0.41$$

$$(1.1 V_o + V_d) = n V_{imax} \cdot d_{min}$$

$$n = \frac{(1.1 V_o + V_d)}{V_{imax} \cdot d_{min}} = 1.35$$

$$N_s = n \cdot N_p = 1.35 \cdot 17 = 23$$

And, N s is equal to n into N p which will turn out to be 1.35 into 17 which is 23 turns. So, N s is 23 turn. If you are using a demagnetising winding; remember, demagnetising winding will be very thin wire because it is only the magnetising current that will flow through it probably will be SWG 45, but you need to use the same number of turns as N p which is 17.

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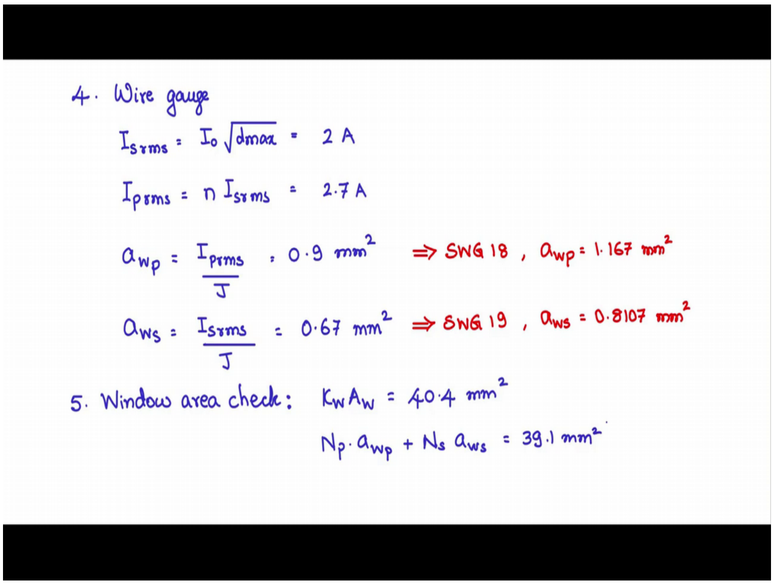

4. Wire gauge

$I_{srms} = I_o \sqrt{d_{max}} = 2\ A$

$I_{prms} = n\, I_{srms} = 2.7\ A$

$a_{wp} = \dfrac{I_{prms}}{J} = 0.9\ mm^2 \Rightarrow$ SWG 18, $a_{wp} = 1.167\ mm^2$

$a_{ws} = \dfrac{I_{srms}}{J} = 0.67\ mm^2 \Rightarrow$ SWG 19, $a_{ws} = 0.8107\ mm^2$

5. Window area check: $K_W A_W = 40.4\ mm^2$

$N_p \cdot a_{wp} + N_s a_{ws} = 39.1\ mm^2$

Next step is to find the wire gauge. So, I s secondary rms is see do I naught into root d is the current rms current that is flowing through the secondary. So, I naught root d max you can calculate around 2 amps, 3 amps into root of 0.45. I p rms is nothing, but n times I secondary rms which is 2.7 amps. And, calculate the a wire cross section of the primary I p rms by J; J you take it as 3 amp per mm square. You will land up with 0.9 mm square. Area of the cross section of the secondary winding wire I s rms by J you have 0.67 mm square. For the primary go to the wire table and you will see that SWG 18 will fit it as a wire cross section of 1.167 mm square and SWG 19 will fit for the secondary a ws will be 0.8107 mm square.

Finally, come and do the crosscheck window area crosscheck to ensure that the windings will fit into the core. K w A w can calculate 40.4 meter mm square and N p a wp plus N s a ws will be equal to 39.1 mm square. So, you see that the window area check is satisfied and the design of the forward converter transformer is complete.