# Switched Mode Power Conversion
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## Lecture - 40
## DC-DC Converter Design

Good day to all of you. In this class, we shall discuss on trying to consolidate the design forces and try to stream line the way in which we would design the various components of the magnetic, magnetic and the electronic components of the DC DC converter. In the last class, you recall that we did discuss briefly on the inductor, the magnetics of the inductor reviewing the basics about it. In this class, let us consolidate the design of the inductor. Then, we shall look at example designs of how we would; rather than example, I would say, the process of the generic process of designing the DC DC converter taking some converter topologies as an example.

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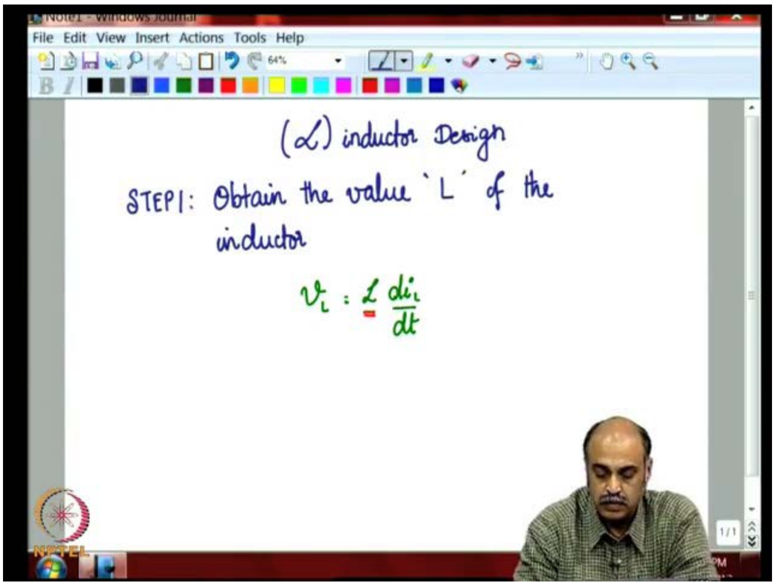

($\alpha$) inductor Design

STEP1: Obtain the value `L` of the inductor

$$v_L = \underline{L}\frac{di_L}{dt}$$

So, let us consolidate the inductor design. So, step one, obtain the value of the inductor. Obtain the value L of the inductor. This is normally obtained using the Faraday's law, the Faraday's equation v L is equal to L d i L by d t. You try to obtain this knowing all other aspects of the faraday's equation. So, this is step one. So, let me name that as step one.

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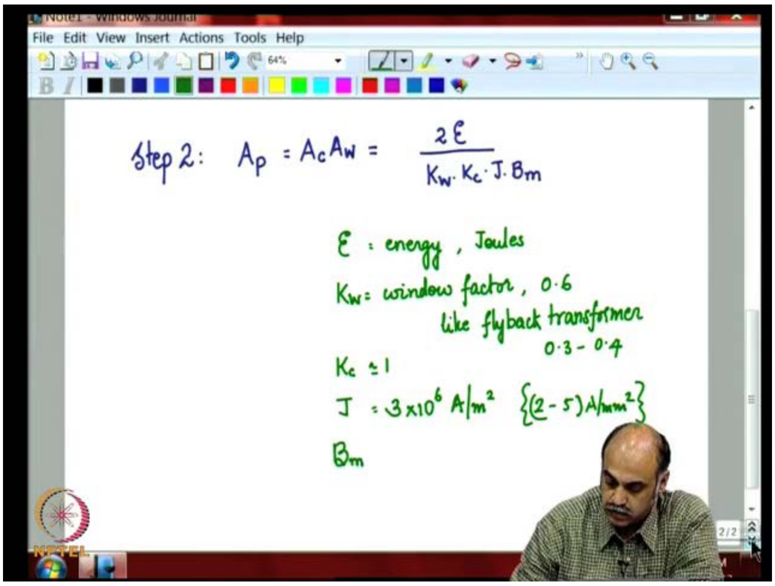

Step 2: $A_p = A_c A_w = \frac{2E}{K_w \cdot K_c \cdot J \cdot B_m}$

$E$ : energy, Joules

$K_w$: window factor, 0.6
like flyback transformer 0.3 - 0.4

$K_c \simeq 1$

$J = 3 \times 10^6 \, A/m^2 \; \{(2-5) \, A/mm^2\}$

$B_m$

Now, step two, step two like we in step two is to obtain the area product as we discussed in the previous class. We would like to link the electrical and the magnetic parameters, magnetic and mechanical parameters. We have done through to physical parameters called the core cross section area and the window area. The core cross section area and the window area are together combined. So, you have the core cross section area, the window area as discussed in the last class; the product of which is called the area product. Again as we discussed in the last class, for the inductor design this is given us two times the energy in joules divided by Kw Kc J Bm.

So, here you have E which is the energy that the inductor needs to store and that is in joules. Kw is a factor for the window area, call the window factor. This has a value of around 0.6 for single winding inductors. For multiple winding inductors like the fly back transformer, see the fly back transformer is not actually a transformer by operation. It is an inductor by operation. It is a multiple winding inductor. For this, the K factor is the order of 0.3 to 0.4 and actually depends upon the windings.

If the number of windings is large, it can go even as low as 0.2, for a very would skill winder. Then, Kc is the fly crust factor. In most of the cases, you can take it approximately equal to 1. J is the current density and expressed in amps per meter square. 3 into 10 to the power of 6 amps per meter square can be your starting value.

Remember that this vary, this varies between 2 amp per meters square, 2 into 10 to the power of 6 amp per meters square to 5 into 10 to the power of 6 amp per meter square. This is the designer choice. Depending upon the power levels, the designer would choose a current density for the cooper in between these ranges that is to 2 to 5 amp per mm square. Then, Bm, Bm is the maximum operating flux.

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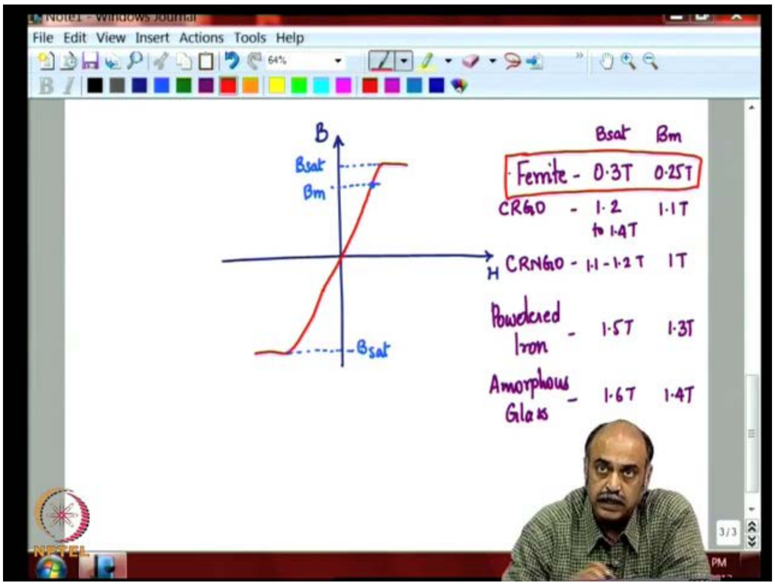

|  | Bsat | Bm |
|---|---|---|
| Ferrite - | 0.3T | 0.25T |
| CRGO - | 1.2 to 1.4T | 1.1T |
| CRNGO - | 1.1 - 1.2 T | 1T |
| Powdered Iron - | 1.5T | 1.3T |
| Amorphous Glass - | 1.6T | 1.4T |

So, if you take the BH curve, a slide deviation, let me have the BH curve, the virgin spec which is like that. So, let us say this is called B sat and this is minus B sat, but the operating point may be much well below B sat. So, let say this is B m.

So, this operating maximum flux density may depend upon the B sat. The B sat depends upon the material. So, if you take for example, a ferrite material which is the one which is normally used for DC DC converters and any high frequency applications, the B sat is around 0.3tesla. Bm, you can choose around 0.25 tesla. If it is the CRGO, CRGO is nothing but the acronym for cold rolled grain oriented silicon steel. This has a flux Bsat of around 1.2 to 1.4tesla. One may operate at 1.1tesla.

CRNGO, this is cold rolled non grain oriented silicon steel, which is normally used for motors where the flux fields are radial in nature. This has 1 to 1.2 tesla as the Bsat, so around 1 tesla. This is 1.1 TO 1.2. Then, you have few other materials like powdered iron, powdered iron around 1.5tesla. So, people may use up to 1.3. You have the amorphous glass 1.6tesla and so on. There are so many materials, but however, most of the DC DC converters use the ferrites. The operated frequency is the order of 20 kilo hertz to 100, 100 or 200 kilo hertz. It depends upon the nature of or the characteristics of the ferrites.

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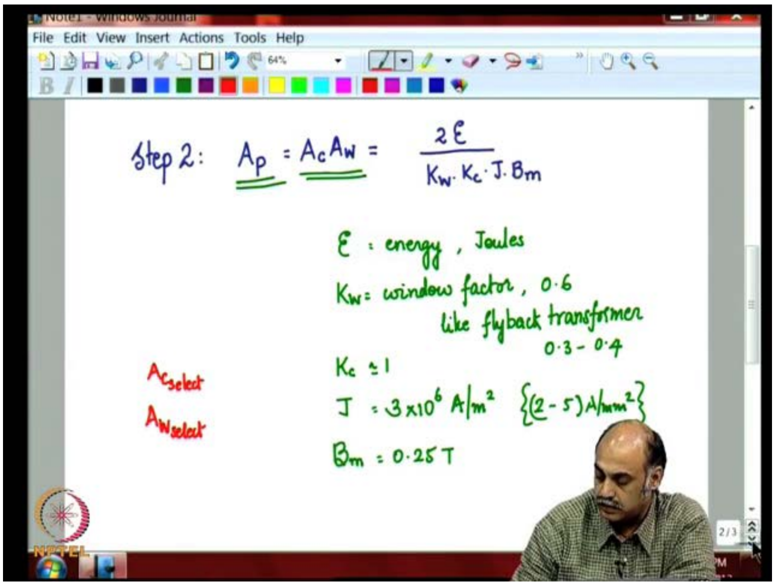

Step 2: $\underline{\underline{A_p}} = \underline{\underline{A_c A_w}} = \frac{2\mathcal{E}}{K_w \cdot K_c \cdot J \cdot B_m}$

$\mathcal{E}$ : energy, Joules

$K_w$ = window factor, 0.6

like flyback transformer 0.3 - 0.4

$K_c \simeq 1$

$J = 3 \times 10^6\ A/m^2$ $\{(2-5)\ A/mm^2\}$

$B_m = 0.25\ T$

$A_{c_{select}}$

$A_{w_{select}}$

So, coming back, Bm is about 0.25tesla for the inductors. So, this may be used to obtain the area product. From the area product, you will select a core having an area product greater than this. You will have Ac selected and Aw selected, which will be slightly different from what you have calculated because you would have chosen a core which slightly higher value of Ap.

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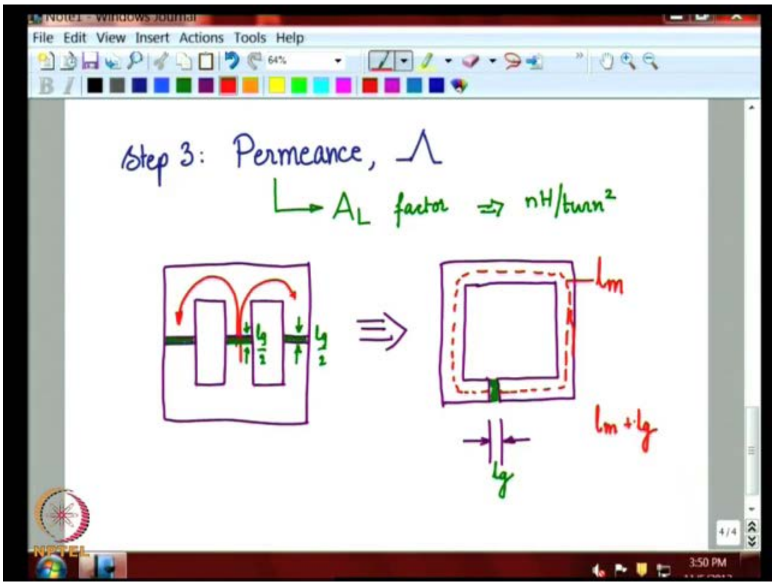

Step 3: Permeance, $\Lambda$

$\hookrightarrow A_L$ factor $\Rightarrow$ nH/turn$^2$

Next, step three, step three, the step three is permeance, written with the up with the capital Greek capital symbol. Now, the permeance, sometimes the inductances are manufactured with the air gaps distributed throughout the core uniformly. These have much lower relative permeability, than the transformer, cores which have very high permeability and permeance. There is no need for energy storage. However, in the case inductance, there is need for energy storage. Therefore, the reluctance has to be higher. As the reluctance is higher, the permeance is lower.

So, if you are using a core, where it is made specifically for inductor application, the manufacturer will give in their data sheet a factor called the AL factor in nano Henry per turns square. It is nothing but the permeance expressed in nano Henry per turns square. If this is not available and you are using a regular transformer core and to the regular transformer core, you are applying an air gap, then you need to do some calculations. Now, let me draw an ee core like this.

Now, let us say these are the two parts. Normally, the central limb, the central limb will have a cross section which is twice the cross sections of the outer limbs, the two outer limps. Therefore, two outer limbs to there will have need to valiant cross section which is same as that of the central limb. So, when the flux, rear of flux flows, it divides and flows through the two limbs. Now, if you provide any, let us say you insert paper of thickness provide an lg by 2, let say of that thickness.

The moment this is raised up, the moment this is raised up, this also will rise up. So, there is a gap which comes through here, each having lg by 2, but as the area of cross section of the outer limbs is half; they are together equal to 1 lg by 2, amount of reluctance. Therefore, equivalently, you could say that this core is something like this where this gap is lg, equivalently lg. This lg by 2 and this lg by 2 together had up to lg. Now, if we have a core cross section like that and let us say this whole length starting from here up to here in the magnetic up to here in the magnetic core, we call that lm. The total path is lm plus lg.

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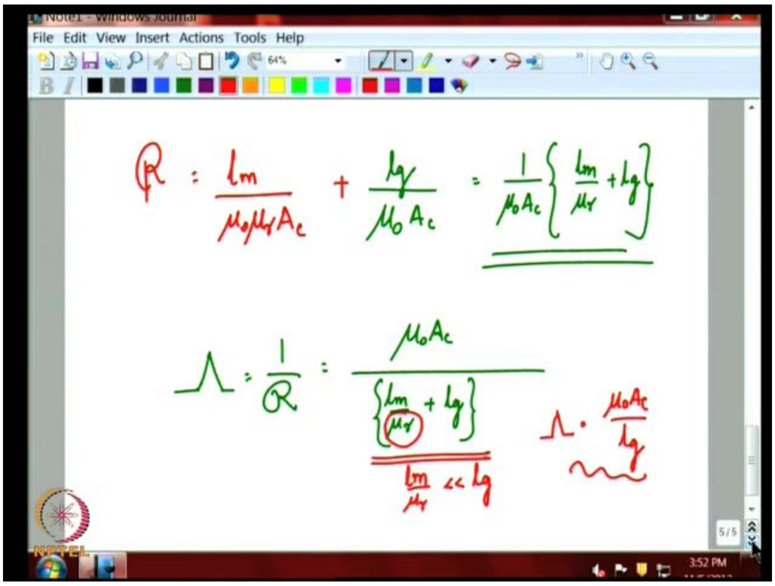

$$\mathcal{R} = \frac{l_m}{\mu_0 \mu_r A_c} + \frac{l_g}{\mu_0 A_c} = \underline{\underline{\frac{1}{\mu_0 A_c}\left\{\frac{l_m}{\mu_r} + l_g\right\}}}$$

$$\Lambda = \frac{1}{\mathcal{R}} = \frac{\mu_0 A_c}{\underline{\underline{\left\{\frac{l_m}{\boxed{\mu_r}} + l_g\right\}}}}$$

$$\frac{l_m}{\mu_r} << l_g$$

$$\underset{\sim\sim}{\Lambda = \frac{\mu_0 A_c}{l_g}}$$

The reluctance is reluctance is lm by mu naught mu r Ac plus the air gap portion mu naught Ac because the relative permeability for air gap is 1. So, this is the reluctance. We can we can take out mu naught Ac. You have lm by mu or plus lg. So, this is the reluctance. What is the permeance? Permeance is nothing but 1 by reluctance. That is given by mu naught Ac by lm by mu or plus lg.

So, understand that here if mu r is very large; it is around 3000 or most of the ferrite materials, if this is a large value, and then lm by mu r can become very small compared to this. That is lm by mu r becomes less compare to lg. Therefore, the permeance of gap core is almost equal to nothing but Ac by lg. However, it is always recommended that you use the exact formula. This is for quick calculation. You could always approximate and use it in this manner.

However, on the other hand, if you have Al factor has given by the manufacture for air gap cores, which are having made for inductor purposes to store energy and from the AL factor, AL factor is nothing but the permeance. Now, what do we do with the permeance? Now, we know that the permeance is linked to the number of the turns.

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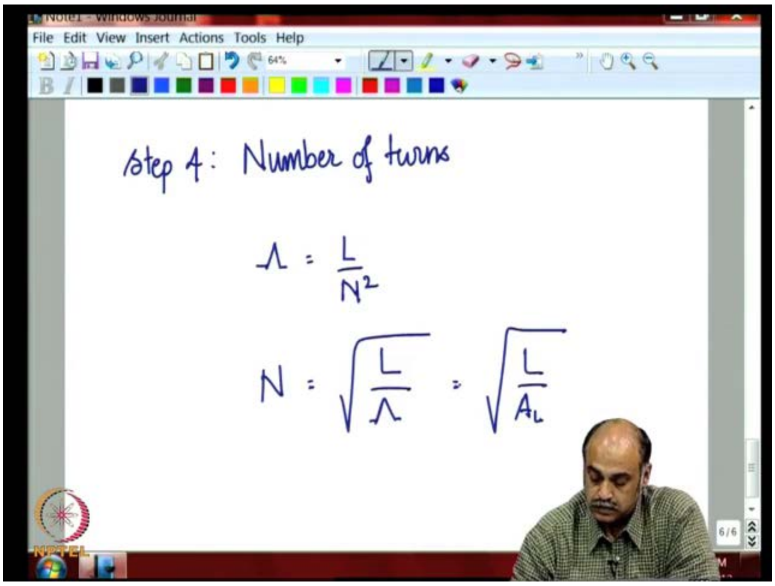

Step 4: Number of turns

$$\Lambda = \frac{L}{N^2}$$

$$N = \sqrt{\frac{L}{\Lambda}} = \sqrt{\frac{L}{A_L}}$$

Therefore, we come to step four, which is calculation of the number of turns. The permeance is nothing but L by N square. N is nothing but root of L by permeance. If the AL factor that is given into the root of L by AL and this way, you calculate. This way, you calculate the number of turns.

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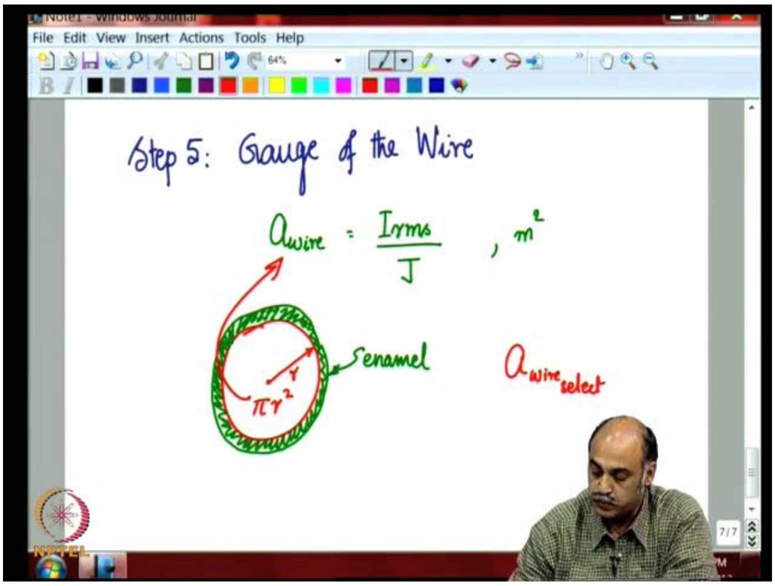

Step 5: Gauge of the Wire

$$a_{wire} = \frac{I_{rms}}{J} \quad , m^2$$

Then, step five, now step five, you need to find out the gauge of the wire, the cooper wire. You recall that in the last class, we discussed about a wire, the cross section of the wire which is equal to Irms, current flowing through the wire and the permissible current density in ampere per meter square. So, you have the rms current in amps by the current density amps per meter square how much you want to permit and you get the wire cross section square wire cross section area in meter square.

Now, once you get the wire cross section area in meter square, go in to the wires table and look at the wires table. Pick out that wire which has slightly more cross section area than what is given here. While you are picking out, be careful to pick the copper cross section area because the wires are normally having two parts. One is the copper inner core with an outer sheet, which is the enamel.

So, in the wire data sheet, in the wire data sheet, while calculating cross section areas, you have to take the copper cross section area or basically the radius of the cooper without the thickness of the enamel. Take the pi r square of the cooper portion of the conductor, the conducting portion of the pi r. So, that would become the wire cross section area. Then, after you have chosen the wire cross section area, you will get a wire which you are going to use. I will call that a wire selected. This is what you will be using to wind.

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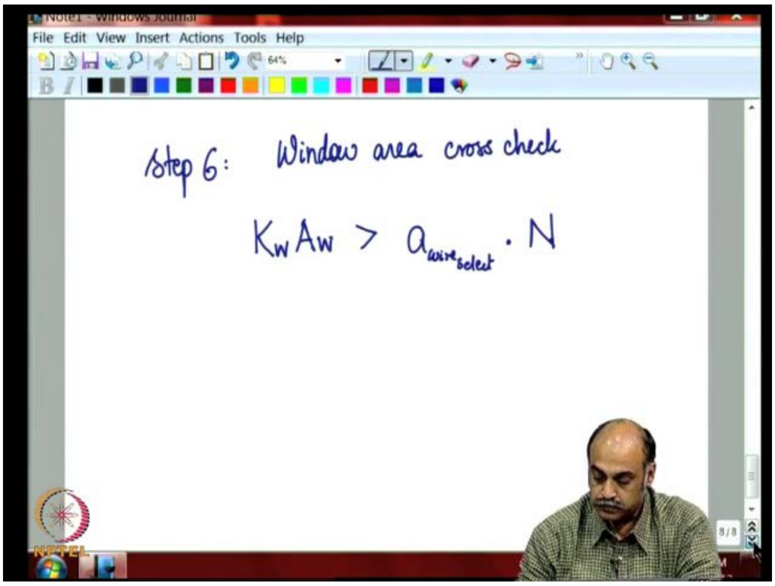

Step 6: Window area cross check

$$K_w A_w > a_{wire_{select}} \cdot N$$

Then, step six, so in step six, you make the window area cross check. So, what is said that we need to check? We need to check that Kw Aw, window factor into the window area is greater than the a wire selected, the selected wire cross section area into the number of turns as calculated in step four from the permeance value. So, if this inequality is satisfied, then you go to the step of actually winding them. Then, you have your inductor which can be inserted into the DC DC converter circuit.

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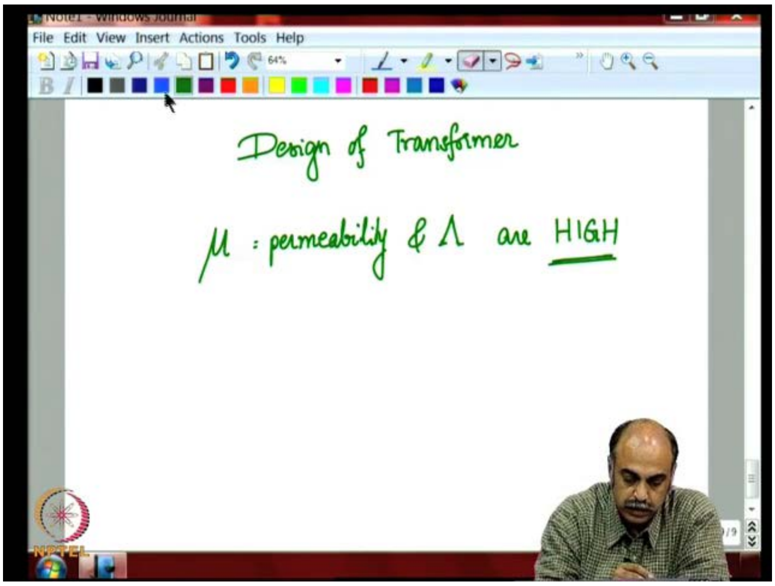

Design of Transformer

$\mu$ : permeability & $\Lambda$ are HIGH

Now, the design of the transformer is also very similar except few points. Let me talk about the dissimilarities in the design of the transformer. You see that there is no energy storage in the transformer. We do not what energy storage in the transformer. Hence, the permeability mu, the permeability, hence the permeance are high. These are required to be high. There is no air gap. The reluctance has to be kept as low as possible. The design is such that the cores will have very high mu r and little or no air gap. Now, when we look at the transformer, here again, we use the two equations, v across the winding. Now, let me go to a new page.

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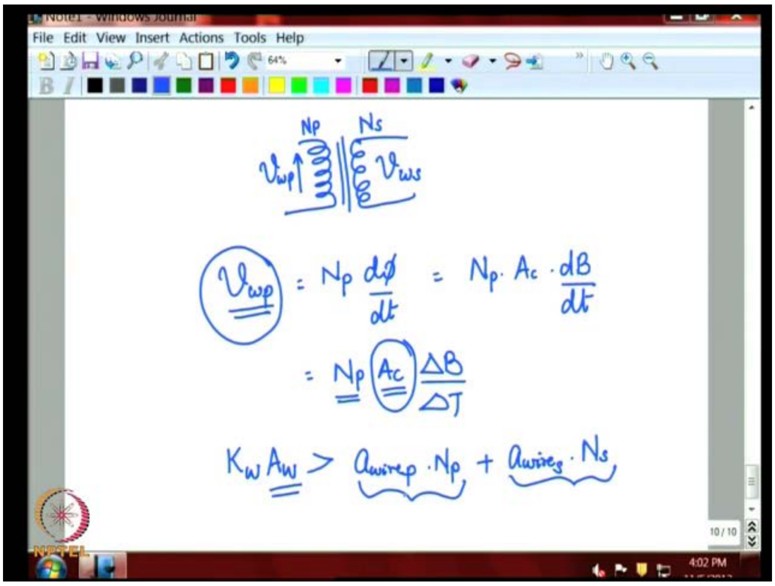

$$\boxed{\underline{V_{wp}}} = N_p \frac{d\phi}{dt} = N_p \cdot A_c \cdot \frac{dB}{dt}$$

$$= \underline{N_p} \boxed{\underline{A_c}} \frac{\Delta B}{\Delta T}$$

$$\underline{K_w A_w} > \underbrace{a_{wirep} \cdot N_p} + \underbrace{a_{wires} \cdot N_s}$$

If you have the transformer winding like this, this is the primary and primary and secondary. This is the voltage across the primary winding, voltage across the secondary winding. Now, voltage across the primary winding is equal to Np d phi by dt, which is equal to Np to Ac to dB divided d t. Now, because the flux, operating flux is in the linear region, you can write it as Np Ac delta B by delta T. So, in time delta T, which is duty cycle into Ts time, what should be the flux swing? The flux swing goes from minus Bm to plus Bm, 0 to Bm whatever depending upon that topology of the circuit in the transformer.

So, these two are design parameters which are decided by the designer. This is the core section area. This is the number of turns Nw, vwp is the voltage applied to the primary which comes from the circuit. Therefore, you see that the voltage and Ac are related through this. The other relationship of course, is very similar Aw Kw Aw should be greater than a wire primary, let us say into Np plus a wire secondary into Ns. This means the same window area should accommodate Np turns of primary wire cross section areas and Ns turns of secondary wire cross section areas.

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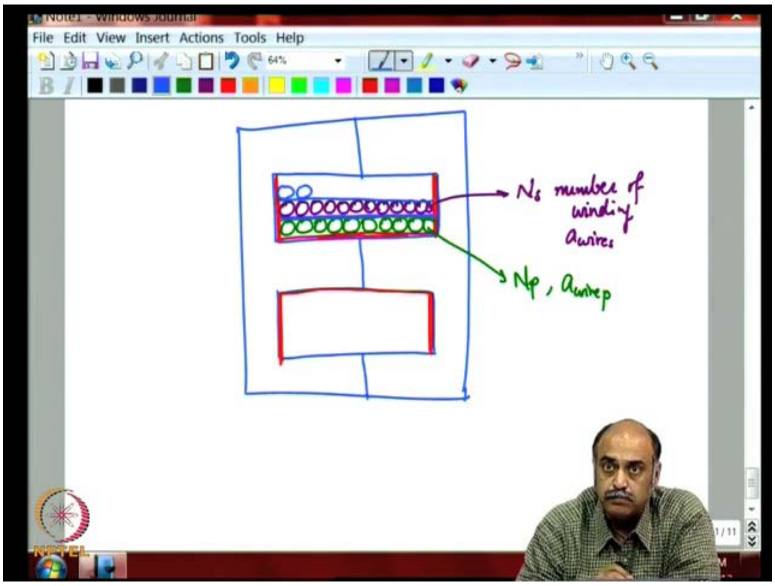

What it would basically mean is that in the window area, if I take a typical core like this, ee core which you are now familiar with and if we you see the bobbin like this, so and top of the bobbin, you wind let us say the primary like this. Then, you would have a layer of insulation. On top of that, you have secondary winding, let us say, Ns. So, let us say this is Ns number of windings of cross section area a wire s. These are Np number of windings of cross section area; a wire p. If there are also still further secondaries, you need to isolate them with further layer of insulation and then more windings.

So, if there is one primary, multiple secondary, all of them should fit into the same window area. Therefore, you will have a wire cross section area into Np for the primary, wire cross section area the secondary wire into ns of the one secondary and so on for all further secondary. So, this relationship has to be has to be, this inequality has to be satisfied, otherwise all other relationships for calculating the number of turns and then the area product, you will see that the other relationship is between this and a wire.

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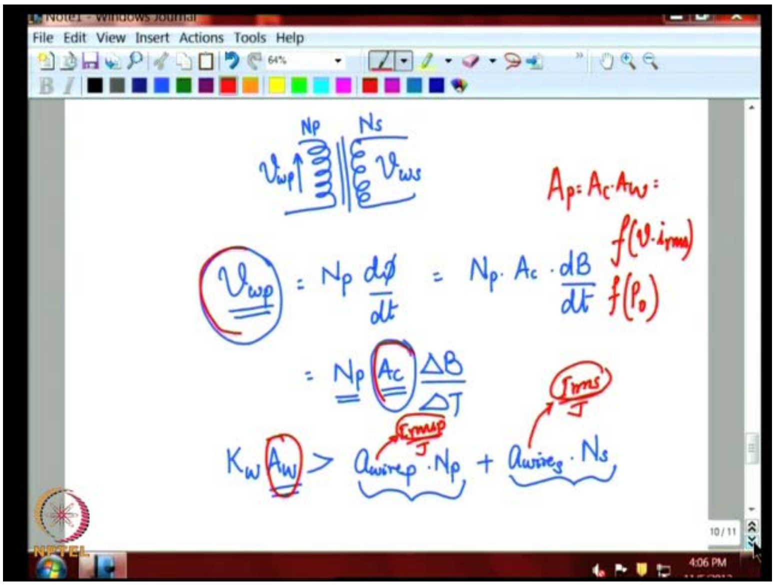

$$A_p = A_c \cdot A_w = f(v \cdot i_{rms})$$

$$f(P_o)$$

$$v_{wp} = N_p \frac{d\phi}{dt} = N_p \cdot A_c \cdot \frac{dB}{dt}$$

$$= N_p A_c \frac{\Delta B}{\Delta T}$$

$$K_w A_w > \underbrace{a_{wirep} \cdot N_p}_{} + \underbrace{a_{wires} \cdot N_s}_{}$$

$$\frac{I_{rmsp}}{J} \qquad \frac{I_{rms}}{J}$$

The a wire is having Irms of the current flowing through this that winding by J. This is also Irms, the primary divided by J. This is the secondary by J. This is of the primary by J. The current and the Aw are linked. In the other earlier equation, the voltage and Ac were linked. Therefore, the area product, Ap which is equal to Ac into Aw is a function of power p. We should say it is a function of v into I rms or a function of power v naught. So, in that manner, you try to do the in this design of the transformer too.

So, what we shall now do is look at how we go about doing the design of a DC DC converter in a systematic way, step by step, just like we did in the inductor. We shall take the case of two DC DC converters, generic DC DC converter example and see how we go about doing that one and use the same method to put them into a program like octave or mat lab. Then, you can iterate the design.

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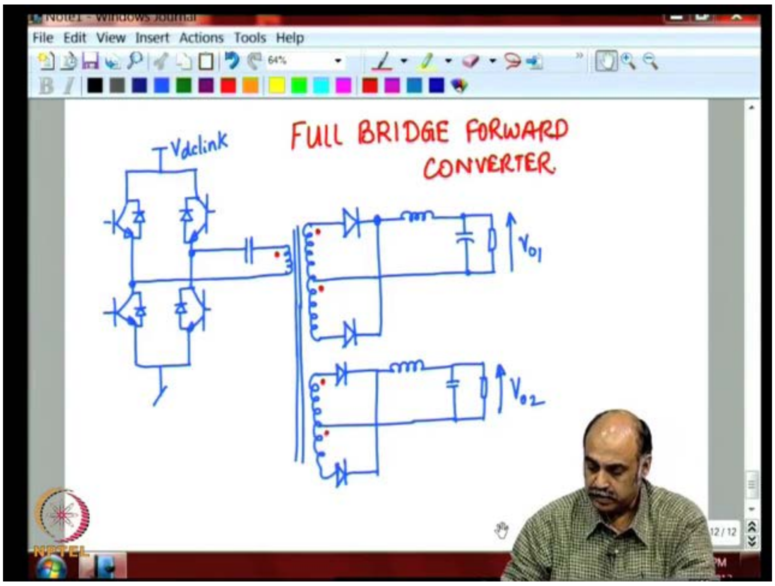

So, first let us take the example design of a full bridge forward converter. So, how does the full bridge forward converter look like? So, let us draw that. We have these transistors. Let us have a power supply which provides the dc link, the input. Then, across the bridge, so these switches what I have written, could mean BJT. It also could mean IJBT. It could also mean MOSFETs. So, consider them to any one of the semi conductor type of switches and you have the reversed diode connected like this. It is assuming that you have these diodes.

If the body diodes are there, you need not put them externally. If they are not there, you have to put them externally. Now, this is the full bridge and this and from this center portion of the full bridge, you have a transformer and the secondary of the transformer is connected in this fashion like this. This is V naught. So, this is one secondary, one primary and power supply, input power supply. If you are having multiple secondaries, what will happen is this portion gets repeated as many times as we have discussed a while back, while doing control of the multiple output transformers.

Now, let us consider this kind of circuit. We want to we want to design the DC DC converter, the power circuit. So, what does it imply? So, what does it mean? It means that you need to rate various components. In the case of the power semiconductor switches, you need to select them. You are not making them. You are selecting them from the manufacturer’s data sheet. So, what is the information that you need? You need to know the current stress and the voltage stress and the thermal stresses that are occurring in this circuit of topology. Appropriately, choose proper device from the manufacturer’s data sheet.

You have a capacitance which blocks any dc which is going through transformer, and therefore prevents the transformer flux from walking away towards saturation. This is in fact called the flux walking transformer. Do not forget the polarities of the forward converter. There is a buck derived forward converter. The next you would, of course, rate these diodes which need to handle the current, which are flowing to the inductor and the load. You need to design the inductor. You need to design the capacitance and for each of the outputs. Then, of course, you need to the sign the transformer.

So, let us see how we would go about doing the design of such a converter. I have purposely taken isolated DC DC convertor case rather than taking material boost convertor or a buck convertor because these isolated convertors are much more used in practice. We shall after this have a brief look at how we go about designing a fly back convertor design, which is actually isolated convertor without transformer. It is not, the isolation is by a multi winding inductor.

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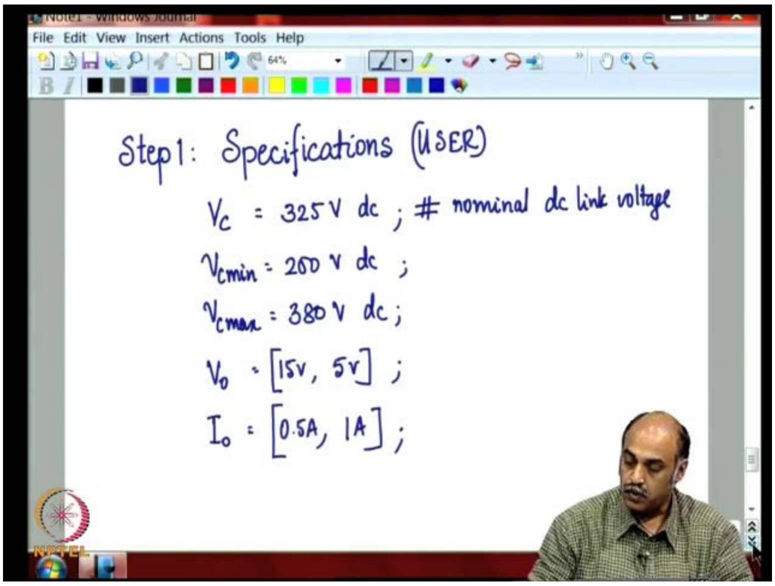

Step 1: Specifications (USER)

$V_c = 325\text{ V dc}$ ; # nominal dc link voltage

$V_{cmin} = 260\text{ V dc}$ ;

$V_{cmax} = 380\text{ V dc}$ ;

$V_o = [15\text{V}, 5\text{V}]$ ;

$I_o = [0.5\text{A}, 1\text{A}]$ ;

So, coming back to this topic, so let us go through the process of designing it step by step. So, step one, so step one, what do we do? We first have to list down the specification of the entire convertor. Now, I will be listing down the specification the convertor. Now, let us say V dc. Now, let us give simple variables, Vc to represent this. This is Vc so that we do not have very long symbols to deal with. Now, Vc, the input dc value, you need to give the numbers. If you are taking from the mains, especially from the Indian mains it is 325 volts d c. Now, this is nothing but the nominal c link voltage.

You should also give what is the minimum value that it will take. Let us say some value, 200 volts, it swings. What is the maximum value? It may probably go up to 380 or even 400 volts dc depending upon the power supply, input mains voltage swing. Then, what is the output V naught? So, V naught is let us say 15 volts. Now, it was just once single winding transformer, we would have put V naught one single scalar value, but if it a multiple winding transformer, it is better to use vector values. Let us say, we need plus 15 volts. Then, you also need 5 volts. Use it as vector.

Likewise, I naught, the output current, so you may want, let us say as 0.5 amps at 15 volts, now 1 amps at the 5 volts output. So, I am just putting some delimiters here, but be careful. It is always better to put all this things into a program file like mat lab or octave and follow the programs syntax accordingly. This is just for a listing down the procedure, our process of finding the proper design values. So, that is the design, that specification that you would get from the user. In fact, we should call it is specification from the user.

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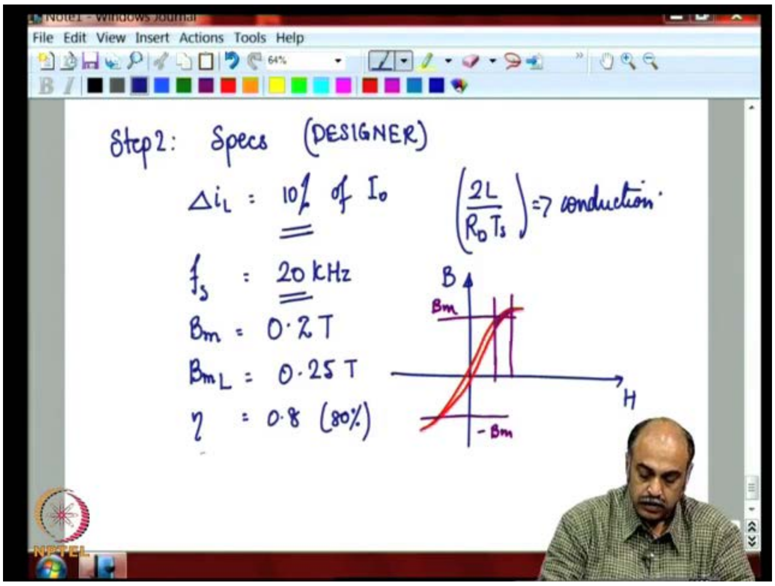

Step 2: Specs (DESIGNER)

$\Delta i_L$ : $\underline{\underline{10\%}}$ of $I_o$

$\left(\frac{2L}{R_o T_s}\right) \Rightarrow$ conduction.

$f_s$ : $\underline{\underline{20\ \text{kHz}}}$

$B_m = 0.2\ T$

$B_{mL} = 0.25\ T$

$\eta = 0.8\ (80\%)$

You need to also put in some specs as a designer. So, let say specs designer, the user need not know what these numbers are. He may not even be aware of the meanings, but the designer will have to list down these things. One is delta iL. You are using an inductor like this buck derived convertor. What is the amount of delta iL you would like to give? We mentioned it right in the beginning. We discussed it is about, we start with a value of 10 percent of I naught that is the maximum load current. It could, of course, vary.

If you know the minimum value of the load that would ever occur on the DC DC convertor that could be also used as one of the parameters arriving at the value of delta iL. If one knows the conduction parameter k, which 2L by RTS, 2L by R naught into TS, this is called as the conduction parameter. If this is known, this also would be used to obtained a value of delta iL. If none is known, then the first starting value of 10 percent of I naught is a good enough ripple current in the inductor or the inductor ripple current. Then, you need to decide the switching frequency.

What is the switching frequency? Do you want to switch 20 kilo hertz, 50 kilo hertz or 100 kilo hertz? So, decide that. I just marked it here as 20 kilo hertz, but it could as well 50 kilo hertz, 100 kilo hertz depending any upon your application. Then, decide the maximum operating plucks density for the transformer. If it is ferrite, fix it at 0.2tesla. The maximum operating flux density for the inductor, fix it at around 0.25tesla. We can always choose a slightly higher operating flux for the inductance because the swing in the case in the inductance is smaller than in the case of the transformer.

This is because if you take the BH curve, we take the BH curve which is of this nature. For a transformer, the swing in the flux is from B, is from minus Bm to Bm, whereas for the inductor, it is in the neighborhood of Bm. It is around these values because the current ripple is within this band. Therefore, you can afford to take slightly higher value of the operating flux density in the case of the inductor than in the case the transformer. Next, you need to have a starting value of efficiencies for the transformers. For low power for application, the efficiency can be as low as 80 percent. So, in case you need to rate the input value, input components like input of the primary of the transformer, you take an approximate efficiency or 80 percent, which will be on the conservative side.

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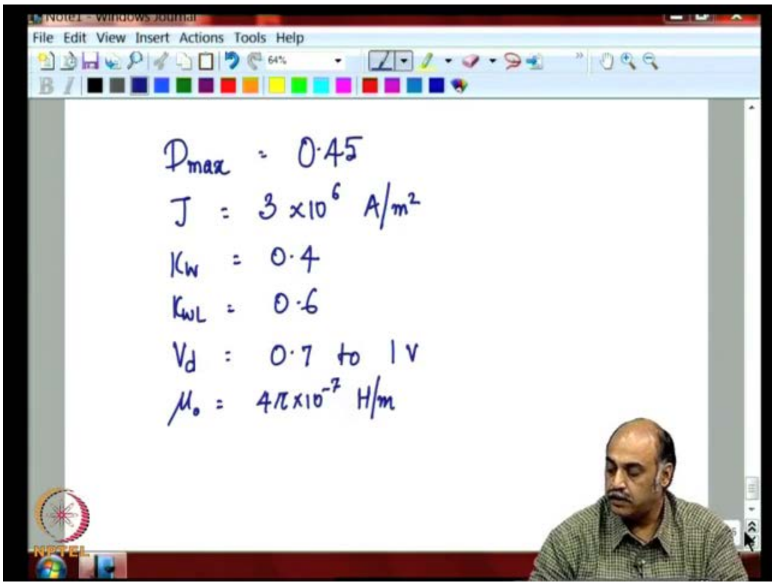

$D_{max} = 0.45$

$J = 3 \times 10^6 \ A/m^2$

$K_W = 0.4$

$K_{WL} = 0.6$

$V_d = 0.7$ to $1 V$

$\mu_0 = 4\pi \times 10^{-7} \ H/m$

Then, you need to calculate what is the max, sorry, not calculate, you need to specify what the max is. Normally, in the case of isolated transformer, isolated DC DC convertors, and the upper limit of D is fix which is not being more than 50 percent. This is because we go more than fifty percent, there is not enough time that for resetting the core. Therefore, the max limit for Dmax is 50 percent. To be on a safer side, normally 0.45 or 45 percent is chosen as the Dmax, but transformer isolated cores.

The current density as we have discussed just now, is around 3 into 10 power 6 and per meters square, Kw of around 0.4 if it is transformer. Kw for the inductor is 0.6. The diode drops. For purpose of calculation rating, you can take it as around 0.7 to 1 volt drop per diode, especially it is higher powers. Mu naught is nothing but 4phi into 10 to the power of minus 7 Henry per meter. So, these are all the values that are needed. Now, with this value, the user spec, the designers spec, you should be able to calculate every component detail.

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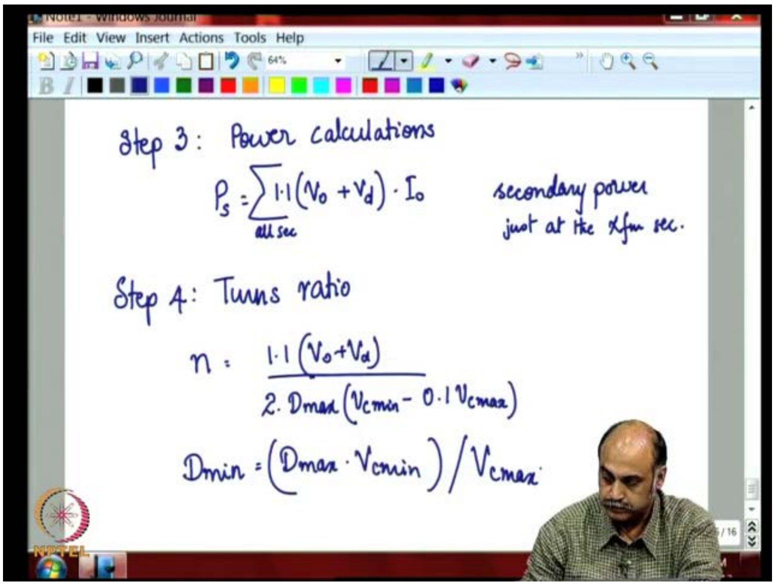

Step 3: Power calculations

$$P_s = \sum_{\text{all sec}} 1.1(V_o + V_d)\cdot I_o$$

secondary power
just at the Xfm sec.

Step 4: Turns ratio

$$n = \frac{1.1(V_o+V_d)}{2\cdot D_{max}(V_{cmin} - 0.1V_{cmax})}$$

$$D_{min} = (D_{max}\cdot V_{cmin})/V_{cmax}$$

Now, the calculations step three, step three, we shall do the power calculations first, power calculations. So, P naught is nothing but V naught plus Vd, a diode drop into I naught. Now, this P naught calculation is nothing but actually the secondary power, secondary power just at the, just at the transformer secondary. In fact, we shall name it as PS rather than P naught, so that one should not confuse it with V naught I naught, which is the actual output power. So, Ps is the secondary power.

Now, if you have many multiple windings, then it is actually sigma of this. Now, if you want to accommodate for the drops winding, resistance drops because let us say, you have a transformer. The transformer has secondary winding and also the windings of the inductor. If you look at this circuit, you will see that V naught, there will be some drops across the diode. So, that is what we have accounted for. There will be drop across the resistance, winding resistance of the inductor. There will be drop across the winding resistance of the transformer. You can account for them in a conservative wave by giving some extra.

So, let us say by giving 10 percent extra voltages more at the secondary. If there are multiple winding, you will have to sum to all secondary, which would give you the total power reflected on the transformer. Then, step four, what is turns ratio? So, the turns ratio is nothing but so let us say 1.1 V naught plus Vd divided by 2 times the max Vc minimum minus 0.1 Vc max. How does this come above? So, Vc minimum minus 0.1

Vc max, now if you look back into the circuit, you will see that this is the minimum, the worst case minus around 10 percent of Vc max which drops across the capacitance. So, that would be the voltage that occurs at the primary of the transformer.

Now, N times will be transferred on to the secondary here and with all the various drop just discussed, so into Dmax times because if this is minimum, the max due to cycle would be maximum would be what the value that would you get here. So, therefore, Vc means minus 0.1. Vc max is nothing but the drop across the flux working capacitance is the occurring at the primary and 1.1 V naught plus Vd is the peak voltage across the secondary. This D max is this, two times D max is basically because of the rectification effect due to the winding, and the center tapped. The effective duty cycle is actually doubled. So, that is the D max that comes into picture. So, after the turns ratio, let us calculate the duty ratio D min nothing but D max into Vc min by Vc max.

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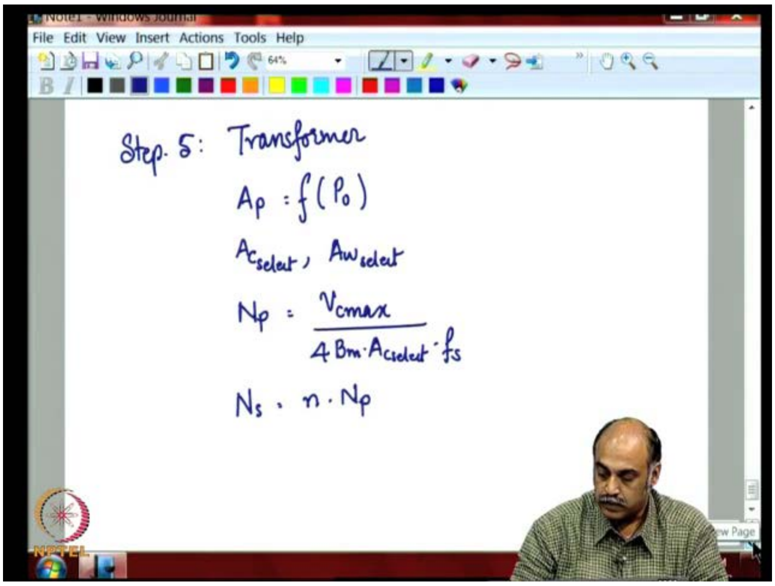

Step. 5: Transformer

$A_p : f(P_o)$

$A_{c_{select}}, A_{w_{select}}$

$$N_p = \frac{V_{cmax}}{4 B_m \cdot A_{c_{select}} \cdot f_s}$$

$N_s = n \cdot N_p$

Now, next step would be to calculate the, design the transformer. So, let us say transformer, so in the transformer, first you have the area product. Calculate the area product which is a function of P naught as we observe. So, each transformer will have different equation for the area product. You can you can find work that out by using the faraday’s first law. The Kw Aw should be greater than A into sigma A into n. Now, based on that, you would select a particular Ap. Therefore, you have Ac selected and Aw selected.

So, once the core has been selected, you can calculate the Np using faraday's law which is nothing but Vc max. It has to support maximum voltage divided by 4Bm Ac selected into f s. It is nothing but from the faraday's law, Ns is nothing but n times Np. So, if you get fractional turns, you rounded to nearest integer. So, if I have multiple turns, multiple windings, then you will see that n is a vector because we had specified V as a vector. Remember that we specified V as a vector. So, you will actually get n as a vector. When you use n here, Ns will be a vector and will have two values. So, you can calculate the windings.

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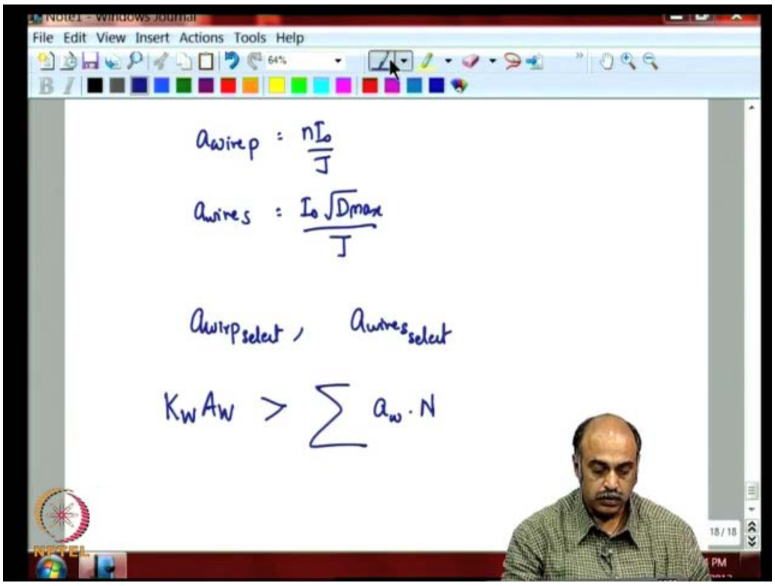

$$a_{wirep} : \frac{nI_o}{J}$$

$$a_{wires} : \frac{I_o\sqrt{D_{max}}}{J}$$

$$a_{wirep_{select}} , \quad a_{wires_{select}}$$

$$K_w A_w > \sum a_w \cdot N$$

After you have calculated the windings, you need to calculate a wire cross section of the primary which is let us say, n I naught by J and a wire cross section of this secondary which is nothing but I naught square root of Dmax by J. So, this all comes from the DC DC convertors comes from the analysis itself. Then, look into the wires table. You will land up with a wire primary selected and a wire secondary. That is what is selected. Check that Kw Aw is greater than sigma all of a wires into N, which would be satisfied.

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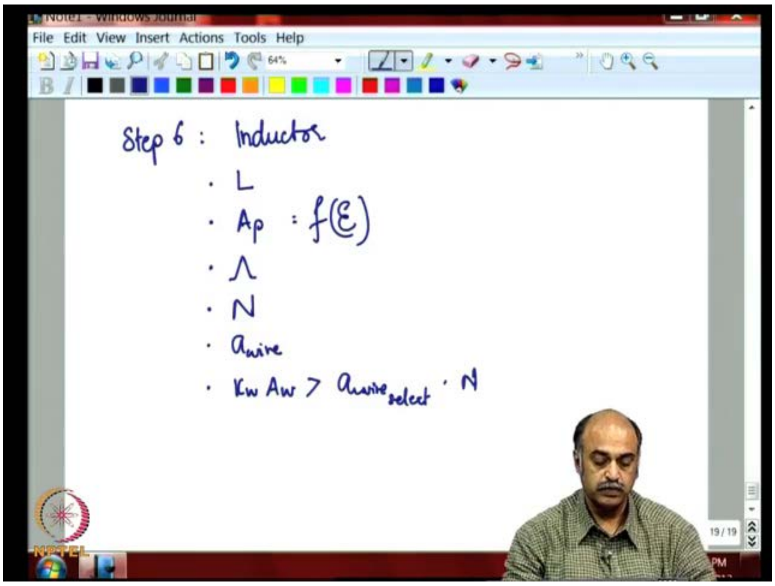

Step 6 : Inductor

- L
- $A_p : f(\mathcal{E})$
- $\Lambda$
- N
- $a_{wire}$
- $K_w A_w > a_{wire_{select}} \cdot N$

Now, after that is done, you would then try to design the inductor. This is step six I suppose. What was the step number, step five, and step six? Step six is the inductor design. So, in the inductor design, we have gone through today, first the value of L. You calculate and then after the value of L, area product which is function of energy in this case because it has to store energy. Then, the permeance, find out the permeance, then the number of turns and the wire gauges. That is the wire and then cross check. See that Aw Kw is greater than a wire selected into N. So, all these you need to do the design the value of the inductor. Notice that all the equations, the numbers can be obtained from the initial specifications.

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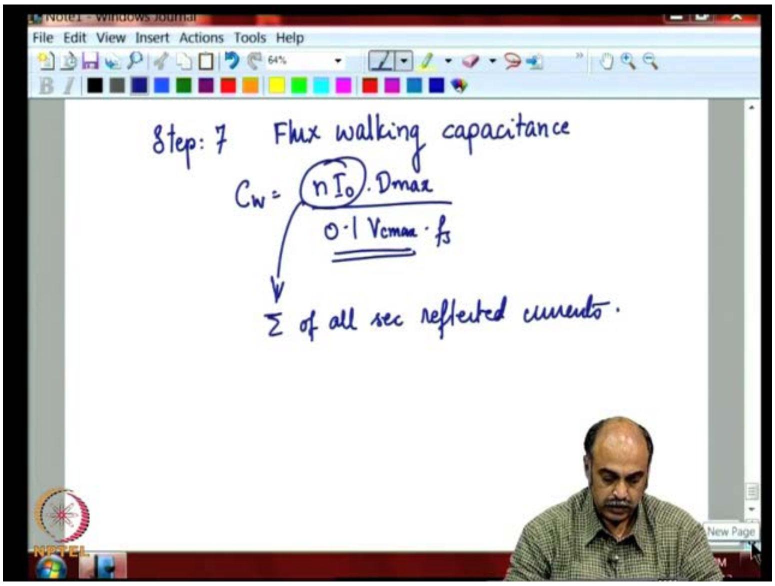

Step: 7 Flux walking capacitance

$$C_W = \frac{\boxed{n I_0} \cdot D_{max}}{0 \cdot 1\, V_{cmax} \cdot f_s}$$

Σ of all sec reflected currents.

Then, you need to rate the flux walking capacitance, step seven, flux walking capacitance, which is the primary capacitance the one in series with the winding to prevent saturation, flux walking saturation that may happen due to the non idealities and non matching power semi conductor devices. So, the flux walking capacitor can be the designed by allowing some 10 percent drop across it and this.

Now, remember that this n I naught is the primary current which is basically the sigma of all. This is the sigma of all secondary reflected currents. The voltage rating of the capacitance is also of this order, greater than that. Then, you read the diodes and the transistors.

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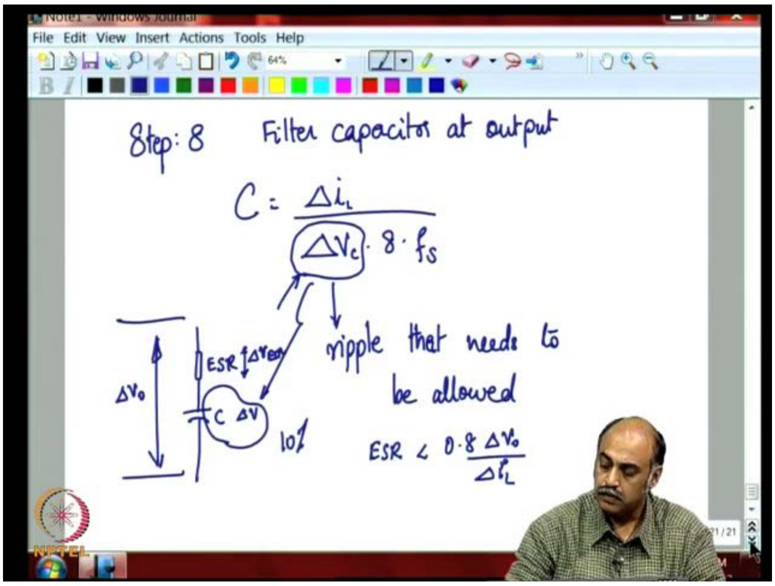

Step: 8 Filter capacitor at output

$$C = \frac{\Delta i_L}{\boxed{\Delta V_c} \cdot 8 \cdot f_s}$$

ripple that needs to be allowed

$$ESR < 0.8 \frac{\Delta V_o}{\Delta i_L}$$

Step eight or we still have the filter capacitor, output will filter capacitor at output, so where you have see which is delta iL, this is what is flowing through the inductor. The ac part flows the capacitor, dc part to the output divide by delta Vc that we need to give into 8 into f s. Now, the delta iL which flows through the capacitance is this much. This is the ripple that you would want to allow that needs to be allowed. Now, the output ripple is combination, is actually a vectorial combination of not only this plus also the ESR of the capacitance. The capacitance has an ESR, which may not be known a priory.

Now, both these actually vectorially add up, this delta as we calculated from here and delta VESR. Both together will contribute to the delta V naught ripple. Now, this portion is normally taken 10 percent of the total output ripple. The remaining is supposed to be across ESR, so that you can have a less stringent ESR requirement of the capacitance, of the capacitor. A very low capacitor can be very expensive. Therefore, you try to allow more drops on into the ESR and try to make it large by putting a larger value of capacitance, lower value of delta V here.

So, just 10 percent of ripple is across C by the fundamental C physics of C delta V variation and the remaining for follows. Therefore, you will be taking 0.1 of the output ripple. Then, you could also estimate the ESR of the capacitance should be less than 0.8 times delta V naught by delta iL.

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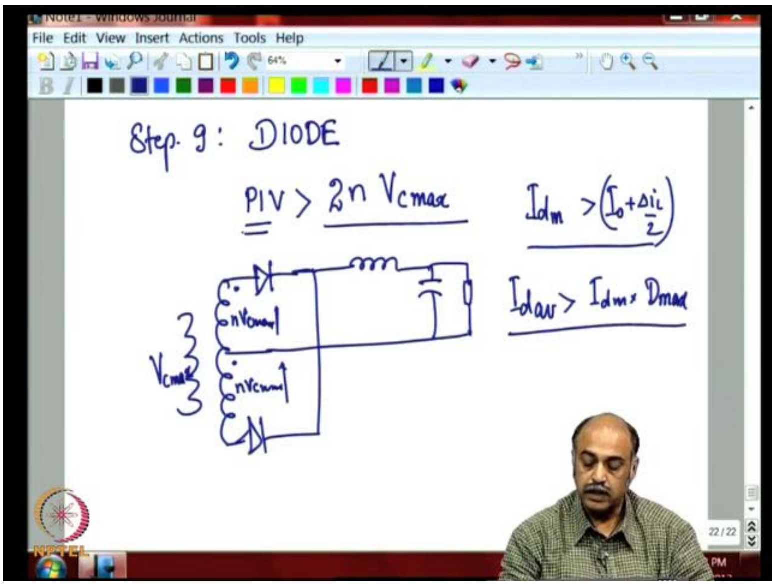

Step. 9 : DIODE

$PIV > 2n\,V_{cmax}$

$I_{dm} > \left(I_o + \frac{\Delta i_L}{2}\right)$

$I_{dav} > I_{dm} \times D_{max}$

Then, you have a step nine, the switches actually, the power switch and the diodes. So, let us say you have a diode first. Now, the secondary diodes will have to have a peak inverse voltage of n times Vc max. Vc max is the maximum that can ever occur across the primary of the full bridge transformer and n times Vc max is coming across the secondary of each of the center tapped winding. Therefore, two times, so if you are having center tapped winding like that, this is Vc max, this is n Vc max. This is n Vc max. So, if this is the dot polarity, you have this two adding up.

Then, one is conducting. The other one is not conducting. What is appearing across that is 2 n Vc max. You can complete the circuit like that. This should be the peak inverse rating of the diode. It should be greater than this. What should be the peak value? The current, the peak value of the current is whatever I naught, I d max should be greater than or I d m value should be than I naught plus delta iL by 2. The average value, I d average should be greater than I d m into 0.5 because maximum duty cycle is less than 0.5 or I d m into d max.

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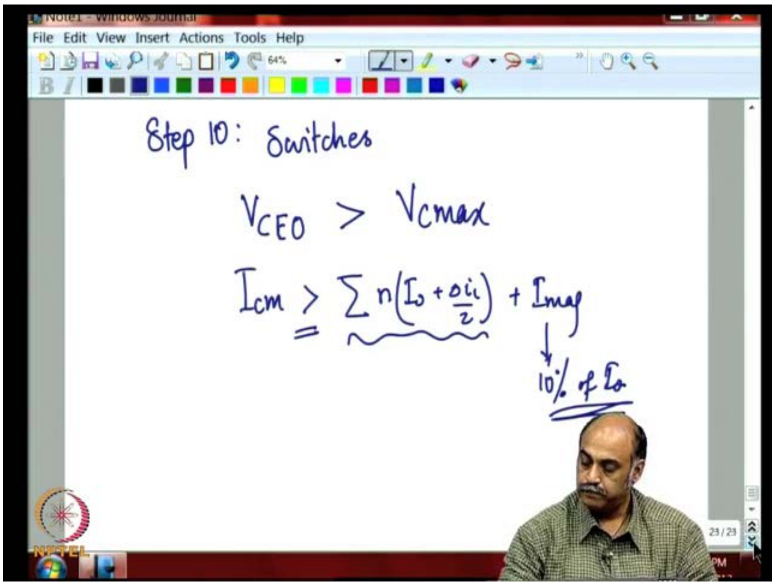

Step 10: Switches

$$V_{CEO} > V_{Cmax}$$

$$I_{cm} \geq \underbrace{\sum n\left(I_o + \frac{\Delta i_L}{2}\right)} + I_{mag}$$

$\downarrow$

10% of $I_o$

So, these would be the ratings of the diode. The step ten is the rating of the switches, power semi conductor switches, V CEO, the collector to emitter, when it is, should be greater than VC max. The current Icm rating should be all the reflected secondaries sigma of the entire n delta iL by 2, reflected secondary peaks plus I magnetizing. What is I magnetizing? It can around 10 percent of I naught to start with. This will be a very small value compared with this value. Anyway, you are going to choose current rating greater than what you have calculated. It should account for the magnetizing. So, this way, you calculate all the components of the DC DC convertors

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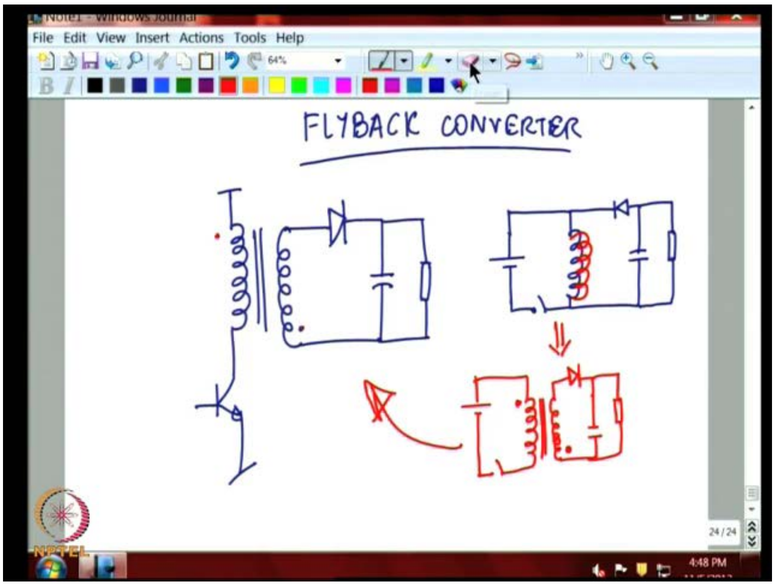

FLYBACK CONVERTER

Now, let us just see one more, the fly back and then conclude. The process is exactly the same. Only the fly back convertor as you know, is nothing but exactly like the non isolated buck used, but you have a winding, another winding across which it is connected. So, how you go about this convertor, sorry for this convertor? Now, you see this similarity. If you are using a non isolated buck boost, you would have done it like this.

Now, by putting this extra winding here on this, this becomes the primary side in the same. Now, instead of hard winding junction point here, you have the mutual coupling in this fashion. By inter changing dot polarity like this rather than having the dot polarity like this, we can do a modification of putting the diode like this and shifting the dot polarity here. So, this will give you a fly back convertor. So, what we essentially do is you do a design exactly like you would in a non isolated buck boost.

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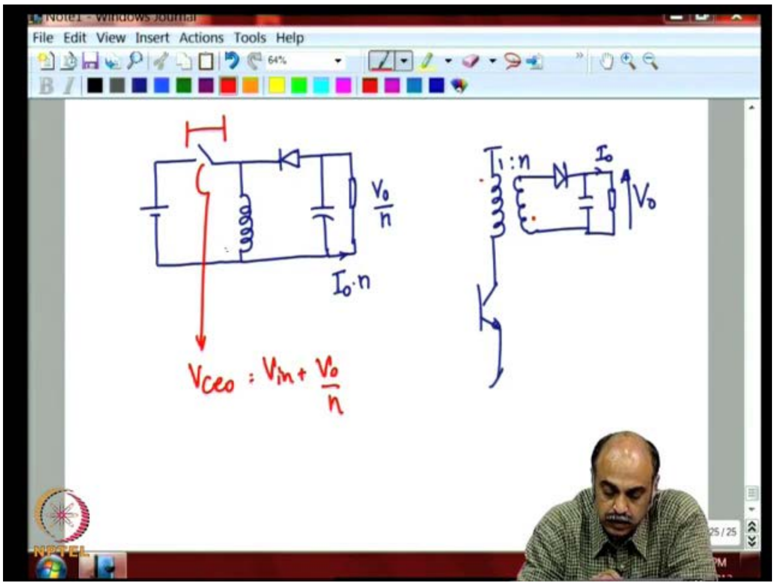

So, the process would be start with start with the buck boost convertor like this. now, let us say that we want some V naught at the output, final output of the isolated fly back, 1 is to n. So, you need be V naught here. Then, if the isolation is removed, this becomes 1 is to 1. It would be V naught by n. Keeping V naught by n as the voltage output of the non isolated buck and I naught as, actually I naught into n, n as the current which flows through it. We keep the power same as isolated case. Do all the design that you would have for the non isolated buck. Find out the out the value of the inductor, the rating of the switch when the switch is on, the current that flows through this.

Peak current would be the inductor current plus delta iL by 2. When it is off, this is connected in the voltage across that will be voltage V in plus V naught by n. So, N would be across this, voltage rating V ceo plus V naught by n same as here. The inductor value can be we calculated. Once the inductor value is calculated, find the energy, energy to area product, area product follow it up by the permeance and then the number of turns and the wire gauge. So, once you have decided that, this is a small modification, you need to do at the inductor and that is the k factor.

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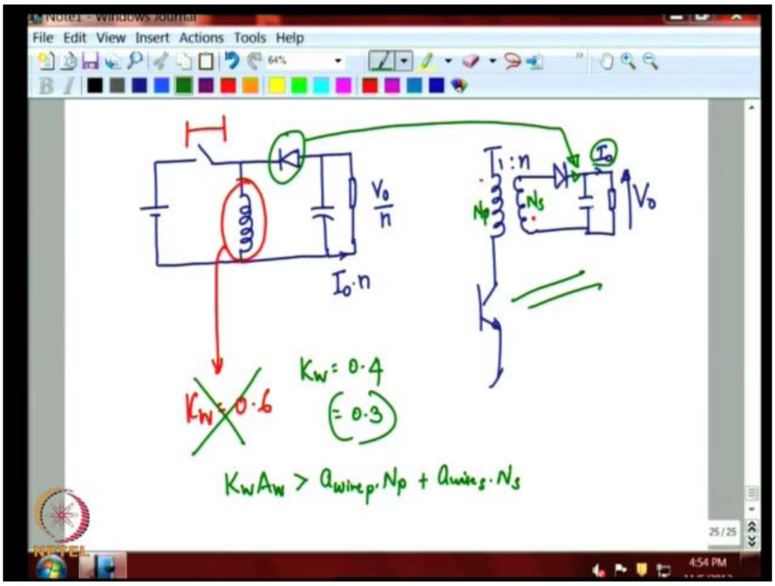

So, when you decide the inductance, now do not take the k factor of Kw of 0.6. Take Kw to of 0.4. Now, if it is still multiplied, many more winding, think of even 0.3. That is one change you do. Then, when you do cross check, Kw Aw should be greater than not just only the primary winding, a wire of the primary 3 into Np plus a wire of the secondary into Ns. This is Np, this is Ns. That would come into the picture. Once that is done and the connections of, connections are made up of according to this, you will get exactly down about that you have decided that 1 is to 1 n ratio will come in figure automatically.

You will get V naught here and I naught Rate this diodes, these diodes according to be secondary current flowing that is I naught currents and the capacitance currents that flow through here and I capacitance for current and I naught. So, accordingly rate the diode without the n factor. Now, this way you can make a quick design of the fly back convertor. Fly back is very, very popular.

Even thought the quality of output is not as good as forward convertor because there is no output filter inductor, the fly back convertor is popular in this basically because of it is very low component count. You see that there is the diode, the capacitance, one inductance cum transformer, the isolator and the switch, the power switch. So, this gives a very cost effective design even though one needs to sacrifice to some extent, the quality of the output voltage.

So, with this, let us conclude this topic of DC DC convertor. I hope that you will be able to design a complete DC converter, analyze it, make the, design the values, and design the controller and implement together in a simulation like in the p spice. Then, subsequently bring it on an electronic bread board and implement it and hardware. So, this sequence, I hope you will be to follow and analyze them fruitfully.

Thank you very much.