Design of Power Electronics Converters
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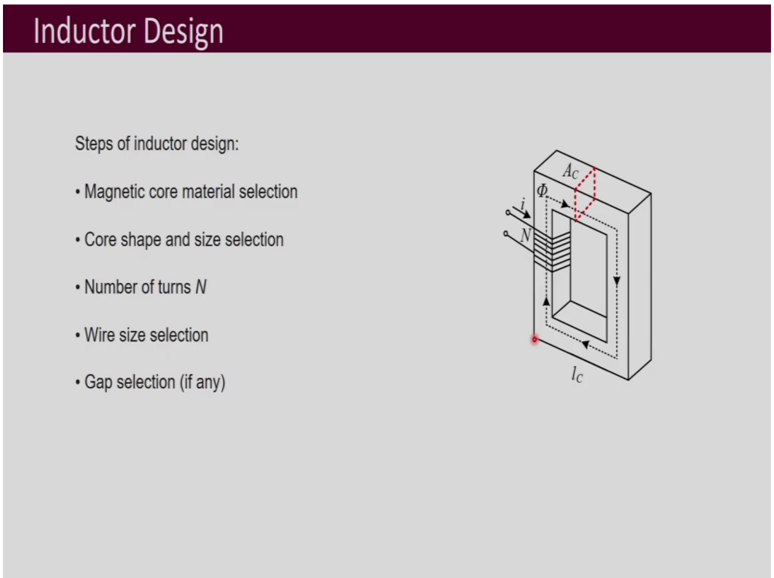
Module: Magnetics Design
Lecture 49
Inductor Design - I

Welcome to the course on Design of Power Electronic Converters. We were in the module of magnetics design and today we will look into inductor design.

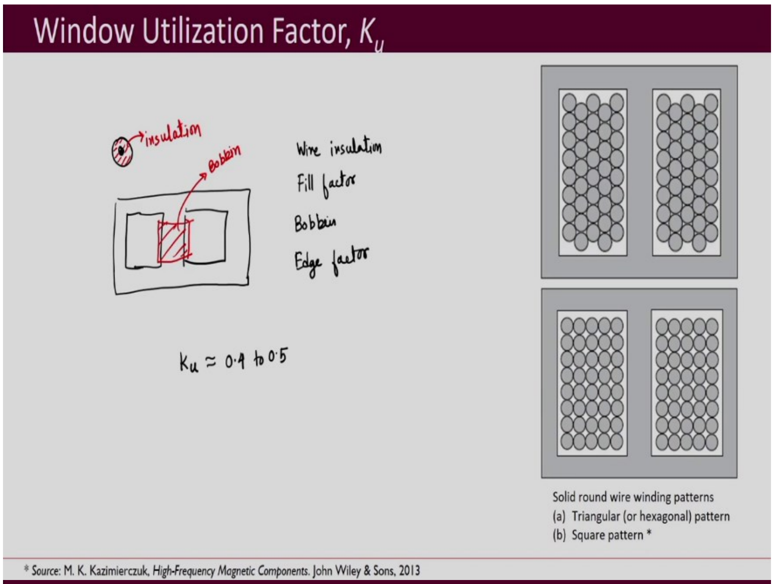


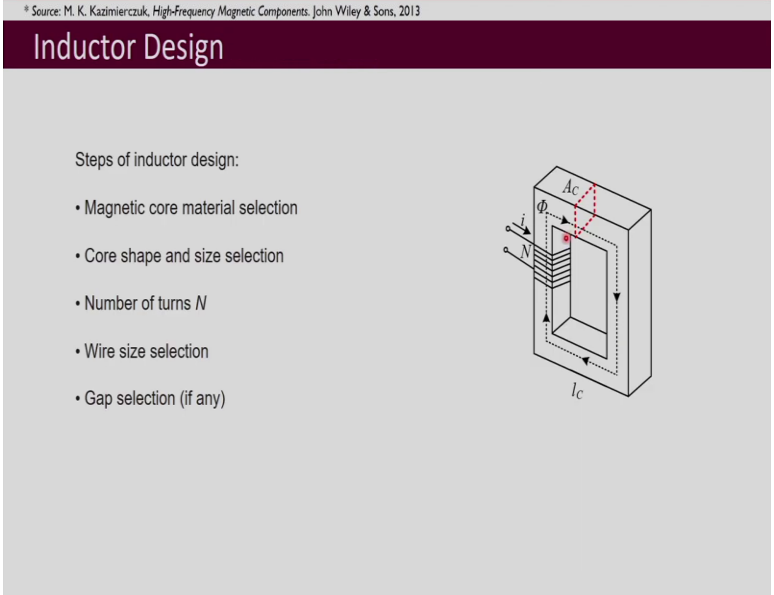
The main steps of inductor design are that first we choose the material. We have discussed the magnetic core material selection in length. So, it depends on many things like the frequency of operation, the required saturation flux density, the permeability and several other factors. So, depending on that we first choose the magnetic material. Now, once you have chosen the magnetic material, you choose ferrite. So, then now with that you will also have an idea of the magnetic flux density or the saturation flux density.

So, you will also be having some idea of the permeability, the range of permeability and the frequency up till which you can use that material. So, based on your need, you choose the material. Once you have chosen, certain parameters are known to you for the inductor design. Then next is the core shape and size selection. So, also we discussed it that there are many different shapes and sizes of cores, which are available and there is no fixed choice for your need. So, depending on the power rating and the size of the inductance or based on it many times you may have an idea of type of core, shape and size to be suitable.

But looking at the charts, the different tables are provided by manufacturers and by doing calculations also you can choose core shape and then of course, the size of that particular shape. So, basically the inductor designing will involve the core and then you have to wind some wires, some conductors on it and it will be having some specific number of turns. So, we will have to decide the number of turns that is required and you also need to choose the wire size. We have discussed this also before that the wires are available in various size.

So, what should be the gauge of the wire which you need for the inductor design.You will be choosing that and for further air gap selection if you need an air gap for the particular magnetic design, then you may also decide the size of that or rather the length of that air gap.





So, let us go further on the magnetics design and for designing magnetics you should be knowing one important thing that is the window utilization factor. Now, what is this window utilization factor? So, this part or this opening in the core or the free space in the core is called as the window. So, this part is the free part, which is called as the window and we wind conductors through this window.

So, now that is the way, in which the wires are going to be placed. Let us say it is a solid round wire, which is going to be the case in most of the time. So, when you place them, you see that you can place it in this manner, where you can see that these are two conductors placed side by side. In between there is another conductor and then like that there is one conductor over here placed like this.

So, this is kind of a triangular or a hexagonal pattern in which the conductors may be packed inside the window. Now, we all want magnetics to be as small in size as possible. So, therefore, we would like to utilize this window area to the fullest. So, that means, we would like to fill this to the maximum extent as possible, but then these are solid wires and if you have a rectangular frame like this, then obviously, you cannot fill the entire area. Because in between also you can see here that there will be some gaps over here, which will be left out.

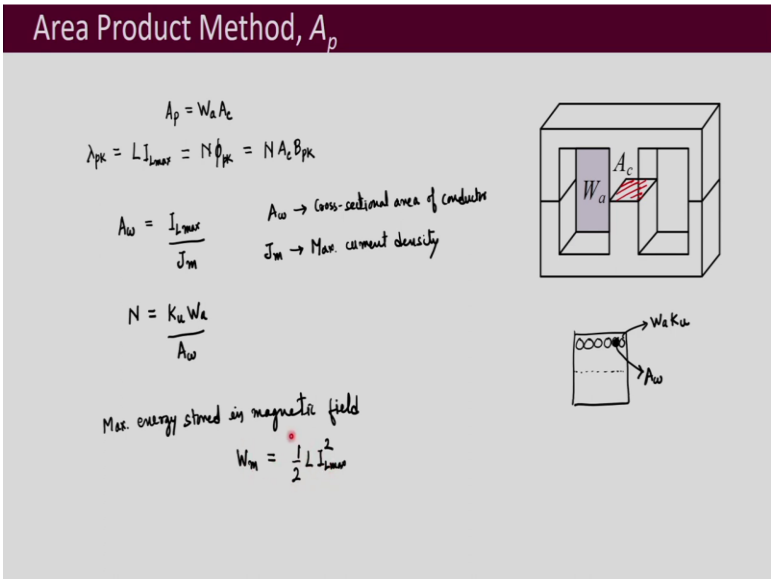
Now, this is one hexagonal pattern, and there could be another pattern which could be like square pattern. You can place the conductors in this way exactly one on top of each other. In that case also you can see that there will be gaps in between and so, those areas cannot be filled by the conductor. So, you can see that area is wasted. So, this is more tight packing as compared to this square pattern. Now, irrespective of which pattern you use, you have to note down that you cannot fill the entire area because you have a round conductor and so, when you place it obviously, some of this space is going to be unutilized.

Apart from that further, you will have the insulation of that conductor. So, this is the conductor inside. So, further in outside area, you will have the insulation. So, this red part is the insulation. So, again that insulation is not contributing to the actual making of the inductor, or I mean for achieving that inductance value it will not contribute. So, then that again can be considered as a space which is unutilized because of the insulation of the conductors, and mostly we will not be using bare conductors. We may be using insulated conductors. So that for insulation its diameter will also lead to some unutilization of the window area.

Apart from that, I had also shown the bobbins previously. So, if this is the window area of the core, then we have seen before here that on the top of it, you will be placing a bobbin. So, that bobbin will also take some space. So, this is the bobbin and I am just showing one part of it. So, that bobbin will also take some space and so that space is also not going to be utilized. Further at the edges or corners also we cannot fill it up and that will also lead to some unutilization of the window area.

So, there are different factors, such that the wire insulation, then the fill factor which you cannot really fill it completely because of the round wires and then the bobbin, for further the edge factors, cannot fill it at the edges. So, like these four there may be other factors as well. So, because of it some of the window is not utilized.

So, this factor is called as the window utilization factor, that means how much of the window area actually we will be able to utilize for making of the magnetics and this is represented as by the symbol K_u and most of the time, these values are taken between *0.4-0.5*. *0.4* is a very good choice and very common choice for the window utilization factor that means we can actually use *40%* of the available window area for the magnetics design.



Next, let us discuss one of the very commonly used methods for the magnetic design which is called as the area product method, it is a very popular method. So, in this case we do a product of this window area, and this window area is represented as W_a and this cross-sectional area A_c. So, this is the cross-sectional area of the core.

So, this cross-sectional area A_c, which is multiplied by the window area. So, area product is defined as

$$A_p = W_a A_c$$

So, now, the peak flux linkage

$$\lambda_{pk} = L\, I_{Lmax}$$

where L is the inductance that you need and I_{Lmax} is the maximum average inductor current for which the inductor has to be designed.

So, we can write it as

$$\lambda_{pk} = L\, I_{Lmax} = N\, \phi_{pk} = NA_c\, B_{pk}$$

A_C is the cross sectional area of the core. Further A_w which is the cross sectional area of the conductor is going to be

$$A_w = \frac{I_{Lmax}}{J_m}$$

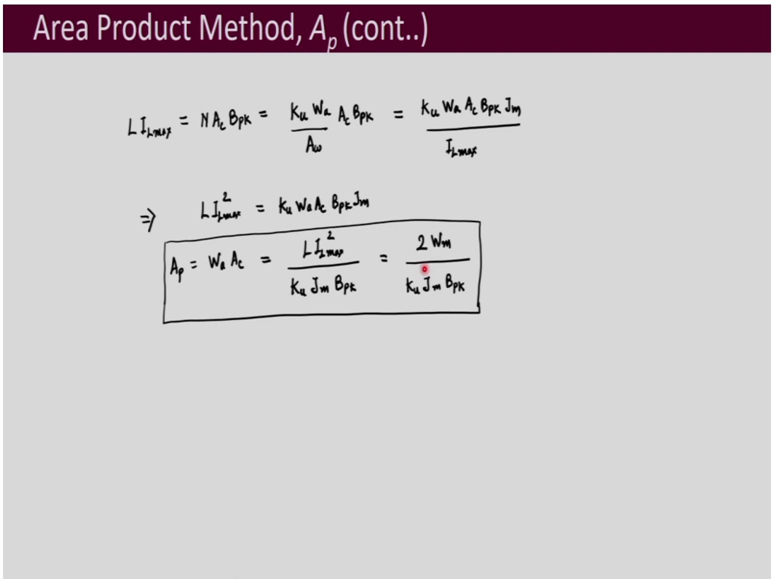
Now, A_w is the cross sectional area of conductor, J_m is the maximum current density. So, further we can write for the number of turns

$$N = \frac{K_u\, W_a}{A_w}$$

Now, from where are we getting this? Now, suppose this is the window area W_a. Now we know that only a part of it can be actually filled because of these different factors that are involved. So, we have the available window area for actual inductance making and that will be K_u into W_a and this is the cross-sectional area of the conductor, A_W. So, when we divided K_u W_a by A_w, we will be obtaining how many number of turns N can be put inside the window area. Further for the maximum energy stored in magnetic field we denote by

$$W_m = \frac{1}{2} L\, I_{Lmax}^2$$

This is the maximum magnetic energy that is going to be stored by that inductor.



So, now further we can write

$$L I_{Lmax} = N A_c\, B_{pk} = \frac{K_u\, W_a}{A_w} A_c\, B_{pk} = \frac{K_u\, W_a\, A_c\, B_{pk}\, J_m}{I_{Lmax}}$$

$$\Rightarrow \quad L\, I_{Lmax}^2 = K_u\, W_a\, A_c\, B_{pk}\, J_m$$

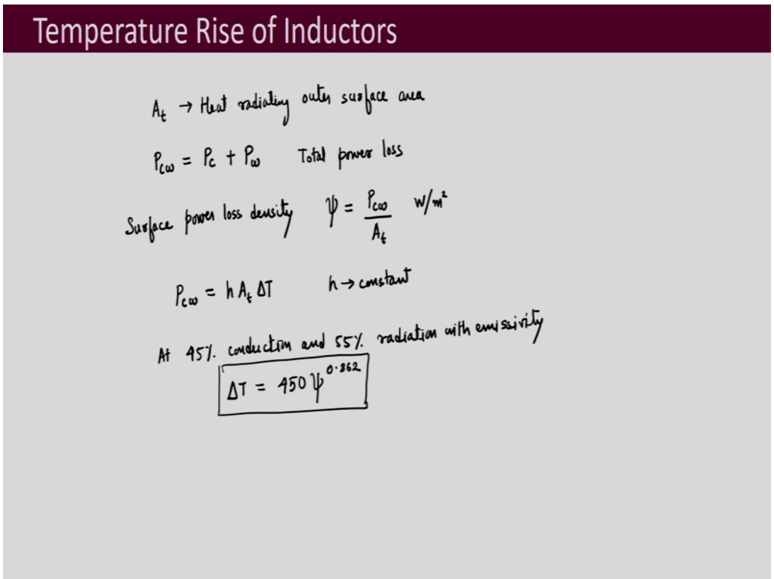
Now, area product

$$A_p = W_a A_c = \frac{L\, I_{Lmax}^2}{K_u\, J_m\, B_{pk}} = \frac{2 W_m}{K_u\, J_m\, B_{pk}}$$

So, this is the equation for the area product. So, from this equation you observe that, this term, area product is inversely proportional to J_m, which is the current density of the conductor and also inversely proportional to peak value of flux density.

We see that this area product is directly proportional to the magnetic energy stored. So, this gives that the area product term which contains the current density term as well as the magnetic flux density, its peak value and it also contains the saturation which means the magnetic stored energy. All these three are presenting in area product term.

So, this is the term which is first calculated and then from the manufacturers data sheets, we see the area products of the cores that they are manufacturing and from then we choose a core which has got area product close to our calculation. So, then when we previously saw the magnetic cores, we discussed. I showed you that manufacturers provide the area product for the core shape and size that they are manufacturing.



In the next let us discuss the temperature rise in the magnetics design. Now, you know that the losses taking place in any magnetics are basically the losses. Those are because of the copper loss and the core loss. So, that is a loss and ultimately it has to get dissipated as heat. So, that heat is to be going through dissipated or radiated through the surface area of the core. So, that's why the temperature rise of the magnetics is calculated using the surface area of the core which is selected. So, let us look into the expression for the temperature rise.

So, let us say the heat is radiating outer surface area for a particular core and P_{cw} is the total core loss which is the sum of the core loss and the copper loss, which is the total power loss.

$$P_{cw} = P_c + P_w$$

Now, we define the term which is called as the surface power loss density. It is denoted by this symbol and given as

$$\psi = \frac{P_{cw}}{A_t} \quad W/m^2$$

So, the temperature rise corresponding to this loss,

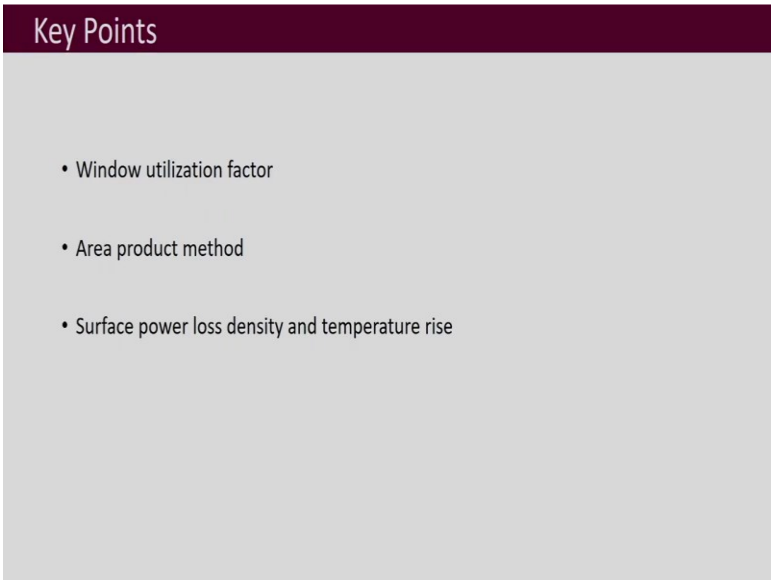
$$P_{cw} = h\, A_t\, \Delta t$$

Now, h is some constant. Now, we will not be discussing in this course from where are we getting this equation. Just take it that you can write this loss as equal to hA_t into ΔT. So, at *45%* of conduction and *55%* radiation with emissivity this temperature rise is

$$\Delta T = 450\, \psi^{0.862}$$

This is the equation for calculation of the temperature rise. So, this equation is important when you select a core and you will be getting this outer surface area A_t. This either will be provided by the manufacturer or you can calculate it yourself using the dimensions of the core.

Once, you know A_t, then you can calculate the surface power loss density based on your calculation of the total power loss and from there you can estimate the temperature rise of the magnetics design. This is very important that you should calculate the temperature rise. Because if the temperature rise of the designs are too high, then that will lead to damage of the magnetics. So, it is not a proper design. So, we will have to redesign with the bigger core. So, when you design a magnetics, you should be calculating this temperature rise to know whether they are under limits or not.



So, the key points of this lecture are that there is one term which is window utilization factor in magnetics design. It is basically the total area actually being utilized for contributing of magnetics design. Then, we are discussing the area product method in this course, for design of magnetics. There are other methods also. But, we have taken up this area product method and then you should also have an estimate of a temperature rise and other important terms associated with the temperature rise is the surface power loss density. Thank you.