CHARGING INFRASTRUCTURE

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Week-09

Lecture-45

Lec 45: Transformer Design for Isolated DC-DC Converter-II

Hello everyone, welcome to the lecture number 45 of this NPTEL lecture series on charging infrastructure and today we will continue our discussion on transformer design what we have started in the last lecture. So, in the last lecture we have seen different you know basic principles related to transformer some of the basic principle which actually help us in defining the different parameters which are used for physically realizing the transformer. then we have seen the losses associated with it there we have seen we have two kinds of losses core loss and winding loss or you can say copper loss and in the core loss again we have seen there are two kinds of losses we have seen hysteresis losses and our eddy current losses both losses we have seen and we have seen in what on what factors those on what parameters those losses depends And since the eddy current and hysteresis losses cannot be measured separately or it is difficult to segregate them, that's why the manufacturers generally provide

$$P_{core} = K_{core}(\Delta B)^{\beta} A_c L_c$$

where this is nothing but the volume of the core.

So generally they provide a curve in the data sheet of core material they will provide a curve indicating core loss per unit volume per unit volume they will say generally defines watt per centimeter cube in watt per centimeter cube it is generally logarithmic curve where both the x and y axis have been indicated in the logarithmic manner and on the right hand side we have on the x axis we have ΔB which is peak of the ac flux magnetic flux density So, that is for different ΔB, we will get different, you know, core loss per unit volume of the core and then for different frequencies, this curve will be plotted and then, you know, depending upon your frequency of operation of your system, you can select, you know, you can also select what will be the frequency of operation of your system and you can also select what is the peak magnetic flux density and accordingly, you can select the core loss per unit volume in the core made up of that core material and then from that once you realize what will be the different core dimensions you can calculate the core volume and there from there you can predict the core losses. So, this is what we have seen in the last class again it depends this particular expression is for a particular for a particular sinusoidal excitation frequency sinusoidal excitation frequency and it may vary for different, you know, for different frequencies, these curves for different frequencies, these traces, you know, for different frequencies.

So, for one particular frequency, the value of the constant K_{core}, which is nothing but a constant, it depends upon the, for different frequency of excitation, this K_{core}value will be different. Now if you see in order to realize physically realize the transformer our main outcome will be i mean while doing the design the outcome will be you know the size of the core which includes core cross section area we have represented by ac the window area we will see later it will be defined by wa we will also see what you mean by window area then mean length per turn which is given by you know generally abbreviated in the form of MLT we will also see what do you mean by MLT and magnetic path length which is given as you know l_c as of now what we have discussed then we have number of turns again for different windings it will be different so it will define an N_1 ,$N_2$and so on let's say there are K-number of findings. so, it will be up to N_k And then finally, one should be able to understand what will be the size of wire, that means what will be the cross-sectional area of the wire which is being used. Obviously, mostly it will be the copper wire having enamel coating to provide the required isolation.

Then we also need to calculate the peak flux density we also must know what will be peak flux density because depending upon peak flux density our core loss and and our winding loss are dependent on this peak flux core peak flux density and we have to now select the optimum value of peak flux density such that these obviously system should must not go to saturation the peak flux density should be well within the maximum saturation value of the magnetic flux density for that particular material and at the same time swing in the bh curve is enormously larger so we must have the considerable amount of core losses and considerable amount of winding losses considerable amount of winding losses. So, thus we have to find the optimum value of this peak flux density which ensures that both the core loss and winding flux or you can say the total loss in the transformer is as minimal as possible. So, then we have understood in order to identify these things, there are some quantities which we will get it from the specification. We will see what are those quantities. Along with that, there are other quantities which has to be determined by first principle.

So for that, we have defined our core loss, which is

$$N_1 = \frac{\lambda_1}{2A_c \Delta B}$$

And then we have defined the ΔB, which is the peak flux density expression. This will give my number of turns to be $\frac{\lambda_1}{2}$ ΔB A_c, where A_c is the angle of cross section of the core. So, this maximum flux density must be ensured that it is must be equal to this swing in the BH loop will be such that the ΔB which we will get must be equal to $\frac{\lambda_1}{2}$ N_1 A_c.

$$\Delta B = \frac{\lambda_1}{2N_1 A_c}$$

and it should obviously make sure the $\Delta B < B_{SAT}$. So that means accordingly we have to select the number of turns such that this ΔB is well within the B_{SAT} value at the same time this ΔB the swing in the flux density must have the optimum value of this maximum flux density swing or you can say the peak value of this magnetic flux density so the transformer has multiple windings and which are wound over the core and this winding assume we have. let's say k-number of windings in a transformer so that we can make it more generalized case. So assume you know we have k-number of windings and they has to be accumulated in the entire window area and that window area this is given by W_a . Now what is this window area we see this is nothing but the area where you know all these windings sits or all the turns in the winding sits. So, if you see from this side it will have something like you know it will have something like this this is nothing but the hash portion if you see from this side the hash portion is nothing but the called as the window area and that window area is given by W_a. So, this is for A_u core you kind of core, now one example of that you know i can show one example on that, so if you look this particular transformer we have the core as i mentioned we have the core. So these are E-core when you keep two E course, it will looks like you know it will complete the entire core and then this is the thing this white color thing is nothing but the bobbin over which this this particular core is been mounted again this is non-metallic made up of non-metallic material and now if you look very carefully it is this area which is nothing but the window area you can say where our windings is actually residing or you can say winding you know you put a winding in this.

And then you take down on this side, and then again take it up, and then again take it to this side. So, it is this area and this area which actually constitute the window area. So, this is actually one of the windows, and it can house a maximum—I mean, x number of turns—with a particular size of copper wire. So, that is why it is this area which is called the window area. In an E-core, you have two windows, and both the windows have the same area, the same value of area. In the case of a C-core or U-core, you have just one window, which is shown over here in this particular—this is the window area we are talking about. Now, since we have K-number of windings, we need to accommodate them in this entire window area W_a.

So, now we have to allocate the fraction of the window area for each winding, and let us take that fraction to be termed as gamma. Now, this gamma j is nothing but the fraction of the window area in the entire window area W_a which is allotted to winding number j. So, for example, assume let us say we have— K-windings which are being put in here. So, these are the turns of those individual windings which are there—the individual copper wires which are going and then coming back. This is the second turn, third turn, fourth turn, like that. Turns are being placed, and out of this entire window area, we have defined only the fraction of that particular window area which is allotted to winding one, and that particular area— We can define it to be nothing but that fraction is nothing but $\gamma_1 W_a$. Similarly, for winding 2, if we take, we have allotted only this particular portion, and that we can define to be $\gamma_2 W_a$. And then we can define this for winding J, which is $\gamma_J W_a$, and this is for winding K, it is $\gamma_k W_a$. In the entire window area, we have defined some portion to winding 1, some portion to winding 2, and so on, some portion to winding K, and that particular portion is defined as nothing but $\gamma_1 W_a$, γ_2

W_a, and so on. Now, this fraction, which is nothing but gamma, has to satisfy a certain condition. Now, this gamma—

Assume for a generalized winding J, this fraction allotted to winding J should be between 0 and 1. That means when gamma becomes 0, it indicates that there is no area which is allotted to that Jth winding, which is not the case because generally, when we have windings in our transformer, there will be some number of turns corresponding to that winding. So, some amount of area has to be allotted to that particular winding. So, that is why this γ_J has to be greater than 0. At the same time, we cannot make $\gamma = 0$, because the moment we give $\gamma = 1$, that means we are now allotting the entire W_a or entire window area to that particular winding, and that shows that we do not have any other winding in the transformer. Generally, we have at least two windings in our transformer, so the γ value has to vary between 0 and 1. Now, this J—here we can write for winding number 1, 2, 3, and so on, going up to K. So, this is what we have understood. Now, at the same time, what we can say is that the summation of all those fractions of the window area allotted has to be equal to 1 because we can write down that

$$\gamma_1 + \gamma_2 + \ldots + \gamma_K = 1$$

$$\gamma_1 W_a + \gamma_2 W_a + \ldots + \gamma_K W_a = W_a$$

because the fraction of window area which is related to individual windings has to sum up and become equal to the window area itself. So, this entire summation, when we do it, becomes equal to the window area, which indicates when we remove this W_a term,

$$\gamma_1 + \gamma_2 + \ldots + \gamma_K = 1$$

which is what we have written over there, so γ must satisfy two conditions one is obviously it should be $0 < \gamma < 1$ and the summation of all the individual gamma that means individual fraction of the window area allotted to individual winding has to be equal to 1 that means summation of fraction of the window area allotted to individual winding has to be equal to 1. Then so, if we try to define the you know copper loss we know that the windings have copper loss and that can be defined as $I^2_{rms}R$ of the winding which is been offered by the winding. So, we can write the copper loss in jth winding depends upon the rj which is the resistance of that jth winding and this rj if we neglect the AC effects I mean high frequency AC effect we neglect the high frequency AC effect which are you know which are you know skin effect and proximity effect if we neglect that then our resistance of the winding is given as rho Lj by Awj where Awj is the cross section of the wire used in the jth winding. Lj is the length of the wire used for wound the winding j. And rho is the wire resistivity. Generally, if you take a copper, so that material has the wire resistivity, which again depends upon the temperature of operation in which temperature you are keeping it. And you have this Ij, which is nothing but the RMS value of, you know, current in the winding j. So, this is the RMS value of current, which is flowing in the Jth winding. So, we can define the copper loss in the jth winding to be I square R

$$Pcu_{1j} = I_j^2 R_j$$

$$R_j = \rho \frac{l_j}{A_{wj}}$$

where I am nothing but the RMS current flowing in the jth winding.

Now, we can also define the length and cross section of the wires which are used in different windings as you know let us define the length and cross sectional area of the wire used in let's say winding J to be this length of the wire Lj we can define it to be

$$L_j = N_j(MLT)$$

Nj multiplied by MLT now this MLT is nothing but mean length per turn and this is nothing but number of turns of the Jth winding where we can say that the Lj is nothing but the length of the wire which is being used to wound the winding J is the length of wire used for Jth winding. Similarly, we can also say that the cross section area of the wire, let's say if you are using the circular wire, then this is nothing but the area of cross section of that particular wire. Assume for the jth winding is nothing but equal to the amount of the window area which is been given multiplied by the fraction of allotted area to the jth winding multiplied by there is a factor which is

$$A_{wj} = \frac{W_a \gamma_j k_u}{N_j}$$

k_u and then this is divided by N_j where again N_j is the number of turns the W_a is the window area γ_J is the fraction of the window area allotted to winding j and k_u is nothing but a factor which is called as the window fill factor. So we can say that this is the area of cross section section of the wire in jth winding W_a is nothing but the window area γ_J is nothing but the fraction of window area allotted to Jth winding and N_j is nothing but the number of turns of jth winding and this k_u is nothing but is the winding fill factor, now this winding fill factor $k_u < 1$, why because the reason of introduction of this winding fill factor is nothing but we have the copper wire which we are using to wound the winding and that copper wire is having the enamel coating and so whenever we are accumulating those wires within that window area there are some portions which we will not be able to use and this is because windings have enamel coating and once you wound one of the turns and you are placing the next turn then you will not able to use the exact space in the window area plus the winding conductors are circular in nature so they are not able to completely take up the window area so that's why there is a term called as the winding field factor.

And also if you see, you know, when you have the circular conductor which are being placed nearby each other, so there is some area which is not being utilized, you know, this particular area which is not being utilized and that will nothing but contribute to the winding field factor and this winding field factor is obviously less than 1. And generally, as per literature, this winding field factor is nothing but equal to $k_u = 0.5$ for low voltage, round wire conductor it is equal to $k_u = 0.65$ for low voltage foil winding that means whenever you are using foil to bound the particular winding also this $k_u = 0.1$ for high voltage transformer winding. So now if you look very carefully, we have understood all the terms which are given over there. But one term which is the mean length per turn is something which we have to obtain or which we have to have the understanding that what is the meaning of this mean length per turn.

So now let us see and understand what is the meaning of mean length per turn. Now if you look very carefully, it is this area through which the windings are bounded, through which the windings are placed. In this area, the windings are being placed. one turn is going into it and then coming back from the other side comes out and then the second turn comes goes into it from the other side comes out and then this is the area where your windings are being made and if you take the bobbin you know the same bobbin we are showing over here the you know the this bobbin will look something like this from here my core goes in if you are having EE core one of the middle leg if you are having a EE core so if this is the if this is our EE core so the middle leg is actually going through the space provided in the middle the other side legs will be going through this place these are for side legs and this is for middle leg

It is going through this particular area. And if you look very carefully, windings will be bounded in this way, in this direction. One turn comes there, from there comes here second turn, third turn. So, if we see from the top side, it will be something like, it will look like this. We have this middle area, which is this area we are talking about, this free area we have, where our E core central leg will go into it.

And then you are putting winding. So let us take winding. So the first winding will be, you know, will be bounded in this manner over this one. The winding will be bounded like this, first winding. And then you have second winding, you have third winding, fourth winding.

And it goes on. you know if you look from here from from this side so this is the place where you can place first winding first layer of winding then the second third fourth fifth and and it goes so on and finally at this place where our course side legs comes in till that point we will be placing the different layers of winding in this window area so that's why we have you know we have different layer from here to here and finally it is this area where our core side legs resides so this is core side legs so assume that worst case scenario our last winding will be placed our last winding will be placed obviously it will have some curvature last winding will be placed something like this and let us define this length to be let's say from the bobbin dimension you can easily get let us define this length to be you know to be E and if we take in this one so our mean length per turn will be somewhere it is this place where our mean the average value or you can say the mean value of the length of the turns first turn is here last turn is here which is you know up till the core side legs we have so let us define some of the dimensions and then try to write for the E core type of structure what will be the MLT so this is my E and here if you see this place where the our windings are bounded this particular winding generally has if you look very carefully this winding will be like you know you have a copper

Copper conductor over which you have the insulation layer, which is the enamel layer insulation, and let us take the length of this insulation layer to be I. I is the, you can say, width of the insulation layer over the copper. Copper winding which is over the copper. So, this is the copper conductor, actually. Now, let us say this is the dimension E. Let us take this dimension, which is going from here till this point, to be D. And then we can define, you know, assume we have this curvature here because, you know, windings when they are wound, they will look like curvature. Assume the radii of this curvature to be A. So, A is the radii of the curvature of the, you know, winding when it is wound. So, we have four this kind of area like this now.

In this winding also, if you see, in this winding also, it will have the copper in between and then you have enamel coating insulation, which is there, and this again has the width I, this insulation layer over the copper conductor. So, this also has the same kind of thing. So, then we can then find the mean length per turn. Which corresponds to this green color dotted line we have drawn. So, this mean length per turn will be, so if you look very carefully, this is my radii A, which is taking this curvature has radii A, and it is a quarter, you know, this is the four ends: one, two, three, four. So here we have four curvatures at the, which are, you can say, roughly at 90^{0}, you know, one, two, three, four at 90^{0}. So, we can say the length. Traveled by, or you can say traversed by, the curvature part.

You can just take 2π our radii, which is A, which has been given. It is 4 times, and since it is just traveling the quarter part, so it is divided by 4 we have. Now, if this is the length transferred by the curvature for the extreme winding, similarly, it will be the same thing for the nearest winding as well. So, we can say the mean length traversed by the curvature part. Will be equal to, you know, here we can just cut down this 4, 4, so we will get $2\pi A$ divided by 2, which will give us πA. So, in MLT, we can just write πA, which actually constitutes curvature part, the mean length covered by the curvature part of this winding, which is wound in the entire window area.

starting from the one side at the wall of bobbin on the other side the side legs of the core and here we have assumed if we see in all these considerations we have assumed that our windings are completely being covered in the entire window area we can say the window area is completely gets accommodated by the winding so that's the assumption we have taken now this will be nothing but so it is the first winding we can take so it is The 1 and 2, two side D. So, it is 2D plus if you see the insulation. So, it is here one insulation will come. Top one insulation will come. Bottom side two insulations will come.

So, it is 4I. This is the insulating part plus this side. So, this side we have taken because this side also is D. Now, we have to take the horizontal part which is nothing but 2E. One E this side, second E this side and then you have in this side you have insulation here, insulation here, insulation placed over here, insulation placed over here. So, it is 4 I we have got.

And since we have to do the mean length, so we can then, you know, this side we can take and this one side, second side we can take. Since we have one will be there on the inner side, another one will be at the outmost side. So it is multiplied by 2. And then finally, we have to take the mean value. So, it is divided by 2.

$$MLT = \pi A + \left[\frac{(2D+4I)+(2E+4I)\times 2}{2}\right]$$

Why is this 4 I there? Because, you know, generally the copper conductor will be there at the top. The copper conductor will be there at the bottom. This side insulation is there. This side insulation is there.

So, it is, you can say, first I, 2nd I, Three I, four I, and this is again, this is, you know, the bobbins' middle area having E. This thing, so I am drawing this part here. So, the windings will be going in this direction with the insulation at the top and the insulation at the bottom. So, this is nothing but the value of MLT. You can define this value of mean length per turn for the E-type of course, which are housed in this kind of bobbins. Similarly, for different kinds of cores like for PQ core, you can define the mean length per turn. So, like this, you know, one can define mean length per turn for that particular core size. Now, after defining our mean length per turn and our length of the wire, which is being used in the winding, and also defining the term area of cross-section of the wire.

Now, let us define our resistance coefficient. Of the jth winding. Now, this resistance we can write down to be, you know,

$$R_j = \rho \frac{L_j}{A_{wj}}$$

where A_{wj} is nothing but the area of cross-section of the wire which is being used to wound that particular winding, and L_j is the length of the wire which is being used in that particular jth winding. Now, this we know that $L_j = \frac{N_j}{MLT}$ is nothing but Nj times MLT, and we know that Awj is nothing but Wa Ku γj / Nj. So, we can then write our $R_j = \rho \frac{N_j^{\,2} MLT}{K_u \gamma_j}$ value to be. Now, the resistance what we obtain over here is neglecting the AC effect because if the AC effect comes into the picture, then you have to also consider this skin effect and proximity effect. But for simplicity, we are now just taking only the DC resistance part. So, the copper loss of the jth winding is nothing but Pcu_j is nothing but

$$Pcu_{1j} = \frac{N_j^2 I_j^2 \rho MLT}{W_a K_u \gamma_j}$$

Where I_j is nothing but the RMS current. So, then we can write once we know our copper loss which is happening in the jth-winding, we can then write the total copper loss of the k-windings to be equal to

$$P_{cu,total} = Pcu_{1j} + Pcu_{2j} + \ldots + Pcu_{Kj}$$

Now this when we put these values from this particular expression what we gonna get is

$$= \frac{\rho MLT}{W_a K_u} \sum_{j=1}^{k} \left(\frac{N_j}{N_1}\right)^2 \frac{I_j^2}{\gamma_j}$$

and then this particular expression we can then write down to be $P_{cu,total}$ is nothing

$$P_{cu,total} = \frac{\rho MLT}{W_a K_u} N_1^{\,2} \sum_{j=1}^{k} \left(\frac{N_j}{N_1}\right)^2 \frac{I_j^2}{\gamma_j}$$

$$\left[N_j = \left(\frac{N_j}{N_1}\right) \times N_1\right]$$

$$N_1 = \frac{\lambda_1}{2 \Delta B A_C}$$

and we can now write our Nj to be nothing but the turns ratio between the jth winding and the first winding or you can say the primary winding multiplied by number of turns in the primary winding and this is nothing but the turns ratio. which is given in the specification or you can obtain it from the specification or you can easily obtain it from the circuit operation so generally we will be knowing this turns ratio. So, from turns ratio we can equate this N_j to be equal to this multiplied by number of turns in the first winding because we don't know what is the number of turns in the different windings but we know the turns ratio and that we will see once we will see the procedure how to determine the transformer from there we can understand how we can obtain the turns ratio. So this particular part we can write rho MLT divided by wa ku we can input this value over here n1 square comes out and this will be nothing but j equal to 1 to k and j by N1 that is nothing but the turns ratio times ij square divided by gamma j where ij is nothing but your rms value of current in the jth winding and gamma j is nothing but the fraction of the window area which has been allotted to the jth winding.

$$P_{cu,total} = \frac{\rho MLT}{W_a K_u}\left(\frac{\lambda_1}{2\Delta B A_C}\right)^2 \sum_{j=1}^{k}\left(\frac{N_j}{N_1}\right)^2 \frac{I_j^2}{\gamma_j}$$

Now if you look very carefully this$P_{cu,total}$ in this particular part when we plot this particular copper loss with respect to γ_1 just with respect to the fraction of area allotted to the first winding when we do so what we will see is that the copper loss corresponding to the winding one is actually infinity when this $\gamma_1 = 0$ it is actually saying that when the $\gamma_1 = 0$ the area allotted to the winding one is equal to zero that means you can say that the area of cross section of the wire which is being used is zero. so that means the area of cross section of the wire is actually zero. So, we can say that our core loss for the winding one, that means Pcu_1 is actually very large. And the moment it reaches to $\gamma_1 = 1$, this particular copper loss becomes smaller because $\gamma_1 = 1$ indicates that the entire window will be allotted to the winding one.

That means we can now use the thicker conductor and that is when our heliocrossing of the wire increases and that is when our copper loss reduces because value of DC resistance reduces. So, what we can say is that from this one that the Pcu_{1j} with respect to γ_1 varies like this. At the same time when we are making the γ_1 reaches to 1 what it indicates the value of γ_2 to γ_3 to γ_k is actually going towards 0 or you are reducing those values that means the amount of area allotted to the winding 2 3 4 up to k is actually very less and that's when we have to use very thin wires and which indicates the higher amount of dc resistors and thus our copper loss in other windings will be more so we can say that summation of other copper losses is actually rising like this we can say this is nothing

$$P_{cu,total} = Pcu_{1j} + Pcu_{2j} + \dots + Pcu_{Kj}$$

it actually rising with respect to the γ_1 or you can say the area allotted to the winding one now if you do the summation the total copper loss if you see it will be something like you know going down and then again going up this is nothing but your pcu total and this particular point where it is you know minimal value is nothing but γ_1 optimum value

That means there will be one point, γ_1 optimum point, where you have the minimum total copper losses. Similarly, you can obtain the γ_2 optimum value, γ_3 optimum value, and so on. So, one must do a certain kind of optimization. It could be linear optimization or some advanced algorithms of optimization and can obtain what could be the minimum or optimum value of γ_1. For that, your total copper loss is minimal.

So, that is the first optimization which you have to do now to ensure you have the minimal copper loss. That means you have to obtain the optimum value of the fraction of winding allotted in the window edges such that the total copper loss is minimal. Similarly, you will get different gamma values such that the total copper loss will be minimal. So, this particular expression we can now use in our maximum flux density expression. That means we can now put

$$N_1 = \frac{\lambda_1}{2\Delta B A_c}$$

and that will give you nothing but

$$P_{cu,total} = \frac{\rho(MLT)}{w_a k_u N_1}$$

$$\lambda^2 = 4\Delta B^2$$

And a law of cross-section of the core going into 1 to k and then turns ratio, which is the specified value given the specification I_j^2/γ_j . If you look from this particular expression, what it indicates is our $P_{cu,total}$ is actually inversely proportional to the ΔB^2. Using this particular expression, if we see. So, we will get our total copper loss is inversely proportional to ΔB^2, and at the same time, one has to do the optimization to obtain the optimum value of γ_1 , γ_2 γ_3 , and so on up to γ_k . That means the optimum value of the fraction of the area allotted to individual K windings. So, we have seen the core loss and the winding copper losses or the copper losses which are happening in the winding. So, we can now write the total power loss in a transformer, which is comprising of the core and the winding, is nothing but $P_{total} = P_{core} + P_{cu,total}$.

That means the core loss which is happening in the core and the winding loss which is happening in the winding due to the resistance of the winding. So and we know that from this particular expression that our core loss is nothing but proportional to $P_{core} \propto (\Delta B)^{\beta}$ where $\beta$is the material property varies between 2.5 to 2.7 value and we have the total copper loss which is nothing but

$$P_{cu,total} \propto \left(\frac{1}{\Delta B}\right)^2$$

so when we see when we plot our losses with respect to ΔB or with respect to the peak value of ac flux density what we will see is that our P_{total} our our copper loss a total copper loss is is reducing with the ΔB with the variation one by ΔB^2 while on the other hand our P_{core} is kind of is increasing with the with the increasing the value of the ac flux density and which is nothing but ourP_{core} . So, when we do summation of that to obtain the overall total loss you know, so this is nothing but our p total we will see that there is some minimum value of this P_{total} and that particular point is nothing but the optimum value of ΔB. so, what we see when we increase the delta b our core losses increase while our copper losses reduce.

$$\frac{d(P_{total})}{d\Delta B} = 0$$

$$\frac{d(P_{total})}{d\Delta B} =- \frac{d(P_{cu1,total})}{d\Delta B}$$

However, there is an optimum value of ΔB_{opt} for where the total loss which is combining of the core loss and the winding copper loss is nothing but the minimum value and that is what one need to find so we need to find optimum value of ΔB for which our P_{total} is minimum. And one way by which you can do is you can then differentiate this P_{total} with respect to ΔB by representing that in the form of ΔB, the P_{core} and $P_{cu,total}$. And then you can equate it to zero. So that implies my, you know, variation of P_{core} with respect to $\Delta B = - P_{cu,total}$.

So from this particular expression when we differentiate this we will and equate to 0 we will get this particular expression and when we will solve this particular thing will result in ΔB optimum value and we can then use this ΔB optimum value is used to obtain the P_{total} minimum or P_{total} minimum or you can say minimum value of value of total transformer losses or total losses in the transformer. So, this indicates that we have to then do the second level of optimization where we have to find out the optimum value of ΔB which will give you the minimum total loss in the transformer.

So in these two lectures what we understood is that there are some understanding we have obtained which is nothing but our P_{core} or you can say the core loss of the in the transformer is nothing but we obtain that expression $k_{core} \Delta B^{\beta} A_c l_c$, second we have obtained the $P_{cu, total}$ value which is again proportional to $\left(\frac{1}{\Delta B}\right)^2$ and we have obtained maximum ac flux density or the maximum value of this flux swing we obtain as

$$\lambda = \frac{1}{2N_1 A_c}$$

and we know that you know we have to do two level of optimization in first optimization we have to obtain the optimum value of γ_1 , γ_2 going up to γ_k optimum value that is first optimization one has to do and then you have to do the ΔB_{opt} optimization such that this particular lead to the minimum total loss in the transformer where this one will give you the minimum copper loss in the transformer winding. so one can use this particular optimization some advanced level optimizations or some simple optimizations to obtain the optimum value of

ΔB and and the optimum value of γ_1 , γ_2 γ_3 , γ_k and this optimum value of ΔB we can then use it to obtain the required number of turns for the primary winding and then using the turns ratio we can obtain the number of turns in different winding. So this is what we have understood and we will develop the steps to physically realize your high frequency transformer model or high frequency transformer. So, we will define the steps following which one can physically realize the transformer.

Thank you very much for patiently listening to this lecture. We will meet you in the next lecture.