EE 564-REPORT OF PROJECT 1

Inductance and Transformer Modeling

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Contents

INTRODUCTION

In this project, it is asked to design and analyze an inductor wrapped around a toroidal core and a high voltage high power transformer. In the inductor design part; linearity of the core, homogeneity of the flux distribution, existence of air gap and fringing flux effect are investigated. On the other hand; effects of varying number of turns and type of the core material are investigated in terms of power loss and cost, in the transformer design part.

Q1) Inductor Design

It is chosen the core with manufacturer part number, 0079439A7 , which is a member of the Kool Mµ MAX family by MAGNETICS. The Kool Mµ MAX is the optimal solution for high efficiency, high power inductors with its high DC bias and low core loss density. Note that the relative permeability of the selected core is 60 for the linear region. In order to have the ability of investigating nonlinear (saturation) characteristic of the core, B-H curve of the selected core is obtained using the manufacturer fitting formula. Using the datasheet and the figure 1, 45.79 AT/cm is used as the linear operating point. Aiming to have rated 10 A DC current, the number of turns is obtained as 49 using the formula, "$N*I_{dc} = H*L_e$".

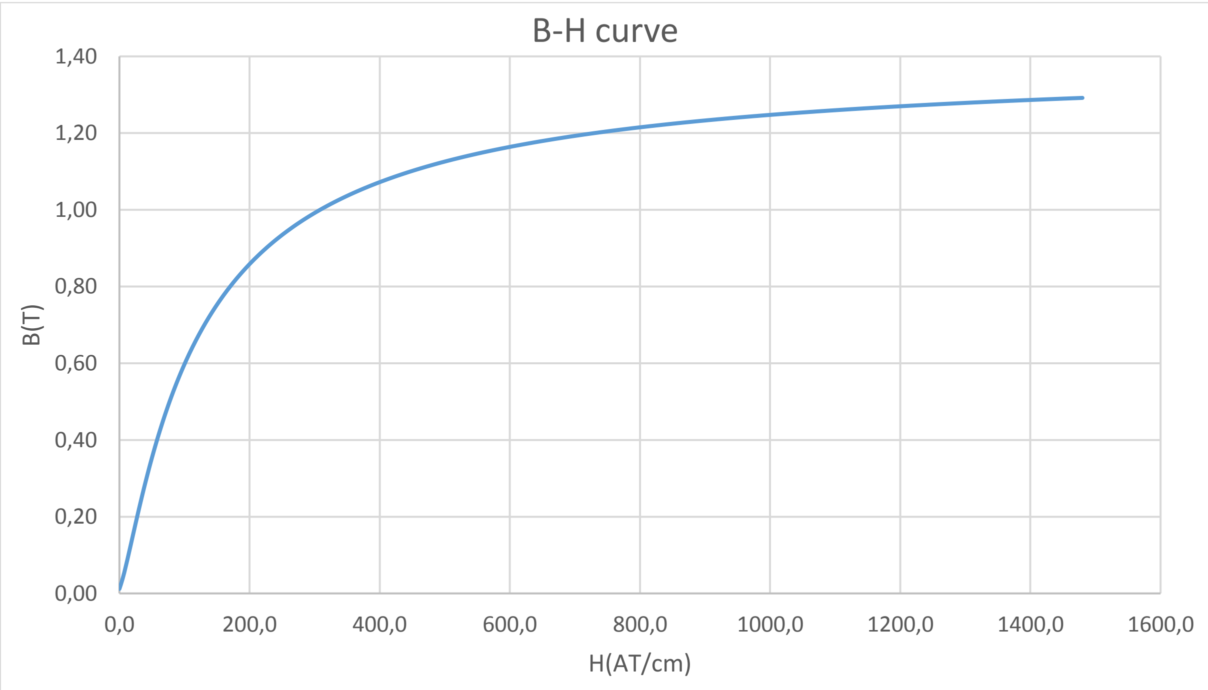

Figure 1 : B vs H curve

Part-A Analytical Calculations

In the analytical calculations;

Inductance is calculated by the formula $L = N^2/R$, where reluctance $R = L/(\mu * A)$.

1-)

The inductance of the coil assuming the flux is homogeneously distributed, and there is no leakage flux, and the core is linear (i.e. constant permeability $\mu_r = 60$) is calculated as 336.5 µH.

2-)

The inductance when the flux is NOT homogeneously distributed, and there is no leakage flux, and the core is linear (i.e. constant permeability $\mu_r = 60$) is calculated as 335.5 µH. Non-homogenous distribution is taken into account by discretized the core into 11 rings. Then, the reluctances for each rings are paralleled, and the equivalent reluctance is calculated.

3-)

Assuming the core is non-linear and the DC current is increased by 50% (i.e. dc current $I_{dc} = 15$ A); the inductance is calculated as 298.2 µH when the flux is homogeneously distributed and the inductance is calculated as 297.4 µH when the flux is NOT homogeneously distributed. Non-linearity is taken into account by using the B-H curve in the figure 1.

4-)

The inductance of the coil assuming the flux is homogeneously distributed, and there is no leakage flux, and the core is linear (i.e. constant permeability $\mu_r = 60$), and there exist a 2mm air-gap in the toroid, and there is NO fringing flux is calculated as 160.03 µH. Existence of air gap is taken into account by obtaining the reluctances of core and air-gap. Then, the reluctances are connected in series, and the equivalent reluctance is calculated.

5-)

The inductance of the coil assuming the flux is homogeneously distributed, and there is no leakage flux, and the core is linear (i.e. constant permeability $\mu_r = 60$), and there exist a 2mm air-gap in the toroid, and there is fringing flux is calculated as 208.3 µH. Existence of fringing flux is taken into account by increasing the area in the calculation of air-gap reluctance. In common sense, a good approximation to consider the fringing flux is to extend the side length of cross sectional area of the core as the length of air-gap.

Q2) Transformer Design

Table 1 & 2 & 3 show the given information for analysis of the transformer design and optimization study.

S	HV	LV	Freq	temp(-30 , +50) (Cooling ONAN) => J A/m^2	Fill Factor
500000	34500	25000	50	3000000	0,30

Table 1 : Transformer operating specifications and characteristic properties

	op B(T)	H(A/m)	u-r	core_loss W/kg (0,95 W/kg @ 1 T)	Lthickness(m)	d(kg/m^3)	cost ($/kg)
steel=>	1,2	1000,0	955,414013	1,368	0,000350	7850	3

Table 2 : Steel core specifications and characteristic properties

	ρ(ohm m)	α per degree C	d(kg/m^3)	cost($/kg)
copper=>	0,0000000168	0,003860	8940,0	7,1

Table 3 : Copper cable specifications and characteristic properties

With the given data, power losses and corresponding efficiencies, and costs are calculated using the attached excel file.

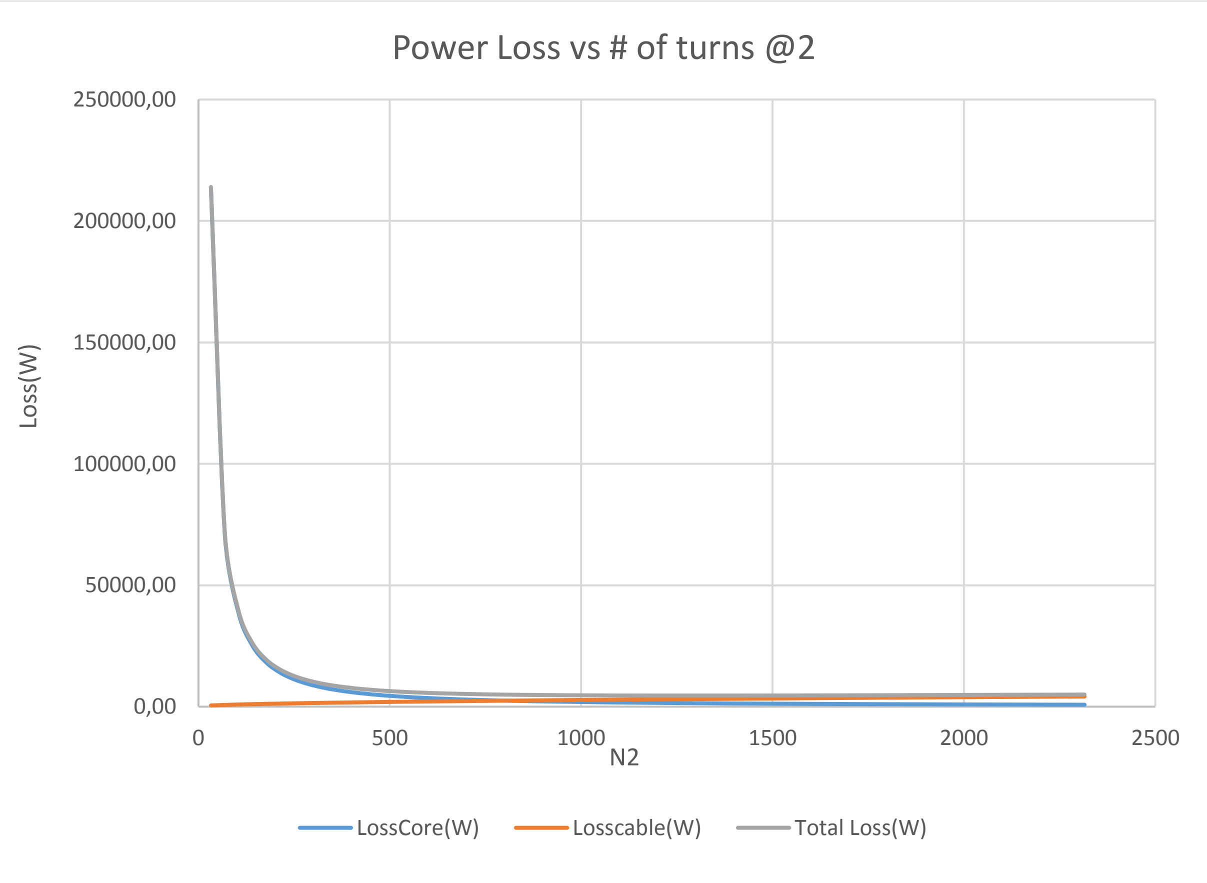

Figure 2 : Power Loss vs number of turns at low voltage (second) side

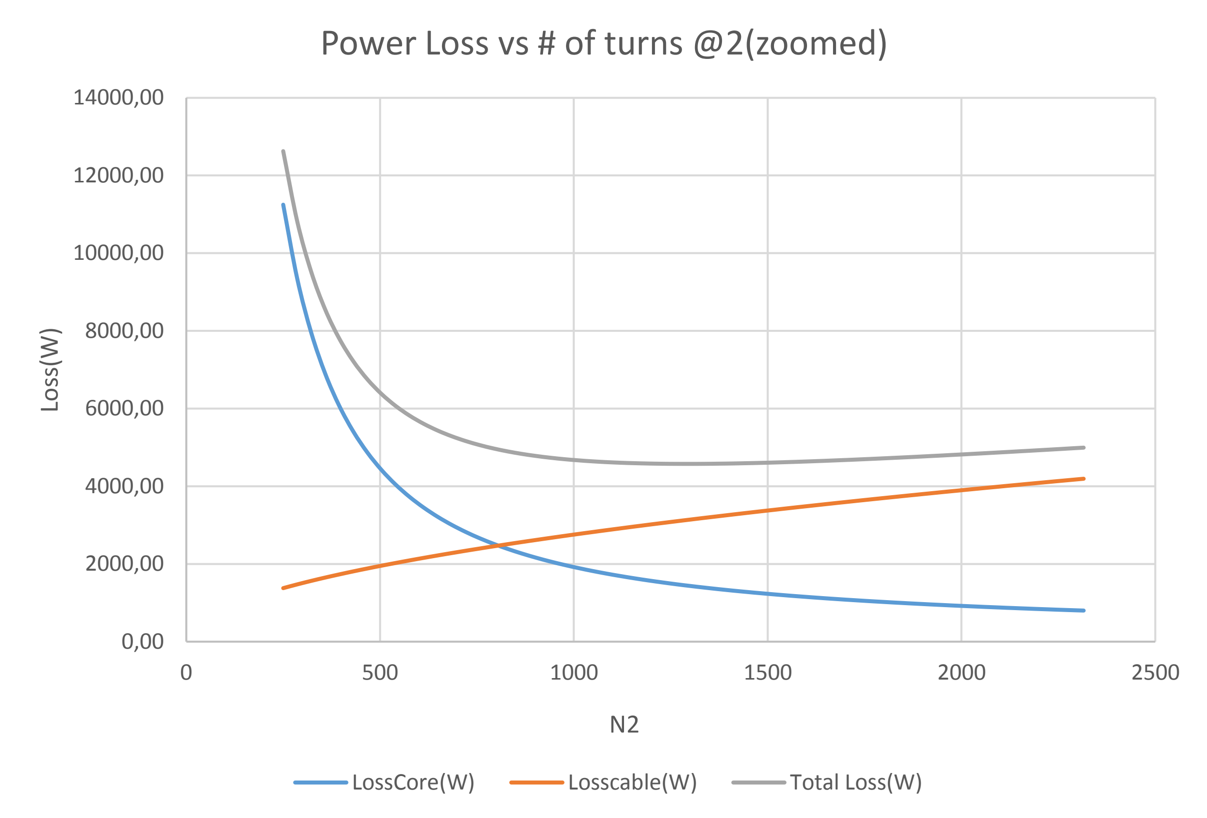

Figure 3 : Zoomed - Power Loss vs number of turns at low voltage (second) side

In Figures 2 & 3, it can be seen that total power loss is decreased to almost minimum value of it when the number of turns at low voltage side (N2) is greater than ~750. Notice that it is a good way to try to get equal core and copper losses in terms of efficiency, which is a very common sense. In the analysis, core and copper losses become almost equal to each other when N2 = 793 > 750. The Figures 2 & 3 also show that highest efficiency is reached with N2 = 1301.

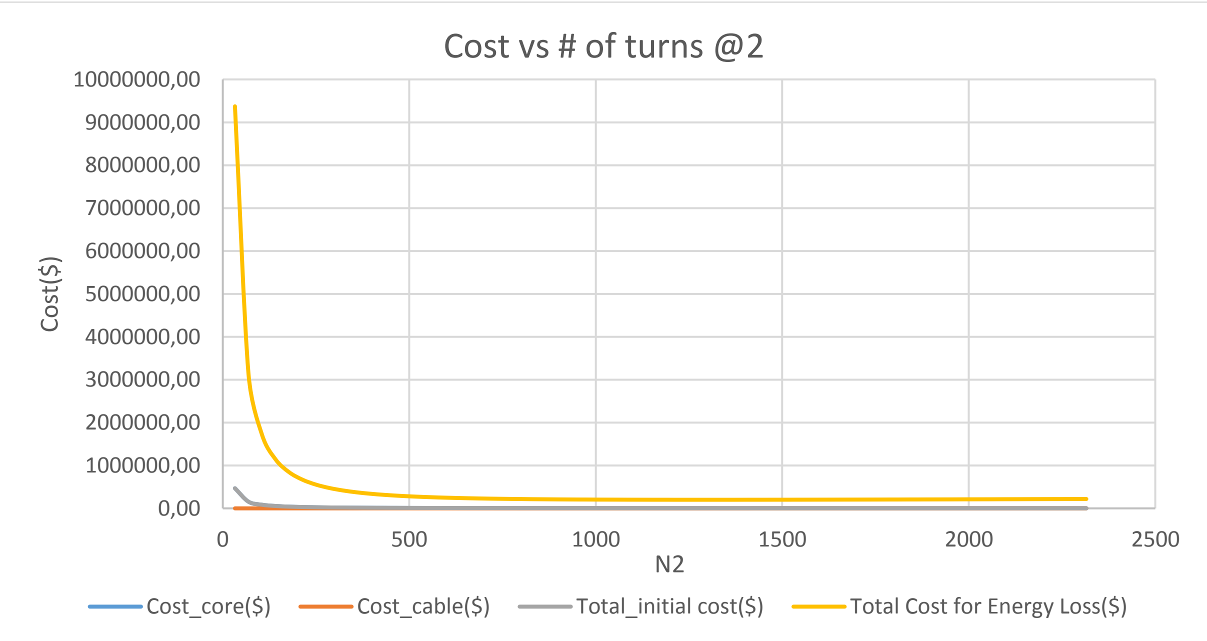

Figure 4 : Cost vs number of turns at low voltage (second) side

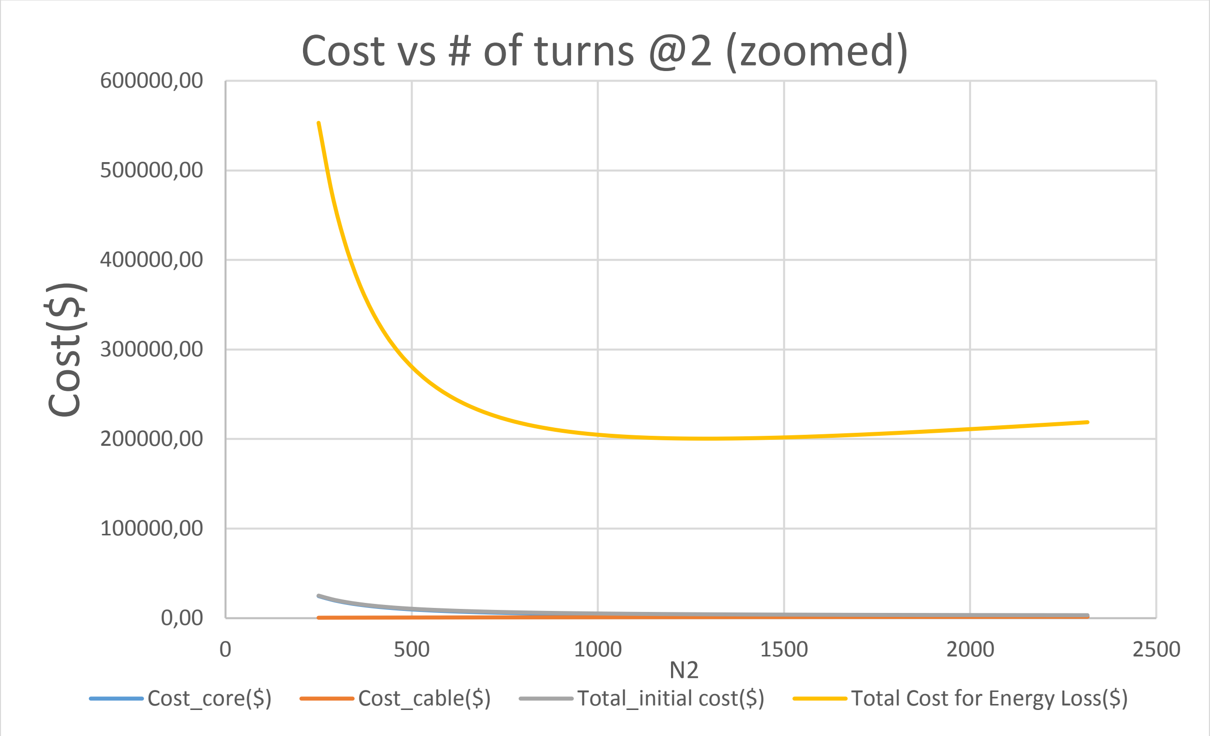

Figure 5 : Zoomed_1 – Cost vs number of turns at low voltage (second) side

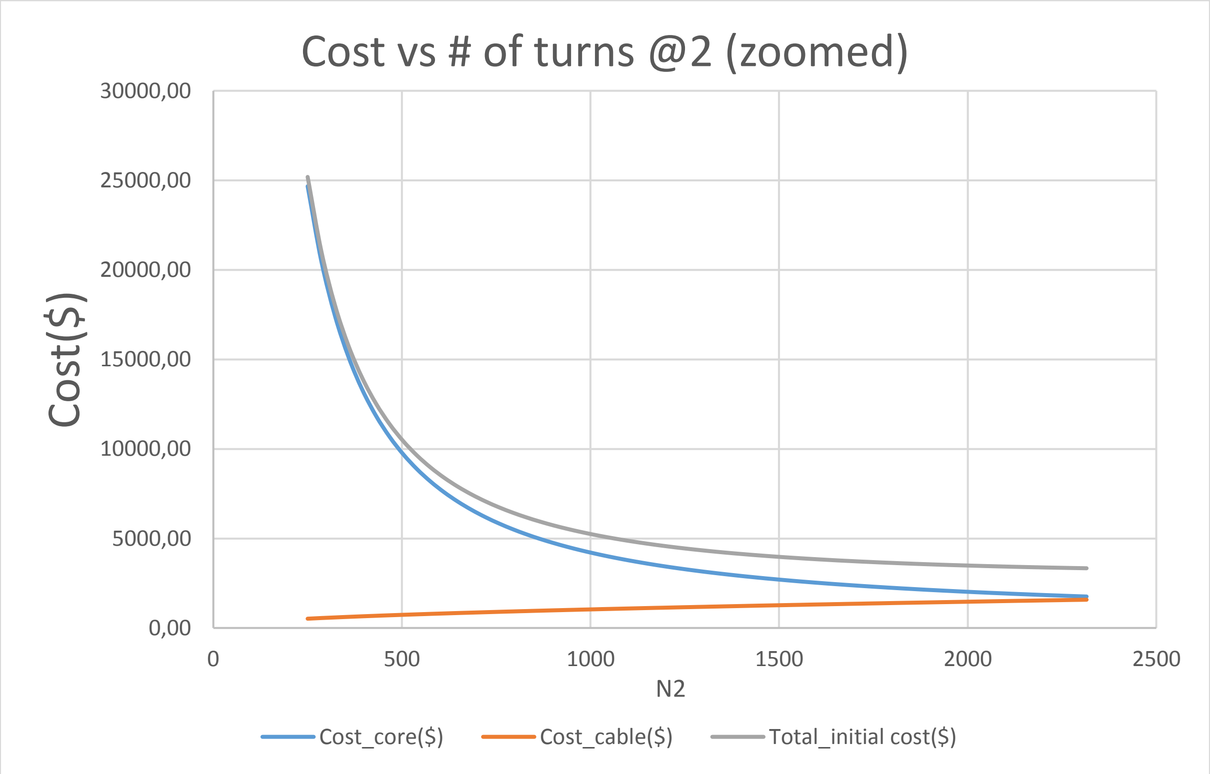

Figure 6 : Zoomed_2 – Cost vs number of turns at low voltage (second) side

In figures 4 & 5, it can be seen that total cost for energy loss calculated assuming 25 years operating duration is much higher than the total initial cost specially at smaller turn numbers. Notice that total cost for energy loss has exatly the same behavior with total power loss as expected. Also, Figure 6 shows that total initial cost is decreased to almost minimum value of it when the number of turns at low voltage side (N2) is greater than ~1250.

CONCLUSION

In the inductor design part, it is observed that the effect of homogeneity is slightly small where the effect of linearity is significantly large. We could observe this fact where the DC current is increased by 50%, because we have chosen an operating point just close to saturation with DC excitation. Therefore, one should choose the operating point carefully and take into account non-linearity of the core in analysis. On the other hand, it is an acceptable simplification to assume homogeneous flux distribution in analysis. In addition, existence of air-gap increases the reluctance significantly, so inductance drops to lower values. When an air-gap exists in the core, it is important to take into account the fringing flux in analysis.

In the transformer design part, making a design with smaller than a certain number of turns may cause dramatic problems like very high power loss and cost is understood. Therefore, it has high importance to investigate the turn number effects in transformer design. Although the cost and core loss of cable are increased with increasing turn number, the core loss and cost at smaller turn numbers are much higher than the ones of cable at higher turn numbers. As a result, observing that total cost for energy loss is much higher than total initial cost, one can optimize the design selecting the turn number(N2 = 1301) which results highest efficiency.