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Supervising the Stacking Factor and Magnetic Flux Density: An Effort to Reduce the Loss of Distribution Transformer

Nahid Hasan, Navila Rahman Nadi, Mustafa Ahmed Haroon, Munem Aziz Akik

Dept.EEE, United International University, Bangladesh, uiu022071002@gmail.com
Dept.EEE, Independent University, Bangladesh, n.rahman387@gmail.com
Dept.EEE, Islamic University of Technologies, Bangladesh, legnatheblue@yahoo.com
Dept. EEE, Ahsanullah University of Science & Technology, Bangladesh, munem26@yahoo.com

ABSTRACT

This study represents an analysis and comparison of the practical framework of several factors such as-design, weight and losses formed in the conventional transformer of same KVA rating. This paper not only signifies the designing frame out factor (i.e. core diameter) but also the calculation of copper weight with loss effects. Magnetic flux density (B_m) and Stacking factor(S_f) is considered as the most significant part of this factor which reduces the loss and cost for same rating transformer (i.e. 200KVA). The Cost of optimized transformer designs varies even though it's in the same conventional transformer rating where as the efficiency is nearby identical.

Keywords: Stacking Factor (S_f) Magnetic Flux Density (B_m), Total Core loss (L_{TCO}) , Total Copper loss (L_{TCP})

1. INTRODUCTION

In Bangladesh most of the cases, the 11/.415 KV transmission line is used by the consumers and in such cases the rated transformer is chosen as 200KVA rather than others. The modern transformer design involves modification of its size, loss, efficiency and cost respectively. Transmitted, distributed and utilized electric powers of electric and electronic circuit devices are varied by the wide ranging of designed transformer [1]. In this paper we have examined two dry types' transformers having a same rating of 200 KVA. Based on this we have set two models named by Model 1 (M_1) and Model 2(M_2). M_1 and M_2 is notified by the core diameter of winding as 15.2 cm and 15.6 cm correspondingly whereas the rating of transformer and transmission line is same.

While maintaining BPDB's (Bangladesh Power Development Board) guaranteed frequency, we initiate the manufacturing design of the transformer is exaggerated by the two factors: Magnetic Flux Density (B_m) and Stacking Factor (S_f).

1.1 Evolve of Magnetic Flux Density (B_m)

Magnetic flux density concept of transformer is espoused from the principal of transformer which reveals the electric current can produce a magnetic field whereas the other states that a changing magnetic field within a coil of wire induces a voltage across the coil end. Magnetic flux is developed by the change of the current in the primary coil [2],[3],[4]. This magnetic flux is the product of B_m and the area through which it cuts. At this juncture, Flux and B_m are related by area [4]. Whereas the cross sectional area is equal to the transformer core, the magnetic field varies with time according to the excitation of the primary coil. So, B_m also varies due to a slight variation in the magnetic field [4]. In practical cases, it's been observed that this slight change in B_m can make a huge impact on core area of the transformer as well as in the loss and cost.

1.2 Perception of Stacking Factor (S_f)

Generally, *Stacking factor* has an impact on core area of winding. In manufacturing, S_f varies for some individual specifications (i.e. the thickness and type of steel) of each size lamination [5]. Usually the manufacturers try to keep the S_f below 1 hence, there is no lamination. On the basis of each coating lamination eddy current loss of core gets reduced although it's has a high flux carrying capacity [6],[7]. And these variations in laminated coat can have an effect on manufacturing.

2. SCRUTINY OF SAME RATED TRANSFORMER

The loss, efficiency and cost of a transformer vary due to its designing factors of manufacture even though it's being in a same transmission line and of same rating. Assumption of cost simply depends on the designing factor, according to our notion we have elected two models which we have disclosed earlier.

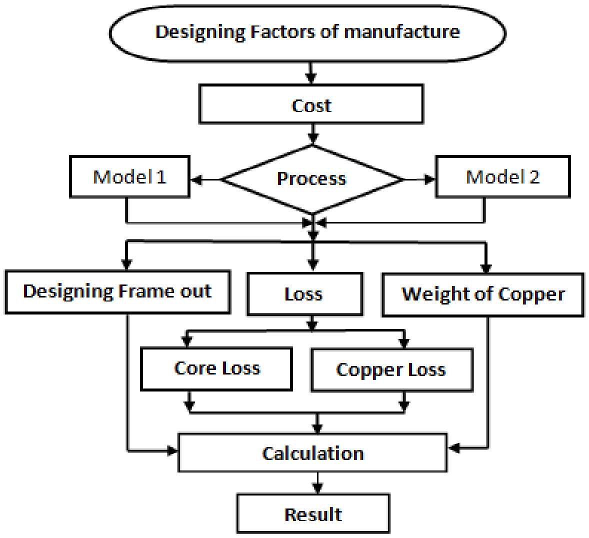

Figure 1: Designing factors of manufacturing

Figure 1 shows that these models are processed inherit on three factors (i.e. designing frame out, Loss and Weight of Copper). From this we can conclude to our result which divulges whether it is cost effective or not. Those factors are briefly discussed furthermore.

2.1 Feature of Designing Frame out

The different manufacturing features opt for customers' requirement. Figure 2 shows the operation of designing frame out factor.

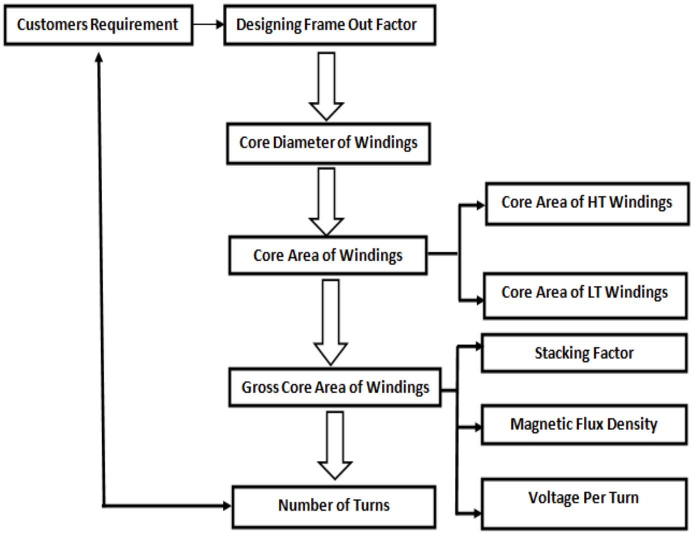

Figure 2: Designing Frame out Factor of a transformer

Due to the requirement of customer we get to know about the rating of transformer and transmission line. According to those values, voltage per turn is being set. From this we can find the gross core area. While calculating the gross core area, it's been seen that gross core area depends on B_m and S_f. Afterwards the net core area is linked by the gross core area and S_f. Therefore, we find the diameter (i.e inner and outer) of core winding. The core diameter increases when there is a gradual increase in the area. As well as the Loss, Efficiency and cost also increases [8].

From this analysis we observe that the core area is inversely proportional with S_f and B_m.

$$A \propto \frac{1}{B_m} \text{ and } A \propto \frac{1}{S_f}$$

That means when B_m decreases the core area increases gradually which makes an impact on loss, efficiency and cost. Same goes for S_f.

From our specified models we found that the core area of $M_1 = 181.12\ cm^2$ and $M_2 = 193.01 cm^2$ whereas in both cases B_m=1.7, S_f =0.96 and S_f =0.93 correspondingly.

2.2 Impact of copper weight of transformer

The Copper weight increases when the core area of winding gets expand. This copper weight makes an impact on loss, efficiency and cost including payback of transformer. In this section, the cost of copper winding is expressed as a function of copper weight which is directly related with the transformer windings (i.e. LT and HT windings). In M_1 and M_2, we found that the total weight of copper is 130.79 kgs and 133.37 kgs respectively.

2.3 Behavior of Losses (Copper and Core)

We originate that, the *Copper Losses* are summarized by the windings due to getting different values of copper weight for our models in previous section. We sum up the copper losses from measuring winding (i.e. LT and HT) losses separately. These losses were cross product by the temperature factor through which we ascertained L_{TCP} that are 2687.32 and 2709 watts (respectively) for our mentioned models.

N.B: BPDB's guaranteed copper loss is 2820 watts at 75^0 Celsius and the manufactures try to maintain their ratings close to it.

In the case of *Core Losses*, by the cross product of total core weight, loss and workman ship per kg. The total weight of core is the summarization of weight of yoke and limb. These weights of yoke and limb depend on basically window height, maximum yoke length and core area. Here, core losses for $M_1 = 379.50$ watts and M_2 =399 watts.

N.B: BPD**B**'s guaranteed copper loss is 2820 watts at 75^0 Celsius and the manufactures try to maintain their ratings close to it.

At last, through adding up the copper and core losses the total loss of transformer is found. In this case, 10% tolerance is taken as granted.

3. ESTIMATION OF DESIGN CONCERN

In the basis of our two models according to the methodology we compute the following factors:

A. Designing frame out factor

Voltage per turns,
$E_t = K\sqrt{KVA}$ (volts)

Gross Core Area,
$A_g = \frac{E_t \times 10000}{4.44 \times f \times B_m \times S_f} (cm^2)$

Net Core Area,
$A = \frac{A_g}{S_f} (cm^2)$

Core Diameter,
$D = \sqrt{\frac{4 \times A}{\pi}}$ (cm)

Here,
$K =$ Constant (0.4 to 0.45)
$KVA =$ Rating of Transformer
E_t = Voltage per turns
$f =$ Frequency
B_m = Flux density
S_f = Stacking factor

Now,
LT coil inside diameter,
$D_{LTI} = D + Clearance\ between\ core\ to\ LT\ coil$ (cm)

LT coil outside diameter,
$D_{LTO} = D_{LTI}$ + ($Thickness\ of\ LT\ strip \times 8$) + ($Insulation\ of\ strip \times 8$)+ $Gap\ between\ two\ layer\ of\ LT\ coil$ (cm)

HT Coil inside Diameter,
$D_{HTI} = D_{LTO} + Gap\ between\ LT\ to\ HT\ coil$ (cm)

HT Coil outside diameter,
$D_{HTO} = D_{HTI} + Thickness\ of\ HT\ coil$ (cm)

Mean diameter of (LT+HT) Winding,
$D_{MW} = \frac{Inside\ diameter\ of\ core + Outside\ diameter\ of\ core}{2}$ (cm)

Window height,
$H_W = Actual\ copper\ height + Border\ of\ coil + Gap\ between\ coil\ and\ core\ youke$ (cm)

Maximum yoke length, L_{MY} = (2× Limb center + maximum width of core) (cm)

B. Copper Weight extent

Length of mean turns, $L_{mt} = D_{MW} \times \pi$
Weight of Winding per Phase, $W_p = L_{mt} \times a \times T \times D_C$
Total weight of winding, $W_{wt} = W_p \times 3$
Total weight of Copper = Total weight of (HT +LT) windings per kg
Here, $a =$ Area of copper
$T =$ No. of turns
D_C =Density of copper

N.B: This calculation is applicable for both LT and HT windings.

C. Loss

Total loss is computed here through summarizing the copper and core losses together.

Copper Loss
Resistance/ Phase R = $\frac{\rho L}{A} = \frac{r \times \pi \times D_{MW} \times T}{A}$ (Ω)

Loss/Phase =$I^2 R$ (Ω)

Total loss in 3 Ǿ = $Loss/Phase \times 3$ (watt)

Total Copper loss= Copper loss in (HT+LT) windings (watts)

Total Copper loss at 75^{0}C, L_{TCP} = $Total\ copper\ loss \times K$

Here, r = 0.019 (resistance/m^2)
Key factor, $K = 1.161$

Core Loss
Weight of Yoke, $W_{yk} = L_{MY} \times A \times 2 \times S_f \times 7.16 \times 10^{-3}$ (kgs)
Weight of limb, $W_{lm} = H_W \times A \times 3 \times S_f \times 7.16 \times 10^{-3}$ (kgs)
Total weight of core,$W_{cr} = W_{lm} + W_{yk}$(kgs)

Total Core loss, $L_{TCO} = W_{cr} \times 0.9 \times 1.45$ (watts)

Here, Core loss per kg = 0.9 watt
Workman ship per kg =1.45 watt.

Total loss = $L_{TCP} + L_{T}$

4. NOTEWORTHY IMPACT

In this paper, we appraise the impact of S_f and B_m by fixing the core diameter (in case of M_1 and M_2). From the following Table1, we can distinguish the variation of B_m from 1.7-1.5 along with the range of S_f from 0.99-0.93 for fixed core diameter.

Table 1: Attributes of fixed diameter

SI No	Magnetic flux (B_m)	Stacking factor (S_f)	Core Diameter (D)
1	1.7	0.96	15.2
		0.93	15.6
2	1.65	0.97	15.25
		0.95	15.6
3	1.6	0.99	15.2
		0.96	15.6
4	1.55	0.98	15.6
5	1.5	0.99	15.6

Figure 3 describes the characteristics of S_f *and* B_m. To keep the diameter fixed, at 10% (almost) change of B_m, S_f changes in a rate of 3 %.

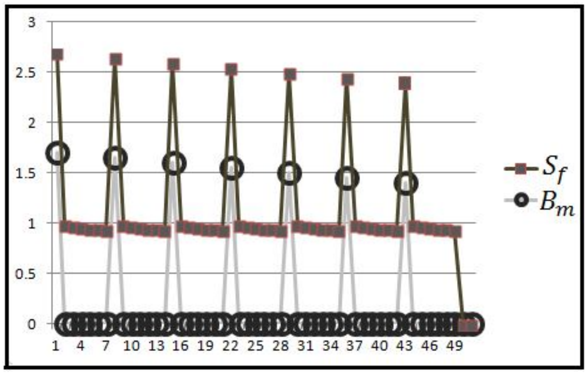

Figure 3: Characteristics of S_f and B_m

Core diameter, D will be decreased at that point when S_f gets increased. We observe this phenomenon from the following Figure 4. When S_f *is nearest* to 1, D must be decreased that means the lamination of core is contaminated.

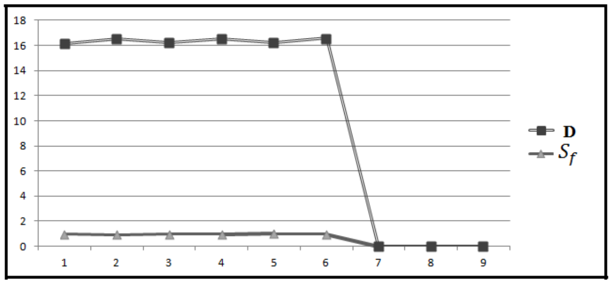

Figure 4: Emphasis of S_f upon D

In earlier section we have observed the effects of S_f and B_m on particular diameters. Also from this we analyze that the net core area and gross core area changes due to S_f and B_m consequently core diameter is calculated from the net and gross core area. The following Table 2 shows the fact.

Table 2: Impact of A_g and A on D

SI No	Magnetic flux (B_m)	Stacking factor (S_f)	Gross Core area (A_g)	Net Core area (A)	Core Diameter (D)
1	1.7	0.99	168.61	169.86	14.7
		0.98	170.33	173.81	14.8
		0.97	172.09	177.41	15
		0.96	**173.88**	**181.12**	**15.2**
		0.95	175.71	184.95	15.3
		0.94	177.58	188.91	15.5
		0.93	**179.496**	**193.01**	**15.6**
2	1.65	0.99	173.73	175.48	14.95
		0.98	175.5	179.08	15.1
		0.97	**177.31**	**182.79**	**15.25**
		0.96	179.16	186.63	15.42
		0.95	**181.04**	**190.57**	**15.6**
		0.94	182.97	194.65	15.74
		0.93	184.94	198.86	15.91
3	1.6	**0.99**	**179.156**	**180.96**	**15.2**
		0.98	180.98	184.67	15.3
		0.97	182.85	188.5	15.4
		0.96	**184.75**	**192.45**	**15.6**
		0.95	186.69	196.51	15.8
		0.94	188.68	200.72	15.9
		0.93	190.71	205.06	16.1
4	1.55	0.99	184.94	186.81	15.4
		0.98	**186.82**	**190.63**	**15.6**
		0.97	188.75	194.59	15.74
		0.96	190.71	198.66	15.9
		0.95	192.72	202.86	16.1
		0.94	194.77	207.2	16.24
		0.93	196.87	211.69	16.42
5	1.5	**0.99**	**191.1**	**193.03**	**15.6**
		0.98	193.05	196.99	15.8
		0.97	195.04	201.07	15.9
		0.96	197.07	205.28	16.1
		0.95	199.15	209.63	16.3
		0.94	201.26	214.11	16.5
		0.93	203.43	218.74	16.6
6	1.45	0.99	197.69	199.69	15.9
		0.98	199.71	203.79	16.1
		0.97	201.77	208.01	16.3
		0.96	203.87	212.36	16.4
		0.95	206.01	216.85	16.62
		0.94	208.21	221.5	16.8
		0.93	210.44	226.78	16.99-17
7	1.4	0.99	204.75	206.82	16.2
		0.98	206.83	211.1	16.3
		0.97	208.97	215.43	16.5
		0.96	211.14	219.93	16.7
		0.95	213.17	222.38	16.8
		0.94	215.64	229.4	17
		0.93	217.96	234.36	17.2

5. CONCLUSION

Figure 5 pretends the block diagram of variable dependency on loss upon cost. From this diagram we can understand that the characteristic of loss, payback & efficiency and cost which are merely dependent on S_f *and* B_m for our precise models. Whereas we saw S_f, loss and cost will be decreased hence B_m, payback & efficiency is saturated or vice versa.

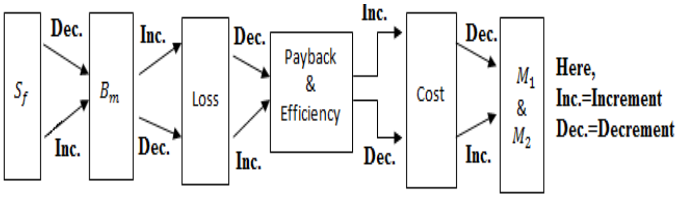

Figure 5: Emphasis of S_f upon D

From Table 3, we summarize that, for M_1 due to a change in B_m and S_f the core loss as well as the total loss varies. In the followed equation we sum up the core losses with the copper losses of the value 2867.32 (watts). On this basis, we found the variation of total loss.

Table 3: Impact of Core Loss for M_1

Core Diameter (D)	Magnetic flux (B_m)	Stacking factor (S_f)	Core Loss (L_{TCO})
M_1 15.2 cm	**1.6**	**0.96**	**391(watt)**
	1.65	**0.97**	**386(watt)**
	1.7	**0.96**	**379(watt)**

$$Total\ \ Loss, L_{M_{1A}} = 2867.32 + 3 = 3078.32\text{(watts)}$$
$$Total\ \ Loss, L_{M_{1B}} = 2867.32 + 3 = 3073.32\text{(watts)}$$
$$Total\ \ Loss, L_{M_{1C}} = 2867.32 + 379. = 3066.82\text{(watts)}$$

For M_2 due to a change in B_m and S_f the core loss as well as the total loss varies which has disclosed in Table 4. In the followed equation we encapsulate the core losses with the copper losses of the value 2709 (watt). We found the variation of total loss based on this.

Table 4: Impact of Core Loss for M_2

Core Diameter(D)	Magnetic flux (B_m)	Stacking factor (S_f)	Core Loss (L_{TCO})
M_2 15.6 cm	**1.6**	**0.96**	**410.67(watt)**
	1.65	**0.95**	**402.42(watt)**
	1.7	**0.93**	**399(watt)**

$$Total\ \ Loss, L_{M_{2A}} = 2709 + 410. = 3119.67\text{(watt)}$$
$$Total\ \ Loss, L_{M_{2B}} = 2709 + 402. = 3111.42\text{(watt)}$$
$$Total\ \ Loss, L_{M_{2C}} = 2709 + 3 = 3108\text{(watt)}$$

According to our calculation we found the variation of total losses. Here, we concoct that if we set S_f as 0.96 whereas B_m in the range of (1.6-1.7), loss will remain same. Hence, we can get an average quality of efficiency with minimum cost including minimum losses.

$$L_{M_{2A}} - L_{M_{1A}}\ 3119.67-3078.32=41.35\text{(watt)}$$
$$L_{M_{2B}} - L_{M_{1B}}\ 3111.42-3073.32=38.1\text{(watt)}$$
$$L_{M_{2C}} - L_{M_{1C}}\ 3108-3066.82 =41.18\text{(watt)}$$

ACKNOWLEDGEMENT

To implement our concept we used practical data and assembled two same rated transformer models for same transmission line having same no of turns while the core diameters is different.

REFERENCES

1. G. Builder, I. C. Hansen and F. Langford-Smith. **Transformers & iron-cored inductors**, *RCA, Radiotron Designers Handbook, 4th ed., ch. 5.*
2. Mauricio Valencia Ferreira da Luz and Patrick Dular. **Analysis of High Frequency power Transformer Windings for leakage Inductance Calculation**, *GRUCAD/EEL/CTC, CP, 476, 88040-900, Florianopolis, SC.*
3. Guemes-Alonso, **J.** Antonio**. A New Method for Calculating of Leakage Reactances and Iron Losses in Transformers,** in *proc. Fifth International Conference on Electrical Machines and Systems, 2001. ICEMS 2001 , vol.1,* pp.178-181 vol.1, 18-20 Aug. 2001
4. John Frederic Whitfield, ***Electrical craft principles***, 4th Edition, vol.2.
5. D. P. Kothari, I .J. Nagrath, ***Electric Machines 4e,*** Tata McGraw Hill Education Private Limited,7 West Patel Nagar,New Delhi 110008, ISBN-13:978-0-07-069967-0, ISBN-10:0-07-069967-4, pp. 15-20.
6. Kuldeep Sahay, Shivendra Pathak, Kuldeep Sahay, ***Basic Concepts Of Electrical Engineering*** , New Age International Publishers, Copyright 2006, New Age International (P) Ltd., ISBN:81-224-1836-8, pp. 80-83.
7. Bhel, ***Transformers***,2nd ed., Tata McGraw-Hill Publishing Company Limited, 7 West Patel Nagar, New Delhi 110008, ISBN-13:978-0-07-048315-6, ISBN-10:0-07-04835-9, pp. 85-8.
8. Indrajit Dasgupta, ***Design Of Transformers,*** Tata McGraw-Hill Publishing Company Limited, 7 West Patel Nagar, New Delhi 110008, Typeset at Script Makers 19,A1-B DDA Market, Paschim Vihar, New Delhi 110063, ISBN-13:978-0-07-043640-4, ISBN-10:0-07-043640-1, pp. 62-67
9. K B Raina, S.K. Bhattacharya, ***Electrical Design Estimating And Costing,*** New Age International (P) Ltd., 4835/24, Ansari Road, Daryaganj, New Delhi-110002, ISBN:81-224-0363-8,pp.362-367.
10. Ewald Fuchs, Mohammad A. S. Masoum, ***Power Quality in Power Systems and Electrical Machines,*** Elsevier Academic press, 30 Coporate Drive, Suite 400, Burlington, MA 01803, USA 525 B Street, Suite 1900, San Diego, California 92101-4495, USA 84 Theobald's Road, London WCIX 8RR, UK. ISBN: 978-0-12-369536-9, pp. 172-177.
11. Martin J. Heathcote. ***The J & P transformer book,*** Oxford University Press,Newnes, 1998, pp.179.
12. Man Mohan and Puneet Kumar Singh, D**istribution Transformer with Amorphus-CRGO Core: An Effort to Reduce the Cost of Amorphous Core Distribution Transformer**, *ARPN Journal of Engineering and Applied Science, vol.7, No.6, ISSN 1819-6608.*
13. Man Mohan, **Amorphous-Core Transformer with Copper Winding Versus Aluminium Winding-A Comparative Study**, *ARPN Journal of Science and Technology, vol.2, No.4, ISSN 2225-7217.*
14. SMITH W.F. **Principles of materials science and engineering**, (McGraw-Hill Series in Materials Science and Engineering, 1986).