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DISTRIBUTION TRANSFORMER WITH CIRCULAR SECTION OF AMORPHOUS-CORE

Dr. Manmohan
Electrical Engineering Department, Faculty of Engineering,
Dayalbagh Educational Institute, Dayalbagh, Agra
Email: a.manmohan@yahoo.co.in , Mobile: +919412895706

ABSTRACT – In distribution transformer design, main stress is to reduce core losses. To reduce core losses in distribution transformer cold-rolled grain oriented (CRGO) steel is preferred by manufacturers. Amorphous material has very less core losses compared to CRGO steel, therefore it is being seen as a good substitute of CRGO steel. Now-a-days some manufacturers are using amorphous material in miniature andmedium size transformers; however the cost of amorphous core transformer is higher than the cost of CRGO core transformer. In amorphous core transformers manufacturers are using square section of core. With square section of core, mean length of winding turn is more which causes more material cost and more copper losses. Here a comparison is being presented among CRGO core distribution transformer(CCDT), amorphous core distribution transformer with square section of core (AMDTS) , and amorphous core distribution transformer with circular section of core(AMDTC), in terms of efficiency and cost. It is shown that the cost of amorphous core transformer reduces and efficiency improves, if a circular section of core is adopted in place of square section.

KEYWORDS- *Amorphous core, CRGO steel, Transformer design, core losses.*

1.INTRODUCTION

Transformer is a device that transfers electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field without a change in the frequency. They play vital role in transmission and distribution of electrical power by stepping up and stepping down the voltage levels [2]. Distribution transformers are used to distribute the electrical power in residential and industrial areas. Distribution transformers areenergized for twenty four hours with wide variation in load, therefore they are designed to have low no-load losses. Under no-load condition only core losses occur in a transformer and copper losses are negligible; therefore no-load losses are also called core losses for a transformer. Core losses depend on peak value of flux density (Bm); they are proportional to square of peak value of flux density; therefore to reduce the core losses distribution transformers are designed with low value of Bm [3]. Now-a-days CRGO steel is being used in distribution transformers for which allowable limit of flux densityisupto 1.55 Tesla [4]; however saturation limit for CRGO steel is 2.03 Tesla [9]. If a distribution transformer with CRGO core is designed above 1.55 Tesla then certainly the cost of the transformer reduces but performance deteriorates. The task of a designer is to make a proper compromise between cost and performance.

2. TRANSFORMER WITH AMORPHOUS CORE (AMDT)

Low loss Transformers are considered `More efficient transformers[1a]. One of the prime components of losses is the core loss. This can be drastically reduced by proper design and using superior grades of electrical steel like CRGO. It can be further reduced in case conventional electrical steel is replaced by amorphous metal [1b]. There has been constant search for transformer core materials, which may have the least loss. Iron-Boron-Silicon Amorphous alloy has evolved as the low loss material for distribution transformers. Molten metal when cooled to solid state at a very high-speed rate, retains a random atomic structure which is non-crystalline. This metal iscalled amorphous. This resembles with glass and is alsoreferred as `glass metal'. Need to achieve the required coolingrate restrict the thickness of the metal to 0.025 mm i.e. almost1/10th of the thickness of conventional CRGO steel. Due tolow saturation limit (1.5 Tesla) in amorphous core [1b], largercore and consequently larger coils and tank size are requiredas compared to CRGO core transformers. The problem hasbeen overcome to some extent with the development ofamorphous metal strips. This is achieved by compactingnumber of thin ribbons. This strip is commonly known as`POWER CORE'. Amorphous strips are four times harder thanCRGO steel[5,6]. Amorphous metal core hassome merits; the non-crystalline structure and randomarrangement of atoms gives low field magnetization and highelectrical resistivity. Due to low field magnetization,hysteresis loss is low and due to high electrical resistivity eddycurrent loss is suppressed. As such core losses of amorphousmetal alloys get reduced by 42 per cent and magnetizingcurrent by 53 percent[6].The most attractive characteristic ofamorphous alloy is obviously its extremely low core loss andlow magnetizing current. The amorphous metal saturates almost at 1.5 Tesla, whereas CRGO steel saturates at almost 2.03 Tesla. Overall cost ofamorphous core transformer is approximately 20 to 30 percenthigher than conventional core transformers [1a]. Theinitial cost of AMDT is more than the cost of conventional CRGO core transformerbut in long run the running cost of transformer will be considerably reduced

Now-a-days some manufacturers are using amorphous material in miniature and medium size transformers [6,7]. In amorphous core transformers manufacturers are using square section of core. With square section of core, mean length of winding-turn is more which causes more material cost and more copper losses. If a circular core is used for amorphous core transformer, then cost of the transformer may be reduced with improvement in efficiency. Here a comparison is being presented among CRGO core distribution transformer (CCDT), amorphous core distribution transformer with square sectionof core (AMDTS) and amorphous core distribution transformer with circular sectionof core (AMDTC) in terms of efficiency and cost

3. CRGO DESIGN (CCDT)

Sectional view of core and winding are shown in Fig-1.

A. Core Design

Voltage per turn, $Et = K\sqrt{Q}$ volts

Q is KVA rating of transformer.

K = Output constant (according to problem)

$Et = 4.44\, f.\Phi m$ volts

$\Phi m = Et / (4.44\, f)$

We know that $\Phi m = Bm.Ai$

Ai = Net Iron Area of core = $\Phi m / Bm$

$Bm = 1.55$ wb/m^2 (according to problem)

For cruciform core

$d = \sqrt{(Ai/0.56)}$

$a = 0.85d$

$b = 0.53d$

B. Window Dimensions

Window space factor $Kw = 12/(30+KV)$

RatingQ = $3.33\, f.Bm.Ai.(Kw.Aw\, .\delta).10^{-3}$ KVA,

Ai = Net Iron Area of core ; δ is current density

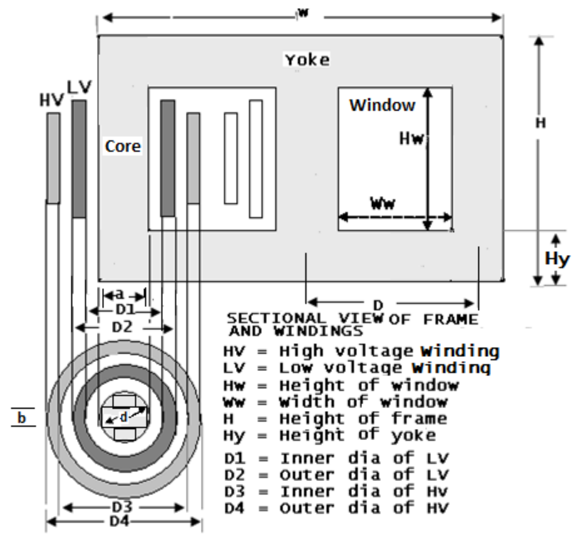

Fig1: CRGO Core

Generally, (Hw / Ww) = 2 to 4

Window area, Aw = Hw x Ww

Distance between adjacent core centers, D = Ww + a

C. Yoke Design

The area of yoke is taken as 1.2 times that of core or limb to reduce the iron losses on yoke.

Ay = 1.2 x Ai

Flux density in yoke

$By = \Phi m / Ay$

$By = (Bm.Ai) / Ay$

Net area of yoke = stacking factor x gross area of yoke

Net area of yoke = 0.9 x gross area of yoke

Taking section of yoke as rectangular,

Depth of yoke, Dy = a

Height of yoke, Hy = gross area of yoke / Dy

D. Overall Dimension Of Frame

Height of frame H = Hw + 2Hy

Length of frame W = 2D + a

Depth of frame = a

4. AMORPHOUS DESIGN WITH SQUARE-SECTION OF CORE (AMDTS)

Sectional view of core and winding are shown in Fig-2.

A. Core Design

$Bm = 1.5$ wb/m^2

Net Cross section of core area Ai = $\Phi m / Bm$

Used square core having Ai = l^2 x (stacking factor)

Here l is the side of square section

B. Window Dimensions

Window space factor $Kw = 12/(30+KV)$

We have Q = 3.33 f.Bm.Ai.(Kw.Aw .δ).10^{-3} KVA
Generally (Hw / Ww) = 2 to 4
Window area, Aw = Hw x Ww
Distance between adjacent core centers, D = Ww + l
C. Yoke Design
The area of yoke is taken same as limb. So,
Ay = Ai
Flux density in yoke By = Bm
Taking section of yoke as square of yoke,
Depth of yoke, Dy = l
Height of yoke, Hy = Ay / Dy
D. Overall Dimension Of Frame
Height of frame H = Hw + 2Hy
Length of frame W = 2D + l
Depth of frame = l

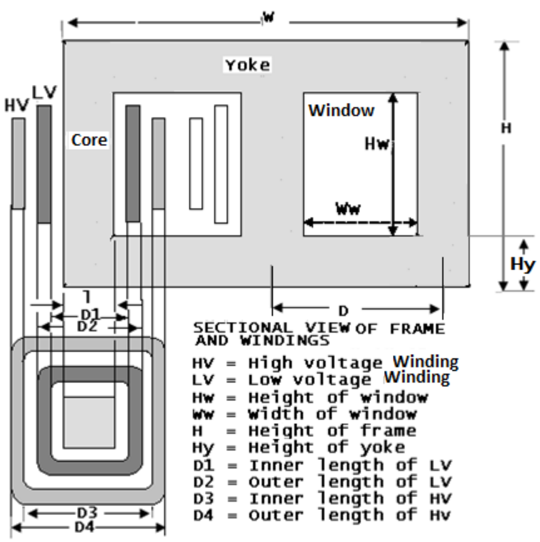

FIG2: Amorphous Core with square section

5.AMORPHOUS DESIGN WITH CIRCULAR SECTION OF CORE (AMDTC)

Amorphous alloy is available in form of ribbons having thickness of 0.025 mm. Therefore a core having cylindrical shape (with circular cross section) may be formed easily.Sectional view of core and winding are shown in Fig-3.

A. Core Design
Flux density in core Bm = 1.5 wb/m^2
Ai = Net Iron Area of core = Φm / Bm
For circular core the dia of the core d = √{Ai/(0.79 x stacking factor)}.
B. Window Dimensions
Hw and Ww are same as in case of AMDTS.
Distance between adjacent core centers, D = Ww + d
C. Yoke Design
The area of yoke Ay = Ai,
Flux density in yoke By = Bm
Taking section of yoke as rectangular,
Depth or thickness of yoke, Dy= d,
Height of yoke, Hy= Ay / Dy
D. Overall Dimension Of Frame
Height of frame H = Hw + 2Hy
Length of frame W = 2D + d
Depth of frame = d,

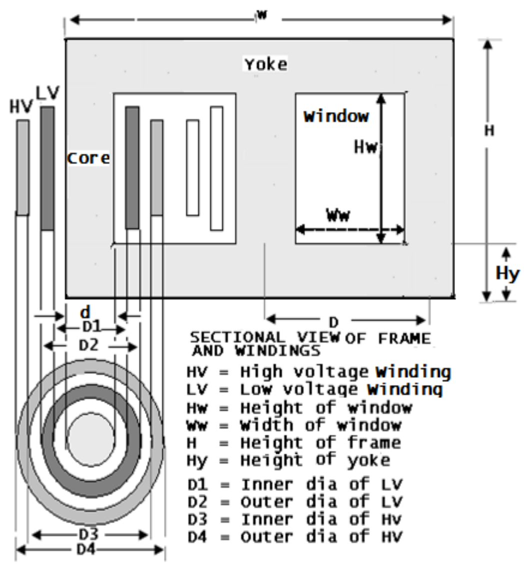

Fig3: Amorphous core with circular section

6. ESTIMATION OF LOSSES

Core losses = specific core loss in watt per Kg. x mass of core
Copper losses = I^2 R, (here current = I, winding resistance = R)

7. ESTIMATION OF COST

Cost of CRGO = rate in Rupees per Kg. x mass of CRGO in the frame
Cost of Amorphous = rate in Rupees per Kg. x mass of amorphous material in frame
Cost of copper winding = rate in Rupees per Kg. x mass of copper in windings.

8. RESULTS AND DISCUSSION

Transformer Rating: 250KVA, 11000/415 V, 50Hz, 3 Phase, Delta/Star, oil natural cooled, Distribution transformer and 5% tapping on HV side.

Calculated main dimensions of core and winding for CCDT, AMDTS and AMDTC are shown in Table-1. On basis of physical dimensions, masses of core and winding are calculated; further on basis of the masses, losses and cost of the transformer are calculated.The calculated losses, efficiency and cost are shown in Table-2.Among CCDT, AMDTS and AMDTC, the CCDT has minimum efficiency with minimum cost. On the other hand the AMDTS has maximum cost with increased efficiency. For AMDTC the cost has been reduced with further increase in efficiency as compared to AMDTS.The cost of AMDTC is more than conventional CCDT. The increased cost of AMDTC may be recovered in few months in terms of energy saved, for this breakeven point (BEP) is determined. To determine breakeven point Total Owning Cost (TOC) of the transformer is calculated [8]-

TOC = Initial cost +cost of energy loss during operation.

As time passes, cost of energy loss increases and the TOC increases with time. The calculated TOC for CCDT and AMDTC are shown in Table-3.Variation of TOC with months is shown in fig 4. The rate of increase of TOC is higher for CCDT as compared to AMDTC. The BEP comes after 12months; therefore AMDTC will be economical after 12 months.

Table-3

Time (Months)	**TOC for CCDT (Rupees)**	**TOC for AMDTC (Rupees)**
0	151721	193243
1	163010	200783
2	174300	208322
3	185590	215862
4	196879	223404
5	208169	230942
6	219458	238481
7	230748	246021
8	242038	253561
9	253327	261101
10	264617	268641
11	275906	276180
12 B.E.P.	**287196**	**283721**
13	298486	291262
14	309776	298803

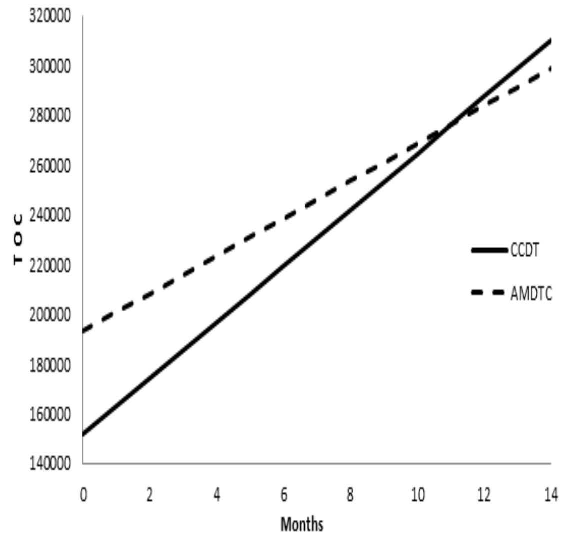

Fig4: Variation of TOC with Months for AMDTC and CCDT

9. CONCLUSION

Among CCDT, AMDTS and AMDTC, the conventional CCDT has minimum efficiency with minimum cost. On the other hand the AMDTS has maximum cost with increased efficiency. For AMDTC the cost has been reduced with further increase in efficiency as compared to AMDTS. The cost of AMDTC is more than conventional CCDT. The increased cost of AMDTC will be recovered in 12 months for a 250 KVA transformer.

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REFERENCES

1.Websites:
a) www.kotsons.com (access on feb11, 2012).
b)www.metglas.com(access on feb11,2012).
2.Martin J.,Heathcote, “J and P Transformer book.”Oxford university press, 1998.
3.SayM.G., “Performance and Design of AC Machines,” Pitman, 1977.
4.Sawhney ,A,K., “Electrical Machine Design,” DhanapatRai publishers, 2006.
5. R. Schulz, N. Chretien, N. Alexandrov, Aubin, R., “A newdesign for amorphous core distribution transformer,” Materials Scienceand Engineering, Volume 99(1-2),pp. 19-21,March 1998.

6. Nicholas DeCristofaro, "Amorphous Metals in Electric-PowerDistribution Application," MRS bulletin, Material Research Society,Vol. 23, No. 5, pp. 50-56, 1998.
7.Puneet K. Singh, Dr. Man Mohan, "Distribution transformer with amorphous core", National conference on advanced trends in power electronics and power systems, organized by Marudhar engineering college Bikaner, pp.9, August 28-29,2010.
8. Amoiralis, Marina and Antonios, "Transformer design and optimization: A literature survey", IEEE trans. on Power delivery vol. 24 No. 4, pp. 1999-2024,.October 2009
9. Transformers by BHEL, Tata Mc-Graw Hill, 2009.

Table-1: Main dimensions

Description	**(CCDT)**	**(AMDTS)**	**(AMDTC)**
Window dimensions Width Ww Height Hw	 179 mm 358.3 mm	 178 mm 357.9 mm	 178 mm 357.9 mm
Core or limb Net iron area Ai Laminations Mass of one limb	 0.0206 m^2 d=191.8 mm, a=163 mm, b=101.6mm 55.63 Kg	 0.02133 m^2 l=146.05 mm 60.95 Kg	 0.02133 m^2 d= 164.8 mm 60.95 Kg
Yoke Depth Dy Height Hy Net Yoke area Ay Length W Mass of one yoke	 163 mm 168.1 mm 0.0247 m^2 847 mm 160 Kg	 146 mm 146 mm 0.02133 m^2 794 mm 112 Kg	 164.8 mm 129.2 mm 0.02133 m^2 794 mm 112 Kg
Total mass of frame	486.88 Kg	453.92 Kg	453.92 Kg
Winding details Turns per phase LV, HV Mean length of turn LV HV Conductor size LV HV Total mass of windings	 34, 1639 644 mm 853 mm 139 mm^2 3 mm^2 194.43 Kg	 34, 1639 647 mm 894 mm 139 mm^2 3 mm^2 199.41 Kg	 34, 1639 573 mm 792 mm 139 mm^2 3 mm^2 176.65 Kg

Table-2: losses, efficiency and cost

Description	**(CCDT)**	**(AMDTS)**	**(AMDTC)**
Core losses in watts	898	83	83
Copper losses in watts	2862	2913	2581
Full load Efficiency at power factor 0.8 lag	**98 %**	98.5 %	**98.7 %**
Cost of core in Rupees	38952	90783	90783
Cost of winding in Rupees	1,12,769	1,15,658	1,02,460
Cost of core and winding in Rupees	**151721**	206442	**193243**

APPENDIX	
Mass density of CRGO steel	7600 Kg / m^3
Mass density of Amorphous	7200 Kg / m^3
Mass density of Copper	8920 Kg / m^3
Price of CRGO steel	80 INR/ Kg
Price of Amorphous	200 INR / Kg
Price of Copper	580 INR/ Kg
Current density (δ)	2.5 Amp./mm^2
$(\text{Specific core loss})_{CRGO}$	1.5 watt / Kg
$(\text{Specific core loss})_{amorphous}$	0.1 watt / Kg