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Evaluation Study of Performance Analysis & Characteristics of Amorphous Core Transformer for Electrical Distribution System

Prof. Kanchan Shriprakash Patil

Department of Electrical Engineering, North Maharashtra University, Jalgaon, Maharashtra, India

ABSTRACT

Nowadays traditional use of other materials such as Al, copper etc increases the transmission losses, cost and reduce the efficiency but on the other hand amorphous core material design that reduces losses upto 25-40 percent improves the efficiency and reduce the cost of production. This paper describes the Energy savings & comparison chart with conventional transformers & similar rating show that iron losses are 30% of the CRGO Transformers. Total owning cost (TOC) is reduced by improvement in environments factor socials & economics costs of generation related to CO2, SO2, & other greenhouse gases emissions. This paper describes the performance characteristics and analysis of amorphous hexa core materials used for transformer in distribution cases with magnetisation characteristics. It describes the various design and advantages of amorphous core transformer with simple structured core transformer.
Keywords:-Amorphous, core losses, core design, ecofriendly distribution transformer, CO2 emission

I. INTRODUCTION

Transformer is the important and crucial part of electrical distribution system. To be economically efficient, transformers should be designed to provide as low power loss as possible. This is especially true for the distribution level where they operate in stand-by mode during significant time and losses in the magnetic core represent an essential part of the total loss. Traditionally, conventional E-shaped cores are used for these transformers. Over the past decades however, a new type of cores from the company Hexaformer AB has entered the market. Such cores have hexagon shaped legs and provide symmetrical magnetic flux paths and have proven to show several advantages over traditional ones, This paper primarily focuses on design of amorphous core distribution transformer. Amorphous metal core has some advantages comapred with the non-crystalline structure and random arrangement of atoms gives low field magnetization and high electrical resistivity. Due to low field magnetization, hysteresis loss is low and due to high electrical resistivity eddy current loss is suppressed. As such core losses of amorphous metal alloys get reduced by 35per cent and magnetizing current by 55 percent.

II. METHODS AND MATERIAL

1. Transformer Mechanism

A transformer is an electrical device that transfers electrical energy between two or more circuits through Electromagnetic induction produces an electromotive force within a conductor which is exposed to time varying magnetic fields. Transformers are used to increase or decrease the alternating voltages in electric power applications.

A varying current in the transformer's primary winding creates a varying magnetic flux in the transformer core and a varying field impinging on the transformer's secondary winding. This varying magnetic field at the secondary winding induces a varying electromotive force (EMF) or voltage in the secondary winding due to electromagnetic induction. A wide range of transformer designs is encountered in electronic and electric power applications. Transformers range in size from RF transformers less than a cubic centimeter in volume to units interconnecting the power grid weighing hundreds of tons.

The transformer is a crucial component in the electrical system. Its main task is to transform voltage from one level to the other and to do this with low losses. On its way from generation sites to consumers, the voltage is transformed up or down several times. Particularly when power is to be transported over long distances, it is most advantageous to use a high voltage level. When the generated power reaches its destination, it is transformed down again for distribution to the customers. The transformer can also be viewed as a device to connect circuits without them having any galvanic contact.

1.2 Losses in transformer

1.2.1 Transformer Losses

An ideal transformer have no energy losses i.e zero losses, and 100% efficient. But in real (In practical) transformers, energy is dissipated in the windings, core, and surrounding structures. Larger transformers are generally more efficient, and those of distribution transformer usually perform better than 98%.Experimental transformers using superconducting (Super conductor is one that in which zero losses occur) windings achieve efficiencies of 99.85% i.e zero transformer losses, but it would be available in coming years.

The different losses in the transformer are as follows,

1.2.2 Copper Losses (Winding Losses)

Current flowing through the windings causes resistive heating of the conductors. At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

Total copper losses. $= I_1^2 . R_1 + I_2^2 R_2 = I_1^2 . R_{01} + I_2^2 R_{02}$

Core or iron losses(Transformer Losses) there are two types of core or iron losses in a transformer

1) Hysteresis Losses(Transformer Losses)

Each time the magnetic field is reversed, a small amount of energy is lost due to hysteresis within the core. For a given core material, the transformer losses are proportional to the frequency, and is a function of the peak flux density to which it is subjected.

We can find Hysteresis losses by this formula.

$$W_h = \eta B^{1.6}_{max} f.v \text{ watt}$$

2) Eddy Current Losses(Transformer Losses)

Ferromagnetic materials are also good conductors, and a core made from such material also constitutes a single short-circuited turn throughout its entire length. Eddy currents therefore circulate within the core in a plane normal to the flux, and are responsible for resistive heating of the core material. The eddy current loss is a complex function of the square of supply frequency and inverse square of the material thickness. Eddy current losses can be reduced by making the core of a stack of plates electrically insulated from each other, rather than a solid block; all transformers operating at low frequencies using laminated or similar cores.

We can find Eddy currents losses by this formula.

$$W_e = PB^2_{max} . f^2 t^2 \text{ Watt}$$

Magnetostriction

Magnetic flux in a ferromagnetic material, such as the core, causes it to physically expand and contract slightly with each cycle of the magnetic field, an effect known as magnetostriction. This produces the buzzing sound commonly associated with transformers, and can cause losses due to frictional heating.

Mechanical Losses (Transformer Losses)

In addition to magnetostriction, the alternating magnetic field causes fluctuating forces between the primary and secondary windings. These incite vibrations within nearby metalwork, adding to the buzzing noise, and consuming a small amount of power.

Stray Losses (Leakages Flux)

Leakage inductance is by itself largely lossless, since energy supplied to its magnetic fields is returned to the supply with the next half-cycle. However, any leakage flux that intercepts nearby conductive materials such as the transformer's support structure will give rise to eddy currents and be converted to heat. There are also radiative losses due to the oscillating magnetic field, but these are usually small

i) **Non Grain Oriented.**

In these types of electrical steels the magnetic properties are practically the same in all direction of magnetization of the material. The term "non grain oriented" is used to these materials as the processes that are different manufactures to create a defined orientation and directionality of the magnetic properties.

ii) Grain-Oriented.

In these types of electrical steels the materials possess magnetic properties which are strongly oriented with respect to the direction of rolling. By a rolling process and annealing, alloys of suitable composition with a crystalline structure of the metal in the grains can be produced, so that the magnetic properties are oriented in the rolling direction are produced much higher.

2. Amorphous Material Characteristics

The Amorphous Metal, an alloy of Fe78-B13-Si9, has non crystalline structure which is formed by cooling molten metal rapidly at cooling rates of 10^6 °C/sec. The atoms do not get arranged as proper grain structure, but are arranged randomly. After annealing under a magnetic field, this alloy exhibits low losses as it gains excellent Magnetic and Chemical properties as compared to the conventional material. Amorphous Metal Distribution Transformers are the proven energy savers and this is because the Amorphous Metal core reduces the No load losses by about 75% when compared to the conventional CRGO grade.

Amorphous (vs) CRGO Core Temperature Rise Factor these photographs show the temperature distribution due to the core losses as observed by an infra-red camera. The Amorphous core indicates a very low temperature rise due to the low inherent core loss as compared to CRGO.

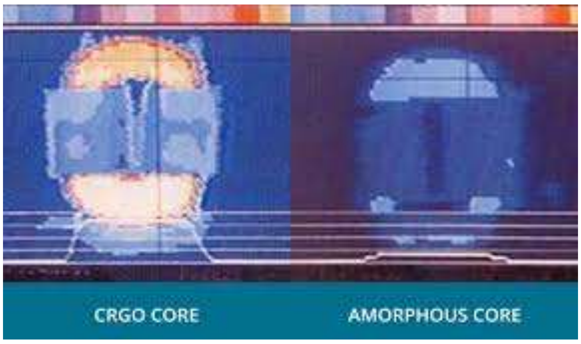


Figure 1. Structure of CRGO and Amorphous Core

Applications

The main application of AMTs are the grid distribution transformers rated at about 50-1000 kVA. These transformers typically run 24 hours a day and at a low load factor (average load divided by nominal load). The no load loss of these transforms makes up a significant part of the loss of the whole distribution net. Amorphous iron is also used in specialized electric motors that operate at high frequencies of perhaps 350 Hz or more.

Advantages and Disadvantages

More efficient transformers lead to a reduction of generation requirement and, when using electric power generated from fossil fuels, less CO2 emissions. This technology has been widely adopted by large developing countries such as China[4] and India[5] where labour cost is low. AMT are in fact more labour-intensive than conventional distribution transformer, a reason that explain a very low adoption in the comparable (by size) European market. These two countries can potentially save 25–30 TWh electricity annually[citation needed], eliminate 6-8 GW generation investment[citation needed], and reduce 20–30 million tons of CO2 emission by fully utilizing this technology No-load loss are reduced by 75% as compared to CRGO transformers Less magnetizing current Cumulative saving of energy cost Total Owning Cost to customer in much less Less Temperature rise of core

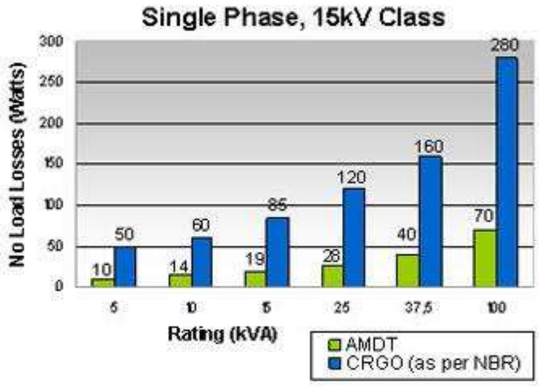


Figure 2. No Load Losses Comparison of Amorphous Metal Core (vs) CRGO Core (as per NBR)

TABLE I. (Comparison Between Amorphous & CRGO Steel)

Properties	**Amorphous Metal Grade26**	**CRGO Steel – Grade M4 (Stacked Core)**
Density	7.19	7.65
Specific resistance	130	45
Saturation flux density	1.58	2.03
Typical core loss at 50 Hz	0.22	0.89
Nominal Thickness	0.025	0.27
Average space factor	0.86	0.97
Available form	Thin sheet/ribbon	Sheet/roll
Annealing Temperature	360	800
Other process	Magnetic field annealing	-
Productivity	Relatively high with less wastage	Low
Core steel grades	Single grade of uniform quality	Multiple grades with varying quality
No load loss	Very low around 70%	Relativley high
Coil winding	Concentric rectangular	Concentric round shaped coils

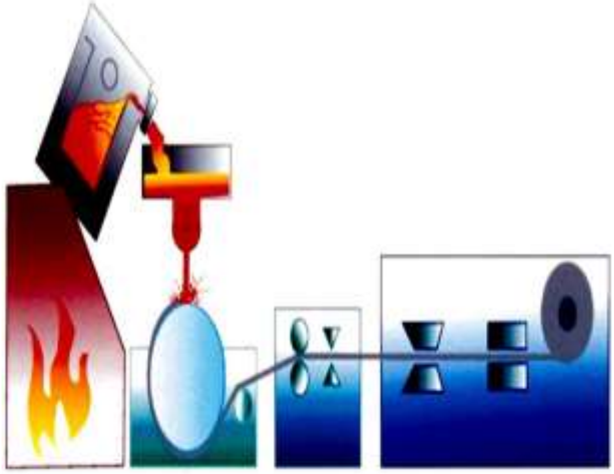


Figure 3. Production process for AMORPHOUS METAL

Figure 4. Amorphous Core designed Transformer shape

III. RESULTS AND DISCUSSION

1. Amorphous Core Transformer Design And Construction

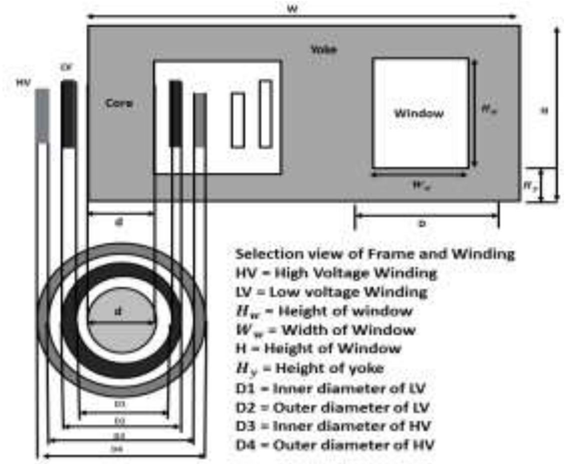


Figure 5. CRGO Core

CRGO DESIGN (CCDT)

Sectional view of core and winding is shown in Figure-1.

A. Core Design

Voltage per turn, $E_t = K\sqrt{Q}$ volts
Q = KVA rating of transformer
K = Output constant (according to problem)
$E_t = 4.44\, f.\Phi_m$ volts
$\Phi_m = E_t / (4.44\, f)$
here f = supply frequency and Φ_m = flux in the core
We know that $\Phi_m = B_m.A_i$
A_i = Net Iron Area of core = Φ_m / B_m
Flux density B_m = 1.55 wb/m2 (according to problem)
For cruciform core
$d = \sqrt{(A_i/0.56)}$
a = 0.85d
b = 0.53d

B. Window Dimensions

Window space factor K_w = 12/ (30+KV)
Rating $Q = 3.33\, f.\, B_m.\, A_i.\, (K_w.\, A_w\, .\delta).10^{-3}$ KVA
A_i = Net Iron Area of core; δ is current density
Generally, (H_w / W_w) = 2 to 4
Window area, $A_w = H_w \times W_w$
Distance between adjacent core centers, $D = W_w + d$

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.
$A_y = 1.2 \times A_i$
Flux density in yoke
$B_y = \Phi_m / A_y$
$B_y = (B_m.\, A_i) / A_y$
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, D_y = a
Height of yoke, H_y = gross area of yoke / D_y

D. Overall dimension of frame

Height of frame $H = H_w + 2H_y$
Length of frame $W = 2D + a$
Depth of frame = a

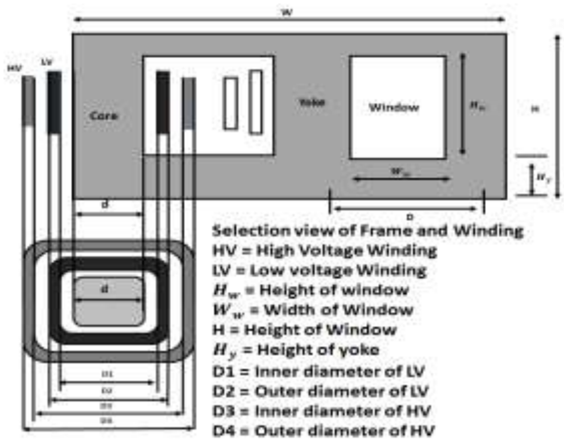


Figure 6. Amorphous Core

2. Amorphous Design (AMDT)

Sectional view of core and winding is shown in Figure-2.

A. Core design

Voltage per turn, $E_t = K\sqrt{Q}$ volts
K = Output constant (according to problem)
$E_t = 4.44\, f.\Phi_m$ volts
$\Phi_m = E_t / (4.44\, f)$
A_i = Net Iron Area of core = Φ_m / B_m
B_m = 1.5 wb/m2
Cross sectional area of core $A_i = \Phi_m / B_m$
Used square core having $A_i = l^2 \times$ stacking factor
Here l is the side of square section,
Taking stacking factor = 0.9, $l = \sqrt{(A_i/0.9)}$

B. Window dimensions

Window space factor Kw = 12/ (30+KV)
We have Q = 3.33 f. Bm. Ai. (Kw. Aw .δ).10-3 KVA
Ai = Net Iron Area, δ = current density in conductor.
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,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

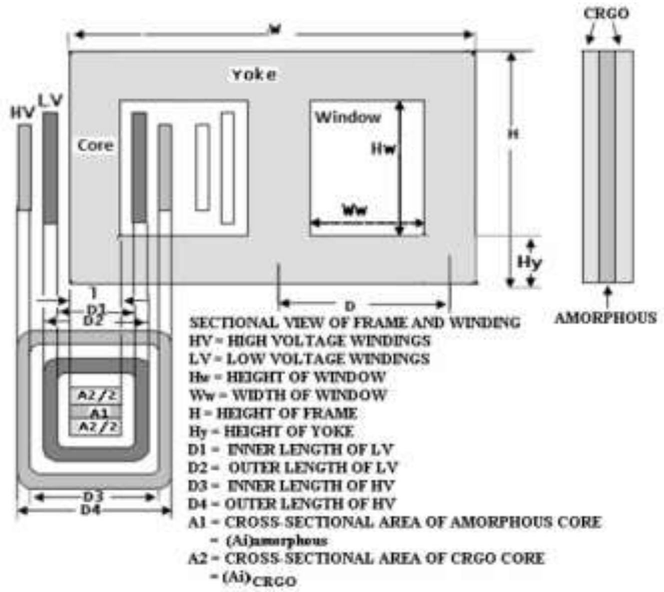


Figure 7. Amorphous CRGO Core

Estimation of Losses:

Core losses in CRGO = (specific core loss in watt per Kg.) CRGO x mass of CRGO in the frame Core losses in amorphous = (specific core loss in watt per Kg.)

Amorphous x mass of amorphous in the frame Copper losses in windings = No-load loss of amorphous core transformers is very low comparing to conventional transformers with silicon steel core.

It results from very low energy loss of amorphous ribbons and also its small thickness, what significant reduces eddy currents flow. The reduction of no-load loss in amorphous transformers is estimated at 70% - 80%.

Estimation of Cost:

Mass of CRGO in the frame = [mass of core + mass of yoke]

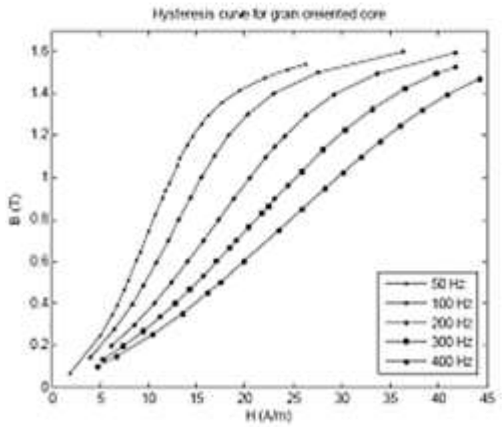
CRGO Mass of amorphous material in the frame = [mass of core + mass of yoke] amorphous Mass of copper in winding = [(mean length of turn) x (number of turns) x (area cross section of conductor) x (mass density of copper)]

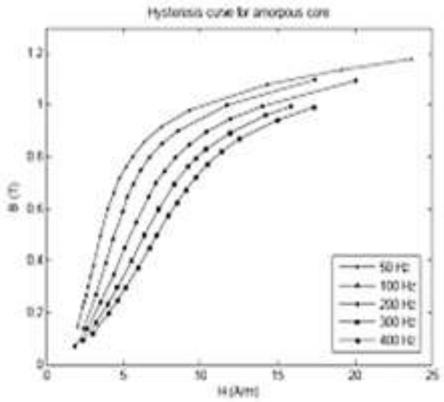
Cost of CRGO = Price per Kg. x mass of CRGO in the frame Cost of Amorphous = Price per Kg. x mass of amorphous material in frame Cost of copper windings = Price per Kg. x mass of copper in windings.

3. Magnetisation curve of Amorphous & CRGO

The magnetization of the transformers in terms of the magnetic flux density and magnetic field (so-called B-H curve), these quantities should be deduced from the measured parameters.

The magnetization curves of the cores are presented in Figures. It is worth noting that the saturation point is lower for the amorphous core than for the grain oriented one (note that the scales on the B-axis are slightly different in the two graphs). The cores are both meant to be operating around 1 T, which is applicable for the grain oriented. For the amorphous however, it is far too close to the saturation point. On the other hand, the linear part of the amorphous curve occurs at a much lower H-field than for the grain oriented, which means a lower magnetizing current. Note that the values of H are the RMS-values.





IV. CONCLUSION

With the help of design of CRGO and amorphous core material we can minimises losses which increases efficiency. Amorphous core transformers have- low core losses, low magnetising current, less zero sequence current, less noise, higher inrush current, more harmonic problem, bigger size, higher initial cost, higher efficiency, and longer life. amorphous materials are energy effective which save energy upto much more extent 60%,Improvement in 'H' factor dealing with really world power supply Though amorphous transformer have initial cost more comparatively higher; it becomes economical after a certain period of time which Perform better in over excitation stage. The initial cost will be reduced because of reduction in manufacturing cost. Amorphous core transformers are energy efficient transformers; If all conventional transformers are replaced by amorphous core transformers, a considerable amount of energy will be saved for a nation amorphous distribution transformers have long been in operation in North America and Asia. The construction and technical aspects are considered to be well known. Finally, the environmental benefits from an amorphous core transformer, with a reduction in CO_2 emission have been clearly indicated in this paper.

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