AN OVERVIEW OF AMORPHOUS CORE DISTRIBUTION TRANSFORMER

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Abstract

More than ever, electric utilities and other users of distribution transformers are emphasizing sustainability and looking for technologies that can lower operating costs, improve energy savings, and reduce environmental impact. Amorphous metal distribution transformer (AMDT) is the product of choice to help achieve these important objectives. Amorphous metal is a unique alloy that exhibits a molecular arrangement that is random in structure, rather than the organized crystalline structure of CRGO core steel. Due to its unique molecular structure, amorphous metal cores are more readily magnetized and demagnetized when energized, resulting in significantly lower energy loss compared to CRGO steel. AMDT technology is considered mature and has been proven to be reliable. Distribution transformers containing amorphous metal cores were first made commercially available in the late 1980's. Since then over 1.3 million AMDT's have been installed worldwide.

1.Introduction

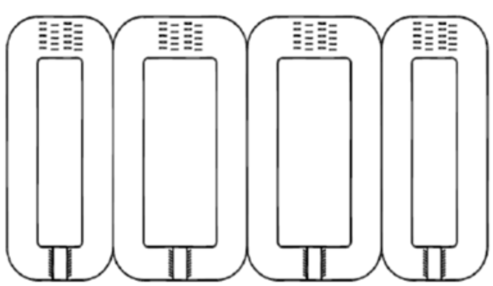
The core of first practical transformer was developed in 1885; it was made of carbon steel. Later, carbon steel was substituted by silicon steel and today most of the power and distribution transformer cores in service are of cold rolled grain oriented silicon steel (CRGO) laminations. Due to global movement of environmental protection, energy saving and noise reduction have been required for transformers, leading to a demand for low core loss and low magnetostriction material. Amorphous alloy exhibit properties of low core loss and low magnetostriction, compared to conventional grain oriented silicon steel. Amorphous alloy exhibits a structure in which the metallic molecules exists in a random pattern. As opposed to the rigid grain oriented structure of silicon steel, this unique structure enables easy magnetization and demagnetization. When energized, the core material switches its magnetization 100 times per second. The extent of energy losses that occur in the core is determined by how easily the core switch magnetization; the easier the switching capability, the lower the losses. The key feature of the amorphous core transformers is the sharp reduction in the no-load losses that occur in the core of transformer. There are several amorphous alloys in market, among them iron-boron-silicon alloy (Fe78B13Si9) has presented the best performance; the core loss in this alloy is about 1/10 of core loss in CRGO steel.

2.Working Methodology

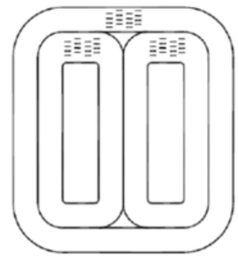
2.1.Amorphous Core

The amorphous alloy is cast in extremely thin ribbons (0.025mm), to achieve the required magnetization properties. The core is manufactured with the help of special purpose automatic machines at plant. The amorphous alloy is received in the form of ribbons. It is then cut to length based on design requirements and arranged in piles for the required core build. These piles are then nested into an annular shape core packet, which is then given the final forms of on a special core former. The formed cores are then annealed in an oven in strong magnetic field which enables the cores to display low core losses. After annealing the sides of core are applied with special glue, and cured in infrared oven. By this the core packet becomes rigid enough to accept winding. The entire core manufacturing process calls for precise controls and proper care while handling. This is made possible by deploying advanced PLC based systems and other control devices at various stages of the core fabrication. To develop a 1-phase and the 3- phase transformers 'C-core' shape of amorphous core is adopted; it is shown in Figure-2.1.a; the cross-section of a C-core is square or rectangular. The configurations adopted for 1-phase and 3-phase transformers of amorphous 'Ccores' are shown in Figure-1b and Figure-1c respectively.

Fig 2.1.a. single phase transformet



3 phase 5 limbs transformer core group



3 phase 3 limbs transformer core group

3. Discussion on Factors Affecting the Design:
3.1. A Comparison with Conventional CRGO-Core Transformers.

(1). Limitations with amorphous alloy are low saturation limit, more hardness and more cost ascompared to CRGO steel (Boyd E.L. and Borst J.D. 1984, Nicols DeCristofaro 1998). Magnetizing characteristics (B-H) of amorphous alloy and CRGO steel are shown in Figure-3.

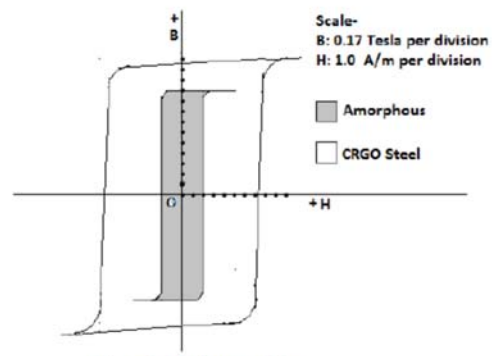


Figure-3: B-H Characteristics

The saturation limit for amorphous alloy (Fe78B13Si9) is 1.69 Tesla; however it is 2.03Tesla for CRGO steel (BHEL 2009). Therefore, amorphous alloy is more suitable for miniature size transformers and distribution transformers, as they are designed for lower flux densities. Distribution transformers are designed for low core loss; the core loss in a material depends on flux density (Bm). The core loss (Pc) in the amorphous alloy is given by (Lee Ji-kwang 1999) - Pc = [6.5(f/1000)1.51 Bm1.74] watts/Kg. Here, 'f' is the supply frequency and 'Bm' is the flux density in the core. Area of B-H loop represents hysteresis loss in a magnetic material. For amorphous alloy, the area of the loop is smaller than that of CRGO steel, as shown in figure-3. (2). For economic design of a transformer, the cross sectional area of the core should be smaller; for smaller cross sectional area the chosen flux density is high and therefore, the core loss increases. If large rating power transformers are designed for low flux density then cross sectional area of core becomes large; for larger cross-sectional area of a core, costs of the core and winding are higher, therefore the cost of the transformer becomes higher (Dasgupta 2011, Sawhney 2006, Say M.G. 1977). Therefore, amorphous alloy is not a suitable choice for large rating power transformers, if economy is an issue. Amorphous core transformers are energy efficient transformers with increased costs (Kennedy B 1998); the cost of amorphous core transformers is 20 to 30 percent higher than that of conventional CRGO core transformers (Puneet K Singh 2010). Cost of a transformer depends on cost of core, cost of winding and manufacturing cost. Costs of core and winding are affected by shape and size of cross-sectional area of core. A core having square or rectangular crosssection is called 1-step core. For square or rectangular cross-section of a core, cost of core is lower but the cost of winding is higher, than that of circular multi-stepped cross-section of core. Selection of number of steps in a core depends on KVA rating of transformer. As the rating of transformer increases, the number of steps in a core increases. For more number of steps, the diameter of circumscribing circle reduces for an iron area of the core, so cost of copper winding reduces, and copper losses are also reduced. However; with the increase in number of steps, the assembly cost of the core increases. Therefore for low rating transformers the square section of the core is economical and for medium and large rating transformers multi-stepped CRGO core is economical. On the other hand, for the amorphouscore transformers of medium and large ratings, the square or rectangular section of core is adopted by manufacturers (Lee Ji-Kwang 1999, Nicols DeCristofaro 1998, Schulz R.N. 1998), the reason is the higher cost of amorphous-core assembly, as compared to CRGO-core assembly.

(3). Stacking factor (Ks) is defined by the ratio between the cross-sectional area of ferromagnetic material and total cross-sectional area of the core. With sheets of CRGO steel it is 0.9 or higher. For amorphous alloy it is in between 0.8 and 0.9 (Bendito et al 1999). With reduced stacking factor the gross cross-sectional area of core becomes larger, resulting overall size to be big. The disadvantage with bigger size is the higher cost, but the advantage is better cooling.

(4). Cost of a transformer is also assessed as Total owning cost (TOC) (Amoiralis 2009). TOC is sum of initial cost of a transformer and cost of energy losses during operation. TOC = (Purchase Price) + (A x Core Loss) + (B x Winding Loss). where, The core loss factor (A) and the winding loss factor (B) can be calculated. For low TOC, the losses in a transformer should be low. As the time passes, the TOC increases. Amorphous metal cores are particularly valuable for transformer users with relatively high “A” factors, because the lower core loss of AMDTs results in substantially reduced cost of ownership, with only a moderate increase in purchase price.

(5). For medium and large rating transformers electromagnetic forces on the windings must also be considered as they are very high (Martin J. Heathcote 1988). Radial electromagnetic forces on the winding are proportional to square of the current (Fr α I2). Under short circuit condition the current in a transformer may be 20 times of rated current, so the electromagnetic force may be 400 times higher than that of normal condition. For square section of core, the shape of the coil is also square, for which radial electromagnetic forces are not uniform around the periphery of the coil. Non uniform radial electromagnetic forces may distort the shape of a coil in a transformer. Therefore square or rectangular section of core is not advisable for medium and large rating transformers. For a multi-stepped core, the shape of the coil is circular, and the radial electromagnetic forces are uniform around periphery of the coil.

(6). Low voltage and high voltage windings are accommodated in the window area (Aw). The ratio between height (Hw) and width of the window (Ww) is chosen 2 or above; for low leakage reactance this ratio should be high (Dasgupta 2011,Sawhney 2006, Say M.G. 1977). The window space factor (Kw) is defined by the ratio between the conductor cross section area and the window area. Insulation and clearance reduce the available area for actual conductor cross section to kw**.**Aw. Window design considerations for conventional CRGO core transformers and amorphous core transformers are same.

(7). In case of 3-phase 3-limb transformer magnetic asymmetry exists, because length of magnetic path are unequal for three fluxes (ΦA , ΦB , and ΦC); here flux ΦB is produced by the winding of central limb, and fluxes ΦA and ΦC are for side limbs (KulkarniS.V., Khaparde S.A. 2005). The length of magnetic path followed by the flux ΦB is less than the length of magnetic path followed by fluxes ΦA and ΦC.; therefore, the reluctance offered by the magnetic path for flux ΦB is less than that of reluctances for ΦA and ΦC. It causes difference in magnetising currents of three phases, which results zero sequence current. In case of amorphous core transformers, the reluctance offered by magnetic path is much less (about 1/4 of reluctance offered in conventional CRGO core transformer), which reduces the magnetic asymmetry, resulting reduction in zero sequence current.

(8). For a convention CRGO core transformers, the magnetising current is 1% to 2% of rated current. The magnetising current drawn by a transformer depends on two factors; one is the nature of B-H curve, and other is number of joints in the core assembly. Comparing between B-H characterics of amorphous alloy and conventional CRGO steel, magnetizing current for amorphous alloy is about one third than that of CRGO steel (BHEL 2009). During construction of conventional CRGO core assembly for a transformer, Mitred joints are used in corners. For 3-phase 3-limb transformer total number of Mitred joints in core assembly is six. However, in Ccore assembly of a 3-phase 3-limb transformer, nonmitred joints are used, and the total number of joints is only three. Therefore, the magnetising force required for C-core assembly is less as compared to conventional CRGO core assembly, which reduces the magnetising current.

(9). When a transformer is switched in, the core is driven into saturation; therefore current inrush comes in picture (Kulkarni S.V., Khaparde S.A. 2005). Because of low saturation limit of amorphous alloy, the magnitude of inrush current is higher in case of amorphous core transformers compared to conventional CRGO core transformers. The inrush current is not harmful for a transformer but may result in the inadvertent operation of overload relays.

(10).In transformers, because of increase in supply voltage, flux density in core increases beyond the designed value, which may result saturation of core. Therefore, the problem of third harmonic comes inpicture because of saturation of core. To reduce this problem, a transformer should be designed for a low value of flux density, which increases the cost of a transformer. In amorphous core transformers the problem of third harmonic is more because of low saturation limit. The problem of third harmonic may be eliminated by adopting zig-zag connection in place of star connection.

(11). Magnetostriction is less in amorphous alloy, compared to CRGO steel (Bendito et al 1999). Therefore, amorphous core transformers have low noise level, so they are friendlier to environment .

(12) Average life of an amorphous core transformer is 30 years; however it is 25 years in case of conventional transformers. Therefore, the average life of amorphous core transformer is more than the average life of conventional transformer.

4. Conclusions

Compared to conventional transformers, 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. Advantages with amorphous core transformer are more, compared to disadvantages. At present, initial cost of amorphous core transformer is comparatively higher; it becomes economical after a certain period of time. In future, as the manufacturing will increase, 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.

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