Amorphous Metal Triangular Cores to Improve Distribution Transformers Design

Ahmad Moradnouri, Pedram Elhaminia and Mehdi Vakilian

***Abstract*— No-load losses in transformers and other power system equipments have a major share in their electric energy losses. This paper reviews the advantages of a triangular core construction made of amorphous materials to develop efficient distribution transformers, through reduction of transformers no-load losses. In whole range of distribution transformers standard power rating, amorphous triangular core transformers and silicon steel triangular core transformers have been designed by use of proposed triangular core distribution transformers design algorithm. The cost and operational parameters of these designs have been compared. No-load losses significantly reduced in amorphous triangular core designs, it can be concluded that although the transformers bid price of amorphous triangular core designs is higher than silicon steel triangular core designs, its Total Owning Cost (TOC) which contains all of the transformer life time operating costs in addition to its cost of purchase is lower. It will be shown that using amorphous triangular core design, the cost of transformer over its life time would be lower. For this design the maximum efficiency occurs at a lower utilization factor. Therefore, in networks having higher peak loads these transformers are more efficient.**

***Keywords*:** Triangular Transformers, Amorphous Metals, Silicon Steel, Optimal Design, No-load losses.

I. Introduction

Distribution Transformer no-load losses are the major part of permanent losses in a power system [1]. By reducing these losses, large amounts of energy and money can be saved annually. The amounts of these losses are determined and presented in [2]–[6]. Power system loss reduction is now a significant concern of energy distributors in each and every country.

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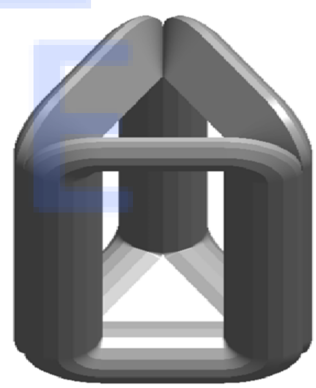
Use of amorphous metals in construction of transformer cores has been proposed in [7]-[12] for reducing transformer no-load losses. Amorphous metal has unique magnetic, mechanical, electrical and corrosion behaviors; which are generally due to non-crystalline structure of this kind of material. They behave as very soft magnetic materials (high magnetic permeability, low coercive force and low hysteresis losses), in some alloys the coefficient of the thermal expansion can be made to be zero, high electrical resistivity and high corrosion resistance are other characteristics of these materials [13].

Magnetizing currents in amorphous core transformers are 30 percent lower than silicon steel core transformers [14], on the other hand amorphous metals have lower saturation point [13] and lower core stacking factor with respect to silicon steel [14], which results in higher winding turns or higher core cross section in the design process considering the same frequency and voltage. Higher winding turns, increase the windings height and diameter, which results in increasing winding copper losses and size of the cores window. Therefore, the size of amorphous core transformers (of a specific power rating) are larger than the corresponding silicon steel core transformers and need more material.

Figure 1 shows side view and top view of the core topology in symmetrical triangular core transformer that is known for material saving with respect to conventional transformers [15]. Core of these transformers is made of three identical rings that come together with 60 degree difference to each other, each rings cross section is approximately in semicircle form, while each limbs cross section has approximately a circular form, rather than the ladder form cross section of the core in conventional transformers.



(a)

(b)

Figure 1. Core topology in symmetrical triangular core transformer. (a) Side View. (b) Top View [17].

Advantages of triangular core transformers were known many years ago but manufacturing technology and magnetic materials were barriers to development and commercial manufacturing of these transformers [16].

Some advantages of triangular transformers are as below:

- Low excitation current harmonics [17]
- Material saving and reducing cost of transformer, typically 27 percent decrease in copper usage, 24 percent decrease in ferromagnetic material usage and 24 percent decrease in transformer cost with respect to conventional core type transformers [15]
- Increasing core mechanical strength due to unified core structure
- No-load loss reduction due to less iron usage, lack of joints and punching despite of conventional laminated cores [18]
- Low stray field emission [17]
- Low noise level due to unified core structure, lack of joints and punching (7 to 10 dB decrease in triangular core transformers with respect to laminated core transformers) [17]-[19].

The common practice is to build the triangular core transformers using silicon steel as the core material. However, in a patent application publication [20], amorphous core triangular transformer has been introduced. In this paper the design of triangular core transformer using amorphous metals as core material is evaluated. This design combines the low no-load loss characteristics of the amorphous metal core transformers with the material saving characteristics of triangular transformers to introduce an optimum transformer design for use in the future.

II. Triangular Core Distribution Transformer Design Algorithm

In this design algorithm [21], some parameters of transformer are considered as design variables and the acceptable range of variation of these variables are specified by transformer designer by considering customer desired characteristics, standards and designer's experiences. In other words transformer designer indirectly specifies the number of designs that the algorithm should develop. For each design, a set of transformer parameters are calculated and some parameters that belong to design constraints, are compared with their reference values. For each design, if these parameters were not in the range of their acceptable reference values, that design will not be accepted. To increase the speed of the algorithm, constraints are checked step by step, which means that for each design if any of constraints is not satisfied, other constraints are not checked and that design will not be saved. The routine calculates TOC and saves it in the design table for each design that satisfies all of the constraints. When all the acceptable designs are developed, these designs are sorted in ascending order of their TOC. Figure 2 shows the flow chart of this design algorithm.

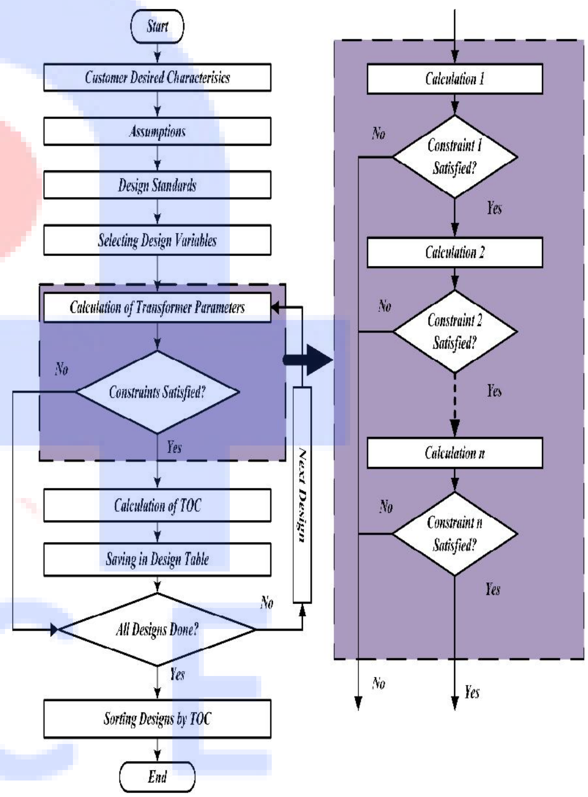


Figure 2. Flow chart of triangular core distribution transformer design algorithm

Core of triangular transformers can be either amorphous metal or silicon steel while the total owning cost of transformer is employed as the objective function in this distribution transformer design algorithm. This transformer design algorithm is employed over the whole range of standard apparent power of triangular core distribution transformer. The computed total owning cost and the operational parameters of these transformers have been compared.

The no-load loss curve, the exciting power curve, the price of core sheets besides all other production cost parameters and non-production cost parameters (when amorphous metals are used versus when silicon steel is used [22]) have been employed in this distribution transformer cost analysis. The prices are determined based on the economic parameters which exist in Iran. To determine the TOC, the no-load loss cost factor ($/W) and the load loss cost factor ($/W) are extracted from [21] (proposed for electric utilities) and are implemented into Equation (1).

$$TOC = Transformer\ Bid\ Price + A\,P_c + BP_k \qquad (1)$$

III. Design Algorithm Results

Figure 3 shows the plot of TOC for both amorphous and silicon steel core designs of triangular core distribution transformers versus standard apparent power ratings. It can be seen, in this figure that the TOC always decreases by using amorphous metals in core construction.

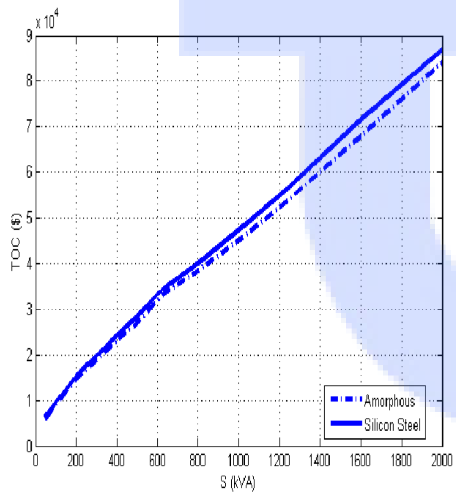


Figure 3. TOC for both amorphous and silicon steel core designs in whole range of triangular core distribution transformer standard apparent power

Figure 4 shows the plot of bid prices for both amorphous and silicon steel core designs in whole range of triangular core distribution transformers of standard apparent power ratings. It is shown in this figure that by using amorphous metals in core construction, the transformer bid price is increased.

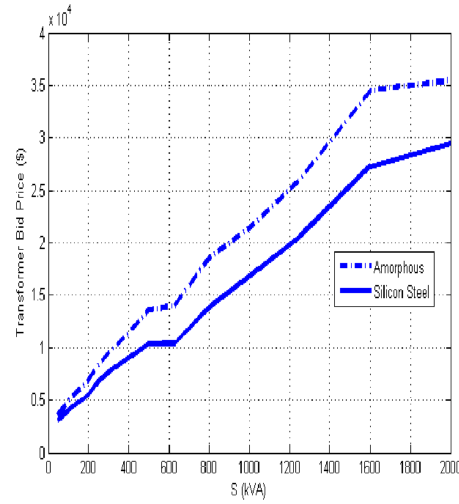


Figure 4. Bid prices for both amorphous and silicon steel triangular core distribution transformer designs versus their power ratings

Figure 5 shows very significant reduction in no-load losses in amorphous triangular core transformer designs which is the main target in using amorphous metals in construction of transformer cores.

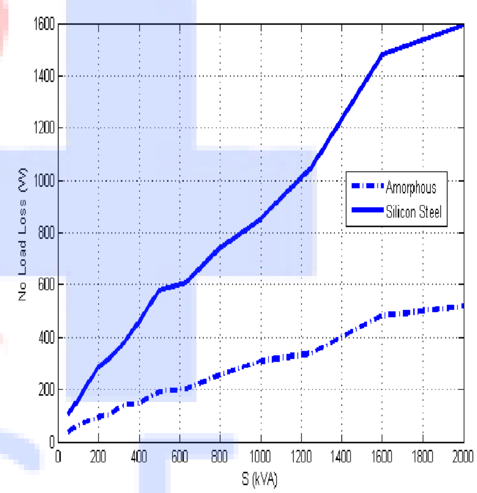


Figure 5. No-load losses for both amorphous and silicon steel core designs in whole range of triangular core distribution transformer standard apparent power

Distribution transformer load losses at its rated power should be lower than a guaranteed value specified by the customer or standard which is considered in the algorithm by a load loss constraint. This is done through design algorithm of this work under a specific load loss constraint. Figure 6 shows the variation of load losses, when amorphous metal or silicon steel is used in core construction of a distribution transformer (having a triangular core), versus its power rating. In general, the load losses in amorphous triangular distribution transformers are higher than in silicon steel triangular core distribution transformers, although this rise is relatively small.

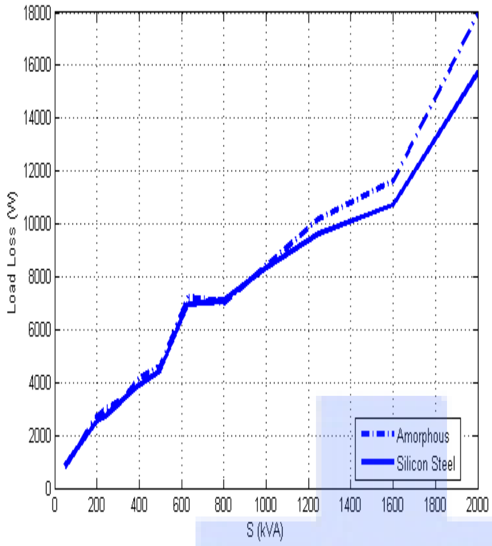


Figure 6. Load losses in both amorphous and silicon steel triangular core distribution transformers designs versus their power ratings

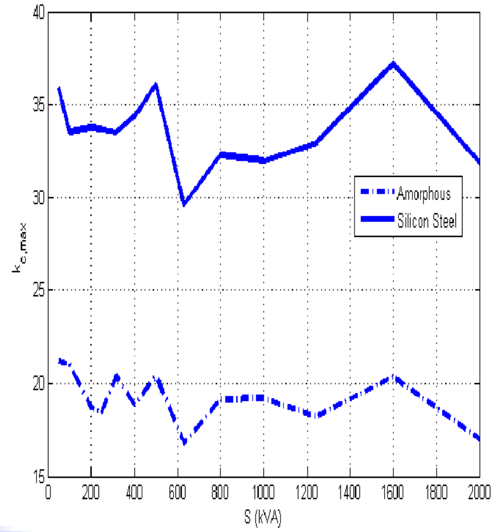


Figure 7. Utilization factor (with maximum efficiency) in both amorphous and silicon steel core distribution transformers designs versus its power rating under a triangular core

Efficiency of transformers can be determined through (2), (3) [23].

$$\eta = \frac{P_{out}}{P_{out} + P_c + P_k}$$

(2)

$$\eta = \frac{k_c S_{rated} \cos\varphi}{k_c S_{rated} \cos\varphi + P_c + k_c^2 P_{k,rated}} \qquad (3)$$

In (3) k_c is the utilization factor and it can be computed using (4) [24].

$$k_c = \frac{S_{out}}{S_{rated}}$$

(4)

When the load losses and no-load losses are equal, the transformer efficiency would be maximized. The utilization factor which corresponds to the maximum efficiency of transformer can be computed from (5) [23].

$$k_{c,\max} = \sqrt{\frac{P_c}{P_{k,rated}}} \qquad (5)$$

Figure 7 shows the utilization factor which corresponds to the maximum efficiency (amorphous triangular core transformers maximum efficiency, corresponds utilization factors which are lower if compared with silicon steel cores of the same design).

IV. DISCUSSION

Figure 8 shows the percent of change in TOC, transformer bid price, no-load losses, load losses and utilization factor with maximum efficiency, in amorphous triangular core distribution transformers with respect to silicon steel triangular core distribution transformers. This figure shows that over the standard power ratings, approximately curves are flat with a very low deviation from the mean value. In average:

Although transformer bid price is increased 25.7 percent the TOC is decreased 4.6 percent, TOC contains all of the transformer life time operating costs in addition to transformer bid price, so this is the best criterion for the transformer selection and has been used in this paper.

No-load losses are decreased by 66 percent that is very important achievement. Large amounts of energy and money can be saved by this achievement.

Load losses are increased by 4.75 percent when an amorphous core triangular transformer is compared with a silicon steel core triangular transformer. However, this increase can be controlled through adjustment of the load loss constraint in the design algorithm.

The amorphous triangular core transformer maximum efficiency obtained at a utilization factor 42.83 percent lower than its value in a silicon steel triangular transformer. This is due to significant reduction in no-load losses of amorphous core transformers.

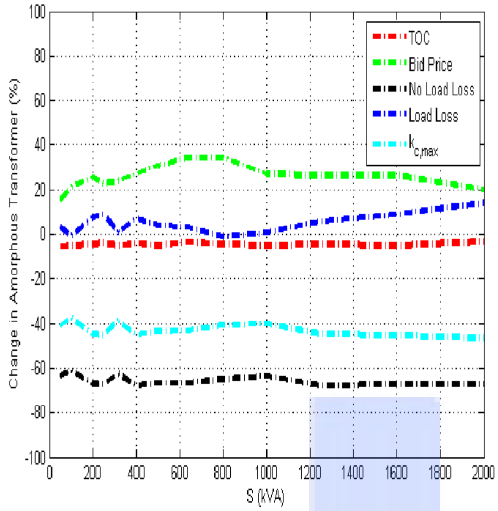


Figure 8. Percent of change in cost and operational parameters, in amorphous triangular core distribution transformers respect to silicon steel triangular core distribution transformers

V. CONCLUSION

Through analysis of distribution transformer (having triangular core) design results with the amorphous metal versus silicon steel, by proposed algorithm for the design of triangular distribution transformers, in average:

Although transformer bid price is increased 25.7 percent the TOC is decreased 4.6 percent, and transformer selection is based on TOC.

No-load losses are decreased by 66 percent that is very important achievement.

Load losses are increased by 4.75, but this increase can be controlled by changing the amount of the load losses constraint in design algorithm.

Also transformer maximum efficiency takes place at utilization factors that are 42.83 percent lower in amorphous triangular core transformers with respect to silicon steel triangular core transformers. This means the application of this transformers are more efficient with higher peaks in load pattern.

Also transformer maximum efficiency takes place at utilization factors that are 42.83 percent lower in amorphous triangular core transformers with respect to silicon steel triangular core transformers, shows that these transformers are more efficient with higher peaks in the load pattern.

Application of amorphous metals as core material in triangular core distribution transformer design (in any standard power rating) is advantageous.

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