ENERGY EFFICIENT GREEN TRANSFORMER MANUFACTURING WITH AMORPHOUS CORES

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Energy Efficient Green Transformer Manufacturing with Amorphous Cores

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***Abstract*— Transformer is one of the most important and vital components in the power system. Distribution transformer with iron-based amorphous metal core is an energy efficient transformer. Core loss from that type of transformer is approximately 25-30% less than conventional type of cold rolled grain oriented silicon steel core (CRGO), namely amorphous core can slash the no-load losses by up to 70% and make possible to build very high effienceny distribution transformer. To reduce the losses of transformer means to contribute to decrease greenhouse gas emissions by reducing the production of energy loss. In EU network are about 5 millon distribution transformers and contributing approximately 30 million tons of CO_2 emissions. There are more than 2,5 million amorphous metal core distribution transformers (AMDT) in worldwide operations. This paper introduces a brief comparison between conventional distribution transformers and amorphous core distribution transformers. Investigation is carried out on the iron-based amorphous wound core distribution transformer production technology. Amorphous ribbon is relatively thin (22-30 µm), hard, stress-sensitive and requires annealing process under a magnetic field to achieve the optimum performance. Result from that the eddy current losses lower as compared to CRGO and ease of magnetization and demagnetization, also lower hysteresis losses. A case study is presented capitalized losses and the payback period over the lifetime. The evaluation states the difference between AMDT and conventional transformers with CRGO.**

Keywords-amorphous metal; CO_2 emission; distribution transformers; energy saving; magnetic performance

I. INTRODUCTION

Energy efficiency is set to be one of European Industry's major challenges. Total energy loss of network is approximately 7-8% of generated energy in EU Countries. High voltage and extra high voltage transmission line losses are nearly 34%, medium and low voltage distribution line losses are 36% and distribution transformer losses are 30% of total energy loss. In EU network are about 5 millon distribution transformers in operation and contributing approximately 30 million tons of CO_2 emissions. The losses in distribution transformers, 2-3% of total electric power production, nearly consist of 30% load losses that vary depending on the transformer load and 70% no-load losses. The worldwide electricity savings potential of switching to high efficiency distribution transformers has not only technically advantageous, but also brings economic and environmental benefits [1-3].

A distribution transformer consists of an iron core with a limb for each of the phases. Distribution transformers with iron-based amorphous metal core are known as energy efficient transformers. Due to atomic structure and thinness of amorphous metal (Fe-based), no load loss (hysteresis and eddy current losses) of transformer can be decreased. Random molecular structure of amorphous metal causes less friction when a magnetic field is applied. As amorphous metals have very thin laminations, the eddy current losses are reduced reasonably. On the other hand, the atomic structure of the amorphous metal alloy gives rise to small saturation values of the magnetic flux density. Another feature of amorphous material is that its one step manufacturing process reduces the production costs considerably.

Amorphous materials hardness, being four to five times harder than silicon iron, is the greatest challenge for transformer manufacturers. Cutting amorphous material by conventional cutting tools wear out the equipment a thousand times faster compared to cutting grain oriented silicon iron. Despite these manufacturing difficulties, very low core loss of amorphous metals worth the effort for production [4].

Core loss of amorphous metal core distribution transformers (AMDT) is approximately 25-30% of conventional type cold rolled grain oriented silicon steel core transformers (CRGO). Amorphous core can slash the no-load losses by up to 70% and make possible to build very high efficiency distribution transformer (Table 1).

TABLE I. THE LOSSES OF AMDT AND CRGO CORES

	Amorphous Core		CRGO Core	
	Eddy Current Losses	**Hysteresis Losses**	**Eddy Current Losses**	**Hysteresis Losses**
Linear Loads	33%	67%	67%	33%
Non-Linear Loads	1,3 x Linear Loads		1,8 x Linear Loads	

The key feature of energy efficiency is the design, cut and fabrication of distribution transformers. It has been found that amorphous alloys used for transformer cores mostly have about 80% iron and 20% boron. Thus B_S, saturation induction (flux density) values of iron amorphous alloys is reduced by about 20% compared with pure iron [5].

II. Application

The design process of transformers is heavily influenced by the need to minimize the losses. Reduction of no-load loss depends on the availability of transformer core with better magnetic performance. ENPAY produces high quality amorphous distributed gap (wound) cores according to consumer specification for single phase and three phases distribution transformer applications by using amorphous metal [6].

Amorphous metal cores also need to be annealed with a magnetic field to achieve lowest possible core loss and excitation levels, but the process also makes the material brittle [7]. Epoxy coating technique is applied to some parts of the cores in order to get better mechanical rigidity. Figure 1 shows various design types of distributed gap amorphous cores.

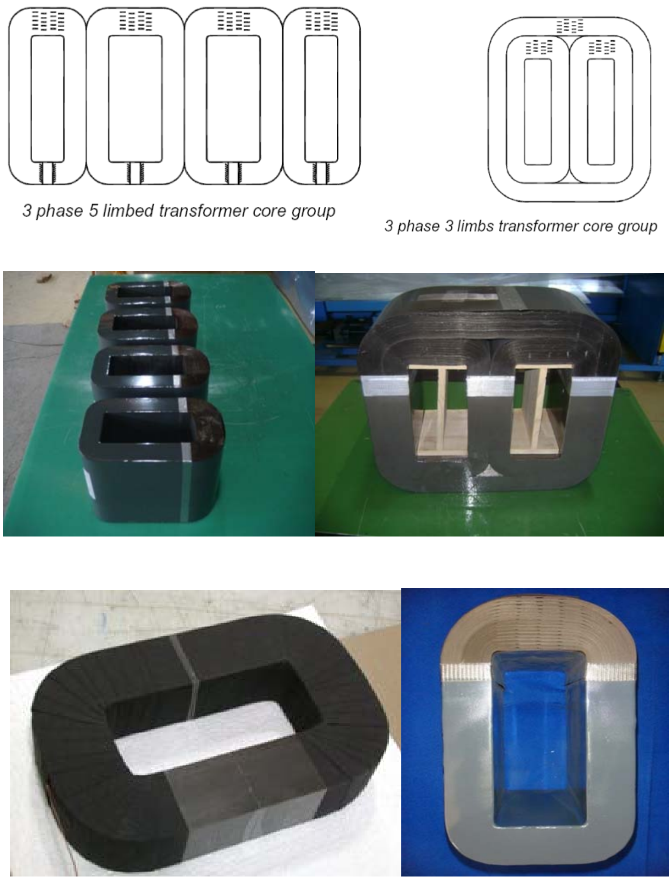

Figure 1. Various types of distributed gap cores

Amorphous metal is produced by rapid solidification and contains no crystalline structure. The amorphous metal sheets used in the distribution transformers are about 25 μm thick. It has high strength, spectacular toughness and excellent magnetic properties.

There are mainly two types of transformer losses: no-load loss (P_0) and load loss (P_K). During normal operation conditions no-load loss is always present and constant, where load loss is purely load dependent. The fundamental components of load loss are high voltage and low voltage resistive winding losses (I^2R), stray losses, lead and bushing losses. Total loss is the summation of load and no-load losses. Linear and non-linear loads affect the total losses considerably. Non-linear loads also bring out harmonics having negative impact on transformer efficiency. Figure 2 shows the effect of load profiles on various oil-immersed transformers with amorphous and CRGO cores [8].

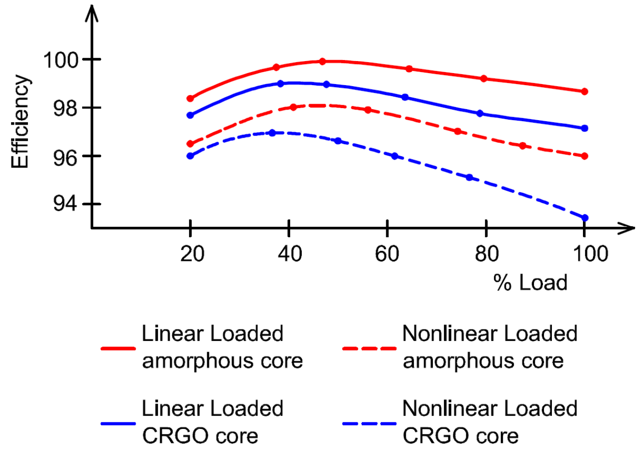

Figure 2. Efficiency grades of various 400 kVA oil-immersed transformers with linear and non-linear loads

Amorphous core can bring about an excellent change in the performance of distribution transformer. As amorphous metal has lower no-load loss than any other electrical steel, AMDT is more suitable for customers with higher no-load loss capitalization factors. It reduces the no-load loss up to 70% with 60-65% lower existing current and a smaller temperature rise as compared to CRGO steel core transformer. Figure 3 shows the efficiency curves of a 2250 kVA transformer with amorphous metal and CRGO cores under linear load.

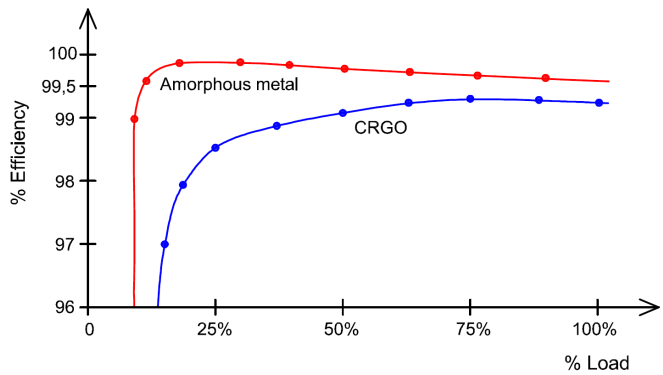

Figure 3. Efficiency curves of 2250 kVA transformer with amorphous and CRGO cores

No-load losses of the transformer are mainly composed of hysteresis losses and eddy current losses in the core. The significant advantage of amorphous metal core transformers is lower no-load losses compared to the CRGO steel transformers. Table 2 shows the measured no-load losses of AMDT cores for 3 different power levels.

TABLE II. MEASURED NO-LOAD LOSSES OF AMDT CORES

Power	Voltage	Core Type	Core Weight	Induction	Unit Loss	No-Load Loss
kVA	kV		Kg	T	W/kg	W
1000	33/0.4	5 LEG	1363,52	1,3	0,29	397,46
250	10/0.4	3 LEG	448,44	1,3	0,25	114,00
100	33/0.4	3 LEG	263	1,3	0,25	65,16

A comparison has done between amorphous, CRGO and CRGO-H0Laser core losses as shown in Table 3. No-load loss of amorphous cores is approximately 70-80% that of CRGO cores. The AMDT option helps to reach efficiency requirements easily and economically. Depending on the load profile, construction of the amorphous core transformer can be adjusted to optimize performance.

TABLE III. COMPARISON BETWEEN AMDT AND CRGO CORE LOSSES

Power	Amorphous (2605SA1)	CRGO	CRGO - H0Laser	Disparity	Disparity
	No-Load Loss	No-Load Loss	No-Load Loss	Amorphous & CRGO	Amorphous & CRGO - H0Laser
kVA	W	W	W	%	%
1000	400	1695	1240	76%	68%
250	114	561	370	80%	69%
100	70	345		80%	

Distribution transformers are typically custom designed due to the customer specifications and technical requirements. Some customers prefer the lowest possible purchase price, ignoring the cost of losses over the transformer lifetime. Generally, such customers, e.g. contractors, are not responsible for the owing or operational costs of the transformers. In addition, the design reflects an optimization between the cost of materials and labor used in the production of the transformer and the cost of losses. The design of the coils has to be adjusted due to the atomic structure of the amorphous metal alloy rising small saturation values of the magnetic flux density. The cross-sectional dimensions of amorphous core have to be enlarged or the number of winding turns in the coils has to be enlarged to keep the magnetic flux density low in the core. This increment on the dimensions of the transformer results in higher initial costs of the unit.

III. CONCLUSION

The main advantages of amorphous metal are the easy magnetization, low magnetic losses, fast flux reversal and better performance under harmonics with non-linear loads. Amorphous cores and transformers consume about 70% less electricity (at no-load) and cause more efficient use of electricity, lower operating costs and less demand on energy resources. The unit cost to produce the amorphous material is considerably lower than the cost to produce other core steels due to one step manufacturing process. The purchase price of AMDTs is barely more than conventional distribution transformers due to their relatively large dimensions, but taking the full life cycle cost into account, selecting AMDT is an economic investment. After comparative analyzing of amorphous alloy transformer and CRGO core transformers, it can be stated that energy efficiency of amorphous cores is superior to CRGO cores. The focus on energy efficiency and environmental sustainability, along with the cost competitiveness now available, make AMDT an attractive choice today. All measurements are very helpful for optimizing design and improving technologies for amorphous metal core distribution transformers.

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ENPAY Transformer Components

ENERGY EFFICIENT GREEN TRANSFORMER MANUFACTURING WITH AMORPHOUS CORES

CONTRIBUTION

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1- ENERGY CHALLENGES with
AMDT Amorphous Metal Distribution Transformers

A SMART SOLUTION

1- ENERGY CHALLENGES with
AMDT Amorphous Metal Distribution Transformers

In the last decades, the economical advantages as well as the environmental requirements are a motive for manufacturing most of Distribution Transformers with Amorphous Metal Cores.

This application is one of the unavoidable in renewable energy distributions(SMART GRIDS). After CHERNOBIL and FUKUSHIMA nuclear catastrophes it is a worldwide tendency to go rapidly out of nuclear and to invest as much as possible renewable energy sources.

To install the Transformers with less loss is more important in renewable and smart distribution systems.

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2-HISTORY

The first amorphous metal (as metallic glas) was produced in 1960 in the Labs of California Institute of Technology . Commercial development came after oil crisis of the 1970’s.

In the year of 1982 , the first Transformer with amorphous metal core went in to commercial use in NORTH CAROLINA. That was pad-mounted 25KVA distribution Transformer.

3- CURRENT GLOBAL ACTIVITIES

AMDT are widely used in major energy markets USA, JAPAN, CHINA, INDIA ,TAIWAN, BANGLADESH, BRASIL and KOREA.
In EUROPE it is still in study.

Potential Producers of AM Ribbon are located in USA,JAPAN,CHINA

In the end of 2010 CHINA installed approx. 70 000 MVA, in INDIA 35 000 MVA.

Demand is increasing worldwide.

The world's largest delivered AMDT was 12/15 MVA in the year 2007.

Amorphous Core give up to 75% energy saving compared to conventional Core (CRGO).

4- SEEDT

Strategies for development and diffusion of Energy Efficient Distribution Transformers (EUROPEAN)

SEEDT reported that ;

- In the last decades was realized significant challenge for **NO LOAD LOSSES REDUCTION.**
- **NO LOAD LOSSES** still account for about two thirds of total losses in DT.
- In the past this proportion was even higher reaching 80 % share of no load losses in total losses.

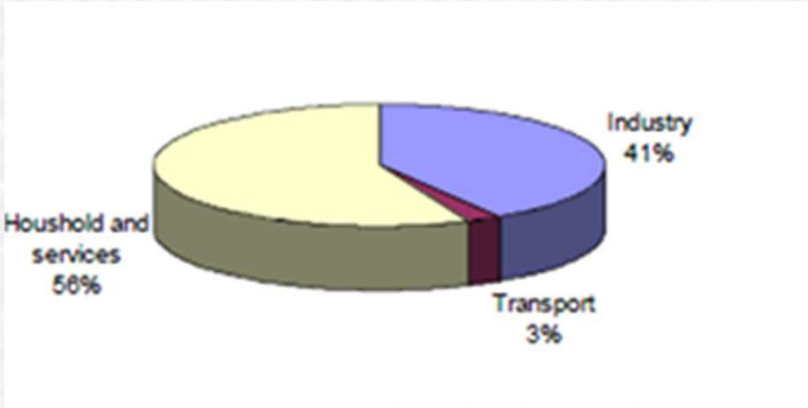
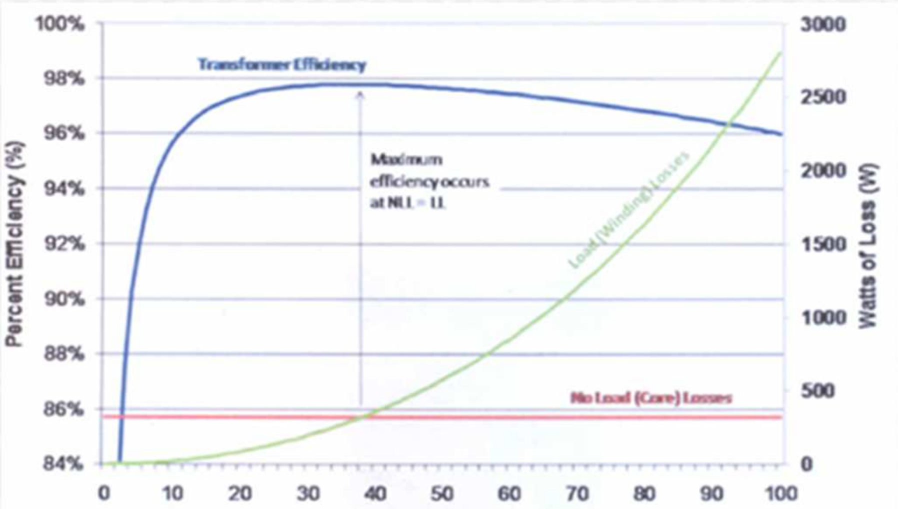


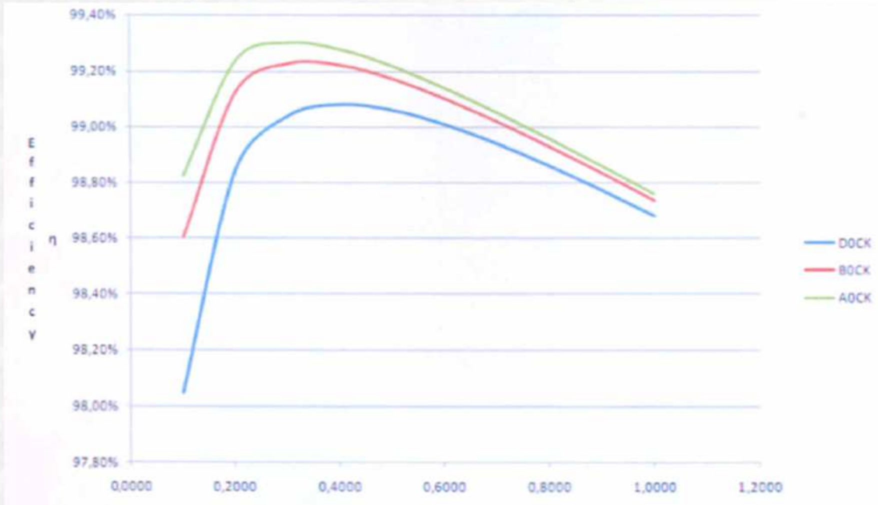
Fig. Division of final electricity consumption by sector (Eurostat 2004)

4- SEEDT



Percent Rated Loading (%)

Transformer efficiency and different losses for 75 kVA oil immersed transformer (VITO & BIOIS, 2011)



Load Factor α =Pavg /S

Transformer efficiency for different classes of 400 kVA oil immersed transformers (D0Ck, B0CK, A0Ck (top), (VITO & BIOIS, 2011)

Energy efficiency is a key point in current European policies and an environmental necessity for the future.

4- SEEDT

TRANSFORMERS HAVE TWO TYPES OF ENERGY LOSSES = A+B

A. **NO LOAD LOSSES (CORE LOSSES) ARE CONTINIOUS NON STOP INDEPENDENT OF LOAD**
B. **LOAD LOSSES (COIL LOSSES) ARE PROPORTIONAL TO THE SQUARE OF LOAD DROWN**

NO LOAD LOSSES = Hysteresis Loss + Eddy current Loss

This two losses are lower in Amorphous Metal

Losses of Distribution Transformers (DT) are 30% of Total Losses in electric Networks – EU – 27.

No Load losses are 70 % of (DT)
Load Losses are 30 % of (DT)

Source: (SEEDT)

5-MAGNETIC PROPERTIES

A) Comparison of magnetic characteristics between amorphous metal and CRGO steel:

Characteristic	Amorphous metal	CRGO Steel
B saturation (T)	1, 56 / 1, 64	2
B design admsib (T)	1, 40 / 1, 55-(1,60 ?)	1,8
Resistivity (ρ)	~130 μ Ω - cm.	~ 50 μ Ω - cm.
Curi temp. ° C	395	
Thickness	~25-30 μ m.	~200-300 μ m.
DC.Magnetic Permeability, Annealed ,max.	600 000	

B) Loss comparison chart of amorphous metal and CRGO

Eddy Current Loss

- Proportional to square of thickness.
- Amorphous metal material thickness = CRGO thickness/10
- Inversely proportional to electrical resistance.
- Amorphous metal resistivity = 3 x CRGO resistivity
- Amorphous metal eddy current loss = 0,1 x CRGO eddy current loss

5-MAGNETIC PROPERTIES

In AMDT
Core Losses under linear Loading:

Hyteresis Losses	≈ 0,8. CRGO
Eddy Losses	≈ 0,1. CRGO
Total Losses	≈ 0,3. CRGO

Core Losses under non linear loading:

In AMDT	≈ 1,3. Linear AMDT
In CRGO	≈ 1,8. Linear CRGO DT

AMDT have high performance In Non Lınear Loads (Under Harmonics)

5-MAGNETIC PROPERTIES

Harmonics Phenomenon

Harmonics Effect on Transformers

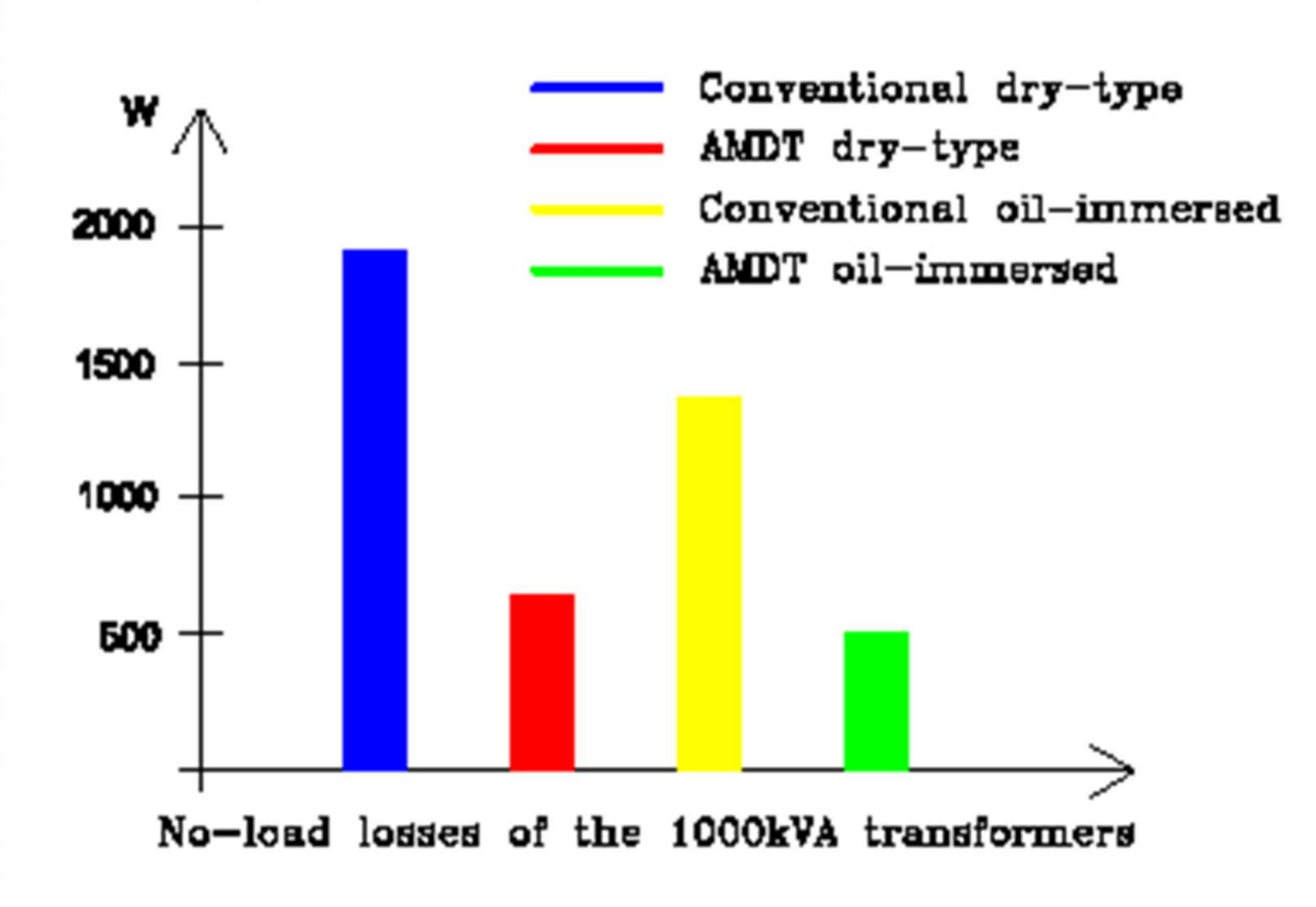
Harmonics affected on both no-load losses and load losses. According to Faraday's Law harmonics affect no load losses only in relation to Voltage Distortion.

Current harmonics are significance in most power systems. Due to skin effect the resistance and I^2R Losses increase. This means in windings harmonic effect in load losses can be bigger.

Harmonics occur mainly due to loads with non-linear characteristics.

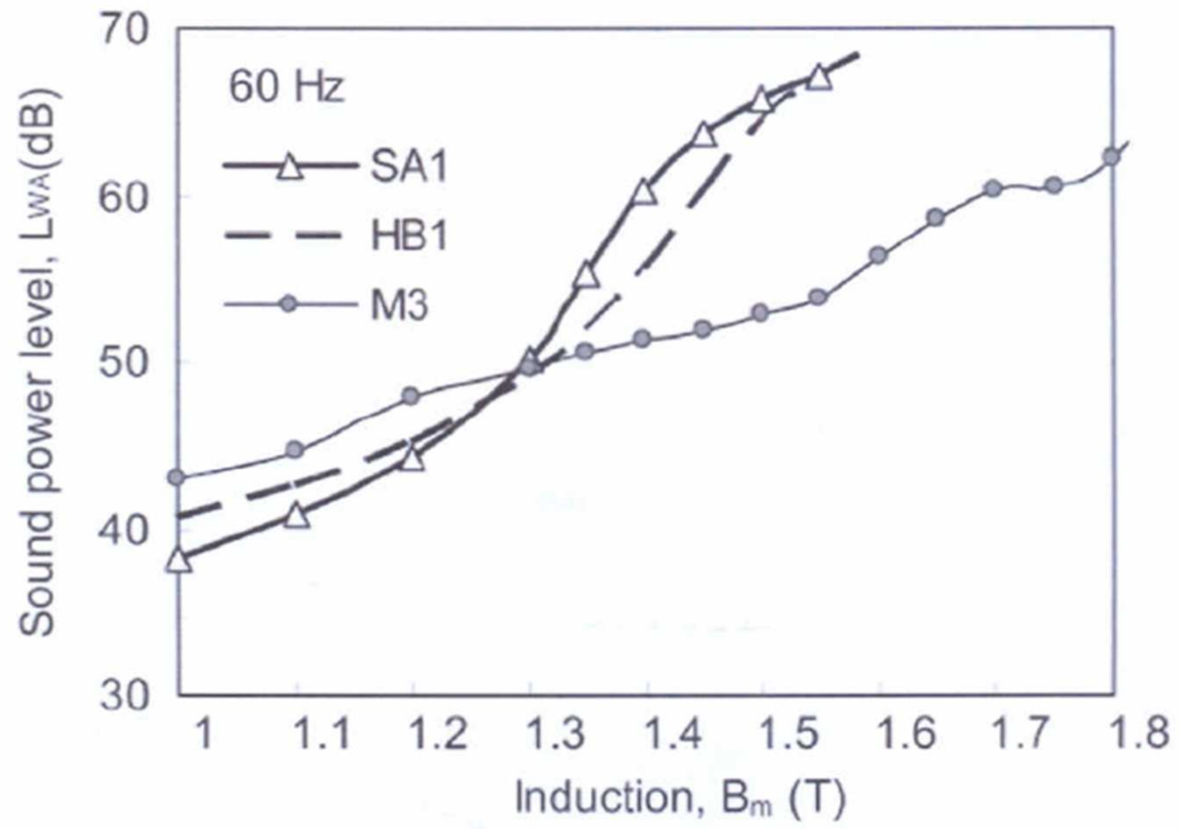
Harmonics lead to increase losses and heating as well as affecting the lifetime of the transformers.

5-MAGNETIC PROPERTIES



5-MAGNETIC PROPERTIES

Sound Level depend to induction



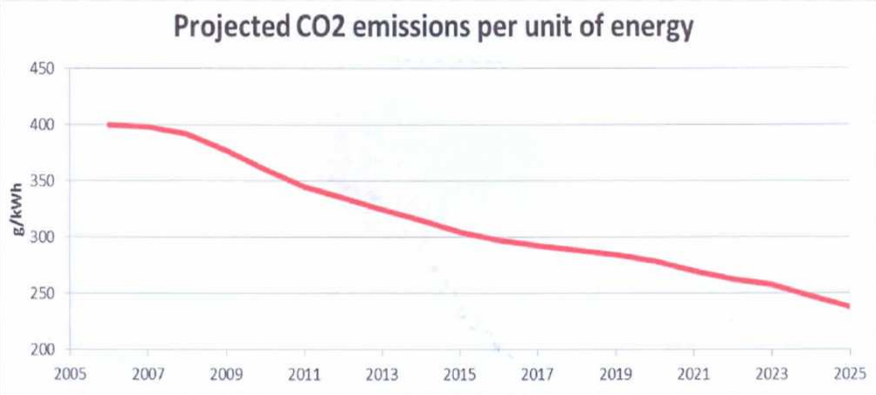
Weighted sound power level at 60 Hz as a function of operating induction on SA1 amorphous material core and M3 silicon steel-based core (Azuma & Hasegawa, 2008).

6- LOWER GREENHOUSE GAS EMISSION

Reduce Carbon Footprints and Earn carbon Credits

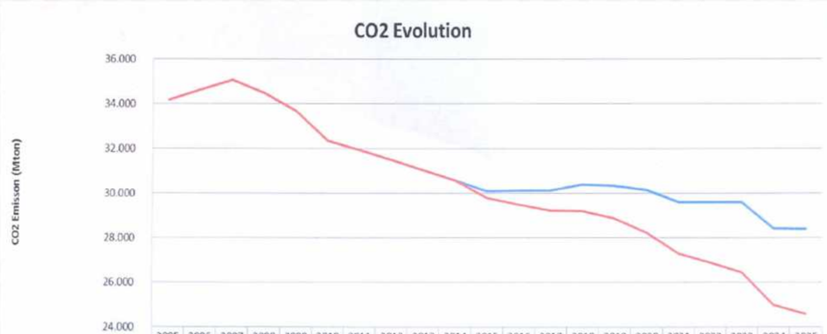
Each ton of carbon is equivalent to one carbon credit. Each carbon credit has a finite dollar value that can be traded.

CO2 emission reduction in EU – 27
3,7 Mill.ton / year
(source : (SEEDT)
1AMDT 400 kVA has a saving of CO2
2,2 ton / year
(Source: (Effitrafo)



Projected CO_2 emissions per unit of electricity in the EU (adapted from (EURELECTRIC, 2010))

The estimated cumulative CO2 emission savings between 2014 and 2025 will be about 21,8 Mton.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Business As Usual (BAU)	34.18	34.63	35.08	34.47	33.65	32.34	31.93	31.50	31.05	30.58	30.10	30.11	30.12	30.39	30.35	30.14	29.59	29.60	29.60	28.42	28.40
MEPS 2014 and 2019	34.18	34.63	35.08	34.47	33.65	32.34	31.93	31.50	31.05	30.58	29.80	29.51	29.23	29.20	28.87	28.23	27.29	26.87	26.45	25.00	24.58

Evolution of CO_2 emissions between 2005 and 2025 (EURELECTRIC, 2010))

7-AMDT CORE MANUFACTURING

Progressive Cutting Line of the ribbon

Preparation of the core

7-AMDT CORE MANUFACTURING

Field Annealing and Drying Ovens

Annealing Temperature : 320 – 350°C

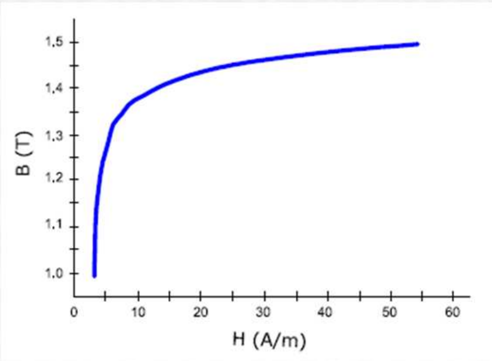
Measuring of thecore losses

7-AMDT CORE MANUFACTURING

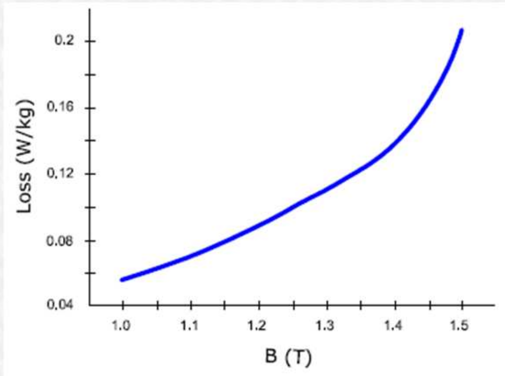
Field Annealing

The magnetic properties of amorphous metal cores are optimized by annealing in an applied magnetic field. Temperature is very important to have acceptable magnetic characteristic. Is the temperature to high, it will cause partial crystallization and increase core loss. If that is too low, residual stress is not adequately relieved.

The magnetic field is used for inducing longitudinal uniaxial anisotropy to reduce the core loss and exiting power.



The measured static B-H curves of annealed amorphous ribbon

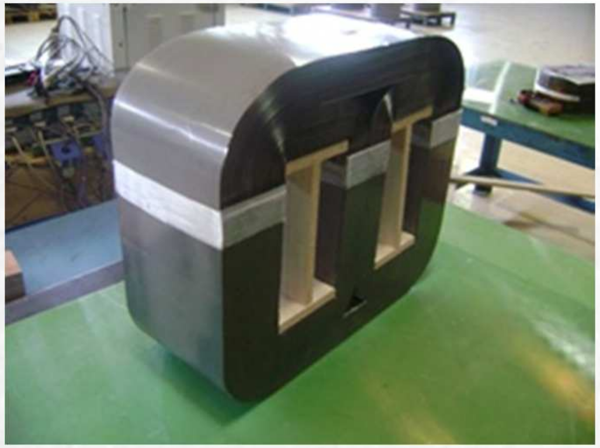


The dependence of measured core loss of annealed amorphous ribbon on flux density at 50 Hz.

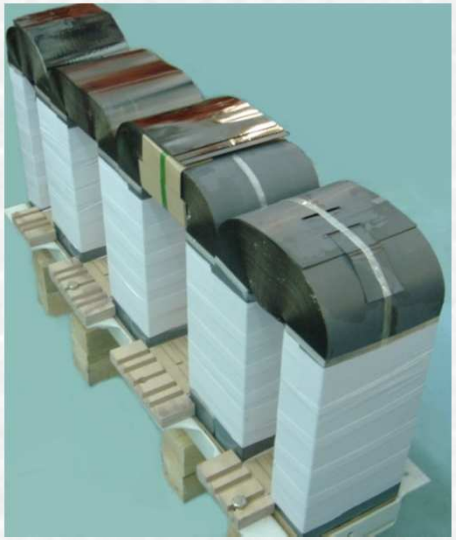
Source : MatInt

8- AMDT CORE

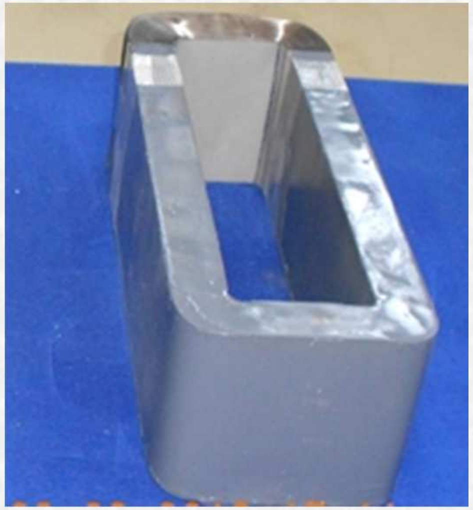
3 phase 5 limbs complete core



3 phase 3 lims core



3 phase 5 limbs core units



Single phase core limb

8- AMDT CORE

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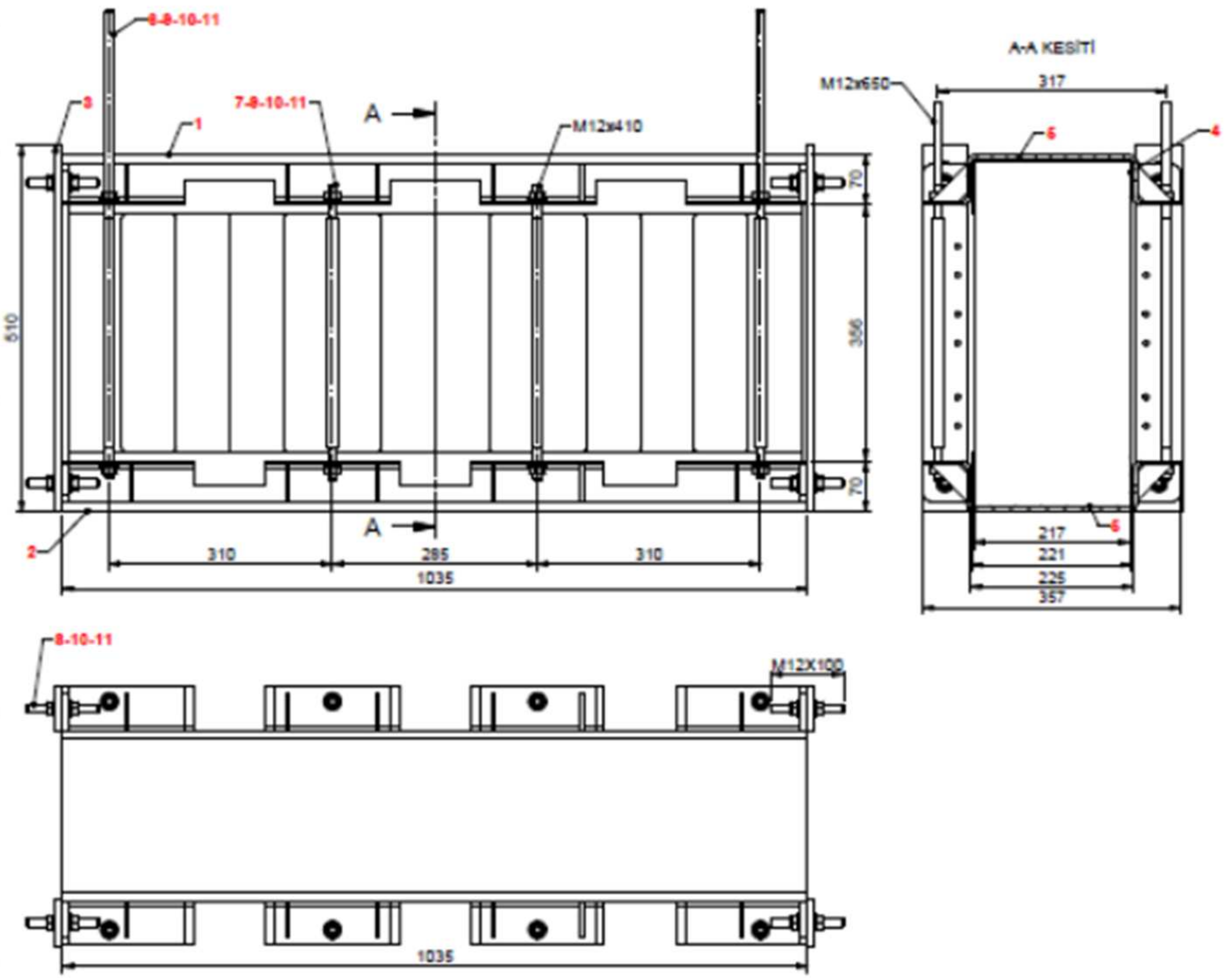
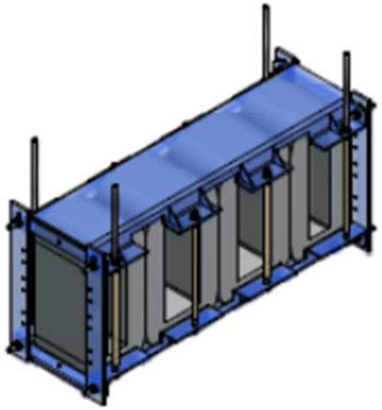




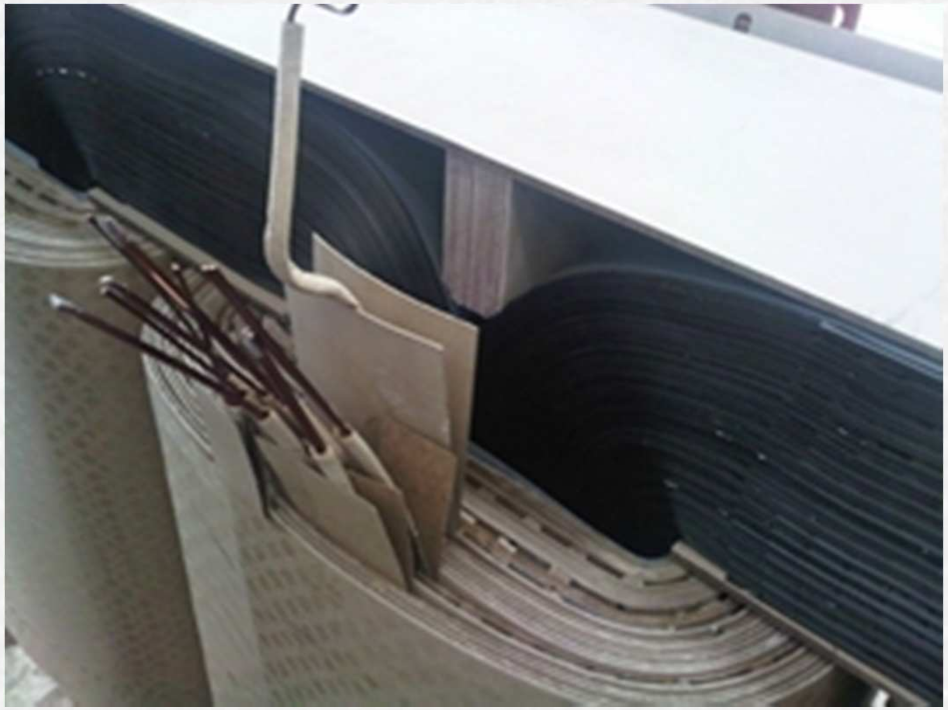
Solid model picture of
3 phase 5 limbs core

Clamping Parts for 250 KVA Amorphous Metal Core

9-WINDINGS

Low Voltage windings: Alu-or copper foils
High voltage windings: Copper wires

Layer insulation: Epoxy Diamond dotted paper



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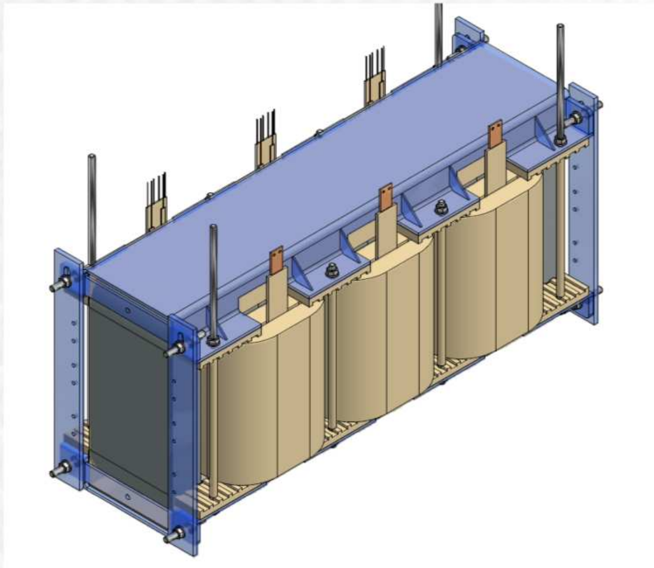
10- ACTIVE PART ASSEMBLY

Active part design proved to be able to withstand short-circuit strength without overstressing the core.



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11-TOTAL OWNERSHIP COST (TOC)

AMDT may be marginally more expensive than CRGO Core types

BUT are more cost effective in the long term and over the whole of life.

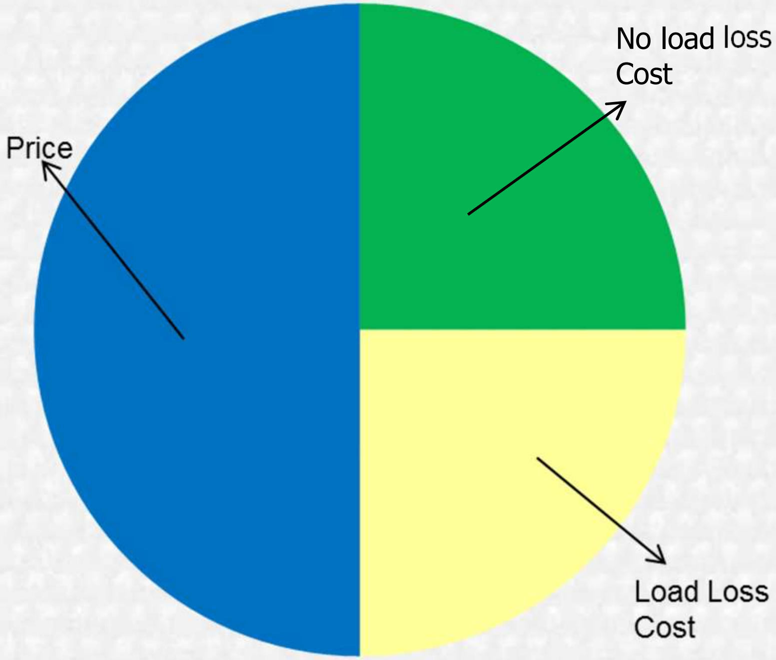
Cost effective transformer calculations should consider capital cost, energy cost, load losses and no load losses to calculate a Total Ownership Cost (TOC)

TOC= (Purchase Price) + (A x Core Loss) + (B x Winding Loss)

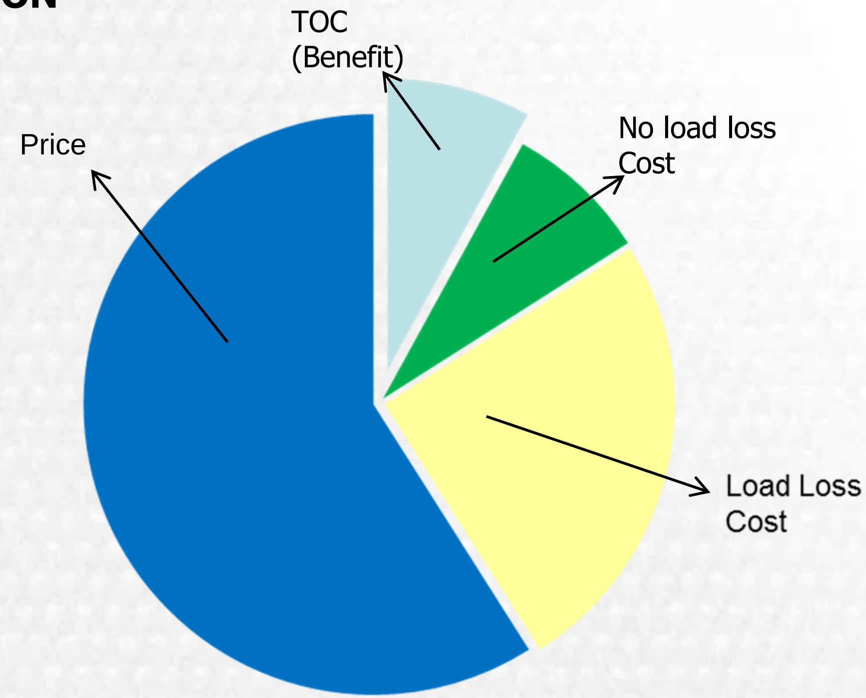
A= Core Loss factor , $ / W
B= Winding Loss Factor, $ /W

11-TOTAL OWNERSHIP COST (TOC)

TOC ILLUSTRATION



CRGO DT



AMDT

(Source Metglas)

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12- CONCLUSION

AMDT have a vital role to meet targets for reducing carbon emissions and cutting running costs.

At present roughly 2 million AMDT is operating worldwide. The increasing number of AMDT results energy saving and reduction of greenhouse gas emission.

In the last decades significant challenge was realized for no-load losses reduction.

As example the annual energy savings estimation of EU countries can be 20 TWh. This is equivalent to 3 nuclear power plant capacity.

AMDT have high performance in non linear loads (under harmonics). Detail information about production of AMDT are studied.

Total Ownership Cost (TOC) Formula shows the long-term Benefit.

AMDT CHALLENGES

COST REDUCTION	HIGHER SATURATION Bs
SIZE REDUCTION	HIGHER LAMINATION FACTOR > 86 %
NOISE REDUCTION	

ENPAY
Transformer Components

Thank You For YOUR Attentions