ENERGY EFFICIENT DISTRIBUTION TRANSFORMERS IN SPAIN: NEW TRENDS

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ABSTRACT

This paper deals with the factors that slow down the manufacturing and installation of low-losses transformers, and proposes some measures to encourage their acquisition. It reviews the savings potential of C-C' and AMDT transformers according to the European standards, and compares the measures taken to promote the use of renewable energies with regard to existing energy efficient policies.

INTRODUCTION

The Spanish electrical market has changed importantly during the last decade (Electrical Act in 1997): the way the generation pool works has been modified, tariffs back up significantly renewable energies, a series of measures promotes cogeneration, users get aids to acquire high efficient domestic appliances, etc. Current regulation furthers efficient generation and consumption, but an efficient power system needs to connect generation to consumers with efficient transmission and distribution networks. In Spain, the former is a regulated trade with acceptable profitability based on standard costs and physical units (inventory); the latter suffers from an insufficient retribution and an important historical income deficit.

Hardly any of the four million European distribution transformers can be considered as "efficient". Whilst most of them were installed when the technology did not allow efficient equipment manufacturing, nowadays technology does not slow down their implementation any longer; the present key points are regulation and market.

Several European projects have shown the interest in acquiring efficient transformers. The Thermie project (1999, co-financed by the European Commission) estimated that energy efficient transformers could save approximately 22 TWh per year by means of C-C' units (CENELEC HD 428); amorphous core transformers could save even more [1]. The Prophet project continued this task in 2004 and arrived at similar conclusions; furthermore, it showed a rising trend in the installation of amorphous transformers in Japan and China, and India and USA install them too. The main countries in Asia and USA are interested in energy efficiency [2]. In USA, 10% of new transformer sales are amorphous transformers (about 100,000 new amorphous transformers per year)[3]; 15% of new pole transformer sales in Japan are amorphous transformers (about 350,000 amorphous transformers were in service in 2003)[4].

At the moment, another EU project is working to highlight energy efficiency on Distribution Transformers, trying to go a step farther. One of the main aims of the SEEDT project is to create a label standard that eases the comparison between transformers in energy-efficiency terms. This project, co-financed by the European Commission, has begun in 2006 and is to work on the matter of energy efficiency on transformers until the beginning of 2008 [5].

In Spain, savings for losses reduction go to the costumer's bills within four years since the last regulation update; that hinders utilities from having a loss-reduction policy. A study made by Endesa in 2003 concluded the profitability of efficient transformers was very damaged by current regulation, which still applies [6]. Substitution of the whole transformer population is not realistic in the medium term, since it requires too high an initial investment and is not economically justifiable, but it would be profitable to install efficient transformers when new assets were needed [6][7].

This paper reviews and compares the savings potential of A-A' and efficient transformers (C-C' and amorphous), deals with some of the present problems the latter have to get in the market, and proposes several measures to encourage their use.

COMPARISON BETWEEN AMORPHOUS AND COLD GRAIN ORIENTED TECHNOLOGIES

Cold grain oriented (CGO) and amorphous cores are very different technologies. Cold grain oriented (CGO) cores are manufactured adding between 3% and 3.5% of silicon to iron. It raises core's resistivity from 10 to 47 μΩ·cm (Fe-3.2%Si) [8]; amorphous metal's resistivity is almost three times higher: 130 μΩ·cm for METGLAS 2605SA1 [9]. CGO sheets minimum thick is 0.23 mm; amorphous metal sheets are usually 0.025 to 0.035 mm. Again, amorphous cores provide lower core losses.

CGO cores use materials with a crystalline atomic structure to obtain an important magnetocrystalline anisotropy. It is possible to achieve losses of 0.85 W/kg (1.7 T and 50 Hz) by means of several techniques, as high permeability steel, refined domain steels, etc. [8]. Amorphous cores have a non-crystalline, anisotropic atomic structure that eases the turning of grains, lowering the coercitive field and raising the remanence. These two factors reduce the hysteresis area and increases squareness, and so losses, which are round about 0.3 W/kg at 1.4 T and 50 Hz [10]. Core reluctance for a size given depends upon the material's permeability; CGO maximum permeability is 40154 (Fe-3.2%Si, 60 Hz, 1.85 T); amorphous materials' permeability is 45000 (50 Hz, 1.4 T, as cast)[8][9].

One of the main problems of amorphous materials is their low saturation magnetic field, which makes necessary to increase the core's area to keep the flux. This comes along bigger load losses (longer windings' cables) or larger size and weight compared to current CGO transformers for a

given a rate plate (larger section windings' cables).
Metglass leads the state-of-the-art AMDT with a new amorphous material (HB1) that yields lower coercitivity, higher saturation magnetic field (1.64 T instead of 1.57 T) and higher BH squareness. When tested, the HB1 core transformer showed about 25% lower losses than that of the SA1 one (1.4T, 50Hz), and 33% lower losses than Si-Fe core transformers (1.7 T, 50 Hz). Noise was 10 dB lower in HB1 than in SA1 alloys, but still over the Si-Fe core transformer [10]; the same happens with size (10% smaller than SA1, but still larger than the Si-Fe transformer).

STUDY 1 – OLD VERSUS NEW TRANSFORMERS

In order to check efficient transformers profitability, two possibilities were analysed using TOC in a population of 5237 transformers on the ENDESA's Spanish network:

- Substitution of existing transformers by new efficient ones (C-C', CENELEC HD428 standard)
- Comparison between installing C-C' transformers instead of a A-A' transformers when necessary

This study is based on no-load losses, given that the load curve will be the same for both the new and the old transformer. Furthermore, distribution transformers are lightly loaded and no-load losses represent the most important part of losses (about 70% of losses on average). A similar relation applies to the costs associated to losses.
The no-load losses average of available technologies at the moment of their installation were calculated in order to estimate the no-load losses of installed transformers. Figure 1 shows the evolution of losses and the estimated average.
According to the results of the first study, only the change of small (50 kVA) and old (manufactured before 1960) transformers were profitable given the present losses-regulation in Spain; this group represents not even a 1% of the universe analysed, and it will possibly be substituted in a short time anyway, since these units are over their average life cycle. The second analysis found out that installing big efficient transformers instead of non-efficient ones (400 kVA, 630 kVA and 1000 kVA) seemed profitable.
Assuming losses-goal revisions by the Spanish regulation take place every 8 years, the over-investment would only be profitable if the transformer were installed during the first three years after the last regulation revision, owing to payback is never less than five years. This is why the Spanish "losses incentive" does not allow utilities to apply a general efficient transformer's acquisition policy.

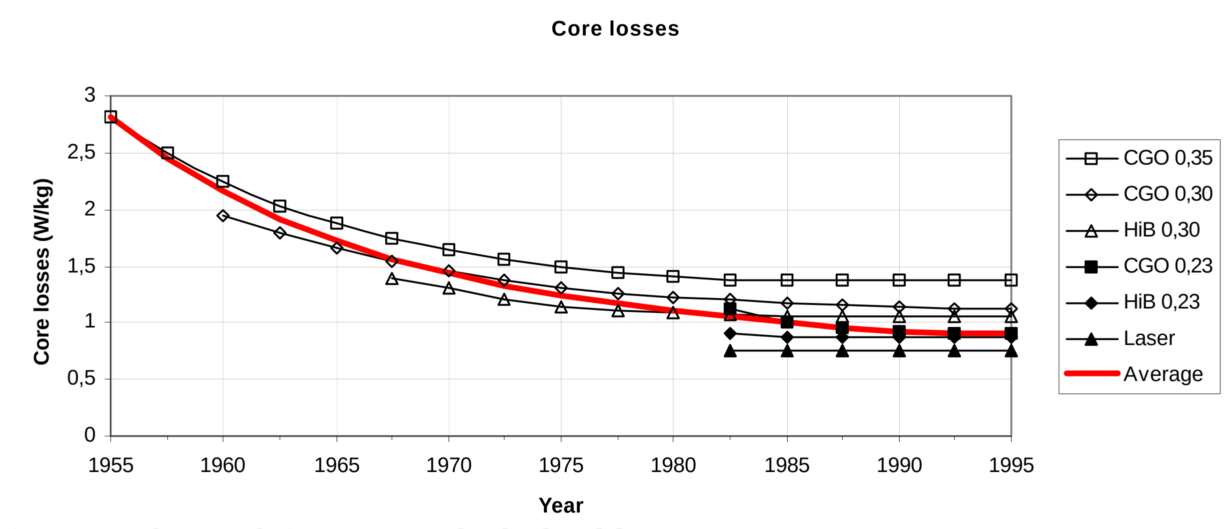

Figure 1 Core losses evolution per year and technology [1]

STUDY 2 – EXISTING VERSUS EFFICIENT TRANSFORMERS

This study was made upon the whole of the Spanish distribution transformer population considering all installed transformers as A-A'. It is a conservative study, since the existing transformers have equal or greater losses than A-A' standard. Two cases have been considered:

- Substitution of existing transformers by a new efficient one (C-C', CENELEC HD428 standard)
- Comparison between installing C-C' transformers instead of A-A' transformers when necessary

This analysis considered both load and no-load losses. Load losses and energy price were calculated in a per-hour base from data published by OMEL (national market operator) in 2005 and load curves from Endesa for several markets (urban, tourist, rural and industrial). The amount and technology of generation were also considered in order to calculate the CO_2 emission's savings and cost; CO_2 emission's price was 22€ per ton. Calculations were performed using data from Endesa and extrapolating the results to the Spanish transformer population; TOC was used again.
The results were similar to the obtained in Study 1. Generally, it is not profitable for Spanish utilities to

substitute existing transformers by C-C' ones given the present national regulation (see Figure 2). When a new transformer must be installed, only transformers bigger than 400 kVA have a payback lower than eight years. Unfortunately, as before, the payback is never less than six years (five years when the cost of emissions is considered). It makes very difficult to utilities to apply a general policy of energy efficient transformer acquisition with the current losses regulation. Figure 3 shows the savings considering the transformer population grows 7.290 transformers per year (average grow of the last three years).

	Spanish Utilities		CO_2 Emissions	Emissions Cost
	∆ Initial Cost (M€)	∆ Annual losses (M€)	Emissions	Cost
Market			tonnes	M€
Urban	76.8	17.6	146.0	3.2
Tourist	7.1	1.4	11.0	0.3
Rural	38.1	3.9	32.0	0.7
Industry	5.2	1.1	9.0	0.2

Figure 2 Comparison between the actual transformer population in Spain (considering all transformers as A-A') and the cost of installing a new population of C-C' transformers (same power rate)

	Spanish Utilities		CO_2 Emissions	Emissions Cost
∆ Annual Market	∆ Initial Cost (M€)	∆ Annual losses (M€)	Tonnes	M€
7290	**4.9**	**0.9**	**7.7**	**0.17**

Figure 3 Comparison between installing new transformers using A-A' efficiency or C-C'

STUDY 3 – C-C' VERSUS AMDT TRANSFORMER

The following study compares two transformers from BEZ (a Slovakian manufacturer) based on the datasheets of both machines. These transformers are manufactured with Metglas cores. Figure 4 shows their characteristics [11], which confirm what was stated above when we compared CGO with amorphous cores. Both are cast resin transformers (only oil filled transformers are generally used by Spanish utilities).

	A-A'	C-C'	Amorphous
HV (V)	10000	10000	10000
LV (V)	400/231	400/231	400/231
No-load losses (W)	2000	1500	650
Load losses (W)	10000	10000	10000
Impedance voltage	6%	6%	6%
Sound power (dB)	68	69	74
Length (mm)	1480	1630	1470
Width (mm)	800	970	970
Higth (mm)	1590	1750	1485
Weigth (kg)	3000	3000	3510
Winding	Al	Al	Cu

Figure 4 Characteristics of two 1000 kVA cast resin transformers

Since load losses are the same, only the no-load losses study applies; the energy saved by installing the amorphous transformer instead of the C-C' transformer amounts 7.45 MWh per year. In fact, the C-C' transformer wastes as much energy as 2.3 amorphous transformers. These losses represent 277 € per year at average energy price in Spain in 2005.

If the A-A' transformer is compared with the amorphous one, the latter saves 11,826 MWh with respect to the former. That means that the A-A' wastes as much energy as 3 amorphous transformers. In economic terms, these losses amount 440 € per year.

Several studies have compared CGO and amorphous transformers in terms of energy efficiency and profitability, and all conclude that amorphous transformers are the most energy efficient options (see figure 5) [10][12].

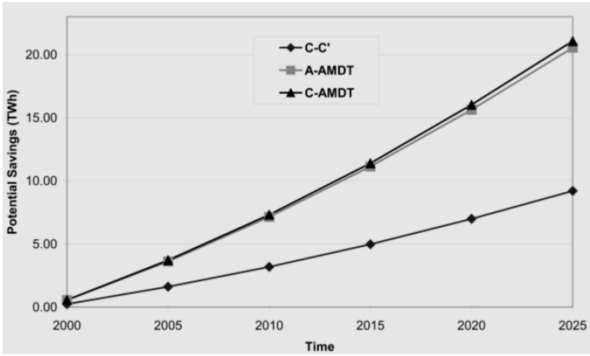

Figure 5 Savings potential if energy-efficient transformers would have been installed in Europe since year 2000 [1]

In economic terms, some studies have calculated that initial overinvestment could be paid back in five or six years for 630 kVA transformers. When bigger transformers are considered, the payback period goes down to 3 years [1][13]. A deeper study of profitability should consider present and future trends of energy prices and both CGO and amorphous transformers. In the present analysis, it has been necessary to change the windings material from aluminium to copper in order to keep load losses constant. It makes the AMDT the heaviest and most expensive transformer of the comparison (see figure 4). In 1999, the Thermie showed that the weight of the amorphous core transformer's copper windings was somewhere between 2 and 2.5 the weight of the C-C' core transformer's aluminium windings. At that time, amorphous transformers were also 50% more expensive than CGO transformers [1]. Fortunately, technology keeps going on and new materials can make these differences decrease and make amorphous transformers even more profitable in both efficiency and economic terms. Nevertheless, reliability improvement and more competitors in cores manufacturing are key points to promote amorphous distribution transformers among utilities in the next decade.

CONCLUSIONS

Given the trend of fuel prices, efficient T&D assets should be regulated in order to allow some clear profitability. If they are not profitable by themselves, and they hardly ever are given their manufacturing techniques and raw materials, regulation should make them economically interesting. New amorphous metal manufacturers are necessary to create a real market of efficient DT in order to decrease prices and compete with the CGO market.

At the moment, most incentives from energy regulation in EU countries apply to home appliances and generation (mainly renewable energies), but they do not apply to transformers (i.e. in Spain the “losses incentive” is not enough to really promote over-investments in low-losses transformers).

The present problem is not related to technology or R&D; it is a matter of proper regulation. In Spain, it provides utilities with two “indirect” ways of recovering part of the initial investment in efficient assets. One of them is the decree 4/2004, which gives some fiscal benefits to those companies investing on equipment that avoids atmospheric pollution. The second way is the decree 1955/2000, which obliges customers to pay certain works and new equipment according to the applied power and voltage.

Nevertheless, these indirect benefits are marginal compared to the aids the government gives to renewable energies, which sell their energy at 575% (solar energy) and 90% (wind energy) the reference tariff. It would be difficult to show that renewable energies are more efficient than not consuming energy, as efficient transformers do. For that reason, efficient equipment could get some kind of bonus for energy savings, as it happens with renewable energies, allowing efficient and non-efficient equipment to compete in the short term, since it would shorten the former’s payback.

Different ways to incent efficient DT could be applied, as some economic help for the initial over-investment when buying an efficient transformer (as it happens with efficient home appliances); this way, part of the over-investment respect to a non-efficient transformer would be covered. It would allow the purchaser to get some payback (and even profits) during the economic life cycle of the transformer, encouraging their use. This aid should be applicable to both utilities and private users. Instead of that, the Energy Efficiency Action Plan 2005-2007 in Spain encourages even more the use of renewable energies, efficient home appliances and co-generation technology, and ignores electricity distribution efficiency [14]. Fortunately, the European Action Plan for Energy Efficiency is preparing “guidelines on good regulatory practices to reduce transmission and distribution losses” [15].

Another key point to boost efficient DT in Europe (and worldwide) is new competitors among amorphous metal manufacturers. The raw material for AMDT cores is highly reliable upon prices and competence, preventing their massive installation. Apart from that, it is necessary to ease the task deciding between efficient and non-efficient equipment by means of some decision-making tool and technical advice and, above all, it is mandatory to change the current regulation to make energy efficient equipment a profitable investment (at least similar to renewables).

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