BENEFITS OF USING HIGH EFFICIENCY POWER EQUIPMENT THAT REDUCE DISTRIBUTION SYSTEM LOSSES

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ABSTRACT

Energy efficiency serves three long term European goals on the agenda of the European Commission: the competitiveness of the European Industry, the environmental protection and the security of supply. In its 2005 Green Paper, the European Commission identified several actions for various industrial sectors in order to improve energy efficiency. In the electricity industry, the European Commission encourages the Distribution Network Operators to innovate in the design and the operation of their networks in order to decrease their technical losses.

In this context, the Distribution Network Operators and the manufacturers are encouraged to make their power equipment more efficient. Among the research options, the new distribution transformer with a higher efficiency in order to reduce the losses are the most promising.
Indeed a significant share of the Distribution Network losses is located in distribution transformers. The distribution transformers no-load losses represent nearly 25% of the total technical losses of the French Distribution Network operated by ERDF. The main innovations contemplated to reduce no-load losses are:

- *Increase the magnetic steel efficiency by decreasing their thickness or by improving the insulation coating.*
- *Increase the size of the magnetic circuit to reduce induction, but with the effect of increasing the weight and the volume of the transformer as well as the load losses due to longer windings.*
- *The European manufacturers also developed their research efforts on the use of amorphous steel. This technology, which implies to significantly modify the manufacturing process, makes it possible to go even further regarding to loss reduction.*

The no-load losses can be reduced by up to 50% using high performance magnetic steels, and that reduction can reach 75% with amorphous steels.

INTRODUCTION

One of the priority approaches to achieving sustainable development involves saving energy. The Kyoto agreement to reduce greenhouse gases by 9%, and also the European Commission's "Energy green paper" that raised this objective to 20% by 2020, encourage manufacturers and distribution network operators to improve distribution network efficiency and, among other things, reduce losses inherent in transformers which contribute to the generation of greenhouse gases.

Depending on the specified performance level, no-load losses in transformers can in fact generate up to a third of the technical losses identified on distribution networks. Load losses are less important since they are proportional to the square of the power flowing through the transformer. However, transformer dimensioning in public distribution, calculated using the peak power, is such that the average load factor is generally low and often less than 20% in rural environments.

In order to get a better idea of what is at stake, a brief review follows of standardisation and practices in different countries in the European Community concerning the choice of distribution transformer losses.

DESCRIPTION OF CURRENT STANDARDS

European study committees create, generate and develop standards relative to products under the authority of the CENELEC (European Electro-technical Standardisation Committee).
Standards concerning power and distribution transformers are drawn up by the CLC/TC14 committee.
The European standard prevails in CENELEC member states and is used as a national standard. Power transformers meet general standards in the EN 60076 series (Euro Norm 60076). EN standards are adopted in a parallel vote with IEC 60076 standards (International Electro-technical Committee).
The EN 60076 standard series defines the general framework and basic principles (terminology, insulation

coordination, tests, tolerances, etc.) but does not give any performance values for losses, dimensions, noise levels or short circuit impedance.
European standard series EN 50464 precisely defines all manufacturing parameters and guaranteed transformer performance values for no-load losses, load losses, short circuit voltage, noise level and temperature rise, to mention just a few.
Standard EN 50464-1, applicable to oil-immersed distribution transformers from 50 kVA to 2500 kVA and higher voltages for equipment not exceeding 36 kV, also gives a choice of preferred lists for no-load losses and load losses; these combinations give a wide range of possibilities. If necessary, an overall cost assessment method integrating the value of losses and the investment cost will allow us to choose a combination.
The harmonisation document HD 538 for dry type distribution transformers is currently being revised and will integrate developments in loss reductions.
There are also other European standards series such as the EN 50216 series which describes transformer accessories or EN 50180, EN 50181, EN 50386, EN 50387 which describe HV and LV bushings.

EUROPEAN PRACTICES

Production and shipping costs and the distance from the place of service will strongly influence the level of distribution transformer losses.
Electrical power production from non-renewable energies such as coal, oil, or gas will be strongly dependent on the fluctuating value of these materials.
Utilities companies and users will then have to compensate for and minimise operating costs and impacts in terms of CO_2 emissions by using transformers with reduced or even very reduced losses.
Transformers with conventional losses are most commonly seen in the industrial sector, where electrical equipment acquisition is more of an economic fact than a global assessment of the purchase cost and losses.
In order to achieve high energy efficiency in delocalised or decentralised production, the use of reduced loss transformers provides economic balance and profitability.
Electrical distribution in countries such as Germany or Austria is provided by regionally located utilities companies. This leads to a wide diversity of offers and a strong tendency to use transformers with low no-load losses (Ao, Co) and average load losses (Bk, Ck).
Over the past 25 years in Northern European countries such as Sweden, Finland and Norway, the choice has been focused on transformers with low no-load losses (Co) and average load losses (Bk, Ck). These choices have been made either with reference to a list of losses or by capitalisation of those losses.
Belgium, Luxembourg, the Netherlands, Spain, Italy or France have tended to focus more on the national standard and only choosing European losses lists with one or two series of no-load and load losses. When two lists are proposed, they choose a low loss list such as Co-Ck or Co-Bk or ones that are similar to these values and a list of moderate losses of type Eo-Ck or Do-Bk or a derivative of these values.

THE POSITION OF EUROPEAN MANUFACTURERS

The association of European manufacturers working under the guidance of T&D Europe (The European association of the electricity transmission and distribution equipment and services industry) submitted recommendations to the European commission for reducing levels of losses in order for it to prepare an action plan moving in this direction.
Generally speaking European manufacturers are favourable to reducing the level of transformer losses which can reach over 50% according to the magnetic materials that are used.

The reduction of losses must take account of the load profile of devices. Other considerations must also be taken into account to determine the reduction level such as noise levels, weight and dimensions for logistics aspects, and whether using encapsulated or immersed transformers,

Other criteria such as the number of installed units, the efficiency of currently installed devices, the cost of new devices, delivery time, usage criteria, component availability, technology and manufacturer capacity must also be taken into account.

We must also account for the fact that transformers are only used by companies and rarely by individuals. They are used in networks and not as a stand-alone product. Waste at the end of the transformer's life cycle will be managed and 99% of materials recycled. Lastly the optimisation must be carried out country by country according to the way that energy is produced.

These recommendations are detailed in the T&D* POSITION PAPER
On "Study for preparing the first Working Plan of the EcoDesign Directive Report for tender No.: ENTR/06/026, published on Nov. 22nd, 2007"

ISO MATERIAL SOLUTION (M140-30-S / M111-30-P)

Many solutions exist to reduce no-load losses in transformers.

No-load losses depend on the induction in the magnetic core, the quality of the magnetic steel, the way that the steel is stacked, but also the way the steel rolls are split, cut and transported.
Each manufacturer has its own performance curve in

Watts/Kg of steel for a given induction which takes account of the above factors.
No-load losses are therefore dependent on the mass of the magnetic steel in the transformer's magnetic core and the induction in the magnetic core and therefore the number of transformer turns and the cross section of the magnetic circuit.
The mass of magnetic steel depends on the number of conductor turns which move through the magnetic circuit window, the cross section of the conductors, the insulator thicknesses and the dielectric distances.

According to these factors, there are many different solutions for each type of magnetic steel which are related to the number of winding turns which gives the magnetic cross section compatible with the transformer loss level.
If we take a product with M140-30-S steel and if we replace it by M111-30-P we can then increase the induction for the same magnetic performance level. The increase in induction is achieved by reducing the product of the magnetic circuit cross section by the number of winding turns.

SOLUTION WITH HIGH PERMEABILITY MATERIALS (M095-27-P / M090-23-P)

HIB high permeability, high performance magnetic steel will be used. At the end of the production process, this steel is subject to an additional irradiation treatment using a laser beam perpendicular to the steel laminating direction, leading to a fine-tuning and reduction in the size of magnetic areas in the material.
This magnetic steel is generally thinner, with 27 / 100 or 23 / 100 mm thickness, compared with thicknesses of 0.30 / 0.35 mm for conventional GO magnetic steel.
The main consequence of scratching (Laser or Mechanical) of this thin steel is to further reduce the specific losses W/Kg.
In the case of very reduced no-load losses, the use of scratched, high permeability HIB magnetic steel can seem to be the most economic solution in designing the transformer.
Indeed, the better magnetic performance of this steel generally allows us to even further increase the level of induction in the magnetic circuit.

CHOICE OF WINDING MATERIAL AND CONDUCTOR MATERIAL

What material should be chosen to produce transformer windings: copper or aluminium?

These materials have been used as conductors in cables, motors and transformers for many years (over 150 years for copper and over 100 years for aluminium). Aluminium was long considered to be a replacement product during dark periods in history and only really found its place in electro-technical products in the 1960's and 70's, although its use in coils had been proven from a technical point of view.
Fluctuations in commodity market values placed a lot of pressure on copper compared with aluminium and the copper/aluminium ratio regularly reaches around 3.
The different comparative physical properties of copper and aluminium mean that for an EN 50464-1 series transformer with identical no-load losses, there is a mass ratio of between 1.9 and 2.2 between copper and aluminium for a design with identical load losses and temperature rises.
The choice of winding materials will therefore be dependent on many different factors such as the current purchase price, material availability, the feasibility of wire drawing, enamelling or conductor tape winding, packaging and its round, rectangular, bar strip or ribbon form.
Windings designed with aluminium conductors take more space and, at an equal no-load loss level, the magnetic circuits have a higher mass by around 15 to 20%. Dielectric liquid cooling tanks for immersed transformers will have to dissipate the same quantity of energy for the same load and no-load losses, and they will therefore basically have the same exchange surfaces with the surrounding air and the same mass whatever materials are employed for the winding conductors. Active parts with aluminium windings will take higher volumes than those for copper winding transformers, but due to the maintaining of the tank exchange surfaces the volume of dielectric liquid will remain virtually unchanged.
A study with fixed load losses and no-load losses using conventional magnetic steel whatever the winding material shows that very low levels of no-load losses can be achieved using increasingly high performance magnetic steel (chapters 5 and 6 of this document). The difference in performance between a conventional magnetic steel and a high performance magnetic steel can reach 50%.
With identical performance levels, the economic advantages of transformers with copper or aluminium windings will depend on the relative masses of the different components, the winding, the dielectric, the magnetic steel, other steels, insulators and their respective prices. The overall optimum will be found by successive iteration until the horizontal asymptote is found of a parabolic iso-price curve.

The choice of conductor material, either copper or aluminium, will therefore be based on an economic optimum that varies from one transformer manufacturer to another depending on its purchasing capacity, employee costs, technical capacity, the availability of the used materials, the value of the transformer's eco-design and the environmental impact this has in the overall system life cycle analysis.

TRANSFORMERS WITH AMORPHOUS MAGNETIC MATERIALS

Amorphous materials were presented as an alternative to grain oriented steel as early as the 1970's for their major advantage of dividing transformer no-load losses by a factor of more than 3. These materials are iron, silicon and borium alloys, free of any crystalline structure and delivered in the form of a very low thickness ribbon which has a much lower saturation level than that of grain oriented steel, thus requiring much heavier magnetic circuits. Other drawbacks have limited the use of these materials:

- High initial cost compared with conventional steel,
- Processing that penalises applications with three-phase transformers.

Therefore, the production of amorphous materials for distribution transformers now scarcely represents 5% of the worldwide production of grain oriented steel intended for the same applications. In addition, the various attempts to introduce amorphous material transformers in Europe have been more or less limited to experiments.

However, there has been renewed interest in this technology in the past few years which cannot only be explained by the major focus on energy savings, but also by recent increases in grain oriented steel prices which have gone a long way to reducing price differentials with amorphous material prices. In this context, in order to explore all imaginable alternatives to propose optimal transformers, French manufacturers have updated studies that were abandoned in previous years.

Nonetheless, two major handicaps remain for the development of such materials:

- The lack of offer: To date only one manufacturer proposes amorphous magnetic materials, leading to uncertainty on the market price and production capacity. Furthermore, this manufacturer only proposes a limited number of ribbon widths, which makes it difficult to optimise the sizing of magnetic circuits.
- The transformer sound level - greater than that of conventional equipment. However, in an increasingly demanding regulatory context, noise is a particularly important aspect for the operator.

COMPARISON OF THE DIFFERENT SOLUTIONS

To conclude on this subject we can say that transformers with the highest efficiency are also the heaviest transformers that include the most noble materials, such as copper or aluminium, and ferromagnetic steel. However, a quantitative assessment reveals that the environmental impact of a transformer is divided between its production phase and its operation phase, in approximately equal proportions. Energy savings targeted during the transformer's operation phase by reducing losses must not therefore overshadow an overall eco-assessment, it being even more justified when we look at new technologies.

POSITION OF THE FRENCH UTILITIES COMPANY ERDF

ERDF has an equipment base of 720,000 public distribution transformers. Losses of these transformers are relatively high (E0-Ck) and represent more than one third of the technical losses generated on the network.

To improve the energy efficiency of its network, ERDF is considering installing reduced loss transformers in the near future. Therefore, a new technical specification for conventional three-phase transformers has just been written (ERDF standard HN 52-S-27). This standard then imposes a minimum loss level (C0-Ck) which corresponds to a reduction of no-load losses by one third. Suppliers have been consulted with a regard to the global cost of the transformer. We are therefore no longer only looking at the transformer acquisition cost but also the capitalised cost of losses throughout the transformer’s life. This new approach gives the possibility of looking at a better loss level than the minimum specified level.

CONCLUSION

This article shows that improvement of the production process or the use of higher performance magnetic steel, or those treated by laser, allows us to significantly reduce the level of iron losses in public distribution transformers. Amorphous steels – which are more expensive but even better performance – are also an interesting alternative due to the recent increase in the cost of magnetic steel. Manufacturers today therefore have several solutions to reduce losses in transformers.

These alternatives offer network managers a real opportunity to reduce losses. The cost of a reduced-loss transformer is certainly higher than that of a conventional transformer, but this cost must be set against the expected loss-related savings throughout the equipment life cycle. In addition, on the European Commission’s recommendation, certain countries have set up an incentive scheme which allows compensation of part of the extra investment.

Therefore, manufacturers, network managers and regulators today have the possibility of contributing to reducing losses in transformers and therefore improving the energy efficiency of networks.