Improvement required in the energy efficiency of our grid networks.

Energy efficiency is set to be one of European industry’s major challenges. The European Commission’s 2005 Green Paper identified various major actions to be conducted in various sectors. In the electricity supply activity, the Commission is primarily encouraging electricity distributors to innovate in order to reduce their technical losses generated in the networks. Therefore network equipment manufacturers are being invited to make significant improvements to the performance of the elements they supply. Distribution transformers are included in this category and it is estimated that their no-load losses account for 25% of all technical losses on the grid.

That said, all these no-load losses are produced regardless of transformer loading, so it would seem crucial to reduce them drastically.

Under the framework of the EuP Directive, the European Commission has instigated a study, due to be published in November 2010, entitled Distribution and Power Transformers, Lot 2, to assess the environmental impact of transformer losses.

A technological breakthrough to match the challenge

Considerable progress has been made in the manufacture of conventional grain-oriented magnetic sheets. Their properties are being constantly improved, while thicknesses have been reduced from 30/100 to 23/100 to lower losses. Further reduction is conceivable and some suppliers are offering 18/100 sheets for testing purposes, however the gains are expected to be low, indicating that we have reached the limitations of this technology.

A technological breakthrough will be required to reduce transformer no-load losses by a factor of 2, 3 or more. Only amorphous sheet can provide this breakthrough, yet although it has been in existence for over 30 years, European manufacturers have considered the limitations associated with its use to be an almost insurmountable barrier.

Nonetheless even though its use is basically still restricted to the Asian Indian markets and locally to the United States and at that, primarily to single-phase <250 kVA transformers, it is becoming more widespread.

European specifications and quality requirements act as constraints

The major European energy supply authorities have written their own specifications on the strength of long experience in energy distribution, applying increasingly stringent service continuity constraints, all of which current technologies cope with, in addition to quality continual improvement in equipment manufacturing, which will also have to apply to amorphous sheet devices.

Amorphous sheet has hardly any impact on the electrical constraints, since if we leave aside the shape of windings and possible pollution from sheet splinters, the same dielectric constraints apply to chassis and internals. The thermal constraints are lower because the losses are reduced. Although the noise levels obtained are higher at the same induction, they fall in line with current noise levels of transformers on the grid, but are not proportional to the loss reduction obtained with amorphous sheet.

Resistance to short-circuit stresses is the issue posing the greatest limitations that we will discuss hereafter.

Bolted short-circuit constraint:

A qualification is conditional on the devices ability to withstand electrodynamics stresses during bolted short circuit tests. This constitutes the major limitation of the specifications and is the hardest for transformers built from amorphous sheet. It is also the main reason why those manufacturers who are using it are restricted to low outputs and single-phase devices, while it is the three-phase 100-1000 kVA range that is likely to interest public distribution authorities.

Maintained and constantly verified quality:

The major European operators have accustomed us to their very high quality demands with regular factory inspections.
Transformers are regularly sampled at the end of manufacturing and are subjected to all the tests including the bolted short-circuit test, leading us to maintain our manufacturing processing capacity to guarantee uniform quality throughout. We will have to apply the same requirements to amorphous sheet transformers.

**The usage constraints of amorphous sheet**

**Limited induction:**
The working induction, limited to 1.35 Tesla, leads to a bulkier active part and greater overall footprint of the transformer. This may be a major limiting factor wherever the customer specifies maximum overall dimensions.

**Limitation in the magnetic circuit design:**
The magnetic circuit comprises single-phase, pre-assembled rolled sheet elements, annealed at about 350°C. That dictates rectangular section design with all the constraints we know of in terms of winding and short-circuit stress resistance.

Another constraint is due to the availability of only a few sheet widths

In silicon sheet technology, the mother rolls are approximately 1000 mm wide and can be used to produce of a wide variety of stages, which is very useful for optimising magnetic circuit families and thus transformers that meet the various national standards in the European Community.

In amorphous sheet technology, the number of sheet widths is currently limited to 3: 142, 170 and 213 mm.

**Intrinsic fragility of the material**

Of all the constraints, material fragility is both the most immediate and the most problematic thus its initial designation, “metallic glass”, speaks for itself. The fragility of amorphous sheet is equivalent to that of glass, and like glass, it bursts into tiny fragments once pushed beyond its bending limit. Sheet splinters are unavoidably produced when opening and closing circuit elements during coil installation, so suitable protection has to be provided throughout the manufacturing process.

**Low resistance to external stresses**

In silicon sheet technology, once the magnetic circuit has been installed it is rigid, and acts as a mechanical support on which all the transformer elements rest. In amorphous technology, the circuit elements are closed at the bottom end. This is a fragile area, which must not be subjected to any stress. The weight of the device, in particular, is to be avoided.

**Specific constraints on the winding**

**Rectangular winding**
The rectangular section of the magnetic circuit calls for winding of the same type, but rectangular windings offer poor resistance to bolted short-circuit stresses.

When the windings are being created, a significant difference arises between the calculated winding thicknesses and the actual thicknesses. This difference is caused by the expansion ratio which is very much higher in rectangular windings than in cylindrical windings. This bulking, which is actually a free space between the conductors is mainly responsible for coil deformation during testing. The high and low voltage range thus increases sharply leading to a significant variation in short-circuit voltage.
Modelling short-circuit constraints
The shapes (curve radii) need to be optimized to limit the bulking and winding voltages. Furthermore, the constraints created by short-circuit stresses need to be modelled.

Free-standing coils
In conventional technology, the magnetic circuit carries the coils and they will be locked onto it. In amorphous technology, it is the magnetic circuit that rests on the windings and their base.

Manufacturing constraints
Avoidance of sheet splinters polluting the transformer and the work areas during manufacturing is of the essence.
This entails constant and suitable cleaning. As the amorphous sheet is only 20-25 microns thick, the splinters tend to stick together easily because they are very light and smooth surfaced. Use of a suction device alone will not suffice. Accordingly, confining the area where the coils are assembled onto the circuit, namely, where they are opened and closed, is recommended.

Special cutting machine:
The sheet is delivered in rolls and has to be cut on a specific machine that is quite different from the shears used for silicon sheet.

Annealing furnace and coating shop:
Once the magnetic circuits have been shaped, they must be annealed at 350°C, which naturally calls for an annealing furnace.
As can be observed on the photo, the circuit wafers (excluding the opening area) are resin-protected – therefore a coating shop must be set up.

Coil winders:
Rectangular winding with pressure rollers on suitable formers at best calls for new coil winder tooling, if not new machines altogether.

Assembly tables:
We have retained the most commonly used assembly principle, namely horizontal assembly, for making our prototypes:
- the coils are laid down (horizontally)
- the open circuit elements are slid into the coils horizontally
- the circuits are closed
- once assembly is completed, the active part is tilted
As mentioned above, the cleaning operation must be integrated into these tables.

Product flow:
As the following photo illustrates, once the magnetic circuit has been assembled using conventional technology, it can be transported to the coil assembly area. In the case of amorphous technology, the circuit elements only form a whole set once they have been secured by the coils. Thus the entire shop floor product flow system needs to be revised.

Silicon sheet magnetic circuit moving on a flow line

Qualification tests on 2 400 kVA 20000/410
transformers

France Transfo has built 2 x 400kVA 20KV/410V prototypes to comply with ERDF specifications in preparation for the industrial manufacture of amorphous sheet distribution transformers. These 2 devices passed all the tests required of them. The maximum recorded short-circuit voltage variation during the bolted short-circuit test was 1.9% on one transformer column.

The ERDF specification stipulates that this variation must not exceed 4% (6% in the IEC standard).

While there was total compliance with the tests, the development of specific parameters on site (installation on a network) needs to be checked as a precautionary measure.

Tests on the network and development of characteristics

5 x 400 kVA 20KV/400V and 195 watt no-load loss transformers have been built and installed on the ERDF network and their performance in terms of the following characteristics will be monitored:

Dielectric strength

Dielectric strength monitoring will enable us to ascertain whether the magnetic circuit is damaged or whether sheet splinters contaminate the oil.

Noise

Amorphous sheet is noticeably noisier for the same induction than silicon sheet and it would seem appropriate to check the stability of this factor at this time.

No-load losses

Amorphous sheet only makes sense because of its exceptionally low losses, but we need to verify that these losses remain low over time.

It is our intention to rerun the routine tests and perform some type tests after one year in operation to check how the transformer’s main characteristics have evolved.

Conclusion and ERDF’s expectations

ERDF has already initiated a distribution network loss reduction process by modifying its specifications for conventional magnetic sheet transformers. ERDF has posted tenders for lowest responsible bidder that incorporate the evaluation of technical losses to encourage suppliers to work in this direction. Thus since the beginning of 2009, ERDF has been purchasing "reduced loss" transformers that enable it to cut no-load losses by 35-55%.

ERDF is interested in amorphous sheet technology to halve its MV/LV transformer no-load losses to take matters forward in its determination to be an exemplary distributor in environmental terms. EDRF is committed to running experiments with this new equipment on the grid to support development of this new technical stage.