THE NEXT GENERATION OF VACUUM INTERRUPTERS; USING A ″DESIGN FOR THE ENVIRONMENT″ APPROACH

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1. Introduction :

A new range of vacuum interrupters termed « VG » has been developed, optimised not only for technical and cost issues such as the short circuit breaking performance and the size of the devices, but also for environmental impact by reviewing completely the design process and manufacturing technology from an environmental standpoint.

Compared to conventional designs this new ALSTOM technology reduces the energy needed for the manufacturing of vacuum interrupters by 40% and the raw materials (copper, ceramics, etc) by 30%. This technology has already been applied to a new range of vacuum interrupters used in switchgear with service voltages up to 38kV, normal currents up to 3150A and short-circuit currents up to 63kA.

2. Design philosophy

Vacuum interrupters are generally seen as being environmentally friendly products in that they use fairly conventional materials, copper, ceramic, silver, Stainless steel, etc, and are sealed for life with absolutely no maintenance required. Even in the extremely rare case of a leak there literally is nothing to leak out to the atmosphere.

However, although the product itself is environmentally friendly, the manufacturing processes for vacuum devices are quite sophisticated, being similar to those used in the solid state electronics industry, and are not so friendly. World-wide, the manufacture of high technology electronic devices places a considerable burden on the environment. It has been estimated [1] that in order to produce one PC memory chip weighing 2 grams, the total materials and fossil fuels needed are 1,400 grams, a ratio of 700:1. To put this into perspective, for an automobile this ratio is only 2:1. A major contributor to this extremely high ratio for electronic components is the high level of cleanliness needed in the manufacturing process, which requires sophisticated “clean room” manufacturing and cleaning techniques to be used [2]. The manufacture of Vacuum Interrupters uses similar manufacturing technology to those for electronic components, with similar levels of cleanliness required, and our estimate for vacuum interrupter manufacture is a ratio of materials and fossil fuels to final product mass of 100:1 for classical manufacturing techniques.

As a result of this high ratio we selected the vacuum interrupter and it’s manufacturing processes as a priority for reducing the environmental impact of our products. In addition we also targeted to use the environmental approach to significantly reduce manufacturing and development costs to the company in order to show that the environmental approach could not only be good for the environment, but also significantly benefit the company financially.

3. The development process

The development of a new range of vacuum interrupters requires a significant research and development effort, followed by a rigorous programme of proof testing and certification. Although improving this process only gives a one off benefit for the environment per project, overall the benefits can be significant and if carefully carried out there is an immediate cost benefit to the company.

At the beginning of vacuum interrupter technology in the 1960’s & 1970’s Vacuum interrupters were developed in a basically empirical manner, with prototype interrupters being built and tested in circuit breakers [3]. Although effective this did not lead to an optimised design, and was expensive particularly in the cost of testing and the construction of large numbers of prototype devices. Twenty years ago this technique was refined by means of a high speed camera used to film the arc in a special demountable vacuum chamber [4]. This together with in-house synthetic testing not only allowed the development process to be speeded up, but also allowed for significant optimisation of the contact geometry, and considerably reduced the cost of development. In addition electrostatic field modelling of the interrupters became possible, using mainframe computers [5]. Over the past ten years the use of computer modelling of the magnetic fields has been introduced on microcomputers, together with progressively more sophisticated modelling software, allowing the full optimisation of not only the arc control geometry, but also the electrical and mechanical design of the interrupter itself.

The environmental approach was applied from the very beginning of the development project. This required analysing the development process itself, and initially this was done from first principles. The selected materials and components were designed to be free from toxic additives, easy to recycle at the end of the product life and suitable for a new environmentally friendly manufacturing process. The development itself was carried out using a maximum of modelling techniques, including mechanical, electrostatic and three-dimensional electro-dynamic calculations.

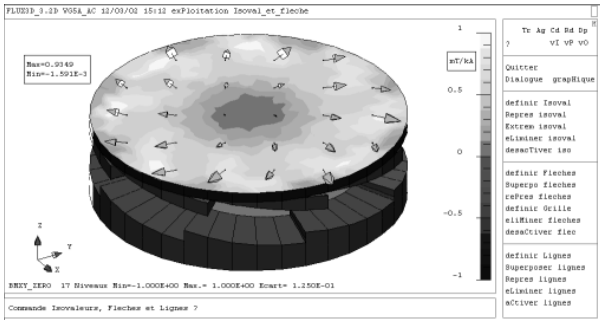

Figure 1 ; Electromagnetic modelling of Arc Control Geometry

These techniques were used to optimise the new design in order to keep prototyping involving energy-, material- and time-intensive tests to a minimum. The costs of short circuit testing and certification are quite significant. By using computer modelling to perform as much predevelopment as possible, we estimate that we reduced the amount of short circuit testing required by a total of ten test shifts for this interrupter range at a saving of ~ 12,000kWhr per shift, giving an overall saving in electrical power of 120,000kWhr. This is in addition to gaining the normal advantages of significant cost saving (~ €15,000 per shift), faster development, and a more optimised design.

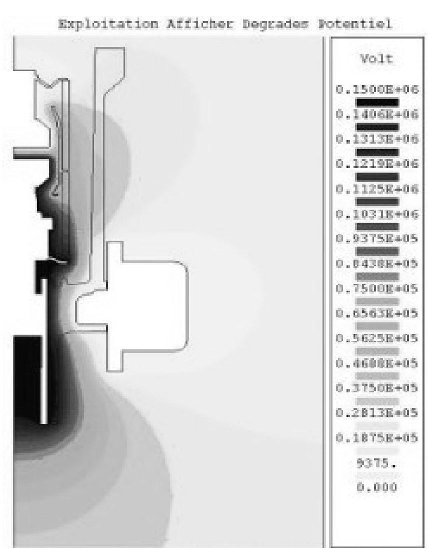

Figure 2 ; Dielectric performance of interrupter mounted in circuit breaker pole

4. The manufacturing process

The manufacturing process of the interrupters themselves was also analysed and optimised. This was the critical part of the project as it is expected that the interrupters developed will remain in manufacture for up to twenty years, with over a million devices projected to be built over this period. As a result any improvements made in the manufacturing process will be multiplied a million times. The design itself resulted in a considerably smaller device, rating for rating, with consequential savings in materials. Overall the average saving in material per interrupter was almost 2.7kg, which equates to 2,660 tonnes of material.

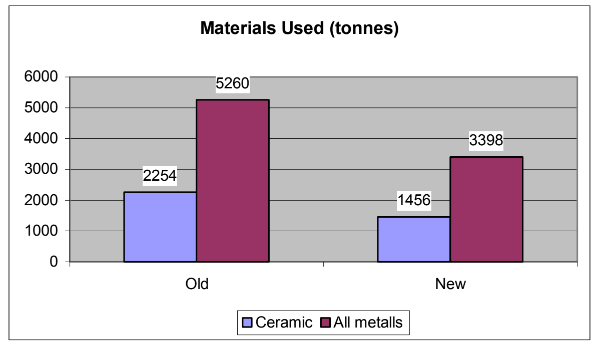

Figure 3; Comparison of materials: old & new design

The manufacturing process splits naturally into three sections, Cleaning/preparation ; Assembly & seal off ; E.P.I.T. (Electrical Processing, Inspection & Test). Each section was dealt with in turn.

Cleaning/preparation

For the surface treatment a new process was developed which uses environmentally friendly cleaning agents and which minimises the use of chemicals and water. An important part of this was the full automation of the processing using a computerised, robotic system. This not only optimised the process giving a high level of consistency of process, but also allowed for a significant reduction in the use of rinse water within the process.

Figure 4 ; Automated chemical cleaning plant.

This means that in total the amount of water used over the 20 years manufacturing life will be reduced from almost 13 million litres to just over 7 million litres, a saving of almost 6 million litres.

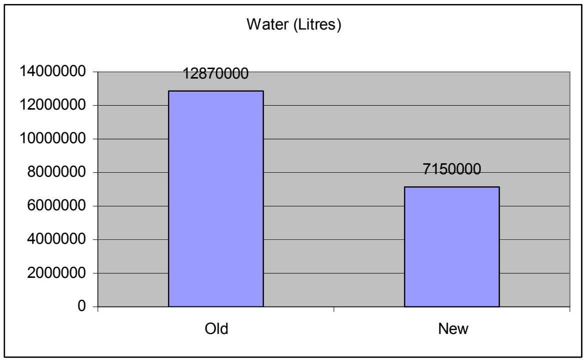

Figure 5; Product Lifetime Savings; Water

Assembly & seal off

The ″One Shot Seal Off″ procedure developed previously by the company [6] [7] allowing a significant reduction in energy used compared with traditional processes was further refined. The processes in use were « Multiple Braze » an old process widely used in the industry whereby interrupters are brazed into subassemblies and then rebrazed for seal off, and also « One Shot Seal Off » a process invented by the company some time ago allowing specially designed interrupters to be assembled and sealed in one operation. The One Shot Seal Off process was selected for the new range, but was re-examined and optimised further. This led to a reduction in furnace time per interrupter from 24 hours to 12 hours, effectively doubling the furnace capacity of the plant.

Figure 6 ; Interrupters assembled ready for One Shot Seal Off process in Vacuum Furnace

The capacity was further increased due to the smaller size and mass of the interrupters allowing more to be loaded at one time giving a total increase in furnace capacity of 2.6 times. This not only gave a large increase in plant capacity, but also significantly reduced the energy needed for vacuum brazing/ seal off. We estimate that the electrical power consumption to manufacture one average interrupter was previously 100kWhr. As a result of this development the new range averages only 60kWhr, giving a lifetime energy saving of 40 million kWhr.

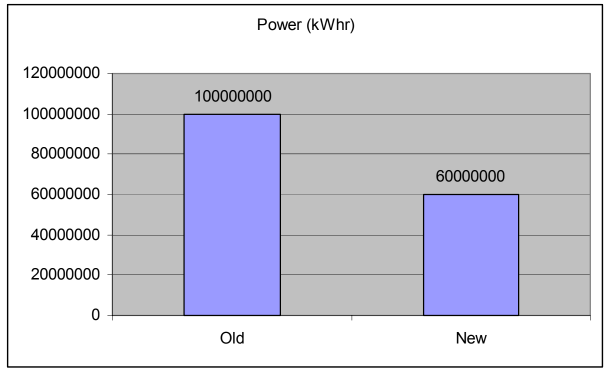

Figure 7; Product Lifetime Savings; Power

E.P.I.T.

The conditioning and testing phase of the manufacturing process was also redesigned, eliminating the use of SF_6 as an insulant for high voltage testing, using compressed Nitrogen instead.

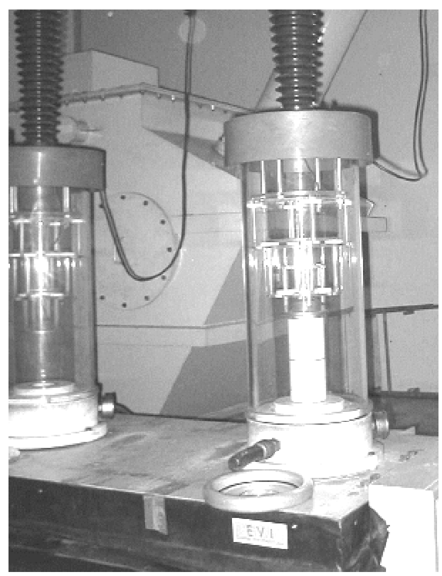

Figure 8; New EPIT voltage processing using compressed N_2 insulation.

Due to careful selection of materials the use of paint was also completely eliminated. In addition the processing and testing procedures were optimised to reduce overall time and energy required. For the packaging and shipment of the final product only recyclable or reusable materials are used.

5. The result

Compared to conventional designs this new ALSTOM technology reduces the energy needed for the manufacturing of vacuum interrupters in total by 40% and the raw materials (copper, ceramics, etc) by over 30%.

Figure 9; Comparison of VG interrupters with previous interrupters: VG on right of each pair.

We estimate that the manufacturing life of these interrupters will be of the order of 20 years. This is based on our experience of the previous generations of vacuum interrupters, together with the fact that although the switchgear will evolve during this period it is not expected that the basic interrupting unit will change significantly.

The environmental impact of the work was analyzed using a computerized tool called EIME (Environmental Information and Management Explorer) developed jointly by ALCATEL, ALSTOM, IBM, LEGRAND, SCHNEIDER ELECTRIC, THOMSON MULTIMEDIA, with the participation of ECOBILAN (PriceWaterhouseCoopers Group) and ADEME (French Environment Agency).

This tool allows designers to evaluate the total impact of their designs both absolutely and relative to a previous design. As can be seen in the example shown, the new VG range shows significant improvement in every one of the environmental factors measured, for the purposes of this comparison the existing design is set to a value of 1 for each factor.

		VG	OLD
Raw Material Depletion	RMD	0.66	1
Energy Depletion	ED	0.40	1
Water Depletion	WD	0.45	1
Global Warming	GW	0.54	1
Ozone Depletion	OD	0.61	1
Air Toxicity	AT	0.57	1
Photochemical Ozone Creation	POC	0.52	1
Air Acidification	AA	0.57	1
Water Toxicity	WT	0.75	1
Water Eutrophication	WE	0.79	1
Hazardous Waste Production	HWP	0.48	1

Figure 10; Environmental Audit Table.

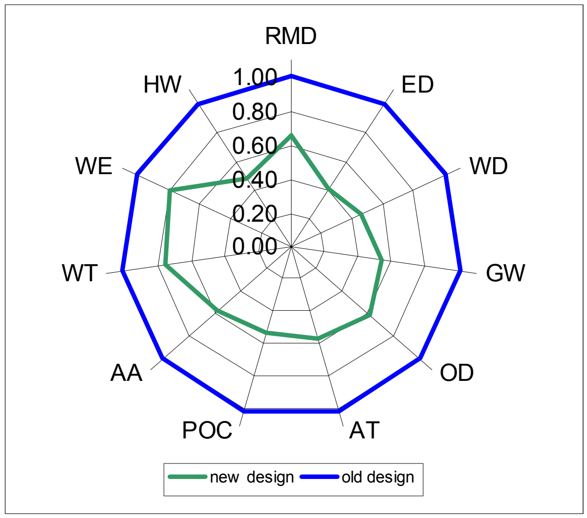

Figure 11; Environmental Audit Radar Graph

Figure 12; New VG Interrupter Range 20kA :63kA.

6. Summary & Conclusions

By considering the whole of a product life cycle from concept to disposal, including the design and development process itself, we have managed to minimise the total environmental impact of a new generation of vacuum interrupters. The importance of this is high, as the expected manufacturing life of the interrupters is of the order of twenty years, and during this period over a million of these devices will be manufactured.

As a direct consequence of this environmental approach the estimated saving to the environment over the life of the products will be 798 tonnes of ceramic, 1,862 tonnes of metal (mainly copper and stainless steel), 5.7 million litres of water, 40 million kWhr of electricity, plus the 120,000 kWhr saved during development . In addition due to the lower resistance of the interrupters in the main circuit, an additional saving in service of ~ 2,700 kWhr will be made. This would normally be simply lost as heating of the atmosphere.

The calculation of these savings is quite conservative, and does not include other savings such as the saving of ~ 50% in transportation and packaging costs due to the significant reduction in size and mass of the devices. Obviously these savings in material and energy translate directly into financial savings, which together with the savings made during the development process add up to a substantial benefit. for the company.

Overall we believe that this project has been very successful in combining significant benefits to the environment, with substantial financial benefits for our company. The message of this is that " Being environmentally friendly makes good business sense".

7. Acknowledgements

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