END OF LIFE MANAGEMENT OF MEDIUM VOLTAGE EQUIPMENTS

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ABSTRACT
The degradation of some natural resources and the increasingly strict regulatory constraints have led a large number of manufacturers to modify their approach to production with the aim of minimizing the consumption of raw materials and optimizing the recovery of spent products. To date, the issue of recycling is addressed in two different ways: firstly, the integration of eco-design to reduce the consumption of materials at source and improve the recovery of the materials at end of life and secondly, the optimization of the end of life management processes in order to recover maximum material at least cost. Indeed, the recycled material regeneration is generally less polluting than virgin material production. In order to improve the environmental quality of its equipment items, AREVA T&D/DRC has chosen to work in parallel on eco-design and to develop an approach to the end of life management of medium-voltage equipment.

INTRODUCTION
AREVA T&D/DRC is doing its best to protect the environment. Our eco-design policy is based on a product Life Cycle approach - an approach which considers the environmental impact at each step in product lifetime, from the selection of the materials to end of life strategies. Indeed, when we continue to design and manufacture products which are more environment-friendly, we undertake an approach to managing products which have reached the end of their lifetime. The objective is to offer customers a clearly-identified circuit in which equipment traceability during de-installation, dismantling and processing are guaranteed at a high level. The experience we have gained is used in the design and development of our new products to reach a recycling rate higher than 70%.

AREVA T&D/DRC will propose an environment-friendly management method for products which have reached the end of their service life. Depending on the type and quantity of the products to be taken into account, one of these options can be chosen as representing a more durable [1], and more ecological solution:
- recycling with the purpose of minimizing the quantity of wastes dispatched to a process burial site
- extension of the product service life through possible overhaul of the critical components.
In this paper, we shall present these two approaches applied to our medium-voltage products. It is important to note that the end of life management of these equipment items is totally different from that of low-voltage equipment items. Accordingly, the European directives WEEE [2] and RoHS [3] are not applied. AREVA T&D/DRC’s strategy is therefore fully voluntary and motivated by the determination to protect the environment and improve the ecological footprint of our products.

MEDIUM VOLTAGE EQUIPMENT
Medium-voltage equipment concerns the power networks supplied either in alternating current at voltages greater than 1 000 V, or in direct current at voltages greater than 1 500 V up to 52kV. It provides the automatic protection of these systems against all the incidents liable to disturb their operation, but also performs on command the operations for modifying the system configuration in normal duty conditions. In general medium voltage equipments have the lifetime longer than twenty years. Indeed, it has to withstand dielectric stresses, ensure the passage of the current without excessive heat-up and without degradation of the contacts, be capable of functioning in severe atmospheric conditions, withstand major earthquakes and, above all, for the circuit breakers, be capable of interrupting all the currents less than or equal to its interrupting capacity. Moreover, it must not require any maintenance throughout its lifetime.

Different systems are used to ensure the dielectric insulation of the medium-voltage equipments: air, liquid (vegetal, mineral or synthetic oils), gases (mainly SF6), solids (thermoset, resins, elastomers, thermoplastics) or hybrids system. The use of a fluorinated gas is justified through its very good dielectric strength which makes the products more compact.

Issue raised by medium-voltage equipment
Medium-voltage equipments differ from low-voltage and high-voltage products in their design, their quantity and the end of life management approach. Indeed, the medium-voltage and high-voltage products can use special-purpose materials to fulfil the electrical current interrupting and insulating functions. For example, SF6 gas, insulating oil, ceramics and thermoset resins. SF6 is an inert gas but which exhibits high greenhouse effect potential; for this reason, its recovery at end of life is mandatory and follows a rigorous procedure. The other materials exhibit primarily recycling constraints. Also, the number of medium-voltage equipment is interesting for organizing a dedicated end of life system.
However, the geographical dispersion of these products adds collection and recycling constraints. Unlike medium-voltage switchgear or high-voltage switchgears have very large dimensions and generally require initial field disassembly to facilitate transportation. Accordingly, this operation requires heavy-duty mechanical equipment and special handling precautions. Furthermore, the system for end of life management of low-voltage switchgear is already established with collection and recycling facilities well established for all the products. Indeed, the quantity of spent products and their dimensions enable easier collection. As a result, recycling systems exist for a major part of the recovered materials.

**END OF PRODUCT LIFETIME**

A product reaches end of lifetime in a variety of cases:
- The service life guaranteed by the manufacturer reaches expiration. Depending on the categories of the machines, this lifetime varies from 20 to 40 years.
- The equipment is defective following a malfunction on the distribution network or a technical problem on the machine
- The product is replaced owing to modifications in the organization of the power network
- The product is degraded during the transportation or installation operations or through external causes such as fires or natural catastrophes

In these cases, the product is no longer fitted to fulfill its original functions. The choice of moving towards a recycling or re-use system after overhaul will depend on the condition of the apparatus, its value and the cost of maintenance. Generally, overhauling the products is worthwhile for equipment which are slightly degraded or which have not undergone major electric shocks. The difficulty is to assess these products in order to really find out the possibilities of upgrading. This is easier with apparatus whose history is known or for which the wear parts are clearly identified. The rest of the apparatus is directed towards the recycling systems.

**APPROACH TO RECYCLING OF MEDIUM-VOLTAGE SWITCHGEAR**

In order to properly manage the recycling of the switchgear at end of lifetime, it is necessary to clearly define all the steps to be followed, from product recovery to material regeneration. For this purpose, we have worked out a general approach for all of our devices and a specific guide for each reference. The general approach is to give the main directives to the actors participating in the end of life phase. Below, we describe the main steps in the management of the AREVA T&D/DRC medium-voltage switchgear, from the de-installation step to the final end use of the materials.

**De-installation**: this operation must be performed by qualified personnel using the appropriate protection means. In all cases, it is indispensable to check that the device is disconnected from the power network and is not energized and does not contain any residual voltage. In this way, it is vital to check that the loaded mechanical parts do not present any danger. In some cases, it will be required to recover the insulating oils and gases before transportation. It is important to note that the manipulation of SF6 gas requires specific authorization (ref regulation EC 842/2006 of 17 May 2006 on certain fluorinated greenhouse gases). Each product containing insulating oil or gas will be marked by a label indicating the quantity of insulator and the position of the recovery point.

Each de-installed product must be accompanied by a decree tracking sheet which includes the reference of the device, its history and the operations performed. Specific events such as fires, technical failures or natural catastrophes must be included. This sheet will follow the product until its regeneration.

**Transportation**: transportation must be carried out while following the safety and environment rules. A follow-up register must be filled in. The user is responsible for ensuring that this step proceeds smoothly. The recovered oils and gases must be sent to the specific processing facilities. The recovered quantities must be measured and recorded in the waste follow-up registers. It is important that the truck drivers be trained in the transportation of these substances.

**Collection**: it is possible to make a temporary collection at the user’s facility in order to optimize transportation to the dismantling centers. If this is not possible, the product will be dispatched directly for dismantling. Depending on the category of the device, it is important to follow the storage rules. The devices for internal use should be stored so as to protect them from corrosion attacks.

**Dismantling**: to date, two possible ways exist: depending on the countries and the geographical location of the customers, AREVA T&D/DRC proposes either to recover its equipment or to direct them straight to local partner companies specializing in the management of electrical and electronic wastes. These companies are then assisted by our departments for the dismantling and recycling procedure. Should the customer choose other suppliers, it is essential to make sure of their qualifications and of the end use of the wastes. However, these suppliers may count on our assistance for the various dismantling and recycling operations.

Before any dismantling operation, it is important to check the existence of a liquid or gas insulator. In this case, the recovery of these products is paramount. This operation requires approval and dedicated installations, particularly for SF6. Depending on the type of device, there exists an appropriate drainage procedure. Before the recovery of the SF6 or insulating oil, it is advised to check
their chemical condition. At all events, the devices which have sustained an electric arc or are heavily damaged will be drained into dedicated containers because the insulating products may be contaminated and harmful. In this article, we shall not detail the procedure for recovering these insulators due to lack of space. Dismantling may be carried out manually, semi-manually or automatically. It is possible to combine these 3 systems to optimize the operation for segregating the components and materials. The objective is to recover the materials for recycling purposes. The choice of the type of dismantling depends on the design of the device, its composition and its cost. Manual dismantling is often more costly than automatic dismantling but presents the advantage of preserving the quality of the recovered materials [4]. A dismantling guide would be offered individually for all AREVA T&D/DRC’s medium-voltage products. This proposal is not unique, but offers an optimized approach based on testing and expert opinion.

Disassembly testing is carried out in conjunction with specialists in the dismantling of electrical and electronic devices and technicians from AREVA T&D/DRC. Our devices are dispatched to WEEE (waste of electrical and electronic equipments) dismantling centers which are not familiar with their design. The first step is to observe the dismantling approach of these operators without the action of our technicians. The aim is to understand the difficulties arising from the dismantling of these products. This enables us both to anticipate additional indications in our dismantling manuals and to include the precautions to be taken for the protection of the dismantlers. The second step is to perform the same operation by internal technicians who have good knowledge of the product and to make the same observations. In both cases, the dismantling operations are filmed and timed. In these two approaches, we try to push manual dismantling as far as possible to understand the limits of recovery of the materials and to identify a time-dependent dismantling cost. On the strength of these results, we decide on the choice of the mode used: generally, we combine the manual mode and the automatic mode. The manual mode is used to separate the components joined by easy-to-detach fastenings such as screwing, positioning and torquing. The semi-manual mode (use of mechanical tools) is used to separate riveted, fitted and enclosed components. The automatic mode is used to detach cast, glued, welded, brazed assemblies. The choice of dismantling mode is linked to various parameters in addition to the fastening mode:

- The recycling compatibility of the assembled materials. When the materials are compatible, they do not need to be separated. This is the case for certain metals such as Low carbon steel for stamping and High elastic limit steel cold forming or certain thermoplastics such as Polycarbonate and terephtalate Polybutadiene.
- The quantity of recovered materials. If the quantity of recovered materials is very small, the priority will be given to crushing. It is possible to determine a reference price of recovered kg per minute per country. For example, in France, the kg of steel should be recovered in less than 1 minute and the kg of copper in less than 3 minutes.
- The quality of the recovered materials. When the quality of the recovered materials is very high, as for some metals, it is preferable to proceed by manual dismantling.
- The dismantling cost: in some countries, manual dismantling costs less than crushing. For example, the average cost of crushing for the whole range of materials in France is 100 to 150 euros per tone and the hourly labor cost in China is 1.5 euros.

At the end of the dismantling phase, the materials are sorted into different containers. During the experimental phase, we present the product to the external dismantling operators without any additional information about the types of material used. By this means, the difficulties in recognizing the materials can be identified and a specific marking for new products can be added. Note that our objective is to mark all the synthetic materials.

End use of the materials: AREVA T&D/DRC’s objective is to optimize the re-use of the recovered materials. By order of priority: recycling is the first way, followed by the re-use of the material (as a load or for a secondary use), then energy extraction. Transfer to a burial facility is reserved for ultimate or wastes which are difficult to re-use. To date, the recyclability rate of our switchgear is greater than 70%. Table (1) presents the proposed end uses for the materials. The values presented in this table are mean values based on testing.

<table>
<thead>
<tr>
<th>Material</th>
<th>% Recycled</th>
<th>% Reused</th>
<th>% Incinerated</th>
<th>% Land filled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>95</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Cooper</td>
<td>95</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>85</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Elastomers</td>
<td>0</td>
<td>90</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Thermoplastics</td>
<td>90</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Thermosets</td>
<td>0</td>
<td>90</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Ceramics</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Vegetal oil</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Synthetic oil</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>SF6</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 1 summarizes the approach for end of life management of our medium-voltage equipment.
LIFETIME EXTENSION

The lifetime extension of medium-voltage switchgear beyond the initial lifetime is possible in some cases. In general, the wear of a product arises both from the functioning and from the degradation of some components. In this type of approach, it is important to think of the overhaul cost and the failure risk. To do this, this operation can be performed for equipment items whose price is greater than the cost of maintenance at end of life. Some medium-voltage cubicles may be suited to this kind of approach. The recovered device has to undergo expert assessment in order to determine the scope for return to operation. This assessment is based on a set of tests which may differ from one device to another. As an illustration, for a circuit breaker:

- Visual inspection of the equipment: number of operations performed, corrosion, wear, cracking,
- Measurement of the open/close rates of the drive: open/close time, synchronisation of phases, reset times,
- Partial discharge test: evaluate interrupting performance
- Resistance measurement: wear of conductive parts.

Other tests may be required to check the working of the device. An overhaul could then enable a return to operation, usually with a limited lifetime.

This path has not yet been thoroughly explored, given the guarantee to be offered for the reinstated devices. This is because any failures present high risks for the safety of the power networks.

CONCLUSIONS

The end of life management of medium-voltage electrical products is an area currently under development. To date, no structures exist dedicated to this type of product. This is due to the fact that these products have a long lifetime and that the existing quantities do not justify such a mobilization. However, the electrical equipment pool worldwide is extensive and old products will reach their end of life in the near future. It is therefore important to prepare carefully and organize suitable systems for de-installation, collection, dismantling and recycling. For this reason, AREVA T&D/DRC has decided to generate end of life management manuals for all these products. These documents will be available for the customers and decommissioning companies. They feature a detailed description of the product, its parts list, the dismantling scenario, the recycling systems and the precautions to be taken. A long period of work will remain to be accomplished afterwards to assist the customers and service suppliers in this end of life management approach. AREVA T&D /DRC is doing everything possible to achieve this goal.

REFERENCES


