Summary

Development of environmentally compatible products comprises the entire life cycle from the very first step of marketing and product planning until disassembling and recycling.

Modern gas-insulated switchgear is designed for a lifetime of more than 30 years.

Despite the long service life, it is necessary to pay special attention to disassembling and recycling at the end of lifetime expectancy.

The paper presents
- the legal situation,
- Siemens’ philosophy on environmentally compatible products and product development guidelines,
- the application of these guidelines on planning, development and manufacturing of gas-insulated switchgear,
- information for the user, e.g. given in product documentation,
- the switchgear recycling procedure implemented at Siemens today.

Introduction

Gas-insulated medium-voltage switchgear is a long-life capital good and an integral part for building and modernizing power distribution systems. It is designed and tested also for operation in severe environmental conditions and has proven its reliability on thousands of units in service.

This type of switchgear is an environmentally compatible product in comparison with conventional switchgear, mainly because of the small switchgear design, the long lifetime and the minimized requirements for the installation room.

Today there are many examples showing that the market expects and remunerates environmentally friendly requirements for the entire product life cycle. Life-cycle cost calculations are increasingly exercising an influence on order placing decisions. This also comprises taking back and disposal of products at the end of the service life.

Legal Situation

For the time being, there are no special legal regulations regarding taking back and disposal of electrical medium-voltage switchgear, neither at national level in Germany nor in Europe. Right now, medium-voltage switchgear is also not liable to the validity of the planned EU Directive on Electrical and Electronic Equipment (WEEE).

Taking back and disposal of switchgear can be agreed upon between the manufacturers’ and the owners’ experts or between owners and recycling companies.

Such agreements are based on the product responsibility as determined in Germany, e.g. in § 22 of the German Waste Management Law (Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Be- seitigung von Abfällen) [3].

As a consequence, there are a lot of individual ordinances for the scope of consumer goods and final customers, e.g. for packaging [4] and batteries [5], which have to be applied to switchgear to some extent, too.

Disposal itself is regularized in specific regulations, e.g. by means of the ordinance to recycling companies [6].

In Germany, manufacturers organized in the ZVEI and owners organized in VDN are conscious of their common responsibility and have undertaken a self-obligation with respect to handling with SF₆-gas [12]. This corresponds with CAPIEL and EURELECTRIC on the European level.

Siemens’ Philosophy

One of the corporate guiding principles of Siemens AG emphasizes the special responsibility for the society and the environment: “We regard ourselves as an integral part of the national economy and feel obliged to society and the environment.”

For Siemens AG, environmental protection is more than observing the applicable regulations. The purpose is to achieve optimal environmental compatibility for the products, taking into account all phases of the product life cycle, as well as economic and technical aspects.
The main items are
- assessing the environmental effects of processes and products already in advance,
- saving natural resources, e.g. by means of minimized use of material and energy as well as maximum recycling rates for unavoidable waste,
- supporting environmentally aware behaviour of the employees at all levels, e.g. by means of reviews after important development steps,
- advising customers for environmentally compatible application of products (ranging from network planning to recycling),
- co-operation with the respective authorities and information of the interested public,
- self-obligation declarations, resulting from active co-operation in associations like ZVEI in Germany or CAPIEL at European level, as e.g. the CAPIEL-Inventory-Methodology for SF₆ [10] or the CAPIEL Environmental Sustainability Declaration as Part of the CAPIEL Environmental Sustainability Dossier [11].

Siemens Product Development Guidelines

The Siemens standard SN 36350 [7] describes the guidelines for the design of environmentally compatible products and their integration into the product planning and development process. Within the Siemens company, this standard has to be applied to all products, i.e. also to gas-insulated medium-voltage switchgear.

The standard covers all aspects of the IEC Publication 109 [8], Environmental Aspects – Inclusion in Electrotechnical Product Standards.

The smaller the total impact on the environment resulting from a product during its entire life cycle, the better its environmental compatibility.

The main principles of environmentally compatible product design are
- taking the product’s entire life cycle into account, from the very first step of marketing and product planning until disassembling and recycling,
- looking at all possible categories of environmental effects including requirements for the installation room and operation as well as service,
- considering the ecological, technical and economical aspects simultaneously during the design process.

Fig. 1 shows the phases of the product life cycle, together with the associated activities related to environmentally compatible product design and the feedback loop for improving the recycling concept.
Product Planning/Development/Manufacture

Comprehensive life-cycle-assessment means that all technical, economical and ecological aspects for a complete life cycle have to be considered.

The main reasons for the positive result of a product assessment of SF₆ insulated switchgear are

- small design with minimized use of material,
- high operational reliability and long service life of more than 30 years due to hermetically sealed enclosure with accordingly low maintenance costs and long investment cycles for replacement,
- minimum requirements for the switchgear room as regards size, ambient conditions and infrastructure.

Meeting these requirements throughout all electrical ratings is a great challenge for the switchgear development.

SF₆-insulated switchgear made by Siemens are completely designed according to the sealed pressure system of IEC 60694 [9] and tested also for operation under severe ambient conditions.

Fig. 2 shows the sectional view of an NXPLUS C panel as a typical example for the design of modern SF₆-insulated medium voltage switchgear.

The heart of the switchgear is the gas-filled sealed-for-life compartment with the switching devices, bars, electrical and mechanical bushings.

To avoid any tightness problems, the stainless-steel vessel is completely welded without any sealed openings. Metal bellows are used as mechanical bushings for operating the circuit breaker and disconnector as well as the SF₆ ready-for-service indicator, which is moved by a magnetic system at both sides of the vessel wall. The electrical bushings for cable and busbar connections are made of epoxy cast resin and are completely welded into the vessel. The necessary pressure relief device is of the "weld-in type" as well. Also, the pipe for evacuating and filling the gas compartment with SF₆ is welded after the tightness test and the filling procedure.

It is especially the concept of the hermetically sealed enclosure by means of completely welded stainless-steel vessels which prevents unpermissible diffusion of insulating gas to the outside and ingress of water vapour to the inside. On the other hand it avoids extensive plastic insulation, which is required for compact air-insulated constructions. Especially under severe climate conditions partial discharges and leakage currents can occur and destroy the plastic insulation.

When the switchgear is taken out of operation after its long life, from today’s point of view, the components can be used for material recycling and energy recovery.

The switchgear is manufactured at the Switchgear Factory in Frankfurt am Main, the Siemens Centre of gas-insulated medium-voltage switchgear.

The production processes are supervised and continuously improved according to the Quality and Environmental Management System ISO 9001 resp. ISO 14001.

For example, the following measures have been introduced:

- Minimization of sheet-steel by specific interleaved stacking software.
- Integral leakage detection during vessel testing to guarantee minimum leakage rates, and supervised SF₆ filling facilities.
- Avoidance of hazardous substances in the individual production processes.
- Minimization of production waste and energy consumption.
Operation and Service Information for the User

Long life of the switchgear is the main contribution to the saving of resources.

The primary part of gas-insulated switchgear is maintenance-free, i.e. no lubricating and cleaning agents are required to maintain operation, thus reducing the consumption of resources during operation.

The secondary system of the switchgear is easily accessible and can easily be checked and retrofitted, if necessary, (hardware and software) according to the needs.

An important part of the documentation from the nameplate to the operating instructions is information for the user such as

- how to take the product out of service and hints for recycling,
- a list with the main materials of the switchgear,
- how to dispose of the materials including SF₆ and batteries of secondary equipment,
- contact partners at Siemens.

Fig. 3 shows the type and amount of materials used in a typical circuit-breaker panel of the NXPLUS C type.

<table>
<thead>
<tr>
<th>Material</th>
<th>weight in kg</th>
<th>used e.g. for</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Steel</td>
<td>400</td>
<td>metal enclosure, operating mechanism</td>
</tr>
<tr>
<td>2  Stainless steel</td>
<td>80</td>
<td>welded vessel</td>
</tr>
<tr>
<td>3  Copper</td>
<td>60</td>
<td>busbars, primary contacts</td>
</tr>
<tr>
<td>4  SF₆-gas</td>
<td>2</td>
<td>insulating gas</td>
</tr>
<tr>
<td>5  Epoxy cast resin</td>
<td>5</td>
<td>bushings</td>
</tr>
<tr>
<td>6  Silicone rubber</td>
<td>7</td>
<td>busbar</td>
</tr>
<tr>
<td>7  Other plastic parts</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>8  Auxiliary devices</td>
<td>50</td>
<td>protection relays, terminals, wiring</td>
</tr>
</tbody>
</table>

Fig. 3: Materials used in a SF₆-insulated NXPLUS C switchgear panel

Disassembling and Recycling

Siemens SF₆-insulated medium-voltage switchgear has been delivered for about 20 years. Due to the long service life, only a few panels are taken back for recycling today.

In spite of this fact, Siemens has already established a process for switchgear recycling together with a certified company R-Plus [2], which is specialized in recycling of electric and electronic devices, see Fig. 4.

![R-Plus Certificate](image)

Fig. 4: R-Plus Certificate

Switchgear which is introduced in the recycling process mainly comes from the following sources:

- Conventional switchgear panels which are replaced by new switchgear.
- Switchgear that has become useless or was destroyed by development or type tests, transport damages, internal arc faults during operation (e.g. due to bad cable connection).
- Switchgear replacement due to disassembly (e.g. in mines) or load increase in the power system or change of system voltage.
Main steps for disassembling medium-voltage switchgear are
- taking the switchgear out of operation by skilled personnel,
- disassembling into individual panels or transport units at site; if required, it is possible to use the professional knowledge of Siemens’ installation departments. While disassembling switchgear of the first generation with one busbar compartment for the whole switchgear, the insulating SF₆-gas must be evacuated at site. In case of hermetically welded switchgear, this is done at the manufacturer’s factory or the recycling company, see Fig. 5,
- transport to a qualified recycling company or the manufacturer’s factory.

For a typical SF₆-insulated switchgear panel, the following procedure is used:
- Disassembling the external parts such as metal enclosure, LV compartment, busbar, etc.
- Evacuation of SF₆.
- Opening the switchgear vessel with plasma-cutter or angle grinder, see Fig. 6.

Recycling is also possible for switchgear that has to be disposed due to internal arc faults. Decomposition products are produced by the interaction between the electric arc and the plastic parts, the insulating gas and the metals used. Such decomposition products maybe hazardous, like with any other fire. Proven measures (e.g. issued by the professional associations as “Berufsgenossenschaft” in Germany) for protection of health after faults have to be observed. After cleaning e.g. with an appropriate industrial vacuum cleaner, or after neutralization of the arc decomposition products with defined procedures, the switchgear can be recycled in the same way as switchgear without fault.

The disassembling and recycling process of the switchgear panels is the key competence of specialized recycling companies in co-operation with the manufacturer. Qualified workers, modern recycling plants and patented procedures ensure safe and economic recycling.

The switchgear is dismantled into its individual components and used for material recycling and, to some extent, energy recovery.
- Removal of all low voltage protection, control and measuring devices, e.g. from the low voltage compartment. Components containing hazardous substances like batteries and electrolytic capacitors must be removed and taken out of the material cycle in a reliable way. Together with other electronic scrap, the materials of the remaining components like printed circuit boards, auxiliary switches, measuring instruments, terminals and cables are separated into sorted fractions in an almost automatic process after passing several chopping and sorting steps. Copper, aluminium, iron and insulating material are thus recovered with a high purity and introduced again in the recycling economy as secondary raw materials.

With these background experiences, today it is already possible to carry out the disassembling process at low cost, so that the profits from material sales compensate the disassembling costs. The primary material is copper at a current market price of about 1,50 €/kg. Considering increasing raw-material prices and higher numbers of recycling units from modernizing programs, in the future the material profits could be higher than the costs for disassembly, bearing part of the costs for logistics and transport.

**Conclusion**

The recycling concept presented in the paper proves that the measures taken during switchgear development have been implemented in a feasible way, and that the switchgear can be recycled economically already today despite low quantities and stable raw-material prices.

The practice obtained with the disassembling and recycling process as well as the experience with operation and service are introduced in the current product planning and development process, as shown in Fig. 1. This know-how is an integral part of the continuous improvement process of the life cycle management for medium-voltage switchgear.

**References**

[3] German waste management law, September 27, 1994; Kreislaufwirtschafts- und Abfallgesetz - KrW-/AbfG v. 27.9.94
[5] German regulation according batteries, July 2, 2001 Batterieverordnung – BattV vom 2.07.01
[9] IEC 60694 Common clauses for high-voltages switchgear and controlgear standards
[10] Capiel Inventory Methodologie for SF6
[12] www.zvei.org/automation ZVEI self-obligation with respect to handling with SF6-gas; ZVEI Erklärung zu SF6 in elektrischen Schaltgeräten und Anlagen