SUSTAINABILITY IN MEDIUM VOLTAGE SWITCHGEAR

Bert TER HEDDE
Eaton Electric – Netherlands
bertterhedde@eaton.com

Alex PIKKERT
Eaton Electric – Netherlands
alexpikkert@eaton.com

Thomas NEURINK
University Utrecht – Netherlands
t.neurink@home.nl

ABSTRACT

Environmental care is getting more important with the minute. Sustainability, environmental friendly materials, avoiding greenhouse gasses, taking the responsibility for the local economic and Life Cycle Assessments are important to companies who do actually really care.
By doing Life Cycle Assessments of various products to determine the environmental impact of a product there can be a process improvement for reducing and even avoiding environmental unfriendly processes. Material choice is even more important to develop an environmental friendly product. This paper describes the various steps taken by Eaton Electric B.V. to set up an LCA calculation for medium voltage switchgear. This LCA is then used in the design process (the cradle to cradle method) to minimize the needed energy during production, assembly, actual use of the product and at the end of life.

HISTORY

The quality of the electricity supply has always been a point of major interest. On the other hand the electricity-market is quite conservative. This implies that long used solutions are often not questioned, so in general no reconsideration takes place, although more economical or technical optimized solutions may exist. In addition to this the technical know-how in the utilities nowadays seems subsidiary to the (short term) economical concerns. [ref 1].
When designing switchgear, the behavior in service has always been the determining factor in the past. Several technical properties of the applied materials like dielectric withstand, ageing sensitiveness, flammability, but also possible by-products in case of internal faults were important. Safety for the operating personal and for the general public has also been of highest importance in the selection of the used tech-nologies. The various arcing and insulating media in medium voltage grids have evolved to a mature situation nowadays, and the pro's and con's of the various media in different applications are not subject to detailed discussion and evaluation anymore. Over the past century a lot of materials have been used as insulating medium. After air, wood, glass, oil and plastics as PVC and polyesters, all with their own positive points and drawbacks, nowadays the main media for insulation are epoxy resin combined in many cases with air or SF_6.[ref 2]. The design changed from bulky open constructions to compact switchgear without direct access to the used internal components, mainly for safety reasons and cost savings for the used operating space. This change also influenced the choice of materials, which became more easy due to the application of new invented construction methods and insulating materials like epoxy resin and plastics. After the historical selection of these technical properties and designs the environmental impact and the related costs became more and more important.

NOWADAYS

Manufacturers are aware of the need for caring for the environment, but the most important driver in this situation is the awareness of the network operators for environmental occurrences during design, construction, operating life time, maintenance and at the end of life of the switchgear in general. Not only the pricing, the application in the network and the operational aspects like ease of use, used volume for switchrooms and safety are evaluated in international tendering processes, but today also the level of sustain-ability and the calculated impact on the environment. The implementation of automated networks with a high level of intelligence is often used for two main reasons, the decrease of network outages to minimize penalties which also increases customer satisfaction, the second reason is the improvement of the environmental issues by analyzing the network for the occurrence of possible failures and mini-mize switching actions, maintenance and repair. More and more knowledge becomes available, expertise is built up and also specialized consultancy companies are entering the market to support the decision makers. [ref 3].
The ultimate goal is to determine the impact on the environment and to identify all possible decreases in the whole chain between manufacturer and user, which are supported by all people involved. The most important subjects are the amount of energy (electricity, heat), the amount of (raw) materials, toxic emissions, social issues like safety and health, fair trade, human rights and child labour. Also information on international level is used for study and retrieving the relevant data. (Capiel, NEMA, IEC, ISO, OECD guidelines). More and more sophisticated software becomes available too (SimaPro).
The Inventory of Carbon & Energy (ICE) from the University of Bath in the UK is an example of a practical database for embodied energy and carbon coefficients for building materials, collected from secondary sources in the public domain. [ref 4].

EATON LIFE CYCLE ASSESSMENT (LCA)

Goal and Scope

Besides that there is nowadays an officially accepted systematic Eaton always took the environmental impact of their switchgear into account. Eaton is already for decades the supplier of air insulated medium voltage switchgear whereas the majority of the competitors is using the gas SF_6 as insulation and switching medium. Therefore the goal of the LCA study was in first instance to justify their environmental friendly focus against an official systematic. Because Eaton constantly improves the way they design, develop and produce their switchgear they also wanted to assess their improvement over the years. To do this an “old” and relatively “young” medium voltage switchgear were compared.

For the assessment a ring main unit (Xiria RMU) and primary switchgear (MMS) were taken as functional units. From both products a single panel circuit-breaker without relays and extra options was assessed.

Fig.1: assessed switchgear Xiria and MMS.

A few items were excluded in the LCA. (table 1)

Included	Excluded
Raw materials	Transport at any condition
Efficiency material use	Customer wishes
Production location	Office work (e.g. invoice)
Ohmic losses	Manuals
Energy use installation	
Expected life time	
Maintenance	
End of life	

Table 1: included and excluded factors.

Data sources

A distinction is made between primary data, specific to Eaton’s switchgears, and secondary data, which are either calculated data or data coming from publically available sources, such as LCI databases. The principal primary data used for this screening LCA are a detailed bill of materials (BOM) for the switchgear, collected by own employees and the efficiency, which allowed the calculation of energy losses during the use phase. In terms of secondary data, by far the most used source of LCI data was the ecoinvent 2.0 LCI database, which contains detailed LCI data for most processes and materials used in this LCA, including electrical component production and end-of-life management. In some cases, the ecoinvent database did not contain data that perfectly reflected the processes that needed to be modeled (e.g. material somewhat different, or production location European rather than American). Best available proxies from ecoinvent were selected in these cases.

Life cycle impact assessment (LCIA)

ISO 14044 does not promote the use of one life cycle impact assessment (LCIA) method over another, leaving the responsibility of method selection to the commissioner. The chosen life cycle impact assessment method is Impact 2002+ [ref 5]. This method translates the LCI into 15 midpoint impact categories. As shown in table 2, thirteen of the fifteen midpoint impact categories can then be grouped, based on natural science-based approaches in four endpoint (damage) impact categories – impacts on human health, ecosystem health, climate change and resources.

Midpoint impact category	Unit	damage category	Unit
Carcinogens	kg chloroethene-eq	Human Health	DALY
Non-Carcinogens	kg chloroethene-eq		
Respiratory inorganics	kg PM2.5-eq		
Ionizing radiation	Bq C-14-eq		
Ozone layer depletion	kg CFC-11-eq		
Respiratory organics	kg ethylene-eq		
Aquatic ecotoxicity	kg TEG water-eq	Ecosystem Quality	PDF *m2*a
Terrestrial ecotoxicity	kg TEG soil-eq		
Terrestrial acid/nutri	kg SO2-eq		
Land occupation	m2organic arable land-eq		
Aquatic acidification	kg SO2-eq	n/a	
Aquatic eutrophication	kg PO4 (P-limited env.) –eq		
Global warming	kg CO2-eq	Climate Change	kg CO2-eq
Non-renewable energy	MJ primary-eq	Resources	MJ primary energy
Mineral extraction	MJ surplus-eq		

Table 2: Midpoint categories of the IMPACT2002+ LCIA method and their associated damage categories.

Life Cycle Inventory

The live cycle inventory stage consisted of gathering the information for the four primary life-cycle phases. The phases are:

- Materials
- Assembly
- Using phase
- End of life

The gathered information per phase was inserted in the program SimaPro. SimaPro is the most widely used LCA software. It offers ultimate flexibility, parameterized modeling, interactive results analysis and is integrated with the ecoinvent database. Within the database high quality and widely accepted inventory data for most commonly used materials and processes is stored.
For the first phase the detailed bill of materials (BOM) from each of the switchgears were generated. The BOM separates the switchgears into groups, each of which contained individual materials. Per material the country of origin and weight (in kg) were gathered. Below table 3 is presented with the identified materials per group and linked to the exact materials in the ecoinvent database.

Metals:	
Steel	Steel ETH U
Sendzimir	Steel, low-alloyed, at plant/RER U + Zinc coating, pieces/RER U
Aluminum	Aluminum, primary, at plant/RER U
Copper	Copper, at regional storage/RER U
Ceramic	Ceramics ETH U
Silver	Silver, at regional storage/RER U
Iron	Crude Iron ETH U
Plastics:	
Epoxy	65% Epoxy Resin, Liquid, at plant/RER U + 35% Sand ETH U
PE	Fleece, polyethylene, at plant/RER U
EPDM	EPDM rubber ETH U
PP	Polypropylene, granulate, at plant/RER U
PC	Polycarbonate, at plant/RER U
TPU	Polyurethane, rigid foam, at plant/RER U
Others:	
Eflex	Portland slag sand cement, at plant/CH U

Table 3: Identified materials per group.

For the assembly life cycle stage the actual assembly of the switchgear and all the needs with it were considered. The energy requirements for the assembly of the switchgears at the Eaton facility in Hengelo, the Netherlands were estimated using the plants total energy divided over the total number of produced switchgear per type (rmu, secondary, primary). Energy requirements for testing the unit were estimated based on the testing protocols used for the switchgears as specified in IEC 62271. Last but not least the efficiency of material usage is taken into account. In this case estimations were made together with production and purchasing.
In the using phase of the LCA a few aspects were assessed. The main aspects are ohmic losses, expected lifetime and maintenance. For the latter the energy use, material use and frequency should be assessed. Because both products are basically maintenance free, this aspect is not contributing and therefore not assessed. In the last phase the end of life scenarios were assessed. This includes recycling, energy recovery and disposal in a landfill way.

Data quality analysis

The quality of data used in the model is not homogenous. Some are reliable (efficiencies of switchgear) while others have been roughly estimated (lifetime). In order to evaluate the quality of data that populates the model, Data Quality Indicators (DQI) were attributed to each flow using the data quality matrix approach. These scores have also been used to evaluate uncertainties on data and, subsequently, analyses uncertainty of the model and results generated.

Impact contributors

The most important potential impact contributors in the model are copper as material, copper during the recycling process, ceramic as material and ceramic during the recycling process (Table 4). This was highlighted in the screening study and efforts were focused on these data for the detailed LCA in order to obtain best quality data possible. DQI scores for these data are therefore very good.

Intermediary flow	Potential impact contribution	Data quality scores					
		U1	U2	U3	U4	U5	U6
Component production							
Material / component							
Metals:							
Copper	3	1	1	1	1	1	3
Copper Alloys	3	2	1	1	1	1	3
Ceramic	5	2	1	1	1	1	3

Table 4: most important impact contributors.

Life Cycle impact Assessment

Per switchgear life cycle profiles were generated in SimaPro. In every life cycle profile the material use and assembly are grouped in one phase called the assembly. For the baseline assessment, life cycle impact assessment (LCIA) results were calculated for both products using the IMPACT 2002+. Next different graphs were generated within SimpaPro to analyze the difference between the two products. An example graph is presented. (Fig. 2).

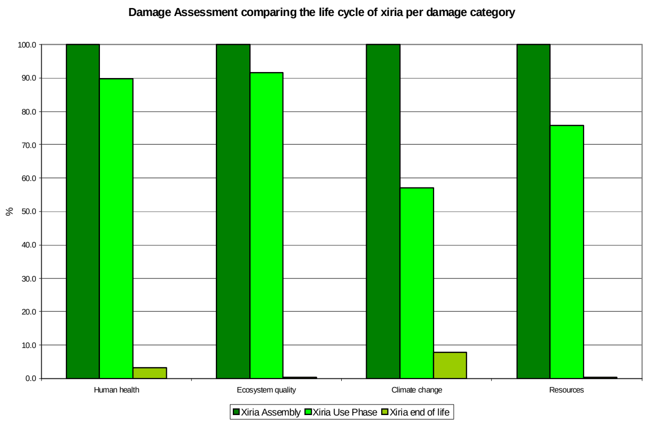

Fig 2: Simapro LCIA graph.

OUTCOME FOR EATON

Looking at the impact factors of the different materials in the ecoinvent 2.0 LCI database and comparing them to some possible alternatives it can be stated that Eaton succeeded in developing sustainable products. Comparing the “old” and “young” product also shows that Eaton succeeded in improving the sustainability of their products over time. The improvements were among others realized by using different processes. The improvements can be linked to the four primary life-cycle phases.

Materials

During the design phase special attention was given to the number of used parts. In this case the philosophy “less is more” was used. Next per part the possible materials were assessed against environmental impact. This for example provided that as less as possible copper is used.

Assembly

By integrating production in the beginning of the development the engineers designed the product in such a way that it is very easy to assemble and therefore saving energy. The assembly line is very “lean” and has a minimized number of assembly steps. Also the necessary machinery energy to assembly the product is minimized. All employees are trained for switching of machines if no longer used. Making sub assemblies of the products is done by machines that produce these products very efficient; for example a smart way of cutting steel plates.

Fig 3: Lean production of the Xiria switchgear system.

Using phase

To reduce the ohmic losses and energy usage of the installation the energy flow within the switchgear is made as short as possible and with a low number of connection points. For making the switchgear maintenance free special attention is given to the housing.

End of life

Majority of the used materials within the switchgears can be completely recycled. Because this is a specialized activity Eaton delegates this to a specialized third party. This company recycles as much as possible. If a part is not recyclable then it will be used for energy recovery and if that is not possible it will be used for landfill.

Extra

Besides all product related impact factors on the environment, Eaton is even approaching it form a bigger perspective. In this respect the production facility has:

- LED lights at the offices
- Controlled lighting; switching per needed area
- Re-use of machine heating for building heating
- Automatic air-conditioning switching

Because the environment also contains human beings, Eaton is also looking at the local society. For this special agree-ments are made with schools, universities and local institutes. Eaton for example funds local social activities and provides that students can execute their practical assignment at their facility.

REFERENCES

[1] A.R.A. Pikkert, G.C. Schoonenberg, “innovative ring main unit design: safety and availability aspects”, Cired Conference, Barcelona, May 2003. paper 1.6

[2] W. Menheere, G. Schoonenberg, J. Verstraten, R. Vervaet, “Comprehensive evaluation of insulating and switching media in MV distribution and MV motor control.”, PCIC conference, Paris, July 2007.

[3] www.Ecofys.com

[4] Prof. Geoff Hammond & Craig Jones, Inventory of Carbon & Energy (ICE), University of Bath, UK, Version 1.6a , Sustainable Energy Research Team (SERT), 2008
www.bath.ac.uk/mech-eng/sert/embodied/

[5] IMPACT 2002+: Jolliet O., Margni M., Humbert S., Payet J., Rebitzer G. and Rosenbaum R. (2003)