RISK MANAGEMENT OF AGEING ASSETS; MINIMUM OIL BREAKERS

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ABSTRACT

A significant number of minimum-oil breakers has been installed in HV substations and distribution cabinets of regional network operator Stedin. E.g. 35% of all bays in HV stations. Eaton, the successor to the original manufacturers Coq and Hazemeyer intended to end the support of these breakers in 2014. The paper describes the ensuing risk evaluation, options and two-track approach chosen by Stedin to manage the risk:

1. *Replacement of switchgear within a period of 20 years,*
2. *Conservation of the 10 – 25kV switchgear that have not been replaced, during 20 years, in cooperation with the successor to the original supplier.*

For conservation, a long term cooperation has been agreed upon with Eaton. For the other track, replacement, a replacement sequence is elaborated.

INTRODUCTION

The electricity grid in the Netherlands was mainly constructed after the second World War, up to around 1980. Today, the ageing of assets installed in those days is a major concern for electrical network operators. One of the concerns is the termination of support by the original supplier, involving amongst others proper maintenance and spare parts.

This paper describes the risk, possible solutions and chosen approach of the (nearby) end of support of the original supplier Eaton of various types of Coq and Hazemeyer switchgear (minimum oil breakers), which comprises e.g. about 35% of all bays today in operation in regional network operator Stedin´s HV substations.

Stedin

Stedin Netbeheer B.V.(hereafter Stedin) is a regional network operator, responsible for transmission and distribution of i.a. electricity in the Randstad, a conurbation in the western Netherlands that includes the cities of The Hague, Rotterdam and Utrecht. Two million customers including households, small business and large industries are connected to Stedin´s electrical grid (see Figure 1).

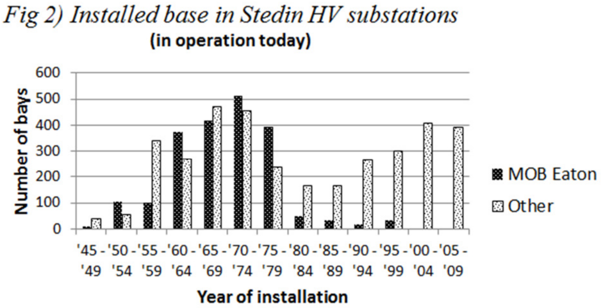
Stedin strives to control its key business risks: quality of supply and safety. These risks are closely related to the public interest and to the reputation of the network operator. Failure of HV (High Voltage) substations is an important risk in quality of supply. Ageing assets which are no longer supported by the original supplier, now or in the near future, are part of that risk. Exactly that was the case for Stedin in December 2010, when Eaton, successor to the original manufacturers, announced to end its support in 2014.

Fig. 1) Stedin in the Netherlands

The operating area of Stedin in the Dutch electricity grid

Large quantities of Eaton´s minimum oil breakers were installed in the Dutch grid in the past. This also concerns the distribution cabinets and HV substations of Stedin, from 10 to 25 kV operating voltage. Many minimum-oil breakers are still in operation, about 2200 bays in HV substations and approximately 3200 in distribution cabinets. See also figure 2, the number of installed bays shown per 5 years.

Fig 2) Installed base in Stedin HV substations



Eaton

Eaton Industries (Netherlands) B.V. (hereafter Eaton) is the legal successor of two Dutch companies who both produced minimum oil circuit breakers (in short: MOB); Hazemeyer and COQ, respectively founded in 1907 and 1916. Since 1963 and 1969 respectively both companies became HOLEC which in 2003 was incorporated in Eaton a diversified global power management company.

The switchgear manufactured by Coq have an oil-filled main bus bar system and oil-filled breaker compartments, usually containing oil-filled breaker tubes (including arc chambers) separated by phase. The systems have separated tanks that are not hermetically sealed. Various components, including the breaker tubes are made of thin layers of resin impregnated paper, Coqolite™. The operating mechanism is often powered pneumatically or hydraulically. The Hazemeyer systems only contain oil in the breaker tubes which is for arc interruption. The rest of the system is usually insulated by resin bonded paper and bitumen or synthetic resin.

RISK

The termination of support by an original equipment manufacturer may eventually lead to:

- increase of the failure frequency,
- long recovery times,
- and even non-repairable loss of function,

as knowledge and experience required for maintenance, inspection and repair is no longer assured from that moment on. The availability of specific spare parts and the possibility of modifications may be affected very soon after the support has ended.

Considering general experience[1] and Stedin experience, a typical risk contributor for MOB is the possibility that the cubicle may burst in case of failure and short circuit, causing a flow of hot oil or gas possibly causing a fire. This is a potential danger for employees (safety) and the entire system could be lost (risk for quality of supply). In practice, these failures typically can happen during or shortly after operation of the switch. Especially in distribution areas where the breaker is operated locally and manually there is a potential danger for personnel.

Failure modes

Much research has been done into the failure mechanisms of minimum oil breakers, but it would be wrong to relate results of any general research indiscriminately to the ageing assets considered here. Based on their experiences, both Stedin and Eaton are of the opinion that (other than a well-documented age-related failure of 25kV bushings) no pure age-related failure causes relevant to the discussed population of MOB have been identified yet. Various failure phenomena are known whose probability is affected by multiple variables, such as failure history, maintenance history, historical and future load, and environmental influences. A multitude of variables in combination with limited availability of data do not constitute a sound basis for statistics, moreover past performance does not guarantee future results. Unknown new failure mechanisms could still be revealed.

Purely based on functionality the most likely major failure modes are:

- No or uncontrolled movement of the contacts,
- Insulation faults.

These failures require unplanned corrective actions to ensure or recover the supply of power, and to recover the functionality of the circuit breaker.

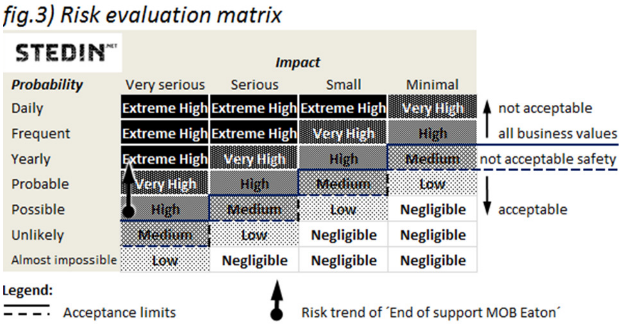
In addition many minor failure types are known, such as small leaks, or problems in control and signalling, which require the scheduling of corrective maintenance actions. The most likely failure modes are determined by Eaton based on consensus within a team of experts. The classification ranges from "occurs monthly" up to "never heard of". The major failure modes of the MOB are almost identical for each type and for example related to contact pressure, oil condition, mechanical adjustments and wear of breaker contacts. Looking at most obvious minor failure forms, several type-specific phenomena exist, related to design or material specifications.

Failure effects and risk classification

Stedin assesses the possible events already mentioned, such as fire and loss of a substation, based on the impact on its five business values: Safety, Quality of supply, Financial performance, Reputation, Law & regulations. Depending on frequency – where Stedin uses a similar scale as Eaton - and severity of possible events, the risk is assessed using a risk matrix that is common in the industry [3]. The admissibility of a risk is limited.

The arrow shown in the risk assessment matrix figure 3, indicates the risk associated with the termination of support by Eaton as a trend over the long term in case Stedin would not find a way to ensure proper maintenance and support. The risk would be unacceptably high and increasing over time by two categories. The qualification of the potential effect as "very serious" is quite conceivable. For example the impact of the loss of a switchgear in a HV substation which feeds 20,000 customers on average, has a huge effect on the CML (Customer Minutes Lost) and SAIDI (System Average Interruption Duration Index).

fig.3) Risk evaluation matrix



Probability	Very serious	Serious	Small	Minimal
Daily	Extreme High	Extreme High	Extreme High	Very High
Frequent	Extreme High	Extreme High	Very High	High
Yearly	Extreme High	Very High	High	Medium
Probable	Very High	High	Medium	Low
Possible	High	Medium	Low	Negligible
Unlikely	Medium	Low	Negligible	Negligible
Almost impossible	Low	Negligible	Negligible	Negligible

The effect of an interruption, goes far beyond energy not supplied or compensation for damages. Due to the 24-hour economy and dependence on IT-systems the cost of outage is significantly higher today than it was 10 to 20 years ago. Nowadays the impact on the reputation of the network operator is much more severe as well, a serious outage attracts much attention in the wider spread social media like Twitter.

TWO-TRACK APPROACH

Given the unacceptably high risk, various options were examined by the network operator to ensure the safety and reliability of HV substations and distribution spaces. In theory, the options were:

- Operation until irretrievable loss of function,
- Preventive Maintenance (old technology),

- Retrofit of critical components (new technology),
- Replacement of the switchgear,
- The above options, combined with cannibalization.

The first option is ruled out, as it would imply perpetuating an unacceptable high risk. The second option is financially attractive, but is limited. The knowledge and experience with MOBs will decrease in time. For the third option, retrofit, no standard solution is commercially available. A customized solution involves technical risk and is relatively expensive. Replacement would be the preferred solution, but can only take place over a relatively long time. This is due to organizational reasons and because of the investment associated with it. Remember, that a large part of all circuit breakers in the Stedin substations is of type MOB. Finally Stedin opted for a two-track approach:

1. Switchgear replacement within a period of 20 years,
2. Conservation of the switchgears that have not been replaced, during 20 years, in cooperation with the successor to the original supplier.

The time factor was important. Replacement of the entire population within 10 years wouldn't be realistic in this case. On the other hand, apart from significant labour cost and shortage of skilled technicians, assuring proper operation and maintenance capabilities for 40 years was unlikely too.

REPLACEMENT STRATEGY

To determine the order of replacement is challenging. An obvious strategy is first to replace switchgears with the highest risk associated. To determine the risk resulting from probability and effect, various concepts can be chosen.

In this case and for HV substations it is assumed that the probability per year that a breaker fails due to improper maintenance or lack of maintenance (if proper support, spare-parts, etc.; are no longer available) is equal for all units and bays. We take into account that no major failure modes are known and described up to today. So, the probability a substation, number i, will fail is proportional to the amount of bays n_i.

Since mainly large industrials are connected to the 25kV grid of Stedin and mainly households are connected to the 10kV and 13kV network, it is assumed for the MOB's that the effect is proportional to the occurred peak S_i in MVA in power consumption (or generation) comprising the entire substation number i during the previous year. Consequently, the relative risk of substation number i is stated:

$$Risk_i = n_i \, . \, S_i$$

Resulting from that concept, the relative risks can be computed and ranked in a descending order, as shown in figure 4. The results are scaled, the highest relative risk is set at 100. Further, the cumulative risk can be calculated; this is also shown in the figure, also with a relative scale, the total risk is set at 100. It appears that the switchgears ranked to the top 5 of relative risk, together represent almost 20% of the total risk while the 5 lowest ranked switchgears only represent around 1% of the risk.

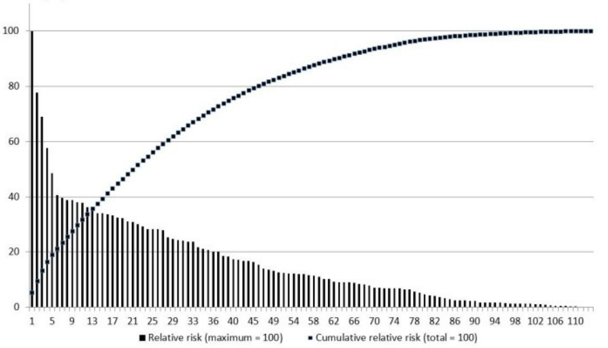


Fig 4) Relative risk order HV substations

This explains the major differences. It is obvious that systems with many bays and a high load - which often goes hand in hand – will have the highest rankings. A slight difference between adjacent systems in the list has little or no practical meaning.

In distribution cabinets the task is even more difficult. Here, MOBs that are considered as the relatively highest risk are the ones containing oil for bus bar insulation without resin bonded paper, thus no barrier between individual phases and no barrier between phase conductor and ground potential. This ranking is due to the potential possibility of moisture affecting the break-down strength of oil [1, 2] and particularly the risk of formation of free water in oil.

The network operator Stedin annually prepares a plan for replacement investments with a horizon of three years in advance. Besides the relative risk of MOBs other factors are considered in the replacement planning of MOB´s in HV substations, such as :

- desirability of remote network control. This applies also to the underlying distribution network (smart grid),
- desirable functionality of protection devices, ageing assets exist here as well,
- reliability of supply in a distribution network,
- capacity planning of the switchgear and the network,
- geographic spread, not all in a small area at the same time.

CONSERVATION STRATEGY

For track 2, conservation for 20 years, a time-based preventive maintenance strategy is chosen based on experiences related to failures, operational requirements, and acceptable degree of non-availability. Eaton and Stedin share the experience that at a low inspection interval some minor failure modes may develop into major failures. Practical experiences and examples were used to determine proper maintenance intervals. Eaton determined what is needed to keep the switchgear and / or parts thereof in a sufficient condition to fulfil the required function properly. The condition of the entire population is assessed on the basis of recent inspections. Maintenance work is standardized as preventive rather than condition based for the individual MOB.

The network operator preferred the manufacturer to be in control of MOB maintenance, because that was the only potential service provider able to ensure a variety of important conditions required for quality maintenance, supply of spare parts and modifications. The required in-house qualifications relate to:

- Specific product related knowledge and experience, including electrical and mechanical design characteristics and specifications,
- documentation thereof in design considerations, standards, guidelines, test reports, maintenance instructions, test specifications, etcetera,
- construction drawings, material requirements and production specifications for replacement parts,
- technology and production tools for parts production,
- assembly & adjustment tools, special test equipment.

The manufacturer didn't like the idea to release its intellectual property on these topics to their competition, but was willing to intensively cooperate with the network operator, resulting into a MOB conservation agreement focused on safety, reliability, availability and efficiency between manufacturer and operator with a term until 2032.

Securing knowledge and skills

In the next 20 years, safety and reliability of ageing assets Eaton MOB will be controlled by workers who never have seen a brand new minimum oil breaker. Securing specific knowledge and capabilities is of great importance in different disciplines within the manufacturer's organization:

- Customer Support
- Customer order engineering
- Work preparation
- Overhaul and repair shop
- Field Service

Knowledge was something that was dealt with differently at the time that MOBs were produced. Raw materials, capital and labour were the means of production. Specifications and inspection criteria were well documented, but tribal knowledge remained in the minds of employees. Personal knowledge is useful when performing field work, but is also essential in making the right decisions when it comes to alternative solutions, or placing old inspection criteria in proper context. Insufficient information or lack of understanding of the original technology could result in unsafe decisions. Personal knowledge is collected recently from individual employees of the inspection and overhaul workshop just before they retired. Most of that know-ledge is documented now. Collection and documentation of personal knowledge regarding MOB has been started within the Field Service group as well.

The documented knowledge is secured in archives. The MOB production archives include some original material and production specifications, product certificates and test reports, particularly of replacement parts. Work instructions for maintenance, overhaul, modifications and testing specifications are secured therein. The installed base archives comprise most of the MOBs and include technical data such as customer order specific specifications and serial numbers. These files are kept up-to-date in case of modifications by Eaton.

Specific capabilities are secured by training. The manufacturer appointed a group of potential MOB experts, taking into account sufficient spread of experience, education, and age. Specific knowledge and skills, are mostly taught through on the job training. The manufacturer is working on formalizing the content of training in order to be able to review specific skills of employees more objectively. Besides knowledge management, the manufacturer also made special arrangements to guarantee availability of materials. Examples thereof are:

- Conditioned storage for breaker components
- Various machines, tools, moulds
- Long-term agreements with sub-suppliers

Data management

Reports of failures, changes, modifications and maintenance activities are documented and distributed in a standardized way, to ensure that Stedin has a full picture of the performance and condition of the ageing assets Eaton MOB, with the option to analyse results in future, e.g. trends in "as found" and "as completed".

CONCLUSION

Knowledge management can have a crucial impact on the service life of electrical equipment. Safety and security of the HV substations and distribution cabinets of Stedin regarding Eaton MOBs is assured for now and in the long term, by means of:

- long-term replacement by Stedin,
- specific maintenance activities by Eaton
- intense cooperation between Stedin and Eaton for the long term as well as knowledge sharing.

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