Development and testing of a new cable connection box for oil filled switch gear to accommodate XLPE cables
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SUMMARY

Stedin BV and other DSOs in the Netherlands operate about 70 substations with 50 kV oil filled switch gear type Coq. This type of switch gear was installed from the 1950’s to the 1980’s and was originally used with oil filled cables and oil filled cable terminals.

In the 1980’s 50 kV XLPE cables became available and had to be connected to the existing bays. At first they were connected with a transition terminal XLPE-oil. Later plug-in connectors were wished for, as they have less fire hazard and are easier to install. In the first decade of the 21st century some “Flinter”-type plug-in cable connection boxes were installed on 50 kV Coq switch gear in projects. Thus further grid development was possible with the existing switch gear.

A review of these early dry type connection boxes in 2012 proved them a safety hazard for personnel and a risk to uninterrupted supply of power to customers. High temperatures of the conductors at high load could lead to stress in the terminal, followed by cracks in the bushing, leakage of oil and possibly a fire hazard to people and the switch gear. Another safety hazard was the possibility of explosion at an internal fault. Finally, high field strength at the receiving end was demonstrated and this may lead to corona discharges and degradation of the material.

A design review was done, and a new type of connection box was developed. Single phase and three phase solutions were explored, with air, SF6 and oil as internal insulation. Finally an oil filled solution with dry external cable connector was chosen. It includes flexibility in the conductors to provide for the thermal expansion at high loads. To cater for pressure reduction at internal faults breaking plates were introduced.

The new connection box design was developed by the OEM (original equipment manufacturer) of the switch gear (now part of Siemens) and reviewed by Stedin. Prototypes for 800 A and 2000 A were produced. Special attention is given to the test requirements. The switch gear was originally designed according to local Dutch KEMA-standards, while the modern cable connection was specified according to IEC 62291-209. The differences between old and new standards will be discussed, and the final test program is shown.

Both types of the termination box were type tested. It was the first time in Europe that the oil filled switch gear with braking plates was tested for an internal fault current. The test was passed successfully.

Now Stedin has certified a safe and reliable cable connection box, in accordance with modern certification and modern cable designs. This new cable connection enables Stedin to continue operation of the Coq switch gear in the grid with improved safety, even while grid capacity is growing and new grid structures are developing.

Keywords
Life extension, Oil filled switch gear, XLPE cable, Cable terminal, Design verification, Type testing, Internal arc test.

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INTRODUCTION

Stedin BV in the Netherlands operates about 30 substations with 50 kV oil filled switch gear type Coq. This type of switch gear was installed from the 1950’s to the 1980’s and was originally used with oil filled cables and oil filled cable terminals. Later XLPE-cables and plug-in connectors were wished for, to replace old cables and speed up project delivery times. From an Asset Management perspective Stedin wants to continue operation of old switch gear as long as possible. The first generation plug-in cable connection box showed problems however and a new solution had to be found. Stedin co-operated with Siemens to develop a new connection box, permitting new connections to and continued operation of the 50 kV grid with Coq switch gear. The process to develop and test the new connection box is described in this paper.

50 kV COQ SWITCH GEAR

In the 1950’s Coq industries developed its D- and O-type oil filled switchgear for 10 – 50 kV. Being much smaller than earlier air insulated switchgear, they rapidly were adopted by major electricity boards in the Netherlands and abroad. Coq supplied most of the switchgear used in the Dutch 50 kV grids during the rapid post World War II expansion. The D-type, also indicated as 0-4-50, will be replaced shortly at Stedin. The new cable connection box is intended for the O-type (0-3-50).

A picture of the switch gear is shown in figure 1. The cross section is shown in figure 2. The switch gear is oil insulated with minimum oil breakers. It has separate compartments for the rail(s), breaker, earthing switch and cable connection(s).

![Figure 1: view of Coq 50 kV switch gear](image1.jpg)  ![Figure 2: cross section of Coq switch gear with connection box, part 3.](image2.jpg)

Traditionally, mass impregnated paper insulated cables were used in 50 kV grids. These cables connect easily with the oil filled switch gear. A simple cable terminal is fitted inside the cable connection box of the switchgear and connected to the copper ends from the bay. The cable connection box is filled with oil. A picture is shown in figure 3. In the 1980’s XLPE-cables were developed for 50 kV. Their plastic isolation was incompatible with oil isolation, so a new cable termination had to be developed. In Holland, the Nederlandse Kabelfabriek (NKF), now part of Prysmian, made a XLPE to oil transition connection for Coq switch gear. It is shown in figure 4. It was used by Stedin and several other grid owners in the Netherlands, and performed well. But it still needed a traditional cable termination, which had to be assembled on site.
PLUG IN CONNECTIONS

At the end of the 20th century, the next step in cable termination technology was marketed: the plug-in technology. XLPE-cable and switch gear are fitted with prefabricated terminals in the factories, and are simply plugged together on site. Thus, connection time on site is greatly reduced. Stedin and its subsidiary Joulz explored this technology in connection with the Coq switch gear. Between 2000 and 2011, 10 bays were refitted with new “Flinter”-type connection boxes and plug in cable terminals. An example of a “Flinter”-box is shown in figure 5.

DESIGN REVIEW

In 2007 a major incident happened in a 50 kV substation in Alblasserdam. A phase-to-earth breakthrough in a traditional oil filled connection box caused a fire. This resulted in the loss of the complete substation.

An investigation revealed, that the cause of the breakdown was a failure of the bushing from the cable connection box to the circuit-breaker compartment. Following the investigation, regular Partial Discharge (PD) measurements were introduced to reveal an early warning for degradation of bushings.
or other discharges. Also, the diverse array of connection boxes was reviewed, to determine whether extra stress on the bushing was plausible.

The design review of the “Flinter”-boxes showed a lack of documentation of the design process. Stedin and DNV-GL were unable to determine which design specifications were used and whether the box was in accordance with the modern IEC standards or with the original Dutch “KEMA standaard”. A primary concern was the voltage withstand capability for impulses voltages; the minimum distance between the conductor and the grounded steel wall of the connection box was not met. Temperature rise at nominal current and short circuit withstand capabilities were not proven, but the dimensions of the “Flinter”-box compared to the old boxes suggested a better performance for the “Flinter”-box.

In the “Flinter”-box, being a three phase box, a three phase short circuit can occur. This is in contrast to the old boxes, which were single phase. This could result in higher forces to the side-walls and bushings.

To summarize, serious concerns with respect to the design of the “Flinter”-cable boxes were found.

NEW CONNECTOR DESIGN

Following the design review, in 2012 Stedin decided to start development of a new cable termination box for Coq switch gear. Stedin contacted Siemens, who had acquired the ownership rights of the Coq 50 kV switch gear from the original manufacturer. Siemens agreed to develop a cable termination box for plug in connection in accordance with present day standards.

The primary design criteria for the new cable box include [1]:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Comparable to old connection box, maximum + 10 % extra weight</td>
</tr>
<tr>
<td>Temperature rise</td>
<td>All parts shall be able to hold the rated continuous current without exceeding the maximum temperature rise as specified in the IEEE or IEC standard</td>
</tr>
<tr>
<td>Lineair expansion</td>
<td>Lineair thermal expansion will not produce mechanical stress on parts of the box or parts of the switch gear</td>
</tr>
<tr>
<td>Safety</td>
<td>Volume expansions after internal short circuits will be controlled and compartmented. Systems will be in accordance with IEC 62271-200</td>
</tr>
<tr>
<td>Connection to cable</td>
<td>Plug in connection according to DIN 47631 and DIN 50181 type Connex (Pfisterer) or similar proven alternative</td>
</tr>
</tbody>
</table>

The electrical specifications are equal to the old connection box:

- Nominal voltage: 52 kV
- Rated bay current: 800 A and 2000 A
- Short circuit current: 29 kA / 3 s
- Dynamic short circuit current: 72.5 kA (29 kA *2.5)

At the start of the design a decision had to be made on the isolation medium in the new connection box. Alternatives to oil are SF6, air, polyuretane and bitumine mass. The compact dimensions of Coq switch gear prevents air insulation. The phase-to-phase distance between the connections to the circuit breaker is 145 mm. A minimum of 360 mm is needed for 60 kV, so this is clearly impossible.

SF6 is a good insulation material and reduces the effect of an internal arc compared to oil insulation. But it needs a leak detection, which is an extra protection element in the Coq. Also, the gas tight
sealing of the bushing to the breaker compartment requires opening of the breaker compartment. For this reasons, SF6 insulation was discarded. Polyuretane solid insulation and bitumeous mass are critical at the copper-insulation boundary. Permanent pressure is needed to prevent cracks. Use in MV-systems has been reported succesfull, but experience at 50 kV and above is very limited.

To summarise, all alternatives to oil have disadvantages.

The major disadvantage of oil is its behaviour at internal arcs. Oil will dissolve in gaseous components and consequently a rapid rise of pressure will occur. This will rip apart the connection box. A rupture disk, directing the pressure wave away from the operator, may mitigate this safety issue.

It was decided to use oil as isolation medium in the new connection box.

In the next design phase a total of 14 possible lay-outs of the connection box were drawn and evaluated on the design criteria. The 14 lay-outs were divided in 1 phase and 3 phase boxes, both with single or double cable concepts.

A decisive criterium was the free space around a cable plug-in female connector, according to EN 50299 figure 2 [2]. It requires a free cylindrical or rectangular space around the connector with a diameter of 430 mm. Only 3-phase single cable lay-outs permits this in the available space for a connection box below the cable disconnector in a 50 kV Coq 800 A cable bay. Thus, it was decided to use the three phase box for a cable feeder. For a 2000 A transformer connection, the Coq bay is much wider. This enables a single phase double cable concept. This was chosen above a three phase concept for its low weight and easier handling.

Also the effect after a intern fault should be significant lower (one phase only) thus limiting damage to fewer components inside the connection box and decreasing repair time of the bay.

Four cable producers were invited by Siemens to discuss using their plug-in cable connector to be used in the connection box. Three were able to supply a 72,5 kV range connector. From these, the Click-fit connector supplied by Prysmian was chosen to be used in the connection box. Best support in the Netherlands and more knowledge of electrical field distribution calculations over its comparitors lead to this choise.

Detailed engineering by Siemens optimised the chosen concepts. The conductor between the cable terminal and the bushing was further engineered, to optimise field distribution while minimising stress to the bushings. Fluid and gasdynamic calculations were carried out, to optimise the dimensions and placing of the breaking plates. The mechanical stress on the bottom plate of the Coq earthing compartment (which carries the weight of the connection box) was checked.

The results were shared with Stedin in progress reports. A drawing and a cross-section model of the 800 A design is shown in figure 6. The exploded view of a 2000 A box is shown in figure 7.

Figure 6: drawing and model of 800 A three phase connection box.
Finally Siemens made proto-types for testing, both for 800 A and 2000 A.

STANDARDS FOR TESTING

Modern requirements for testing of switch gear and cable terminations can be found in IEC standards:
- IEC 60060-1
- IEC 60270
- IEC 62271, parts 200 and 209
Test voltages refer to the rated voltage Ur = 72.5 kV. The main test voltages are:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage test</td>
<td>140 kV</td>
</tr>
<tr>
<td>Impuls voltage test</td>
<td>325 kV</td>
</tr>
<tr>
<td>Partial discharge measurements</td>
<td>87 kV (&lt;10 pC)</td>
</tr>
</tbody>
</table>

These are tough criteria for equipment in grids with a operational voltage of 50 kV +/- 10 %.

Coq switchgear was developed, when modern standards did not yet exist. Original documentation of Coq industries BV indicate a rated voltage of 52 kV and test voltages:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage test</td>
<td>120 kV</td>
</tr>
<tr>
<td>Impuls voltage test</td>
<td>295 kV</td>
</tr>
<tr>
<td>Partial discharge measurements</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Upon delivery, the Stedin Coq switch gear now in use, were tested according to local Dutch standards, supplied by KEMA (now DNV-GL):
- KEMA GI68 KEMA specificatie gesloten installaties (1968); superseded by
- KEMA S4 KEMA specificatie gesloten schakelinstallaties 1 t/m 72,5 kV voor binnenopstelling [3], (for switch gear);
- KEMA S8 KEMA specificatie voor eindsluittingen met kunststofkabels [4], (for XLPE cables);
- KEMA S10 KEMA specificatie voor met geëxtrudeerde kunststof geïsoleerde éénfase kabels 50, 110 en 150 kV en de bijhorende garnituren [5], (for XLPE cables and accessories).

For test voltages S4 refers to the old IEC 694, with additional rated voltages of 30 and 60 kV. Those voltage ranges are suitable for the traditional grid voltages in the Netherlands: 25 kV and 50 kV. For 60 kV the test voltages according to KEMA S4 and S10 are:
<table>
<thead>
<tr>
<th>Test Type</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage test</td>
<td>115 kV</td>
</tr>
<tr>
<td>Impuls voltage test</td>
<td>280 kV</td>
</tr>
<tr>
<td>Partial discharge measurements S4</td>
<td>66 kV (&lt;100 pC) and 38 kV (&lt;5 pC)</td>
</tr>
<tr>
<td>Partial discharge measurements S10</td>
<td>50 kV (&lt;10 pC) and 38 kV (&lt;5 pC)</td>
</tr>
</tbody>
</table>

KEMA test voltages are similar to Coq’s, but include PD measurements.

It was decided to test the connection boxes both to KEMA and modern IEC standards. The test was considered successful if KEMA tests were passed, but Stedin and Siemens would like to know whether the new connection box design was compliant with modern standards for 72.5 kV.

For the temperature rise test at nominal current and the short circuit test no big deviations exist between old and new standards. All refer to the nominal current and maximum fault current, which has not been altered.

The old standards do not specify any internal arc test. The traditional connection boxes and the new 2000 A box are single phase, so any internal arc will be driven by phase-earth faults only. The new connection box for 800 A is a three phase design, which allows phase-phase short circuit. The 800 A connections box will be tested for an internal arc with 16 kA, the maximum short circuit current in Stedin’s 50 kV grid. The 2000 A box will be tested with 11 kA, the earth fault current.

**TEST RESULTS**

The tests were carried out at the test laboratory of Austrian Institute of Technology (AIT) in Wien, Austria. They were witnessed by representatives of Siemens and Stedin.

The results of the 800 A box type test are reported in Prüfbericht/Test Report 2.03.02963.1.0 [6].

The AC voltage tests and lightning impulse withstand voltage tests were passed without discharge on all phases. PD measurements were passed with a maximum of 4.2 pC at 87.8 kV.

The temperature rise test was passed with a maximum of 8.2 K temperature rise and no increase in resistance of the conductors. The short circuit test was executed with an increase of less than 20% in measured resistance. The short circuit tests, three phase with the test value of 29 kA/3s and phase to earth with 29 kA/1s, were passed successfully.

*Figure 8: 800 A prototype in test lab before test*
Finally the internal arc test was passed without fragmentation or holes in the enclosure, or loss of the earthing point. Deformation of the coverings did occur, as well as loss of oil. But the deformation was within the limits and oil was not directed in the direction of a person standing before the installation. The pictures below in figure 9 show deformation and oil spill.

![Deformation and oil spill](image)

Figure 9: oil spill and deformation during internal arc test.

The 2000 A single phase connection box was subjected to AC voltage tests, PD measurements, temperature rise test and internal fault test. The results of the 2000 A box type test are reported in Prüfbericht/Test Report SGP-06720 [7].

It passed all tests for 60 kV rated voltage. It passed the AC voltage test and impulse voltage test for 72,5 kV switch gear, but failed for partial discharges (> 10 pC at 72 kV test voltage)

**CONCLUSION**

Close coöperation between a grid owner (Stedin) and a manufacturer (Siemens) made it possible to develop a new connection box with plug in cable connection to the old 50 kV Coq switchgear. In a structurized development process two types of connection boxes were developed and tested. Stedin now has a proven connection box available for making new connections to its 50 kV grid using existing Coq switchgear. It expands the life time of existing assets and optimises grid operation.

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[3] KEMA specificatie gesloten schakelinstallaties 1 t/m 72,5 kV voor binnenopstelling (Kema NV, 1986, the Netherlands)
[4] KEMA specificatie voor met geëxtrudeerde kunststof geïsoleerde hoogspanningskabels 1 t/m 30 kV en de bijhorende garnituren (KEMA NV, 1981, the Netherlands)
[5] KEMA specificatie voor met geëxtrudeerde kunststof geïsoleerde éénfase kabels 50, 110 en 150 kV en de bijhorende garnituren (Kema NV, 1981, the Netherlands)
[6] Prüfbericht/Test Report 2.03.02963.1.0 (Austrian Institute of Technology, 04-09-2015, Austria)