EXTENSION OF PERFORMANCES OF MEDIUM VOLTAGE SWITCHING EQUIPMENT

F. Petroni, R. Emma*,
*Enel Distribuzione Rome - Italy
Fiorangelo.petroni@enel.it; Roberto.emma@enel.it

M. de Nigris, A. Geroli, R. Berti◆
◆Cesi S.p.a Milan - Italy
denigris@cesi.it; geroli@cesi.it; berti@cesi.it

SUMMARY

The liberalization of the electricity market motivates distribution utilities to limit investments for the renewal of equipment and for their maintenance though increasing the system availability and the quality of service.

In this frame, Enel Distribuzione S.p.A. has carried out in collaboration with CESI the verification of the possibility to extend the performances of medium voltage switching equipment beyond their design data, with particular reference to:

- Pre-fabricated switching equipment with metallic enclosure and air insulation (compact switchboard) whose nominal current has been extended from 1250 to 1600 A;
- SF₆ circuit breaker 24kV-630A-12.5 kA whose lifecycle capabilities have been checked for a prolonged endurance cycle.

The paper reports the motivation, development and results of these activities discussing their implications.

1. INTRODUCTION

Much pressure is imposed on distribution utilities in terms of availability of the supply and quality of service. Rules imposed by National Authorities impose requirements always more stringent and bonus/fees approaches are widely applied to motivate a steady increase in the levels of quality. On the other hand, liberalisation processes and the consequent outstanding attention to investment and operation cost containment require a careful and constant cost/benefit evaluation.

In this framework new technical solutions aimed at a simplification of the schemes, reduction of purchasing cost, interoperability are gaining importance together with all operations which can assure a reliable extension of the service life of existing equipment. This paper describes and discusses the activities carried out by Enel Distribuzione in cooperation with CESI aimed at the design and check of switching equipment having an extended application range and/or having a prolonged expected service life.

2. EXTENSION OF THE APPLICATION RANGE OF DISTRIBUTION SWITCHBOARDS

Enel Distribuzione has developed and patented [1] an advanced and environmental-friendly pre-fabricated substation, whose main features have been presented in previous papers [2, 3]. A very important piece of equipment within the substation is represented by the compact switchboard installed into a container having commercial size (see Figure 1).

The basic design was developed for a nominal current of 1250A and a target use with distribution transformers rated 25 MVA. More than 1500 pieces were installed cumulating more than 3000 years-board with no major inconvenience. This type of board has been used (with the permission of ENEL, the owner of the relevant European patent) also by other utilities such as ACEA and EDF. The low production and installation costs, as well as it reduced impact on the environment have motivated the study for an upgrading of such type of equipment also on installations having higher current requirements. The switchboard has been upgraded to 1600A and tests have been carried out with success in CESI. This type of equipment with extended rating is suitable for installations with a 20kV transformers rated 40 MVA, covering more than 90% of ENEL requirements.

As shown in Figure 2, every single compact switchboard element is the most simple enclosure for the circuit breaker, the switchboard core. In the simplified design, busbar and cables disconnectors could be removed, their function being efficiently carried out by a lifting system included in the cubicle; this system moves the circuit breaker from the on position (high) to disconnected position (low) by means of a tangent screw to transmit the motion. The lifting system has been successfully subjected to a mechanical endurance test made of 1000 simulated operations, to verify the effective ability of the device to perform as disconnector.
The removal of the disconnectors has a dramatic beneficial effect in the reduction of the overall switchboard cost: in fact, at present, the cost of every single switchboard unit, including the cubicle and the circuit breaker, is about 5-6 k€. The economical advantages of this technical solution has motivated Enel Distribuzione to extend the use of compact devices from primary substations (HV-MV) to “satellite centres”. These are MV shunting stations used in densely populated areas, like major Italian cities, to virtually shift primary substations busbars to barycentric points of the distribution network. Moreover, the use of compact switchboard is being studied for use in some MV substations where a high automation degree is about to be implemented.

About 1500 units have been installed in the last 3 years showing very good performances. These encouraging results motivated to envisage the extension of the use of these devices, designing a 1600 A version, in addition to 1250 A unit. In this way it is foreseen to use compact switchboards in those primary substation equipped with a 20 kV - 40 MVA power transformer, covering roughly 90% of Enel Distribuzione demand for primary substation MV switchboards.

A major concern in the design of new 1600 A rated compact switchboards, has been the need to keep unchanged the outline dimensions of cubicle, in order to reuse as much elements as possible from the 1250A design. The main problem was to limit the heat generation inside the transformer and the connector module because internal arc resistance requirements inhibit any increase in the ventilation. To cope with this limitation, a reduction of contact resistance was envisaged and achieved using materials with lower resistivity and optimizing the contact surfaces. The above-mentioned design criteria were confirmed by checking the outline dimensions: the only difference being in a slightly taller design (20 mm higher than the old one) because of the increased size of bus-bar.

Transformers module rated 1600 A are capable to receive two 630 mm² cables which can carry the whole switchboard rated current (1600 A) when they are installed in a way suitable to allow free-air cooling. In order to avoid cables capacity reduction care must be taken during their installation.

The design modifications necessary for the withdrawable 1600 A rated vacuum circuit breaker were determined from the results of the temperature-rise tests carried out on the 1250 A rated inside the respective switchgear (Enel Specification DY697). In particular the terminal contact in correspondence of the cables and bus-bar has been modified and the connection between top vacuum bottle and bus-bar terminal has been improved. For some manufacturers it was more difficult to improve the capability of the top terminal due to the limit established by top bushing diameter (110 mm). For one of them it was enough to increase the contact area of the bottom terminal, consequently reducing the electrical resistance.

### Comparative environmental performances assessment

A comparison of the environmental performances of the new and the old version of the air insulated compact switchboard in every phase of their life was performed with a Life Cycle Assessment (LCA) according to ISO 14040 series using LCA software TEAM of Ecobilan Group. The composition and the main features of the two switchboards are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Main features of air insulated compact switchboards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1250 A rated version</strong></td>
</tr>
<tr>
<td>Width×depth×height of units (mm)</td>
</tr>
<tr>
<td>Composition*</td>
</tr>
<tr>
<td>Electrical resistance of units (µΩ)</td>
</tr>
<tr>
<td>Total surface (m²)</td>
</tr>
<tr>
<td>Total Weight (kg)</td>
</tr>
<tr>
<td>Package weight (kg)</td>
</tr>
</tbody>
</table>

* width of TR and CS units  
** Legend:  
L = outgoing line 630A feeder unit  
R = rephasing capacitor unit  
CS = busbar connector unit  
SH = shunt CB unit for the selfextinction of phase-to-ground arcs  
TR = incoming 1250A or 1600A transformer feeder unit  
TV = protection and instrument voltage transformer truck  
BSE = busbar system earthing truck  
SS = busbar passing unit  
A = accessories  
SA = auxiliary services unit

The functional unit was defined as “The distribution of energy, supplied by two 25 MVA transformers of a HV/MV distribution substation, to 20 MV line feeders across 25 years, according to a typical load curve as shown in Figure 3”.

The two configurations ensure the same functional unit. Their life service is considered lasting 25 years, considering after that period an unacceptable decrease in the reliability owing to wear or obsolescence. Breakdown for internal arc or fire and the primary recycling of some parts to repair other devices are excluded.

A “from cradle to grave” approach for comparative LCA was adopted and the life cycle of the functional unit is composed of the following main phases:

(a) Production comprising raw materials acquisition.
(b) Transportation including the transportation and the installation of the switchboard within its building and related fuel consumption. Energy consumption for assembly is negligible.
(c) Use including energy consumption, linked to the losses of the switchgear and the fuse links owing to Joule effect, and the lubricant and fuel consumption for maintenance, carried out every 3 years. The losses of the switchboards are calculated from the load curve of Figure 3 applying a utilization factor: 30% for unit with 630 A circuit breakers and 40% for 1250 A and 1600 A circuit breaker units.

A fuse link replacement was foreseen due to a prevision of 20 years life duration while their end-of-life is included in switchboard end-of-life phase. As SF6 of SA unit is sealed for life no gas emissions to the atmosphere are considered.

(d) End-of-life considering:
- the dismantling of the switchboard and its transportation to a waste collector;
- the management of the waste in which metals are recycled with 99% mass efficiency in a closed loop avoiding use of primary materials;
- the wood package and polymeric insulating materials are incinerated with energy recovery, the porcelain crushed and recycled as road mantle filling and the PE package is
- the SF6 removal from the SA unit and transportation to SF6 manufacturer for its recycling, the enclosure cleaned with water-diluted soda and a flow of nitrogen to neutralize decomposition products and the neutralization of the cleaning solution with CO2 scrubbing.

The impact categories chosen for the comparison were:
1. CML Depletion of non renewable resources (NRRD),
2. IPCC effect over 20 years Greenhouse effect (GW),
3. CML Air acidification (AA),
4. CML Eutrophication (EU),
5. USES 2.0 model Human toxicity (HTX)
6. WMO low Depletion of the ozone layer (OLD)
7. WMO average Photochemical oxidant formation (POF)

Moreover the following critical flows were included:
- Waste hazardous production (WH)
- Waste total production (WT)
- Total primary energy consumption (TEP).

The results of LCA comparison between the two version of the compact switchboard are given in table 2

### Table 2: The environmental impacts of each phase of life cycle of the two version of the air insulated compact switchboard

<table>
<thead>
<tr>
<th>Environmental stress factor</th>
<th>Units</th>
<th>Production</th>
<th>Transport</th>
<th>Use</th>
<th>End-of-life</th>
<th>Whole Life Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1250 A rated Switchgear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH</td>
<td>kg</td>
<td>9.07</td>
<td>0.0006</td>
<td>7.13</td>
<td>3.32</td>
<td>19.52</td>
</tr>
<tr>
<td>WT</td>
<td>kg</td>
<td>1263.18</td>
<td>0.48</td>
<td>1376.29</td>
<td>-843.60</td>
<td>1796.35</td>
</tr>
<tr>
<td>TEP</td>
<td>MJ</td>
<td>678769.32</td>
<td>14341.82</td>
<td>502733.00</td>
<td>-5659067.3</td>
<td>630973.41</td>
</tr>
<tr>
<td>AA</td>
<td>g eq. H+</td>
<td>10825.94</td>
<td>421.60</td>
<td>12307.24</td>
<td>-7735.29</td>
<td>15819.48</td>
</tr>
<tr>
<td>NRRD</td>
<td>frac. of reserve</td>
<td>2.19E-09</td>
<td>1.40E-12</td>
<td>6.93E-11</td>
<td>-2.16E-09</td>
<td>1.04E-10</td>
</tr>
<tr>
<td>EU</td>
<td>g eq. PO4</td>
<td>16691.24</td>
<td>2215.75</td>
<td>9001.33</td>
<td>-9867.41</td>
<td>18040.91</td>
</tr>
<tr>
<td>GW</td>
<td>g eq. CO2</td>
<td>67894960.44</td>
<td>1334994.49</td>
<td>50615072.15</td>
<td>-56309793.38</td>
<td>63535167.59</td>
</tr>
<tr>
<td>HTX</td>
<td>g eq. 1,4-dichlorobenzene</td>
<td>5472624.80</td>
<td>2621.31</td>
<td>6134993.02</td>
<td>-8512837.10</td>
<td>3097402.04</td>
</tr>
<tr>
<td>OLD</td>
<td>g eq. CFC-11</td>
<td>6.66</td>
<td>0.0013</td>
<td>17.14</td>
<td>-5.99</td>
<td>17.82</td>
</tr>
<tr>
<td>POF</td>
<td>g eq. ethylene</td>
<td>133047.47</td>
<td>2057.63</td>
<td>27359.36</td>
<td>-8858.70</td>
<td>33865.75</td>
</tr>
<tr>
<td><strong>1600 A rated Switchgear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH</td>
<td>kg</td>
<td>9.08</td>
<td>0.0007</td>
<td>7.01</td>
<td>3.49</td>
<td>19.58</td>
</tr>
<tr>
<td>WT</td>
<td>kg</td>
<td>1445.60</td>
<td>0.5455</td>
<td>1353.15</td>
<td>-965.80</td>
<td>1833.50</td>
</tr>
<tr>
<td>TEP</td>
<td>MJ</td>
<td>775124.56</td>
<td>16294.3817</td>
<td>495319.57</td>
<td>-649058.03</td>
<td>637686.48</td>
</tr>
<tr>
<td>AA</td>
<td>g eq. H+</td>
<td>11687.17</td>
<td>479.0003</td>
<td>12101.76</td>
<td>-8285.73</td>
<td>15982.20</td>
</tr>
<tr>
<td>NRRD</td>
<td>frac. of reserve</td>
<td>2.25E-09</td>
<td>1.5917E-12</td>
<td>6.84E-11</td>
<td>-2.21E-09</td>
<td>1.05E-10</td>
</tr>
<tr>
<td>EU</td>
<td>g eq. PO4</td>
<td>187680.20</td>
<td>2517.4078</td>
<td>8857.44</td>
<td>-11603.44</td>
<td>18539.60</td>
</tr>
<tr>
<td>GW</td>
<td>g eq. CO2</td>
<td>78693753.60</td>
<td>1516746.9028</td>
<td>49767807.76</td>
<td>-65769219.89</td>
<td>64210020.08</td>
</tr>
<tr>
<td>HTX</td>
<td>g eq. 1,4-dichlorobenzene</td>
<td>5999593.66</td>
<td>2978.2825</td>
<td>586864.94</td>
<td>-8666060.77</td>
<td>3205518.10</td>
</tr>
<tr>
<td>OLD</td>
<td>g eq. CFC-11</td>
<td>7.26</td>
<td>0.0015</td>
<td>16.90</td>
<td>-6.23</td>
<td>17.93</td>
</tr>
</tbody>
</table>

CIRED2005

Session No 1
The analysis of the environmental profiles of the old and new whole life cycle.

Figure 4 shows the impacts of 1600 A switchboards, with reference to 1250 A switchboard for every phases and for whole life cycle.

The weight increase was ~14% due to 2672 kg of steel and ~14 kg of copper added in the new version of compact switchboard and affects its Production phase with an average rise of pollution about 10%. Only Waste Hazardous is unchanged.

For End-of-life phase the comparison in Figure 4 is made between the absolute values of the impacts except for Waste Hazardous. That means the 1600 A rated version end-of-life allows a greater reduction of the other environmental stresses than the 1250 A version because more steel and copper can be recycled in a closed loop avoiding their use in Production phase.

The 14% increase of the impacts of Transport phase in 1600 a version is simply due to the greater fuel consumption to transport and install a heavier switchboard.

Owing to a smaller electrical resistance of incoming transformer feeder and busbar connector units of the 1600 A rate switchboard, less electricity has to be produced to compensate its losses. This means a 5% reduction in Human Toxicity and a 2% decrease of the other releases and consumption during use phase.

The comparison of the life cycle between the old and new version shows a ~2.3% rise of the 1600 A rated switchboard environmental burden.

4. EXTENDING THE SERVICE LIFE OF SF₆ CIRCUIT BREAKER.

In Italy, the quality standards for both electric energy and natural gas distribution are set by a public institution, the Autorità per l’Energia Elettrica e il Gas (AEEG). At present, the system is based on a bonus/fee mechanism, calculated as a function of quality objectives in a time span of three years.

One of the main parameters of the quality evaluation for electric energy distribution companies is the average of total black out time for every LV customer; incidentally, the present value of this parameter is 86 min. AEEG distinguishes between long (i.e. lasting more than 3 minutes), and short (i.e. lasting less than 3 minutes), blackouts; short blackout are not taken into consideration in the calculation of above mentioned parameter bonus/fee method. For this reason Enel Distribuzione has modified the re-closing cycle of automatic MV lines, with the target of re-energizing the line within three minutes from the failure. The previous cycle scheduled a fast re-closing (O-0,3 s-CO-30 s-CO) followed by two slow ones (120 s-CO-120 s-CO); with the new cycle the slow re-closings are now faster (70 s-CO-70 s-CO). In this way the full re-closing cycle can be performed within 3 minutes. The nominal re-closing sequence of SF₆ breakers bought by Enel from 1979, features the standard O-0,3 s-CO-30s-CO sequence, in compliance with Enel Specifications. Conventional circuit breakers adopted are rated 24kV-630A-12.5kA. In order to check the capability of the conventional circuit breakers adopted by Enel Distribuzione to the new sequence requirements, some samples taken from Enel Distribuzione stocks were subjected to a laboratory investigation comprising the following tests:

- measurement of the contact resistance;
- short circuit tests with the operating sequence O-0.3s-CO-30s-CO-60s-CO-60s-CO;
- dielectric power frequency withstand test;

The peculiar type of sequence adopted during the short circuit tests requires to maintain the same current value during the entire test sequence, thus preventing the possibility to use short circuit generators. Tests were carried out in short circuit laboratory directly supplied by the network; the required TRV was obtained by means of capacitances and resistors suitably selected for the specific application. The contact resistance of each phase measured before and after the test sequence showed stable values; moreover all dielectric power frequency tests passed successfully at 80% of the rated power frequency insulation level. The measurement of the arcing time during the entire sequence showed no significant difference between the different shots applied, demonstrating that no apparent important degradation was caused by the short circuit current.

The extended test sequence allowed to state that the conventional circuit breaker of the type subjected to the test is fit for the new type of operation foreseen by Enel Distribuzione. Moreover, the stability of all operating parameters motivated to check the possibility of an extension of the service life of such devices. The entire test program was then repeated to support this assumption. Here again, on the sample tested a complete stability of all parameters was observed. Therefore, not only this type of circuit breaker appears suitable for the expected revised operating sequence but its service life can be imagined to be by far longer than that previously expected. This fact would allow, if verified on other samples, models and manufacturers, to postpone replacement investments thus obtaining important gains.
5. CONCLUSIONS

- Enel Distribuzione has developed and patented an advanced and environmental-friendly pre-fabricated substation, characterised, on the MV side, by the presence of a compact and simplified switchboard housed in a container of commercial size;

- The basic design of the switchboard was developed for a nominal current of 1250A and a target use with distribution transformers rated 25 MVA and has successively been upgraded to 1600A to make it suitable for installations with a 20kV transformers rated 40 MVA, covering more than 90% of ENEL requirements;

- The upgraded design has been tested with success both from the mechanical and electrical points of view;

- The comparison of the environmental performances has been carried out according to the LCA protocol and has shown that, with the “less is better” logic, the old version is a more environmental friendly solution, but the worsening is little if the very high improvement of the 1600 A version electrical performance is considered.

- In order to comply with more stringent requirements of quality of supply, Enel Distribuzione has modified the reclosing cycle of automatic MV lines, with the target of re-energizing the line within three minutes from the failure. The new operating sequence on circuit breakers is O-0.3s-CO-30s-CO-60s-CO-60s-CO;

- Some samples were subjected to a laboratory test campaign that has demonstrated that the conventional circuit breaker of the type subjected to the test is fit for the new type of operation.

- The stability of all operating parameters motivated to check the possibility of an extension of the service life of such devices, by means of a repetition of the entire test program. The successful results of the test campaign conducted demonstrated that the service life of the samples tested can be imagined to be by far longer than that previously expected, thus allowing to postpone replacement investments.

References