ABSTRACT

Overall context of the study

For more than 30 years the French Distribution Network Operator ERDF has used low voltage mains cables complying with the French national standard NF C33 210. Over the years the design has been progressively improved to a point where further optimisation would be difficult. Today, the increasing pressure of continually rising raw materials costs has lead to a new drive for further optimisation. Additionally other environmental, legal and ecological constraints need to be considered regarding the continued use of heavy metals, such as lead, in the cable construction.

In a project designed to provide a technical solution to this problem ERDF, with the support of its Research and Development Division EDF R&D, started a so called productivity partnership with its cable suppliers. It consisted in a joint project team investigating all the technical aspects that were likely to reduce the overall cost of the cable design, with a view of both parties sharing any potential profits resulting from the proposed improvements. This joint work with manufacturers enabled to reach a new optimised design for the cable.

On its side EDF Energy has used for many years low voltage mains cables complying with the British national standards BS 7870-3.40 and ES 20-0960. As for ERDF the design is subject to the recent steep increase in raw materials costs (particularly for copper included in the EDF Energy cable), coupled with comparatively low purchase volumes.

So EDF Energy was also looking to optimize its cable design. Based on joint discussions and works within the EDF group it appeared that the design of the new targeted French cable could be of great interest for EDF Energy from both technical and economic point of view.

Purpose of this paper

This paper presents the study that has been carried out to define this new LV mains cable whose development is currently in progress. It focuses on a few technical aspects that have been dealt with to succeed in the definition of the new design. It also provides concomitantly with some economic considerations.

CHARACTERISTICS OF CURRENT CABLES

The cable currently used by ERDF consists of:
- three sector-shaped XLPE insulated stranded aluminium phase conductors (cross-sections : 95, 150, 240 mm²),
- a round lead covered stranded aluminium neutral,
- a galvanized steel tape screen to provide both third-party and mechanical protection
- an external PVC sheath,
- a number of fillers which provide both longitudinal water-tightness and prevent mechanical movement of the cable components.

The cable currently used by EDF Energy is composed of:
- three sector-shaped solid aluminium XLPE insulated phases (cross-sections : 95, 185, 300 mm²),
- an extruded rubber bedding layer,
- a concentric copper neutral earth conductor to provide a earthed metallic screen for third-party protection,
- an external PVC sheath.

MAIN EVOLUTIONS OF THE NEW DESIGN

Three possible design changes were investigated and incorporated in a revised cable design:
- Removal of the steam cross linking process (insulation).
- Sheath and insulation thickness reduction.
- Change of the current neutral conductor under lead sheath with a round solid aluminium neutral conductor with an equivalent diameter to the existing design.

The two first points can surely be considered as design improvements whereas the last one is a major change. Each of these modifications was validated by series of tests and experiments in the field. The key requirement was to
ensure compatibility with existing distribution network accessories and boxes which would be potentially used with the new cable design.

**Removal of the steam cross linking process**

The steam cross-linking process used up to now fixes the thermal behaviour of the phase conductor’s insulation. It is obtained by the grafting of molecules between polyethylene chains to create tri-dimensional edifices. By this operation, the thermoplastic material becomes thermosetting (heat stable).

The possibility of removal of the steam cross linking process has been validated by tests:
- A first one consisted in making some insulations naturally cross-linked to be able to determine if the necessary time between manufacturing and assembly was not a future difficulty. As a result it appeared that during the first hours after loading a new underground link (temperature near 90°C), the complete cross-linking process would be completed.
- Other tests were carried out to check the insulation resistance to cracks (fissures) before complete cross-linking. Neither propagation of fissures (calibrated cracks and connector teeth fingerprinting) nor creep of insulation sheath under connector teeth appeared and the electric resistance did not increase beyond the required value.

These tests results lead to the conclusion that the cross-linking process can end naturally without any consequences on the insulation sheath behavior. As a benefit the possible removal of the steam cross-linking process allows to reduce the amount of energy required for manufacturing and the costs associated with the operation and maintenance of required manufacturing plant.

**Sheath and insulation thickness reduction**

Changing the requirements for how the insulation thickness was specified instead of specifying an average thickness with a minimal value at one point, specifying a minimum thickness guaranteed at any point was considered. This change allows manufacturers to optimize their fabrication process with the reduction of the insulation thickness by a few tenths of millimeter on both the phase conductors insulators and external sheath. As a benefit the raw material volumes used for manufacturing LV mains cables can be significantly reduced.

**Major changes in the neutral conductor design**

The new cable design should be constituted with the same elements except the neutral conductor for which the following major changes were applied:
- Removal of the existing lead sheath around the neutral conductor.
- Replacement of the current stranded aluminium neutral conductor with a solid one whose external diameter is the one of the existing neutral measured on lead. The major reason is to ensure the complete compatibility of the system components (accessories interoperability).

This evolution should lead to significant savings for the following reasons:
- The lead mechanical presses used to sheath the conductor are aged and difficult to maintain.
- The suppression of lead will allow to answer to environmental and health purposes.
- The lead price is replaced with the aluminium price (the final price of neutral will be 15% less).
- The neutral conductor would be issued from aluminium wires without any transformation (machine wire).

**VALIDATION OF THE NEW DESIGN**

**Lifespan considerations**

Before changing the cable design we have to check its lifespan that will be at least equivalent to the one of the current cable. Regarding these aspects we know that penetration of water through the PVC sheathing is a reality. So, in our study, the corrosion phenomenon (and notably the corrosion kinetics) is the predominant degradation mode which is likely to impact metallic components incorporated in the cable (galvanized steel, aluminium).

Corrosion is an electrochemical reaction between metal (or an alloy) and an aqueous phase. It involves a deterioration slow or fast, progressive, of the metal related to its environment (air, water, alkaline or acid medium, etc.). That can affect its aspect, its surface quality or its mechanical, physical or chemical properties.

**Investigation test definition**

To check the new cable design withstand to corrosion an investigation test was defined consisting in 24-hour cycles based on alternation of phases of salt fog atmosphere, rinsing and temperature rise:
- 14 hours under 55°C and salt fog (concentration: 25% of [NaCl]).
- 1 hour at ambient temperature after rinsing by pulverization.
- 8 hours at 10°C ambient temperature.
- 1 hour at ambient temperature.

The objective of the test is to accelerate the corrosion of the different metallic components of the cable, which depends on the potential of dissolution of metals in contact. The following table gives the potentials of dissolution in an aqueous medium of the metals considered in the study.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Dissolution potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
<td>- 510 mV / ECS</td>
</tr>
<tr>
<td>Steel (Fe)</td>
<td>- 610 mV / ECS</td>
</tr>
</tbody>
</table>
Aluminium (1050A) (Al) - 750 mV / ECS
Zinc (Zn) - 1 130 mV / ECS

The relative position of two metals on the scale of the potentials of dissolution makes it possible to expect what metal will be the anode. In case of coupling of these metals, the most electronegative metal will dissolve first. Regarding these aspects of corrosion a comparative method has been applied to validate the new design in reference to the current one.

Corrosion of iron becomes visible only from 14 days knowing that an expected lifespan of 30 years corresponds to a number of cycles comprised between 7 and 14 cycles. The results of the visual examination of samples of the current and new designs were logically similar as the design of the galvanized steel screen is the same.

Beyond this visual examination the most relevant indicator to check the residual state of the galvanized steel tapes is the measurement of the loss of mass. The mass is measured on a new sample before and after the corrosion test. With each preset stage of ageing, we measure the mass of the tapes. We compare these masses and we calculate the relative loss of mass.

From the results obtained and the model of evolution proposed below, we projected the relative mass loss of the two designs of cable. The evolutions show that the behaviour of two constructions is very close with a light "ignition retard" for the new design.

The ageing of the old and new designs have been assessed and compared. The tests results related to the corrosion of the galvanized steel screen and the solid aluminium neutral conductors are as follows.

**Corrosion of the galvanized steel screen**

After each period defined in the test plan (7, 14, 28 and 42 days) a visual examination of the samples (current and new designs) was carried out. Photographs were taken to be able to appreciate the surface quality of the samples after different periods of ageing. An important degradation of the surface quality of the galvanized steel screens was stated. Zinc, as sacrificial anode, disappears gradually to let appear the steel of the tapes which corrodes.

On photography after 7 days, the apparent white powder is zinc oxide.

Corrosion of the solid aluminium neutral

The mostly significant indicator which can give us indication on the behaviour of the new complex “screen / neutral” is the relative mass loss of the neutral conductor. The results of relative mass loss are as follows.

So we can thus conclude from the test results that the behaviour of the galvanized steel screen is almost identical in the two cable constructions. The behaviour in time is slightly better in the case of the new cable design.
It can be seen that the behaviour of the corrosion is not the same of the galvanized steel screen. However the major conclusion related to this curve is that the relative mass loss is only about 2% after 42 cycles which is few considering that a test period of 42 cycles is a very hard constraint with regard to the expected lifespan of 30 years. Moreover it has to be noted that despite this relative mass loss of 2% the resulting mass of aluminium of the neutral conductor will be more important as the neutral cross-section in the new design is more important than the one in the current design (compensation of the removed lead with aluminium).

**Complementary measurement to evaluate the ageing of the new complex**

In France, the screen is used to ensure the third-party protection. So in case of degradation by corrosion, the resistance of contact has to be as good as possible to evacuate fault currents in case of aggression of sheath by blunt tools. During the test, measurements of the resistance between the screen and the neutral conductor was carried out on the two designs to estimate the progression of this value.

![Graph showing the evolution of the contact resistance of the complex screen/neutral of the NF C 33-210 design](image1)

![Graph showing the evolution of the contact resistance of the new complex screen/neutral](image2)

These diagrams show clearly that the resistance of contact evolves much less with the new optimized design than with the current one. The absence of lead makes it possible to obtain this result. In case of short-circuit, tests performed at “les Renardières” on ageing samples showed that the behaviour of the new complex is quite better.

**ECONOMIC CONSIDERATIONS**

In parallel with the technical validation described above an economic study was performed to ensure the pertinence of the improvements proposed for the new optimized design.

A decomposition of the cable purchase cost has been established with the support of ERDF suppliers. In practice the cost of each raw material used in the cable construction was assessed for both the current and new optimized designs. Thus the economic weight of each main component was defined: PVC sheath, galvanized steel tape screen, fillers, aluminium core of phase and neutral conductors, lead sheath, XLPE insulation thickness…

It cleared appeared that technical improvements of the new optimized design could lead to significant savings of a few percents compared to the current design.

Then the economic comparison was extended to the British cable design. A comparison of the purchase costs of the current British cables and the French ones (current and new optimized designs) was established for the different cross-sections considered. This economic comparison highlighted the interest for EDF Energy to move towards the new optimized design while adopting the same range of cross-sections 95, 150, 240 mm² and keeping a dedicated cross-section 300 mm² for specific needs of electricity distribution (mainly in London).

**PROSPECTS**

Works of this study have proved the technical and economic pertinence for the ERDF and EDF Energy utilities of the EDF group to get a common LV mains cable based on the new optimized design described in this paper.

The development of this new optimized cable is currently in progress. At the same time the good expected compatibility of the design with existing accessories of the French and British networks is also underway by means of concrete mountings to be carried out on the field by both ERDF and EDF Energy jointers.

The implementation of this new common cable on the ERDF and EDF Energy networks will bring the following advantages:
- Significant reduction of the purchase costs.
- Better answer regarding environmental concerns thanks to the suppression of lead.
- Harmonization between companies of the EDF group.