On the way to compare the polarity reversal withstand capability of HVDC mass-impregnated and extruded cable systems

Massimo **MARZINOTTO;** TERNA, Viale Galbani 70, 00156 Roma (Italy)
Giovanni **MAZZANTI;** Dept. El. Electron. Inform. Engineering – University of Bologna (Italy)
Uberto **VERCELLOTTI;** CESI S.p.A., Viale Rubattino 54, 20100 Milano (Italy)
Heiko **JAHN;** FGH Engineering & Test GmbH, Mannheim (Germany)

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Presenter: ***Dott. Ing. Uberto Vercellotti***

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Background

HVDC technology is a **growing field in the T&D sector**, allowing **transmission** of **bulk quantities of energy** with a **reduced impact** on infrastructures and **reduced losses.** The performance level of today's HVDC solutions allow to achieve **advantages from technical, economic and environmental** points of view.

These are the **main reasons** why **HVDC** is seen as the backbone for "super grid" or a high-capacity transmission network for efficiently moving electrical energy to load centres.

In **Germany wind energy parks** at the **North** Sea coast need a **connection to Southern energy consuming industry**.

The **acceptance of new OHL decreases** more and more, therefore **space saving solutions** and T&D technologies with high efficiencies are **required**, e.g. so called hybrid solutions with AC and DC overhead lines on a common tower.

Where such solutions are not possible the **request for laying cables is increasing** and it is essential to **provide testing solutions** to manufacturers and utilities.

Test procedures

While **for extruded cables for AC application already IEC standards** exist, the **DC application is not yet standardised**.

Started with **ELECTRA No. 72 in 1980** and continued with **ELECTRA No. 189 in 2000 recommendations** for testing of DC cables were present. These recommendations were based on the availability of paper-insulated cables, oil-filled paper insulated cables and internal gas pressure cables.

Increasing demand for **extruded cables for DC application** for higher DC transmission voltages **resulted in the CIGRÉ reports 219 and 496**.
Until today neither IEC/IEEE standards are available for the testing of extruded cables for DC application, even if the **future standard IEC 62895** "HVDC power transmission cables with extruded insulation and their accessories for rated voltage up to 320 kV for land applications – Test methods and requirements" is under preparation.

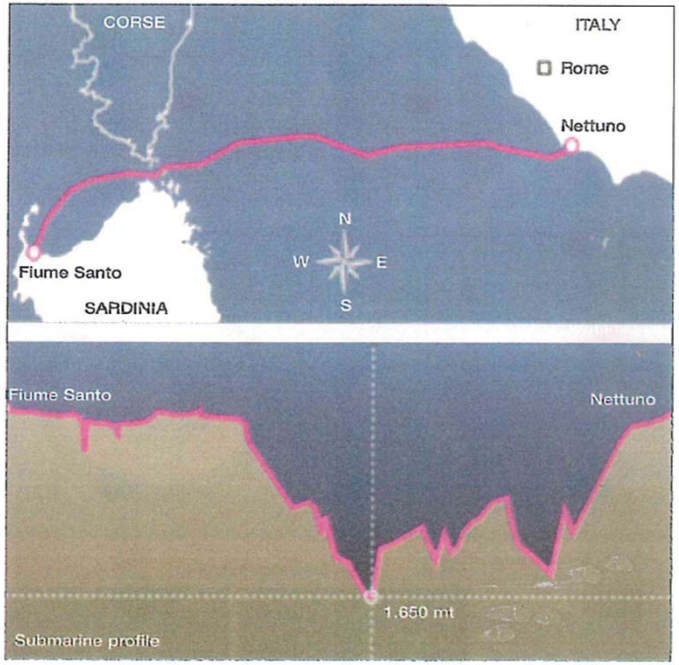
Key operational issue

The **reversal of voltage polarity (PR) is essential in HVDC cable systems** with Current Source Converters (CSC), since it enables to **revert the direction of the power flow**.
Mass Impregnated Non-Draining (**MIND**) **cables** are known to be able to **withstand the voltage polarity reversal** without particular problems. Such ability is assessed by performing a dedicated polarity reversal loading cycle test with voltage polarity reversals every 4 hours, acc. to **Electra 189, 2000**.

Since long ago **TERNA**, has introduced in its test protocols for HVDC MIND-insulated cable systems the so-called "**sustained PR loading cycle test**".

This test has proved to be **very effective for an assessment of the cable system performances** in the presence of polarity reversal during cable tests of different HVDC interties: the Italy-Greece and **SAPEI** and the up-coming Italy-Montenegro.

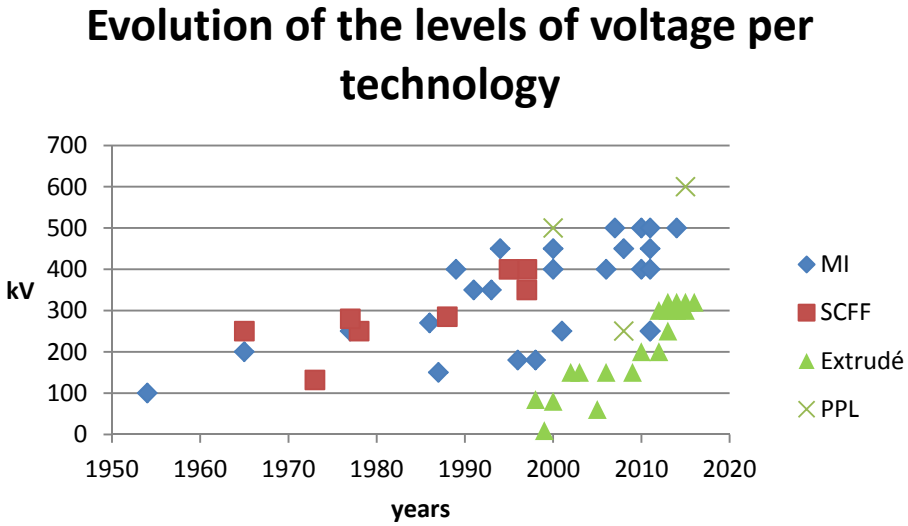
On the contrary, **HVDC cables with extruded insulation are known to suffer PR** by much.



Market trends

In the meantime **HVDC extruded cable systems** have gained fast **increasing shares in the HVDC cable** system market during the last decade, with many land and especially submarine HVDC cable links of the extruded type commissioned worldwide.

HVDC extruded cable systems with voltage and power ratings **up to 320 kV and 1000 MW**, respectively, are commercially available.
However, most if not all of these systems work with Voltage Source Converters (**VSC**) because of their unsatisfactory behavior in the presence of voltage polarity reversal.



This behavior has hampered the development of HVDC extruded cable systems with Current Source Converters (CSC).

TERNA research program on Polarity Reversal

However, the latest R&D activities led some manufacturers to **develop HVDC extruded cable** systems that are claimed to be **capable to withstand PR**.

Since the **experience is quite scarce**, **PR loading cycle tests** capable to compare the performances of extruded cables and accessories in the presence of polarity reversal with the known behavior of MIND cables and accessories **are required**.

TERNA decided to **invest in a research activity based on the assessment of the behavior of DC extruded cables under polarity reversal stress**.

TERNA has involved **CESI with its HVDC facilities and few major HVDC extruded cable world manufacturers**.

Tests, already **ongoing**, are performed in the new HVDC test labs of CESI in Mannheim, Germany: the hall size is 60x26x21 (LxWxH) meters with 3 independent areas (26x20m each) separated by movable walls to manage three different test facilities with 3 HVDC generators 800 kV, 1200 kV and 1600 kV.

This test campaign has been mainly based on two main sections: the ageing section made of a mixed solution of both load cycles and PR a sustained voltage polarity

Voltage levels and duration of the various stages of the tests have been **selected** on the one hand from the **experience** gained by **TERNA** in testing MIND cables, and on the other hand on dedicated aging and life models developed for extruded cables in cooperation with the **University of Bologna**, Italy.

Specific numerical models, under development between TERNA and the University of Bologna, for the evaluation of life expectations of cable types **have been used** to select both accelerated test duration and the number of Polarity Reversal stress to be performed.

As mentioned above, the test program is made of two main sections, the ageing section and the sustained reversal polarity stress section (formally a second ageing section):

1) The first **ageing section** is mainly based on the **procedure suggested** in **for cables** to be installed in systems that **allowed the voltage polarity reversal**. Specific accelerated ageing factors have been selected.

2) As far as the **second section** is concerned, a proper sustained Polarity Reversal stress section has been adopted formally **based on the experience** that **TERNA** gained through the years on tests made **on MIND cables**.

Space charges vs voltage polarity inversion

Since very early trials **HVDC cables** with extruded insulation were found to **suffer under PR**, especially those cables **where standard XLPE** compounds for AC usage were **employed**.

This evidence, supported by plenty experimental data, proved that PR **causes a reduction in the life of extruded insulation**.
Since long time, the **problems** for HVDC extruded cables under PR have been **addressed to the space charge accumulated** in the extruded insulation under a DC voltage.
Indeed, the high resistivity of the extruded polymeric materials in conjunction with temperature and field variations may lead to electric charge carriers to be trapped within the insulation wall thickness.
Two types of space charge distributions may arise close to the electrodes:
1) homocharge (with the same polarity as the adjacent electrode) occurs when charge injection/extraction prevails over charge transport and makes the electric field lower at the electrodes and higher in the bulk insulation; 2) heterocharge (with the opposite polarity to the adjacent electrode) occurs when charge transport prevails over charge injection/extraction and makes the field higher near the electrodes and lower in the bulk.

Conclusions

At the time that this paper is being written, the **tests are still ongoing**.
The **aim** is to **gather information** about the current state of the art in extruded HVDC cables under polarity reversal stress.
The **outcomes** of such tests unfortunately **cannot be disclosed** without agreement among all the parties involved.

It is important to point out that this **research program** has been **undertaken by TERNA in order to increase the knowledge of innovative materials and components for HVDC cable systems**.
This information is not only a **benefit for cable suppliers** but **also** for the **TSOs** that will be the end users of such technology in which **a high reliability level is always strongly demanded**.

The **availability of a Third Party laboratory represents a fundamental step forward in the HVDC cable system market**, where extruded cable systems have gained fast increasing shares during the last decade, with many land and submarine HVDC cable links of the extruded type.

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Many thanks for your attention

ANY QUESTIONS ?

Contact: CESI-Milano, ITALY Dr.-Ing. Uberto Vercellotti
Tel: +39 02 21255386 e-mail: vercellotti@cesi.it

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