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525 kV HVDC cables with HPTE insulation

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ABSTRACT

HPTE technology, based on the use of high performance thermoplastic materials as insulation package of power cables, is a reality in the field of MV cables and has been extended to 150kV HV systems since 2014 [1] and up to 320kV since 2015 [2].

The next step has been to develop HVDC land and submarine transmission system using HPTE technology. It has been achieved by qualifying a 525kV HVDC system made of cables and factory joints.

The main feature is the development of the dedicated technology. On the one hand, the cable prototype manufacturing has implied the existing technology to be adapted to 525kV HVDC system and large conductor range. On the other hand, the joint manufacturing has been fully developed using intrusion moulding.

KEYWORDS

HVDC, thermoplastic, insulation, PP, HPTE, intrusion moulding.

INTRODUCTION

HVDC extruded cable systems are a technology whose leading edge is currently fast moving forward in the strategic HVDC power transmission market. The field has become more and more competitive compared to HVAC power transmission, especially for bulk power transmission over long distances, which is due to many technical and commercial advantages. The main trend has been to increase current and voltage levels. For the last years, 320kV HVDC systems have already been developed, qualified and installed in numerous cases. Both conductor size and voltage level are under development to increase transmission power capacity.

Most of HVDC systems in service use paper-oil insulated cables for both land and submarine applications. Nowadays, new HVDC systems are mostly based on the use of XLPE insulated cables which performances are becoming consolidated by their use in HVAC applications. However, XLPE is submitted to a longer degassing phase in order to decrease the amount of by-products after crosslinking. That feature must be stressed because the presence of by-products can play a very negative role in terms of insulation electrical resistivity and space charge accumulation. Consequently, by-products presence decreases the cable electrical properties, especially in DC application which is more sensitive to such defect. To reduce the by-products effect, very long degassing period is the commonly adopted solution for HVDC cable manufacturing.

New alternative material solutions exist: modified XLPE (with a smaller quantity of peroxide than the common version), XLPE with nano-fillers and thermoplastic materials [3].

In such circumstances, developing a new cable system seems very attractive for both manufacturers and transmission operators: at the same time, it assures the actual general performances of transmission system (namely the maximum current transmissible) and get along without chemical crosslinking during the production process.

Freshly developed HPTE cables provide the previously mentioned appropriate features for HVDC systems. The new technology, using materials based on fully thermoplastic PP insulation with enhanced thermo-mechanical properties, proves that a proper selection of non-crosslinking polymeric insulation materials can be a real and competitive alternative for both HVAC and HVDC applications.

The paper describes the activity performed in terms of development of the new insulation for HVDC cables based on HPTE technology, production of cable prototype for 525 kV insulation class, factory joint manufacturing process development, electrical assessment of the prototype and subsequent type test on a complete system, based on Cigré recommendation TB 496 [4].

HPTE CABLE TECHNOLOGY

Extrusion technology

HPTE technology was developed in the beginning of 2000's in order to apply the benefits of thermoplastic materials to MV and HV cables systems. However, the production of 525 kV HVDC cables required further improvements compared to the process of 320 kV HVDC cable. Because of the higher insulation thickness, several actions were taken in order to get a high-reliable product.

An optimized mixing of the polymers and liquid additives was studied. Fluid dynamic simulations were performed and, by an iterative process, tuned screw profiles were developed. In parallel the injection of the liquid additives was also included in the simulations and improvements have been made.

The cooling of the triple-layer insulation was also deeply studied in order to get the best morphological configuration of the polymeric insulation. Simulations and practical experiences were performed. The thermal profile of a suitable gradient cooling is now mastered and well defined. Besides, thanks to this optimized gradual cooling, the residual tension of the HPTE insulation appears to be inferior to the one commonly observed on the HVDC XLPE cables. Indeed, the shrinkage test according to IEC 60811-502 has proved that, after 6 hours at 130°C, the HPTE material shrinks by 1% whereas a XLPE material for DC application shrinks by 3.5% up to 5% [5].

During the investigations, it appeared that the filtration during insulation process could also be optimized and at a level far beyond the XLPE, both for the SC and insulation. It was also noticed that a higher level of filtration had a direct and positive impact on the reliability and performances of the triple-layer insulation.

The design of a dedicated extrusion line for this kind of product is now well defined. It could permit to achieve high-performing and highly reliable HVDC HPTE cables.

Investigation technology

In order to validate the improvements performed on the extrusion technology, many small prototypes (70mm2 Al conductor with 5.5mm of insulation wall thickness) and full size cables were produced. They were then extensively tested.

Due to the thermoplastic nature of the HPTE insulation, the traditional methods used for the investigation of the cables are not working as well as for the XLPE cables. New investigation methods have been studied. One is the CT scan permitting to improve the reliability of the analysis through the use of software.

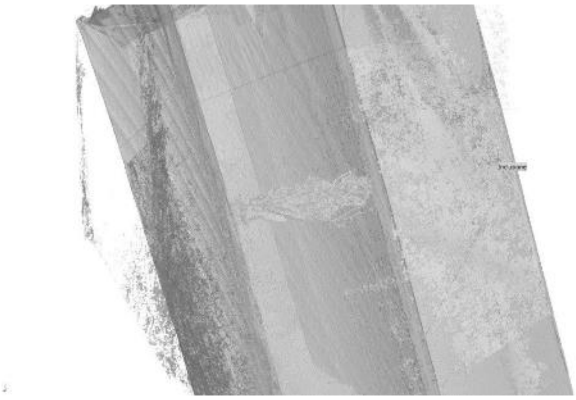

Figure 1 CT scan of a breakdown occured during an extensive test

CABLE MAIN RESULTS

The cable prototype is a 2000mm2 Cu 525kV with HPTE insulation. Main cable core dimensions are hereunder reported:

- Conductor: copper, 2000 mm² round compact
- Conductor screen, nominal diameter: 58.6 mm
- Insulating layer, nominal diameter: 108.6 mm
- Insulation screen, nominal diameter: 111.6 mm

The cable production has been completed with water-blocking tapes, lead and HDPE jackets.

A system composed of the above-mentioned 525 kV HVDC extruded land cable with HTPE insulation and two anti-explosion outdoor sealing ends with composite insulator has been successfully submitted to the electrical type testing in accordance with CIGRE TB 496 [4].

The system has passed all the electrical tests requested for a VSC (Voltage Source Converter) 525 kV system by the CIGRE TB 496 under the supervision of an external and independent inspector.

Test	TB496	IEC 62067	Result
Mechanical preconditioning / bending test	4.4.1	12.4.3	Passed
Load cycle test	4.4.2.3		Passed
Switching impulse withstand test (VSC systems)	4.4.3.3		Passed
Lightning impulse withstand test	4.4.3.4		Passed
Subsequent DC test	4.4.3.5		Passed

FLEXIBLE JOINT

Factory joint, also called flexible joint, is a joint assembled in the factory between manufacturing lengths before armoring the cable. It is needed when the delivery length is longer than the individual manufacturing length. That makes it suitable to submarine application due to the very long cable lengths. That joint is generally a reconstruction of the cable up to the plastic sheath and has the same or slightly larger diameter than the original cable.

Classic reconstruction process includes: preparation of the cable ends, conductor jointing (by compression, brazing…), taping and curing of each layer (conductor screen, insulation and insulation screen), lead sheath reinstating and welding, and finally plastic sheath reconstruction (by extrusion, molding, heat shrinkage…).

A proper and reliable rebuilding of the layers of the insulation system is essential to guarantee that the joint has the same performances, both thermo-mechanical and electrical, of the remaining portions of the cable insulation system.

For XLPE materials, semiconductive and insulating layer reconstruction is often performed by winding uncured tapes of the same material as the cable in a very accurate and clean way to avoid formation of voids or other defects due to impurities which can give place to electrical problems, such as partial discharges or breakdown in AC application. After completing the taping of each layer of the insulation system, the applied material is melted and cross-linked under well-defined values of temperature and pressure, in order to become a continuous and homogeneous layer. Thermoplastic materials have shown better versatility than XLPE if an intrusion process is used. Moreover, that jointing process can be cumbersome and time-consuming.

HPTE FLEXIBLE JOINT TECHNOLOGY

An alternative process to taping is intrusion molding. It consists in thermoplastic joint insulation layer reconstruction wherein extruded insulating thermoplastic material fills a mold which covers the reconstruction zone. When the mold is full, the intruded material is cooled until the solidification of the intruded material. Then, the mold can be dismounted and the reconstruction process continues by winding the outer semiconducting layer.

During their manufacturing, thermoplastics must face intrinsic processing problems. Due to the absence of curing stage, the reconstruction of the insulation system in cable joint cannot rely upon curing for stabilization while reheating original cable insulation. Moreover, another critical feature of thermoplastic materials is the shrinkage effect during cooling. That phenomenon risks creating microvoids and detachments at the interface between original and intruded materials, especially insulation and inner semiconducting layers.

The main process feature is to continuously intrude material into the mold, even when it is full, until the material is cooled and solidified. It prevents shrinkage phenomena and microvoid formation. The process comprises the monitoring of the mold filling by pressure reading and extrusion screw rotation speed controlling. Indeed, pressure monitoring provides information about the shrinkage of the thermoplastic insulating material.

NON-ELECTRICAL AND ELECTRICAL TESTS OF THE FLEXIBLE JOINT

First, feasibility trials have been performed to check the mechanical and rheological properties of the intruded joint. 1000 mm^2 Cu 150kV AC 2m-long cables were used from December 2015 to April 2016. The first positive results have been the correct mold filling by thermoplastic material while assuring no deformation of the original cable insulation, a perfect adhesion between the original inner semiconductive and the injected insulation, and a perfect adhesion between the original and the injected insulation materials.

Then, a full-size mold has been designed to test the electrical properties of such joint technology. The actual HPTE cable used is a 2000 mm^2 Cu 525kV DC cable. The previous results about mechanical and rheological properties of the intrusion have been confirmed on the full-size prototype. Moreover, it has successfully passed a range of internal preliminary test, included the so-called thermal stability test and a polarity reversal electrical test of ±760kV for LCC system application.

CONCLUSION

After the first achievements of HPTE technology in the field of MV and HVAC cables, its HVDC application has been a very decisive milestone by providing a reliable and efficient technology to HVDC cables systems.

The HPTE cable manufacturing technology has confirmed its reliability and its robustness in HV application by leveraging the experience made with 150kV and 320kV cables for the last years and improving performances for 525kV systems. Indeed, the HPTE insulated cable has been successfully qualified at 525kV in 2016 through an electrical type test for VSC systems according to Cigré TB496.

The use of thermoplastic material allows producing very long cable runs, thus reducing the number of factory joints and improving the system reliability. However, efforts have been made for improving the process for manufacturing factory joints and the results were more than satisfactory. HPTE insulation material intrinsic properties have pushed the development of a new efficient way of factory joint manufacturing. In fact, its HPTE insulation material application provides a solid foundation upon which to develop that technology applied to conventional and future insulation materials. Its reliability, its high electrical and mechanical performances have confirmed the reality of a common technological platform for EHV AC and DC cable systems.

REFERENCES

[1] Alberto BAREGGI *et al.*, 2014, “Development and qualification of 150 kV cable produced with highly innovative HPTE technology”, CIGRE 2014

[2] Alberto BAREGGI *et al.*, 2015, “Development and

high temperature qualification of innovative 320 kV DC cable with superiorly stable insulation system", Jicable'15, Versailles (France).

[3] Giovanni POZZATI, 2016, "Contribution PS3 Q1", CIGRE 2016

[4] CIGRE TB 496 "Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500 kV – Working Group B1.32", April 2012

[5] IEC 60811-502 "Electric and optical fibre cables – Test methods for non-metallic materials – Part 502: Mechanical tests – Shrinkage test for insulations", March 2012

GLOSSARY

DC: Direct Current
EHV: Extra High Voltage
HPTE: High Performance Thermoplastic Elastomer
HV: High Voltage
HVDC: High Voltage Direct Current
HVAC: High Voltage Alternate Current
LCC: Line-Commutated Current Source Converters
MV: Medium Voltage
TT: Type Test
VSC: Voltage Source Converters