COMPARATIVE RESEARCH BETWEEN XLPE AND P-LASER MV-CABLE

Piet SOEPBOER
Enexis Netbeheer – the Netherlands
piet.soepboer@enexis.nl

Blandine HENNUY
ENGIE-Laborelec - Belgium
blandine.hennuy@engie.com

Jos VAN ROSSUM
Prysmian Netherlands – the Netherlands
jos.vanrossum@prysmiangroup.com

Tjeerd BROERSMA
Enexis Netbeheer – the Netherlands
tjeerd.broersma@enexis.nl

Robin SIMAL
ENGIE-Laborelec - Belgium
robin.simal@engie.com

Sander LAUWERS
Prysmian Netherlands – the Netherlands
sander.lauwers@prysmiangroup.com

ABSTRACT

A few years ago, Cable manufacturer Prysmian developed a new insulation material for MV-cables called "P-laser" which is based on PP instead of PE [1]. Dutch DSO Enexis, research institute ENGIE-Laborelec and Prysmian Netherlands together set up and conducted a research project to investigate the behaviour of a P-laser cable in comparison with an identical cable with XLPE-insulation. Based on the outcome of this study Enexis decided to introduce P-laser as one of their standard cable types.

INTRODUCTION

The cable tender of Enexis in 2016 was partially awarded to Prysmian Netherlands with the possibility to purchase cable with P-laser insulation. The advantages of this "High Performance Thermoplastic Elastomer" insulation are e.g. its recyclability and lower CO2-emissions during production. Enexis however learned from its experiences after purchasing the 1st generation XLPE cable in the '70's. To prevent a similar scenario, a research project was set up by Enexis in collaboration with ENGIE-Laborelec and Prysmian in order to investigate the behaviour of a 1x630Al P-laser 6/10kV cable in comparison with an identical XLPE cable.

Based on earlier studies on P-laser and based on how MV-cables are installed and operated in the network of Enexis, the following tests were determined and performed:

1. Verification with standard NEN-HD 620 S2 [2] and setting reference values for cable comparison.
2. Ampacity-in-air test (comparison of temperatures and cable loads of XLPE and P-laser).
3. Overbending test (cable behaviour under a too small bend radius at -15 °C, 90 °C and 110 ° C).
4. Short-circuit test (short-circuit behaviour up to 250 °C on the minimum permissible bend radius).

After these electrical and mechanical tests, DSC, DMA, dimension measurements and stereomicroscopy analysis were performed by ENGIE-Laborelec to study the material properties.

An investigation on watertree sensitivity was left out because this was already investigated by Enexis and ENGIE-Laborelec in a preliminary phase showing not a single watertree in P-laser insulation [3].

VERIFICATION TESTS

During the verification test it was concluded that both cables for the comparative research fulfil the requirements of standard NEN-HD 620 S2 and that valid type test certificates and test reports are available. Dimension measurements according to IEC 60811-1-1 [4] were performed on straight cable samples. The reference thicknesses are given in table 1.

	Requirement	XLPE	P-Laser
Conductor screen	≥ 0.5 mm	0.623 mm	0.637 mm
Insulation (nom 3.4 mm)	≥ 2.96 mm	3.530 mm	3.620 mm
Insulation screen	≥ 0.5 mm	0.629 mm	0.627 mm

Table 1: Reference thicknesses.

The average insulation thickness of the XLPE cable under test appeared to be 3.53 mm and the average insulation thickness of P-laser 3.62 mm where the standard requires a nominal thickness of 3.4 mm. A theoretical verification of this small overdimensioning showed an insignificant influence of less than 1% on the cable ampacity.

The thermal conductivity was determined by the "Hot Disc TPS" Method according to ISO 22007-2 [5] and out of these results it was concluded that the measured thermal resistivity of P-laser (4.55 K.m/W) is in line with the value in the available literature (4.5 K.m/W).

The DSC analysis showed that the observed melting temperatures are those that can be expected for XLPE and HPTE and that these are sufficiently higher than the nominal operating temperatures of XLPE and P-laser.

The detected glass transition temperatures (-31°C to -49°C) of P-Laser and XLPE cable during the DMA analysis are significant lower than the lowest temperature ever measured in the Netherlands (-27.4°C on 27 January 1942 in Winterswijk). From that it can be concluded that there is no risk for both materials in relation to the usual storage and processing temperatures of cables at Enexis.

AMPACITY-IN-AIR TEST

A piece of P-Laser cable and a piece of XLPE cable with lengths of 8 meters were installed in a test loop according to figure 1. Three thermocouples (Tc) were placed on each cable with a spacing of 1 m in between. The current and the conductor temperatures were recorded by means of a data logger. A current transformer was used to inject the current until the desired temperature was reached (tests were conducted at conductor temperatures of 30 °C, 60 °C, 90°C and 110°C). After heating up to the relevant conductor temperature, the temperatures were kept stable for 2 hours by "freezing" the current.

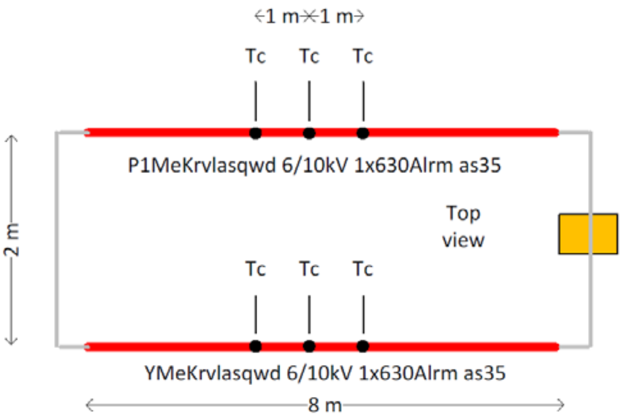

Figure 1: Test loop for the ampacity test.

Assuming a max. permissible equal conductor temperature of 90 ° C, the ampacity of the tested P-laser cable is lower than that of the XLPE cable (1046 A vs. 1156 A). This is due to the higher thermal resistivity of P-laser. However, considering the max. permissible conductor temperature based on P-laser's properties, the P-laser cable can be loaded up to a nominal temperature of 110 °C where XLPE is limited to 90 °C. Based on these nominal temperatures the tested P laser cable has a higher ampacity than XLPE (1190 A vs. 1156 A). Furthermore, it was found that the P-Laser cable showed a 7°C higher core temperature than the XLPE cable at its maximum permissible current i.e. at its nominal temperature of 90 °C. A study on the impact of this higher temperature on accessories was not included in the comparative research project because a relevant study on three MV-joint types with satisfactory outcome was already performed in 2007 by Prysmian and Dutch DSO Liander [6, 7, 8].

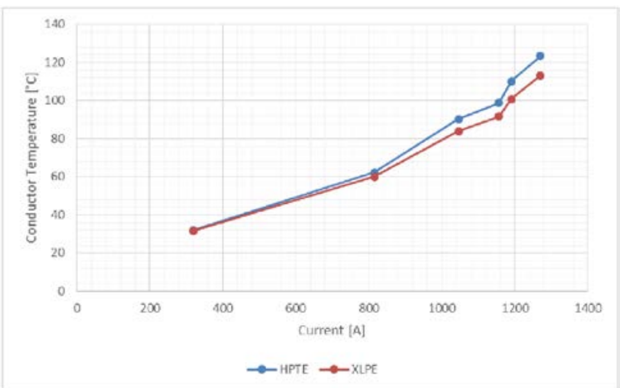

Figure 2: Temperature as a function of current.

OVERBENDING TEST

The performed overbending test is a self-defined test in order to investigate and compare the cables' behaviour under circumstances that might be present in the practise of cable installation e.g. the possible cable storage at low temperatures and the impact of possible installation by means of a bend radius that is too small. For this purpose, the test set-up in figure 3 was chosen. Cable pieces of 6 m long were installed in a bend with a diameter equal to 2 * 0.75 * the minimum permitted bend radius (2 * 0.75 * 0.9 = 1.35 m). The test loop was closed with an equal cable equipped with a thermocouple to measure the temperature on the conductor. During the overbending test, the same cable piece was bent and straightened several times, underwent several temperature changes and was subjected to high voltage AC-tests and partial discharge tests according to NEN-HD 620 S2. The complete overbending test program is described in table 1. To achieve the high temperatures, a current transformer has been used. To reach the low temperature, a cold room has been used. The ambient temperature was approximately 20 °C.

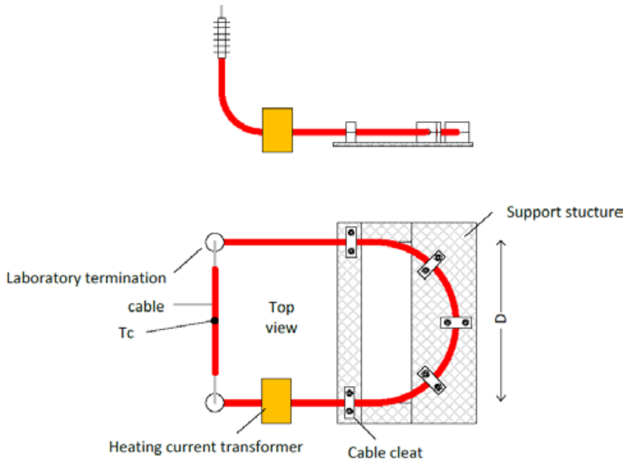

Figure 3: Test loop for the overbending test.

Bended/Straight	Temperature	
Straight	Ambient	30kV/15 min and PD at 1,7U0
Bended	Ambient	30kV/15 min and PD at 1,7U0
Bended	-15°C	24h
Bended	-15°C	30kV/15 min
Bended	Ambient	PD at 1,7U0
Straight	Ambient	30kV/15 min and PD at 1,7U0
Bended	Ambient	30kV/15 min and PD at 1,7U0
Bended	90°C	24h
Bended	90°C	30kV/15 min
Bended	Ambient	PD at 1,7U0
Straight	Ambient	30kV/15 min and PD at 1,7U0
Bended	Ambient	30kV/15 min and PD at 1,7U0
Bended	110°C	24h
Bended	110°C	30kV/15 min
Bended	Ambient	PD at 1,7U0
Straight	Ambient	30kV/15 min and PD at 1,7U0

Table 2: Overbending test programme.

The XLPE and P-laser cable samples both passed the overbending test showing an equal behaviour on PD-level and PD-noise level. No irregularities were found in the afterwards performed DSC and DMA analysis by ENGIE-Laborelec. Compared to the reference samples, both the selected XLPE and P-laser samples however showed some dimensional differences after the overbending test:

- The thickness of the conductor screen became larger for the XLPE sample after the overbending test. At the P-laser sample the thickness of the conductor screen became a bit smaller.
- The insulation thickness of the P-Laser sample became a bit larger after the overbending test. No significant difference was noted for the XLPE sample.
- The thickness of the insulation screen of the P-Laser sample after the overbending test became a bit smaller. No significant difference was noted for XLPE.

These dimensional changes were probably caused by the extreme bending of the test samples vs. unbended reference samples, the cable clamps used for fixing the test samples (reference samples never were clamped) or by the high temperature and the thermoplastic character of P-laser. In NEN-HD 620 S2 there are no dimension requirements after carrying out type tests. The measured thicknesses after the overbending test of the conductor screen, insulation and insulation screen of both the XLPE and P-Laser samples however still fulfilled the minimum "design requirements" of NEN-HD 620 S2. Based on the above, the measured thicknesses are considered as acceptable and the observed dimensional differences are considered as insignificant.

SHORT-CIRCUIT TEST

Due to the thermoplastic nature of P-laser, the short-circuit behaviour was investigated. No short-circuit tests are defined in standard NEN-HD 620 S2. Therefore, it was decided to perform a short-circuit test based on IEC 61442 [9] and HD 629-1 [10]. According to these standards for cable accessories, 2 short-circuit tests were carried out. For this test, the test set-up in figure 4 was chosen. Cable pieces of 6 m long were installed in a bend with a diameter equal to 2 times the minimum permitted bend radius (2 * 0.9 = 1.8 m). The test loop was equipped with a thermo-

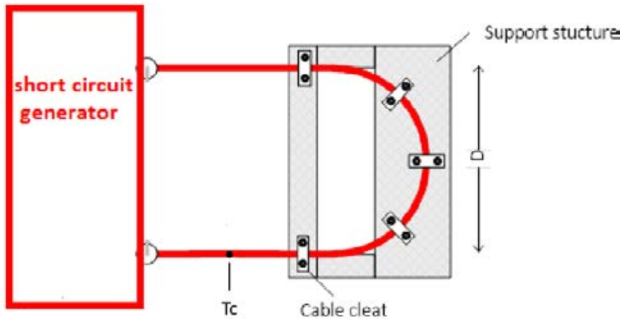

Figure 4: Test loop for the short-circuit test.

couple to measure the temperature on the conductor. A first short circuit test was conducted at a short-circuit current of 31.5kA during 2.7s. These values are prescribed by Enexis in specifications and can be seen as the worst-case scenario occurring in the network, including a significant safety margin. For the second short-circuit test, values of 50kA/2.25s were chosen to achieve a short-circuit end-temperature of 250 °C within 5 seconds. This short-circuit temperature for XLPE was retrieved from standard NEN-HD 620 S2. Both P-laser and XLPE passed the short-circuit tests based on the normative criterion of "no breakdown". Both samples also passed the included high-voltage test and met the requirements regarding noise level and PD level regarding the partial discharge measurement.

No irregularities and no differences between P-laser and XLPE were observed after the 31.5kA/2.7s short-circuit test and successive DSC, DMA, dimension measurements and stereomicroscopy analysis. After the 50kA/2.25s short-circuit test, first it was observed that the insulation of both XLPE and P-laser was shrunk with respect to the conductor.

After the 50kA/2.25s short-circuit test, another difference was visually determined between the shrinkage behaviour of P-laser with respect to XLPE (see figure 5). In P-laser, the conductor screen and the insulation bonded thereto had shrunk back approximately 12mm further than the insulation screen and the insulation bonded thereto.

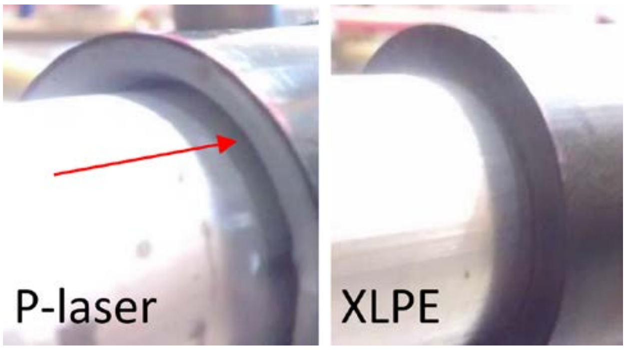

Figure 5: Observed shrink behaviour at 50kA/2.25s.

This difference in "shrinkage shape" is probably caused by the thermoplastic nature of P-laser and the high end-temperature of 250 °C achieved during the test. This temperature is above the "melting point" of P-laser. The impact of the observed shrinkage shape of P-laser in practice is however negligible as this phenomenon only occurs at the end of the cable i.e. where the cable is terminated in an accessory. In this case, the stress control in this part is taken over by the accessory and this (peeled) cable part is located within the stress controlling body of the accessory at a position where this does not cause risks regarding partial discharges or a disturbed electrical field.

During the dimensional comparison of the cable samples, located at a distance from the cable clamps, no significant differences were observed between the reference values and the values after performing the short-circuit test. This was valid for the conductor screen, the insulation, the insulation screen, and the outer sheath. All measured values were within the limits of the design criteria imposed in NEN-HD 620 S2. This is valid for both the XLPE and the P-Laser cable as well as the samples of the 31.5kA/2.7s and the 50 kA/2.25s short-circuit test.

Regarding the cable samples located beneath and directly next to the cable clamps, both the XLPE and the P-Laser cable appeared strongly distorted after the 50kA/2.25s short-circuit test (figure 6). For P-laser both the internal semiconductive screens and the insulation no longer complied with the values in the design requirements of NEN-HD 620 S2, where this was also the case for the insulation of the XLPE cable. This may be due to the thermoplastic character of P-Laser and the high temperature of 250 °C at the short-circuit test. This makes the different layers highly deformable in combination with the high mechanical stress caused by the short-circuit forces. In this respect it should also be noted that IEC 60986 recommends that the end-temperature of thermoplastic insulation materials should be reduced by 10 °C when the cable is clamped. This was not taken into account in the tests carried out on P-laser for the purpose of a fair comparison with XLPE. After the 31.5kA/2.7s short-circuit test, both the XLPE and P-laser samples beneath and directly next to the clamps showed no dimensional changes with respect to the reference values.

Figure 6: Example of distorted shape at P-laser and XLPE after the 50 kA/2.25s short-circuit test.

Regarding the thickness of the outer-sheath the measured values at both the P-laser and the XLPE cable were within the limits of the design criteria imposed in NEN-HD 620 S2. Compared to the DSC and DMA analysis on reference samples and samples after the overbending test, DSC and DMA analysis on samples after the short circuit test did not lead to new insights and conclusions.

CONTEMPLATION

During visual inspections carried out after the conducted tests, a deviation of material thicknesses was observed several times compared to the "design requirements" in NEN-HD 620 S2. This raised the question whether the dimension requirements in the "design requirements" should also be applicable after the execution of (type) tests. We would like to address this issue to the members of the national and international standards committees for medium-voltage cables.

Based on the obtained test results, additional calculations on the conductor end-temperatures and occurring forces in various short-circuit situations have been performed as a risk analysis regarding the shrinkage and deformation behavior of P-laser. These calculations showed that the short-circuit force, using the Enexis specification, is minimum 3.88 times lower than the force that occurred during the 50 kA/2.25s short-circuit test. Furthermore, the calculations showed that the conductor end temperature during the short circuit at the Enexis specification, ranges between 53°C and 145°C where at the comparative 50 kA/2.25s short-circuit test an end temperature of 250°C was used. Taken this into account, it can be concluded that, even assuming the worst-case scenario in the network of Enexis, the chance of deformation of the insulation and semiconductive layers of P-Laser and XLPE is negligible.

CONCLUSION

Under practical conditions, P-laser and XLPE show similar performance. Based on the recyclability of P-laser cable and the results of this comparative research and former studies, Enexis has decided to standardize P-laser insulated cable for utilization in its MV-network next to the already existing standard XLPE-cable.

REFERENCES

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