OALC-5, AN OPTIMISED SOLUTION FOR REGIONAL SYSTEMS

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Abstract: Concurrently to long haul and ultra-long haul systems such as trans-Atlantic or trans-Pacific crossings, short/medium haul regional repeated systems represent a non negligible share of the submarine transmissions systems applications. These systems require only low powering voltage, thus providing an opportunity for the use of a further cost-effective, optimised cable design compared to what is required for the long haul systems.

1 INTRODUCTION

This paper presents such an optimised cable design, particularly well suited for short to medium-haul distances. The development of this cable has been based on an extensive knowledge of the well known, field proven steel-tube design. Cable construction, protection range and product main features are presented as well as the specific evaluation and qualification tests that were undertaken to demonstrate its suitability for applications on systems powered up to 6kV, including short term and long term electrical tests. In addition to this qualification tests a comprehensive series of characterization tests was conducted to better assess cable performance capability and product electrical reliability. Test results, including tests realized on samples on which controlled defects were made such as flats and indentations, are presented. The paper concludes on the advantages of this optimised cable design for medium/short haul transmission systems and its suitability for use on regional systems powered up to 6kV, covering ranges up to 3,000km.

2 OALC-5 DESIGN & MAIN FEATURES

2.1 Cable construction

The OALC-5 cable design is based on Alcatel-Lucent field proven OALC-4 structure. Cable electrical performance requirements being less stringent, the insulation wall thickness has been modified to fit the cost-effective OALC-5 power feeding need.

The OALC-5 natural high density insulating polyethylene was chosen some years ago for the OALC-4 cable, based on electrical reliability, ageing behaviour, abrasion resistance and process-ability requirements. Numerous tests were at that time performed to select this polyethylene among several other grades, such as:

- dielectric strength
- electrical ageing and HV breakdown on samples aged in sea water
- water intake evaluated through ageing in sea water followed by a Karl Fisher titration
- ageing performances: stress cracking, UV exposure tests
- abrasion on plaques (Taber), cables and scratching

In addition a design of experiment (DOE) was conducted to optimise the extrusion process parameters, so that the best possible level of performance and reliability achievable with this material is reached.

The deep sea LW cable construction is completed with Lightweight Protected and Armoured cable types to form the OALC-5 cables family shown in Figure 1.

Figure 1: OALC-5 cables family

The OALC-5 jointing and extremity boxes benefit from design and qualification work already performed on OALC-4 ones. They are identical in design and performances to our well-known field proven jointing and extremity boxes. In addition this cable has been UJ qualified in the following combinations: LW/LW, LWP/LWP, SA/SA, DA/DA, LW/LWP, LW/SA, LWP/SA and SA/DA.

2.2 Functionalities and performances

The OALC-5 product has been designed to be used on short and medium haul repeated systems that may include a large proportion of armoured cables. Typically, depending on fibre count and span, systems range from 500 to 2000 km.

The OALC-5 cable and joint main features are detailed below:

- maximum fiber count: 12
- qualified fiber types include G655, G654 and G652 fibers
- powering up to 6kV for 25 years
- ohmic resistance lower than or equal to 1.6 Ohm/km at 10°C
- insulation resistance higher than 10^5 MΩ.km
- depth capability up to 8000m
- NPTS, NOTS, NTTS and UTS performances as shown in table 1
- Temperature range in operation: -10°C to +35°C
- Temperature range for handling, laying or recovery: -10°C to +50°C
- Temperature range for storage: -20°C to +50°C
- 25 years lifetime design

OALC-5	recovery depth (m)	NTTS (kN)	NOTS (kN)	NPTS (kN)	UTS (kN)
LW	8000	50	30	20	60
LWP	7000	50	30	20	60
SA	2000	160	130	50	190
DA	500	200	150	50	270

Table 1: Maximum deployment and recovery depths and cable NTTS for each OALC-5 cable type under standard conditions

3 PRODUCT QUALIFICATION

3.1 Mechanical tests

The OALC-5 cable optical unit (stainless steel loose tube) and the strength member (protective vault and copper conductor) designs being the same as the OALC-4 and the armouring designs being known, it takes full benefit from the experience that has been accumulated throughout the years on our cables and joint design, qualification, manufacture, deployment and in field experience.

The OALC-5 mechanical qualification has been based on OALC-4 qualification protocol:

- Mechanical testing: tensile test under free gyration on cable and joint, long length tensile test, cable transfer, sheave test on joints, torsion test on joints, interlayer adherence test, minimum bending radius test, reverse bending test, bump and vibration tests on joint, crush and impact tests
- Environmental testing: isostatic pressure test, ageing test, thermal test, water ingress test, accelerated corrosion test on joints
- Electrical testing: ohmic resistance, electromagnetic and electroding cable performance (HV performance was evaluated through a specific testing plan, presented in paragraph 4.2 below)

Additional tests as combined tensile test or round the sheave fatigue tests have as well been performed on SA/SA and DA/DA joints.

All mechanical results were found fully compliant with the requirements and no significant attenuation variation has been noticed after testing.

All the mechanical tests have been followed by hydraulic pressure and high voltage tests on the tested samples to check that the tests performed did not affect the main functions of the cable. Results have been found fully conforming as well.

3.2 Electrical tests

As part of the OALC-5 qualification, extensive electrical tests have been performed in order to ensure that the cable wall thickness and PE quality are compatible with the powering requirements (up to 6kV for 25 years).

Electrical tests conditions have been defined on the basis of the required powering taking into account a very pessimistic n factor equal to 3.

These tests were conducted on both sound cable samples and samples containing defects made on purpose: composite conductor bare strands made both in plug and non-plug areas, indentations and flats. Bare strands were made in accordance with approved repair procedures, to confirm that this repair technique can be safely used. Indentations and flat defects were made under controlled conditions, and were intended to evaluate what could be the impact of a cable insulation damage.

A first series of tests consisted in applying a high voltage for a short duration on a series of short length samples (approx. 6 meters), submitted to 175 kV maintained for 9 hours.

Some of the short length samples were containing above mentioned defects; all testing results on these samples were fully successful.

A second series of qualification tests consisted in submitting cable samples to long term accelerated ageing tests with polarity reversal. Tests were conducted on short length samples, some of them containing bare strands and insulation defects as described above. Test conditions (45 kV applied for 6 months, with polarity reversals after 2 and 5 months) were designed to be more stringent than the cable electrical performances during its 25 years lifetime. Results were compliant for all samples.

In total more than 35 samples taken from 5 different production runs were successfully tested.

Complementary tests have been carried out as well to validate jointing and extremity boxes reliability up to 6kV for 25 years. Moulding and remoulding samples covering the range of significant process parameters have been submitted to the following test sequence: visual and X-Ray examination, High Voltage tests, microtomes, inspection. Results were conforming to the requirements.

4 PRODUCT ELECTRICAL CHARACTERIZATION

In order to better estimate the OALC-5 electrical reliability margin, more pronounced defects were tested as part of a characterization plan, such as deeper V indentations and flats made to leave an even thinner PE thickness. Sound cables and bare strands in plug and non-plug areas have also been more severely tested. All these tests results have been taken into account to estimate the OALC-5 actual electrical n factor (parameter driving the time/voltage relationship). This factor is the best way to estimate the product margin vs. qualification levels; the higher the n factor is compared to the figure retained for qualification, the better is the cable dielectric performance.

Two types of tests are implemented to determine this n factor:

- Ramp to failure test consisting in ramping up the voltage at a rate close to 25kV /min, up to the insulation electrical breakdown;
- Aging tests consisting of the application of a constant voltage to the samples and determining the time to breakdown.

In both cases samples of cables are submerged in water and high voltage is applied on the conductor.

The n factor is calculated with the slopes of the two Weibull plots.

Such an evaluation is considered to provide a reliable estimation for the n factor when at least 20 samples have been tested up to ramp failure and at least 20 samples aged up to breakdown.

4.1 Ramp to failure tests

Both OALC-5 sound cables, cable containing bare strands and cables samples with defects (V indentation and flats) have been tested up to high voltage failure.

No significant difference has been found between results obtained on sound cable and bare strands. Although the controlled defects are not supposed to correspond to a "normal situation", in order to have a pessimistic view of our n factor, they have been included in the following calculation. In total 81 results have been plotted together in a Weibull curve as shown below.

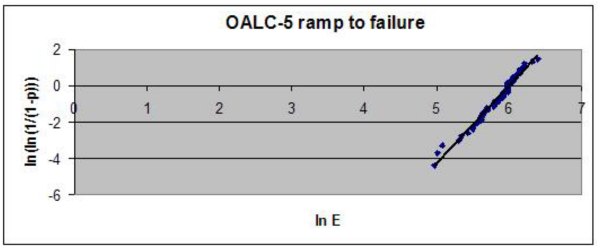

Figure 2: Ramp to failure test results

The correlation is very good with a correlation coefficient of 0.98.

Failure breakdown voltage corresponding to a failure probability equal to 63% has been found greater than 400 kV on this collection of sound, repaired and damaged samples.

4.2 Aging tests

The ageing voltage level was defined to reach a compromise between the time anticipated to perform the characterization, the equipment performance and availability based on the ramp to failure cable performances. The ageing test level has been fixed at 175kV. This level has also been defined depending on the minimum acceptable duration of an ageing test which we have considered to be around 3 weeks.

OALC-5 sound cables and bare strands have been electrically aged under this protocol.

As for the ramp to failure tests, no significant difference has been found between results obtained on sound cable and bare strands. In order to have a pessimistic view of our n factor, as for the ramp to failure, results obtained on test samples with V indentation and flats have been included in the following calculation.

The 20 results obtained so far have been plotted together in a Weibull curve shown below in figure 3 – tests are currently continuing.

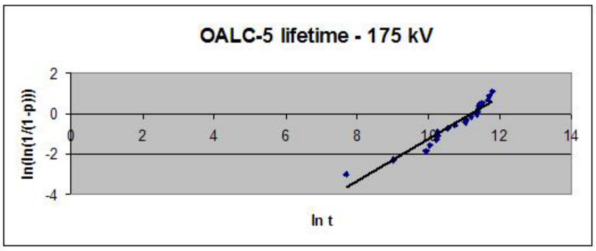

Figure 3: Lifetime test results

The correlation is as well very good with a correlation coefficient of 0.94.

4.3 n factor

The calculated n factor has been evaluated from the above results and found to be greater than the n=3 value used to qualify the OALC-5 cable, validating the electrical qualification protocol.

Further analysis was conducted on these results to evaluate the impact of the cable extrusion process. First results show that significantly better n factor results can be obtained when using a high pressure extrusion process, as opposed to an “atmospheric” process in which the cable cooling is made in low pressurized water troughs. The n factor could then be multiplied by 1.5 with this high pressure insulation process. This is probably linked to the polyethylene cristallinity; further study is on going to determine influent parameters regarding cable electrical performances.

5 CONCLUSION

The OALC-5 cable has been developed and qualified to offer an optimised solution to fit short/medium haul system requirements. More than 6500 km of this new cable type have already been manufactured since its qualification.

This cable is a new cost effective product for regional solutions.

The Alcatel-Lucent steel tube technology fully meets the present and future systems requirements. Depending on length, three cables types can now be proposed:

- The URC-2 unrepeated cable for short haul systems
- The OALC-5 for regional systems
- The OALC-4 for long haul systems

All cable designs have taken into account the overall system reliability as a key feature.

6 GLOSSARY

NZDSF: Non Zero Dispersion Shifted Fibers

OALC: Optically Amplified Line Cable

URC: Unrepeated Cable

LW: Lightweight

LWP: Lightweight Protected

SA: Single Armoured

DA: Double Armoured

NTTS: Nominal Transient Tensile Strength - maximum tension that can be applied to the cable during a cumulative period of one hour, without significant reduction of NPTS/NOTS

NOTS: Nominal Operating Tensile Strength - maximum tension that can be applied to the cable during the time necessary to make cable joints, without significant reduction of NPTS

NPTS: Nominal Permanent Tensile Strength - maximum tension that the cable can withstand during the system lifetime without any impairment of fibres or degradation of the overall cable performance

UTS: Ultimate Cable Tensile Strength - maximum tension that can be applied to the cable without causing cable break