ENHANCING POWER CABLE STANDARDS TO IMPROVE RELIABILITY OF OFFSHORE WINDFARMS

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INTRODUCTION

The growth in UK offshore windfarm construction has revived the medium voltage subsea cable market. The new polymeric subsea cable circuits that are being laid to connect offshore turbines to onshore electricity networks are fundamental to the reliability and thus the cost effectiveness of the windfarm scheme. A significant proportion of the cost of a windfarm scheme is due to the subsea cable circuit and with the cost of cable repairs in bad weather being upwards of €200,000 per day, greater focus must be placed on the long-term reliability of subsea circuits.

At present, the offshore windfarm industry continues to apply land-cable standards for subsea cable circuits. The existing medium voltage cable standards do not address long-term exposure in tidal seawater.

This discussion paper presents a case for the inclusion of additional test regime guidelines in national and international standards in order to enable the procurement of appropriately designed polymeric subsea cables that will deliver enhanced reliability.

MV CABLE SPECIFICATIONS

Since deregulation of the UK Transmission and Distribution networks there has been a gradual but steady trend to adopt European specifications to enable greater product choice. This has meant cable documents such as the Electricity Association’s EATS 09-17 [1] and the British Standard’s BS6622 [2] have given way to International Electrotechnical Committee’s IEC60502-2 specification.

IEC60502-2 [3] is a general specification that is mainly used by electricity utilities and the construction industry for the procurement of land cable, which is manufactured in discrete lengths and is not continuously submerged in tidal seawater for the duration of their operational life. Thus, the scope of this standard is questionable for the procurement of long length polymeric subsea cable.

Specifying test regimes that address the installation and operating conditions of the cable and introducing design enhancements can improve the level of risk proportioned to the subsea cable circuit.

The following points relate to the main deficiencies of the current standards. These points are discussed in further detail.

• Mechanical Performance
• Corrosion Performance
• Routine Electrical Testing
• Installation and Commissioning
• Waterblocking Compounds
• Insulation Design
• Insulation Degassing
• Core Screen Technology

MECHANICAL PERFORMANCE

The design of a subsea cable has to be more substantial than a land cable as the mechanical loads it will be subject to are more onerous during installation, dynamic section behaviour and interaction with water currents.

The mechanical design of a subsea cable has a direct bearing on performance. Careful attention must be paid to the design of the armouring as it will bear the brunt of the mechanical forces sustained during manufacture, installation and operation – poor armour design will expose the cable cores to excessive mechanical strain.

Other subsea industries such as high-voltage interconnectors and oil exploration assess cable capability by testing. In the case of interconnectors, the cables undergo a mechanical type test in accordance with the recommendations of CIGRE [4], while the oil and gas industry assess capability by calculation [5] and computational modelling then verify by fatigue testing [6].

CORROSION PERFORMANCE

A careful assessment of corrosion issue is required especially in wet cable designs. A breach in an oversheath is potentially fatal as metallic elements are at different voltages and will drive the corrosion mechanism.

Polyethylene oversheaths are used on some land cable designs to improve corrosion performance [7]. However, a similar solution can only be employed on short length subsea cable as such designs do not give rise to the excessive standing voltages that can cause electrical failure of the oversheath and thus create a corrosion path.

Previously, long-length high-voltage interconnectors have overcome this issue by introducing short-circuiting studs to the
cable sheath design [8]. The manufacture of these studs can be complex and has more recently been replaced by a semi-conducting oversheath. While, this appears to be a major advancement in design questions must still be asked about product performance in respect of long term functionality.

**ROUTINE ELECTRICAL TESTING**

**Joints**

It is usual to have factory joints in subsea cables. The joint is a potential weak point during operation, to ensure it has been manufactured correctly each joint should undergo an AC withstand test.

Technically, a factory joint is an accessory and should be the subject of IEC60502-4 [9] but as this type of joint is not inserted "on-site" this tends to be overlooked. In practice, subsea cables are being purchased as complete lengths. These cable lengths contain factory-made joints that may not undergo a routine quality test until the whole cable has been manufactured.

Typically, a 20km circuit of 33kV, 3-core polymeric cable can have in the region of 60 joints. As the routine test is usually a 15 minute DC withstand, it is highly unlikely that any potential weakness in a factory-made joint will be detected prior to installation.

AC test procedures do exist for the routine testing of factory-made joints. The reverse voltage test is a good example. This method involves fixing the conductor at earth and applying the test voltage to the core screen of the joint but this technique requires specialist knowledge.

**Cable**

It must be noted that when manufacturing a continuous long-length of polymeric cable the number of routine material sampling points is significantly reduced, which decreases the likelihood of finding manufacturing defects.

It is essential that the completed cable is AC tested to a minimum of Uo. DC testing is not a sufficiently robust test to find a progressive defect in its earliest stages and more importantly DC testing is known to adversely affect the operational performance of AC XLPE insulation [10][11][12][13].

An AC routine test costs up to €25,000 but it will make a substantial cost difference to the scheme cost if it identifies a problem before the cable is installed.

If AC testing is not possible a hyperbaric DC test should be employed [6]. The hyperbaric DC test is used extensively by the oil-and-gas industry and is designed to weed out any potential problems by driving water into any defects that may cause the insulation to fail when energised.

**INSTALLATION AND COMMISSIONING**

Most subsea cables have integral fibreoptic cables. The status of the fibreoptic can be used to monitor the cable status during installation when the cable can be at its most vulnerable.

After installation a further electrical test is required to seek out any progressive defects that may have been introduced during installation. Again, an AC withstand test should be employed. This can be in the form of a soak test at operating voltage or an overvoltage test using power-frequency or very low frequency (VLF) test voltage.

There is a limited benefit in trying to measure partial discharge (pd) activity on long-length polymeric cable. The resistance of polymeric cable screens significantly attenuates the high frequency pd signals. Practical experience has shown that a pd source cannot be readily detected using a conventional pd detector for distances greater than 2km in length. This means that a pd source at a distance greater than 2km from either end of the cable cannot be identified.

A more cost-effective alternative is to conduct a time domain reflectometry (TDR) map or fingerprint of the cable. The TDR detects changes in impedance rather than specific electrical events. TDR it is not a sensitive measurement technique and it will not necessarily detect progressive faults in its earliest stages but is very robust and has proven invaluable when locating cable faults.

**WATERBLOCKING**

Statistics show that faults on subsea cable circuits can be expected at a rate of 1.3x10^-2 per year per km. With the windfarm schemes currently under consideration having an average length-to-shore of 20km, it can be surmised that one cable fault will occur every five years of operation [14][15].

What is more, it is suggested [16], that repairs will not be conducted during winter months meaning that a faulted cable will remain at sea for a minimum of 3 months. In such circumstances, waterblocking is of the utmost importance.

Waterblocking directly affects the reliability of a post fault subsea cable. If seawater reaches the conductor and then can flow along its length, firstly by water pressure then by capillary action, on re-energisation water treeing is likely to occur which will ultimately result in premature insulation failure.

IEC60502-2 makes no reference to the use of waterblocking for subsea cables. Provision must be made for assessing waterblocking constructions in seawater.
INSULATION DESIGN

IEC60502-2 offers no scope for employing cables of lower design stress and hence lower capacitance, which can generate cables that are statistically more reliable and reduce dielectric losses. Statistically, it is possible to increase the cable reliability by decreasing the cable insulation's electrical design stress [17][18]. However, reducing design stresses creates larger diameter cables. The economic implication of a bigger cable has to be balanced with the economics of the installation and rating issues.

INSULATION DEGASSING

XLPE cable can have up to 2% by-product content after extrusion and crosslinking. These by-products diffuse out of the insulation with time.

For a long-length XLPE cable with a radial moisture barrier (sheath) this phenomenon is of particular importance. If the cable has not been adequately degassed the by-product will travel along the length of the cable creating pressure zones underneath the sheath. As the cable is loaded more gas is evolved and the pressure will increase to a point where it can breach the sheath. Foil laminate sheath designs are particularly susceptible.

CORE SCREENS

The interaction between screens and core insulation is complex. Screen and insulation material compatibility is paramount and neither can be specified in isolation.

The propensity of semiconducting core screens to absorb water, or seawater, and the impact on screen functionality is not addressed by IEC60502-2. This is of particular importance in wet-design cables.

Recent research has shown that the time to electrical failure of semiconducting screens in seawater is reduced by more than 30% when compared with tap water. Thus, it is important that the screen/insulation package demonstrates its resilience is seawater [19][20].

FURTHER POINTS OF IMPORTANCE

Ratings

Cable rating should be completed during the design phase of a windfarm scheme and conducted in accordance with IEC60287 [21].

The cable rating when buried in the seabed must not be overlooked as seabed conditions can change unexpectedly and lead to thermal runaway [22]. However, specific attention must be given to the cable rating in air and J-tubes as these are known bottlenecks.

Further steps can be taken to monitor cable rating by using real time thermal rating systems that utilise the integral fibre-optic cables that are commonly part of the subsea cable construction [23].

Faults and Repairs

Pinpointing a fault in a long-length subsea cable is not an easy process and requires specialist knowledge. No single technique can be employed with confidence. It is usual to use a combination of the following techniques to find faults; measuring insulation resistance, conductor resistance balancing, TDR mapping and tone testing. On detecting a fault a post-mortem is essential in order to determine whether it is cost effective to repair or replace the cable.

The cost of subsea cable repairs range from €0.7M to €1.4M. Typically, these costs include the cost of repair joints and a length of spare cable inserted into the section where the fault occurred. It should be noted that these costs could escalate significantly if a circuit is system critical.

One such circumstance occurred recently when an XLPE cable failed on an oil-and-gas project. The cable had to be repaired immediately to avoid revenue losses. The repair was attempted in autumnal conditions and lasted around 40 days incurring installation costs alone of over €4M.

SUGGESTIONS

It is the opinion of the authors that the reliability of offshore windfarm schemes would be enhanced by modifying MV standards to include:-

- Mechanical performance assessments for subsea cable circuits that connect offshore industries.
- Corrosion best practice and rudimentary performance criteria for subsea cable construction.
- A routine AC electrical test, or a hyperbaric test, for completed subsea cable and factory-made joints.
- Greater emphasis on an AC commissioning test procedure.
- An amendment to current watertightness tests to include provision for the use of seawater.
- A minimum nominal insulation thickness rather than a nominal thickness.
- The inclusion of a test to determine a safe by-product concentration for long-length cables with a radial moisture barrier [24].
- Provision for wet-design cable screens and insulation to undergo an accelerated lifetime test in seawater.

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[9] IEC60502-4, "Test requirements on accessories for cables with rated voltages form 6kV(Um=7.2kV) up to 30kV (Um=36kV)"


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