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Accelerated reliability testing of articulated cable bend restrictor for offshore wind applications

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ABSTRACT

Power cable failures for offshore marine energy applications are a growing concern since experience from offshore wind has shown repeated failures of inter-array and export cables. These failures may be mitigated by dedicated cable protection systems, such as bend restrictors. This paper presents the rationale and the results for accelerated reliability tests of an articulated bend restrictor. The tests are a collaborative effort between the University of Exeter, CPNL Engineering and NSW, supported by the EU MARINET programme.

The tests have been carried out at full-scale and exposed the static submarine power cable, fitted with an articulated pipe bend restrictor, to mechanical load regimes exceeding the allowable design loads in order to provoke accelerated wear and component failures. The tested load cases combined cyclic bending motions with oscillating tensile forces. A range of acceleration factors have been applied in respect to the 1:50 years load case, subjecting each of the three restrictor samples to 25,000 bending cycles (50,000 tensile cycles). The static power cable was also loaded beyond its intended use, testing the worst case scenario of repeated dynamic loading, purposely inflicting failure modes for investigation. Throughout the test the static submarine power cable sustained over 77,000 bending cycles.

The test demonstrated the integrity of the cable protection system with quantified wear rates obtained through 3D scanning of the individual shells. The static power cable also maintained its integrity throughout the accelerated test regime. None of the failure modes, mainly fatigue cracks and fretting of individual wires, identified by cable dissection would have caused a direct loss of service. The observed failure modes could also be predicted through numerical load analysis, giving confidence in the utilised mechanical modelling and cross-sectional analysis for dynamic applications.

1. Introduction

Offshore wind energy has reached a stage where it is a substantial part of the installed generation capacity, with ambitious plans to further increase its share. The UK is currently the world leader with 3.7 GW of installed and grid connected

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offshore turbines (as of end 2013) being part of a total of 48 GW offshore wind projects in operation and under development [1]. As of July 2014, the combined capacity of grid-connected offshore wind projects in European waters amounts to 7.3 GW [2].

The industry is under increased scrutiny to achieve competitive levelised cost of electricity favourably below the symbolic £100/MW h mark in the mid (2020) to long-term (2050) [3]. One of the crucial factors to achieve this is high system reliability to ensure high operational availabilities with target levels above 97%. The system reliability level of onshore wind turbines which is in the order of 2.4 failures per turbine per year [4] has to be matched or improved in order to achieve economically viable availability levels [5]. A recent study [6] for offshore wind turbine reliability data calculates 8.3 failures per turbine per year.

One of the emerging challenges to achieve these high availability levels is the reliability of inter-array and export cables. A recent industry estimate [7] is that whilst only about 10% of the capital expenditure for offshore wind installations is associated with the cable cost, 90% of reported insurance claims are attributed to cable failures. Failure consequences incur both plant downtime as well as considerable replacement and repair cost. Failure rate levels for onshore medium voltage cables range typically between 2 and 3 failures per 100 km per year, whilst some UK offshore wind installations report failure rates between 5 and 8 faults per 100 km per year [8]. The problem is exacerbated by the fact that offshore locations increase unplanned maintenance cost for cable faults by a factor of 10–100, compared to onshore incidents.

The root causes of cable failures are reported [9,8] to be a combination of poor installation practice, inadequate design of the cable itself and related accessories as well as inadequate mechanical protection for the given environmental load conditions. Apart from the first cause, the failure mechanism is driven by the wave and tidal/current interactions with exposed cable sections, causing external abrasion and mechanical wear as well as cyclic bending, resulting in premature cable failures.

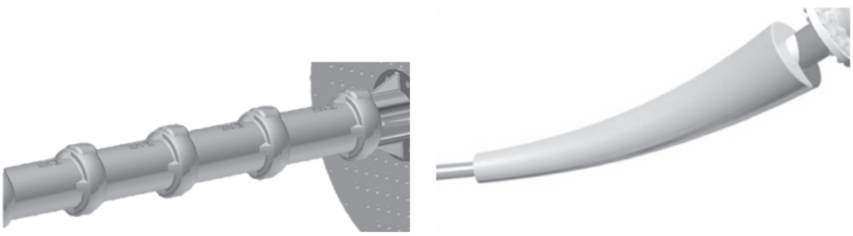
Accelerated testing seeks to increase component stress levels with the assumption that the damage accumulates over the lifetime of the component. The objective is to accelerate the time needed to observe failure modes by using test regimes which are representative of the conditions expected in the field [10]. These types of tests allow to test the long-term behaviour of components within feasible cost and time budgets. The benefits of accelerated testing to obtain more accurate reliability predictions despite limited operating experience are described in [11]. More specifically [12] have carried out performance comparison tests for mooring lines under accelerated loading conditions. A number of studies also report the dedicated testing of submarine power cables. A review of typical mechanical tests for submarine dynamic power cables is presented in [13]. Further detailed studies focussing on the fatigue failure of the copper conductors of marine power cables have been carried out by both numerically [14] and experimentally [15,16]. The authors are not aware of any study that reports the behaviour of a dynamic power cable armoured with a cable protection system.

A number of companies have developed cable protection systems that aim to prevent cable failures. An extensive review of cable protection measures is given in [17,18] describing the range of installation techniques and available cable protection systems. The main length of the subsea cable is buried where possible. The burial depth is depending on the seabed conditions, installation method and on the exposure risk of the cable, incl. fishing, vessel activity, waves and tides and is typically quantified by the Burial protection index (BPI) [19]. Where the cable cannot be buried alternative protection measures have to be taken, such as concrete mattresses, rock dumping or cable protection systems. Bend restrictors are one example of cable protection systems and will be the focus of this paper.

Cable protection systems (CPS) are commonly used in the oil and gas and offshore wind industry to prevent damage to an umbilical cable (or riser) from overbending. There are two types of CPS, *bend restrictors* and *bend stiffeners*. Indicative drawings are shown in Fig. 1.

Bend restrictors (Fig. 1(a)) usually comprise a number of interlocking elements which are compliant until a specified bend angle/bending radius, greater than the MBR of the cable, is reached. The elements thus protect the cable from overbending. The bend limiter accepts the bending moments, once the design angle/bend radius is reached. They are best suited to protect the cable during installation and operation in static or quasi-static conditions.

Bend stiffeners (Fig. 1(b)) are tapered mouldings that add local stiffness to cable or umbilical to limit the bending stresses and curvature to acceptable levels, avoiding failures due to fatigue and overbending. They are best suited for dynamic



(a) Bend restrictor (b) Bend stiffener

Fig. 1. Mechanical cable protection systems.