System Impedance Measurements of Power Cable Umbilicals

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ABSTRACT

This paper considers measurements of electrical parameters for subsea power umbilicals. Electrical system parameters given in the umbilical datasheets may be inadequate for dimensioning the electrical system as they often are IEC-specifications. The parameters may be estimated by finite element analyses, but the models used in these analyses must be calibrated for different umbilical designs. A measurement method giving all relevant electrical parameters for power system calculations and model calibrations is therefore established. The method is tested on several umbilical and power cable designs from different manufacturers through ten years work.

KEYWORDS

Umbilical, cross talk, impedance, calculation, measurement, method, procedure

INTRODUCTION

The demand for electric power in the oil and gas sector is increasing as processing systems are moved subsea. These systems are supplied by high voltage (HV) cables concealed in a special designed umbilical together with hydraulic lines, service lines, injection systems, fibre optics, communication cables and low voltage supply cables for instrumentation and control. Typical loads are variable speed drives operating at frequencies varying from 50 to 200 Hz. As the umbilicals are exposed to large mechanical static and dynamic forces during installation and operation, proper armouring (steel reinforcements, carbon fibres etc.) is required.

For designing the electrical system, the characteristic electrical properties of all elements at relevant frequencies are required. The phase impedances of all power circuits (positive, negative and zero sequence) are needed to calculate impedance asymmetry related to motors and generators acceptance levels, fault currents, corrosion issues and leakage currents. For the remaining umbilical components, induced currents and voltages are of importance. The datasheet values are often IEC specifications, not giving sufficient information needed for accurate calculation of the sequence impedances related to the specific umbilical design.

Present, there is no established method for measuring the characteristic electric parameters for power umbilicals. [1, 2, 3] consider measurements of parameters for power cables, but neither the measurement method, procedure, test-setup nor result processing is given in detail. In this paper, a detailed measurement procedure for power umbilicals is established, providing all relevant electrical data and properties. This includes measurements of per phase impedances for all power circuits and induced voltages and currents in all conducting materials for relevant grounding conditions. An important issue is how the parameters depend on different operation conditions (voltage, current and frequency), grounding and temperature.

The test procedure is intended for limited tests lengths onshore. As a consequence, seawater influence is not included in the procedure.

PHASE IMPEDANCE CALCULATIONS

IEC 60287 is the natural place to look for sequence impedance formulas, but neither positive, negative nor zero sequence impedance is mentioned in the standard. These are needed for analysing non-symmetric faults. There exist formulas in the standard for phase resistance calculations including influences from steel wires. The results from these formulas only give rough estimates of the actual resistance. The influence of steel pipes, multiple high voltage conductors, multiple steel wire layers and other conducting elements is not straight forward to include. No relevant formulas for phase inductance have been found in the standard.

The phase resistance of an armoured cable consisting of three conductors (245 kV, 500 mm^2) has been calculated and measured, [1]. The deviation of the analytical and measured resistance is 20 % as seen in Table 1 for this specific cable. As umbilicals are more complex than this cable with more elements influencing the resistance, a larger deviation is expected.

Table 1: Calculated and measured positive sequence for three phase cable (245 kV, 500 mm^2) at 50 Hz, [1].

Parameter	IEC 60287	Measured
Resistance [Ω/km]	0.084	0.067

It is possible to calculate the phase impedances analytically by use of geometric mean distance. Per phase reactance (X_1) of a triangular configuration is given in formula 1, where μ is magnetic permeability, f power frequency, D centre-to-centre conductor distance and d the conductor diameter.

$$X_1 = j\mu f \cdot \ln\frac{D}{0.39d}\left[\frac{\Omega}{km}\right] \quad [1]$$

This formula assumes, amongst other, massive conductors, homogenous current density in conductors, neglected induced currents in screens, armouring etc. and identical magnetic permeability in the conductors as surrounding medium.