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# TECHNICAL REPORT

Nexans

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| **Dong 36 kV Horns Rev 2** | **28595-EVT-RT-19262** | **E4** |

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| **Design Report Submarine Composite Cable System** | **Page 1 of 11 + Appendix** | **EXTERNAL** |

**Scope:**
This document describes the design of the Dong 36kV Horns Rev 2 – PCC cables.

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# 1. INTRODUCTION

## 1.1 General

This document describes the design of the Dong 36kV Horns Rev 2 – PCC cables.

The submarine composite cable contains 3 phases and an integrated fibre optic cable. The fibre optic cable contains 96 single mode fibres.

The designation of the cable is;
TKRA 36 kV 3x1x300mm$^2$ KQ + FO

where;
T means XLPE insulation
K means lead sheath
R means one layer of round, steel wires
A means outer serving of PP-yarn and Bitumen
3x1x means three phases where each phases are covered by a lead sheath
300mm$^2$ are the cross section of the conductor
KQ means copper conductor filled with a semiconducting compound (solarite)
FO means there are an integrated fiber optic element

## 1.2 Main Data

Main electrical data relevant for cable design

| | |
|---|---|
| Nominal voltage (U/ $U_0$) | 34/19.6 kV |
| Maximum voltage of system (Um) | 36 kV |
| Nominal transmission capacity, each cable | 33 MVA |
| Nominal current, $I_n$ | 560 A |
| Maximum short-circuit current, 3-phase in 1 sec. | 20 kA |
| Maximum earth fault current, in 1 sec. | 1 kA |
| LIWL: 1.2/50 μs | 170 kV |
| Frequency | 50 Hz |
| System earthing | Resistance earthed |
| Cable screen earthing | Both ends |
| Max. conductor temperature @ normal operation | 90 °C |
| Load factor | 100 % |
| Design life | 25 years |

# 2. REFERENCES

## 2.1 National and International standards

| Document | Edition | Title |
|---|---|---|
| IEC 60228 | 2004 | Conductors of insulated cables |
| IEC 60502-2 | 2005 | Power cables with extruded insulation and their accessories for rated voltages from 1kV ($U_m$=1.2kV) up to 30kV ($U_m$=36kV) |
| IEC 60811-1-1 | 1993 | Common test methods for insulating and sheathing materials of electric cables – Part 1: Methods for general application – Section 1: Measurement of thickness and overall dimensions – Tests for determining the mechanical properties. |
| CIGRE WG 21-02 | 2000 | Recommendations for Testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to150 (170) kV. (Electra No. 189, April 2000) |
| IEC 60287-1-1 | 2006 | Electric cables – Calculation of current rating - Part 1-1: Current rating equations (100 % load factor) and calculation of losses - General |
| IEC 60287-2-1 | 2006 | Electric cables – Calculation of current rating Part 2-1: Thermal resistance |
| IEC 60885-2 | 1987 | Electric test methods for electric cables. Part 2: Partial discharge tests. |
| IEC 60885-3 | 1988 | Electric test methods for electric cables. Part 3: Test methods for partial discharge measurements on lengths of extruded power cables. |
| IEC 60949 | 1988 | Calculations of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects. |
| CIGRE WG 21-02 | 1997 | Recommendations for mechanical tests on submarine cables (Electra No.171, 1997) |

## 2.2 Other references

| Document Name | Document Number |
|---|---|
| Purchase order | |
| Cross Section Drawing Submarine Composite Cable System | 28595-EVT-XC-203129 |
| Technical Description Fibre Optic Element | 28595-TTA-RT-19263 |
| Inspection and Test Plan – Submarine Composite Cable Manufacturing | 28595-EQA-TQ-19258 |
| Routine and Factory Acceptance Test Programme - Submarine Composite Cable | 28595-EVT-PT-19266 |

# 3. DESIGN DESCRIPTION

## 3.1 Design data

### 3.1.1 Cable design

Conductor
The conductors shall be a plain, circular, stranded, annealed and compressed copper conductor of strands according to IEC 60228 class 2. The interstices between the strands are filled with a semiconducting compound (solarite) to prevent longitudinal water penetration if exposed to water (in case of a damaged cable).

Conductor Screen
The conductor screen consists of an extruded layer of semi-conducting compound.

Insulation
The insulation system consists of an extruded layer of cross-linked polyethylene (XLPE) The lead sheath applied over the insulation system creates a dry insulation system, which provides excellent long term properties.

Insulation Screen
The insulation screen consists of an extruded layer of semi-conducting compound.

Insulation System
The three layers making up the insulation system

- Conductor screen
- Insulation
- Insulation screen

are applied in a triple head and cured and cooled in an atmosphere of dry nitrogen.

Longitudinal Water-block
Each phase conductor shall have a longitudinal water-block between insulation screen and lead sheath. The water-blocking consists of water-swellable tape. Red, blue and yellow phase markings are applied beneath the semi-conducting water-swellable tape. The tape for phase marking is not semiconductive, but so small that their conductivity is not of importance.

Lead Sheath
A lead sheath is applied on each individual insulated core using F3 alloy.
The lead sheath will function as a water barrier (Dry insulation system) and has the capacity to carry single-phase-to-earth fault current.

PE sheath

The cable shall have a semi conducting jacket covering the lead sheath. The sheath shall be extruded semi conducting polyethylene. The main purpose of the PE sheath is to act as a mechanical protection of the cable elements.

Lay-up of Phases

The PE- and lead-sheathed cores and one fiber optic element are laid up, with polypropylene yarn fillers in the interstices. A wrapping of two layers of tape is applied over the assembly.

Fiber Optic Element

One fiber optic element with single mode fibers is integrated in the power cable and is located between the polypropylene yarn fillers in one of the interstices between the power cable cores.

Armour Bedding

The armour bedding consists of one layer of polypropylene yarn and bitumen.

Armour

The armour consists of one layer of round, galvanized steel wires embedded in bitumen.

Outer Serving

The serving consists of two layers of polypropylene yarns, the inner with a bitumen compound. The polypropylene yarn is selected for its excellent mechanical and ageing characteristics. The yarns will not be degraded by biological action. The cable will be marked to ensure clear identification by means of yellow polypropylene yarns between the otherwise black yarns of the outer layer.

Marking

Five PP-yarn strands in the outer layer of the serving will have orange colour.
Each 100 m of the finished delivery length will be marked with durable, ROV readable and high mechanical strength markings.

### 3.1.2 TKRA 36 kV 3x1x300 mm² KQ + FO

| | | |
|---|---|---|
| Conductor | Diameter of conductor<br>Round stranded compressed copper conductor of 19 wires filled with a semiconducting compound | 20.5 mm |
| Conductor screen | Extruded layer of semiconducting crosslinked polyethylene | |
| Insulation | Nominal thickness<br>Diameter over insulation<br>Extruded layer of insulating crosslinked polyethylene (XLPE) | 8.0 mm<br>38.9 mm |
| Insulation screen | Extruded layer of semiconducting crosslinked polyethylene | |
| Longitudinal water-block | Semiconducting water-swellable tape | |
| Lead sheath | Nominal thickness<br>The sheathing material is lead alloy | 1.9 mm |
| Phase sheath | Nominal thickness<br>Extruded sheath of polyethylene | 1.8 mm |
| Laying up | The cores are laid up.<br>Polypropylene yarn fillers and a fibre optic cable are located in the interstices between the cores | |
| Binder tape | Two layers of binder tape | |
| Bedding | Polypropylene yarn and bitumen | |
| Armour | Shape of armour wires<br>Dimension of armour wires<br>Number of armour wires, approx<br>One layer of galvanized steel wires | Round<br>4.2 mm ∅<br>83 |
| Outer serving | Two layers of polypropylene yarn and bitumen | |
| Diameter | Diameter of cable, approx. | 129mm |
| Weight | Total weight of cable in air, approx.<br>Total weight of cable in water, approx. | 34 kg/m<br>23 kg/m |

## 3.2 Electrical data

### 3.2.1 TKRA 36 kV 3x1x300 mm² KQ + FO

| | | |
|---|---|---|
| Current rating | Current rating in seabed<br>Current rating in J-tube | 565 A<br>580 A |
| Conductor temperature | Max. permissible conductor temperature | 90 °C |
| Ambient conditions | Max. ambient air temperature<br>Max. ambient temperature for the cable in seabed at burial depth<br>Max. burial depth in seabed<br>Thermal resistivity of seabed<br>Load factor<br>Lead sheaths and armour bonded and earthed at both ends | 20 °C<br><br>12 °C<br>1.0 m<br>1.0 K.m/W<br>100 % |
| Frequency | Frequency | 50 Hz |
| Short circuit current | Permissible thermal short circuit current for 1 second:<br>- in the conductor<br>- in the lead sheaths | <br>42 kA<br>3x6.7 kA |
| Rated voltage | Rated RMS system voltage (U)<br>Rated RMS voltage between conductor and screen ($U_o$) | 34 kV<br>19.6 kV |
| Highest voltage | Highest continuous RMS system voltage ($U_m$) | 36 kV |
| Basic insulation level | Lightning impulse withstand voltage (1.2/50 µsec.) | 170 kV |
| Electrical stress | Maximum electrical stress in insulation at maximum voltage $U_m$ | 3.4 kV/mm |
| Conductor resistance | Max. DC resistance at 20 °C<br>AC resistance at 90 °C | 0.0601 Ω/km<br>0.0784 Ω/km |
| Cable impedance | Cable impedance at 560 A (33 MVA) | 0.097 + j0.12 Ω/km |
| Capacitance | Capacitance between conductor and screen | 0.25 µF/km |
| Charging current | Charging current at 34 kV | 1.6 A/km |
| Loss angle | Maximum value at ambient temperature and rated voltage | 0.004 |
| Losses | Losses at 34 kV and 560 A (33 MVA):<br>- conductor losses<br>- dielectric losses<br>- sheath losses<br>- armour loss<br>Total losses per cable | <br>3x24.4 W/m<br>3x0.1 W/m<br>3x1.3 W/m<br>13.9 W/m<br>91.3 W/m |

## 3.3 Mechanical data

### 3.3.1 Tension during installation

Proposed tension during installation according to Electra 171:

$T = 1.3 \cdot w \cdot d_1 + H$

where w: weight of 1m cable, in Newtons, minus the weight of an equal water volume, in Newton/m (weight in water)

$d_1$: max. laying depth, in meters
For this project, max. laying depth: $d_1$ = 30 m

H: max. allowable bottom tension, in Newtons
$H = 0.2 \cdot w \cdot d_2$, where $d_{2,\,min}$ = 200 m

<u>TKRA 36 kV 3x1x300 mm$^2$</u>
Weight in water: 23.0 kg/m
H = 0.2 x 23.0 x 9.81 x 200 x $10^{-3}$ = 9.0 kN
T = (1.3 x 23.0 x 9.81 x 30) x $10^{-3}$ + 9.0 = 17.8 kN

As stated in 3.32, the cable is designed for a maximum permissible tension of minimum 45 kN. This means that the cable has by far sufficient tensile strength to be installed at a water depth of 30 m.

### 3.3.2 TKRA 36 kV 3x1x300 mm$^2$ KQ + FO

| | | |
|---|---|---|
| Bending radius | Minimum permissible bending radius during spooling | 2.0 m |
| Bending radius | Minimum permissible bending radius during coiling | 3.9 m |
| Pulling tension | Maximum permissible pulling tension | 45 kN |

### 3.3.3 Thermal design

The cables are designed to carry continuous loads under the conditions stated in *1.2 Main Data*.

Formulas used for the current rating and in short circuit calculations for conductor and for screen are quoted in Appendix 1, 2 and 3 respectively.

# 4. FIBRE OPTIC CABLE

Se doc 28595-TTa-RT-19263, Technical Description Fibre Optic Element.

# APPENDIX 1

## CALCULATION OF THE CURRENT RATING

**(2 pages)**

# Appendix 1

CALCULATION OF THE CURRENT RATING

The permissible current rating is obtained from the following formula according to IEC Publication 287: "Calculation of continuous rating of cables".

$$I = \left[ \frac{(\Theta_c - \Theta_a) - W_d \left[0.5T_1 + n(T_2 + T_3 + T_4)\right]}{RT_1 + nR(1+\lambda_1)T_2 + nR(1+\lambda_1+\lambda_2)(T_3+T_4)} \right]^{\frac{1}{2}}$$

Where:

I = current flowing in the conductor (A)

$\Theta_c$ = maximum operating temperature of conductor (°C)

$\Theta_a$ = ambient temperature (°C)

R = a.c. resistance per unit length of the conductor at maximum operating temperature (Ω/m)

$W_d$ = dielectric losses per unit length per phase (K.m/W)

$T_1$ = thermal resistance per unit length between the conductor and the sheath (K.m/W)

$T_2$ = thermal resistance per unit length of the bedding between sheath and armour (K.m/W)

$T_3$ = thermal resistance per unit length of the external serving (K.m/W)

$T_4$ = thermal resistance per unit length between the cable surface and the surrounding medium modified according to Neher-McGrath to account for cyclic load (K.m/W)

$\lambda_1$ = ratio of the losses in the metal sheath to total losses in all conductors in the cable (K.m/W)

$\lambda_2$ = ratio of the losses in the armour sheath to total losses in all conductors in the cable (K.m/W)

n = number of cores

# APPENDIX 2

## CALCULATION OF PERMISSIBLE SHORT CIRCUIT CURRENT IN CONDUCTOR

**(1 page)**

# Appendix 2

CALCULATION OF PERMISSIBLE SHORT CIRCUIT CURRENT IN CONDUCTOR

The permissible short circuit current in each conductor is obtained from the following formulas according to IEC Publication 949: "Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects".

$$I = \varepsilon \cdot I_{AD}$$

$$I_{AD} = \left[ \frac{K^2 \cdot S^2 \cdot \ln\left( \frac{\Theta_f + \beta}{\Theta_i + \beta} \right)}{t} \right]^{\frac{1}{2}}$$

$$\varepsilon = \left[ 1 + X \sqrt{\frac{t}{S}} + Y \left( \frac{t}{S} \right) \right]^{\frac{1}{2}}$$

$I$ = permissible short-circuit current

$I_{AD}$ = short-circuit current calculated on adiabatic basis

$\varepsilon$ = factor to allow for heat loss into adjacent components

K = constant depending on material

S = cross-section of conductor

$\Theta_f$ = final temperature

$\Theta_i$ = initial temperature

$\beta$ = reciprocal of temperature coefficient of resistance of the current carrying component at 0 °C

t = duration of short-circuit

X,Y = constants for stranded conductor incorporating the thermal contact factor of 0.7 (ref. IEC 60949 section 5.2 with table 3)

# APPENDIX 3

## CALCULATION OF PERMISSIBLE SHORT CIRCUIT CURRENT IN SCREEN

**(2 pages)**

# Appendix 3

CALCULATION OF PERMISSIBLE SHORT CIRCUIT CURRENT IN SCREEN

At each end the lead sheath and the armour wires will be connected together and grounded. In addition there will be contact between the armour and the surroundings along the cable route. A short circuit current will therefore be divided between the 3 elements in the cable and ground.

In the following only the elements in the cable itself are considered.

If only the lead sheath on one phase is considered the permissible short circuit current in this is obtained from the following formulas according to IEC Publication 949: "Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects".

$$I = \varepsilon \cdot I_{AD}$$

$$I_{AD} = \left[ \frac{K^2 \cdot S^2 \cdot \ln\left(\frac{\Theta_f + \beta}{\Theta_i + \beta}\right)}{t} \right]^{\frac{1}{2}}$$

$$\varepsilon = 1 + 0.61 \cdot M \cdot \sqrt{t} - 0.069 \cdot \left(M \cdot \sqrt{t}\right)^2 + 0.0043 \cdot \left(M \cdot \sqrt{t}\right)^3$$

$$M = \frac{\left(\sqrt{\frac{\sigma_2}{\rho_2}} + \sqrt{\frac{\sigma_3}{\rho_3}}\right)}{2 \cdot \sigma_1 \cdot \delta \cdot 10^{-3}} \cdot F$$

| | | |
|---|---|---|
| I | = | permissible short-circuit current |
| $I_{AD}$ | = | short-circuit current calculated on adiabatic basis |
| $\varepsilon$ | = | factor to allow for heat loss into adjacent components |
| K | = | constant depending on material |
| S | = | cross-section of conductor |

$\Theta_f$ = final temperature

$\Theta_i$ = initial temperature

$\beta$ = reciprocal of temperature coefficient of resistance of the current carrying component at 0°C

t = duration of short-circuit

$\sigma_2$, $\sigma_3$ = volumetric specific heat of media either side of the sheath

$\rho_2$, $\rho_3$ = thermal resistivity of the media either side of the sheath

$\sigma_1$ = volumetric specific heat of the sheath

$\delta$ = thickness of the sheath