Transient analysis of 3-core SL-type submarine cables with jacket around each core

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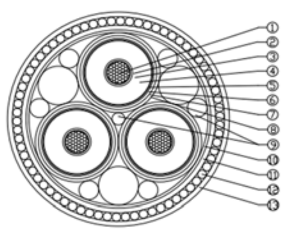
The IEC Standards 60853-1 and -2 give the formulae for the calculation of the cable conductor temperature variations when a step load is applied at time t=0. The method used in the standard is based on a reduction of a multi-loop ladder network representing lump parameter thermal model of the cable to a two-loop circuit and then solving the resulting differential equations using a Laplace transform.

This paper will address two issues related to calculation of the transient rating of 3-core submarine cables with lead sheath or concentric wire screen around each core.

1. The IEC Standard 60853-2 gives equations for the reduction of a multi-loop thermal network of an SL-type cable to its two-loop equivalent for the calculation of the partial transients for long and short durations and cyclic loading. The first task of this paper is to show that the equations given in the standards need to be modified as they are in error in some parts.
2. The second task is to introduce a new model for the most common construction of the 3-core submarine cables with polyethylene layer over each lead sheath (or concentric wires) and common armour (either single or double). The IEC Standard does not deal with such cables at all.
3. The final task will be to discuss the calculation of the current ratings of 3-core submarine cables with non-magnetic armour.

The diagram below shows a typical SL-type submarine cable with a jacket around each core.

SUBMARINE CABLE: Cu/XLPE/Pb/SCPE/PPY/SRGSWA*/PPY
*Single Round Galvanized Steel Wire Armour

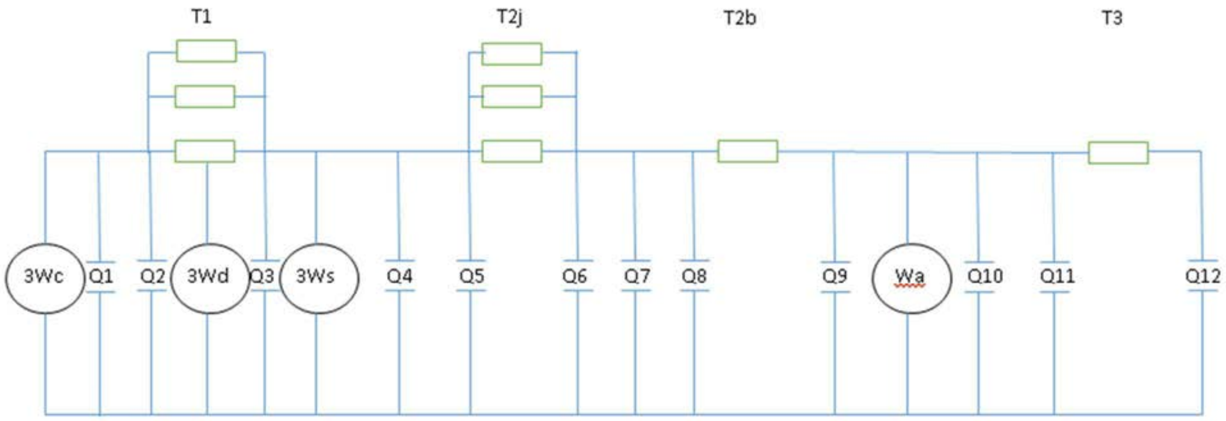


General Description:	
Type of cable:	**SUBMARINE CABLE** Cu/XLPE/Pb/SCPE/PPY/SRGSWA/PPY
Standard specification:	IEC 60840 where applicable
Rated voltage Uo/U (Umax):	87/150 (170) kV
Number of power cores x Nominal cross-section:	3x1200 mm²
Approximate cable overall diameter:	238 mm
Installation conditions:	
Soil thermal resistivity: 1.2 K.m/W Depth of laying: 2.0 m Ground temperature: 25°C One thermally independent cable Metallic sheaths and armour solidly bonded Cyclic load: 1.2 h at 100%, 10.8 h at 65% and 12 h at 40% (Load Factor = 0.54)	

		Thickness (mm)	Approx. out diameter (mm)
1.	Round stranded compacted copper watertight conductor 1200 mm² class 2 according to IEC 60228, bare **or** enamelled wires (can be produced with alternating lay direction or the same lay direction)	No. of strands: 91 **Note:** Can also be manufactured with 127 strands if this improves conductor AC resistance	42.5
2.	Semiconducting waterblocking tape(s) overlapped	0.28	43.06
3.	Extruded semiconducting compound bonded to the insulation	1.2	45.46
4.	XLPE insulation according to IEC 60840	18.42	82.30
5.	Extruded semiconducting compound bonded to the insulation	1.0	84.30
6.	Semiconducting waterblocking tape(s)	1.7	87.7
7.	Lead alloy sheath	2.93	93.56
8.	Semiconductive PE sheath	3.44	100.43
9.	Non-hygroscopic fillers	-	Diameter of laid-up cores: 216.92
10.	Semiconducting binding tapes laid with overlap	0.36	217.64
11.	Polypropylene yarns bedding	1.0	219.64
12.	Galvanized steel wire armour **or** stainless steel (a-magnetic) wire armour	Nominal wire diameter: 6.0 mm Number of wires: 109 Length of lay: 3400 mm	231.64
13.	Polypropylene yarns serving	3.0	237.64

The numerical values shown above will be used in an illustrative calculation of the cyclic loading for this cable.

An example of the new model is shown below with an assumption of a long duration transient (insulation capacitance is split into two components rather than four).



$$Q_1 = Q_c,\quad Q_2 = pQ_i,\quad Q_3 = (1-p)Q_i,\quad Q_4 = Q_s,\quad Q_5 = p'Q_j,\quad Q_6 = (1-p')Q_j$$
$$Q_7 = Q_f,\quad Q_8 = p''Q_b,\quad Q_9 = (1-p'')Q_b,\quad Q_{10} = Q_a,\quad Q_{11} = p'''Q_{sr},\quad Q_{12} = (1-p''')Q_{sr}$$

Subscripts *i, s, j, f, b, a* and *sr* correspond to insulation, sheath, jacket, filler, bedding, armour and serving, respectively. p, p', p'' and p''' represent Van Wormer coefficients for insulation, jacket, bedding and serving, respectively.

Detailed calculations of a cyclic rating factor for such a network will be shown in the paper. In addition, a comparison will be made with the calculations performed in North America and elsewhere, which apply the Neher-McGrath method for cyclic rating computations. The paper will show that the rating obtained with both approaches can be vastly different and a discussion will be offered on the reasons for this and possible remedies.