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Simulations of losses in armoured three-core submarine cables using 3D FEM compared to measurements

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SUMMARY

This paper presents the results from both measurements and FEM simulations of cable losses in four different cable designs. These cable designs are additional to the already presented designs in an earlier paper [10]. The measurements of total cable losses were performed on armoured cables. The armour was then removed, and the cable losses were measured once more. This measurement approach enables the use of the differential method, i.e., the difference in losses with and without armour to yield the losses *due* to the armour, including losses *in* the armour itself and increased losses in the conductor and metal sheath.

FEM simulations were performed for each of these cable designs and the results were compared with the corresponding measurement results. The differences between simulations and measurements were within expected tolerances in cable designs and measurement errors. This analysis provided a validation of the simulation method, as well as a possibility for further studies, such as the origin and distribution of the losses, enabled by the detailed information available from the FEM simulations.

From analysis of the FEM results it has been determined that, apart from armour losses, the sheath losses are affected by the presence of magnetic armour. IEC 60287 applies a factor of 1.5 to the sheath-losses due to circulating currents to account for this effect. The results confirm that this factor is accurate for fully armoured cables, while for cables with armour partly replaced with plastic wires this factor can be reduced. Furthermore, it is clear from the FEM analysis that when adjusting the armour losses to a correct level it is important to also include the sheath eddy currents as these are not negligible but result in significant losses. Examples of total sheath losses increasing with 30% due to eddy currents have been seen. Finally, also the conductor losses are affected by the presence of the armour wires.

KEYWORDS

Armour, Loss, FEM, Measurement

1. INTRODUCTION

The armour losses in three-core submarine cables are well known to be overestimated in the current IEC standard [1]. This has been addressed in several publications, for example, [2-10].

At Jicable 2019 a simulation method in 3D FEM was presented with verification by measurements on several cables [10].
In this paper measurements from four additional cable designs are presented. The cables are all three-core cables with either aluminium or copper conductor with conductor cross-sections between 1000 and 1800 mm^2. Cables with either magnetic or nonmagnetic armour are considered, as well as the impact of replacing some armour wires with PE wires.

The measurements are then compared to the results from the FEM simulations. The simulation and measurement show good agreement.

Finally, the simulation results are used to further study separate losses of the cable to gain further understanding on how the losses in a three-core cable are affected by the presence of the armour wires. When reducing the armour losses to a more correct value, it is important to also take into consideration the increased conductor and sheath losses as well as the often-neglected eddy currents in the sheath.

2. MEASUREMENT SETUP

The measurement setup was the same as earlier established and presented [4][10], except that the measurements are performed both manually and by means of a logger.

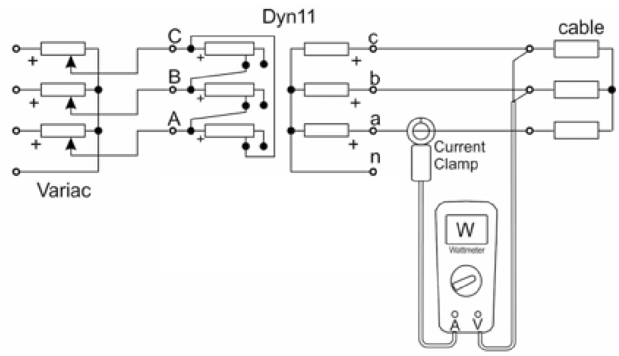

Figure 1 Measurement setup

In brief the measurement setup shown in Figure 1 involved the following:
- The cable samples were between 65 and 71 m long
- The cable samples were placed on wooden blocks
- For the armoured cable samples the armour was removed from the ends, but the sections without armour were kept as short as possible
- The metal sheaths were star connected at both ends
- The armour was not connected to the sheaths
- One end of the sample was connected to the power supply via a three-phase transformer
- Connection leads to the transformer were kept as short as possible and were bundled to avoid asymmetric currents and voltages
- The measurement instrument used enables both manual measurements and connection to a logger
- The measurement instrument measures voltage, current, power, apparent power, reactive power, and temperature.
- All measurements were performed at high current, i.e., 900/815 A
- Although for all alternatives also the current dependency has been evaluated the results were as expected and in agreement with earlier publications, [4] [7] [10], thus, the details are not presented in this paper.

Once the measurements were performed on the armoured sample, the armour was removed, and the measurements repeated on the unarmoured sample. The test setup for both measurements was the same.

3. MEASUREMENT METHOD

The measurements are performed with connection setup as shown in Figure 1 by means of the single-phase wattmeter method for measurement of cable parameters. The corresponding phasor diagram is given in Figure 2.

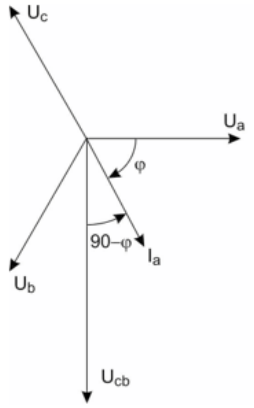

Figure 2 Phasor diagram

The measurement method main principles are:

- The wattmeter measures the load factor cos (90-φ), thus, to improve the accuracy of the wattmeter, for each phase current the opposite phase to phase voltage is measured. The measurements are performed for all three phases, the measured parameters are transformed to phase parameters and the mean value is used for determination of the losses per phase.
- All measurements are performed at room temperature. As the measurements are performed quickly the temperature rise of the conductor is only some fraction of a degree and negligible at the outer layer of the cable due to the cable time constant.
- When the measurements are performed for a set of currents, the measurements are always commenced with the highest current and then reduced to the lower values. For loss measurements it is essential that conductor currents have a magnitude in the range of the rated current of the cable.
- The same set of currents are used for measurements with and without armour. As removing the armour will require adjustment of the voltage this is enabled with variac regulation of primary voltage of the transformer.
- Connection leads for voltage measurement were applied directly on the cable conductors to exclude losses in connection leads between transformer and cable conductors.
- For each set of measurements conductor current, phase to phase voltage, active power, apparent power, load factor, sheath current and temperature are logged. The same procedure is performed on armoured and unarmoured cable.
- Once all data is available, the losses due to armour are calculated as difference between measurement on cable with armour and cable with removed armour.

The measured total loss per cable phase with armour is denoted, P_{WA}, and without armour, P_{WOA}. The increased losses per unit length due to armour can be extracted as follows

$$W_A = \frac{P_{WA} - P_{WOA}}{L} \tag{1}$$

Where L is the length of test sample.

The sheath current is measured, which enables calculation of the increase in sheath circulating losses by,

$$k_{sheath\ current} = \left(\frac{I_{Sheath-WA}}{I_{Sheath-WOA}}\right)^2 \tag{2}$$

This factor describes the increase in losses due to circulating sheath currents and it is considered to be 1.5 for lead sheathed cables with magnetic armour [§2.3.10 in IEC 60287].

Defining the factor for increased sheath current losses, the sheath losses can be removed from W_A by

$$W_{A-sheath\ loss} = W_A - (1 - k_{sheath\ current}) I^2_{Sheath-WOA} \cdot R_{sh} \tag{3}$$

4. FINITE ELEMENT MODEL

A FEM based method for simulating losses in an armoured three-core cable was presented at Jicable '19 [10]. The method is based on a 3D FEM computation where the Electromagnetic problem is solved. The model is based on an imposed three-phase current in the conductors where the induced losses in each metallic part of the cable are studied. An example of the 3D model is shown in Figure 3.

The model uses a course mesh which enables the model to solve quickly without affecting the results in any significant way. In [10] the results for various mesh sizes were presented and it could be concluded that results were essentially constant.

Only the real part of the relative permeability, μ_r, of the armour wires is considered in the FEM model. This means that the losses due to eddy currents are obtained from the simulations while the magnetic hysteresis losses are calculated in the post processing. The post processing function is based on measured parameters for specific armour wires and the local peak magnetic B-fields from the simulation.

The model is dependent on a correctly selected relative permeability for the steel wires. The relative permeability is dependent on material properties, such as steel type and armour wire diameter. But it is also dependent on the magnetic flux at the wire, which is dependent on the current in the conductor. This means that a single value for a specific cable design in not sufficient, but one needs to find the correct value for each current. This can be found using the average H-field at the wires in the model compared to the measured μ-vs-H values for the wires. Where these values match, the correct μ value to be used in the simulation is found. An example is shown in Figure 4. This gives a unique permeability value for each current value used in the simulations.

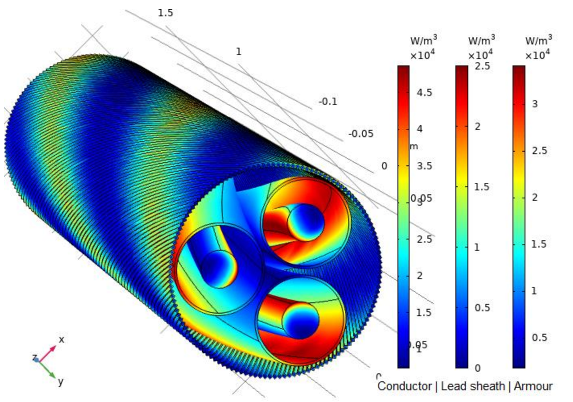

Figure 3. Example of result from FEM simulations. Note that each metal part, i.e., conductor, sheath, and armour, has its own colour scale to make the losses more visible.

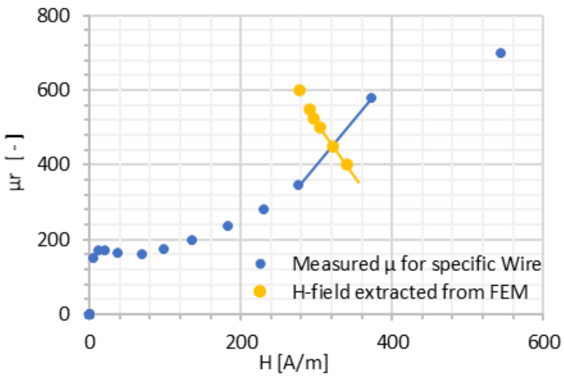

Figure 4. Example of finding correct permeability, μ, for a specific cable design, current and armour wires. The correct μ value is found at the intersection of the lines.

5. CABLE DESIGNS

Four different cable designs are considered in this paper. They have been chosen to show how different parameters affect the armour losses as well as enabling a possibility to verify the simulations with FEM for various designs to show that it gives accurate results for a large spread of cable designs.

Cable 1, 2 and 3 are all cables with aluminium conductor of three different sizes, 1200, 1800 and 1000 mm^2. All three cables have 5 mm armour wires of galvanized steel, grade 34, but cable 2 and 3 have 50% of the wires replaced with PE wires.

The fourth cable has a 1000 mm^2 copper conductor with stainless steel armouring.

The cable designs are summarized in Table 1 where all parameters required to perform an IEC loss calculation, or an FEM analysis are available.

Table 1. Cable design descriptions

Cable ID		**1**	**2**	**3**	**4**
Conductor size	mm^2	1200	1800	1000	1000
Conductor material		Al	Al	Al	Cu
Voltage U	kV	220	220	220	220
Armour type		Grade 34	Grade 34	Grade 34	Stainless
Wire diameter	mm	5	5	5	4
Number of wires (Steel/Plastic)	Pcs	135/0	74/73	65/65	130/0
Lay length of conductor/ Lay direction (L-Left; R-Right)	mm	2300 (L)	3000 (L)	2650 (L)	2200 (L)
Lay length of armour/ Lay direction (L-Left; R-Right)	mm	2825 (R)	3000 (R)	2445 (R)	1875 (R)
Conductor resistance	Ω/km	0.0247	0.0165	0.0291	0.0176
Sheath resistance	Ω/km	0.2603	0.2207	0.2793	0.3980
Conductor diameter	mm	41.5	50.5	37.9	37.9
Diameter under lead sheath	mm	95.9	104.8	91.0	75.6
Thickness of lead sheath	mm	2.7	2.9	2.6	2.2
Power core diameter	mm	106.3	115.6	96.2	84.6
Diameter under armour	mm	230.4	250.5	222.0	183.5

6. IEC CABLE RATING

Cable resistances and loss factors for each of the cables presented in the previous section are calculated using the cable rating standard, IEC 60287 [1]. These values are presented in Table 2 and will later be used for comparison to measurements and simulations of the specific cables. The table also includes the eddy current loss factor, λ_1'', even if IEC specifies that it can be neglected. The reason for inclusion of this loss factor here is that it is valuable to have at comparison with the FEM simulations and in addition, CIGRE WG B1.56 [11] recommends it to be included in the cable-rating calculation. The AC resistance is calculated as IEC prescribes but with inclusion of the lay factor, LF, on conductor resistance due to the stranding of cores.

$$R_{ac} = LF \cdot R_{dc}\left(1 + y_s + y_p\right) \quad (4)$$

CIGRE WG B1.56 recommends that a factor 1.5 is multiplied to the y_s and y_p for armoured cables. This factor is not included in the results in the table for better comparison to the simulations but will be further evaluated in the discussion chapter.

Table 2. Summary of IEC 60287 parameters of the considered cables

Cable design		**1**	**2**	**3**	**4**
R_{dc}	Ω/km of core	0.0247	0.0165	0.0291	0.0176
y_s		0.1217	0.2433	0.0901	0.2190
y_p		0.0420	0.0825	0.0294	0.1088
IEC R_{ac}	Ω/km of cable	0.0292	0.0221	0.0330	0.0237
IEC λ_1'		0.4590	0.6909	0.3789	0.2524
IEC λ_1''		0.0871	0.1345	0.0722	0.0703
IEC λ_2		0.5725	0.7928	0.5250	0.0000
Measurement current	A	900	900	815	900
Sheath current	A	204.4	236.9	172.3	109.7
Conductor losses	W/m	23.7	17.9	21.9	19.2
Sheath losses	W/m	12.9	14.8	9.9	6.2
Armour losses	W/m	13.6	14.2	11.5	0.0

7. MEASUREMENT

Measurements have been performed on the sample cables and the difference method was applied as described in section 3. The results are presented in Table 3.

In addition to the difference method the total losses in the cable could also be estimated using

$$W_{cable} = \frac{P_{WA}}{L} \tag{5}$$

This estimate is however more sensitive to the length of the test object and the test setup as end effects will affect the results more than for the W_A where most of the measurement errors would be removed when subtracting the measurement without armour from the one with armour. But it still provides some extra value in the comparison with IEC and simulations.

Table 3. Measurement results for the considered cable samples

Cable design		**1**	**2**	**3**	**4**
L	m	71	71	65	67
I_c	A	900	900	815	900
P_{WA}	kW	3.03	2.59	2.30	1.71
P_{WOA}	kW	2.39	2.00	1.93	1.68
$I_{Sheath-WA}$	A	178.4	178.6	160.2	96.6
$I_{Sheath-WOA}$	A	142.1	156.7	137.8	96.3
$k_{sheath\ current}$		1.58	1.30	1.35	1.01
W_A	W/m	9.5	8.6	5.8	0.3
$W_{A-\ sheath\ loss}$	W/m	6.4	6.9	3.9	0.3
W_{cable}	W/m	42.8	36.3	35.6	25.7

8. SIMULATIONS

Simulations have been performed for the same cables, using the same imposed current, I_c, as were used in the measurements. Simulations are performed with and without armour and results are provided in Table 4 and Table 5 respectively.

The relative permeability, μ_r, is found by combining the magnetic field strength at the wires in the FEM simulation and the measured μ-vs-H values for the specific wire type. The values used for each cable design are provided in the table.

The results from the simulations are the sheath current, I_s, the conductor AC resistance, R_{ac}, and the cable losses as,

W_c	Conductor losses per phase (W/m)
$W_{s\ circulating}$	Sheath losses per phase due to circulating current (W/m)
$W_{s\ eddy}$	Sheath losses per phase due to eddy current (W/m)
W_a	Armour losses per phase (W/m)
W_{tot}	Sum of all losses above, per phase (W/m)

The FEM simulations do not distinguish between eddy current losses and circulating current losses; thus, the circulating current losses are estimated by

$$W_{s\ circulating} = I_s^2 \cdot R_s \tag{6}$$

while the remaining losses are considered to be eddy current losses. As the sheath currents are subject to some proximity effect and therefore increased resistance this is a slight underestimate of circulating losses and an overestimate of eddy current losses.

Table 4. Results from simulations with armour wires

Cable design		**1**	**2**	**3**	**4**
I_c	A	900.0	900.0	815.0	900.0
μ_r		430.0	490.0	504.0	1.0
I_s	A	201.7	210.1	163.6	106.3
W_c	W/m	24.80	18.72	22.57	18.94
$W_{s\ circulating}$	W/m	10.59	9.74	7.48	4.55
$W_{s\ eddy}$	W/m	3.30	2.83	2.27	1.13
W_a	W/m	3.73	3.61	3.63	2.54E-04
W_{tot}	W/m	42.42	34.89	35.94	24.62
R_{ac}	Ohm/km	0.0306	0.0231	0.0340	0.0234

Table 5. Results from simulations without armour wires

Cable design		**1**	**2**	**3**	**4**
I_c	A	900	900	815	900
μ_r		-	-	-	-
I_s	A	163.8	185.0	139.3	106.3
W_c	W/m	23.90	18.13	22.10	18.94
$W_{s\ circulating}$	W/m	6.98	7.55	5.42	4.55
$W_{s\ eddy}$	W/m	1.86	1.98	1.44	1.13
W_a	W/m	0.00	0.00	0.00	0.00
W_{tot}	W/m	32.75	27.67	28.96	24.62
R_{ac}	Ohm/km	0.0295	0.0224	0.0333	0.0234

9. DISCUSSION

In this section the previous calculations, measurements and simulations will be compared, and the results discussed starting from total losses and going into details.

9.1. COMPARISON BETWEEN MEASUREMENTS, SIMULATIONS AND IEC CALCULATIONS

Figure 5 shows the total measured losses compared with simulation results and IEC calculations. The measurements cannot distinguish between the different types of losses, but it is possible to extract the total cable losses and the losses due to the armouring. Thus, the stacked columns representing the measured losses are presented by only two parts, the yellow one for losses due to armour and the squared part for all other losses. For both FEM simulation and IEC each loss category can be calculated separately which is why the stacked columns for both cases include four parts and the yellow part represents the armour losses and not the losses due to armouring. Consequently, the comparison of the yellow parts between measurements and simulations/IEC is not relevant as for measurements the yellow part also includes increased conductor and sheath losses.

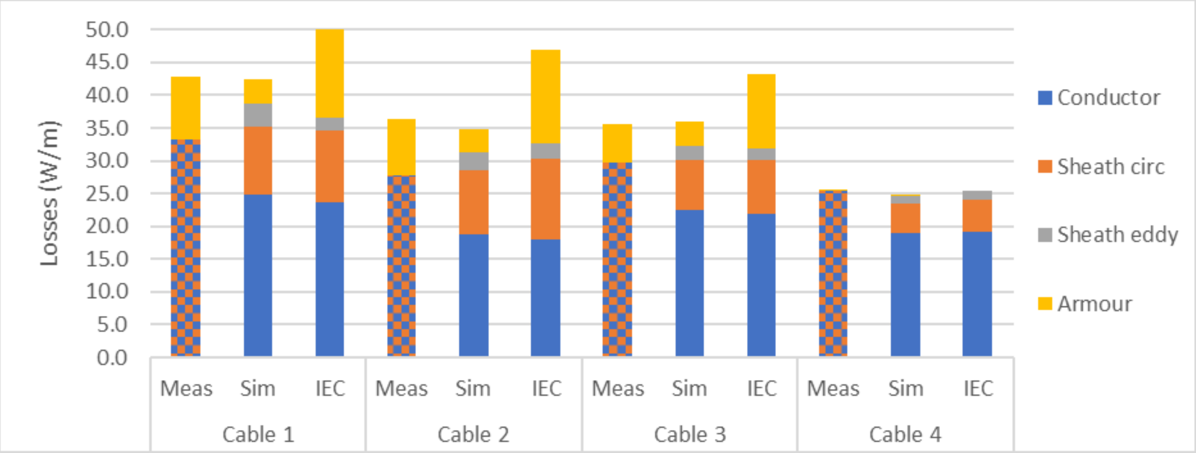

Figure 5. Comparison of losses in the cables between measurements, simulations and IEC. Measurements and simulation do give results in close range while IEC results are much larger.

It can be seen in the figure that the measurement matches very well with the simulation results while IEC losses are significantly larger. The difference between simulation and measurement is less than 5% for all cables and for two of the cables it is less than 1%. A detailed comparison is found in Table 6. The difference is defined as,

$$\Delta = \frac{W_{meas} - W_{simulation}}{W_{meas}} \tag{7}$$

Table 6. Difference between measurement and the simulation/IEC calculation [% difference from measured total loss].

	Cable 1	Cable 2	Cable 3	Cable 4
Simulation	-0.9	-3.9	1.0	-4.2
IEC	17.4	29.1	21.6	-1.2

Further, the impact of armour, i.e., loss increase due to armour, can be compared between the measured values and values from the FEM simulations. This is presented in Figure 6. Cable 1 and 4 provide results that are within 0.3 W/m while cable 2 and 3 have an offset of 1-1.5 W/m. This is however still within expected offset due to measurement error and uncertainty in geometry and resistance of the measured cable compared to the simulated one. Overall, both these comparisons show that there is a good match between the simulations and the measurements.

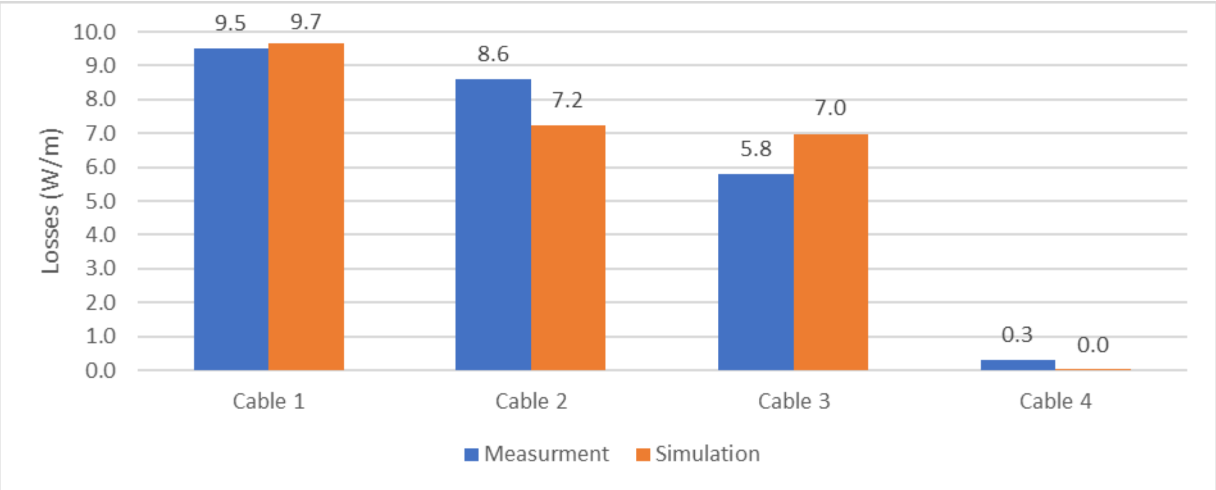

Figure 6. Comparison of increase of losses due to the armour between measurement and simulation

9.2. CONDUCTOR AC RESISTANCE

IEC 60287 [1] has neglected the impact of magnetic armour on the conductor AC resistance.

$$R_{ac} = R'(1 + y_s + y_p) \tag{8}$$

CIGRE WG B1.56 [11] has suggested a correction of this based on the formulas for pipe type cables, §2.1.5 of IEC 60287 [1], which provides the following formula,

$$R_{ac} = R'\left(1 + 1.5(y_s + y_p)\right) \tag{9}$$

That formula is expected to provide a conservative AC resistance, but it might be too conservative. It is expected that the skin effect is not affected by the presence of magnetic armour, but the proximity effect should be increased. A further possible formula could then be suggested,

$$R_{ac} = R'(1 + y_s + 1.5y_p) \tag{10}$$

AC resistance using each of the formulas has been calculated and are compared with the results from the simulations, see Figure 7. It can be seen that for cables 1-3 the IEC formula always gives about 1% lower AC resistance than simulations. The formula suggested by B1.56 clearly gives a conservative result, but it overestimates the AC resistance with 5-10%. Finally, the new suggested formula with factor 1.5 only on the proximity effect always gives a conservative result but at maximum 2% for cables 1-3. Cable 4 has nonmagnetic armour and no increase in AC resistance is expected for this cable. That is also confirmed by the simulations that gives about 1% lower resistance than the IEC formula.

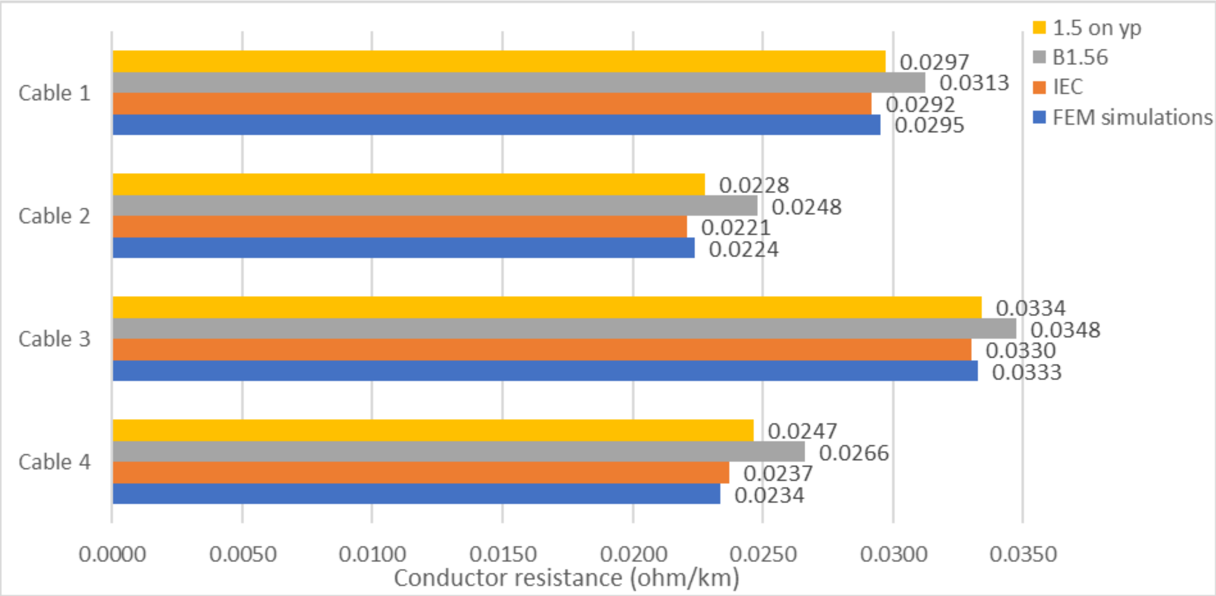

Figure 7. Comparison of FEM to three different formulas for calculating AC resistance. The result shows that AC resistance is affected by the presence of magnetic armour wires and increasing the proximity effect by a factor 1.5 gives results near simulations. For cable 4 with nonmagnetic armour no increase in the AC resistance is seen.

9.3. INCREASED SHEATH LOSSES DUE TO ARMOUR

It is well known that the sheath current increases due to the presence of armour. As per §2.3.10 of IEC standard [1] the sheath losses are increased by 50% by adding the factor 1.5 which gives the following formula,

$$R_{ac} = \frac{R_s}{R}\frac{1.5}{1 + \left(\frac{R_s}{X}\right)^2} \tag{11}$$

Figure 8 shows the increase in sheath circulating current losses due the presence of armour wires both from the measurements and from the simulations. For cable 1, which has 100% armour wire cover, the factor from IEC appears to be correct as measurement and simulation give 1.58 and 1.52 respectively. While for cable 2 and 3 which have 50% galvanised armour wires and 50% PE wires, the increase in sheath losses is smaller. A factor between 1.3 and 1.4 appears to be reasonable for these specific cable designs. For the cable with non-magnetic armour no increase in sheath losses from circulating currents is seen.

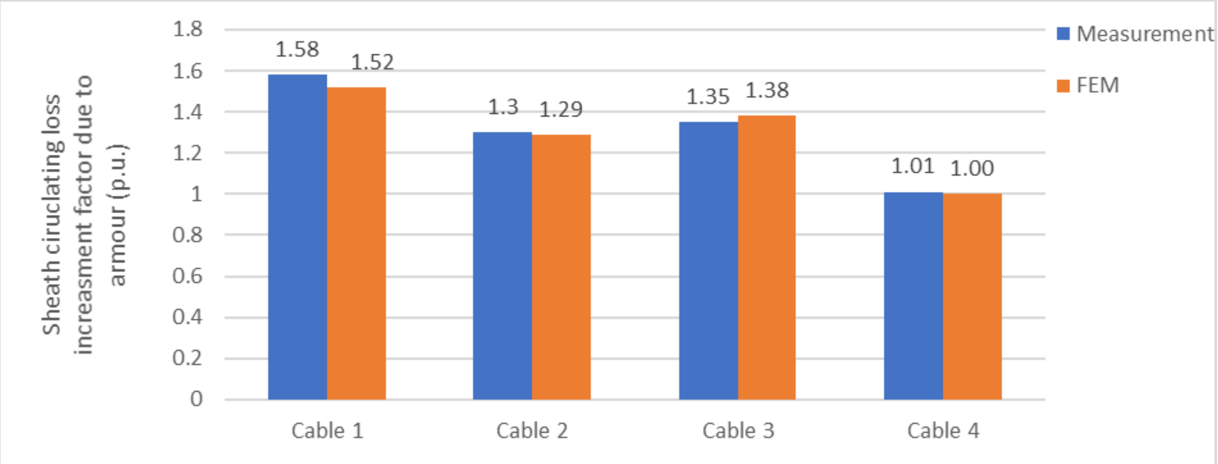

Figure 8. Increase in circulating sheath losses due to the presence of armour. The factor 1.5 from the IEC formula is confirmed for cable with 100% armour wires while for the two cables with 50% PE wires a lower increase is seen. For cable with nonmagnetic armour the sheath current is not increased.

9.4. EDDY CURRENTS

IEC 60287 [1] specifies that eddy currents could be neglected for cables with both ends bonded. It does however provide a method for calculation of eddy currents which can be applied also for both-ends-bonded cables. The recommendation of CIGRE WG B1.56 [11] is to include these losses in the cable rating and the simulations performed for the example cables shows that this is a valid recommendation. The losses due to eddy currents are much larger than what can be considered neglectable and the losses are larger than the results of the IEC formula except for the cable with stainless steel. This implies that it could be also an effect on the eddy currents due to the presence of armour wires.

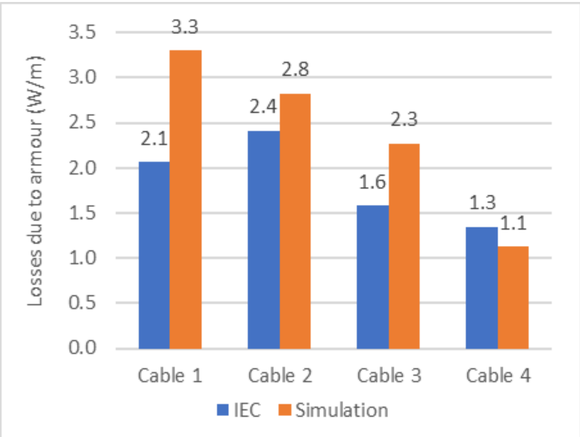

Figure 9. FEM simulations vs. IEC comparison of Eddy current losses. The simulations give significantly higher losses than with the IEC formula when magnetic armour is present.

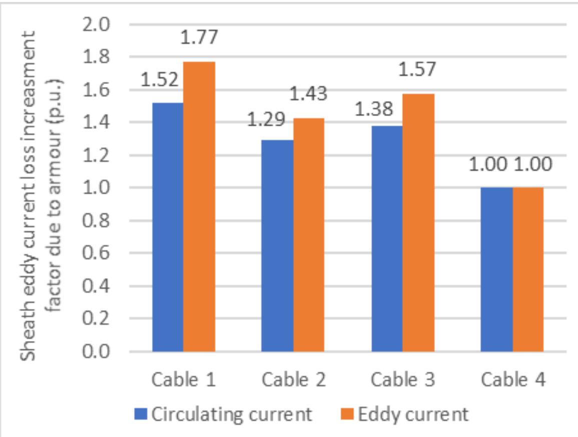

Figure 10. Increase of eddy current losses due to presence of armour compared to increase of circulating current losses.

As simulations were performed with and without armour wires, further studies of the impact could be done. From Figure 9 it is evident that the results from FEM simulation show higher values of eddy current losses compared to IEC values. In Figure 10, a comparison between increase of eddy current losses and circulating sheath current losses due to presence of armour are presented. For all cables, except the one with stainless steel, the eddy current losses are increased with a factor of 1.4 to 1.7, while the circulating current losses are increased by a factor of 1.3 to 1.5. The larger increase in losses from eddy currents than from circulating currents could be due to the simple separation of losses performed in the simulation, neglecting any AC resistance effect on the sheath. It is anyway clear that also the eddy currents are affected by the presence of armour around the cable and that some factor in the IEC formulas is required. Same factor as applied to circulating current and AC resistance, i.e., 1.5, could be reasonable based on the results from the analysed cable designs and until further studies are presented.

10. CONCLUSIONS

Armour losses modelled using FEM showed good agreement with measured losses with and without armour. This means that the FEM simulations can be used to simulate the losses in new cable designs and the results can be used to determine the required conductor cross section.

The interpretation of the measured and modelled loss components leads to the following conclusions and possible recommendations for improving the IEC norms:

- Conductor AC resistance is affected by the magnetic armour and a modification of that AC resistance formula is recommended to account for that by multiplying y_p with 1.5, as in eq. 10.
- Sheath losses are affected by the presence of armour wires. The IEC60287 recommends an increment factor of 1.5 for armoured cable and this was shown to be correct for fully armoured cables. For cable with 50% PE wires this factor could be reduced to 1.3-1.4 for the example cables in this paper.
- The losses from eddy currents should not be neglected as they are a large part of the sheath losses in submarine cables with lead sheaths. The eddy currents are also affected by the presence of magnetic armour and a factor of 1.5 is recommended also for eddy currents.
- Armour losses are shown to be overestimated in the standard. Simulations using FEM is shown to be a good way to estimate those losses.

Even if simulations are possible, it is always wise to measure a cable sample after manufacturing to verify the losses in the final design, especially if there are large differences in the new cable compared to what has been verified before.

BIBLIOGRAPHY

[1] IEC 60287-1-1, Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses (2014-11).

[2] R. Stølan, “Losses and inductive parameters in subsea power cables” (MSc thesis NTNU, 2009)

[3] J.J. Bremnes, G. Evenset, R. Stølan, “Power loss and inductance of steel armoured multi-core cables: comparison of IEC values with “2.5D” FEA results and measurements” (CIGRE 2010, B1-116)

[4] D. Palmgren, J. Karlstrand, G. Henning, “Armour loss in three-core submarine XLPE cables”, (Jicable 2011, A.7.3)

[5] J.A. Pilgrim et al.,” Current Rating Optimization for Offshore Wind Farm Export Cables” (CIGRE 2014, B1-108)

[6] M Hatlo, J. Bremsnes, “Current dependent armour loss in three-core cables: comparison of FEA results and measurements”, (CIGRE 2014, B1-306)

[7] W. Frelin, C. Moreau, D. Willén, C. Thidemann, V. Waschk, G. De Robien, N. Boudinet, “Measurements of losses on three-core submarine power cables” (Jicable 2015, B3.7)

[8] P. Maioli, M. Bechis, G. Dell’Anna, “AC Resistance of Submarine Cables” (Jicable 2015, E5.2)

[9] W. Frelin et al., “Armour loss measurements in three-core Medium-Voltage cables: Comparison with IEC standards and FEM calculations” (CIRED 2015 paper 1001)

[10] D. Willen, C. Thidemann, O. Thyrvin, D. Winkel, V. M. R. Zermeno, “Fast modelling of armour losses in 3D validated by measurements“, (Jicable 2019, C7.4)

[11] CIGRE Working Group B1.56, "Power Cable Rating Examples for Calculation Tool Verifications" (DRAFT version 19.09.2019).