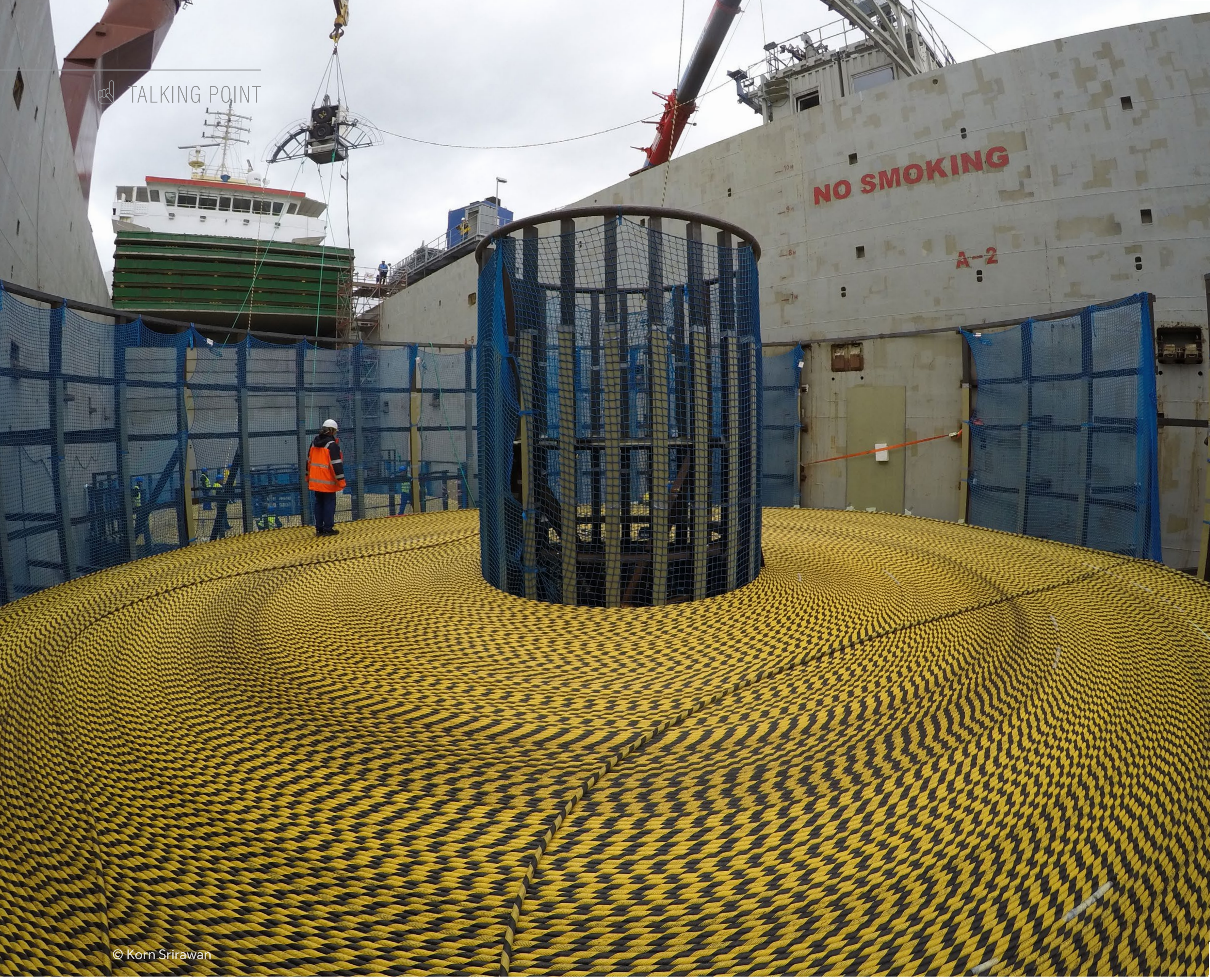


Cable on a turn table

Challenges and solutions in factory testing cable segments

In the current landscape of global energy infrastructure development, the necessity for efficient and reliable transmission systems has become increasingly pronounced, driven predominantly by the imperative of sustainable energy transition. In response to this pressing need, the deployment of high-voltage direct current (HVDC) submarine cables has emerged as a pivotal solution for transmitting electricity over vast distances, particularly across challenging subsea terrains.

The Xlink project stands as a testament to this evolution, aiming to connect Great Britain to Morocco via a sprawling submarine cable network spanning approximately 3800 km. Amidst this ambitious project lies the challenge of ensuring the reliability and integrity of the cable segments, particularly during factory testing. This article deals with the testing of these cable segments, highlighting the challenges encountered and proposing scientific solutions to overcome them.

Resonance principle

At the heart of factory testing lies the resonance principle, a well-established method for generating high test voltages in large-capacity specimens. However, when applied to testing long cables, certain fundamental considerations come into play. The adjustment of inductivity and frequency is crucial in optimising the test circuit for resonance conditions, ensuring efficient testing while minimising losses. Understanding the interplay between resistance, voltage increase, and quality factor is essential for designing an effective test system.

Testing of long cables: technical limitations and solutions

The testing of long cables presents unique challenges, primarily stemming from the escalation of current and losses with increasing cable length. Cubic augmentation of cable losses and the resulting overheating underscores the technical limitations concerning the testable length, particularly at cable ends. Implementing feeding at both cable ends proves instrumental in mitigating losses, significantly reducing them compared to single-sided feeding. Moreover, the optimisation of screen design and material composition offers further avenues for minimising losses and enhancing test efficiency.

Testing of DC cables: design considerations and testability

Unlike alternating current (AC) cables, the evaluation of direct current (DC) cables necessitates accounting for all losses occurring at test frequencies, even those absent during DC operation. Cable design plays a pivotal role in determining testability, with factors such as material composition, mechanical properties, and leak tightness in sea water or soil influencing the testing process. Ensuring the operational safety of DC cables requires a comprehensive understanding of their thermal properties, particularly during factory testing.

Example: project Xlink

In the Xlink project, which is to supply up to 7 million households in Great Britain with green electricity, the objective is to equip the 3,800 km DC cable with the lowest possible number of field joints built at sea, which therefore cannot be electrically tested. The laying section length will be approximately 160 km. In the cable factory, these 160 km sections are assembled from individual production lengths on turntables using factory joints.

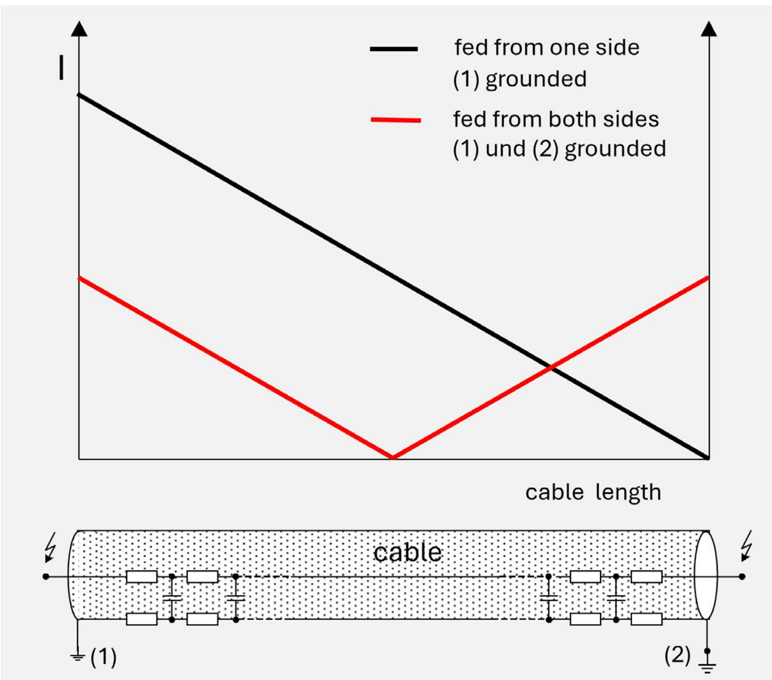
The individual production lengths are subjected to individual testing with HVAC in accordance with CIGRE 852 [2]. For this purpose, AC cable testing in a frequency range between 10 to 300 Hz is required in accordance with CIGRE 490 [3]. The individual partial lengths, including the factory joints, are therefore to be tested at the agreed AC voltage of 450 kV.

CIGRE 852 also requires the factory joints to be tested at the same voltage, even though the cable itself has already been tested. However, as the production processes for manufacturing these long cables involve multiple mechanical loads, testing at this voltage is recommended.

However, as the level of the test voltage on the cable must be agreed as a parameter, it is the joint responsibility of the cable operator, insurance provider, and cable manufacturer, together with the manufacturer of the test equipment, to describe the test procedure in detail and to also take the manufacturing logistics into consideration.

Tests of the factory joints, assembled in the factory under optimal conditions, may be done at lower voltages under certain circumstances, rather than the repeated cable testing. That means that individual factory joints may only be subjected to AC withstand voltage tests.

The cable also has armouring for mechanical protection, but that will not have been fitted at the time of the HVAC tests.



test current distribution along a cable depending on the kind of feeding

Feeding from one side only:

$$I_{(1)} = I_{test} \qquad P_{sheath} = I_{test}^2 \frac{R_{sheath}}{3}$$

Feeding from both sides:

$$I_{(1)} = \frac{I_{test}}{2} \qquad P_{sheath} = I_{test}^2 \frac{R_{sheath}}{12}$$

Feeding from both sides may reduce the losses to 25 % !

The feeding at both cable ends reduces the losses to 25% compared with a single-sided feed. This idealised representation requires the same reactor power at both ends with identical cables of the same type for the overall length. The real load therefore deviates from this idealised view

The total capacity thus reaches 41.8 µF. With this data, an AC apparent test power of 2660 MVA would already be reached at 50 Hz, at a test current of 5915 A. This shows how appropriate and important it is to permit AC tests up to 10 Hz for long cables. At a test current of 1183 A and with feed-in from two sides, there is still 591 A per cable end. Even this current can exceed the permitted current for the lead sheath, which is subjected to the full charging current during AC testing.

Systems are available for such tests in the 10 Hz range, like the following example of a reactor dimensioned for a rated frequency of 12 Hz.

In order to test all 160 km, completely assembled, at 450 kV, 24 reactors are required, in pairs connected in series, with the corresponding exciter transformers and frequency inverters. The test current at a resonance frequency of 12.2 Hz is 1440 A.

At this test voltage, the cable has dielectric losses of approx. 1.06 MW, which are distributed evenly along the cable length. The test current of 720 A fed in at each cable end, produces an additional 5.34 MW, together with the dielectric losses, the result is roughly 87 W/m at each end of the cable. Together with the losses of the test system, the total losses are already approximately 11.4 MW.

Therefore, in this example, both the test object and also the test system contribute roughly half of the total losses of this test setup.

It is now the cable manufacturer's responsibility to calculate the temperature rise of the cable ends within the turntable and determine the permissibility. On the other hand, the cable manufacturer can also influence the currents that occur during the test and the thermal loads by designing the cable accordingly or agreeing appropriate test sequences.

Note also that due to the current in the screen, voltage drops occur along the screen to earthed parts like the turntable, the roller pathways or the armouring. For tests at 450 kV/AC, voltage differences between the cable screen and the earth potential of approximately 4.2 kV, can occur in the middle of the total length.

The number of reactors can be reduced until the test frequency reaches 10 Hz, while the nominal current of both the reactors and the power supply is so that the test current of the cable is not exceeded. However, the test voltage is to be reduced to 395 kV. Only 18 reactors are then required. The reduced test voltage could be compensated by extending the test duration accordingly. However, this would have to be agreed separately. The test voltage reduction becomes necessary for the cable lengths of 120 km or more.

However, if tests are conducted at 450 kV per 80 km or 120 km cable, then after connecting two 80 km cables or one 120 km cable with a 40 km cable, only one factory joint remains that must be tested at a reduced test voltage.

Reducing the test voltage also offers a way of restoring testability if the power supply is not sufficient due to losses that have not been considered or insufficient quality factor of the test setup.

Test reactor 225 kV
Reactor data: Rated voltage: 225 kV
Rated current: 122 A

Conclusion

The testing of cable segments for the Xlink project presents a myriad of challenges, ranging from technical limitations to design considerations. However, scientific solutions abound, offering avenues for overcoming these challenges and ensuring the operational reliability of the cable network. Collaboration between stakeholders, adherence to stringent quality standards, and the continuous advancement of testing methodologies are essential in realising the vision of a reliable and efficient submarine cable network for renewable energy transmission.

Depending on the test methods, DC submarine cable lengths of up to 160 km can therefore be tested with HVAC.

The following criteria are decisive for determining the maximum testable length of a cable: design and technology of the cable manufacturing process; defined test voltages and test duration, minimum test frequency; the type and number of the connections between the cable screen and armouring; and ability to provide the active power for testing from the grid or generators.

This makes quality assurance of DC submarine cables possible for very long cables, as corresponding test sources and the necessary measuring equipment are available.

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Resonant test system for very long cables