Offshore Wind Accelerator

Fibre Optic Cable Protection Assessment

Literature review

Contents

The Offshore Wind Accelerator

The Offshore Wind Accelerator (OWA) is the Carbon Trust's flagship collaborative research, development and deployment programme. The joint initiative was set up between the Carbon Trust and nine offshore wind developers in 2008, with the aim to reduce the cost of offshore wind to be competitive with conventional energy generation, as well as provide insights regarding industry standard (and best practice) health and safety requirements.

The current phase involves participation and funding from eight international energy companies: EnBW, Equinor, Ørsted, RWE, ScottishPower Renewables, Shell, SSE Renewables, and Vattenfall Wind Power, who collectively represent 75% of Europe's installed offshore wind capacity. This project also received partial funding from the Scottish Government.

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This document was produced on behalf of the Offshore Wind Accelerator by RINA Tech UK Ltd, with technical review by the Offshore Wind Accelerator Cables Technical Working Group.

With a history going back 150 years, the RINA Group is a global corporation that provides engineering and consultancy services, as well as testing, inspection and certification.

Executive summary

Since 2014, more than six faults on three-core submarine cables have been reported where the root cause of a fault has been assigned to the interaction between the power cable and the metallic part of an integrated fibre optic cable (FOC). This has led to some concern in industries designing, installing and operating offshore cable assets.

The Carbon Trust Offshore Wind Accelerator launched the Fibre Optic Cable Protection Assessment project with the key aim to confirm or dismiss the reports that the faults have been caused by an interaction between the power cores and the FOC. The project was divided into three sections, each with a separate report.

Literature review: undertake an in-depth literature review to identify published information covering the modelling and calculations of the conditions relating to faults caused by interactions between FOCs and power cores in submarine cables.

Induced voltage modelling: carry out calculations and modelling to assess the effectiveness of using semi-conductive sheaths and high resistance metallic parts in the FOC to reduce the risk of failures due to interaction between the FOC and the power cores.

Design and testing recommendations: propose specifications for cable designs that would minimise the risk of failures due to interaction between the power cores and the fibre optic elements of the cable.

The literature search carried out by RINA has shown that the published information relating to failures of high voltage (HV) subsea cables is very sparse.

No published papers were found that directly addressed the technical aspect of how an interaction between power cores and an FOC could lead to a failure.

Gustavsen, 2018, demonstrated how voltages may be induced on the metal tubes of a power umbilical owing to the capacitive charging current in the power cores.

Other documents have been provided by the Carbon Trust, on behalf of the Offshore Wind Accelerator, from Nexans (Nexans, 2017) and Ørsted (T. Kvarts, 2018). These papers and presentations directly address the issue of possible interactions between an FOC and the power cores in an HV submarine cable. The Ørsted paper provides a detailed description of the calculation method used. The method follows the same principles used by Gustavsen, and it is considered to be valid. The Nexans paper does not provide details of the calculation method but the results presented indicate that it is similar to the Ørsted method.

The Ørsted calculations have been replicated and extended to investigate a complete break in the FOC tube and sheath, the possibility of tracking across the sheath, and the effect of an intermediate insulating layer such as adhesive between the sheath and tube.

A further paper from Nexans was presented at Jicable in June 2019. The paper provides a detailed description of the calculation method for induced voltage in the presence of a semi-conducting cable sheath. The calculation method follows the same principles as those in the Ørsted paper and draws the same conclusions.

1. Literature review

1.1 Literature search

Prior to carrying out the literature search, the author was aware of two published documents that discussed the failure mode that is being considered. Both of these were Offshore Wind Programme Board (OWPB) documents:

Export Cable Reliability – Description of Concerns, dated July 2017.

Export Cable Reliability – Alternatives to Interstitial FIMT Optical Fibres, dated September 2017.

These documents address the impact of the failures and consider possible alternatives to the existing export cables where the fibre optic cable has a metal tube and is within the export cable. Thus, although these reports provide a background to the failure mode they do not include technical details.

Literature searches were carried out with the aim of identifying published papers or articles covering cable faults and in particular documents reporting on the interaction between power cores and fibre optic in subsea cables. The abstracts obtained from the searches were reviewed by the project team to determine which documents were relevant to the project and full copies of those documents have been obtained.

Because the failure mode being investigated appears to be a very recent phenomenon, the searches were limited to papers published in 2005 and later.

The searches were mainly carried out in the IEEExplore, Proquest, Inspec and Google Scholar databases. The initial search looked in the narrow field of 'interaction between power cores and optical fibre cables'. This search resulted in no hits.

The searches were expanded to cover a wider area using the terms in Table 1. The number of hits from the Inspec database are given in Table 1 and there were a similar number from the IEEExplore database and fewer from the other sources. Many of the hits from different databases were duplicates of those from other databases.

Table 1: Search results from the Inspec database

Key words	Results
Subsea/submarine/export cables	1,238 hits
Combining above with reliability	219 hits
Combining with damage	67 hits
Combining with fibre optic cores	28 hits
Combining with AC corrosion	2 hits
Combining with failure	76 hits
Searched for "export cable reliability" as a title	0 hits
Searched for a specific windfarm that was known to have suffered failures	3 hits

None of the publications that were found in the searches addressed the issue of interaction between an FOC in a cable and the power cores leading to a failure. A very limited number of published documents made any mention of export cable failures and the publications stated that there was a lack of data. For example, the paper 'Review of Offshore Cable Reliability Metrics' (J. Warnock, 2017) states 'If literature is examined it can be seen that reliability figures and failure data from offshore cables is sparse'. A summary of the same paper presents cable failure rates for ten offshore wind farms. The summary states that the failure data had not been found in published literature but was collated through investigation of news articles, Notice to Mariners, and SeaFish report.

The literature search carried out has confirmed the findings of others; there is a lack of published data. Although there were several relevant hits in published papers, none of these found mention of a windfarm that is known to have suffered an export cable failure attributed to the interaction being considered.

The author is aware that legal proceedings are underway for at least three of the failures that have been attributed to power core/FOC interaction. It is considered likely that this will account for the lack of published technical data.

Some failure data has been made available, privately, from part of the insurance industry. This data shows 26 claims relating to export cable damage; no details are given.

Of the published information found during the literature search one paper was found that could have some relevance. This paper discusses AC corrosion of pipes in subsea umbilicals that also contain power cores. The paper is: 'Voltages and AC Corrosion on Metallic Tubes in Umbilical Cables Caused by Magnetic Induction From Power Cable Charging Currents' published in IEEE Transactions on Power Delivery PP(99):1-1 November 2018 (Gustavsen, 2018). The references in this paper do not mention other papers on a similar subject.

1.2 Papers

1.2.1 AC corrosion

Gustavsen 2018 references the OWPG report of July 2017, mentioned above, as one driver for carrying out the study, together with failures in power umbilicals. The paper only considers induced voltages due to capacitive charging currents. It considered that the tubes are bonded to earth at both ends and hence circulating currents will flow and there will be no voltage induced on the tubes due to the load currents. However, the paper considers that the variation in power cable charging current along the length of the cable will lead to a voltage existing on the tubes in the umbilical. The paper presents methods of calculating this voltage for three designs of cable: cores without metal sheath but with semi-conductive core sheath, cores with metallic sheath and semi-conductive core sheath, and cores with a metallic sheath and an insulating core sheath. The second design is representative of export or interconnector cables.

The paper considers insulated tubes rather than tubes with a semi-conducting sheath, hence there is a slight difference from some of the export cables where the FOC has a semi-conducting sheath. However, the presence of induced voltage due to charging currents is not an aspect of the failure mode that has been previously considered in this context. Hence this paper will provide a useful contribution to this project.

As with some of the export cable failures, the paper on umbilicals considers that there has to be some damage to the sheath of the tube/FOC before the induced voltage will cause further damage. One calculated example is given for a 15km, 11kV umbilical, which shows that if there is a small puncture in the insulation then a tube with 1.6mm wall thickness would be expected to corrode through in 93 days.

Power umbilicals are similar to subsea export cables in that they both contain power cores and other metallic components. The major difference between power umbilicals and subsea export cables are the operating voltage, the spacing between the power cores, and the positioning of the metal tubes relative to the power cores. Also, the metal tubes may or may not be coated and if they are coated they will have an insulating sheath.

The author has reviewed the calculations presented in the paper and found the approach to be valid. The calculations presented in the paper will be reproduced and the method applied to the geometry of a typical export cable.

1.2.2 Papers from the Offshore Wind Accelerator

On behalf of the Offshore Wind Accelerator, the Carbon Trust has provided papers prepared by both Nexans and Ørsted which address the issues associated with induced voltages in FOCs in export cables.

The Nexans paper 'Integration of Fibre Optic Element in Armoured Three Core Submarine Cables' (Nexans, 2017) is intended to demonstrate that the Nexans design eliminates the risk by minimising the voltage and current in the steel tube of the FOC. The paper includes a number of graphs demonstrating the different effects with different material parameters such as the conductivity of the metal tube containing the optical fibres and the conductivity of the sheaths of the FOC and power cores. The paper does not set out the calculation method used to obtain the graphs. However, the shape of the graphs presented indicate that the approach to the calculations is valid. The paper considers both the voltage on the FOC due to charging currents and that induced by the load current. The paper only considers FOCs with a copper tube or a stainless steel tube. It does not consider an FOC with a stainless steel tube and aluminium wire armour. It is considered that the design of aluminium armoured wire is similar to that of a copper tube. This is because the induced current in the FOC will be much higher than for a design with only a stainless steel tube.

The approach adopted by Nexans is to argue that if the metal part of the FOC has a high resistance then the current flow in the tube will be low and hence the current across any break in the tube will be low. Also, if the sheath of the FOC has sufficient conductivity then it will carry the current across any break without generating sufficient heat to initiate degradation. The Nexans paper appears to only consider the situation where the metal tube has parted but the sheath of the FOC remains intact. The effect of both the metal tube and the sheath parting, such that the current flow is through seawater that has entered the gap, is not considered.

The service failures the author has seen have occurred in FOCs with copper tubes and FOCs with stainless steel tubes with aluminium wire armour. The author is not aware of how many export cables installed to date have a stainless steel tube with no armour. However, the author is aware of one export cable with a stainless steel tube and no armour where breaks were found in the tube before installation but the details of this are confidential.

Ørsted prepared a paper for Jicable 2019 (T. Kvarts, 2019). They also made a presentation at ICC in Spring 2018. The paper and the presentation are on the same subject and provide similar information, with the paper having more detail. The Ørsted paper sets out the details of the calculations that have been carried out. The author has reviewed the approach that has been taken and the equations and equivalent circuit used by Ørsted. The calculation methods used are considered to be appropriate and valid.

As with the Nexans paper, the Ørsted paper considers induced voltages due to both the capacitive current and the load current. Ørsted demonstrated that the higher the resistance of the metal tube/armour the lower the energy dissipated at any break and hence the lower the risk of degradation. They also demonstrated that the resistance of the sheath of the FOC has a significant effect on the induced voltage on the metal tube. The lower the resistance of the sheath the lower the induced voltage. Also, with a low resistance sheath the current in the tube can 'bypass' any break in the tube by flowing through the sheath.

The Ørsted paper does not consider the effect of a complete break in the FOC. With a high resistance tube, it is likely that the current flow through the seawater to the lead sheaths of the power cores would not result in significant heating or corrosion but this is not mentioned. Also, where there is a break in the tube it is assumed that the current will flow through the bulk of the semi-conducting sheath. The possibility of current 'tracking' along the inside surface of the sheath is not considered. If such tracking occurred it could result in eroding carbon tracks across the surface and ultimate failure, even at low currents. If the resistivity of the sheath is sufficiently low then the results given in the paper indicate that there would not be sufficient voltage across the break to initiate tracking.

The Ørsted calculations are replicated in the induced voltage modelling report to investigate the effect of a complete break of the FOC and the possibility of tracking. It has also been noted that on one design of FOC that there was a thin film of adhesive bonding the sheath of the FOC to the tube. This adhesive was insulating and hence it would largely negate the benefits of a semi-conducting sheath. The effect of such a resistance is to be investigated.

The papers from Nexans and Ørsted are generally aimed at demonstrating how the risk of faults due to interaction between the power cores and the FOC can be minimised. Calculations are carried out in the induced voltage modelling report based on the properties of the FOCs in the failures it has examined to determine the likely current and power dissipation at a break in the FOC. This will support the investigation into whether the assumed failure mode is valid.

1.2.3 Jicable 2019

In addition to the Ørsted paper there was a paper from JK Cablegrid (J. Karlstrand, 2019) that was prepared on behalf of Nexans. This paper covered the same points as those in the Ørsted paper but with an alternative calculation method. The Ørsted paper used circuit simulation software to provide a solution for the situation where the fibre optic cable has a semi-conductive sheath. The JK Cablegrid paper used transmission line theory to arrive at the solution, as well as including equations for the situation where the metallic parts of the fibre optic cable is only bonded at one end.

Both the Ørsted and JK Cablegrid papers reached the same conclusions. These are that it is preferable for the FOC to have a semi-conducting sheath with a resistivity of not more than

1000Ω·m, and the metallic part of the FOC should be high resistance so as to reduce the heat generated in the event of a discontinuity in the metallic part.

The JK Cablegrid paper states that they are aware of failures involving FOCs where the fibres were enclosed in a relatively large diameter copper tube and where the fibres were in a smaller stainless steel tube with aluminium wire armour. JK Cablegrid are not aware of failures involving FOCs with just a smaller stainless steel tube and no armour (high resistance metallic part). Although the author is also not aware of power cable failures associated with this type of FOC there has been at least one mechanical failure of an FOC with a stainless steel tube and no armour. The author's understanding is that the export cable was damaged during handling and the damage to the FOC was identified before the cable was energised.

2. Conclusions

The literature search has shown that the published information relating to failures of HV subsea cables is very sparse. No published papers were found that addressed the technical aspect of how an interaction between power cores and an FOC could lead to a failure. One paper was found that demonstrated how voltages may be induced on the metal tubes of an umbilical due to the capacitive charging current in the power cores.

Other documents have been provided by the Carbon Trust from Nexans and Ørsted. These papers and presentations directly address the issue of possible interactions between an FOC and the power cores in an HV submarine cable. The Ørsted paper provides a detailed description of the calculation method they used. The method follows the same principles used in the AC corrosion paper and it is considered to be valid. The Nexans paper does not provide details of the calculation method but the results presented indicate that it is similar to the Ørsted method. The results presented by JK Cablegrid also lead to the same conclusions as those drawn by Nexans and Ørsted.

The Ørsted and JK Cablegrid calculations have been replicated in the induced voltage modelling report and extended to investigate a complete break in the FOC tube and sheath, the possibility of tracking across the sheath and the effect of an intermediate insulating layer, such as adhesive between the sheath and tube.

3. References

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