Predicting Dynamic Subsea Cable Failure for Floating Offshore Wind

David Young | September 2018 | AP-0016

Introduction

The UK's Climate Change Act aims to reduce total carbon emissions by 80% by 2050. Offshore renewable technologies offer a low-carbon alternative to traditional energy by combustion means. Being ideally-placed to take advantage of natural resources in wind, waves, and tides will allow the UK to become a world leader in offshore renewable energy. Whether a wind, wave or tidal device is used to extract energy from these resources, subsea cables are needed to bring that energy back to land. Therefore, ensuring these cables can survive offshore is crucial.

Technological advancements in the offshore wind industry, coupled with economies of scale, are increasing the viability of large offshore turbines. These larger turbines are moving further offshore to take advantage of the higher wind speeds available. However, this increase in distance from the coast can coincide with greater water depths. Traditional bottom-fixed wind turbine technologies are not able to accommodate these greater water depths, giving rise to new floating wind turbine platforms. Significant advances have been made in floating wind turbine technologies, with 80MW of floating wind capacity estimated to be installed in the UK by 2020.

All floating structures will require cables to run through the water column, from their substructure base to the seabed. This exposes the cables to the dynamic forces produced by marine currents and the movement of waves. Cables can fail due to mechanical and electrical stresses. The next generation of dynamic cables will need to be robust enough to survive with having larger stresses acting on them. These greater stresses will cause the cables to fatigue faster than those in a conventional static cable configuration, resulting in a greater risk of cable failure.

This paper aims to elucidate to the reader the work undertaken by the Offshore Renewable Energy (ORE) Catapult to better understand the failure mechanisms of dynamic subsea cables. Finally, this paper hopes to illustrate how a better understanding of these failures can create models for testing and validating cable configurations proposed for dynamic subsea applications.

Headlines

- Subsea power cables on floating offshore wind projects experience greater levels of mechanical stress due to the dynamic environment, leading to an increase in cable failures.
- ORE Catapult research is studying how cables interact with ocean waves, currents and the movement of floating platforms to produce models that can help predict dynamic cable failures and aid preventative maintenance, reducing the cost of floating offshore wind.
- It is hoped that the final electro-mechanical model will provide greater investor confidence and stimulate further development in offshore renewable energy technologies for both floating wind and wave energy projects.

UK Floating Offshore Wind: Market Overview

Figure 1: The HyWind Scotland project's last floating offshore wind turbine sets sail from Stord, Norway, en route to its destination off Peterhead, Scotland. Credit: Øyvind Gravås/Statoil

The proliferation of floating offshore wind creates opportunities to build wind farms in deeper waters, where wind speeds are higher, than traditional bottom-fixed platforms. Governments looking to decarbonise their energy systems are viewing floating offshore wind as an emerging technology to achieve this cost-effectively. The ability to reach areas of strong wind resource in deep waters can deliver low carbon energy to the grid. If these sites are in deep water but also near shore, floating wind provides the double benefit of reducing transmission losses. Furthermore, situating wind turbines further offshore reduces their visual impact.

Figures indicate that 48MW of floating wind capacity will be installed in UK waters by 2020. October 2017 saw the opening of the Hywind Scotland floating wind project 25km off the east coast of Scotland. The 30MW project consists of five turbines that are 253 metres tall, with 78 metres being submerged, and the turbines themselves attached to the seabed by tendons. The Kincardine Pilot project, 15km off the east coast of Scotland, will add a further 50MW.

These developments and predictions present the UK with the opportunity to build on its world-leading position, and develop supply chains to penetrate future international markets – for example, Japan has made inroads into floating offshore wind with the Fukushima Demonstration floating wind farm.

Challenges with Current Cable Systems

Figure 2: A cross-section of a static subsea power cable.

Traditional subsea cables are manufactured to meet the requirements of a static offshore wind farm. A renewable energy insurer[1] outlined that during 2007-2014, 83% of construction projects had a cable-related incident, amounting to a total cost of USD $234M to insurers and over USD $38M to project teams and contractors.

In 2015 alone, insurance claims relating to cables in the UK accounted for 77% of the total global cost of offshore wind farm losses. Another insurer[2] estimates that 95% of all offshore wind projects experienced one or more cable-related claims.

Traditionally, cable claims were related to incorrect cable installation or load out, or incorrect operation. Approximately one-in-five failed due to an electrical fault. However, in the past two years, insurers have seen a trend begin to emerge with claims related to internal faults in the cable, after only a few years of operation. While insurers do not go into the finer details of the failure mode, these cables are expected to have a lifetime of 20-25 years.

Failure after only a few years of operation is a concern and suggests there is need for a better understanding of how these cables are fatiguing in service. This fatigue is suspected to be down to either mechanical or electrical stresses.

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1. GCUBE. “Down to the Wire: An Insurance Buyer’s Guide to Subsea Cabling Incidents”, presented at Subsea Power Cables Conference, London 2014.
2. CODAN. “Insuring Offshore Cables, an insurers’ perspective”, presented at 6TH Annual Advanced Submarine Power C able and Interconnection Forum, Berlin, June 2017.

Static cables were designed for service in environments wholly different to those experienced by cables for floating offshore wind. The dynamic cables will be exposed to sea currents, action of the waves and the movement of the floating turbine platform itself.

Operating in a more dynamic environment will expose the cables to greater mechanical stresses and strain. Therefore, the cables themselves will need to be designed to account for this. For example, they may need to be designed with greater levels of armouring for protection, metallic sheaths may need to be removed due to fatigue and replaced with plastic, and bending stiffness and weight may need to be redesigned for dynamic applications. Furthermore, as offshore cables are already failing unexpectedly in service in static applications, a more dynamic environment will also have unexpected failures, if not more than in a static environment.

The Dynamic Subsea Cable Project

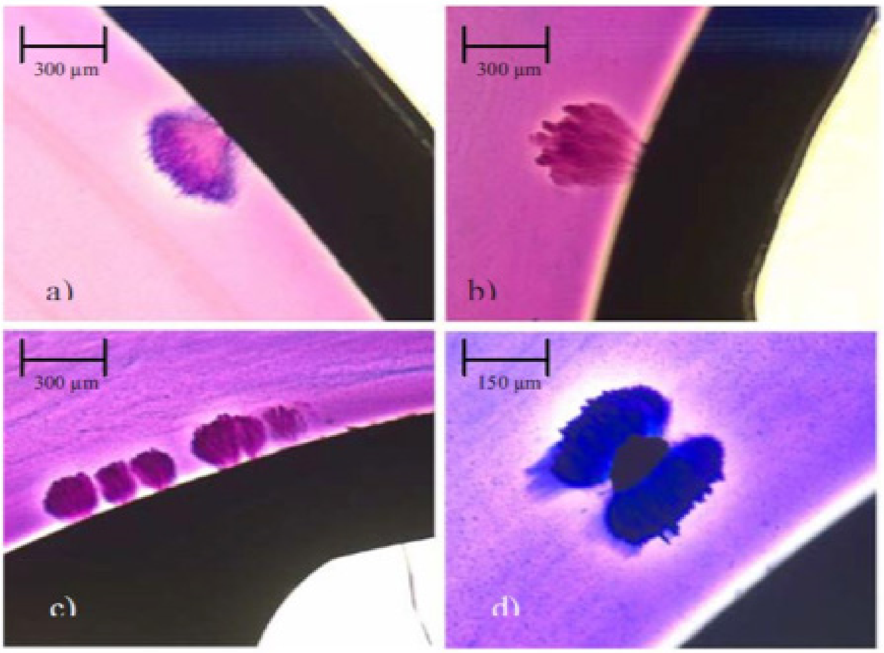

Figure 3: Differing types of water trees within cable insulation layers

ORE Catapult, in partnership with the Industrial Doctoral Centre for Offshore Renewable Energy, IDCORE, is investigating dynamic subsea cables for floating offshore wind. The research project aims to take a holistic approach, looking at how the cables interact with the waves, currents and the movement of the floating platform.

How these actions impact the mechanical stresses the cable experiences is to be studied, in addition to the electrical stresses induced from the energising of the cable. As previously mentioned, cables are expected to fatigue due to mechanical and electrical forces and therefore a focus has been given to determining whether or not there is a coupling effect between the two. The final outcome is to produce models which can help predict when and where a dynamic cable may fail along its length.

A well-known phenomenon that occurs across the cross section of a cable's insulation is the growth of tree-like structures known as water trees, as shown in Figure 3[3]. Much research has gone into determining how these tree-shaped structures initiate and propagate. One school of thought is that they initiate at points of imperfection – either at the surface of the insulation, due to damage or wear, or an imperfection within the insulation itself.

This imperfection allows for the distortion of the electric field produced by the current in the cable cores, producing Maxwell forces that essentially "bore" channels through the insulation. As these trees bridge the insulation cross-section they weaken its integrity, and thus an electrical failure can occur. It should be noted that these trees do not need to traverse the entire cross-section for this failure to occur.

Water trees are believed to have a "pearl and string" structure as shown in Figure 4[4]. The pearls can be thought of as being micro-voids, or pores, within the insulation with the channels opening and connecting the pores as a result of the Maxwell forces. Frustratingly, when investigating these trees post-service, the channels close up quickly and disappear, and thus need to be dyed quickly to continue to be seen at a later date. Furthermore these pores allow for water to condense within the cable cross section, further distorting the electric field, and accelerating the channel growth between adjacent pores. Crucially these trees take time to grow and propagate, adding to the theory they are responsible for unexpected failures years into an otherwise healthy cable's lifetime.

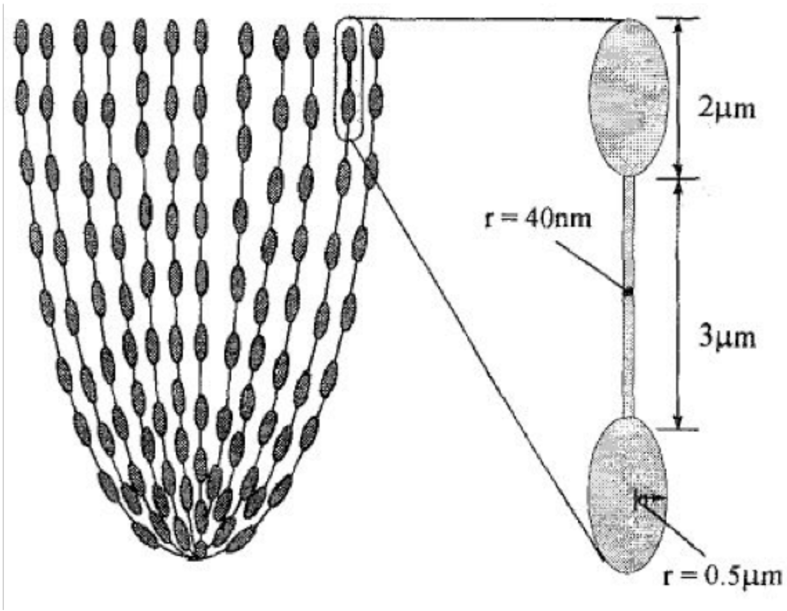

Figure 4: Simplified schematic showing micro-void "pearls" interconnected by small channel "strings".

The Catapult's ongoing research project will investigate whether, as a result of the dynamic environment the cable is operating in, the mechanical stresses can cause micro-pores to form within the insulation of the cable. Secondly, the impact of the electrical stresses as a result of the electric field distortion due to water present within the micro-pores will be investigated. The coupling of the

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[3] Nordas, S et al. "The influence of Strain on Water Treeing in XLPE Power Cables". 2010.

[4] Hvidsten, S. et al. "Understanding Water Treeing Mechanisms in the Development of Diagnostic Test Methods", IEEE Transaction on Dielectrics and Electrical Insulation, 1998.

mechanical and electrical stresses is to be investigated to see, when combined, what impact they have on the propagation of the water trees, and from this whether cable failure can be predicted.

Project Outcomes

The overall outcome of the research project is to produce a final electro-mechanical model which can predict cable failure due to electrical and mechanical interactions. The benefit of this is that the model can be used to provide a new cable testing solution and testing validation. Looking further than the immediate benefits, there is a potential for the model to be used as a cable health monitoring tool, aiding in preventative maintenance to offshore cables. This should contribute to the overall reduction of offshore cable failures, reducing costs and number of insurance claims. It is hoped that this will provide investors with greater levels of confidence, and stimulate further development in offshore renewable energy technologies. Finally, it is important to note that the benefits of these models will not only be applicable to floating offshore wind applications, but also future wave energy technologies as these too are envisioned to require dynamic cables.

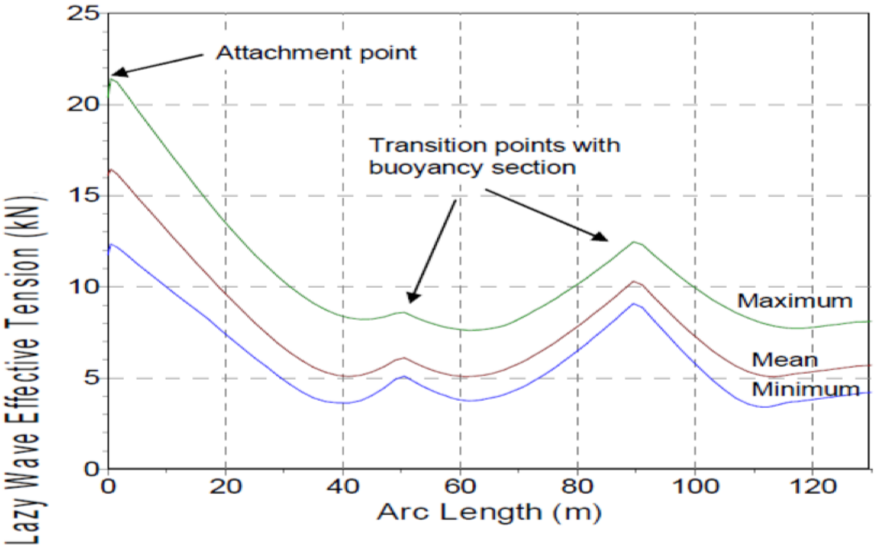

Figure 5: Effective tension along subsea cable length, with peaks identified

Results

A dynamic model of a 66kV cable connected to a tension leg platform floating wind structure was completed as part of the research project. A 66kV cable was chosen to be modelled for inter array cables. It is anticipated that the market is moving towards more widespread adoption of 66kV cabling due to it offering a 20-30% reduction in cable length lay when compared to traditional 33kV cables, thus reducing costs. The environment that the cable was modelled in was deduced from wave buoy data collected off the coast of the Catapult's National Renewable Energy Centre in Blyth, Northumberland. The outcome of this model was that it highlighted areas along the length of the cable that experience the highest tension and mechanical forces and are potential hotspots for cable failure, coinciding with works previously conducted and illustrated in Figure 5[5].

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[5] 5. Thies, P. et al. "Assessing mechanical loading regimes and fatigue life of marine power cables in marine energy applications", Proceedings of the Institution of Mechanical Engineers Part O Journal of Risk and Reliability, 2011.

A model cross-section of the cable and all its corresponding interlayer components has been constructed. The outputs of the dynamic model allow us to apply these forces to the cable cross-section, to determine where the stresses concentrate. This allows us to determine which components of the cable cross-section are exposed to the greatest forces and mechanical fatigue damage. Furthermore, we can estimate what stresses the specific insulation layers of the cable will experience. This knowledge will then allow for the modelling of the micro-pores in the cable's insulation.

A later phase of the project will then quantify the impact of electrical stresses and how these contribute to the electric field distortion in the insulation layers. The coupling of these electric field distortions with the presence of the water-filled micro-pores previously modelled will then be investigated. It is envisioned that this will give an estimate of how long it will take for these water trees to grow to a cause a fault, thus predicting where and when a cable fault may occur for dynamic cables.

Conclusion

Developments in floating offshore wind will create new challenges for the longevity of subsea power cables. These vital connectors are expected to experience greater levels of mechanical stress due to the dynamic environment, giving way to an increase in cable failures. Such failures are of great expense to renewable energy insurers and wind farm operators.

This research project consists of developing models that will couple these mechanical stresses with the electrical stresses of the energised cable – the purpose of which is to provide a tool which can be used for cable health monitoring and cable failure estimation and location prediction. The desired outcome of this improved understanding of cable failure is to prevent unexpected cable faults and aid in the preparation of preventative cable maintenance. This is expected to help reach the overall goal of reducing the number of offshore cable failures, therefore reducing the cost of floating offshore wind farms.

Appendices

Recommended Reading

Down to the Wire: An Insurance Buyer's Guide to Subsea Cabling Incidents, GCube Underwriting, 2016
Insuring Offshore Cables: An Insurer's Perspective, Codan, June 2017
The Influence of Strain on Water Treeing in XLPE Power Cables, Nordas, S et al, 2010.
Understanding Water Treeing Mechanisms in the Development of Diagnostic Test Methods, IEEE Transaction on Dielectrics and Electrical Insulation, 1998.
Assessing Mechnical Loading Regimes and Fatigue Life of Marine Power Cables in Marine Energy Applications, Proceedings of the Institution of Mechanical Engineers Part O Journal of Risk and Reliability, 2011.

Author Profile

David is a research engineer at the Industrial Doctorate Centre of Offshore Renewable Energy, IDCORE. He is completing his doctorate thesis on predicting dynamic subsea cable failures in conjunction with the Offshore Renewable Energy Catapult. He holds a Master of Engineering degree in Chemical Engineering and has previous experience working in environmental engineering and the oil and gas sector.

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