INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

Topical Expert Meeting #95 on

Improving the reliability and availability of electrical infrastructure components

IEA Wind Task 11

April 8-9, 2019

ORE Catapult, Charles Parsons Technology Centre, Blyth, England

Host and Technical lead:
Paul McKeever, ORE Catapult
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Executive Summary of TEM#95

Introduction

A reliable electrical infrastructure is essential to ensure availability of assets offshore. The offshore environment is a challenging place to minimize maintenance costs and deliver reliable operation. Some of the costliest component interruptions to system availability, and therefore a significant scope for improvement, are the export and array cables.

Approximately 80% of insurance claims in the offshore wind industry are linked to cable failures[1]. This amounts to an annual cost of hundreds of millions of euros to the industry. Despite cables only contributing up to 10% of the total initial investment, cable failures account for the largest proportion of an offshore windfarm's downtime. A typical export cable repair takes approximately 3 to 5 months for an unexpected fault, with the average repair cost estimated to be £12.5 million[2]. Consequently, cable incidents are one of the main risks affecting the continued reduction of the Levelised Cost of Energy (LCOE) for offshore wind.

With a large proportion of offshore renewable energy insurance claims relating to electrical infrastructure incidents, it is crucial to make progress in improving the reliability of these components. Developing a sound understanding of these critical cable assets and their associated failures will help to reduce system downtime and lack of availability, as well as the overall maintenance costs and LCOE.

The objective of International Energy Agency (IEA) topical expert meeting (TEM) number 95 was to identify means to improve the reliability and availability of offshore cables. Presentations addressed test methodologies, cable health assessment, cable monitoring and modelling. Group discussions focused on the need for new cable designs, driven by post mortem analysis, demonstration sites for new cable designs, the need for continuous monitoring of cables measured against the cost to do so and expectations or predictions for the offshore cable industry in the near- and medium-term future.

Meeting Overview

ORE Catapult (OREC) hosted TEM#95 on April 8th and 9th at the Charles Parsons Technology Center in Blyth, Northumberland. Paul McKeever and Chong Ng, both from OREC, were the main hosts of the TEM.

22 experts from 7 different countries came to discuss the availability and reliability of electrical infrastructure components. 16 presentations were provided by participants.

The presentations given on the first day addressed two topics: test methodologies and health assessment, monitoring & modelling. Lively discussions took place on the necessity to add electrical and thermal testing to the standard mechanical testing of cables, on what the wind industry can learn from Oil and Gas on this topic and on how important it is to monitor cable burial depth in order to decrease developer's risks.

Day 2 started off where with a second series of presentations on health assessment, monitoring and modelling. Then a new topic was addressed by several additional presentations: new materials, designs and wider infrastructure component considerations.

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[1] https://www.dnvgl.com/news/offshore-wind-industry-joins-forces-to-reduce-costs-of-cable-failures-117811

[2] Offshore Wind Programme Board, Export cable reliability description of concerns, May 2017

Following all the inputs received through the presentations given over the two days, the participants broke out into two groups to discuss where the industry want to be in 5-10 years & identify the challenges. In plenum, discussions were led in order to seek consensus on which areas should be the focus of an international collaboration initiative. The results were in short: developing a common data base on cable failures (with inputs from the developers and insurance companies), validation of new test methodologies better aligned with offshore conditions (dynamic cables), development of a risk model framework (guidelines for risk/cost analysis), life extension/residual life assessment methodology through the development of health monitoring guidelines or standards and forensic analysis methodology (ex. post-mortem cable analysis). All represented organizations have expressed a wish and interest to work together on those topics and ORE Catapult will consider the process of coming up with a Research Task proposal for a future ExCo meeting.

Main Results

The IEA Wind TEM#95 covered the current state of the art of the subsea cabling industry for offshore wind and identified near term challenges the sector will face moving forward. Following presentations, during discussions, and throughout the breakout sessions several topics emerged as reoccurring themes. There is a lack of collaboration regarding data sharing of cable failures, furthermore the data which is currently shared is of insufficient detail. New testing methodologies and development of standards is required as the industry grows to include new dynamic cable systems. New testing and cable design standards are required and should have input from cable postmortem analyses. Cable health monitoring during lifetime operation, and leading from this cable life extension, are areas that were identified requiring new technologies and innovations. Finally, potential learning opportunities regarding the dynamic cables from the oil and gas industry as offshore wind moves to floating offshore wind turbines was identified.

Developing new test facilities was not a key point of discussion, rather improvements to existing facilities, the testing standards and development of representative testing of what occurs in field, i.e. simultaneous mechanical, electrical, and thermal testing of cables.

Key outcomes identified during the meeting are summarized as:

- The need for a working group to facilitate sharing of cable failure data. This should include input from offshore wind farm developers and insurance providers since these are currently seen as ‘barriers’ to cable failure data sharing.
- Development of a risk model framework to provide guidelines on cable failure risk and cost analysis.
- Development of new cable health monitoring guidelines and standards.
- Development of cable postmortem guidelines and standards.
- Validation of new testing methodologies and new testing standards is required that are aligned with the trajectory of the offshore cable industry, i.e. dynamic cabling.
- A need for simultaneous electrical, mechanical, and thermal testing of cables. The ability to submerge cables during testing was also identified as desirable.

Summary of Presentations

The information in this section provides an overview and selected highlights of each of the presentations given during the meeting.

Presentations from TEM#95 are available on the IEA Wind website, on the dedicated TEM#95 community page. Access for download can be requested from the Task 11 Operating Agent.

Nadine Mournir of Planair SA (Task 11 operating agent) provided an overview of the IEA and IEA Wind Task 11. Background information on the IEA and successful TEM's and tasks was presented. The history of IEA Wind tasks was presented as well as a discussion on recent TEM's and plans for moving TEM topics to full IEA wind tasks. Discussion on expanding networks of experts and researchers by communicating findings between IEA and TCP (Technology Calibration Practice) was discussed in depth. Active participation of 20 communities with over 1300 users was highlighted.

Paul McKeever of ORE Catapult provided an introductory overview of the UK Catapult network and the global market potential of offshore renewables. The mission and vision of ORE Catapult was discussed as well as ORE Catapults impact on the offshore renewable sector to date. The three directorates of ORE Catapult were described. An overview of the two-day TEM95 agenda was given.

Alex Neumann of ORE Catapult provided an overview of the UK Catapult network and the potential of offshore renewables. The capabilities of ORE Catapult's high voltage lab was presented including specialist testing services that can be provided. This included representative testing to accelerate new technologies to market including pre-qualification testing, wet cable pre-qualification, wet cable accelerated ageing, fatigue testing for dynamic cables and wet high voltage cable dock testing.

James Pilgrim from the University of Southampton presented on the mechanical properties & multi-factor fatigue of cables. An overview of factors to consider was given when discussing cable bending stiffness, axial stiffness and torsion stiffness. The complexity of multi-factor fatigue was described and highlighted the testing sequence of individual mechanical, electrical, and thermal testing of cables is not the same as a simultaneous mechanical, electrical, and thermal testing of a cable. Future challenges to cable testing were also highlighted.

Peter Halswell from the University of Exeter presented on dynamic power cable modelling and mechanical reliability test approaches. An overview to the Dynamic Marine Component (DMaC) testing facility at the University of Exeter was given, as well as dynamic power cable modelling. Recent work at the University of Exeter on power cable degradation, bend restrictor testing and power cable properties was described.

Justin Dix from the University of Southampton presented on sediment (soil) controls on lifetime HV cable performance. Substrate control and its impact on HV cable thermal performance was described, in addition to an overview of the relevant IEC 60287 Standard. Work on the thermal modelling of a power cable was presented as well as the interactions of burial depth and permeability controls on distributed temperature sensing systems (DTS) temperature. A case study of a 3D Chirp System Offshore Field Survey was discussed including its performance at tracking cables at differing cable burial depths in clay bedrock.

Brian Stewart from the University of Strathclyde presented a health assessment framework for power cables. A methodology for a novel cable health index diagnostics tool was discussed, derived from data driven models and physics of failure-based models. The health index tool incorporated a life estimation model based on temperature, insulation resistance and a partial discharge health index. Recent work and examples of this health index in practice were given.

Roel Vanthillo of Marlinks presented a continuous cable burial depth measurement technology. This technology operates by means of a thermal model of the cable, including a thermal model of the burial seabed, to deduce the cables burial depth. Recent validation results of the technology were presented and the cost benefit of employing such a technology were discussed.

Hugh Martindale of AgileTek delivered a presentation on cable bend stiffness modelling. Recent modelling work on cable armour wire bending moment contributions to cable stiffness was described. The importance that a cable's bending stiffness is not a constant value was emphasized and discussed. The impact of temperature on cable bending stiffness was also discussed as higher temperatures may soften bitumen layers of the cable, reducing bending stiffness.

Tony Chen from the University of Manchester gave an overview of the high voltage cable research at the University. Electrical trees as a degradation mechanism of polymeric cable insulations were described. Developments in 3D imaging the electrical trees was presented with the laboratory techniques described. The techniques described included nano XCT-imaging, tracking and interfaces and 3D images generated from partial discharge monitoring. A case study on cable sealing ends and asset management and condition monitoring techniques was described.

Jeremy Featherstone of JDR Cables presented on a supplier's perspective on array cable reliability. This presentation is not currently available to the IEA Wind website.

Paul Jarman from the University of Manchester gave a presentation on transformer reliability, failure mechanisms and asset management. An overview to the team and facilities at Manchester was given. The failure rate of substation transformers was described in addition to the failure causes and failure location on the transformer. The condition assessment for transformers was described as well as the appropriate assessment testing. An overview of transformer condition monitoring was given in relation to partial discharge detection and location.

Juan-Andrés Pérez-Rúa of DTU Wind Energy gave a presentation on the optimum sizing of offshore wind power plants export cables. The problem of how to correctly size an export cable was discussed including the relevant standards, IEC-60287 and CIGRÉ B1.40. A solution to dynamic cable rating was proposed that considers the cable ultimate strength, electro-thermal stress, lifetime estimation and stability limits. A methodology on how to determine lifetime estimation for an offshore wind farms high voltage AC export cable was described. A case study of this methodology applied to an offshore wind farm in the Baltic sea was presented. This proposed methodology can reduce export cable costs and a 5% reduction on LCOE can be achieved.

David Young of ORE Catapult gave a presentation on research into dynamic cables fatigue and solutions. The failure rates and causes of offshore cables was described, with a focus on the insulation degradation processes. Water treeing within the cable insulation was discussed as a concern for offshore cables. Recent modelling working showing the combined mechanical and electrical modelling of a dynamic cable was presented and the corresponding impact on dynamic cable fatigue.

Wah Siew from the University of Strathclyde gave a presentation on new cable insulation materials and other HV cable components. This presentation is currently not available on the IEA Wind website.

Breakout Session Notes

A breakout session was held on where the industry wants to be in 5-10 years and identify the challenges. The group was divided into two groups to foster participation. The outcomes of the two groups were discussed with the full group of meeting participants. The groups were asked to focus on the following three main topics:

- Test methodologies / understanding failure modes
- Health assessment, monitoring and modelling
- New materials, designs and wider electrical infrastructure considerations

The following sections provide a consolidated summary of the thoughts and notes from each of the breakout sessions. Raw notes from each of the breakout sessions is provided in Appendix Four.

Test methodologies / understanding failure modes

- The testing of dynamic cables was raised as a large concern as the industry begins inclusion of floating offshore wind. The question of how these dynamic cables will be tested; individually mechanically then electrically or simultaneously mechanically and electrically, was raised. Furthermore, the question of new designs for dynamic cables over traditional designs was raised, including the need for new materials appropriate for dynamic operation.
- The opportunity to learn from the oil and gas industry in relation to its dynamic cables and umbilical cables was realized. The use of OrcaFlex software, traditionally developed for the oil and gas industry, was identified as a tool moving forward. It was however discussed that the cable industry for offshore renewables sector will need to evolve past oil and gas to accommodate appropriate cost reductions.
- Floating platforms were discussed and the need for a gap analysis exercise between floating wind platforms and oil and gas platforms was suggested.
- The interaction of mooring line decisions on a dynamic cable's performance was discussed. A better understanding of this interaction and the associated cable failure mechanisms was identified.
- The link between mechanical, electrical, and thermal stresses acting on a cable was identified as a gap in current understanding. The failure modes that occur because of these combined factors was highlighted to be of concern moving forward. A better understanding of a cables thermal rating was discussed as desirable. It was suggested here that the offshore cable industry could learn from the aerospace industry.
- In general, it was accepted that electrical testing of cables is more developed than the mechanical testing of cables. Further development of testing standards to reflect this was discussed.
- Failures related to fibre optic issues within the cable was discussed. These failures have led to redesigns of some cables and the lack of a suitable test for these cables was identified.
- There was a discussion and concern regarding installation errors and how these "probably" account for cable failures both in the immediate and long term.
- The need to develop mechanical testing methodologies of the cable and the cable connector was identified as a future priority.

- Failures were discussed and it was suggested that they mostly occur at the cable connectors. An estimate of 90% of cable failures are thought to occur here however there was no definitive agreed number for this percentage are a lot of unknowns around the failure mechanisms still exist.
- A different test methodology for cable terminations was described as desirable for future testing.
- Inrush current modelling was identified as having a gap between the expected and actual results. Earthing was discussed as a possible factor here, and it was suggested that earthing at both ends could help with this modelling.
- It was discussed that cable testing should be used as an opportunity to validate cable lifetime modelling, and that cable testing should evolve past a simple pass/fail criterion.

<u>Health assessment, monitoring and modelling</u>

- The continuous monitoring of a cable's health performance during its operation was described as the ideal, however the practicalities to achieve this when balanced with the cost to do so are unknown.
- It was questioned what parameters should be monitored during a cable's installation and operation. Distributed thermal sensing (DTS) was suggested however the wider question of other measurable parameters remained.
- The question of how to monitor mechanical and electrical interactions during a cable's operation. It was suggested monitor both as the monitoring that is done today is insufficient.
- The lack of current data for what is being monitored today is apparent, and the data that is made available is not always of the desired quality.
- It was suggested to develop an OWA type forum (potential dedicated IEA task?) to encourage data sharing, but the question of if developers would be willing to share their data was identified as a potential roadblock.
- The implementation of a cable SPARTA system was suggested or a JIP database of cable failures. It was identified that this might appear overly similar to a CIGRE working group so it was discussed that it would be necessary to ensure no overlap between what was proposed here and the existing working groups. Any future working groups would benefit from including developers and insurers.
- Insurance and political pressures were discussed as potential roadblocks to collaboration and sharing of cable failure data.
- A risk model framework was discussed and the need for the development of a guideline to create a risk and cost model.
- Modelling of cable life extension that incorporates a cables health assessment was discussed. This would provide opportunities for development of residual life assessment methodologies and overall health monitoring guidelines.
- It was identified that there is a need for a residual life methodology.
- It was identified that there is a need for cable forensic analysis methodologies.

New materials, design and wider electrical infrastructure considerations

- Future designs of cables, static or dynamic, should be driven by learnings from cable post-mortems analyses. Furthermore, the question of new designs for dynamic cables over traditional designs was raised, including the need for new materials appropriate for dynamic operation.
- There is a need for in situ testing of cables.
- Demonstration sites for new cable designs, monitoring technologies or otherwise were identified as a benefit to reduce future risk of failure.
- Cable connectors and their failures are still not understood. It was discussed they may require new designs as well as the potential for a universal cable connector.

Conclusions & Next Steps

ORE Catapult (OREC) hosted TEM#95 on April 8th and 9th, 2019, at the Charles Parsons Technology Center in Blyth, Northumberland. 22 experts from 7 different countries came to discuss the availability and reliability of electrical infrastructure components. 16 presentations were provided by participants.

Breakout sessions were held on where the industry wants to be in 5-10 years and identified the challenges. Discussions were led to seek consensus on which areas should be the focus of an international collaborative initiative. The sessions focused on the following three main topics:

- Test methodologies / understanding failure modes
- Health assessment, monitoring and modelling
- New materials, designs and wider electrical infrastructure considerations

Participants expressed interest in collaborating to develop a common cable failure database that includes input from offshore wind farm developers and insurance providers, since these are currently seen as 'barriers' to cable failure data sharing.

There was interest in developing a risk model framework to provide guidelines on cable failure risk and cost analysis. Further to this, developing cable health monitoring guidelines and standards as well as cable postmortem standards were seen as significant and necessary steps to provide cable life extension methodologies and forensic analysis methodologies. Both of which were identified as lacking or absent.

Validation of new testing methodologies and new testing standards are required that are aligned with the trajectory of the offshore cable industry, i.e. dynamic cabling. A consensus was reached that simultaneous electrical, mechanical, and thermal testing should be strived for. It was also agreed the ability to submerge cables during future testing is desirable.

All represented organizations have expressed a wish and interest to work together on those topics and ORE Catapult will consider the process of coming up with a Research Task proposal for a future IEA ExCo meeting (date TBC).

APPENDIX ONE – TEM#95 Introductory Note

Dr Stephen Wyatt – Offshore Renewable Energy Catapult (OREC)
Dr Chong Ng – OREC
Paul McKeever – OREC
David Young - OREC
Alex Neumann – OREC
Prof. Keith Bell – University of Strathclyde (UOS)
Prof. Brian Stewart – UOS
Prof. Ian Cotton – University of Manchester (UOM)

BACKGROUND

A reliable electrical infrastructure is instrumental in maximising the system availability of assets offshore. At the component level, the offshore environment is a challenging place to minimise maintenance costs and deliver reliable operation. Some of the most costly component interruptions to system availability, and therefore a significant scope for improvement, are static and dynamic power cables. To ensure a structured event, the main focus is given to offshore cables. However, other key elements of the electrical infrastructure, such as the transformers, HVDC converters and substations, are hoped to be discussed at future topical expert meetings (TEMs).

Approximately 80% of insurance claims in the offshore wind industry are linked to cable failures[3]. This amounts to an annual cost of hundreds of millions of euros to the industry. Despite cables only contributing up to 10% of the total initial investment, cable failures account for the largest proportion of an offshore windfarm's downtime. A typical export cable repair takes roughly 3 to 5 months for an unexpected fault, with the average repair cost estimated to be £12.5 million[4]. Consequently, cable incidents are one of the main risks affecting the continued reduction of the Levelised Cost of Energy (LCOE) for offshore wind.

The cause of cable incidents during normal operation, and excluding third party interference, can be approximately grouped into mechanical damage, water ingress and overheating which all lead to electrical failure or breakdown of the insulation layers[5]. Mechanical damage incorporates activities during and after installation, when the cable is most exposed to damage. However, damage during manufacture, transport and handling is also possible. Figure 1 illustrates a breakdown of the cause of these cable related incidents (albeit the percentage contributions of the causes of failure are constantly changing as the industry evolves).

[3] https://www.dnvgl.com/news/offshore-wind-industry-joins-forces-to-reduce-costs-of-cable-failures-117811
[4] Offshore Wind Programme Board, Export cable reliability description of concerns, May 2017
[5] Marazzato H, Barber K, Jansen M, Graeme B. Cable Condition Monitoring to Improve Reliability. Olex Australia; 2004.

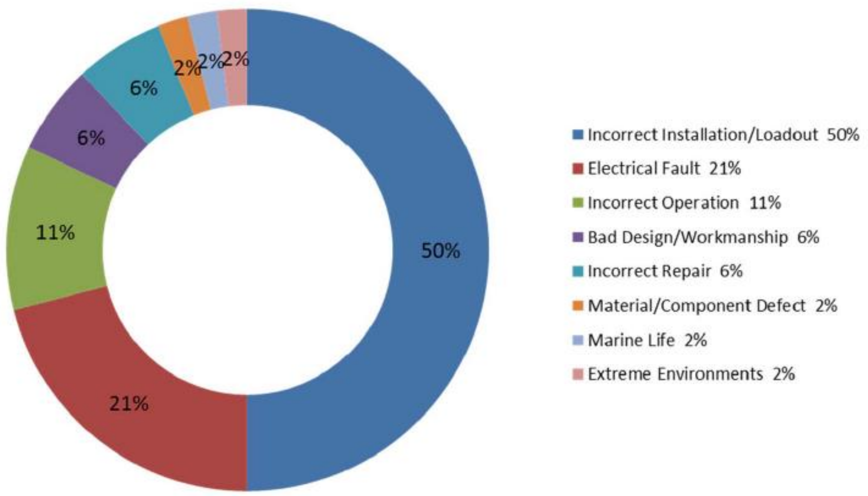

Figure 1 Breakdown of cable related incidents by cause[6]

Offshore wind farms are increasing both in turbine size but also their distance from the shore (and subsequently, their operational water depth). This move is introducing the need for new substructures, including floating platforms. Floating platform wind turbines, or floating wind, are expected to be employed in water depths from 50-200m, with the Carbon Trust estimating up to 90MW of floating wind to be installed by the end of 2018[7]. Floating platforms will introduce new challenges for the dynamic cables that hang from the base of the platform to the seabed. This cable installation arrangement will expose the cables to the dynamic forces of the environment they are installed in, including the actions of the waves, current flows and movement of the platform itself in response to wind/turbine interactions. Cables exposed to dynamic environmental loadings will experience dynamic mechanical stresses over their cross sections and along their length. This is a new operational consideration as traditional fixed bottom platforms have allowed cables to operate statically. With these new operating conditions and increased number of windfarms offshore, the cost of cable related incidents is expected to increase considerably.

It has been reported that 60km of array cables at the London Array windfarm after 5 years' service are to be replaced, with cable "fatigue life" issues cited as the reasoning[8]. Incidents like this are only expected to rise as dynamic cables are introduced, due to their increased complexity. This underpins the need to enhance our knowledge of the failure mechanisms and fatigue life calculation of offshore cables in order to improve designs, and create more representative testing regimes. Great effort must be taken to improve health monitoring, not just in cable deployment but also operation. This will permit preventative maintenance and even identify the fault location, greatly reducing downtimes. Furthermore, development of universal subsea cable connectors can further reduce replacement costs and lead times.

With a large proportion of offshore renewable energy insurance claims relating to electrical infrastructure incidents, it is crucial to make progress in improving the reliability of these components. Developing a sound understanding of these critical cable assets and their associated failures will help to reduce system downtime and lack of availability, as well as the overall maintenance costs and LCOE.

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[6] from GCube (presented at Subsea Power Cables Conference, London 2014)
[7] Carbon Trust. Floating Wind Joint Industry Project: Policy & Regulatory Appraisal [Internet]. 2017 [cited 2018 Mar 14]. Available from: https://www.carbontrust.com/resources/reports/technology/floating-wind-policy/
[8] reNEWS ISSUE 390.

OBJECTIVES

The Offshore Renewable Energy Catapult and the Universities of Strathclyde and Manchester have proposed an IEA Wind Task 11 Topical Expert Meeting (TEM) on improving the reliability and availability of electrical infrastructure components (with a focus on cables). At this meeting, participants will be expected to exchange information and ideas to improve cable component reliability and the availability of the system as a whole. Specific topics to be discussed include:

- Electrical infrastructure health monitoring development
- Electrical infrastructure health monitoring demonstration
- Subsea connectors
- New materials for future High Voltage insulation systems
- Understanding loading and failure in cables
- Understanding cable fatigue
- Representative accelerated testing of cables and electrical infrastructure
- Understanding seabed/cable interactions
- Improved standards, regulation and legislation for electrical infrastructure

TENTATIVE PROGRAM

Northumberland on 8/9 April 2019. The program will include:

- Introduction by host (OREC)
- Introduction of participants
- Presentations from participants covering the topics listed above
- Break-out sessions in the areas of a) health monitoring, b) new materials and components, and c) understanding failure modes and test methodologies.
- Summarising the results of the breakout sessions
- Discussion on the need of improving existing standards, regulations and legislations
- Recommendations for next steps

INTENDED PARTICIPATION

Participation is expected from academia, research institutes, OEM's, wind farm owner operators, cable manufacturers and installers. All attendees will be asked to present their experience in one of the listed topic areas.

EXPECTED OUTCOMES

The outcome of this meeting will be a report summarising:

- Presentations from the participants
- Recommendation and summaries for all three areas discussed: a) health monitoring, b) new materials and components, and c) understanding failure modes and test methodologies
- Recommendations for changes to the existing standards, regulations and legislations
- Research activities required to support the recommendations

APPENDIX TWO - Meeting Agenda

Location: Charles Parsons Technology Center, Blyth, Northumberland, England

Monday, 8 April 2019

Time	**Topic**	**Presenter**
11:30 AM	Day 1 Registration and Lunch at CPTC building, ORE Catapult	All
12:30 PM	Participant Introductions	All
1:00 PM	Welcome and Meeting Overview	Steve Wyatt/Paul McKeever, *ORE Catapult*
1:15 PM	IEA Wind TCP and Task 11	Nadine Mounir, *IEA Wind*
	Theme 1 – Understanding failure modes/test methodologies	
1:30 PM	Electrical infrastructure testing methodologies	Alex Neumann, *ORE Catapult*
1:50 PM	Experience in multi-factor high voltage cable fatigue testing	James Pilgrim, *UoSouthampton*
2:10 PM	Dynamic power cable modelling and mechanical reliability test approaches	Philipp Thies, UoExeter
2.30 PM	Experiments involving cables and sediment interaction	Justin Dix, *UoSouthampton*
2.50 PM	Q&A	All
3:10 PM	Break	
3.25 PM	Site Tour	All
	Theme 2 – Health assessment, monitoring & modelling – Part 1	
5.00 PM	A health assessment framework for power cables	Brian Stewart, *UoStrathclyde*
5:20 PM	Continuous burial depth monitoring using DTS	Roel Vanthillo, *Marlinks*
5:40 PM	Q&A	All
5.50 PM	Day 1 Wrap-Up	Steve Wyatt/Paul McKeever, *ORE Catapult*
6.00 PM	Day 1 Close	
7:30 PM	Dinner (Newcastle upon Tyne)	All

Tuesday, 9 April 2019

Time	Topic	Presenter
8:30 AM	Day 2 Registration and Coffee	All
9:00 AM	Day 2 Overview	Steve Wyatt/Paul McKeever, *ORE Catapult*
	Theme 2 – Health assessment, monitoring & modelling – Part 2	
9.15 AM	Cable bend stiffness modelling	Hugh Martindale, AgileTek Engineering
9.35 AM	Electrical trees and partial discharge monitoring	Tony Chen, *UoManchester*
9.55 AM	Q&A	All
	Theme 3 – New materials, designs and wider infrastructure component considerations	
10.05 AM	Transformer reliability, failure mechanisms and condition assessment from a transmission utility perspective	Paul Jarman, *UoManchester*
10:25 AM	Optimum sizing of offshore wind farm export cables	Juan-Andres Perez-Rua, *DTU*
10.45 AM	Break	
11.00 AM	Dynamic cables (fatigue and solutions)	David Young, *UoEdinburgh/ORE Catapult*
11.20 AM	New insulation material for HV components	Wah Siew, *UoStrathclyde*
11.40 AM	Q&A	All
	Breakout and discussion sessions	
12.00 PM	Breakout session: where do we want/need to be in 5-10 years & identification of challenges	All
12:45 PM	Lunch	
1.45 PM	Breakout session presentations & discussions	All
2.15 PM	Plenum discussion: international collaboration opportunities	All
2.45 PM	Day 2 Wrap-Up	Steve Wyatt/Paul McKeever, *ORE Catapult*
3.00 PM	Event Close	

APPENDIX THREE - Meeting Participants

The meeting was attended by 22 participants from 7 countries. Following is the list of participants and their affiliations.

Name	Country	Company/Organization
Alex Neumann	UK	ORE Catapult
Ana Maria Ringlever	Netherlands	Van Oord
Ajai Ahluwalia	UK/Norway	Equinor
Brian Stewart	UK	University of Strathclyde
Chong Ng	UK	ORE Catapult
Daniele Giustini	Ireland	GDI-Transmission Engineering & Maintenance
David Young	UK	University of Edinburgh/ORE Catapult
Derek Craig	UK	ORE Catapult
Hugh Martindale	UK	AgileTek Engineering
James Pilgrim	UK	University of Southampton
Jeremy Featherstone	UK	JDR Cables
Juan-Andres Perez-Rua	Denmark	DTU
Justin Dix	UK	University of Southampton
Ki-Yeoung Kweon	Korea	KETEP
Nadine Mounir	Switzerland	IEA Wind
Pete Halswell	UK	University of Exeter
Paul Jarman	UK	University of Manchester
Paul McKeever	UK	ORE Catapult
Roel Vanthillo	Belgium	Marlinks
Thomas Wildsmith	UK	ORE Catapult
Tony Chen	UK	University of Manchester
Wah Siew	UK	University of Strathclyde

APPENDIX FOUR – TEM#95 Raw Breakout Session Notes

The raw notes from the breakout sessions are listed here to address the key question; "Where do we want to be in 5-10 years? & identify the challenges". For completeness, pictures of the original flip chart notes are included.

Theme 1

Test methodologies:

- How to test dynamic cables (standard)
    - Separate or together?
- Learn from oil and gas
    - But evolve for cost reductions
- Floating platforms
    - Identify common & differences between floating wind and Oil & Gas
- Mechanical prop. driven by installation
- Better understanding of thermal rating
- Link between mech. coupling thermal & electrical unknown
    - Could we learn from aerospace?
- Fiber optic problem led to re-design
    - Suitable tests still not fully developed (elec. more than mechanical)
- Mechanical testing cable and connector
    - Failure modes (90%?)→ usually connection & joints
- Different tests around terminations
    - In rush current → modelling?
        - gap between expected & actual (earthing?)
        - earth at both ends?

Theme 2

Health assessment, monitoring and modelling:

- Lack of data & quality data
- OWA Forum → developer data (will they share?)
- Cable SPARTA
- Insurance / political pressures (prevents collaboration)
- CIGRE working group
- Owner data collection & management of it
- How do mechanical/electrical interact (monitor both): the monitoring currently done is not sufficient
- Continuous monitoring vs. cost (DTS) → what to monitor?

Theme 3

New materials and design

- Designs driven by post-mortems
- In-situ testing
- Demo-sites
- Connectors – why are they failing?

Summary

1. Database (SPARTA / JIP)
   - From high level to detailed
   - Check for overlaps with CIGRE
   - Include developers, insurances
2. Test/validation methodology
   - Analyse current cable failure
   - Validation not just test (fail/pass)
   - New (dynamic) cable validation
3. Risk model framework
   a. Guidelines for creating risk (and cost) model
4. Life extension / residual life assessment methodology
   a. Health monitoring guideline
   b. Standard residual life assessment methodology
5. Forensic analysis methodology

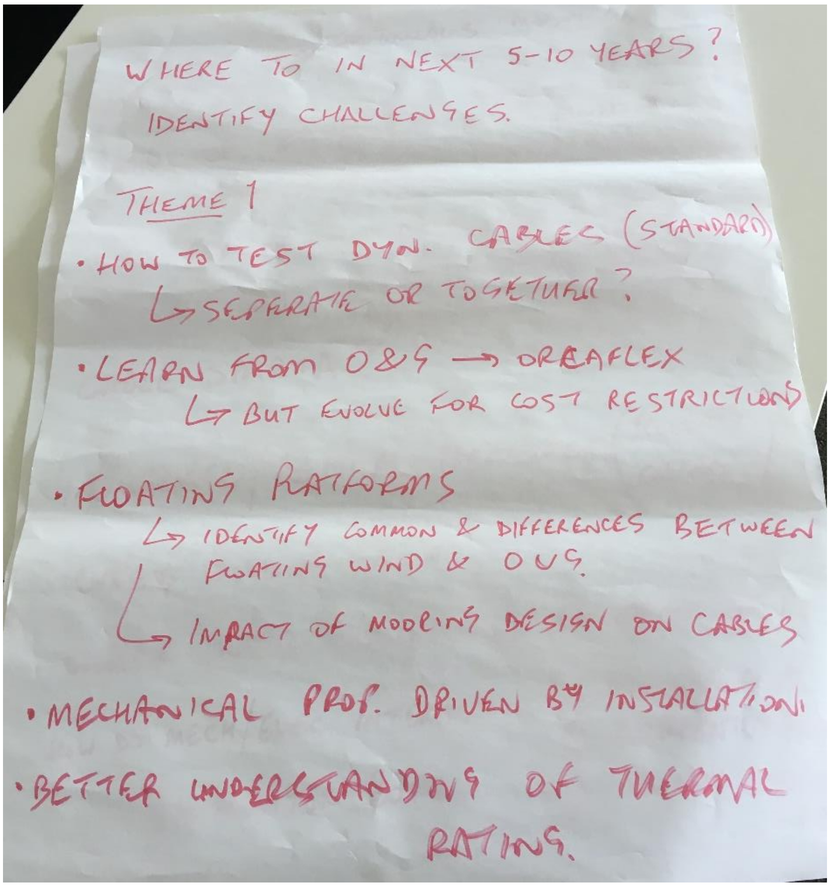

Figure 2 – Breakout Session - Theme 1 Notes

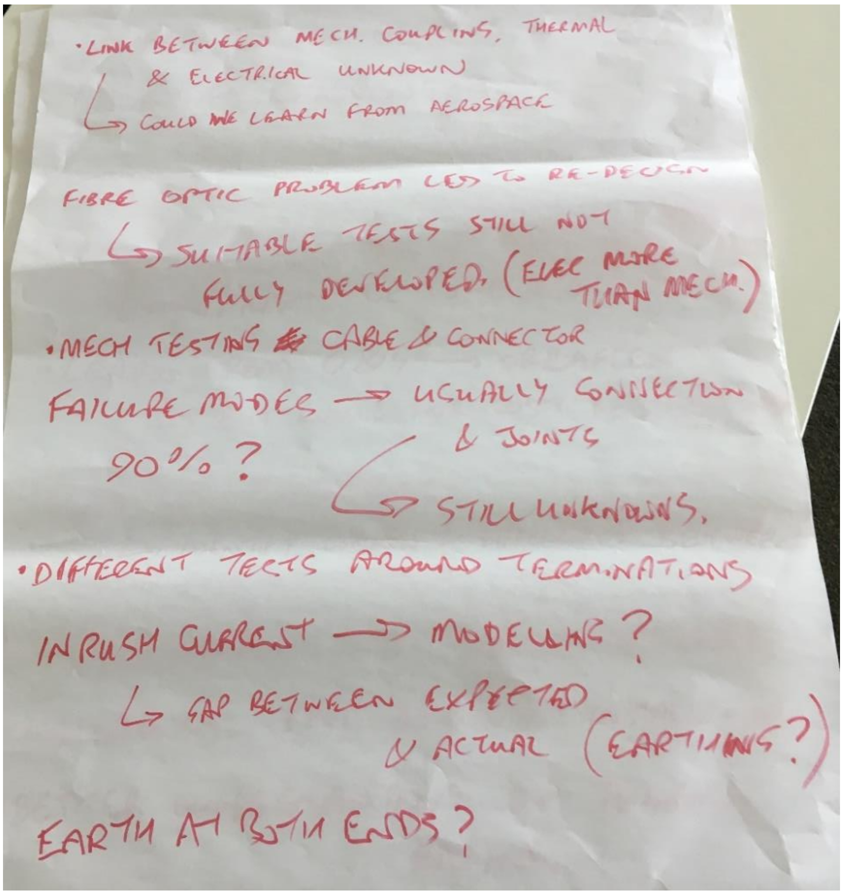

Figure 3 – Breakout Session - Theme 1 Notes continued

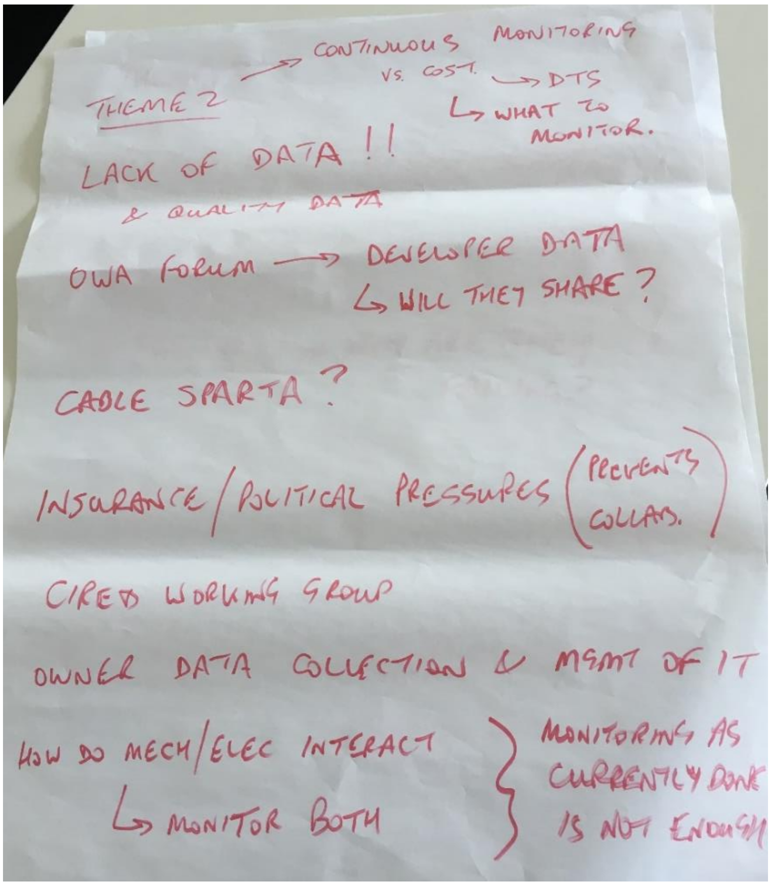

Figure 4 – Breakout Session - Theme 2 Notes

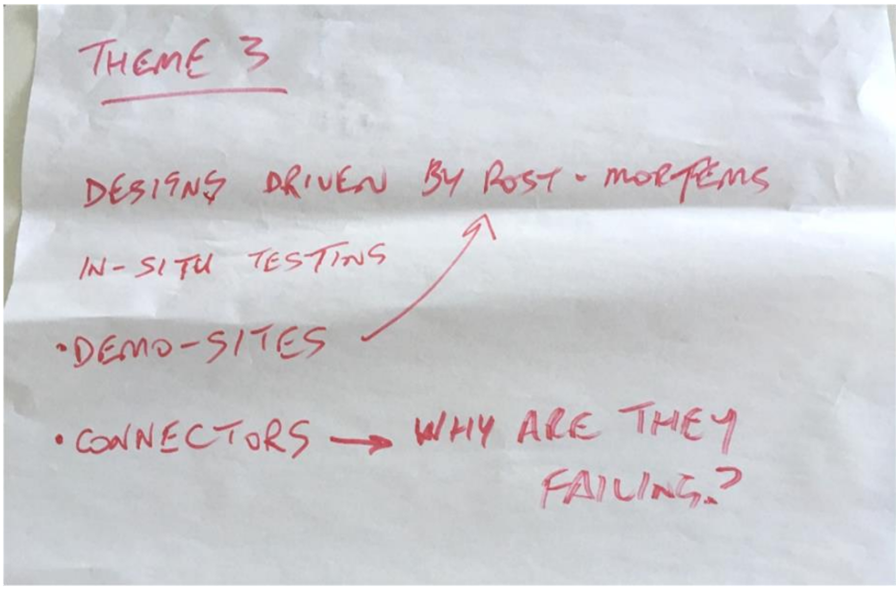

Figure 5 – Breakout Session - Theme 3 Notes

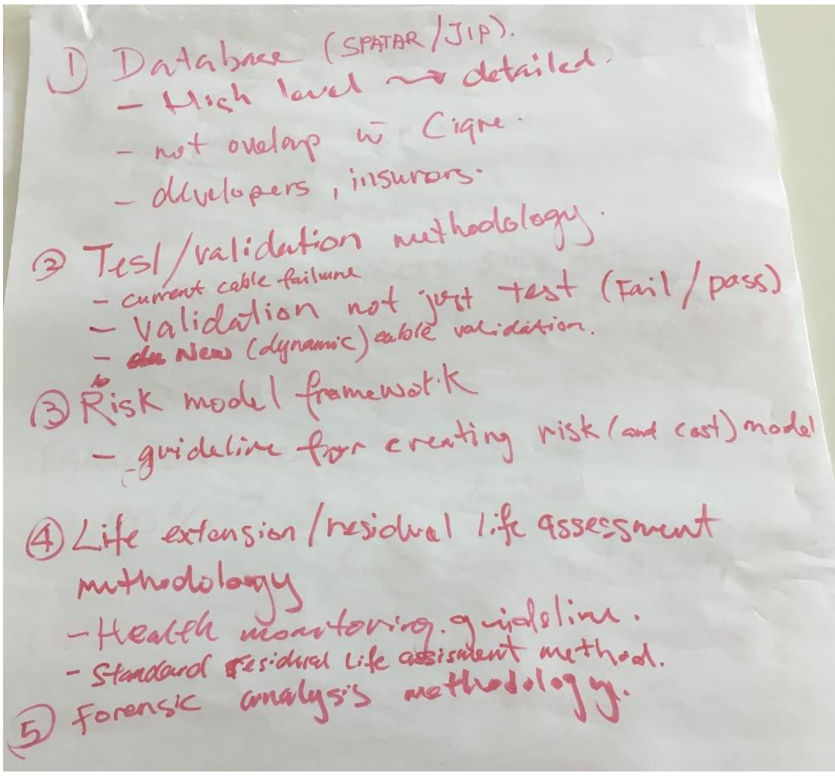

Figure 6 – Breakout Session - Summary

APPENDIX FIVE - IEA Agreement

International Energy Agency Agreement

Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, CWEA, Denmark, the European Commission, Finland, France, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom, the United States and WindEurope are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Three Subtasks

The task includes three subtasks.

The objective of the first subtask is to develop recommended practices (RP) in collaboration with the other IEA Tasks.

The objective of the second subtask is to conduct Topical Expert Meetings (TEM) in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, TEMs are arranged four times a year. Additional TEM types that would allow shorter reaction times, broader audience and augmented visibility are currently being researched.

The objective of the third subtask is to provide room for exchanges within the wind energy expert community. This is done through the IEA Wind platform with online communities.

Documentation

Since these activities were initiated in 1978, more than 90 volumes of proceedings have been published. In the series of Recommended Practices, 20 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task. Some documents are publicly available one year after first publication.

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COUNTRY	**INSTITUTION**
Belgium	Government of Belgium
Canada	Natural Resources Canada
Denmark	Danish Energy Authority
Finland	Business Finland
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Ireland	Sustainable Energy Authority of Ireland (SEI)
Italy	Ricerca sul sistema energetico (RSE S.p.A.)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Mexico	Instituto de Investigaciones Electricas (IIE)
Netherlands	Ministry of Economic Affairs
Norway	The Norwegian Water Resources and Energy Directorate (NVE)
Republic of China	Chinese Wind Energy Association (CWEA)
Republic of Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT)
Sweden	Energimyndigheten - Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy (SFOE)
United Kingdom	Offshore Renewable Energy CATAPULT
United States	The U.S Department of Energy (DOE)