Operations and Maintenance of Offshore Transmission Assets

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Transmission Investment

- With investor partners, Transmission Investment develop, procure, construct, own and operate transmission assets
- Particularly active in offshore transmission with operational experience of assets now > 10 years old
- In-depth experience of electricity supply industry
- Seven OFTO projects
- FAB HVDC interconnector

TRANSMISSION INVESTMENT

Gutteridge Haskins & Davey (GHD)

- GHD is one of the world's leading professional services companies operating in the global market sectors of water, energy and resources, environment, property and buildings, and transportation
- Employee owned organisation with over 10,000 employees globally
- UK energy team based in Newcastle and Guildford
- GHD team members have worked on all Transmission Investment assets

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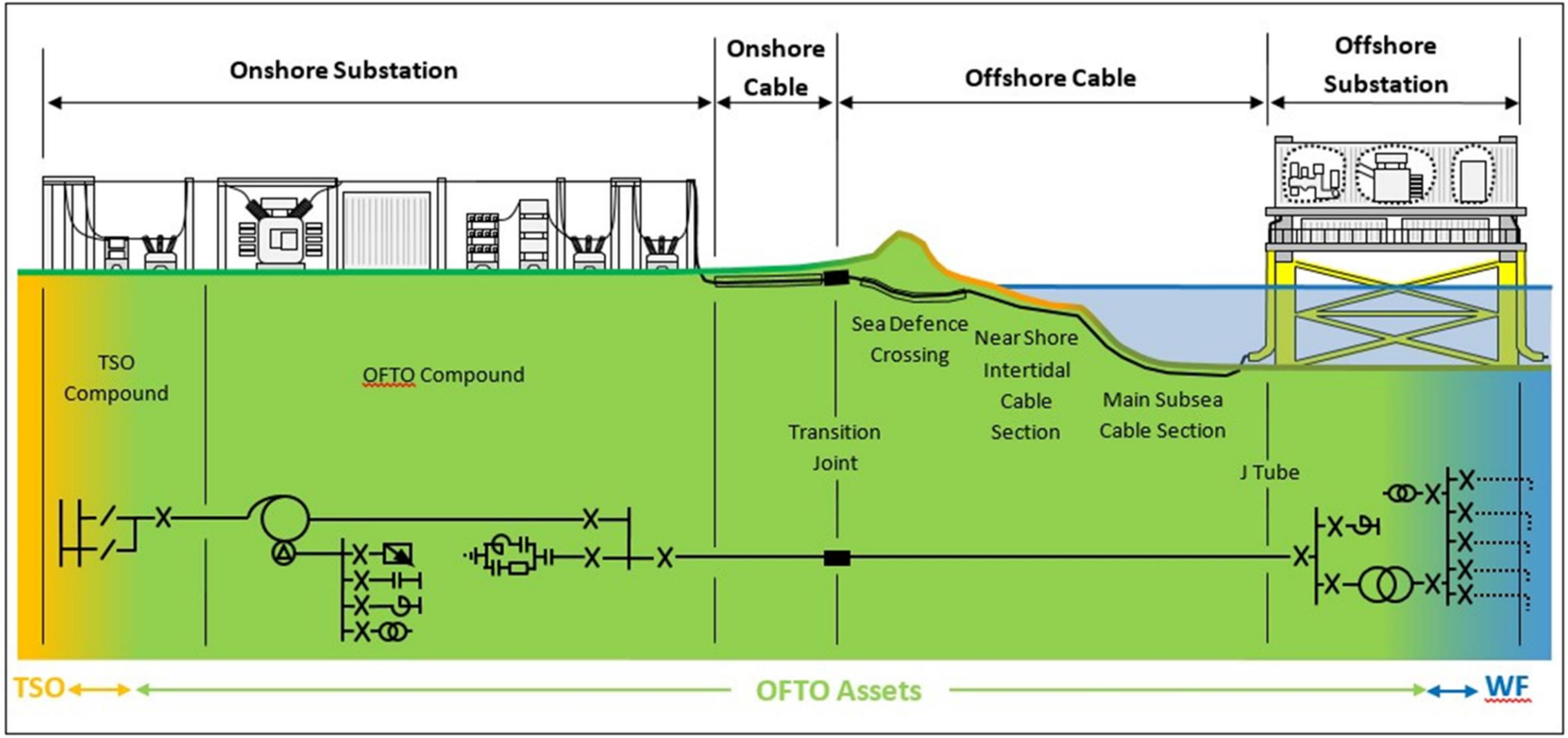
Offshore Transmission

- Presentation based on CIGRE 2018 Session Paper B3-204

- Experience in UK with offshore windfarms since 2000
- Has been rapid growth in offshore wind generation
- 20 Offshore Transmission Owners operational
- Assets built by Developer/Generator and transferred under Ofgem regime
- TI was first OFTO in 2011, assets now > 10 years operational experience
- Assets include:
  - Offshore substations
  - Onshore substations
  - Offshore Cables
  - Onshore cables

Offshore Transmission Assets



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OFTOs and OFTO Regime

- Ofgem competitive process for grant of offshore transmission licence
- Value of assets determined by Ofgem (£30m to approx. £500m to date), condition and suitability of assets determined through Due Diligence by OFTO
- 5 Tender Rounds complete, 6th underway with asset values up to £1400m
- Generator has to comply with Grid Code, OFTO as a Transmission Operator has to comply with System Operator Transmission Owner (STC) code
- OFTO awarded 20/25 year license following competitive process to own, operate, maintain and decommission assets
- OFTO revenue determined by base revenue adjusted based on performance (bank better than target performance to offset worse than target performance)
- Possible licence extension after 20/25 years, depending on generation
- OFTO regime has been deemed a success by Ofgem with cost savings and new players/investors participating in transmission

Transmission Investment OFTOs Portfolio

Dudgeon

Financial Close	Transfer Value
November 2018	£298m

Robin Rigg (W)

Financial Close	Transfer Value
March 2011	£66m

Gunfleet Sands

Financial Close	Transfer Value
July 2011	£50m

Barrow

Financial Close	Transfer Value
Sept 2011	£34m

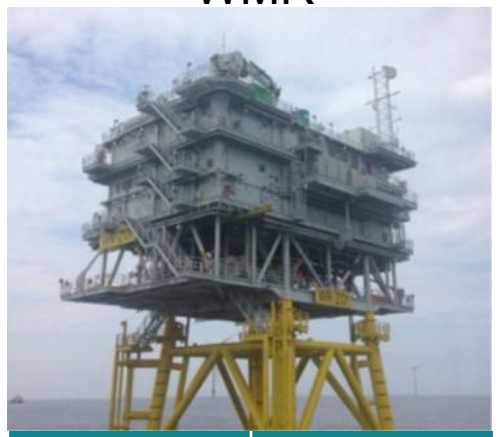
Lincs

Financial Close	Transfer Value
November 2014	£308m

Ormonde

Financial Close	Transfer Value
July 2012	£104m

WMR

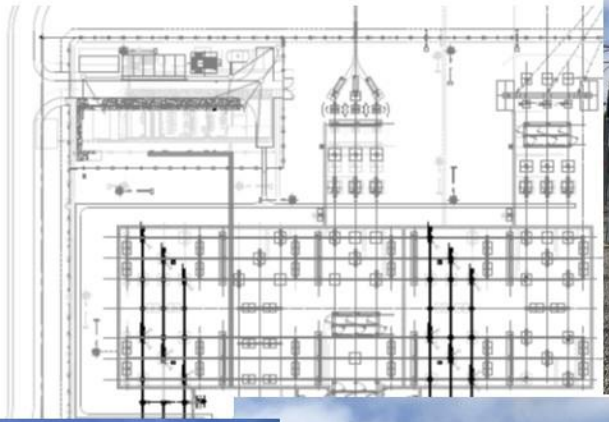


Financial Close	Transfer Value
February 2015	£172m

Transmission Investment OFTOs Portfolio

Summary of assets

- 300 km subsea cable
- 140 km of onshore cable
- 32 transformers (>1.6 GVA)
- 54 bays switchgear ≥ 132 kV
- Six offshore substation platforms



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Comparisons of Onshore v Offshore – high level

Offshore Substations

- Weatherproofing for marine environment
- Protective coatings and treatments
- Maritime systems
- Logistics for personnel and equipment with additional factors for safety of personnel
- Required integrity of secondary systems

Onshore substations

- Basically same but more reactive compensation equipment

Cables

- Offshore cables very different to onshore
- Extensive use of Horizontal Directional Drill techniques

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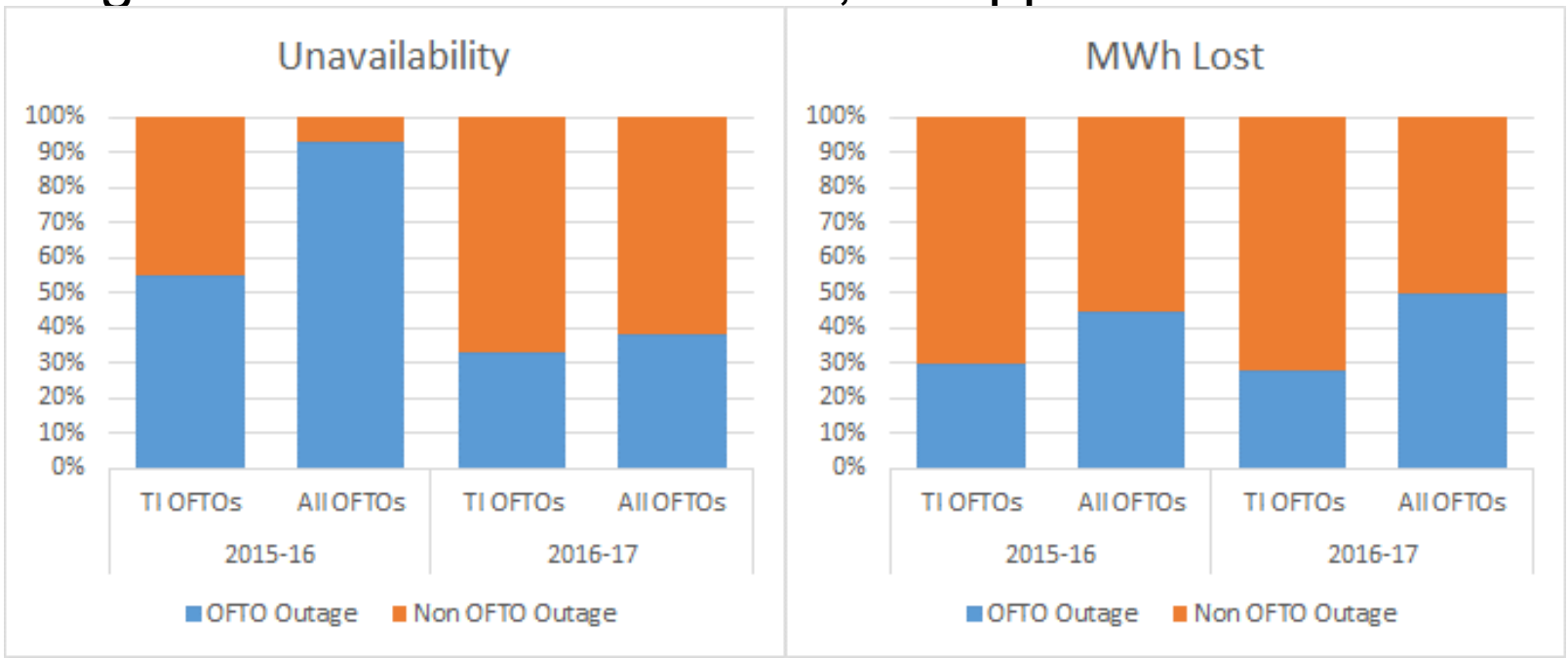
OFTO Performance

- Annual availability figures for OFTOs since 2011 (2017 figures)
  - Best - 100%
  - Worst - 82.47%
  - Average - 99.76%

- Most outages due to Generator/TSO, so opportunities for better coordination



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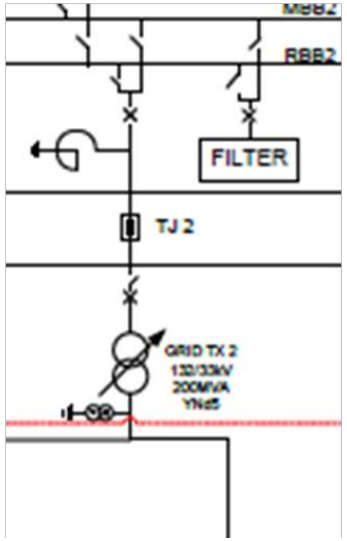
Experience and Lessons Learnt -1

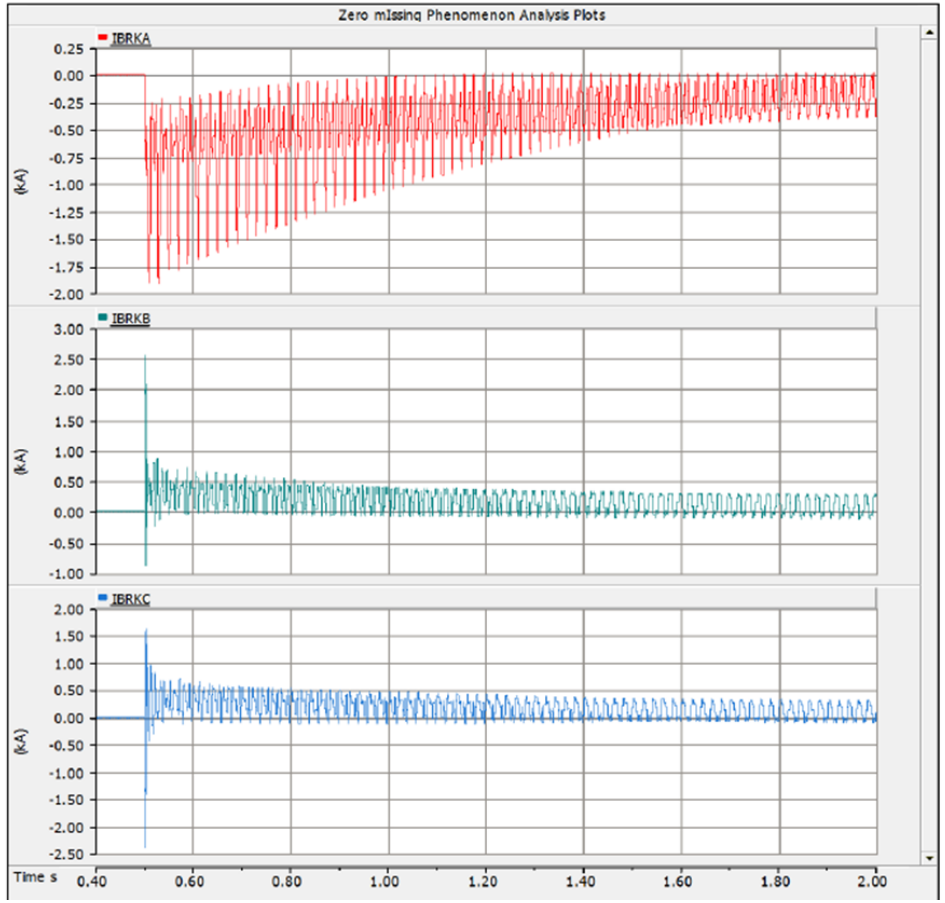
- Variety of OSP arrangements, no consistent design philosophy, Deck /Module and integrated structure have +/- aspects
- No consistent transformer rating philosophy
  - N-1 preferred
  - ONAN preferred
  - Vacuum on load tap changers essential
- Very limited application of synthetic ester transformer fluids
- Transformer designs are generally onshore adapted
- Access to cables for HV testing

Experience and Lessons Learnt -2

- Switchgear has to be capable of switching long cables
  - Potential for zero miss phenomena to occur
  - Controlled switching has caused some unreliability

- **Missing Zero phenomena**
- **Occurs when energising >50% compensated cable.**
- **No current zero for >1 sec.**
- **Point on wave switching is one solution.**

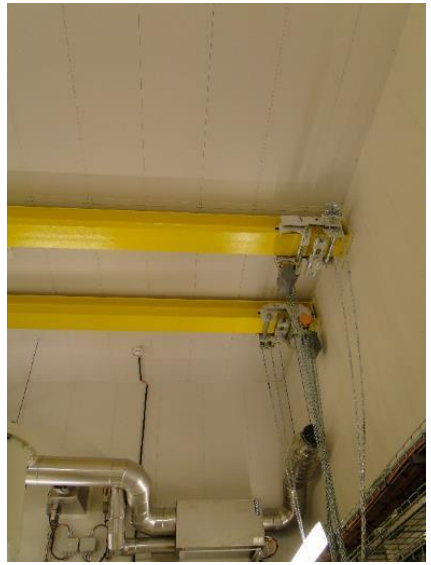




Experience and Lessons Learnt - 3

Switchgear

- Consider how to access export cable for HV testing through GIS switchgear. HV disconnection of VTs.
- Consider lifting for maintenance / repairs
- Trapped charge can be a problem - consider how to dissipate it - wound VTs have limited capacity ~80km cable



Experience and Lessons Learnt - 4

- Generators have been one of the most troublesome pieces of auxiliary equipment
  - Suitably oversized but also for cranes etc.
  - Periodic on load testing via a load bank
  - Minimum 10 days fuel reserve required
  - Transfer of generator fuel from vessels requires more consideration

Experience and Lessons Learnt - 5

- Mix of static and variable compensation equipment often combined with capability of WTGs
- Dynamic compensation by SVC & STATCOM has been applied on most projects, some experience:
  - Some control system designs such that single mal-operation can cause entire loss of output
  - Controllers prone to spurious glitches which are “accepted” by suppliers
  - Inadequate control and protection settings resulting in unnecessary trips or excessive switching of mechanically switched elements
  - Inadequate specifications for some circuit elements e.g. air cored reactors
  - Performance of SVC/STATCOMs needs to improve
  - Long term service agreements necessary for SVC/STATCOM and SCADA system

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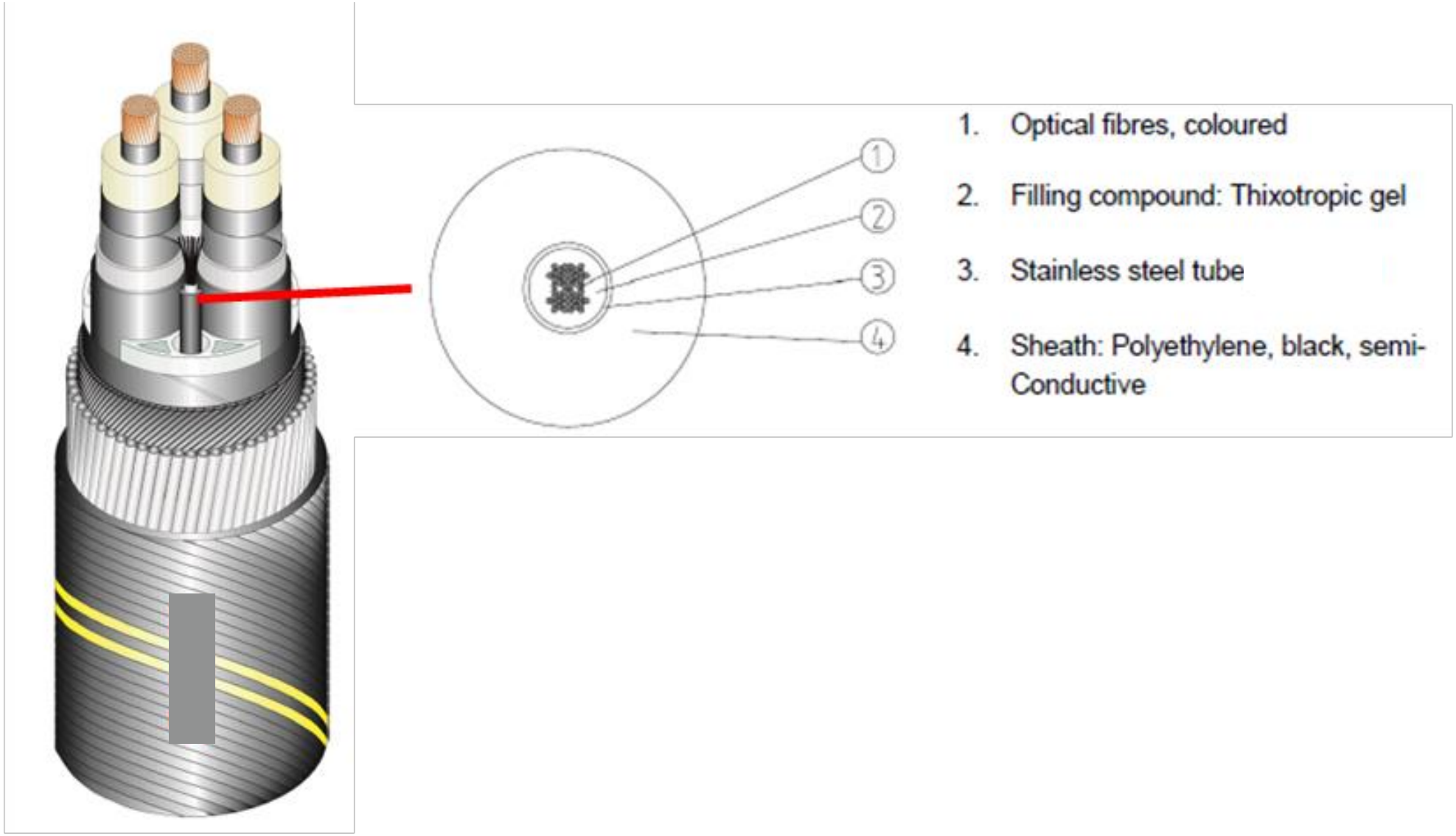
Subsea Cables

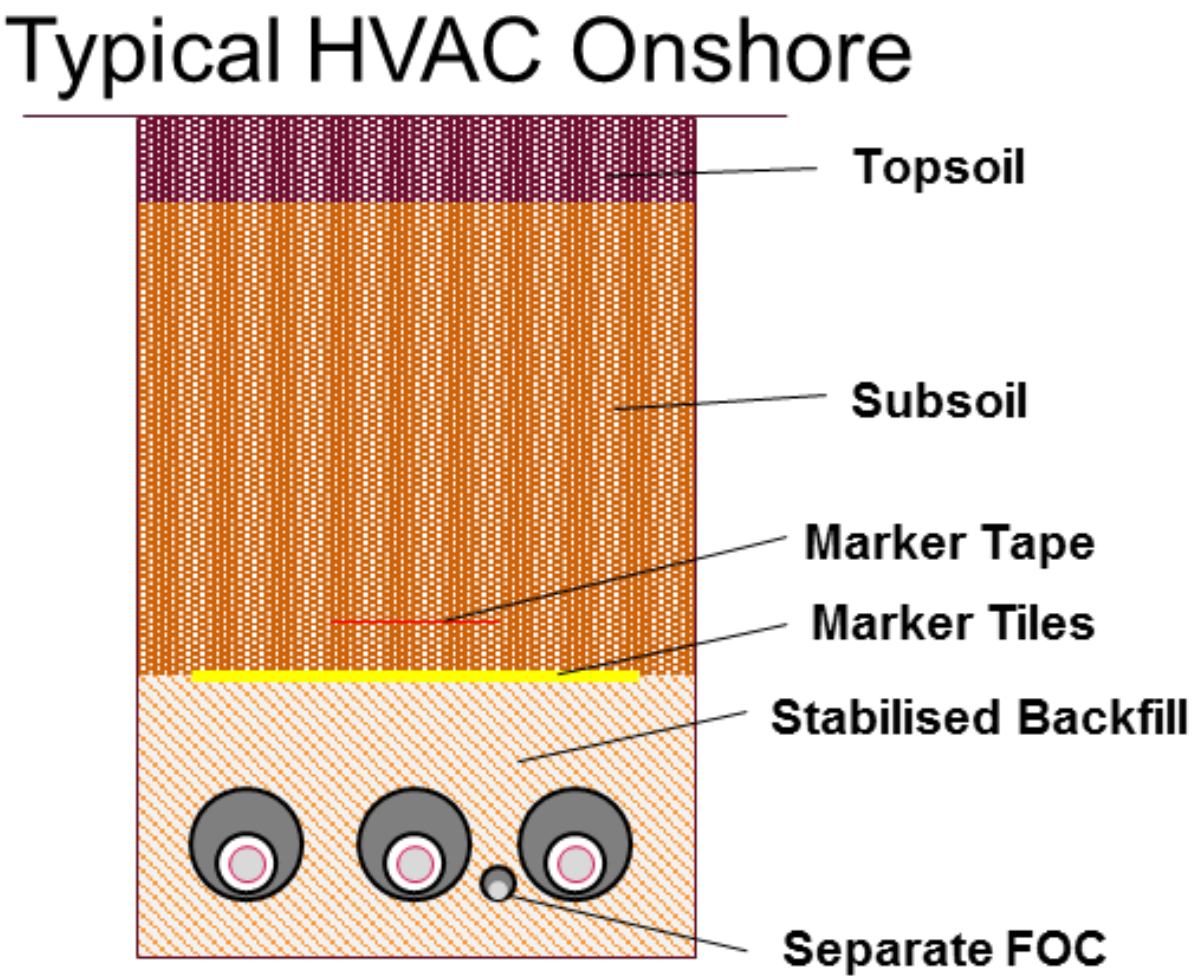
- Are a significant part of the offshore transmission system
- Several issues have been encountered on subsea cables:
  - Cable Burial Risk Assessments (CBRA) were not done in robust manner on early projects
  - Poor performance of cable suppliers and installers
  - Cable unreliability due to impact of integrated Fibre Optic Cables (FOC)
- A number of cable failures have occurred due to issues with particular FOC
- Insurers and lenders industry now very sensitive to subsea cables

Subsea Cables – Typical Design

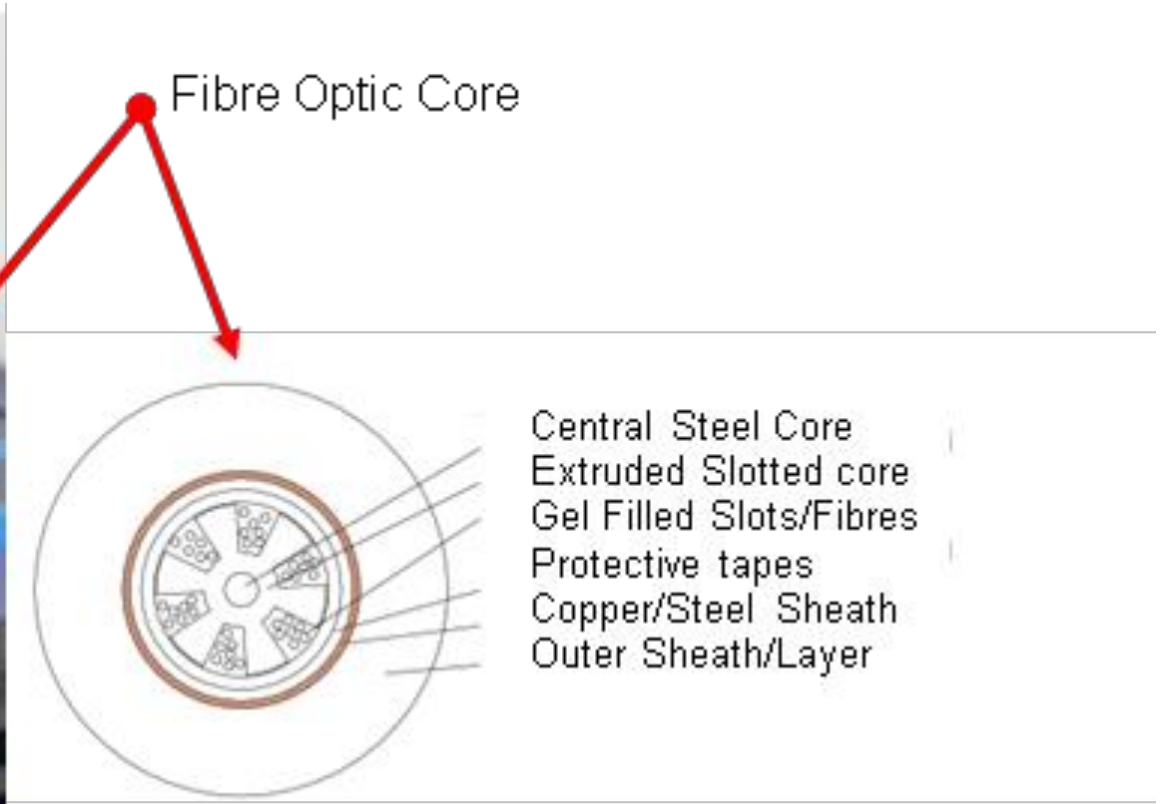


1. Optical fibres, coloured
2. Filling compound: Thixotropic gel
3. Stainless steel tube
4. Sheath: Polyethylene, black, semi-Conductive

Onshore Cables – Typical Design



Subsea Cables – Fibre Optic Core Issue



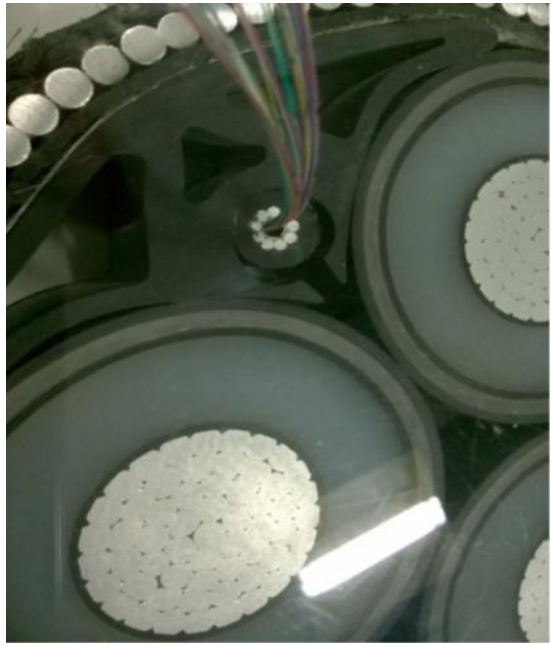
Fibre Optic Cores – Failure Risk Factors

- Failures have been limited to particular suppliers/designs of FOC
- Type of metallic tube for FOC
- Use of Aluminum armouring around FOC
- Low conductivity sheath around FOC tube
- Longer cable route lengths
- Inadequate earthing of metallic FOC tubes
- Highly loaded cable circuits

Issues now better understood and monitored

Fibre Optic Cores – Failure mechanism

- Failures don’t need mechanical damage to cable
- Variations in FOC sheath conductivity can occur
- Induced currents and voltages in FOC metallic sheath can lead to localized heating
- Heating can cause damage to lead sheath as well as power core
- Failure of power core can result from FOC deterioration
- Monitoring of fibres can be used as early warning signal



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Conclusions - 1

- Based on more than ten years operational experience it is concluded that offshore substations and offshore transmission assets can be operated safely and reliably
- The recommendations within TB 483 have been proven
- There are a number of design and operational practices which are recommended:
    - Operational access offshore needs to be fully considered in the design of the OSP
    - Equipment needs to be robust, reliable and resilient
    - Ideally equipment design should have proven offshore performance

Conclusions - 2

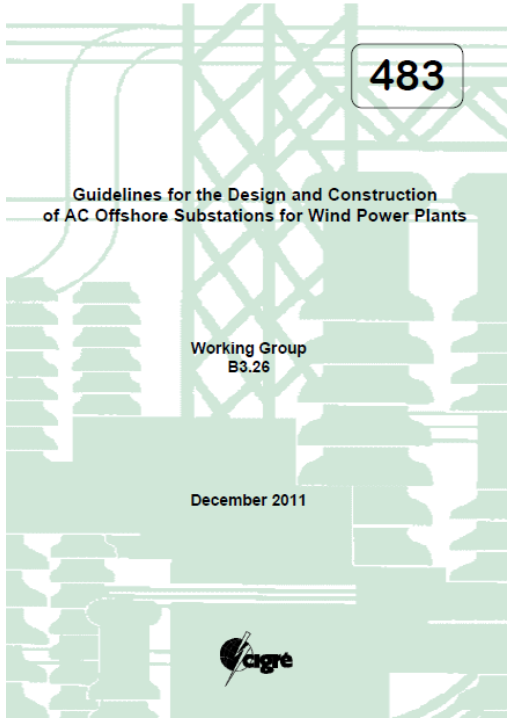
- Further recommendations:
    - More condition monitoring and remote diagnostics
    - Fully consider maintenance; aspects such as access, lifting and weather in design
    - Minimise impact of failure of a single system
    - Combine maintenance activities through planning
    - Spares should be purchased at time of EPC contract
    - Thorough inspections in autumn before winter

Where next?

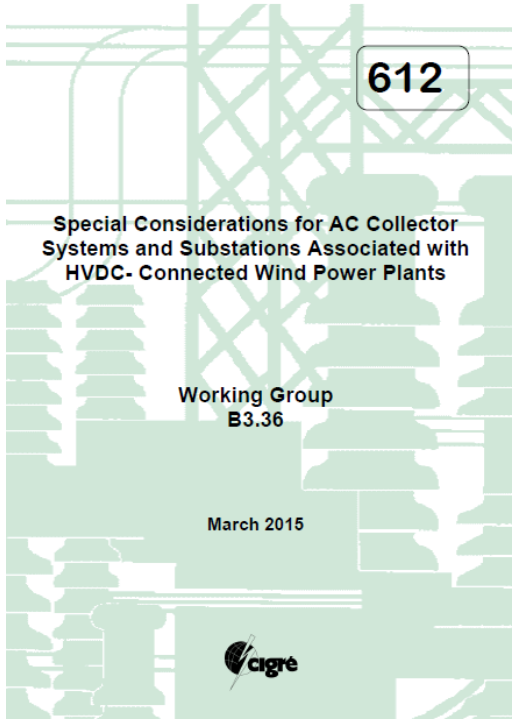
- More offshore wind farms and OFTOs coming
- TR6 currently underway
  - Beatrice (£498.5m Ofgem Initial Transfer Value)
  - Hornsea 1 (£1,396 Ofgem Initial Transfer Value)
  - East Anglia 1 (£813.6m Ofgem Initial Transfer Value)
- Potential for OFTO build rather than Generator build
- First HVDC connected project likely in 2022 (Norfolk Vanguard/Boreas)

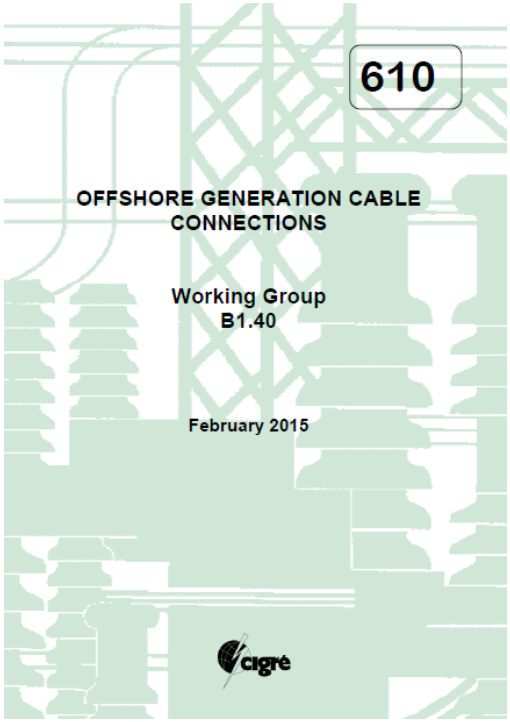
Some further reading

CIGRE TB 483 “Guidelines for the Design and Construction of AC Offshore Substations for Wind Power Plants”



CIGRE TB 612 “Special Considerations for AC Collector Systems and Substations Associated with HVDC Connected Wind Power Plants”





CIGRE TB 610 “Offshore Generation Cable Connections”

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Questions?