Paris Session 2022

For power system expertise

A new era of submarine cables

Presented by WGs from Study committee B1

Tutorial Session CIGRE – August 30th 2022

Table of contents

cigre.scb1.cag@gmail.com

Introduction

The expansive growth in renewable energy requires submarine cables in new areas.

- The distance from shore to windfarms are increasing.
- Traditional loading with 8 hours high load, 16 hours low load are not representative for windfarms.
- Ground cable loss calculations are not relevant and newer approaches are needed.
- Cables are being installed in platforms in deeper waters, thus need dynamic installations.
- Installation techniques have evolved in line with new cable systems.

For power system expertise

Part 1
Background
Design overview

Background

In 2011 Cigré Study Committee B1 established Working Group B1.40 to investigate a Technical Brochure as a guide on “Offshore Generation Cable Connections”

TB as a guide

- Offshore generation cable connections
- Generally about submarine cables

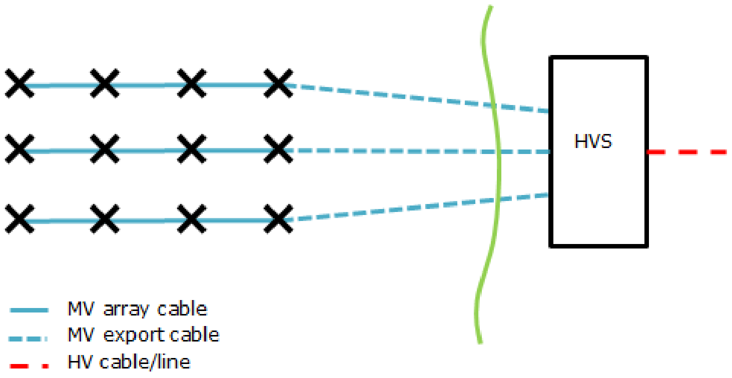
cigre
For power system expertise

Background

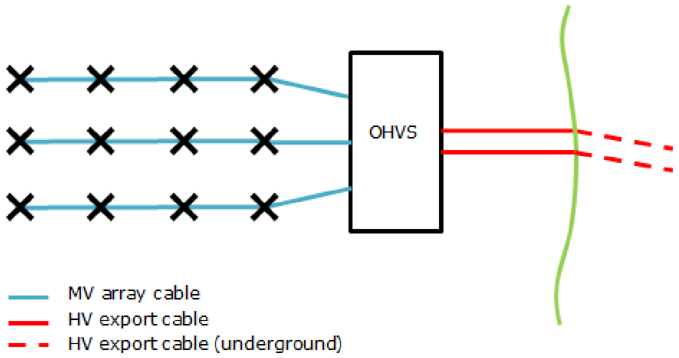
- Many offshore power plants – and more to come
- Offshore work always critical and expensive
- Submarine cables – an important part of an offshore generation project
- Difficult to install and repair
- Must be handled with care
- Reduce risks
- Optimize design, layout, surveys, installation and maintenance
- Well prepared projects

Design overview

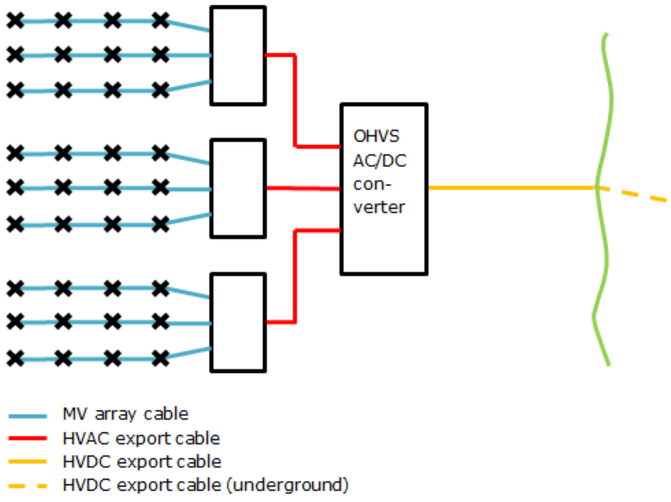
Possible solutions



Medium voltage



HVAC



HVDC

Design overview

MVAC

Array cable

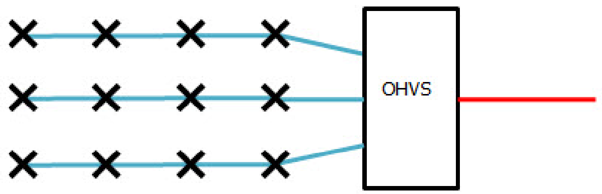
HVAC

Export cable

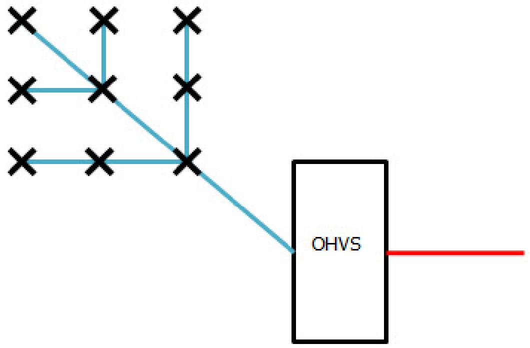
HVDC
Export cable

Design overview

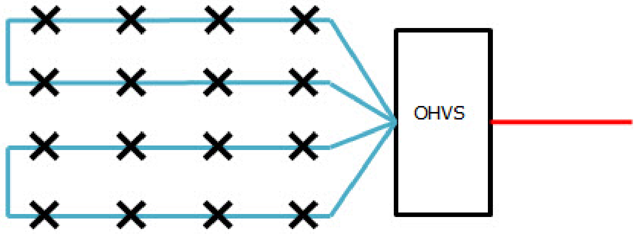
Configuration of array cables



Radial connection



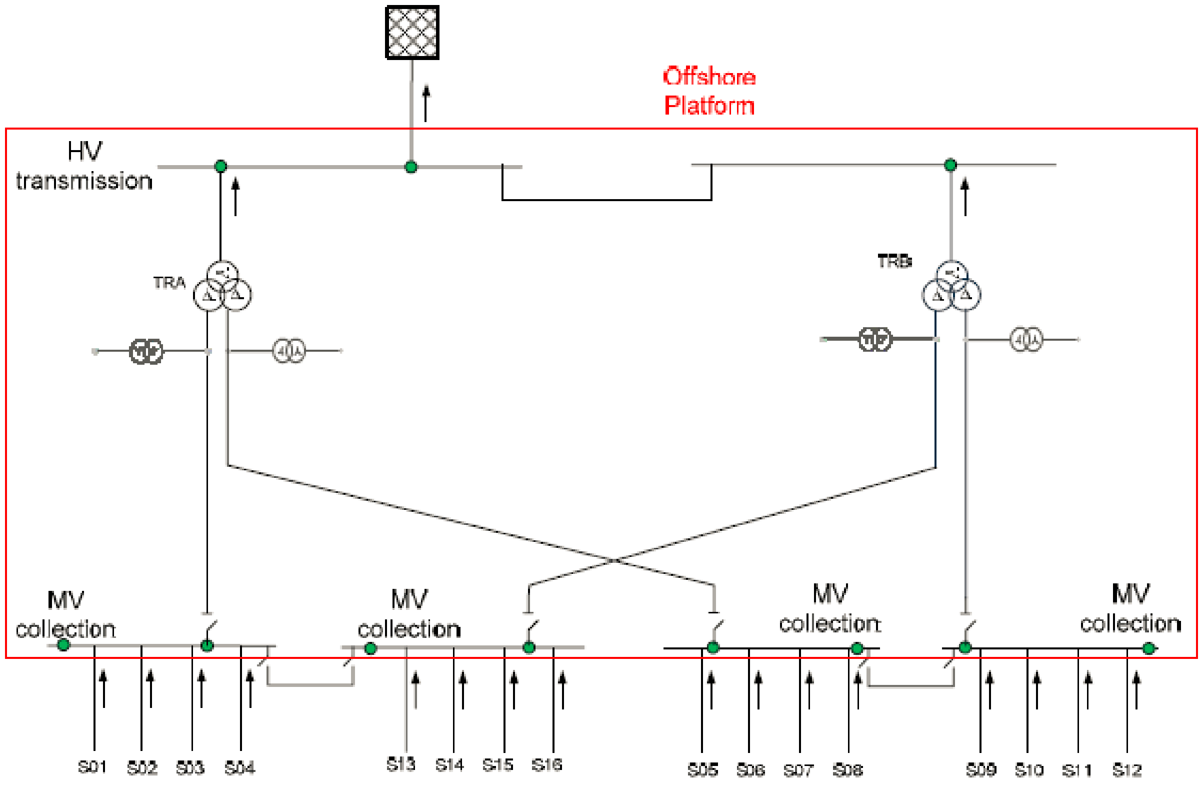
Branched connection



Closed loop

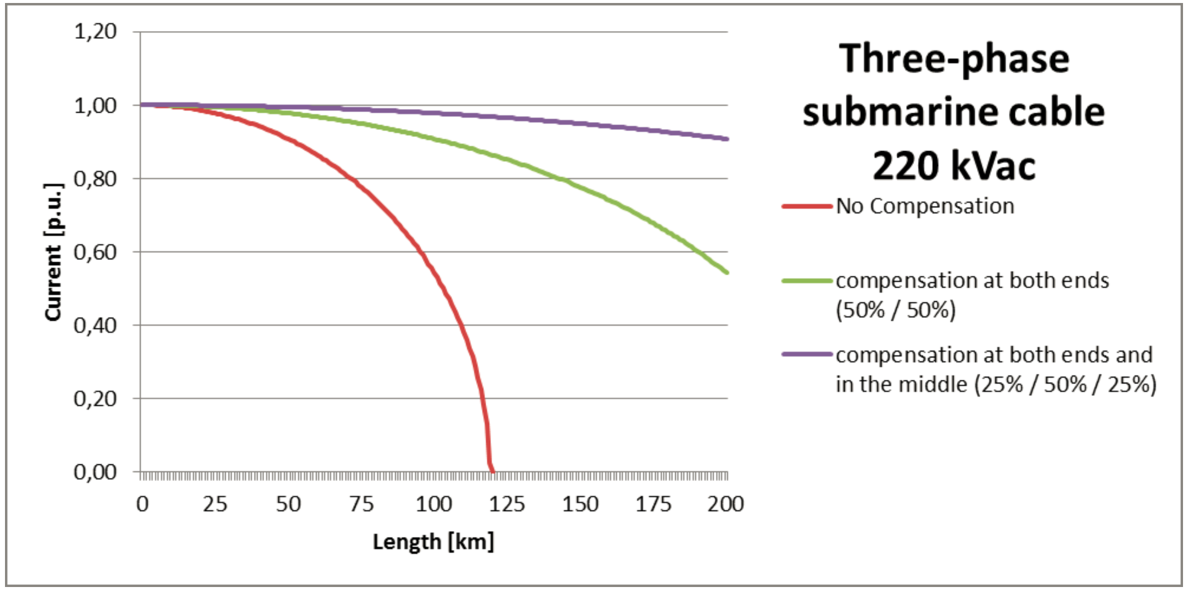
Design overview

Array cables and offshore substation (TB 483)



- Configuration of turbines
- 30-35 MW in each string
- MV switchgear – 2500 A
- Several busbars and transformers
- Voltage level U_m = 36 kV
- New level U_m = 72 kV
- Future level U_m = 132 kV

Design overview



AC – solutions

- One or more parallel 3-core export cables
- Reactive compensation on land and if necessary offshore

Reactive compensation in AC systems

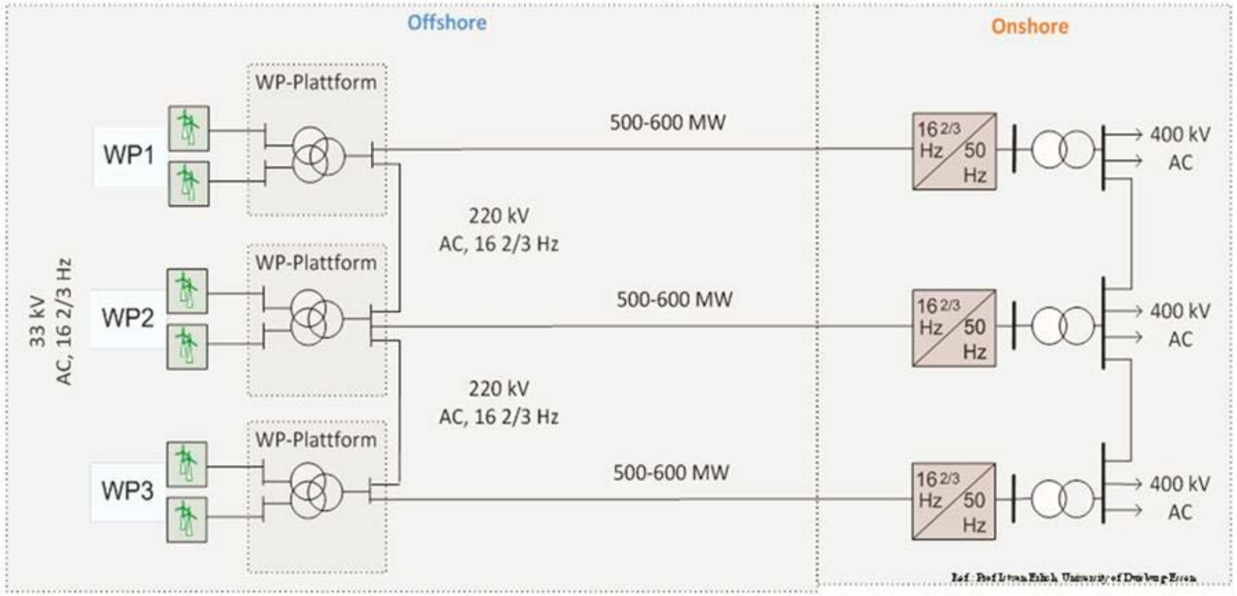
- To increase the transmission capacity of the cables
- To reduce losses
- To ensure stable system voltage
- By the turbines
- By additional shunt-reactors

New TB 640 – ratings calculation

For power system expertise

Design overview

Special solution: Lower frequency transmission (e.g. 16.7 Hz)



- Long ordinary AC cables
- Turbines – 16.7 Hz
- Larger transformers
- Back-to-Back converter needed on shore
- No experience so far

Design overview

- **System studies and simulations**
  - Alternative designs
  - Load flow and short circuit calculations
  - Dynamic simulations of interaction between wind farm and connecting grid
  - Insulation coordination using transient simulations
  - Protection coordination
  - Harmonic study
  - Reliability study
  - Grounding study

Part 2
Loading Pattern of cables

Background

- In 2017 a TF "Loading patterns on cables connected to windfarms“ was set up.
- The TF could identify several topics and compiled terms of reference that have been accepted at the 74th SCB1 meeting held in Paris in 2018. The working group B1.67 was been set up with the title "Loading Patterns on Windfarm Array and Export Cables". The outcome should be a technical brochure and a tutorial

Terms of Reference (TOR)

- To suggest and discuss various methods of assessment and assess the suitability of the method(s) given the benefits and limitations. The availability and the validity of data and what data is required are very important factors.
- To study the impact of the different technical regimes, operating regime, and effects of overplanting, high wind ride through and other potential future impacts to the technical regime, to the methods of load representation and to the owners/designers/operators of the assets.
- To study the impact on the models with respect to the differences in environmental considerations from around the world.
- To discuss the impact of the load representation method(s) and where applicable, to determine the benefits and disadvantages of the different dynamic thermal models based upon a load representation(s).
- To study how the degree of cable design optimization, environmental factors, and regulatory regime affect the requirement to have thermal monitoring.
- To discuss the benefits of dynamically rated cable systems. This can be further broken down to installation conditions, statutory constraints and economic impact.
- To comment on the bi-lateral influence of the method(s), the economic regime(s) and political stakeholders and the bearing it may have on the Total Cost of Energy / Total Cost of Ownership.

cigre
For power system expertise

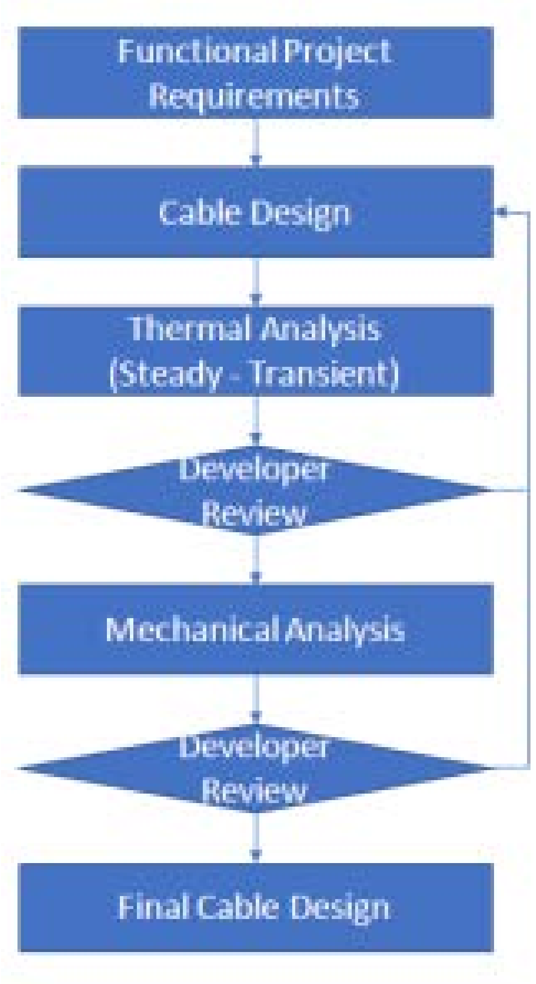
Introduction

Work flow for the design of the cable system

As starting point for cable design and thermal analyses there should be available:

- Functional project requirements of the windfarm and a generic cable system
- The location and the maximal load of the windfarm
- The cable route with crossings, hot spots, environmental conditions
- The grid connection rules

The layout of the brochure will reflect the design process and it is divided in 3 parts; these are as follows.

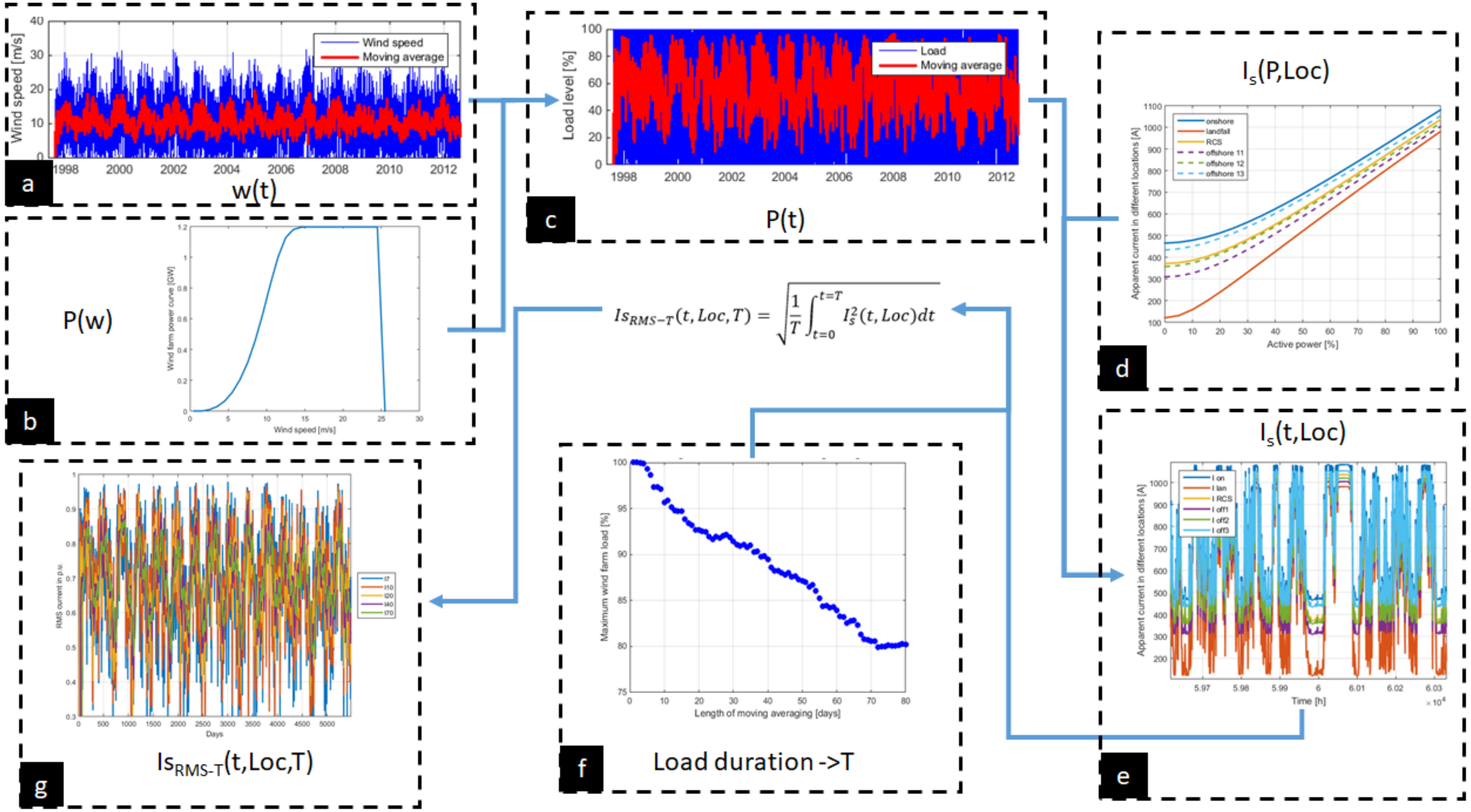


Part 1: Inputs and constraints

- **Environmental conditions as wind speed, seasonal variations, soil conditions …**
- **Market conditions**

  Will be used in Part 3 as inputs for the economical analyses
  - Regulatory
  - Governance
  - Developer
  - Asset Management
- **Influencing electrical factors as there are:**
  - Power generation
  - Reactive power
  - Voltage parameters
  - Frequency and harmonic assessment
- **Load profile models**
  - How to generate load profiles
  - Generate load profiles: continuous, cyclic, two-step, multi-step
- **Overview of available cable designs**

Example of generating a load profile

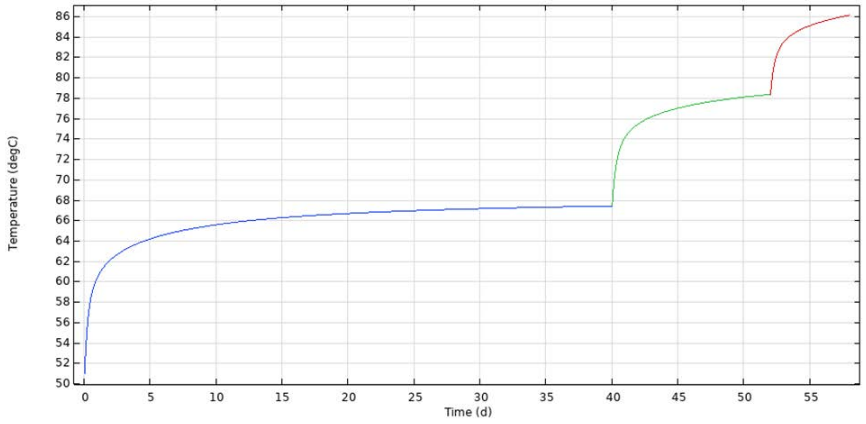


Part 2: Dynamic Cable Rating

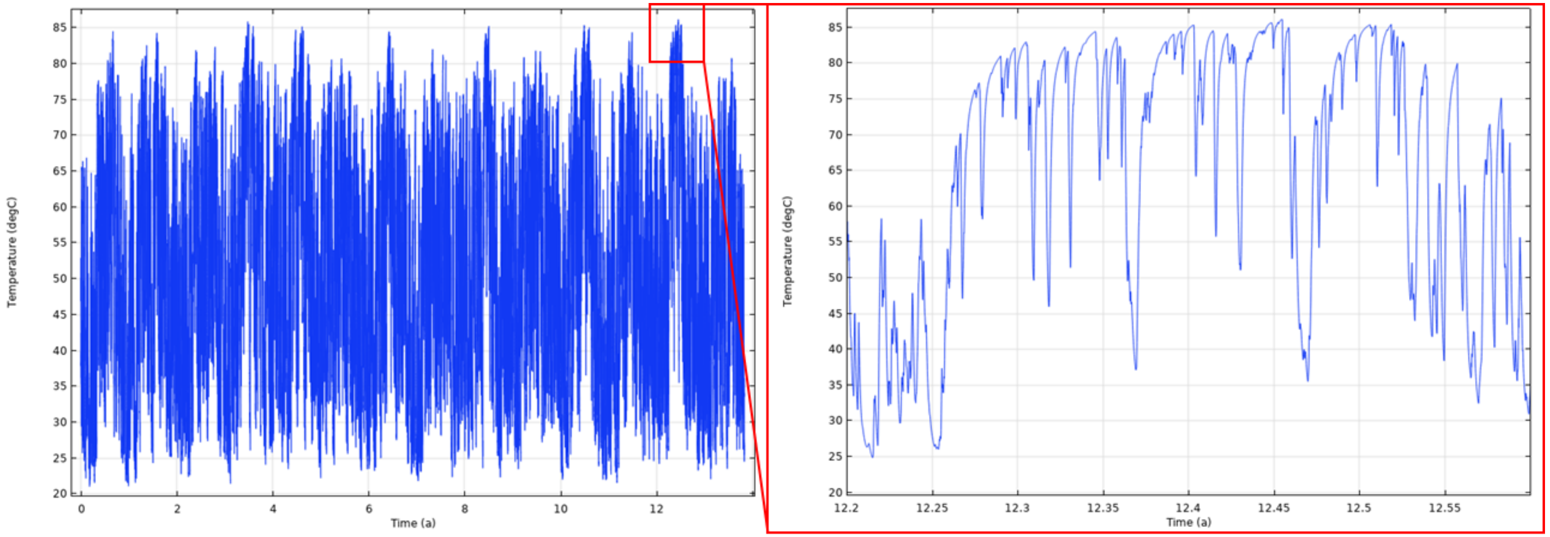
- Short review of available cable design with references to related TB’s
- Overview of methods to calculate dynamical cable ratings
  - Analytical methods
  - Finite elements analysis method
  - Different methods and approaches are presented
  - Recommendations what input data is relevant and should be used
  - Different calculation models are compared and rated
  - Dynamic ratings are evaluated on the basis of examples
- The basic idea of this part is to assist in:
  - using the most appropriate calculation method for a given task
  - focusing on the essential parameters of the thermal rating
  - guidance for rating the result

Calculation Example

Conductor temperature transient according to dynamic load curve



Graph and detail showing the conductor temperature and detail at peak temperature with actual load conditions



Part 3: Evaluation and Analysis 1

- Evaluation from engineering perspective
  - Theoretical precision
  - Sensitivity analysis
  - Risk assessment
- Evaluation from economical perspective
  - CAPEX
    - Cable supply
    - Installation
  - OPEX
    - Losses
    - Curtailment
    - Maintenance
  - Case study
    - Based on the method from IEC 60287-3-2:2012, expended to included above factors.
    - Comparison on CAPEX+OPEX of systems from different rating method.
    - Dependencies of total cost on internal (windfarm) and external (electric market) factors

Part 3: Evaluation and Analysis 2

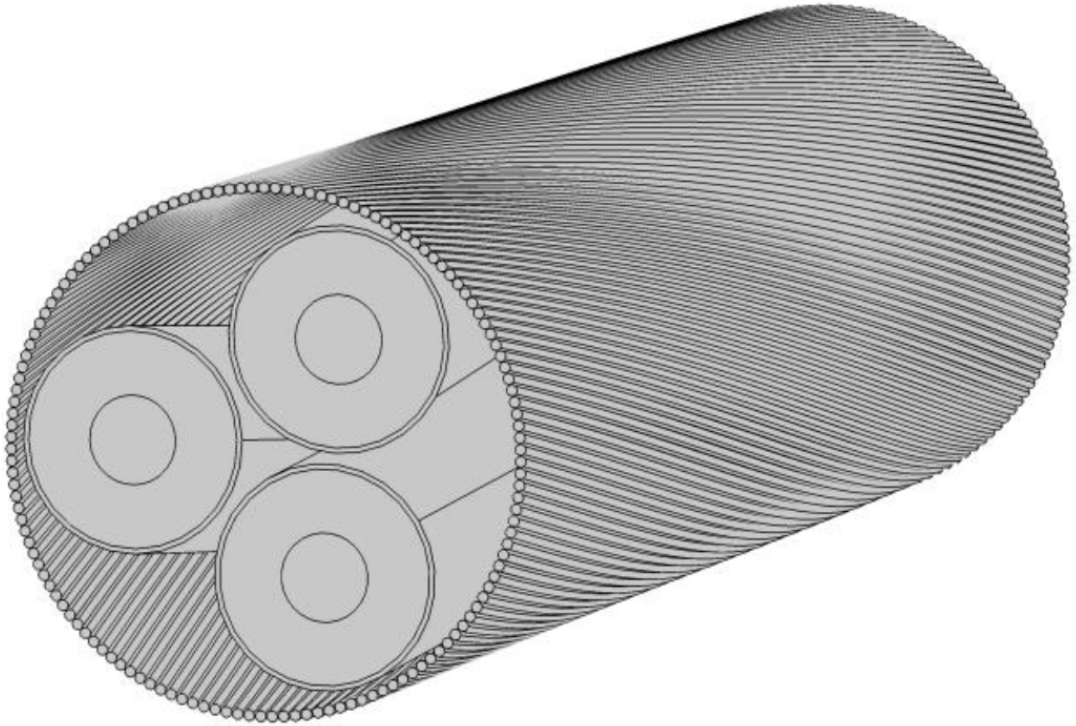
Final decision process:

1. There is only one solution -> go ahead
2. Several solutions possible ->
   - Identify the key items that lead to the different solutions
   - Doublecheck with the wind farm developer whether it is possible to adjust such key items

Part 3
Losses in armoured three core cables

Background

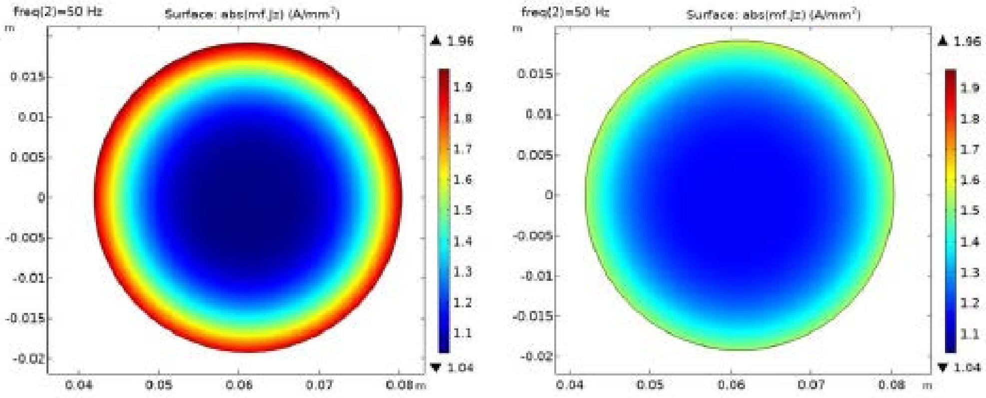
- IEC 60287-1-1
  - ✓ **Semi empirical**
  - ✓ **Smaller conductors**
  - ✓ **Common sheath**
- Evolving cable designs
  - ✓ **Greater insulation thickness**
  - ✓ **Larger conductor cross sections**
- Insufficient accuracy
  - ✓ **Over estimating (usually) losses**
  - ✓ **Increased cable cost**
  - ✓ **Significant impact for today's larger cable projects**

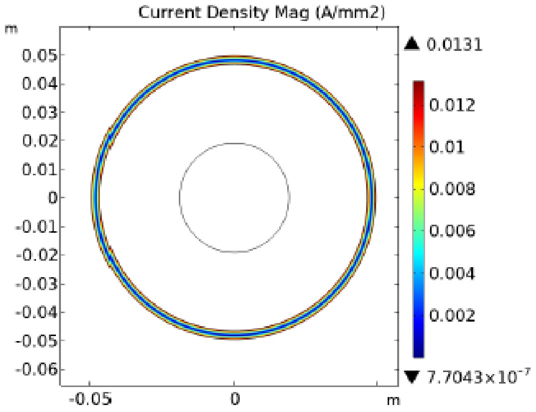


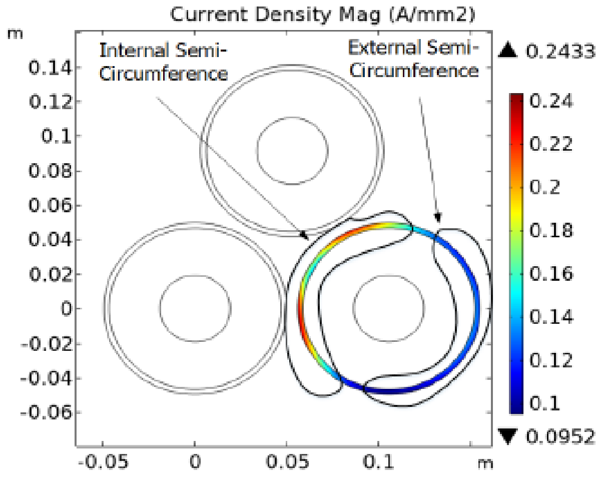
Technical Brochure Structure

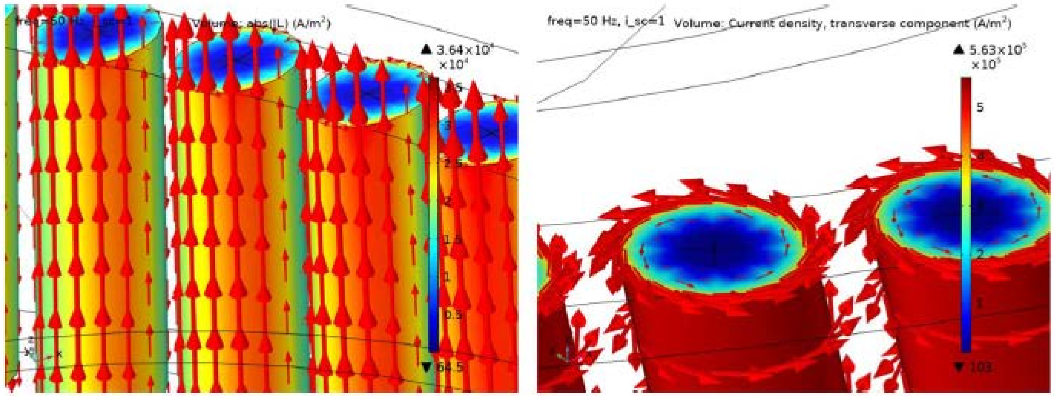
- Chapter 1 Introduction
- Chapter 2 Cable losses overview
- Chapter 3 Calculation methods
- Chapter 4 Impedance measurements
- Chapter 5 Magnetic permeability measurements
- Chapter 6 Finite Element Analysis
- Chapter 7 Discussion
- Appendix C Application of formula
- Appendix D Impedance measurement procedure
- Appendix E Comparison of results

Cable losses overview







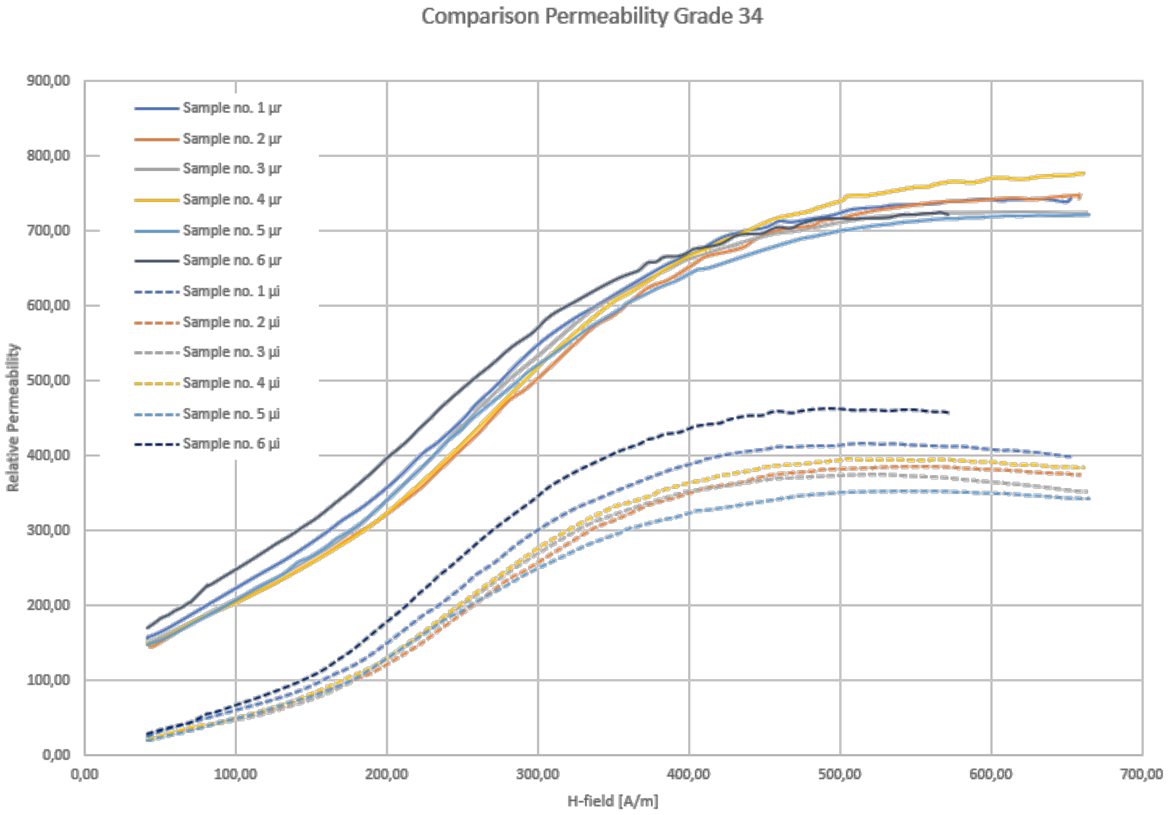


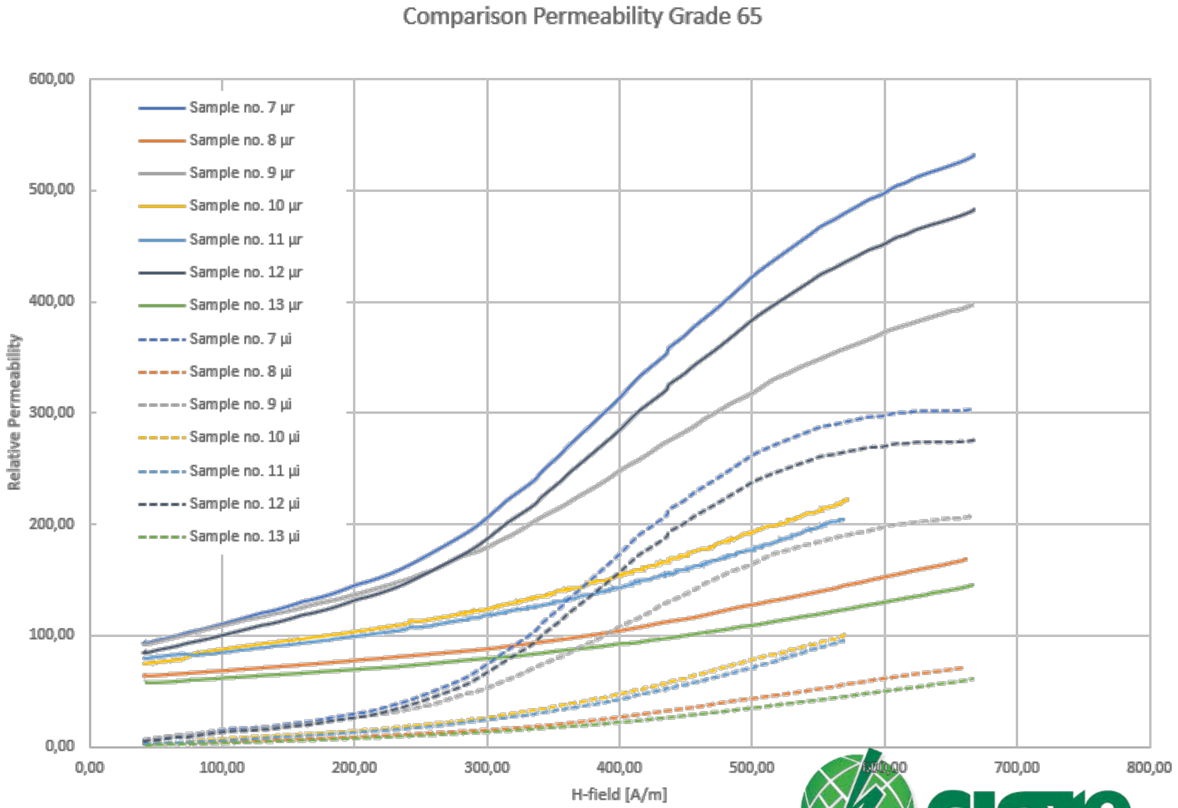
Calculation methods

- Method 1
  - ✓ **Analytic**
  - ✓ **Developed by the WG**
  - ✓ **Inductive coupling between all metallic elements are included**
  - ✓ **Complete derivation provided**
  - ✓ **Example of application in appendix**
- Method 2
  - ✓ **Numerical**
  - ✓ **Published in IEEE 2014**
  - ✓ **Script available**
- 3D FEA
  - ✓ **Cable designs beyond formulas capabilities**
  - ✓ **Compared with results from parallel development outside WG**

Magnetic permeability measurements

- Grade 34: Re/Im ≈ 7/24 %
- Grade 65: Re/Im ≈ 72/80 %

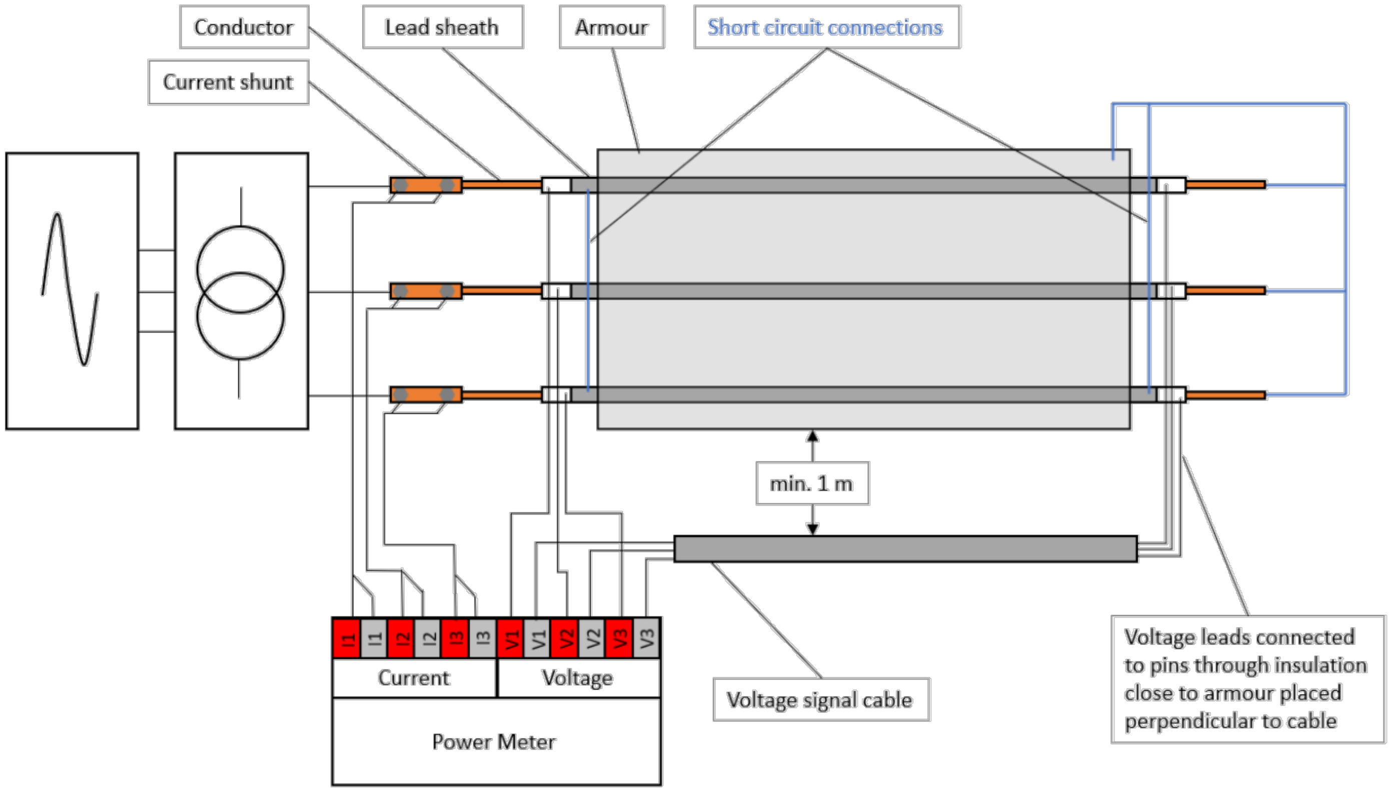




For power system expertise

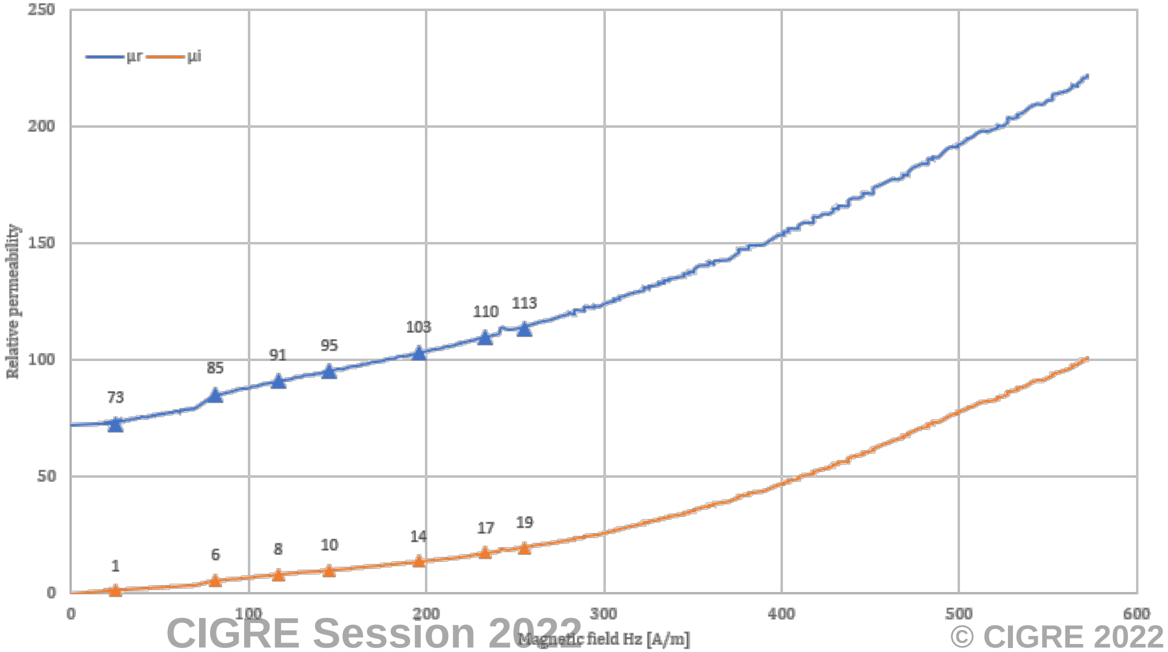
Impedance measurements

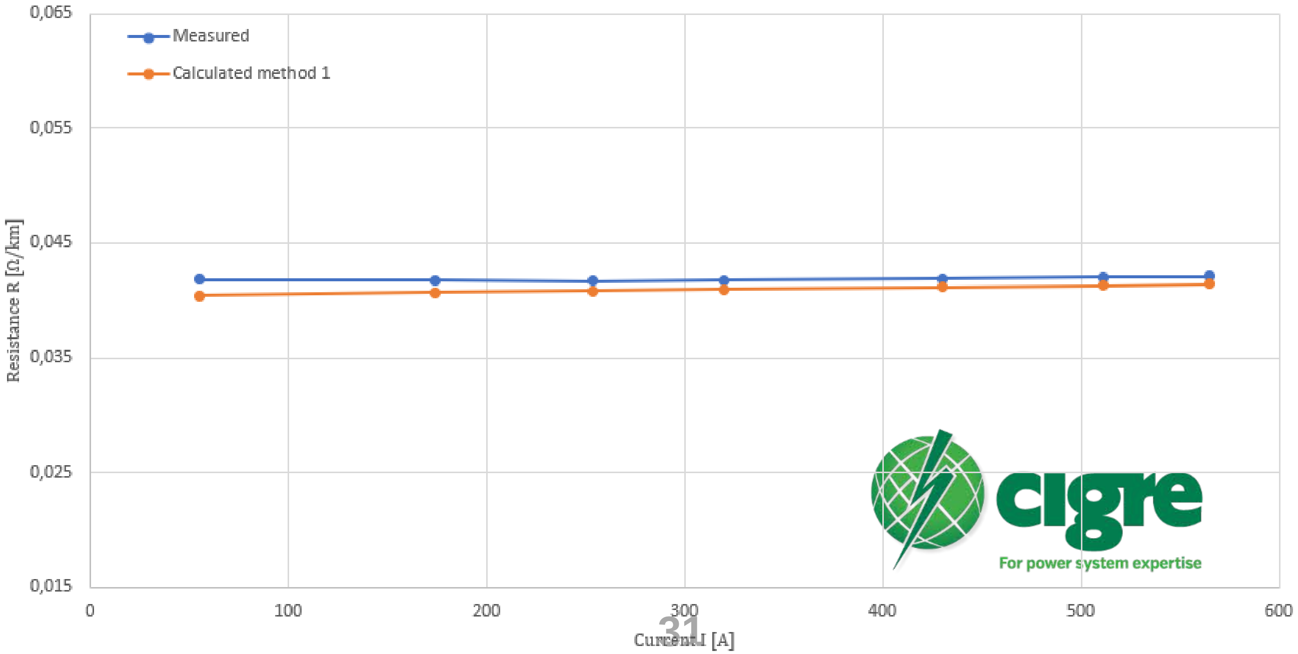
- General aspects
  - ✓ **External influences**
  - ✓ **Preparation**
  - ✓ **Equipment**
  - ✓ **Connections**
  - ✓ **Measurements**
- Procedure
  - ✓ **Recommended procedure**
- Example in appendix
  - ✓ **Actual measurement**
  - ✓ **Considering all aspects**
  - ✓ **Post processing**
  - ✓ **Comparison**



Comparison of results

- Impedance measurements at 7 different current magnitudes
- Permeability measurements
- Method 1 calculations with correct parameters
- Resistance increasing with increasing current
- Deviation < 2%





Motivation

- Required conductor cross section calculated using Method 1 and IEC
- 1200 mm^2 Al cable as reference

Calculation method	Grade 34 Contra lay (950 A)	Grade 65 Contra lay (990 A)	Grade 34 Uni lay (1025 A)
Method 1	1200 mm^2	1200 mm^2	1200 mm^2
IEC 60287	1600 mm^2	1800 mm^2	2000 mm^2

Motivation

- 1200 mm^2 **Cu** cable as reference

Calculation method	Grade 34 Contra lay (1041 A)	Grade 65 Contra lay (1098 A)	Grade 34 Uni lay (1157 A)
Method 1	1200 mm^2	1200 mm^2	1200 mm^2
IEC 60287	1800 mm^2	> 2000 mm^2 (alternate 2 x cables)	

Cable 100 km	Material cost savings (%)	Weight reduction (% / tonne)	Installation campaigns
Gr 34 Contra lay	27	19 / 2277	1 (vs. 2)

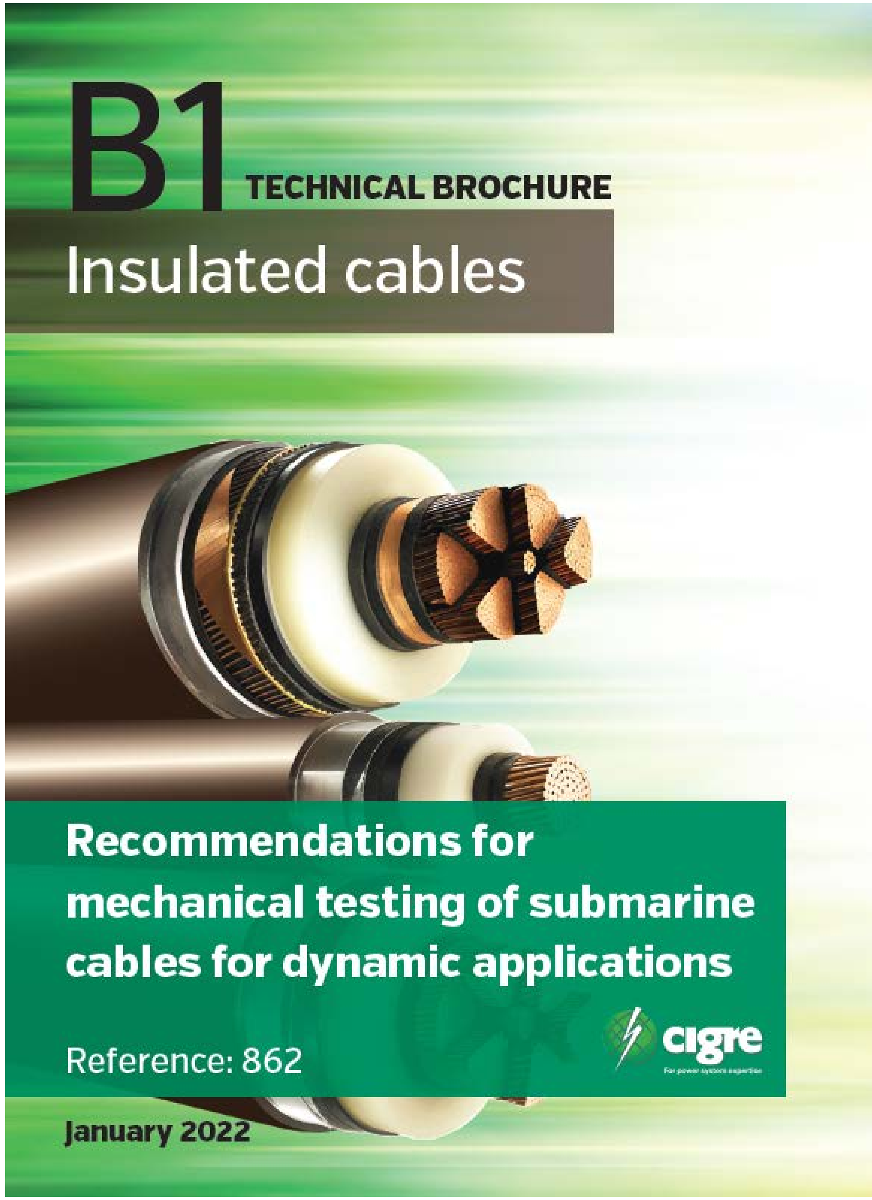
Conclusion

- Analytic formulas for common cable designs
- 3D FEA for other cable designs
- Impedance measurement procedure
- Magnetic permeability measurements
- Significant improvement in ampacity or reduced cost

Part 4
Dynamic Testing

Introduction

- Technical Brochure 862, **Recommendations for mechanical testing of submarine cables for dynamic application,** was published in January 2022



Background to TB862

- Development of floating wind farms
  - ✓ **Increasing need for HVAC dynamic cables**
  - ✓ **Dynamic cables connected to floating platforms must be able to withstand dynamic loads during service life**
  - ✓ **New requirements compared to cable systems for fixed wind farms and O&G**

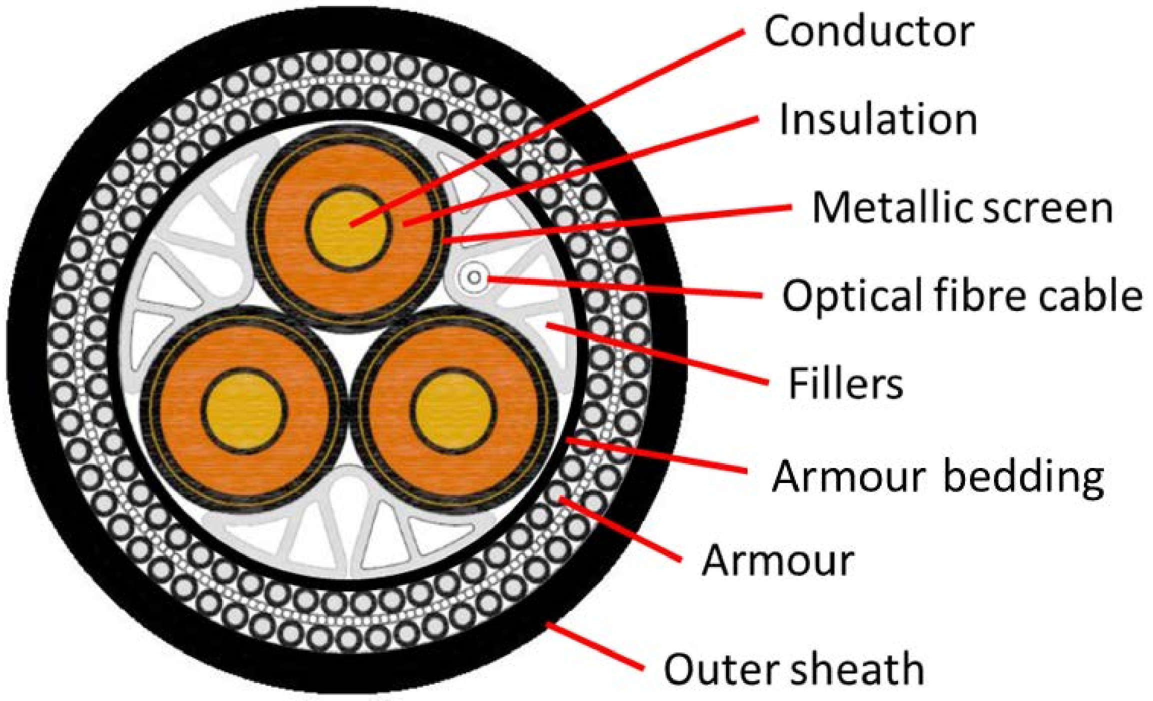
- Existing Standards developed for O&G (Oil & Gas) umbilical cable systems but..
  - ✓ **Project characteristics are different (external constraints, expectancy duration life, safety factor, etc)**

➡ **Clear guidelines are needed to design and test the dynamic cable system for floating platforms and floating wind turbines**

cigre
For power system expertise

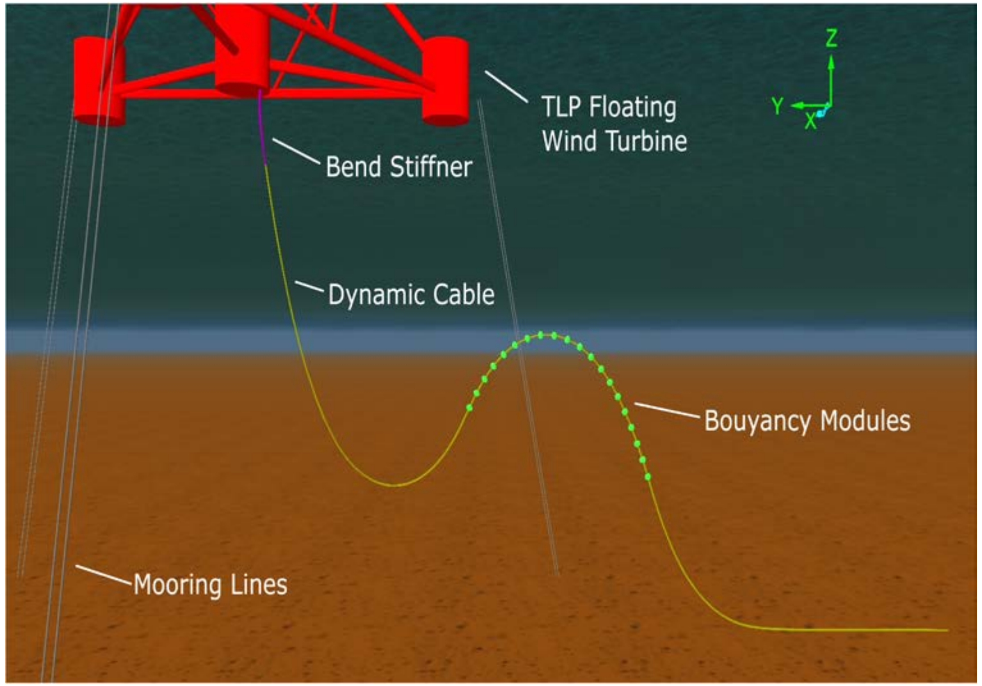
Dynamic cable design, example

- Designed to endure repeated bending and tensile loads
- Wet design cables:
  - ✓ **Screen made of wires, tapes or braid**
- Dry design cables:
  - ✓ **Screen made of welded metal tape, either smooth or corrugated**
- Armour bedding over core assembly
- Torsional balanced design featuring double armour
- Extruded outer sheath



Dynamic cable configuration

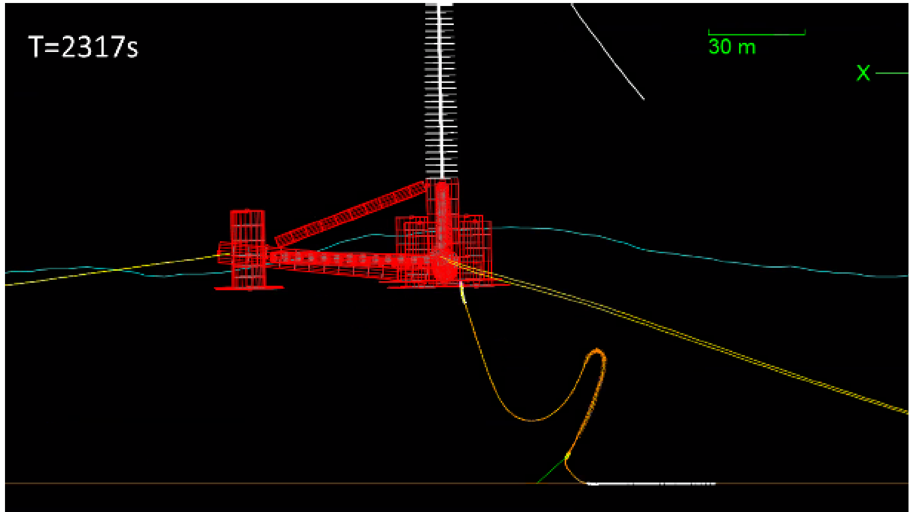
- The dynamic cable configuration between seabed and floating platform is an important part of the system design
- Ancillary equipment is used to achieve configuration (e.g. buoyancy modules and hold down clamps)
- Configuration design is influenced by several factors such as platform offset, environmental conditions, cable properties, etc.
- Global analysis is performed to design and optimize the configuration



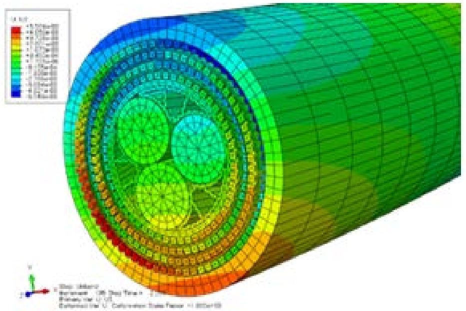
Example of subsea cable configuration

Analysis related to dynamic cables

- **Global analysis** is performed to analyse the response of different components of an offshore system, typically encompassing:
  - ✓ **Extreme weather conditions**, for example a 50 years storm event
  - ✓ **Fatigue loading** on the cable due to repeated dynamic motions over full operational lifetime
- **Local analysis** is used to translate the global loads onto the cable into local loads (stress/strain) in the different cable components
- Resulting component stress is used as input for the fatigue damage accumulation
- Results from analysis will be **basis for test program**



Example of global analysis model


Example of local analysis model

Dynamic cable testing

- Dynamic cables can be exposed to a wide range of loading conditions
- Testing is needed to demonstrate that the cable design can withstand the expected loads during the cable's planned service life
- Mechanical tests for dynamic cables described in TB862:
  - ✓ **Full-scale fatigue test**
  - ✓ **Bend stiffness test**
  - ✓ **Axial compression test**
  - ✓ **Clamp squeeze test**
  - ✓ **Clamp slippage test**
  - ✓ **Component testing**

Full-scale fatigue test

Introduction

- **Purpose:** to verify that the dynamic cable can withstand the expected fatigue loads experienced during service life
- TB 862 expands on TB 623 and provides further details, considerations and recommendations. The main additions are:
  - ✓ **Example of test setups and block program**
  - ✓ **More details and considerations related to test sample and test setup**
  - ✓ **Acceptance criteria to cover cables of wet or laminate design**
  - ✓ **Monitoring techniques during the fatigue test**
  - ✓ **Recommendations on range of approval of the full-scale fatigue test**

For power system expertise

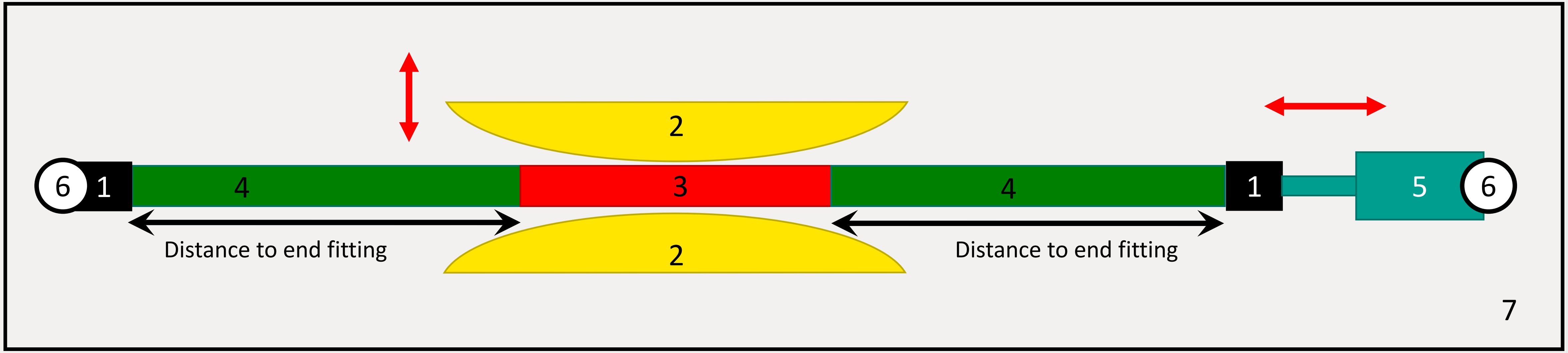
Full-scale fatigue test

Test conditions

- Cyclic bending with tension applied on cable
- Total number of cycles should be **at least 1 500 000**
- The cyclic bending is divided into **at least five blocks**, each with different bending radius and number of cycles
- Two different methods can be used for controlling bend radius:
  - ✓ **Tension and angle method, with bend stiffener**
  - ✓ **Tension and template method**
- Block definition:
  - ✓ **Based on result from fatigue analysis**
  - ✓ **Accelerate the service life, obtaining a similar distribution of fatigue damage between small and large bend cycles as experienced during service life**

Full-scale fatigue test

Example Test Setup : Tensile and template fatigue test bench scheme*



1 – Cable termination
2 – Frame template (fixed BR)
3 – Fatigue loaded section of cable
4 – Cable – End length
5 – Linear tensile actuator
6 – Pivot point of cable
7 – Test bench frame

*Tensile and angle flex fatigue test bench scheme, using bend stiffener, can also be used

Full-scale fatigue test

Test Blocks for tension and curvature, example

Testing block	Number of cycles	Tensile load [kN]	Curvature range [rad/m]	Fatigue damage per cycle	Block damage
1	973,459	80	0.029	4.58 . 10-12	4.46 . 10-6
2	370,043	80	0.057	1.34 . 10-10	4.97 . 10-5
3	122,231	80	0.085	9.90 . 10-10	1.21 . 10-4
4	25,979	80	0.11	3.60 . 10-9	9.34 . 10-5
5	6,623	80	0.135	1.00 . 10-8	6.63 . 10-5
6	1,815	80	0.16	2.34 . 10-8	4.25 . 10-5
7	253	80	0.207	8.49 . 10-8	2.15 . 10-5
8	61	110	0.341	1.11 . 10-6	6.76 . 10-5
Overall:	**1,500,464**				**4.67 . 10-4**

Full-scale fatigue test

Pass/fail criteria

- Electrical routine test followed by dissection as in TB 623
- Additional requirements **in bold**:
  - ✓ Cracks or holes in the outer sheath
  - ✓ Permanent bird caging or break of more than two armour wires per layer
  - ✓ Cracks or holes in the core sheath
  - ✓ Cracking or damages to the insulation
  - ✓ Damages to conductor which could have a detrimental effect on the cable performance
  - ✓ **Breaks or cracks in the metallic screen**
  - ✓ **Breaks or cracks of fibre optic cable sheath or metallic tube**
- Additional recommendation for dry cables with glued foil sheath:
  - ✓ **Adhesion and peel strength of the laminated metal foil according to TB 446 section 2.3.1**

Conclusion

- Fast growth of floating wind expected
- Requires dynamic cables with a specific design approach:
  - ✓ **Iterative design process including global & local analysis**
  - ✓ **Full-scale fatigue test**
- TB 862 gives recommendations on each step of this design and testing

Part 5
Installation of submarine power cables

Introduction 1:2

The use of submarine power cables is becoming more and more widespread and therefore a need is seen for guidelines concerning installation of submarine power cables.

WG B1.65 has therefore compiled a **common guideline** that can form a central basis for handling submarine cable installations that can be considered by a number of stakeholders:

- Utilities
- Developers
- Manufactures
- Involved consultants
- Testing agencies
- Insurances
- Authorities
- And other stakeholders

The TB covers the entire lifetime of the submarine cable system / project (*from concept idea to decommissioning with the installation being the focus of the brochure*)

For power system expertise

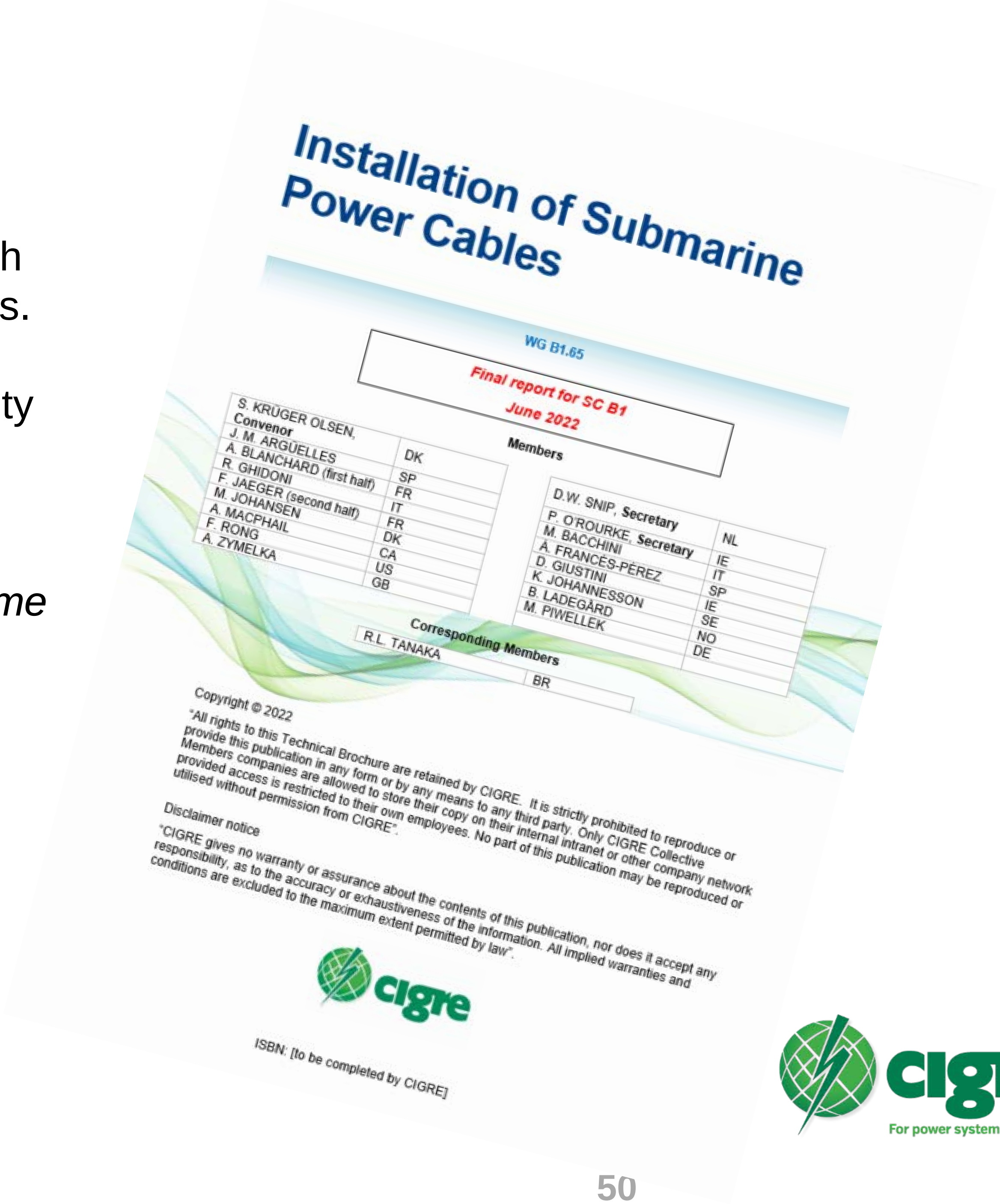
Introduction 2:2

The document covers from 30 kV to 550 kV for both AC and DC application with various insulation types.

The Focus of the document is the installation activity in the seabed including landfall and offshore asset operations

Dynamic submarine cables are also covered to some extend…

Array cable	Export cable AC	HVDC export cable
		
Extruded insulation		
		
EPR insulation		Mass Impregnated paper insulation (MI)


Installation of Submarine Power Cables

WG B1.65

Final report for SC B1

June 2022

Members

S. KRÜGER OLSEN, Convenor — DK
J. M. ARGÜELLES — SP
A. BLANCHARD (first half) — FR
R. GHIDONI — IT
F. JAEGER (second half) — FR
M. JOHANSEN — DK
A. MACPHAIL — CA
F. RONG — US
A. ZYMELKA — GB

D.W. SNIP, Secretary — NL
P. O'ROURKE, Secretary — IE
M. BACCHINI — IT
A. FRANCÉS-PÉREZ — SP
D. GIUSTINI — IE
K. JOHANNESSON — SE
B. LADEGÅRD — NO
M. PIWELLEK — DE

Corresponding Members

R.L. TANAKA — BR

Copyright © 2022

"All rights to this Technical Brochure are retained by CIGRE. It is strictly prohibited to reproduce or provide this publication in any form or by any means to any third party. Only CIGRE Collective Members companies are allowed to store their copy on their internal intranet or other company network provided access is restricted to their own employees. No part of this publication may be reproduced or utilised without permission from CIGRE".

Disclaimer notice

"CIGRE gives no warranty or assurance about the contents of this publication, nor does it accept any responsibility, as to the accuracy or exhaustiveness of the information. All implied warranties and conditions are excluded to the maximum extent permitted by law".

cigre

ISBN: [to be completed by CIGRE]

cigre
For power system expertise

What does the Technical Brochure cover?

- The TB covers aspects concerning **installation of submarine power cables** and to some extend the impact on needed cables mechanical requirements/specifications

- **Consenting / Permitting** aspects are also covered

- Aspects concerning **mechanical testing** are not covered as this is handled by CIGRE TB623 – Recommendation for mechanical testing of submarine cables & CIGRE TB862 - Recommendations for mechanical testing of submarine cables for dynamic applications

- **Electrical testing** AC and DC cables are not covered either as this is covered by CIGRE TB490 & CIGRE TB852 (extruded insulation) / TB853 (lapped insulation)

- Specific use of submarine cable for **connection of offshore wind generation** are not covered as such. These aspects are covered in CIGRE TB610

Structure of the TB

Chapter 2 *- Consents and Permitting*

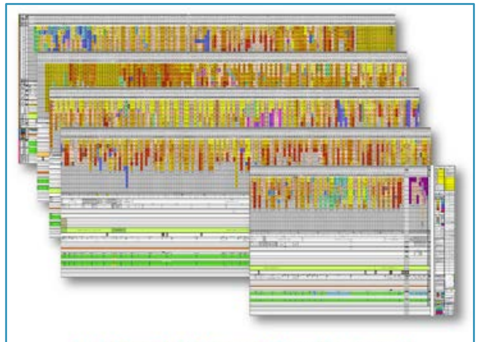
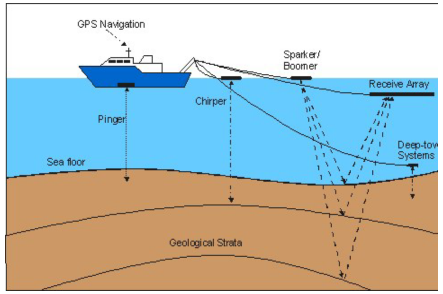
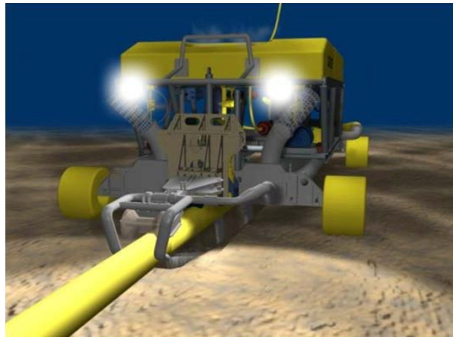


Figure 3-4 Example of a Burial Assessment Study table for an interconnector.

Chapter 3 *- Submarine cable installation engineering*

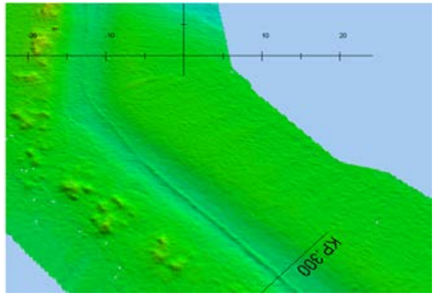


Chapter 4 *- Seabed survey and site investigations*



Chapter 5 *- Installation tools and considerations*

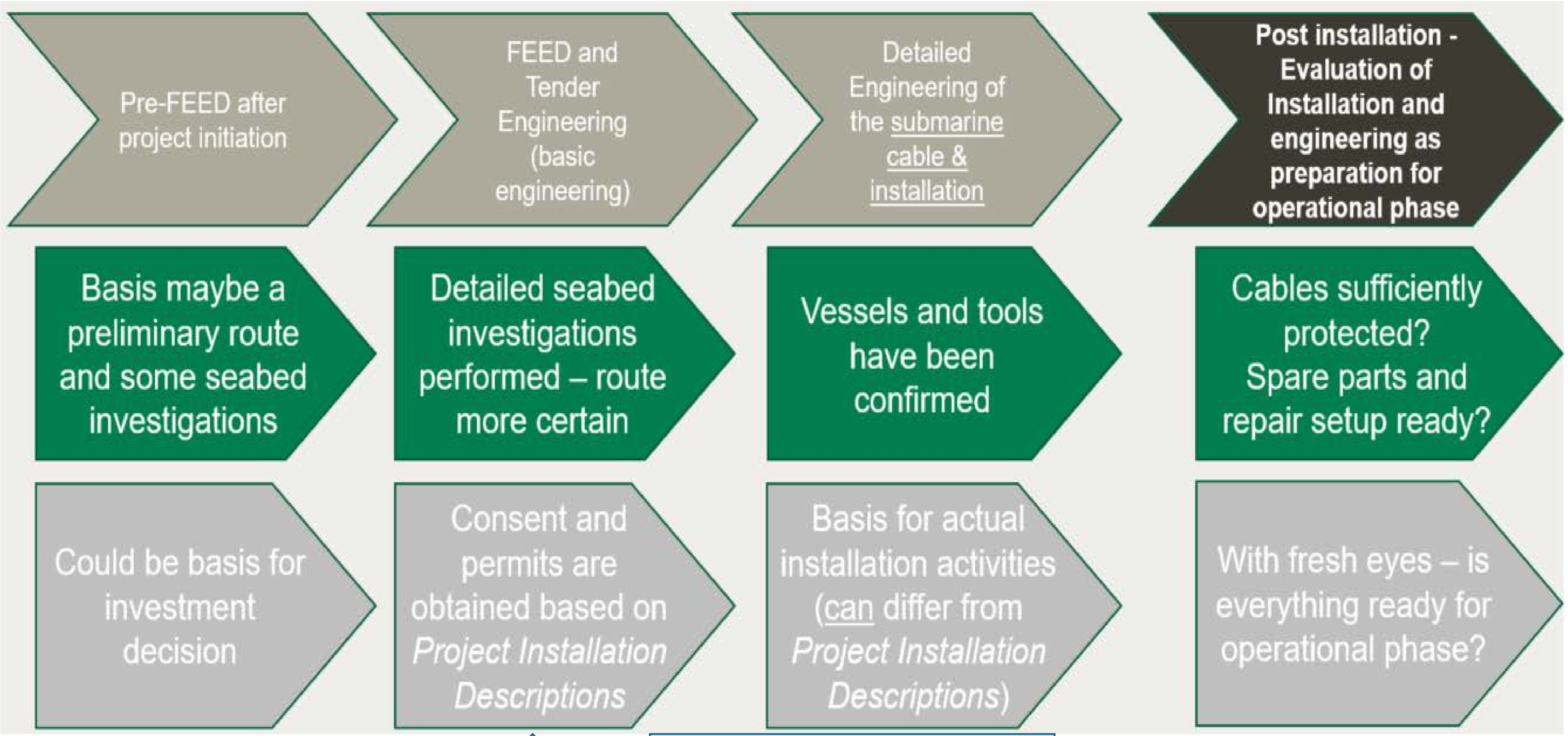
Chapter 6 *- Execution of installation including remedial work*



Chapter 7 *- Operation, maintenance, and decommissioning*

For power system expertise

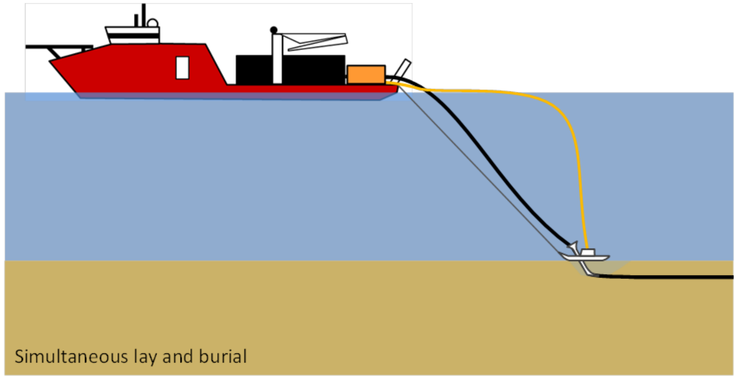
Engineering model considered



Important choices are made when not all aspects are fixed

Choosing the installation approach – often during FEED and tender engineering phase

Design decision on the cable protection principle based on a **BAS (Burial Assessment Study)** including **CBRA / RBBD studies**

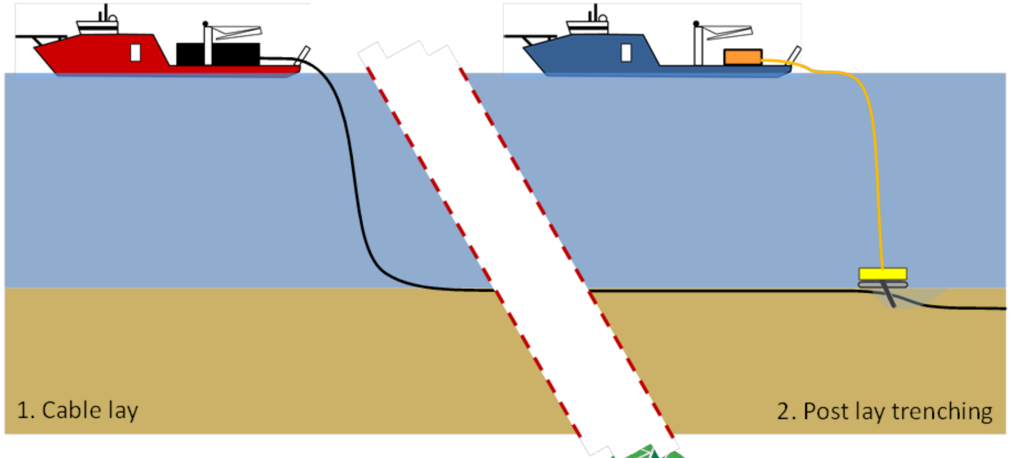


Cable protection concept depends on seabed information:

- **Simultaneous lay and burial** (example **cable plough**)
- **Pre-trenching/cutting** of the seabed as a preparation before cable laying (pre-excavation, cutting wheel)
- **Post-lay burial/protection** (jetting)

Care must be taken to prepare for **mitigations** (remedial work) if the tools are not interacting with the seabed as expected.

It is important that these **mitigations** are considered and included in **Project Descriptions** used as basis for obtaining consent and permissions.



Route Development

Cable route study

- Existing and new information concerning installation conditions, constraints, crossings, identify and reduce gaps in knowledge

Survey & Site Investigations

- Marine survey (geophysical)
- UXO survey, identification and clearance (always needed for full route?)
- Landfall and intertidal survey
- Environmental survey
- Geophysical
- Geotechnical
  - Vibratory core
  - CPT
  - SPT
- Thermal resistivity
- Ambient temperature

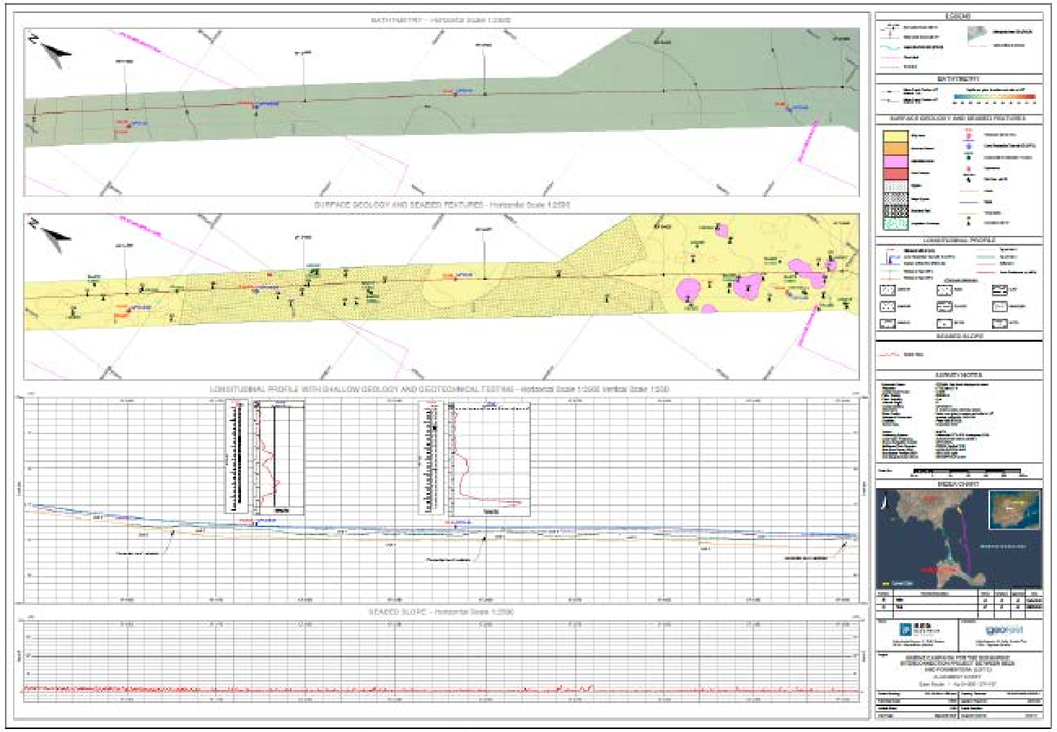


Figure 4-6 Typical alignment sheet.

Vessel Selection for cable laying and other activities

What does the task actually require?

- Barge capable of grounding out? (relevant for shallow waters installation in zones with significant tide)?
- Barge with a six-anchor mooring system?
- Installation vessel with DP1, DP2, DP3 capabilities?

To be considered:

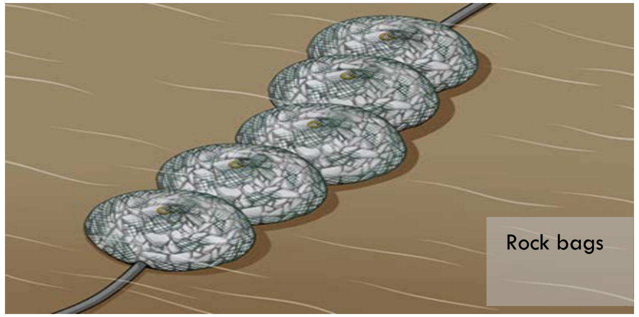
- Regional seaworthiness
- Anchoring system
- Actual Need for DP1, 2 or 3 – or can a barge do the job?
- Positioning & survey equipment
- Dynamic positioning and reference system
- Alarm system (example anchor alarm)
- Cranes and lifting capabilities
- Cable management and installation tools

cigre
For power system expertise

Tools for cable protection (Burial & Protection)

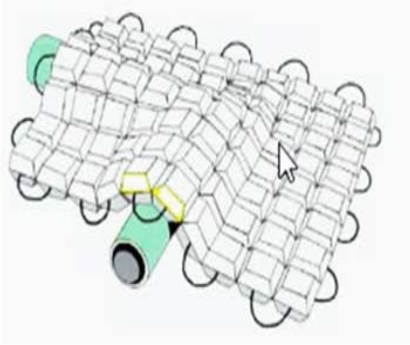
- Cable protection is actually needed along the entire route?
- Burial tool and equipment selection
- Route preparation (improvement/dredging)
- Protection methods

- Jetting
- Pre-trenching
- Ploughs
- Vertical injector
- Rock placement / concrete mattresses
- Handling of unplanned seabed conditions?



Rock bags

Steel shells



Concrete mattresses

Choosing the right tools for the job!

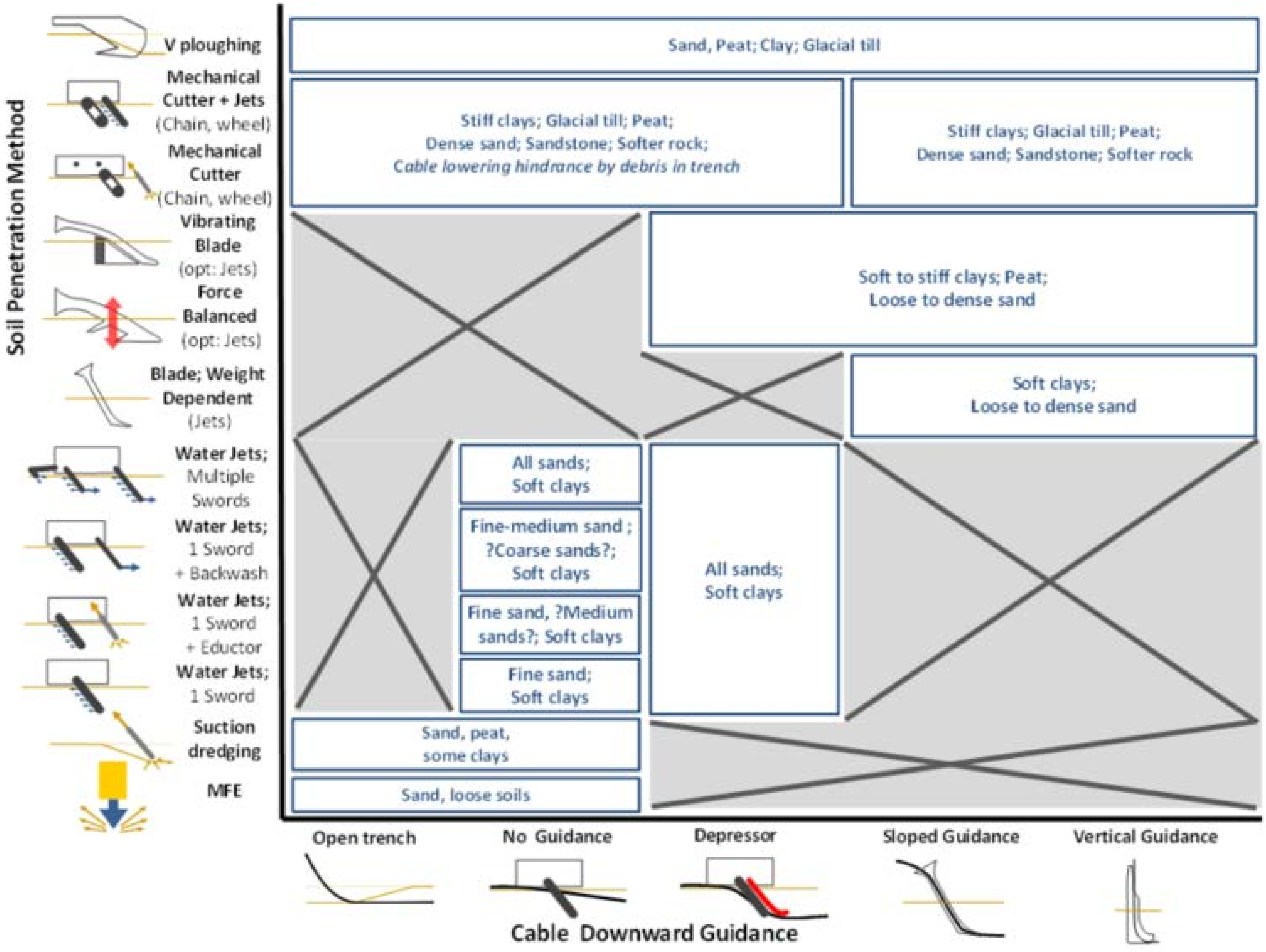


Figure 3-38 Illustration of overall suitability of tools in different soils vs. cable downward guidance methods

- **Collected site data will determine which tools are suitable.**

Often this is a **compromise**, the cost could also play a role together with the willingness to take a risk – i.e. accept a lower protection level locally

- **Prepared for mitigations:**

if the tools are not functioning as expected it will play a role on which other tools can be used

More information and insight still to come

- Next step is presentation of the Tutorial covering the work of CIGRE WG B1.65 in full

- Hope as many as possible attend the presentation when ready

Copyright & Disclaimer notice

For power system expertise