SUPERNODE™

SUPERCONDUCTORS DELIVERING CARBON NEUTRALITY

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OUR MISSION

TO **HARNESS** THE BEST RENEWABLES FASTER

TO **BUILD AND GROW** OUR RENEWABLE INDUSTRY

TO **UPDATE** THE NETWORK INFASTRUCTURE FOR THE ENHANCED ELECTRICITY AGE

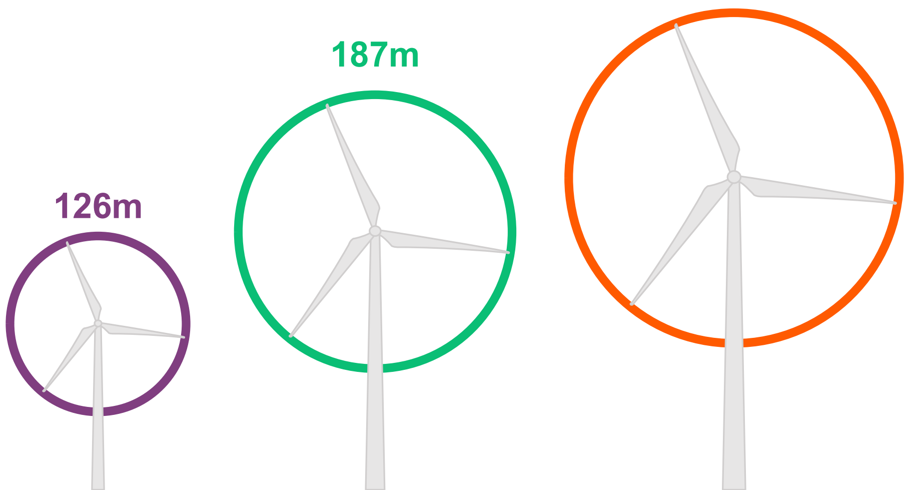
TO **DECARBONISE** THE GLOBAL ECONOMY

RATIONALE FOR SUPERCONDUCTING TRANSMISSION

THE GROWTH AND CHALLENGES OF OFFSHORE WIND

WIND TURBINE ADVANCEMENTS

126m | 187m | 220m



2007
6 MW

2016
8 MW

2021
15 MW

PLATFORM SIZE AND COST

2015
DolWin2
916 MW

2017
DolWin3
900 MW

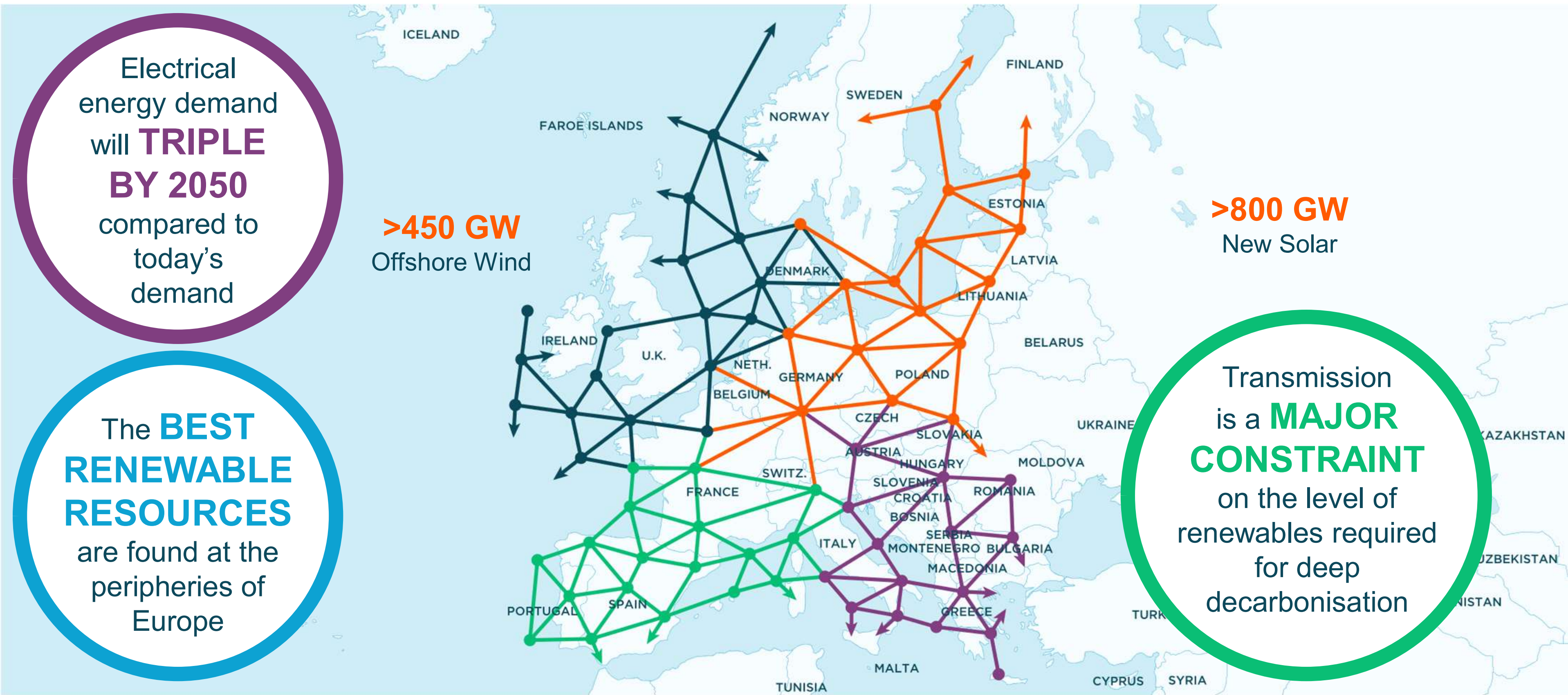
2019
BorWin3
900 MW

2023
DolWin6
900 MW

THE NEED FOR A SUPERGRID

Electrical energy demand will **TRIPLE BY 2050** compared to today's demand

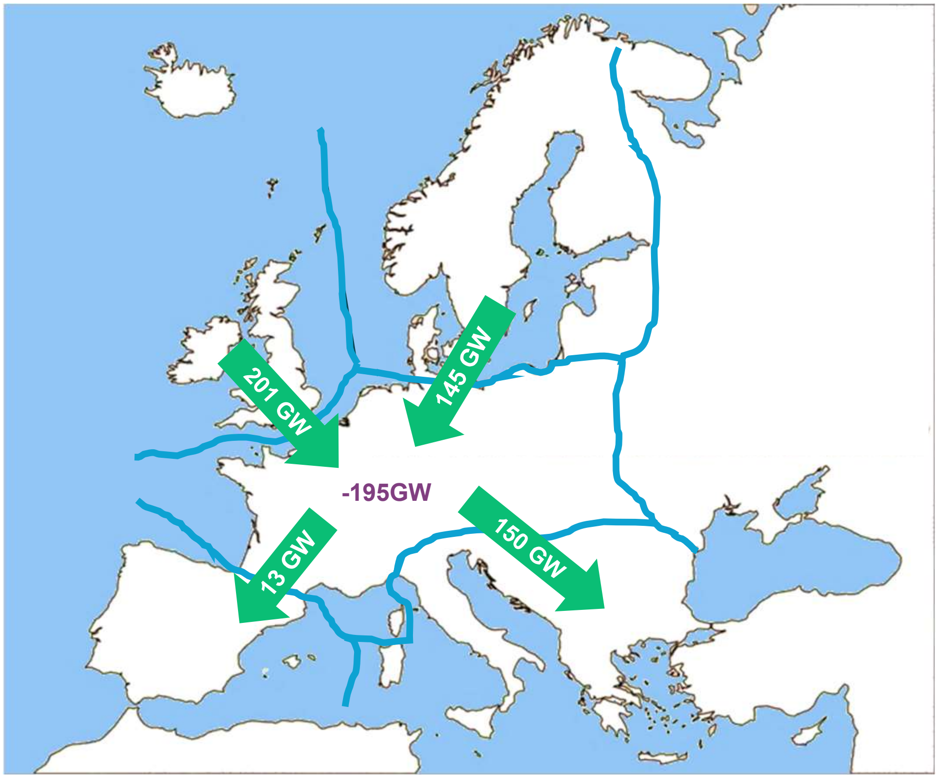
The **BEST RENEWABLE RESOURCES** are found at the peripheries of Europe



Transmission is a **MAJOR CONSTRAINT** on the level of renewables required for deep decarbonisation

SCENARIO 1: WINTER AFTERNOON/HIGH WIND

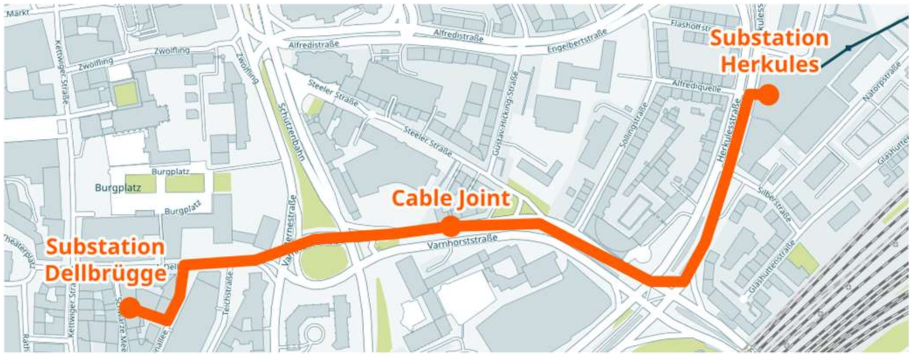
- 346 GW of excess generation in the British Isles and Nordic Regions
- Central Europe requires 179 GW
- The Iberian peninsula requires 13 GW
- South East Europe requires 150 GW
- 346 GW enters Central Europe, 163 GW leaves through to the southern regions
- Power shifts from the northern regions into central Europe, meeting demand there, and shifting through to the southern regions.



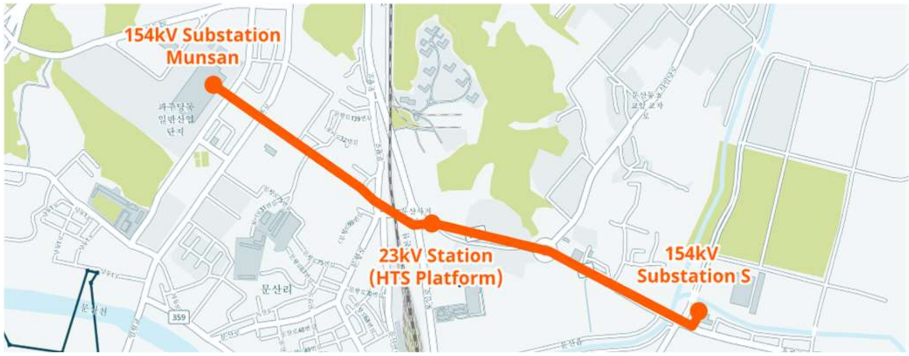
SUPERCONDUCTORS FOR TRANSMISSION

SUPERCONDUCTOR CABLE SYSTEMS IN PRACTICE

Ampacity Installation, Essen, Germany [1]



Shingal Project, Seoul, S. Korea [2]



Active Superconductor Projects		
2013	Operational	Ampacity, Essen [40MVA, 10kV]
2018	Demonstration	Horizon's 'Best Paths' Project [3.2GW, 320kV]
2019	Commercial	Shingal, Seoul [50MVA, 23kV]
Due 2021	Under construction	REG, Chicago
Planned	Feasibility study phase	Superlink, Munich (1st phase) [500MVA, 110kV]

1. https://ieeexplore.ieee.org/document/6683508
2. https://iopscience.iop.org/article/10.1088/1361-6668/ab6ec3/meta

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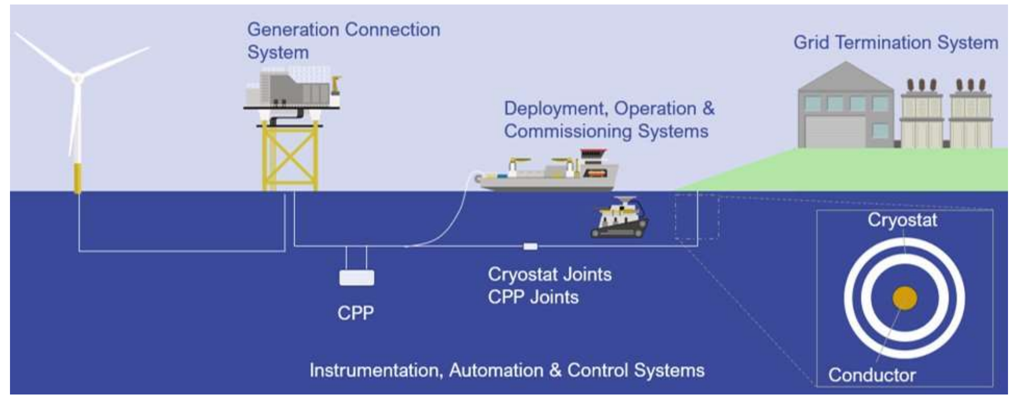
SUPERNODE CABLE SYSTEM DEVELOPMENT

SUPERNODE'S R&D PROGRAM IS DEVELOPING SUPERCONDUCTING CABLE TECHNOLOGY FOCUSED ON:

- **MVDC, 2GW+, 100km offshore transmission**
- Marine deployment
- Marine environment O&M
- **High Capacity, long distance terrestrial transmission**
- Optimal loss management
- Cooling and pumping stations
- Reliability & robustness
- **Achieved Statement of Feasibility for our offshore transmission cable system.**



DNV·GL STATEMENT OF FEASIBILITY

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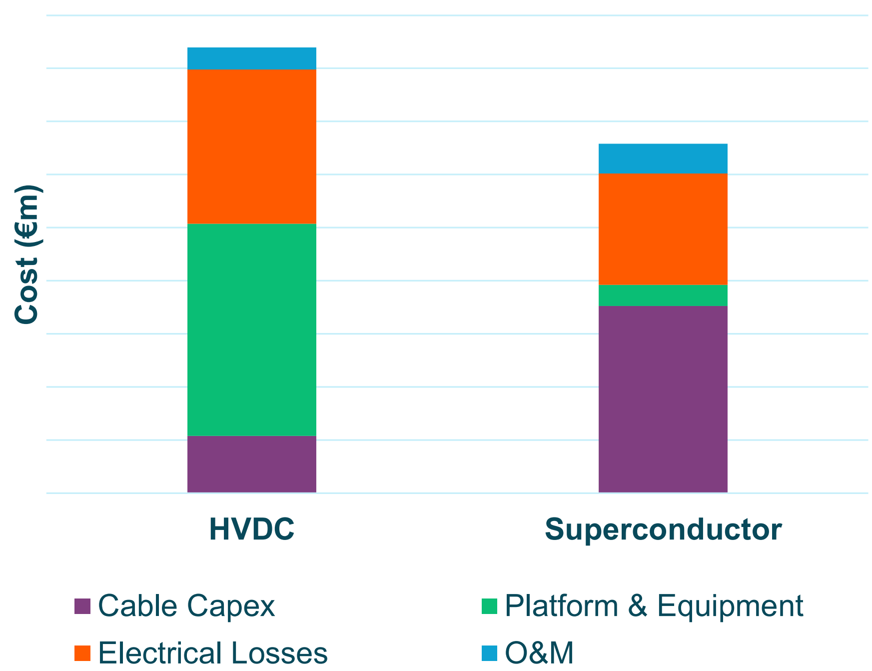
SUPERNODE AS A TECHNOLOGICAL DISRUPTOR

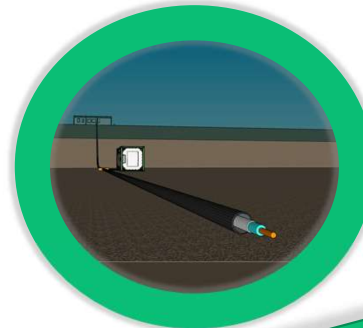
SUPERCONDUCTOR CABLE TECHNOLOGY

- SuperNode is developing superconducting cable systems for bulk power transfer
- SuperNode is developing technology in the areas of cryostats, cryogenics, materials, and transmission

2GW OFFSHORE SYSTEM – 100KM OFFSHORE



SUPERNODE TECHNOLOGY DEVELOPMENT TIMELINE



Prototype validation of HTS Cable System Prototype – performance & reliability verified

SNL Technology Centre for subsystem prototype testing & high-tech manufacturing

Key patents, proof of concept testing for advanced cryostat & thermal systems

2025

2023

2022

2021

2020

2019

Design and manufacture of HTS Cable System Prototype

Benchmark testing – Gen 01 Cryostat HTS

Statement of Feasibility from DNV

Market review & HTS Cable **Technology concept**

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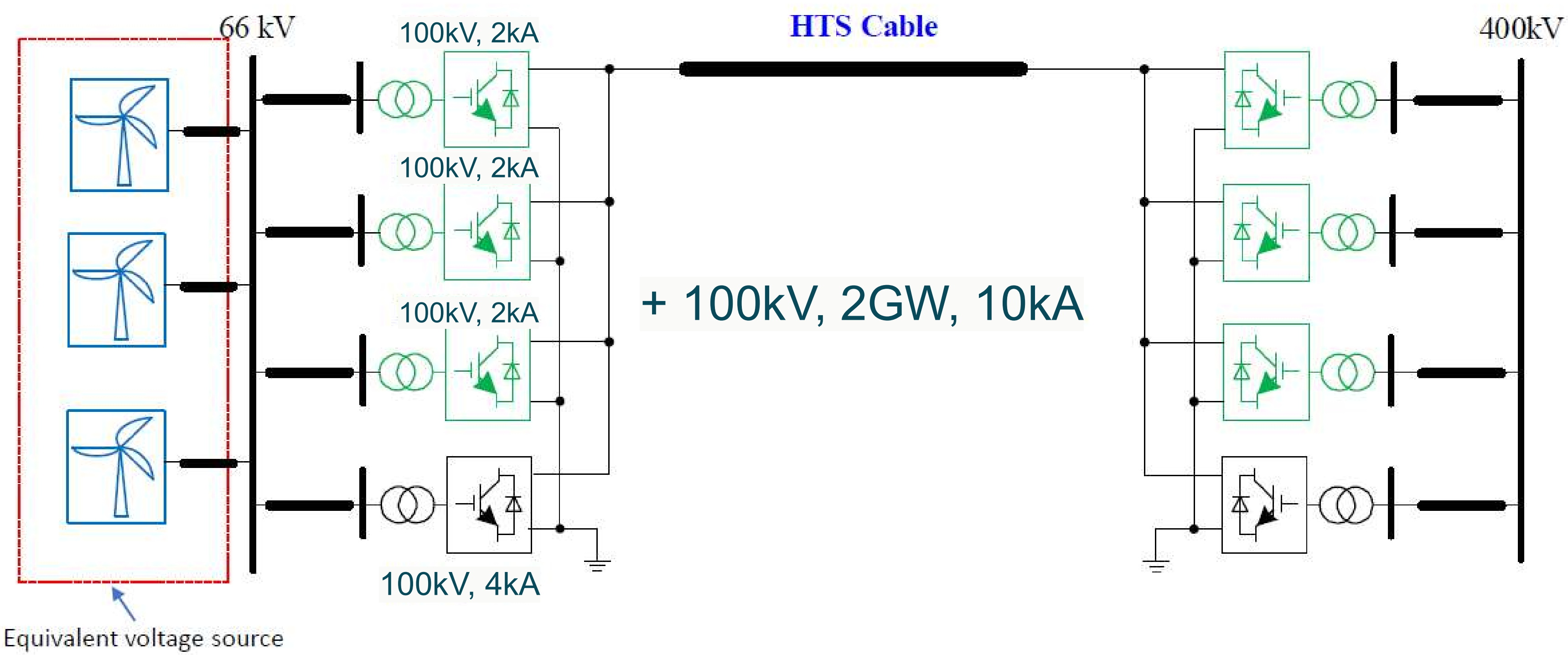
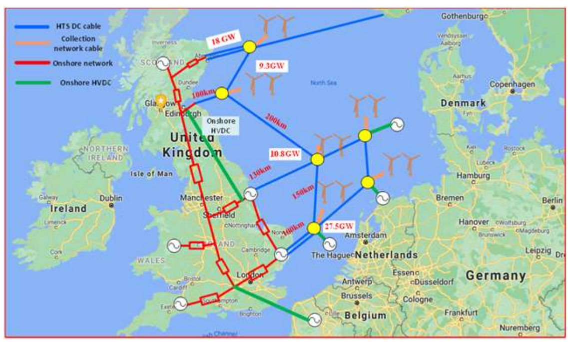
SUPERNODE CABLE INTEGRATION – PARALLEL CONNECTION



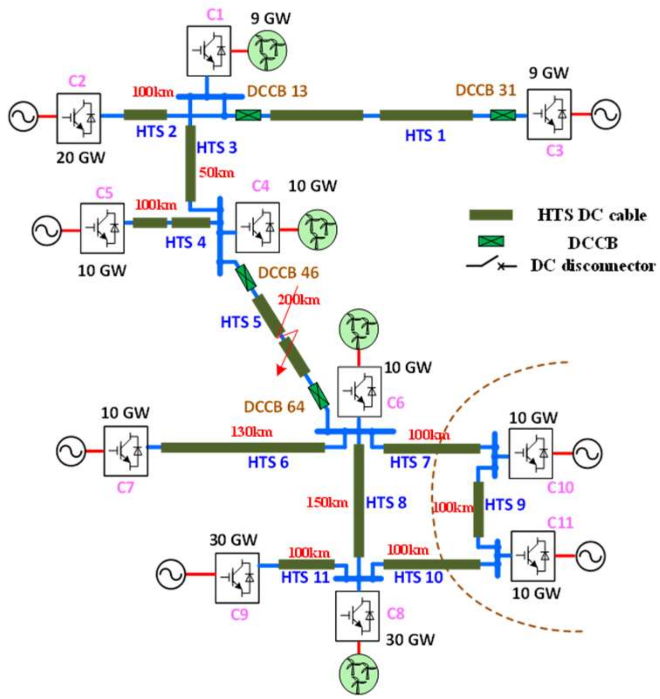
SUPERNODE CABLE INTEGRATION – MESHED GRIDS

SUPERNODE & UNIVERSITY OF STRATHCLYDE ON GOING COLLABORATION WORK

Study based on PROMOTioN 'HUB' concept

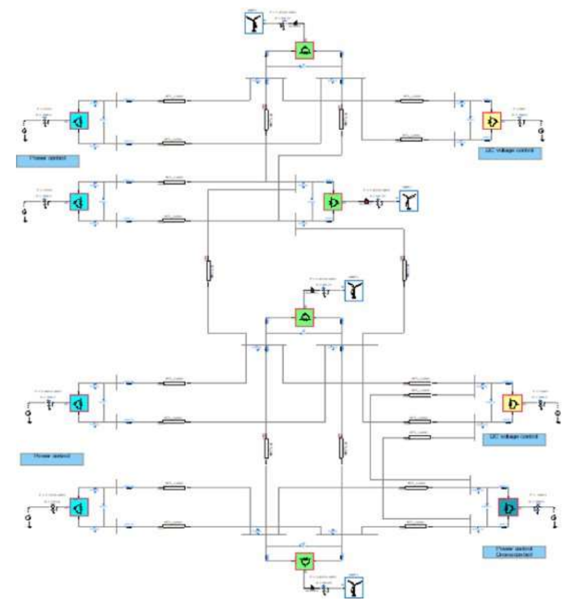


POWER FLOW MODELING AND FAULT PROTECTION STUDY

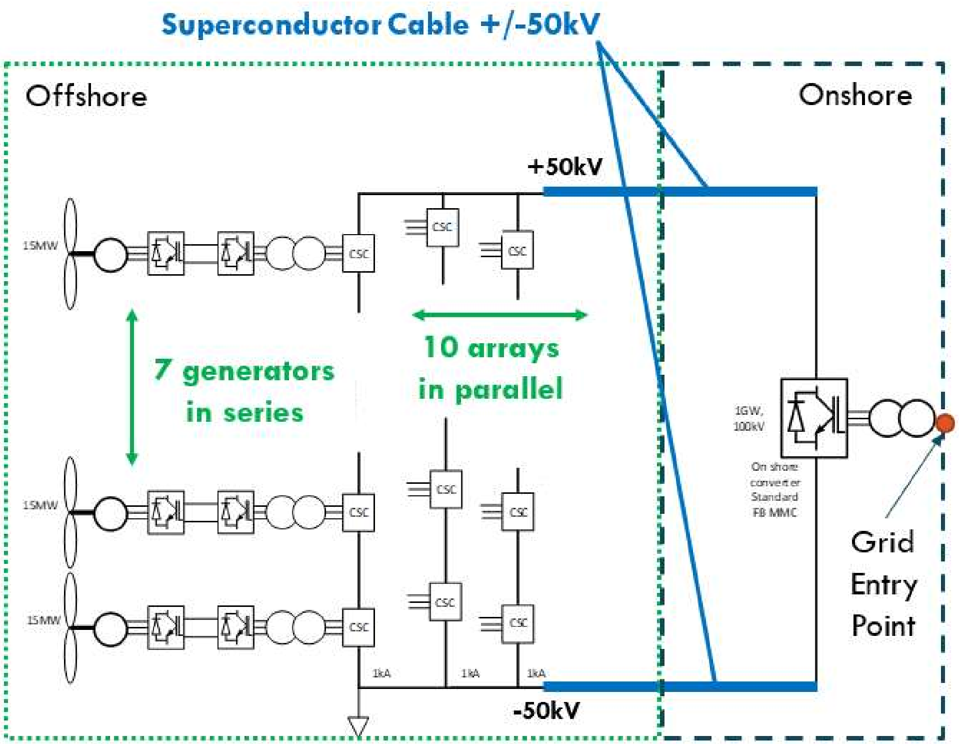


SIMULATION MODEL IN PSCAD

- Evaluated system behavior
- Test performance of control strategy
- Perform DC fault studies



SUPERNODE CABLE INTEGRATION – WTG MATRIX CONNECTION



DC Array with 7 Turbines
- 100MW, +/-50kV, 1kA

System (10 Arrays)
- 1000MW, 70 turbines, +/-50kV, 10kA

Onshore converter
- Full-bridge Modular Multilevel Converter, DC Voltage regulation

PUBLICATIONS

SuperNode & University of Strathclyde *IEEE* – Published

DC Fault Study of a Point-to-Point HVDC System Integrating Offshore Wind Farm using High-Temperature Superconductor DC Cables

Wang Xiang, *Member, IEEE*, Weijia Yuan, Lie Xu, *Senior Member, IEEE*, Eoin Hodge, John Fitzgerald, Paul McKeever, Keith Bell, *Member, IEEE*

Abstract—**This paper presents a feasibility study of an offshore wind farm (OWF) HVDC integration system using high-temperature superconductor (HTS) DC cables. A representative ±100kV/2GW point-to-point OWF HVDC system is proposed including HTS DC cables and two converter stations using modular multilevel converters (MMCs). To be compatible with the high current rating of the HTS cables, each of the offshore and onshore converter stations consists of three MMCs in parallel. To study the interaction between HTS DC cables and MMCs, a multiple lumped π-section model of a HTS DC cable considering electrical and thermal functionality is developed. This paper provides a critical assessment of the proposed HVDC-HTS system, with emphasis on the performance under fast DC fault transients. Detailed simulations presented in this paper reveal that the HVDC-HTS system provides effective current limiting against DC cable short circuit faults.**

Index Terms—**DC fault, HVDC transmission, high temperature superconducting, modular multilevel converter, renewable energy, wind energy.**

I. Introduction

The issues of global warming and climate change have boosted the requirement for renewable energy. Recently, both the *United Kingdom* and the *European Commission* have set targets for net-zero greenhouse gas emissions by 2050 with requirements for carbon-neutral or even carbon-negative electricity supply. As part of the pathway towards that goal, the UK government aims to have 40 GW of offshore wind farm (OWF) capacity operational by 2030. To achieve this, offshore wind power transmission using modular multilevel converter (MMC) based high-voltage direct current (HVDC) technology will play an important role [1][2]. Up to the time of writing, more than ten MMC-HVDC projects have been commissioned globally to integrate OWFs.

With the increased scale of OWFs, the needs for 5 to 20 GW *Pan-European* transmission corridors and HVDC transmission at higher power rating (e.g. 2GW per connection) are emerging. However, conventional HVDC cables are limited in terms of current levels which in turn, limits their power transfer capability (e.g. 700 MW per cable). For this reason, to develop large-scale offshore DC networks, large numbers of DC cables will be required, which are costly, difficult to install and have a significant environmental footprint, an issue of particular sensitivity for when cables are brought onshore [3]-[5]. To increase power transfer capacity, ultra-high voltage HVDC cables (above 600kV) are being developed, but these ultra-high voltages will increase electrical insulation cost and the footprint of converter stations which will have a major impact on cost, particularly for stations on offshore platforms.

One promising solution proposed to address this challenge is to adopt the second-generation high-temperature superconductor (HTS) cables [6][7]. The HTS DC cables have the merits of a very high current capacity, smaller overall size, and higher efficiency. Several superconducting materials are now commercially available at an increasingly affordable price for HTS applications and industrial manufacture [8]-[13].

In reference [9], 1 km of HTS DC power cable is installed in the 80 kV/60MW *Hanlim* line commutation converter (LCC) based HVDC system. Steady-state and DC fault transient studies were carried out on the system. Owing to the current control and the voltage-dependent current limiter (VDCOL) of the LCC rectifier and the unidirectional conduction of the LCC inverter, it was found that the peak value of DC overcurrent was lower than the critical current of the HTS DC cable. Thus, quenching did not occur and the HTS DC power cable was safe during DC faults. A prototype of 100m/3.25 kA/80kV HTS DC cable was further developed in *South Korea* and successfully passed the qualification tests [10]. Reference [11] simulated an LCC-HVDC transmission system incorporating a 300km HTS DC cable, where the HTS DC cable resistance was modeled using a pre-defined piece-wise function of time. Similar to [9], reference [11] also showed that the HTS based LCC-HVDC system can effectively limit the fault currents during DC faults, thereby, providing self-protection capability.

Reference [12] simulated replacement of the line commutation converter (LCC) in [9] by a two-level voltage source converter (VSC). The two-level VSCs and HTS DC cables are modeled using a Real-Time Digital Simulator (RTDS). The steady-state analysis results revealed that the harmonic current generated by VSCs causes an AC power loss in the HTS DC power cable. However, no DC fault studies were reported in [12]. Reference [13] studied the control and modeling of a four-terminal VSC-HVDC system based on HTS DC cables, in which the HTS DC cables were modeled using geometry characteristics provided by the *Electric Power Research Institute* (EPRI). However, this model is not generic and cannot be applied to HTS DC cables with other design configurations. Reference [14] undertook an economic evaluation of integration with OWFs. It is shown that a two-stage DC collector grid, which consists of a ±2.5 kV cluster collector network using conventional DC cables and a ±20 kV wind park collector network using HTS DC cables, together with a ±150 kV HTS HVDC transmission system offers reduced losses and is cost-competitive with respect to AC connection systems. In June 2019, it was reported that the *Nexans* company successfully completed qualification tests on a 30m/10kA/320kV HTS cable, which was developed as part of the EU-funded *Best Paths* project [15].

As can be seen from above literature review, most of the existing publications focus on the steady-state, DC fault transient studies and qualification tests of the HTS DC cables

SuperNode & University of Aberdeen – accepted for publication Q4 2021

Assessment of interconnection options for 1GW remote offshore wind farm utilising superconducting HVDC cable without offshore platform

Preferential subjects addressed: 2b, 2c

Dragan Jovcic	Peng Li	Eoin Hodge,	John Fitzgerald,
d.jovcic@abdn.ac.uk	peng.li@abdn.ac.uk	eoin.hodge@supernode.energy	john.fitzgerald@supernode.energy
University of Aberdeen Aberdeen, UK	University of Aberdeen Aberdeen, UK	Supernode Ltd, Dublin, Ireland	Supernode Ltd, Dublin, Ireland

Abstract

This paper analyses feasibility and benefits of using superconducting DC cables for interconnecting large and remote offshore wind farms. The study has shortlisted 4 feasible offshore topologies for energy conversion assuming 1GW wind farm, using 100kV superconducting cable. It is presumed that offshore platforms will not be needed with any of the topologies and considers conventional, 15MW, type 4 generators where possible.

Topologies 1 and 2 consider parallel connection of wind generators, and the initial design study shows excellent efficiency and operating flexibility. Topology 1 employs only one converter bridge, but gearbox is needed for the generator and transformer will be large. It is concluded that the converter in topology 1 requires large number of IGBT modules (600 approximately), and this has consequences for the costs and poses challenges with the converter size. Topology 2 employs AC/DC bridge and another DC/DC converter, all located in the generator tower, and simulation demonstrates good performance and efficiency.

Topologies 3 and 4 utilise 10 arrays with 7 generators series connected in each array. The study shows that only 42 IGBTs and 42 diodes are needed for the main bridge, and it is proposed to use platforms to enable transmission-level insulation. The operation at variable power is simulated and it is confirmed that reverse power flow on individual machines is also possible. The topologies with series-parallel offshore connection have disadvantage in operating flexibility and may result in lower efficiency, or power curtailment or require some overdesign.

The study concludes that superconducting DC cable technology brings benefits in lowering transmission voltage, and facilitating higher currents at low losses, which simplifies and reduces costs of the collection systems for large offshore wind farms.

SuperNode & University of Aberdeen - Research paper under peer review by the *Electric Power System Research Journal*

Title :

Analysis of Bidirectional 15MW Current Source DC/DC Converter for Series-Connected Superconducting-Based 1GW/100kV Offshore Wind Farm

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