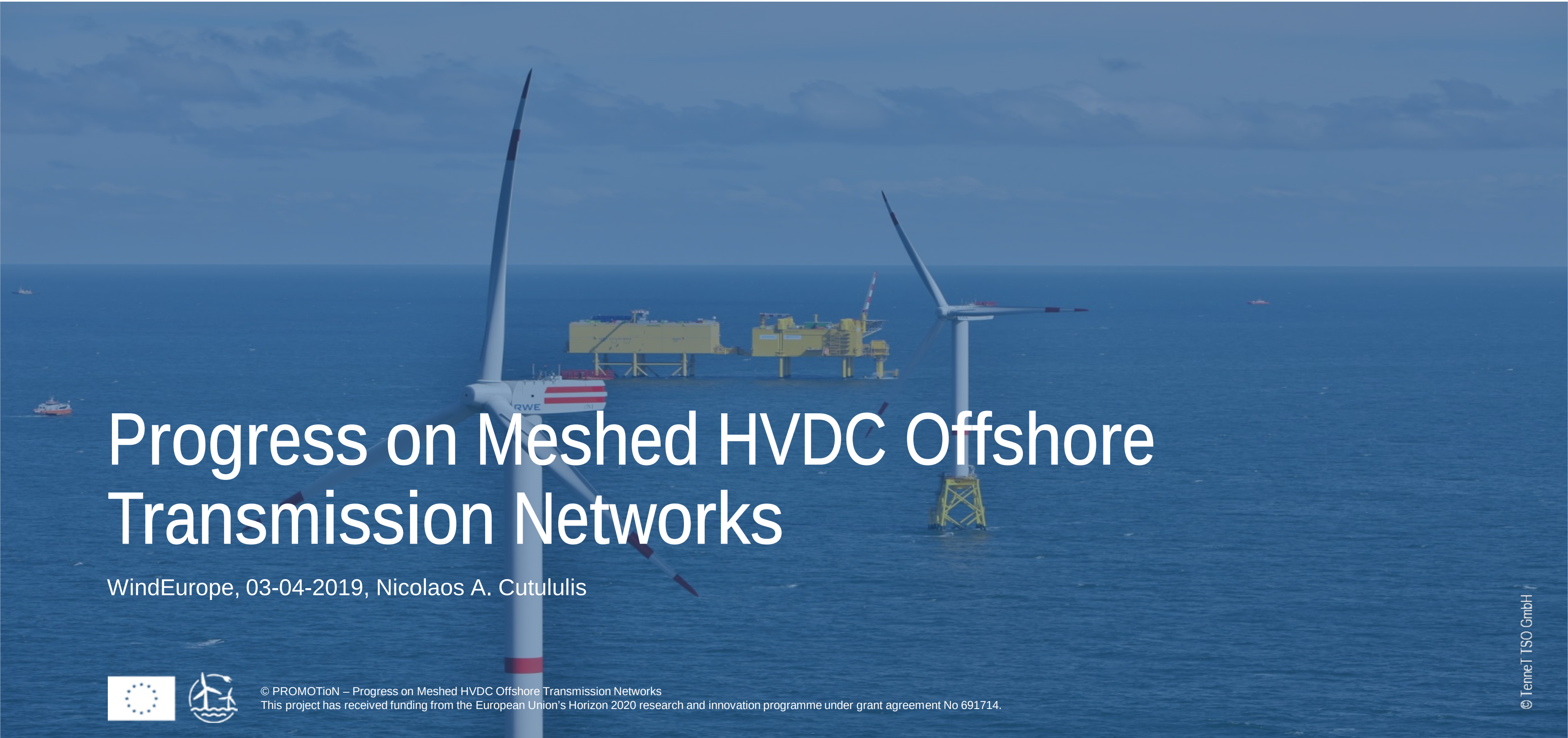
PROMOTiON
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



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Progress on Meshed HVDC Offshore Transmission Networks

WindEurope, 03-04-2019, Nicolaos A. Cutululis

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

European Commission Energy Strategy 2030

40%	32%	27%	15%
Cut in greenhouse gas emissions compared to 1990 levels	Share of renewable energy consumption	Energy savings compared with the business-as-usual scenario	Electricity interconnection target

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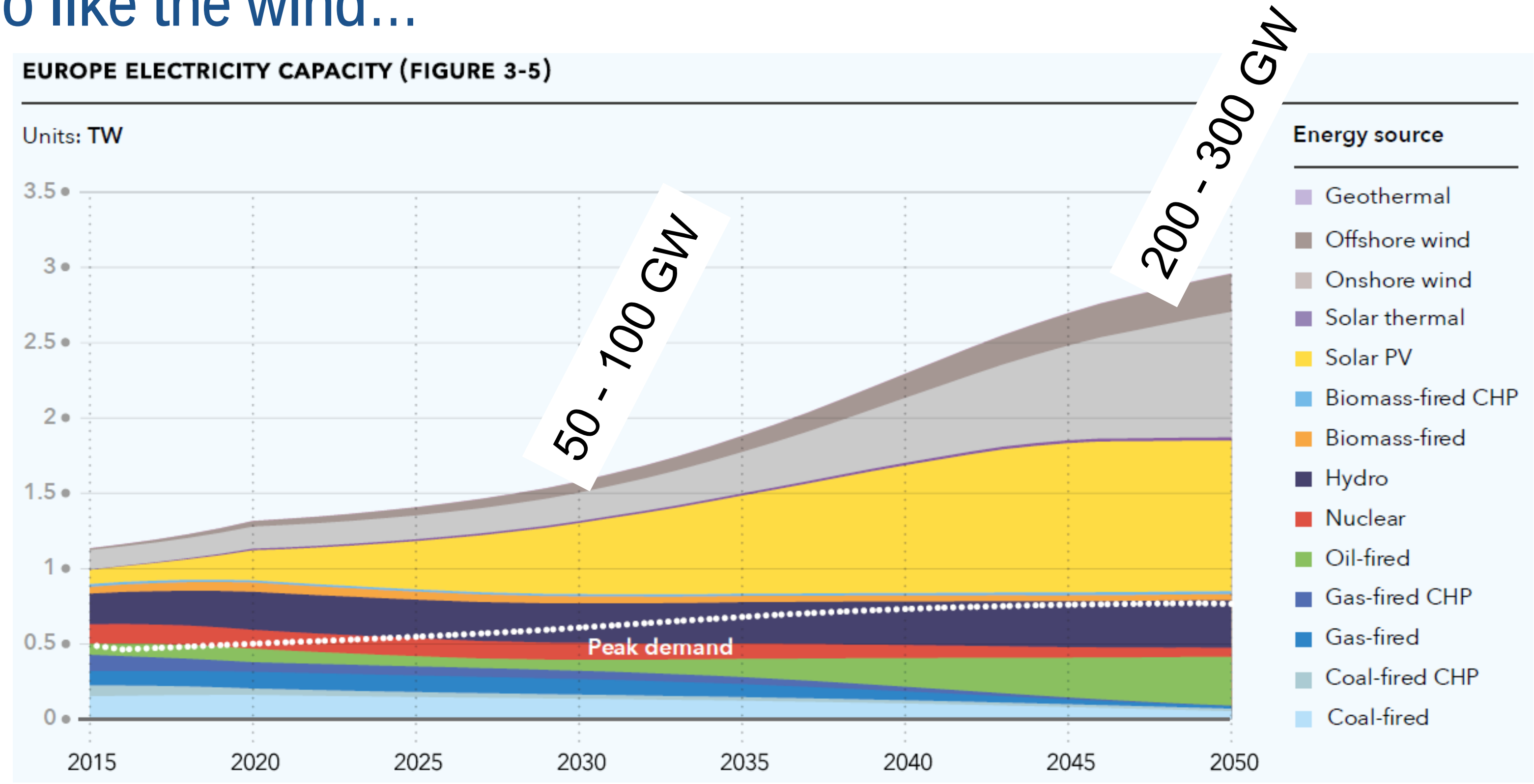
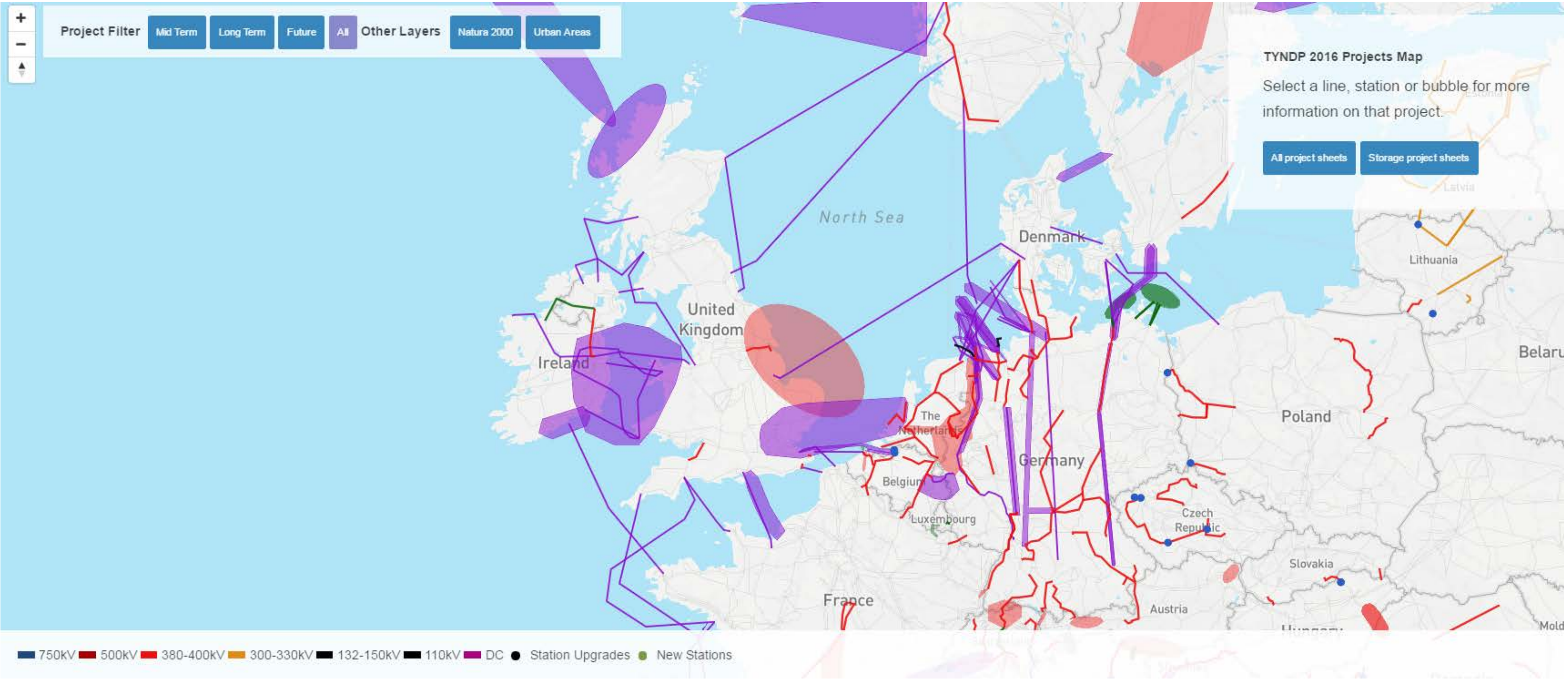
Go like the wind…



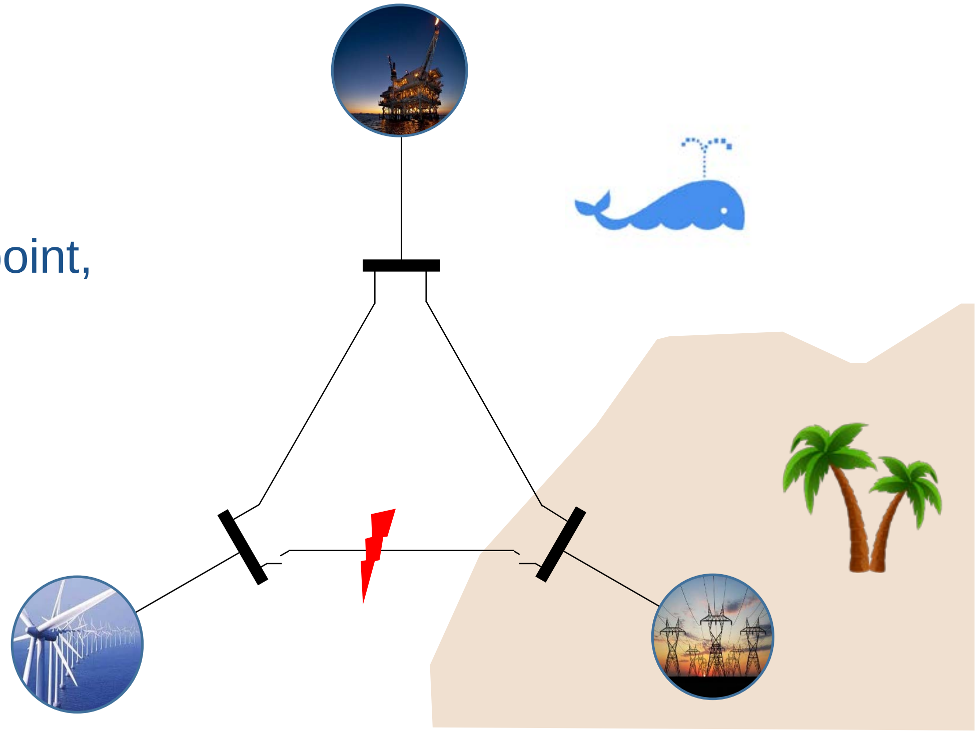
Source: DNV GL - Energy Transition Outlook

New Transmission Infrastructure



Why a meshed grid?

- Different types of offshore users
  - Consumers
  - Producers
  - Interconnectors
- Traditionally connected point-to-point, dedicated connection
  - Lower utilisation
  - Reliability offshore
- Mesh offers benefit



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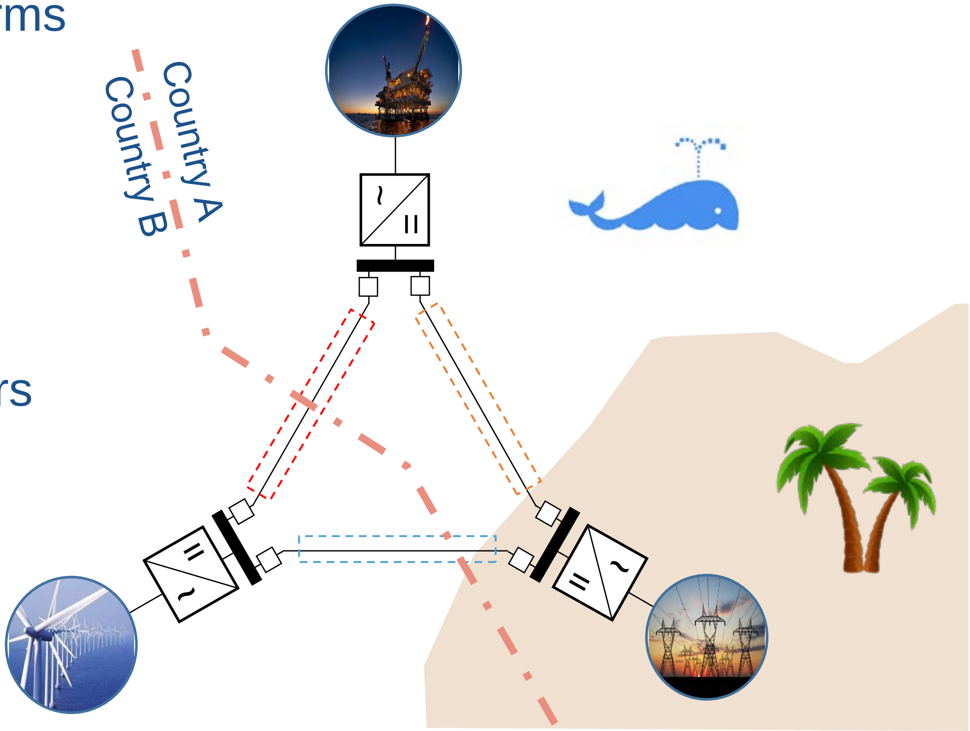
Challenges

- Offshore requires cables & platforms
- Long cables require HVDC
- HVDC requires converters
- HVDC network requires HVDC control & protection system
- HVDC protection system requires HVDC switchgear / circuit breakers
- Transnational network
  - Regulatory differences
  - Business models
  - Governance
  - Financing



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Objectives

1. Identify **technical requirements** and investigate possible **topologies** for **meshed HVDC offshore grids**
2. Develop **protection schemes** and **components** for HVDC grids
3. Establish components' **interoperability and initiate standardisation**
4. **Demonstrate** cost-effective offshore HVDC equipment
5. Develop recommendations for a coherent EU and national **regulatory framework** for HVDC offshore grids
6. Develop **recommendations for financing mechanisms** for offshore grid infrastructure deployment
7. Develop a **deployment plan** for HVDC grid implementation

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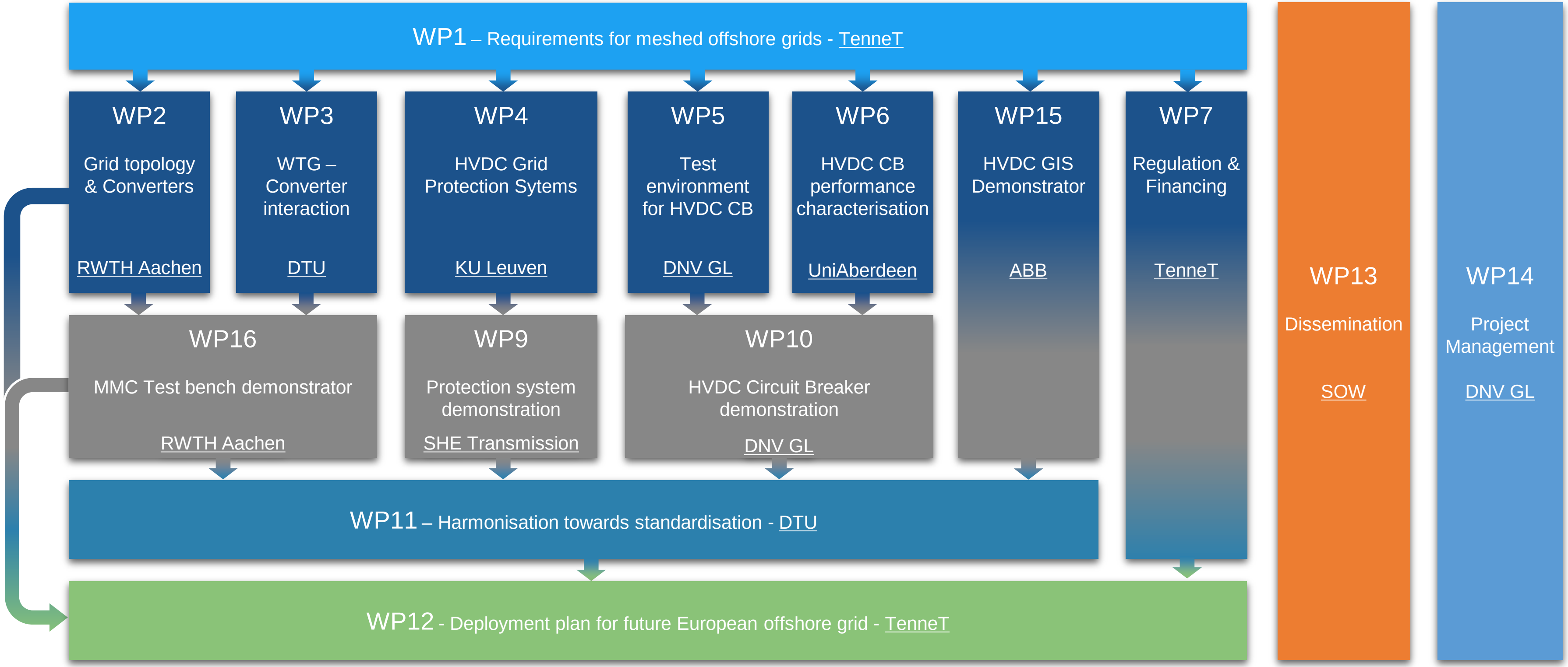
PROMOTioN Project organisation

Work packages



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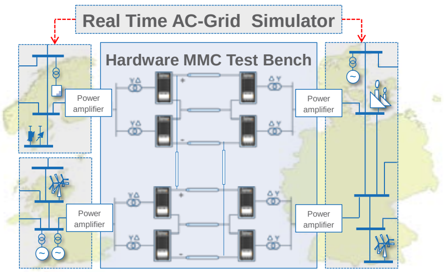
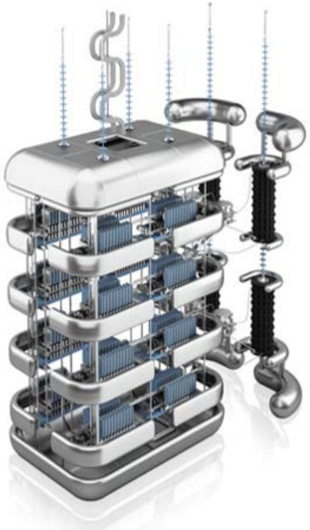
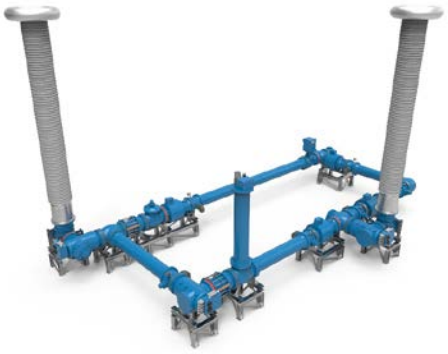
Demonstrators







HVDC network control

MMC test bench
RWTH Aachen
Aachen, Germany

HVDC network protection

Multi-terminal test centre
SHE Transmission
Glasgow, UK

HVDC circuit breakers

KEMA High Power Lab
DNV GL
Arnhem, Netherlands

HVDC gas insulated system

KEMA High Voltage Lab
DNV GL
Arnhem, Netherlands

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Statistics

33 partners

11 countries

4 years

42 million EUR

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Partners

TenneT Taking power further

sse

ENERGINET DK

Rte

SVENSKA KRAFTNÄT

EIRGRID

ABB

MITSUBISHI ELECTRIC

SIEMENS

GE

Prysmian Group

SCiBreak Enabling the Supergrid

MHI VESTAS OFFSHORE WIND

DNV·GL

TRACTEBEL Engineering GDF SUEZ

DEUTSCHE WINDGUARD

Ørsted

Statoil

RWTH AACHEN UNIVERSITY

UNIVERSITY OF ABERDEEN

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

KTH VETENSKAP OCH KONST

DTU

KU LEUVEN

TU Delft

rijksuniversiteit groningen

European University Institute

University of Strathclyde

STIFTUNG OFFSHORE WINDENERGIE

CARBON TRUST

T&D europe

FGH

SuperGrid Institute

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WTG Control capability evolution

Grid Following	Grid Supporting	Grid Forming
P Control	ω Support	ω Control
Q Control	V Support	V Control
Require powered grid	Require powered grid	Islanded operation SCR=0
High SCR	Low SCR	Zero Inertia
High Inertia	Low Inertia	Shared control effort

Increasing percentage of PE based renewable energy →

Source: Prof. R. Blasco-Jimenez, UPV
rblasco@upv.es

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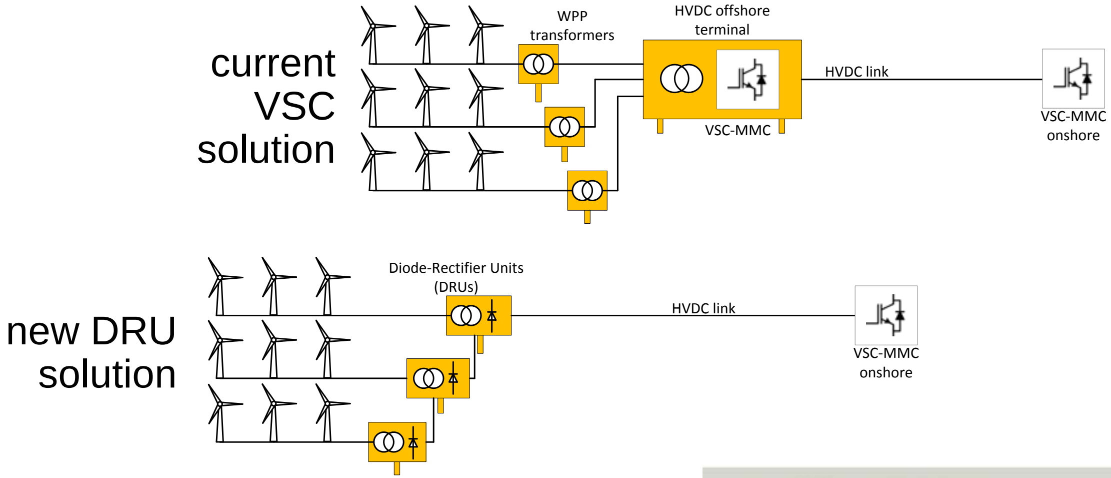
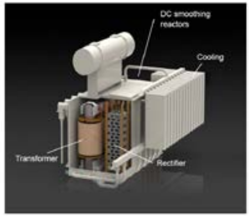
Diode Rectifier Units as offshore HVDC



Key features of the Modular Diode Rectifier Unit

- Encapsulated, rugged equipment
- Bio degradable and flame retardant insulation
- Simple and robust power electronics
- Small platform with easy transport and installation
- High reliability, minimal maintenance
- No offshore DC converter as single point of failure
- Flexible offshore installation options due to modular rectifier concept



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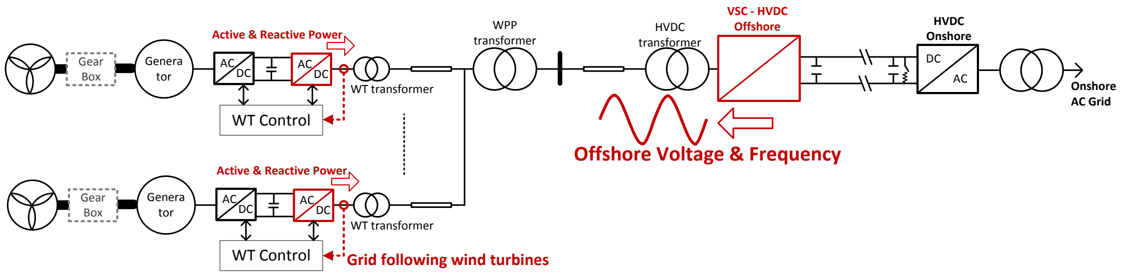
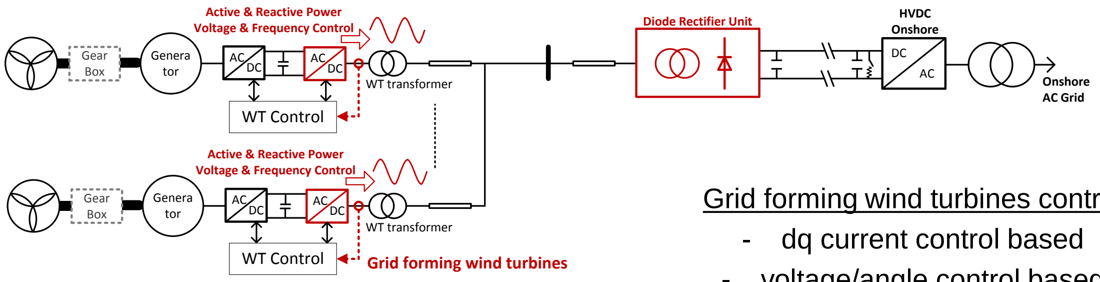
Grid Forming Wind Turbines





<u>Grid forming wind turbines control</u>

- dq current control based
- voltage/angle control based
- GPS synchronization based
- master/slave based

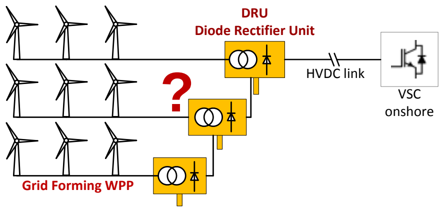
Objectives

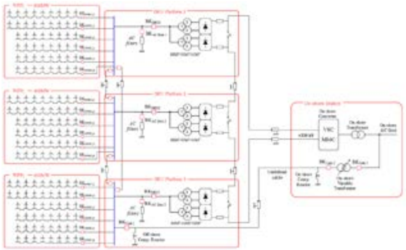
Objective 1
Define functional requirements to OWFs

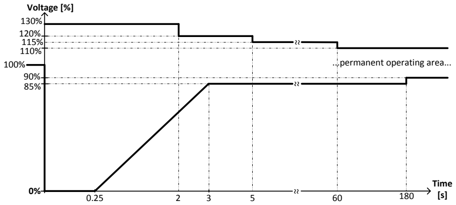
Objective 2
Develop test cases & control algorithms

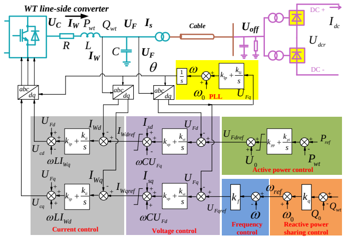
Objective 3
Define & apply compliance evaluation

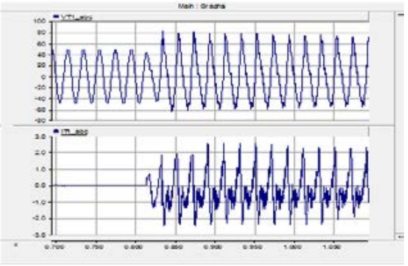
Objective 4
Recommend grid code requirements



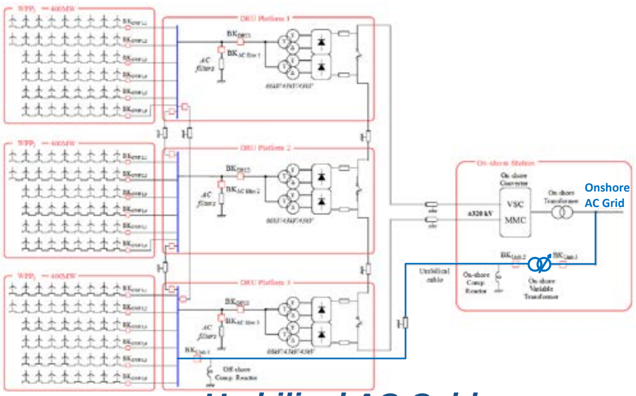




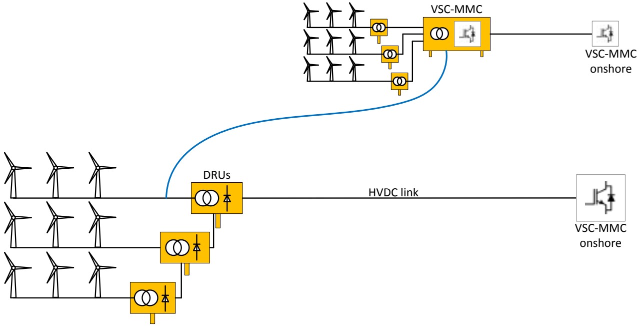




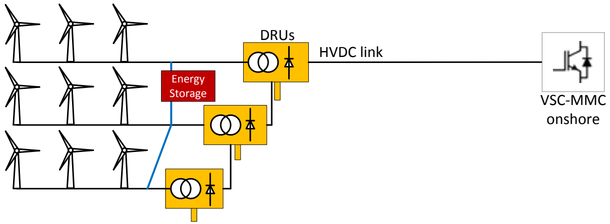
Offshore AC Grid Start-up Options



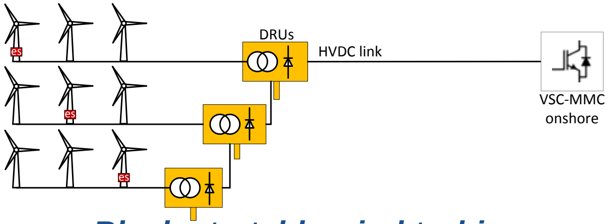
Umbilical AC Cable



Nearby VSC-HVDC (or AC)



Local Energy Storage (e.g. battery, diesel)



Black-startable wind turbines

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Some results – AC grid start-up (string connection)

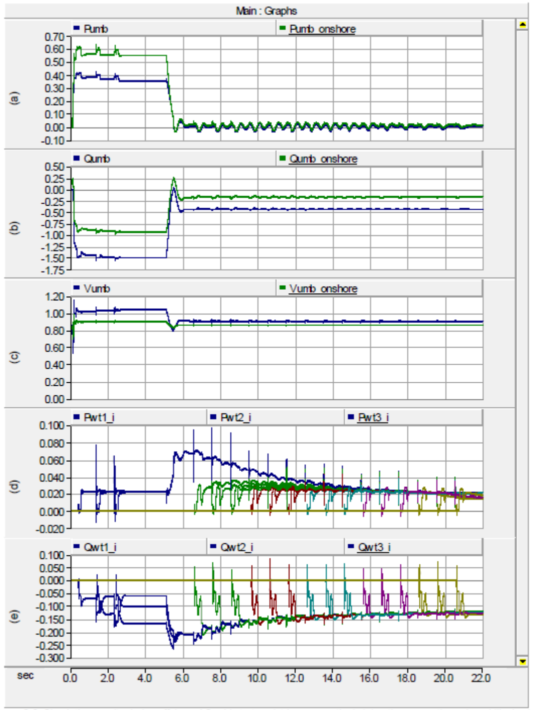
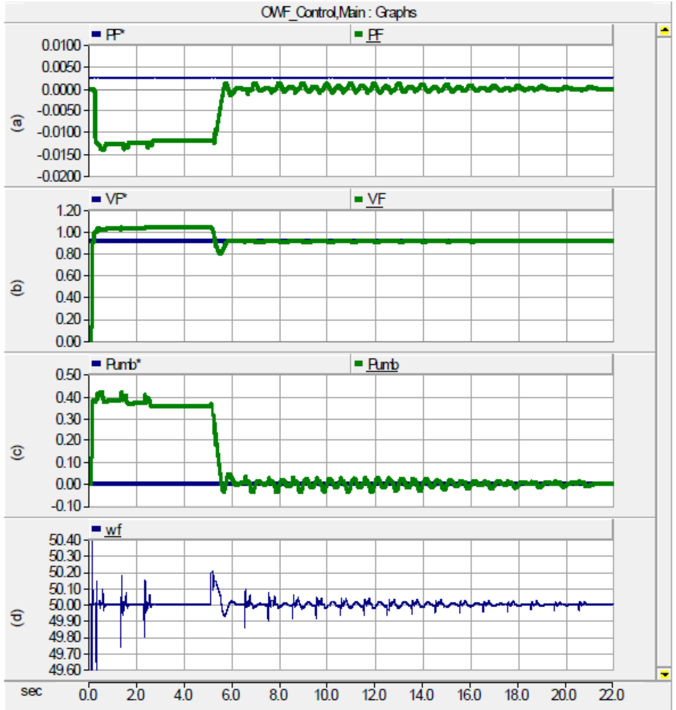
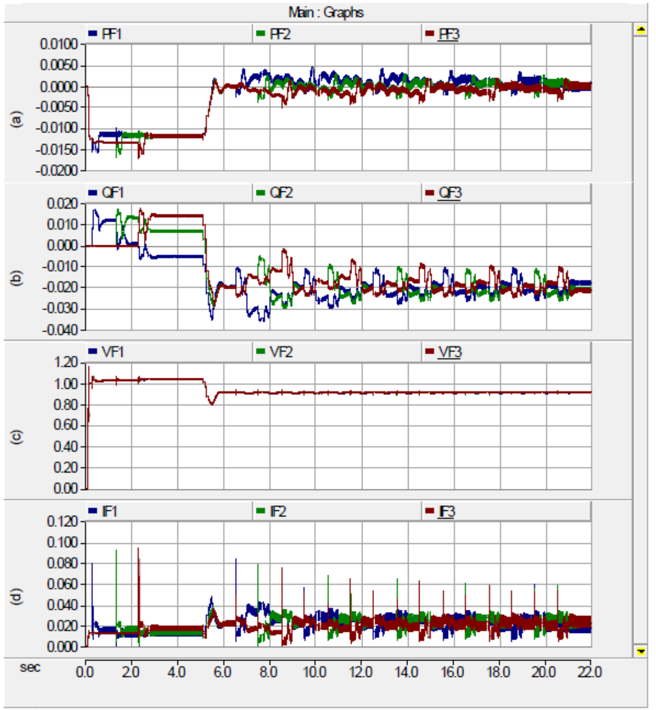


Figure 2-6: Simulation results during offshore AC grid start-up (string connection): (a) active power through umbilical cable measured at umbilical offshore and on-shore ends; (b) reactive power through umbilical cable measured at offshore and on-shore ends; (c) offshore and on-shore AC voltages; (d) WTG active power P_{WT-ij}; (e) WTG reactive power Q_{WT-ij}.



gure 2-7: Simulation results during offshore AC grid start-up (string connection): (a) total OWF active power; (b) offshore voltage V_{F1}; (c) active power through the umbilical cable; (d) frequency of the offshore AC grid.



igure 2-8: (d) Simulation results during offshore AC grid start-up (string connection): (a) active power delivered by each /F-i; (b) reactive power generated by each OWF-i, (c) voltage at terminals of each DRU platform; (d) current through ea OWF-i.

www.promotion-offshore.net, Deliverable 3.4: Results on control strategies of WPPs connected to DR-HVDC

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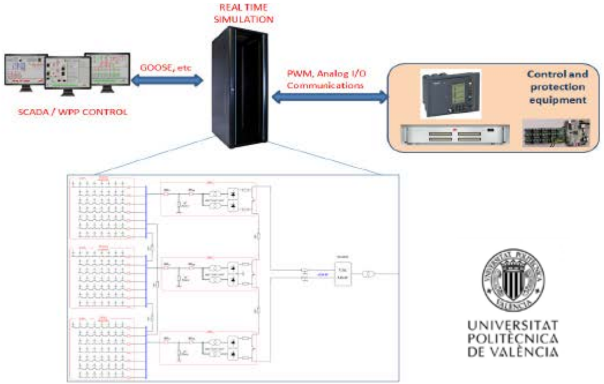
Next steps - Demonstrator

- CHIL validation (WP16 – DNV-GL, RWTH Aachen, UPV):
  - DRU connected grid forming wind power plants
  - Black start for HVAC connected wind power plants
  - Black start for HVDC connected wind power plants
  - HVDC grid connected WPPs



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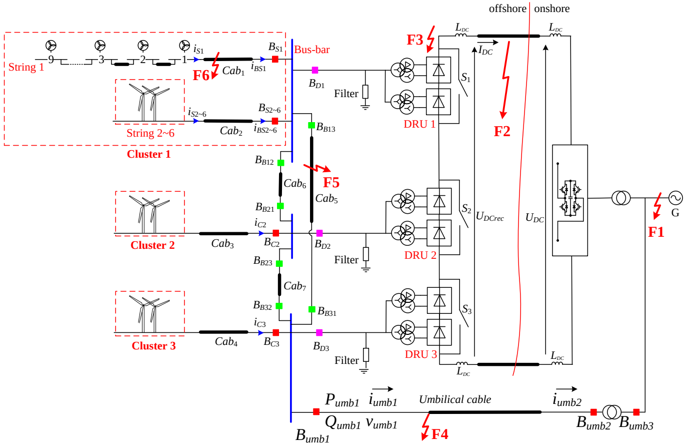
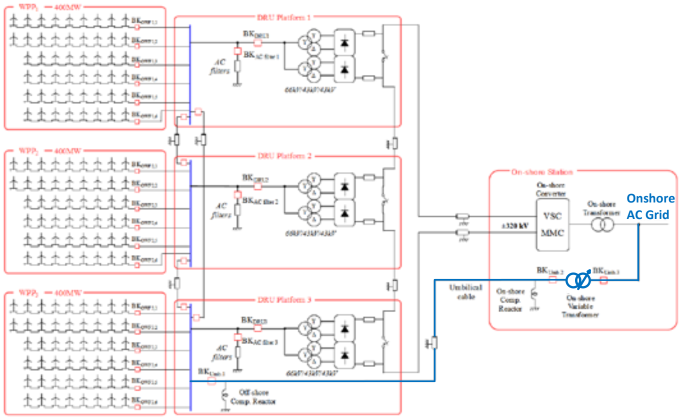
WP3 Preliminary list of Recommendations for Requirements DRU-HVDC connected WPPs

- **Grid forming WTs for DRU connection**
  - Energization
  - Operational ranges (e.g. V, f, df/dt)
  - Control gains (e.g. droop, reserve)
  - Onshore and offshore FRT (100% Power-Electronics)



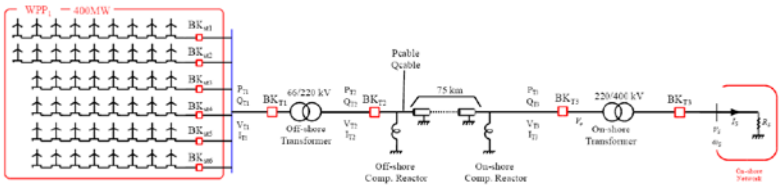


https://www.promotion-offshore.net/fileadmin/PDFs/D3.1_PROMOTioN_Deliverable_3.1_Detailed_functional_requirements_to_WPPs.pdf
https://www.promotion-offshore.net/fileadmin/PDFs/D3.4_PROMOTioN_Results_on_control_strategies_of_WPPs_connected_to_DR-HVDC.pdf

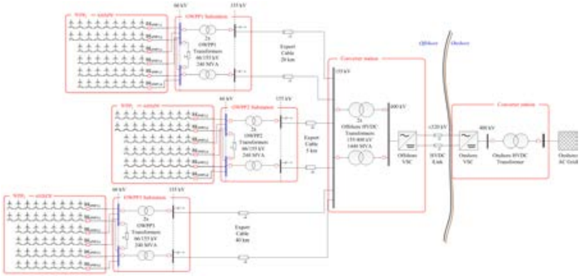
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

WP3 Preliminary list of Recommendations for Requirements HVAC & VSC-HVDC connected WPPs

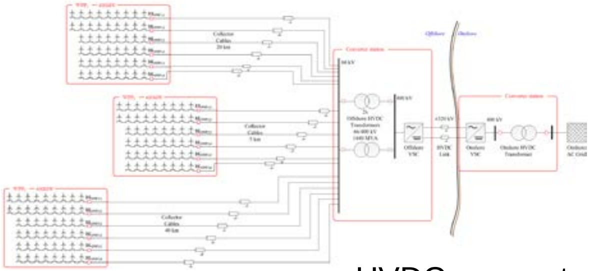
➢ **Self-Energization and Black Start requirements for OWPPs**



HVAC-connected OWPP



HVDC-connected OWPP(s)
with AC collector substation(s)



HVDC-connected OWPP(s)
directly (66kV) connected to the HVDC

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APPENDIX

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