Grid Integration of Renewables

InnoDC Project H2020

Marie Sklodowska-Curie funding European Union Horizon 2020 research & innovation

KIC Master Course

20 October 2020

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INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Motivation

- United Nations’ Sustainable Development Goals

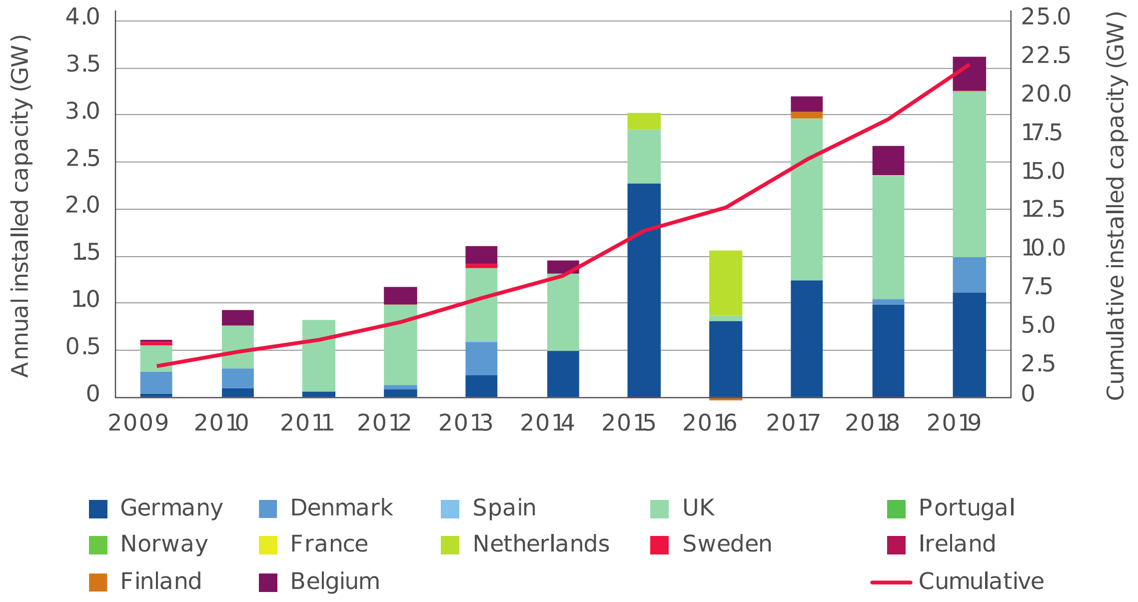
Combating climate change and its impacts, Paris Agreement at COP21

- Europe’s Energy Transition over the next 20-40 years

Targets by 2020, 2030 and 2050

- Increasing share of renewable energy resources in Europe, especially offshore wind energy
- Challenges in the operation of offshore grids and hybrid AC/DC systems

Annual of offshore installations by country (left axis) and cumulative capacity(right axis)



Source: WindEurope

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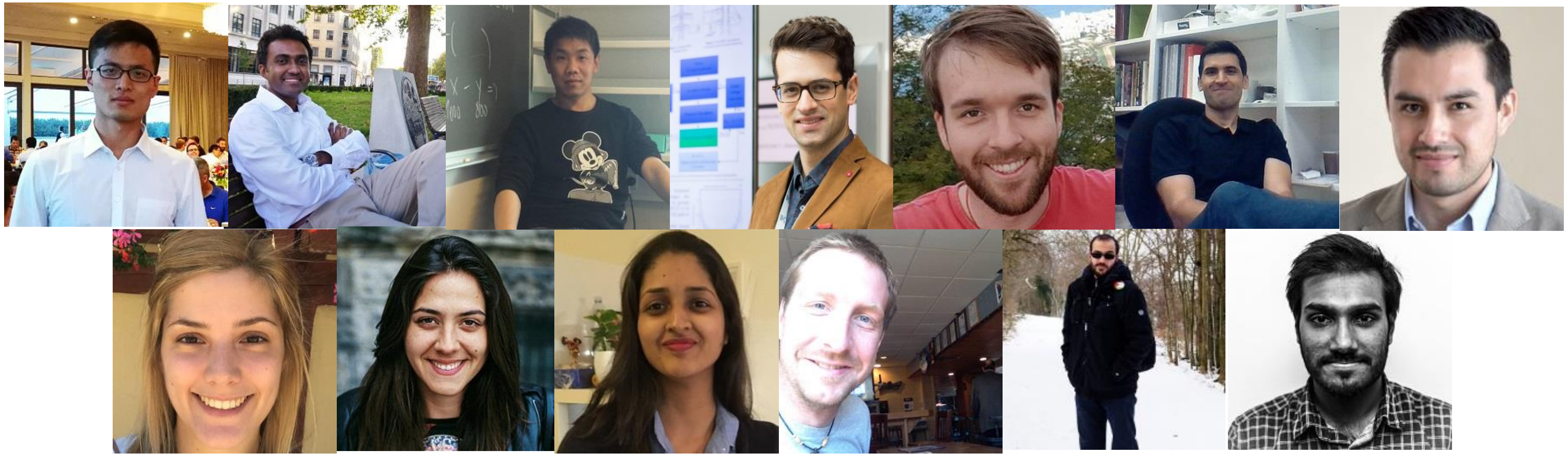
Objectives

- To find innovative solutions to contribute to practical installation and operation of DC grids for offshore wind power
- To develop the most appropriate models and methods to study and manage future offshore grids and hybrid AC/DC systems
- Research outcomes are of direct use to the developers of (computational) tools and services
- To develop a pool of researchers in this in-demand field (offshore wind and DC grids) by providing them with both technical and personal and communication skills, innovative mind-set, entrepreneurship, and leadership and management skills
- Enhance the collaboration between EU universities and companies



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InnoDC Project - Partners

6 x Countries - 15 x Partners

Start: 01/09/2017
End: 31/08/2021

University Beneficiaries:

- Cardiff University
- Universitat Politècnica de Catalunya
- Universidad Do Porto
- Danmarks Tekniske Universitet
- Katholieke Universiteit Leuven

Non-academic Beneficiaries:

- CINERGIA, Spain
- EFACEC, Portugal
- Ecole Central de Lille
- ELIA, Belgium

Partner organisations (training & secondments):

- Vattenfall
- Toshiba
- Friends of the Supergrid
- Enersynt Belgium
- China Electric Power Research Institute
- Red Eléctrica de España

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Research topics

Connection and integration

Control

Stability

Protection

Device perfomance

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Connection and integration

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Cost Effective Solutions for Offshore Wind Transmission

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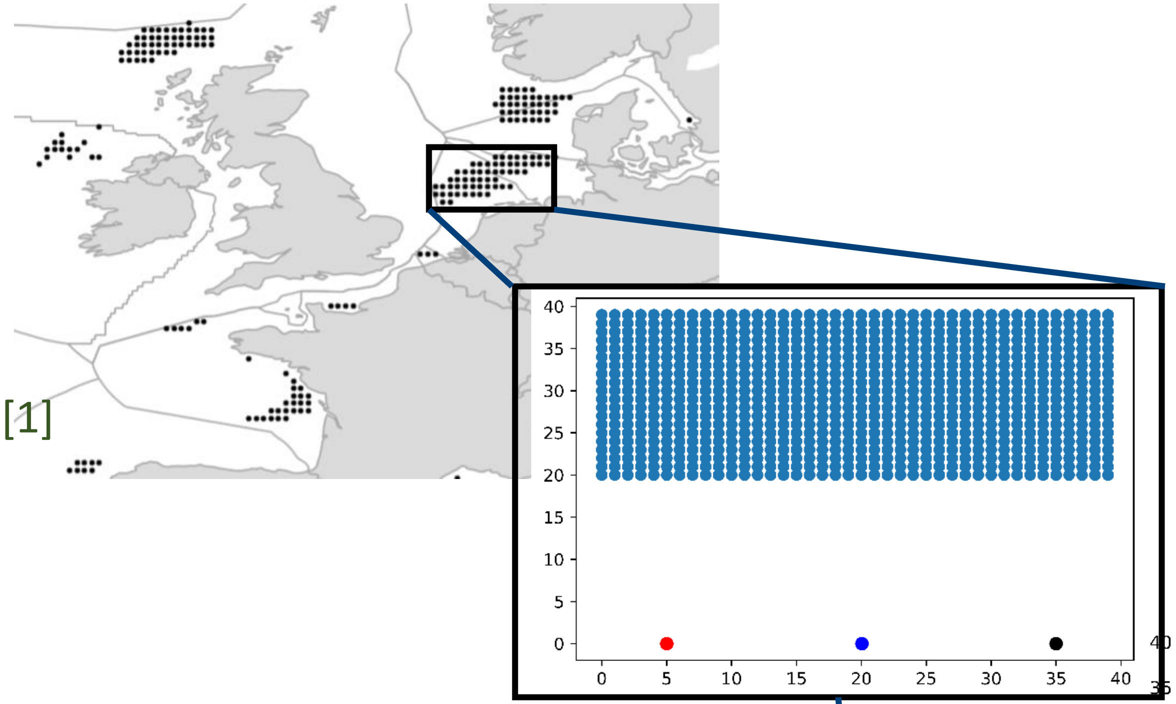
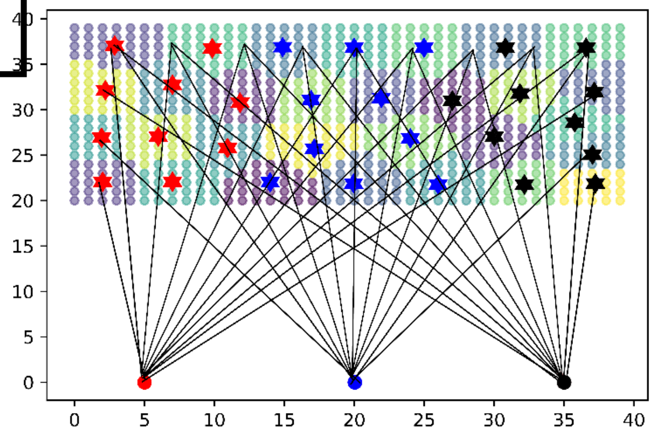
Problem Overview



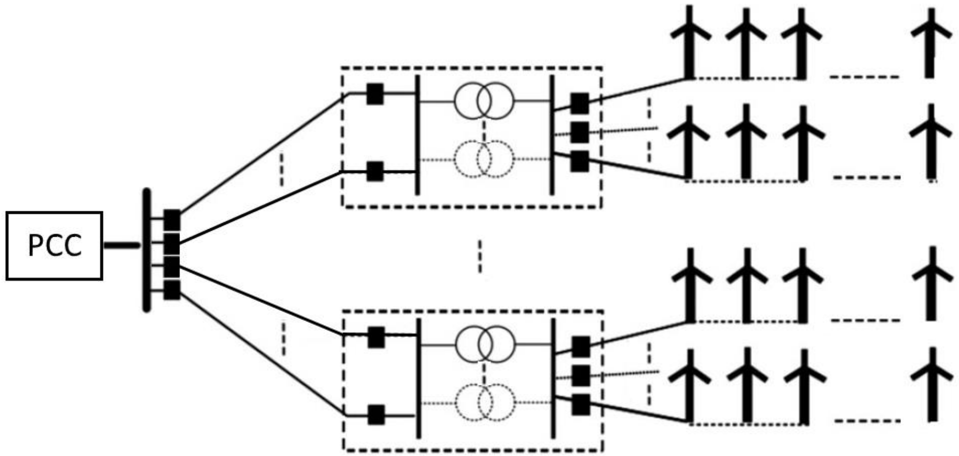
[1]

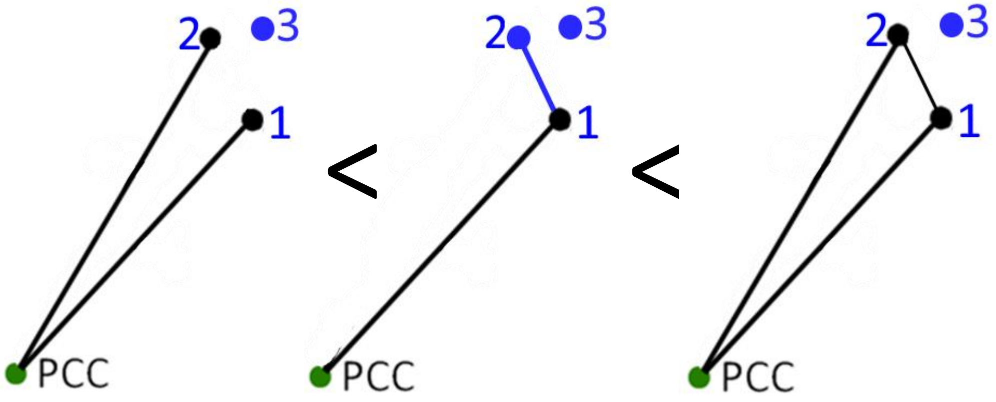
How to find the Optimal HV Transmission Topology?

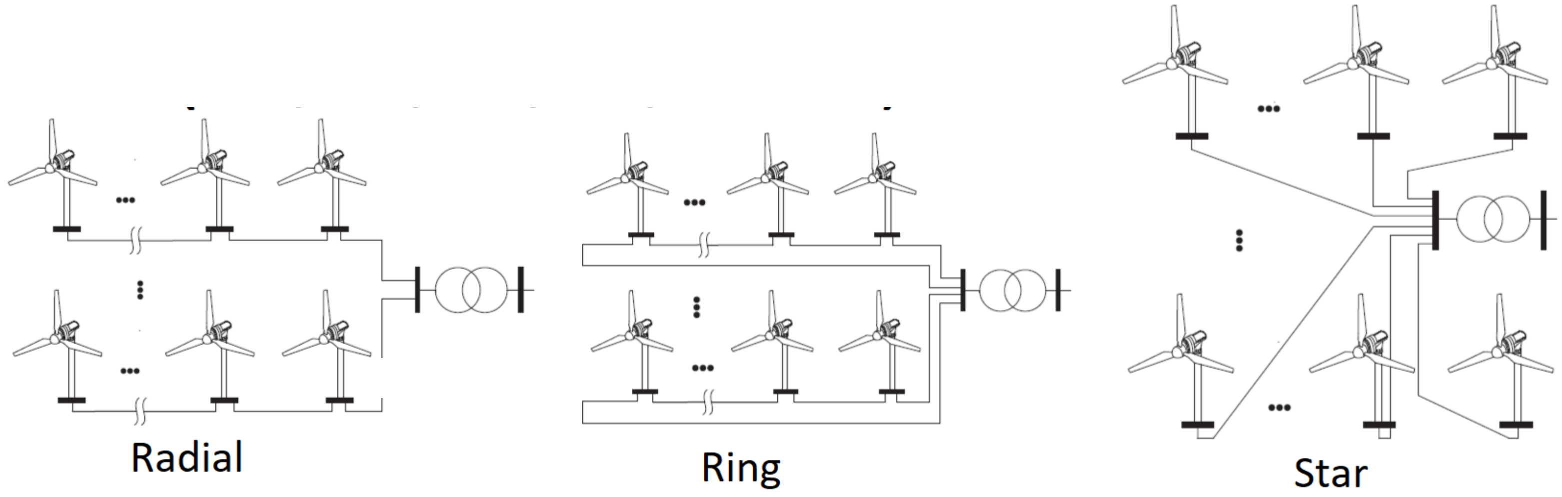


[1] Supplementary material for "Assessing the Economic Value of Renewable Resource Complementarity for Power Systems: an ETSO-E study". Radu et al.

Medium/High Voltage Topologies

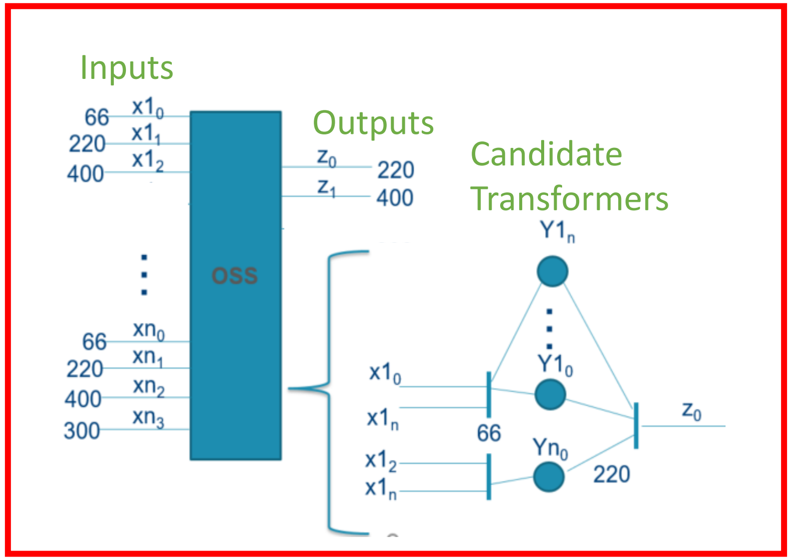






Optimization

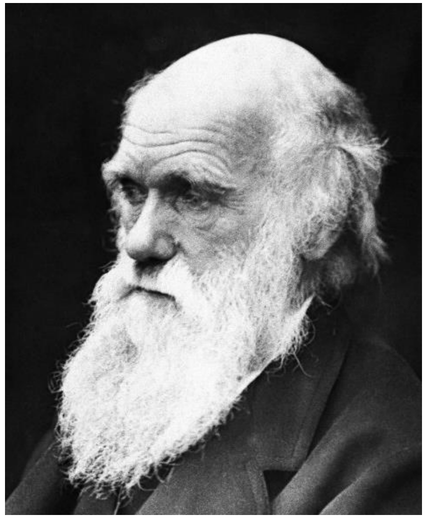
Constraint Programming



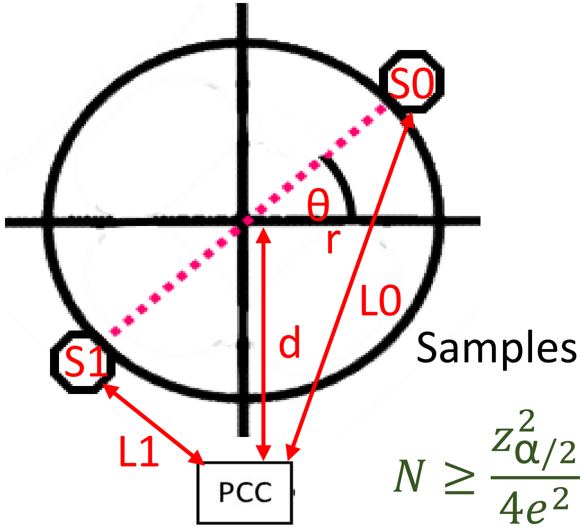
Problem Size →

← Optimality Guarantee

Heuristics



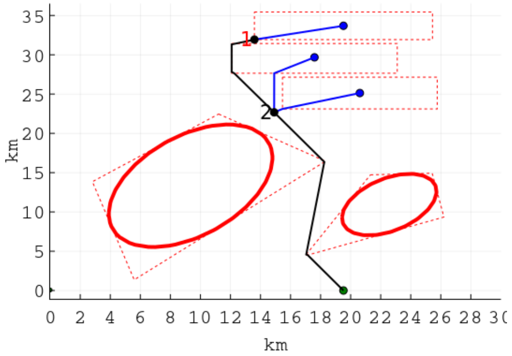
Data Driven – M.L.



$$N \geq \frac{z^2_{\alpha/2}}{4e^2}$$

Error (e)	α	N
0.01	0.01	16513

Route Finding



Convex Optimization

Greedy Search

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HV Transmission Topology Optimization

Pre-Process

Route finding Algorithm A* approximates relative layout considering Marine environment.

Radial Problem Size Reduction

Constraints obtained via M.L. filter possible radial connections.

Greedy Search

Optimal radial topology consisting of a single export cable is obtained.

Meshed Problem Size Reduction

Constraints obtained via M.L. filter possible meshed connections.

Finalize Topology

Optimal meshed and >1 export cable radial Topologies obtained.

DC Collection Systems for Offshore Wind Collector Systems

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Why DC collection systems

- Lower collection system cable losses over MVac cables
- Required only 2 cables to export power
- Use of dcWTs could eliminate bulky 50/60 Hz power transformers
- Increase power density of WTs with the increase of single WT capacity

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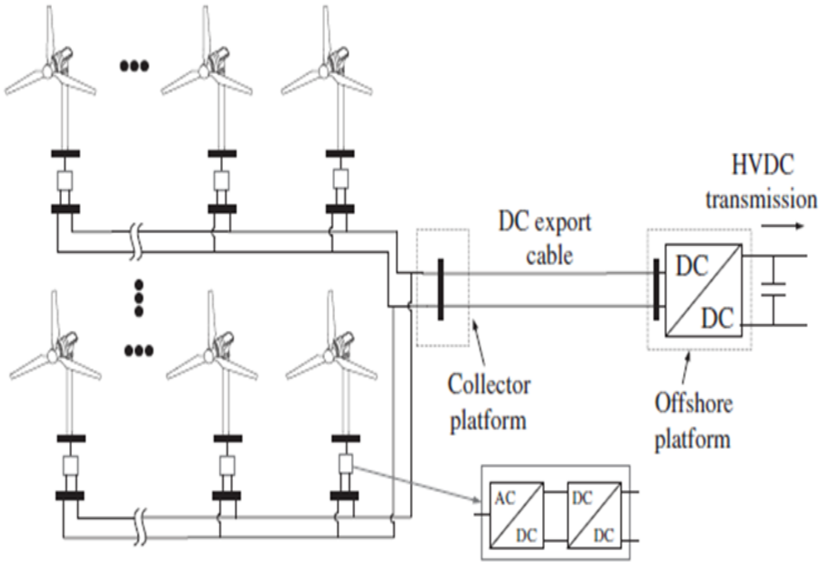
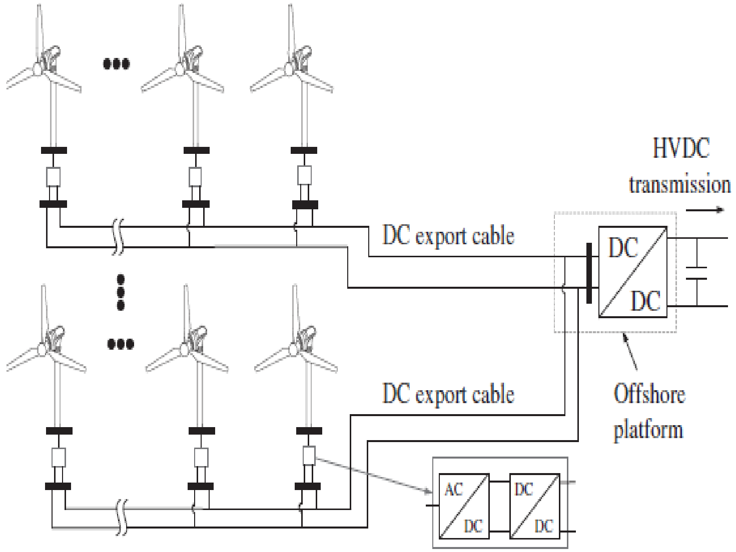
Offshore Wind dc Collection Systems

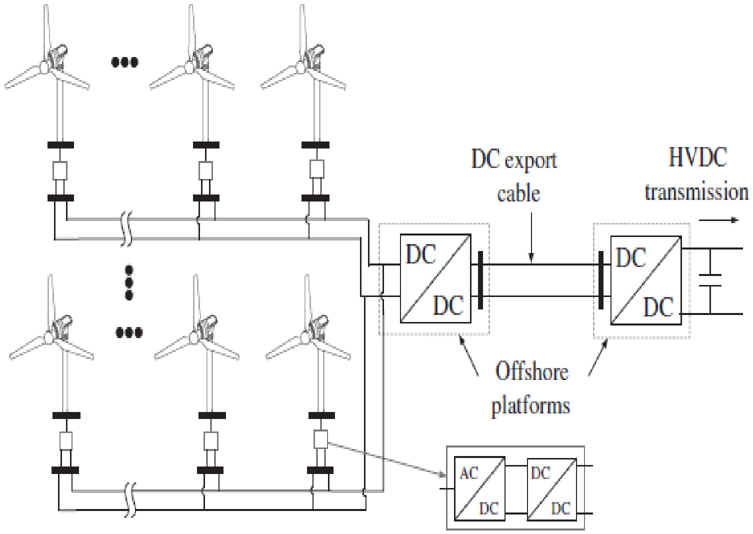
Shunt Topologies



(a)



(b)



DC/DC power converter in the intermediate offshore platform to reduce cable losses

(c)

Dirk Van, Hertem, Gomis-Bellmunt Oriol, and Liang Jun. "Offshore Wind Power Plants (OWPPs)." In *HVDC Grids:For Offshore and Supergrid of the Future*, 528: Wiley-IEEE Press, 2016.

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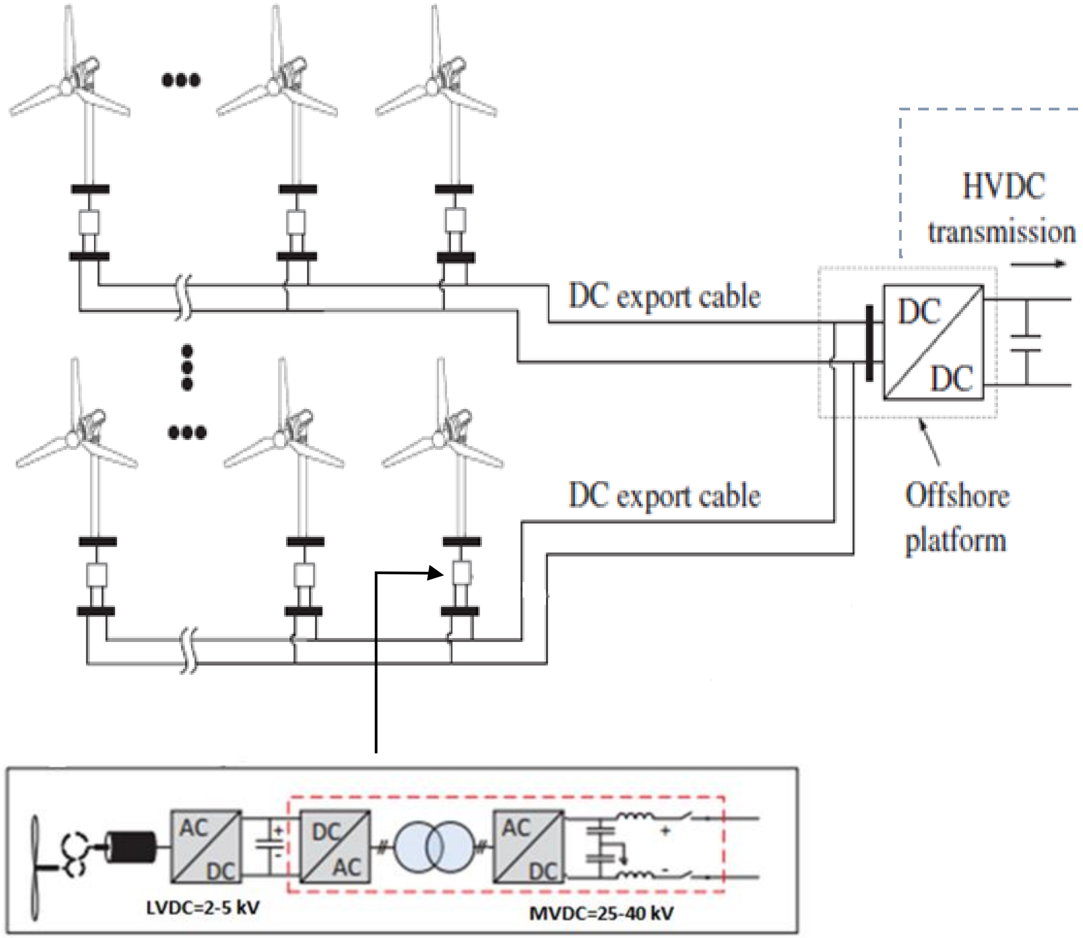
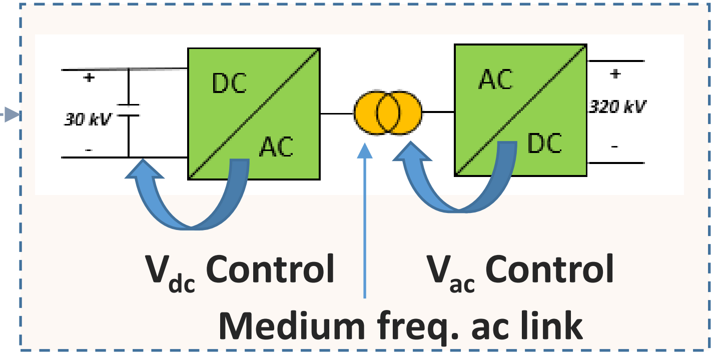
Key Research Questions

- Identification of reliable dc collection systems from the pool candidates
- Which converter topology is best suit for offshore dc collection platform in terms of reliability and cost
- Impact of cable network reliability in reliability assessment of Offshore wind farms
- Identification of suitable dcWT configuration based on physics-of-failure and mission profile

Offshore wind dc Collection systems



V_{dc} Control P Control – MPPT or P*



DC Collection System Platform

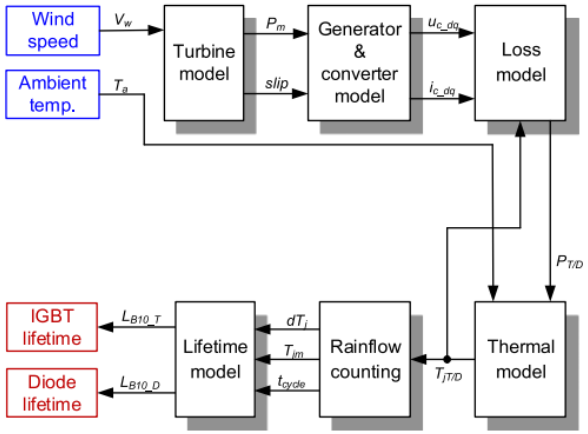
2L
3L-NPC
MMC

MMC

Reliability Methods

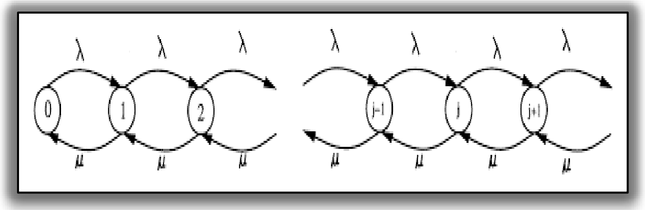
dcWT

Physics-of-failure based PE devices reliability analysis with different mission profiles



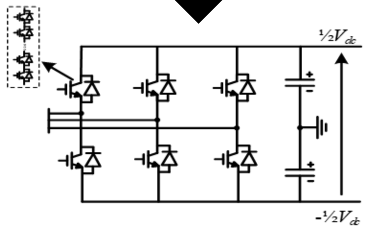
Collection System

Time-homogenous Markov Chain models

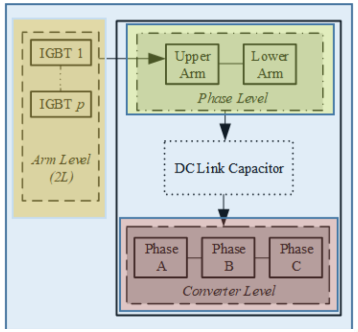


Collection Platform

Reliability Block Diagram(RBD) based analysis



a) Two Level VSC



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Tools for techno-economic analysis of transmission systems for offshore wind power plants

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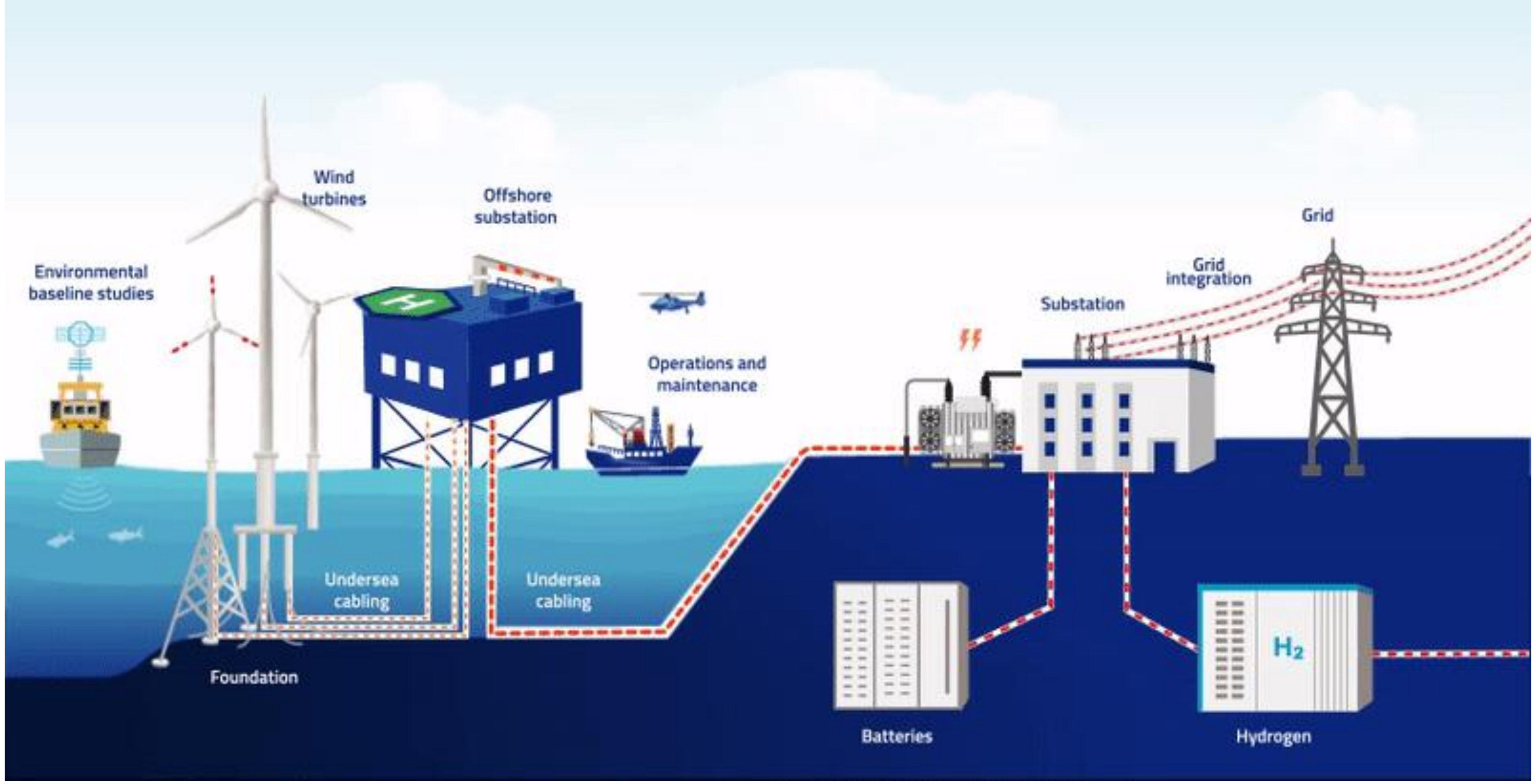
Objectives



Development of a tool for technical and economic comparison analysis of the different transmission systems including all aspects as technology, efficiency, reliability and availability of components

Source: Worley https://www.worley.com/what-we-do/our-markets/new-energy/wind

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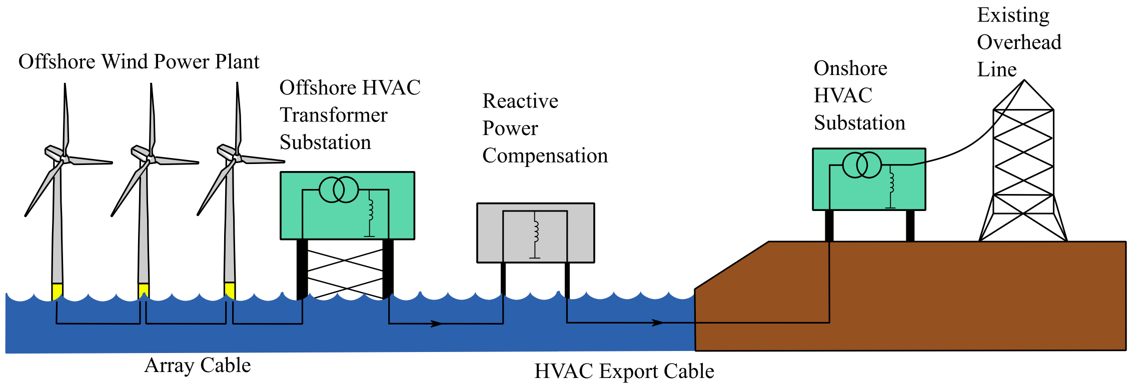
HVAC vs HVDC

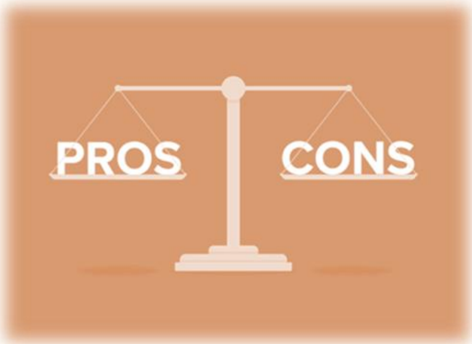


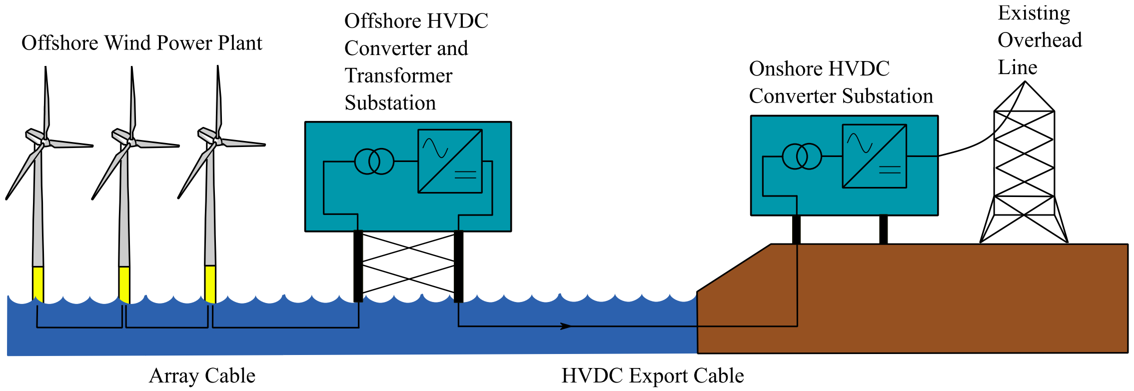
Well known technology

Reactive power compensation

Limited transferred power

Long distances





Cost

DC breakers

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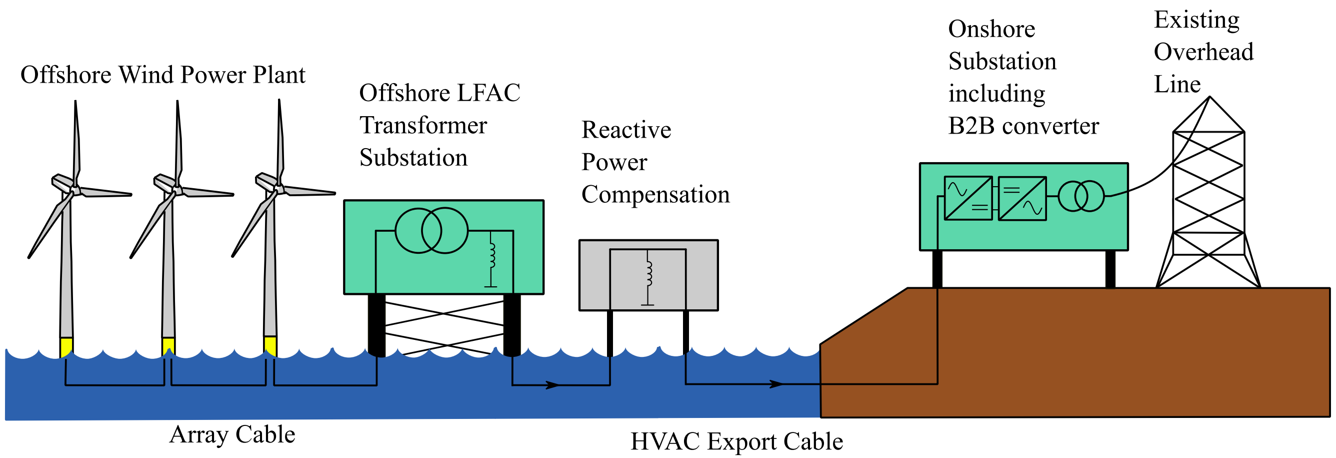
Low-frequency technology



Lower charging current and reactive power

Possibility of using AC breakers

Core of transformer is bigger

Cost of B2B converter

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Defining initial parameters

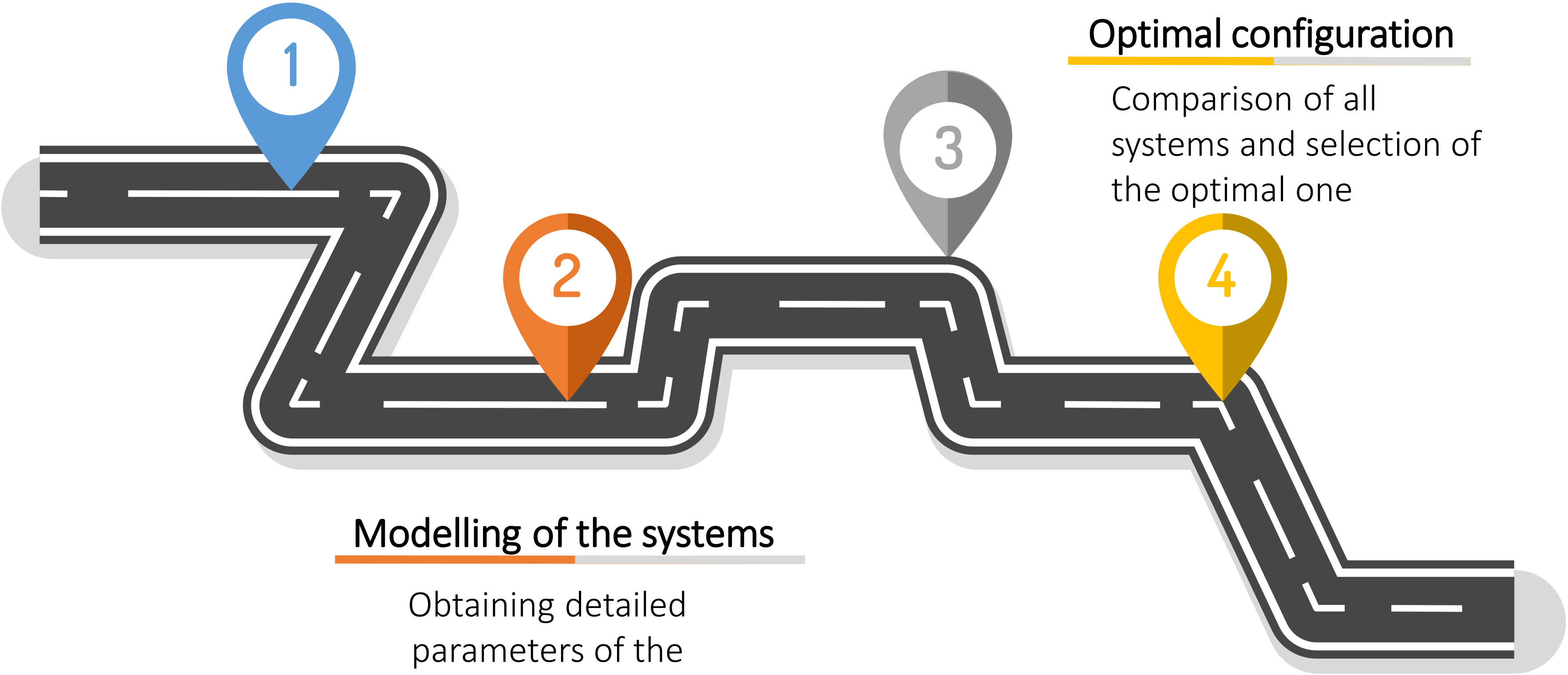
OWPP rated power
Transmission distance
Grid parameters

Optimization of the system

Minimizing power losses and cost of components while complying with operational limits and calculation of total cost

Optimal configuration

Comparison of all systems and selection of the optimal one



Modelling of the systems

Obtaining detailed parameters of the components and its cost functions

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Reliable operation of hybrid AC/DC power systems in different time frames under uncertainty

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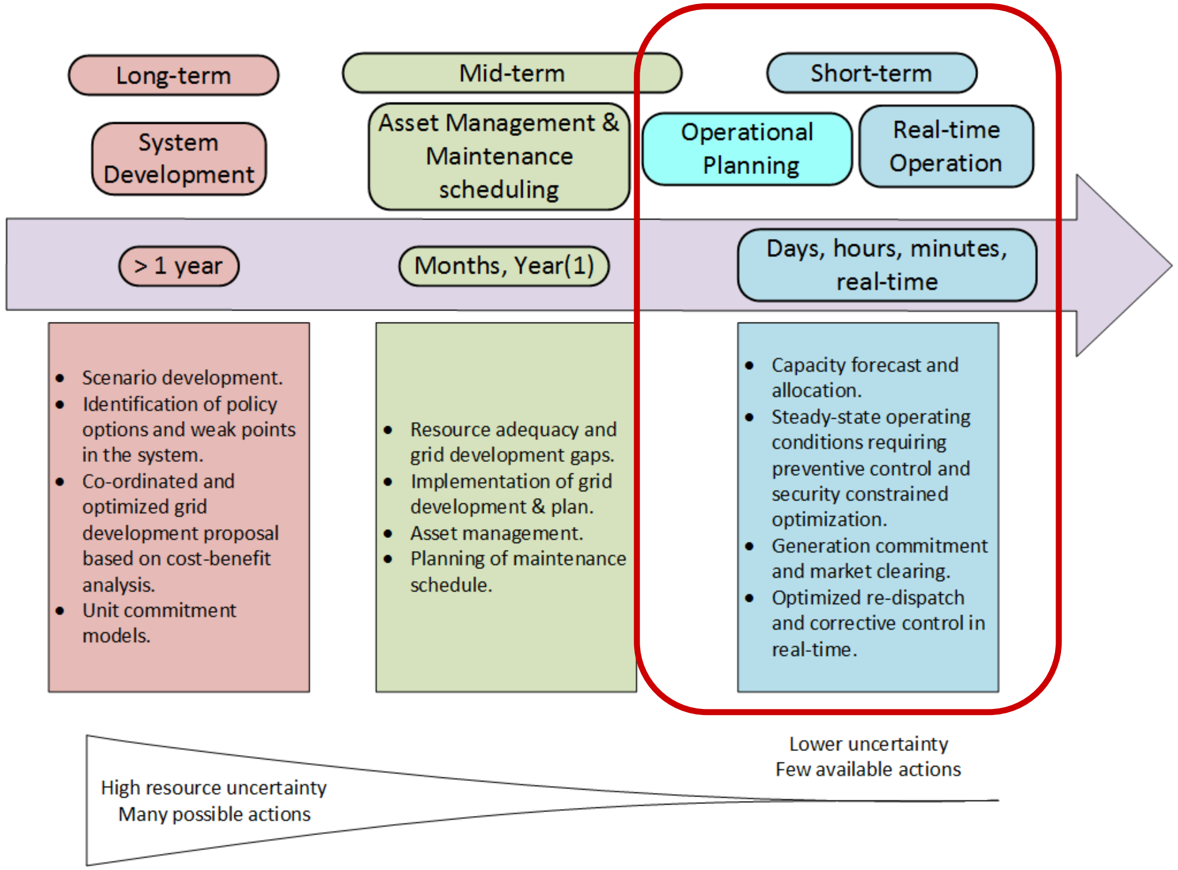
Current practices in Reliability management

- Present reliability assessment based on deterministic N-1 criterion
- Fixed set of most credible N-1 contingencies with equal probability
- Time frames - from year(s)-ahead up to real-time operation
  - Reliable grid operation → Short-term time frames
- Reliable operation – System operator managing sequence of decisions under uncertainty
  - Unplanned generation and load variations, market factors
- Current approaches
  - Preventive security
  - Preventive-corrective security
- Preventive-corrective : allows for preventive and post-contingency corrective actions



Source: Van Hertem, D., Gomis-Bellmunt, O., Liang, J.,"HVDC Grids For Offshore and Supergrid of the Future", Wiley IEEE Press, February 2016

Challenges in reliable operation

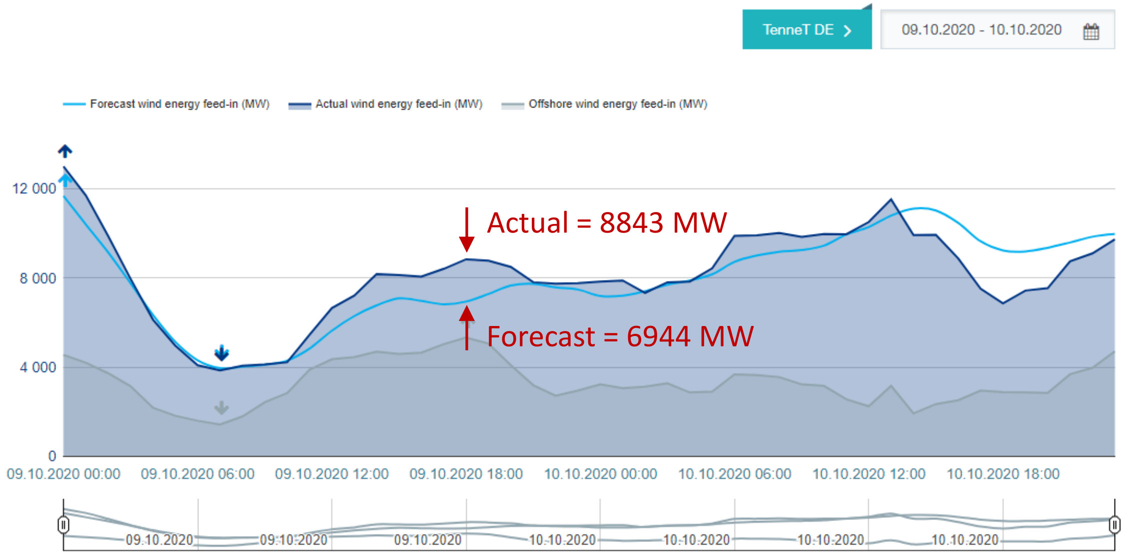
Shortcomings of N-1 criterion

- Likelihood and impact of contingency not considered, interdependencies ignored
- No economic consideration of corrective actions
- May lead to cases of higher operational costs/ higher risks

Greater integration of RES, smart grids and intra-day markets

- Escalation in system uncertainties
- Consider additional contingencies e.g. also for unpredictable injections from RES
- Equal probabilities, static list of contingencies not optimal

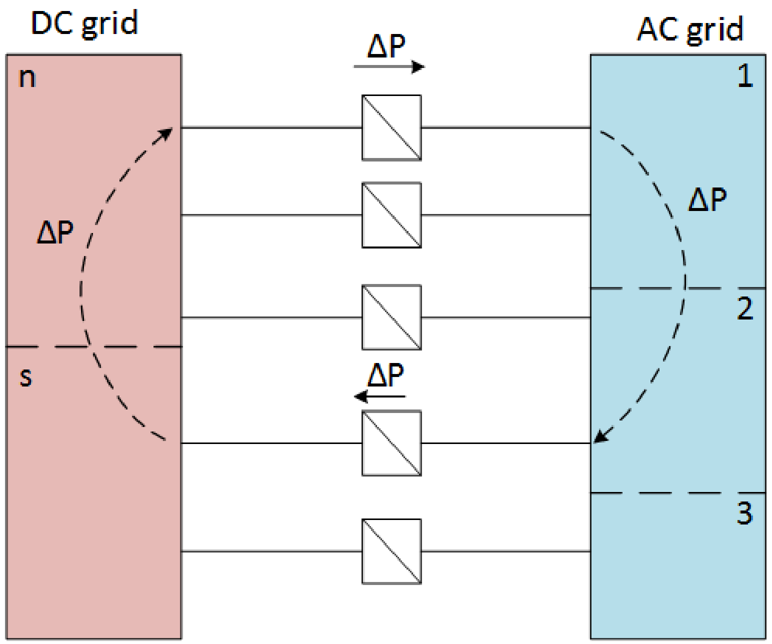
Day ahead generation forecast & actual wind as per TenneT TSO, Germany for 9th-10th October 2020



→ Probabilistic/ Risk-based reliability criteria !

HVDC in reliable operation

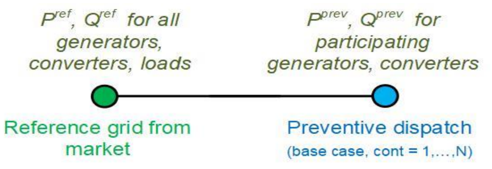
- Flexibility from AC/DC converter (active as well as reactive power) can be utilized as control action for reliable operation
  - Control transmission capacity between zones
  - Congestion Management
  - Converter redispatch can be utilized as a preventive measure
  - Faster corrective control after contingency in real-time (owing to smaller time-constants)
  - Economical than re-dispatch, load curtailment



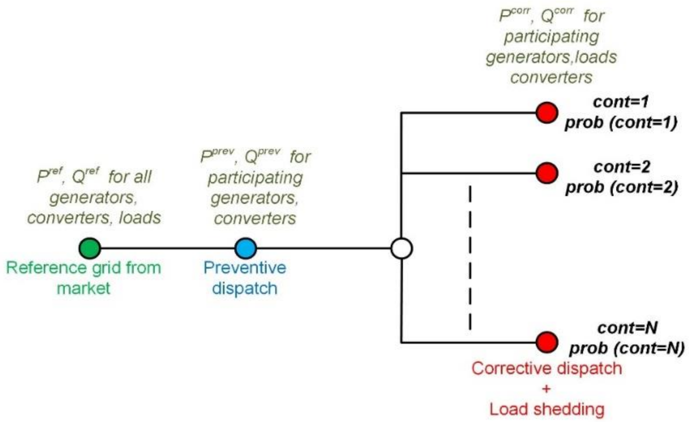
Source: Van Hertem, D., Gomis-Bellmunt, O., Liang, J., "HVDC Grids For Offshore and Supergrid of the Future", Wiley IEEE Press, February 2016

Framework for reliable AC/DC grid operation

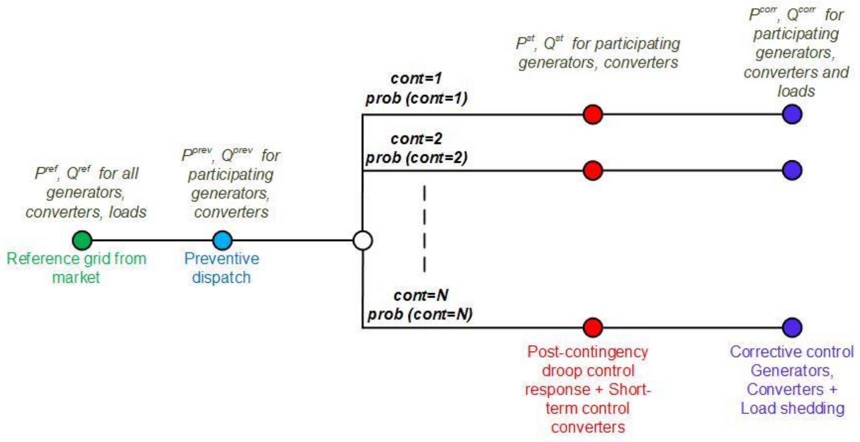
- Implementation of preventive and preventive-corrective security-constrained optimal power flow (SCOPF) models for hybrid AC/DC systems



(a) Preventive SCOPF model for AC/DC system



(b) Preventive-corrective (P-C) SCOPF model for AC/DC system



(c) Preventive-short-term-corrective (P-ST-C) SCOPF model (single time instant) for AC/DC system

- Comparison of purely preventive and preventive-corrective security approaches
- Analyze the impact of contingency probability and the generator corrective cost coefficient on total risk and trade-off between preventive actions cost and corrective actions risk
- Evaluate flexibility offered by fast dynamics of AC/DC converters after a contingency

Framework for reliable AC/DC grid operation

- AC/DC grid security-based optimization: large-scale non-linear non-convex optimization problem
- Convex relaxations for lesser computational burden, global optimum
- Extension of current AC/DC SCOPF model to multiple time frames
    - Based on dynamic receding horizon approach
- Consideration of generation, load uncertainties into the AC/DC SCOPF model