DC Collection Systems for Offshore Wind Power Plants: *A Holistic Reliability Approach*

Gayan Abeynayake

InnoDC ESR-02

Cardiff University, UK

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Content

- Overall Progress
- Key Research Objective
- Reliability- and Cost- based selection of DC collection systems
- Selection of Multi-level converters for MVdc Offshore Wind Collection Systems
- Impact of the Cable Network Reliability in Availability Assessment of Offshore Wind Farms

To-date Publications during the PhD

[1] G. Abeynayake, G. Li, T. Joseph, J. Liang and W. Ming, "Reliability and Cost-oriented Analysis, Comparison and Selection of Multi-level MVdc Converters," in *IEEE Transactions on Power Delivery*, Jan 2021 *(Early Access)*

[2] Gayan Abeynayake, Tom Van Acker, Dirk Van Hertem, Jun Liang, "Analytical Model for Availability Assessment of Large-Scale Offshore Wind Farms including their Collector System", *IEEE Transactions on Sustainable Energy* [Under Revision]

[3] G. Abeynayake, J. Liang, A. Moon, J. Yu, "Analysis and Control of MVDC Demonstration Project in the UK: ANGLE-DC", *Distribution & Utilization Journal*, July 2020.

[4] G. Abeynayake, G. Li, J. Liang and N. A. Cutululis, "A Review on MVdc Collection Systems for High-Power Offshore Wind Farms," 2019 *14th Conference on Industrial and Information Systems (ICIIS)*, Kandy, Sri Lanka, 2019, pp. 407-412.

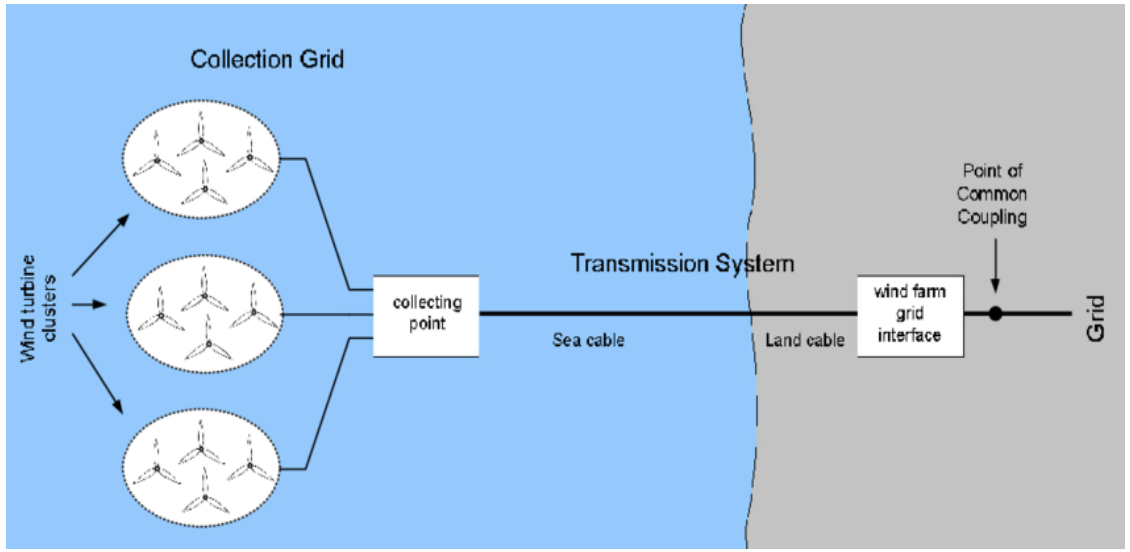
[5] G. Abeynayake et al., "Reliability Evaluation of Voltage Source Converters for MVDC Applications," *2019 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia)*, Chengdu, China, 2019, pp. 2566-2570.

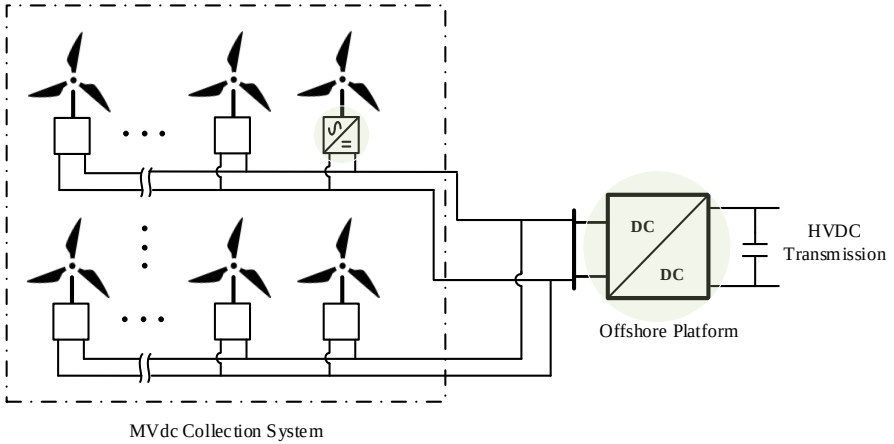
[6] G. Abeynayake, X. Li, L. Yao, J. Liang, F. Cheng, "Recent Development and Prospect of Offshore Wind Power in Europe", *Journal of Global Energy Interconnection*, Vol. 2 No. 2, Mar. 2019.

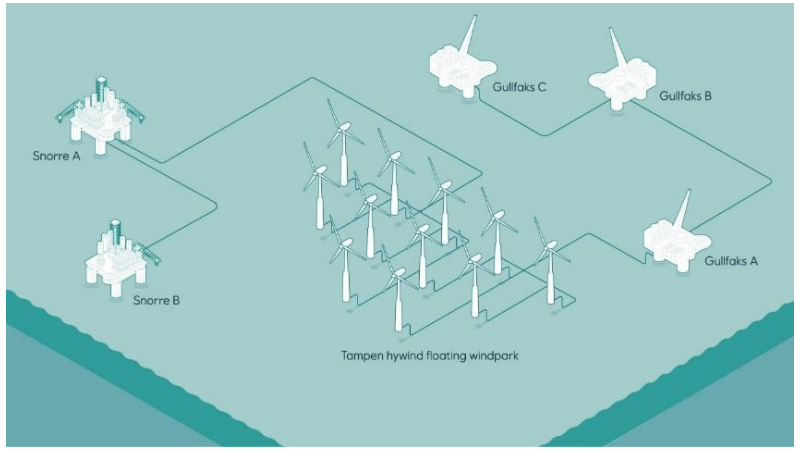
[7] G. Abeynayake, R. Sun, J. Liang, "Reliability and Economic Evaluation of Offshore Wind Power DC Collection Systems", *in preparation to submit to Energies special issue on "Innovative HVDC and MVDC Connection Schemes for Offshore Wind Farms"*

[8] Gayan Abeynayake, Jun Liang, "Lifetime Estimation of dc-Wind Turbine Considering Mission Profile and Thermal Loading", WESC 2021 [Abstract Accepted to present at Wind Energy Science Conference - May 2021, Hannover, Germany (Online)]

Requirement of Reliability



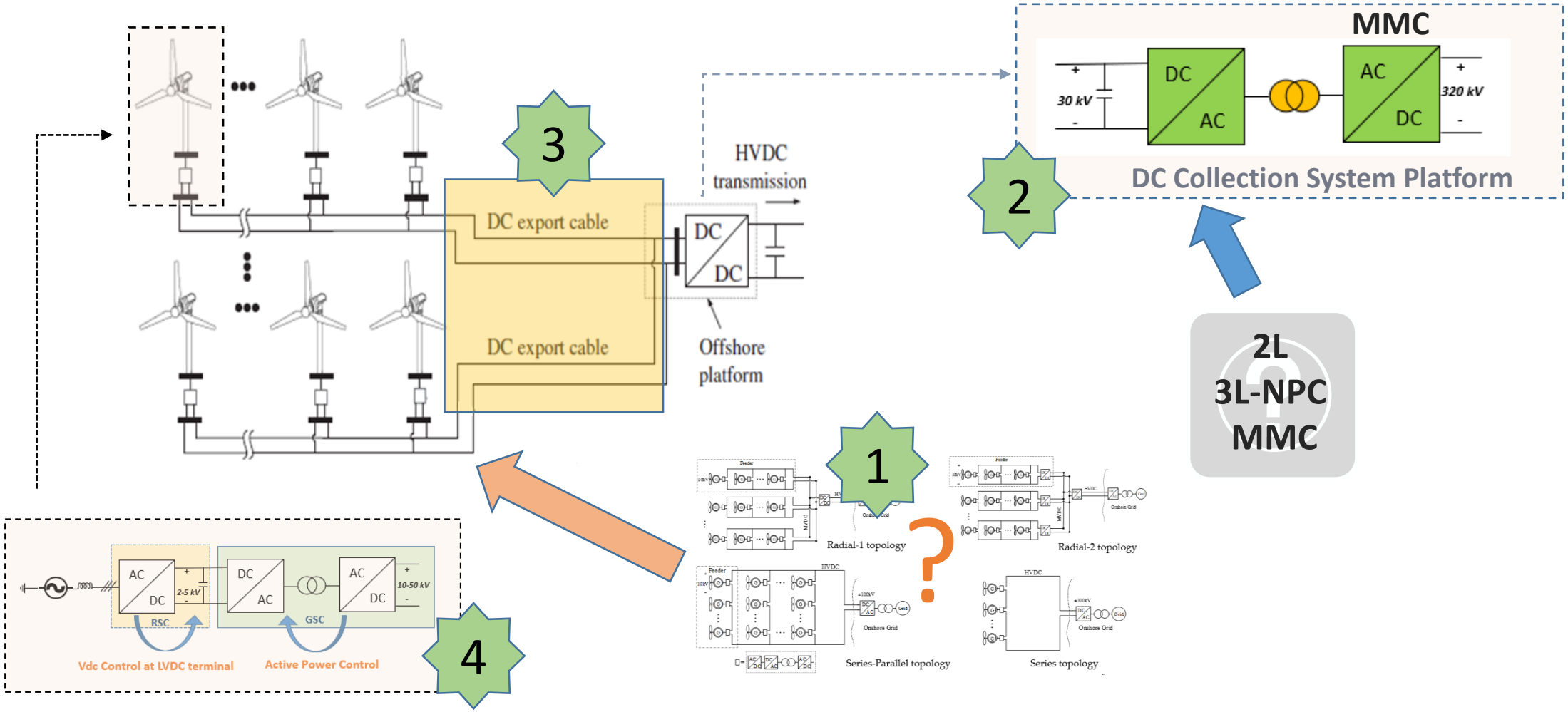




Making Initial Planning Decisions

Reliability-oriented Maintenance Planning

Reliability Requirements

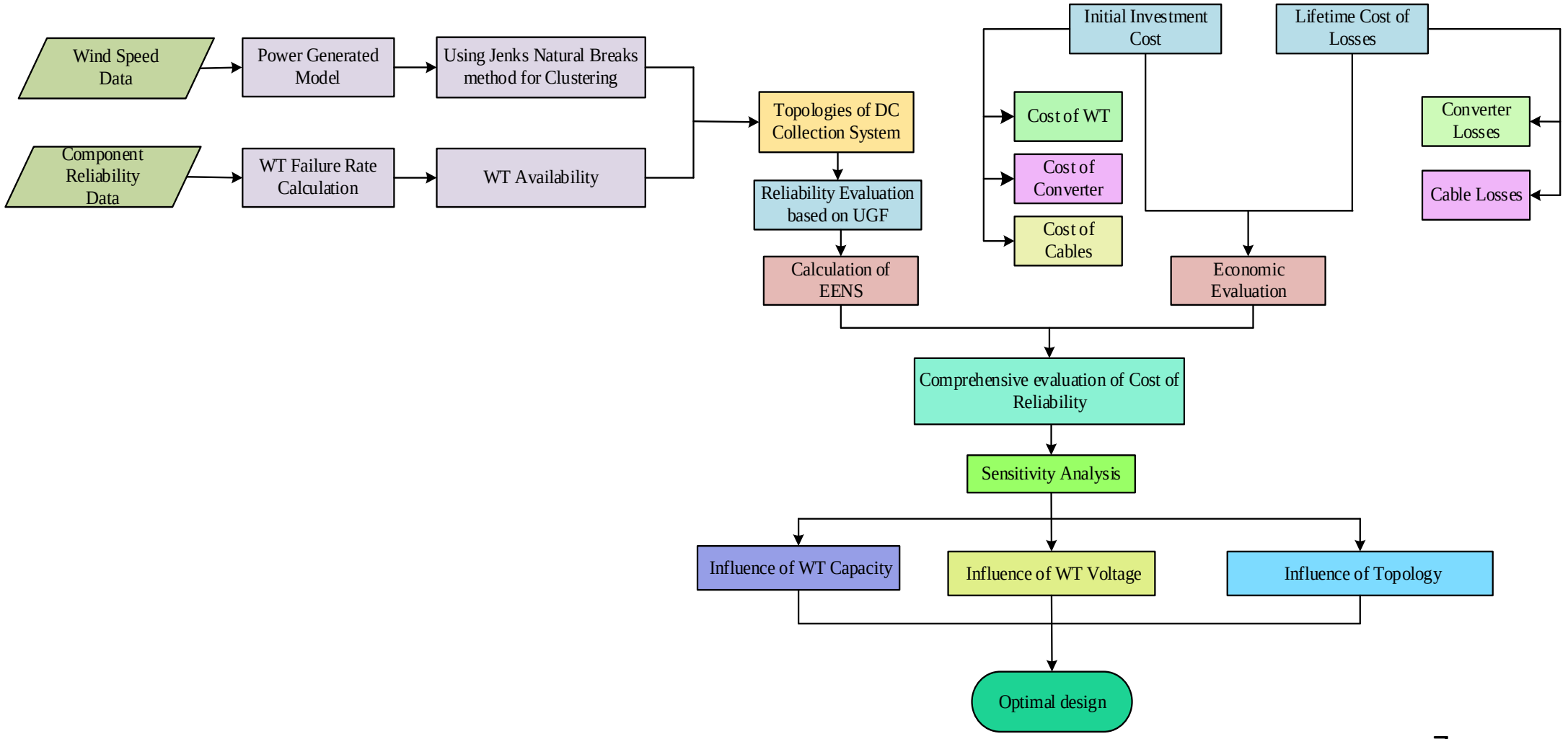


1. DC Collection System Topology Selection based on Reliability and Cost

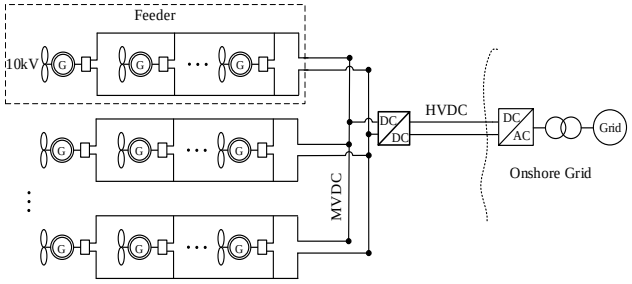
Work based on:

G. Abeynayake, R. Sun, J. Liang, "Reliability and Economic Evaluation of Offshore Wind Power DC Collection Systems", in preparation to submit to *Energies* special issue on *"Innovative HVDC and MVDC Connection Schemes for Offshore Wind Farms"*

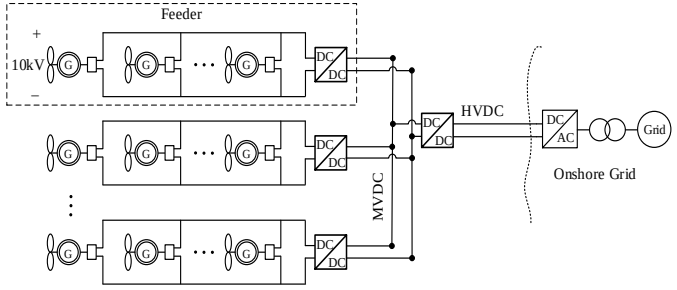
Selection Methodology



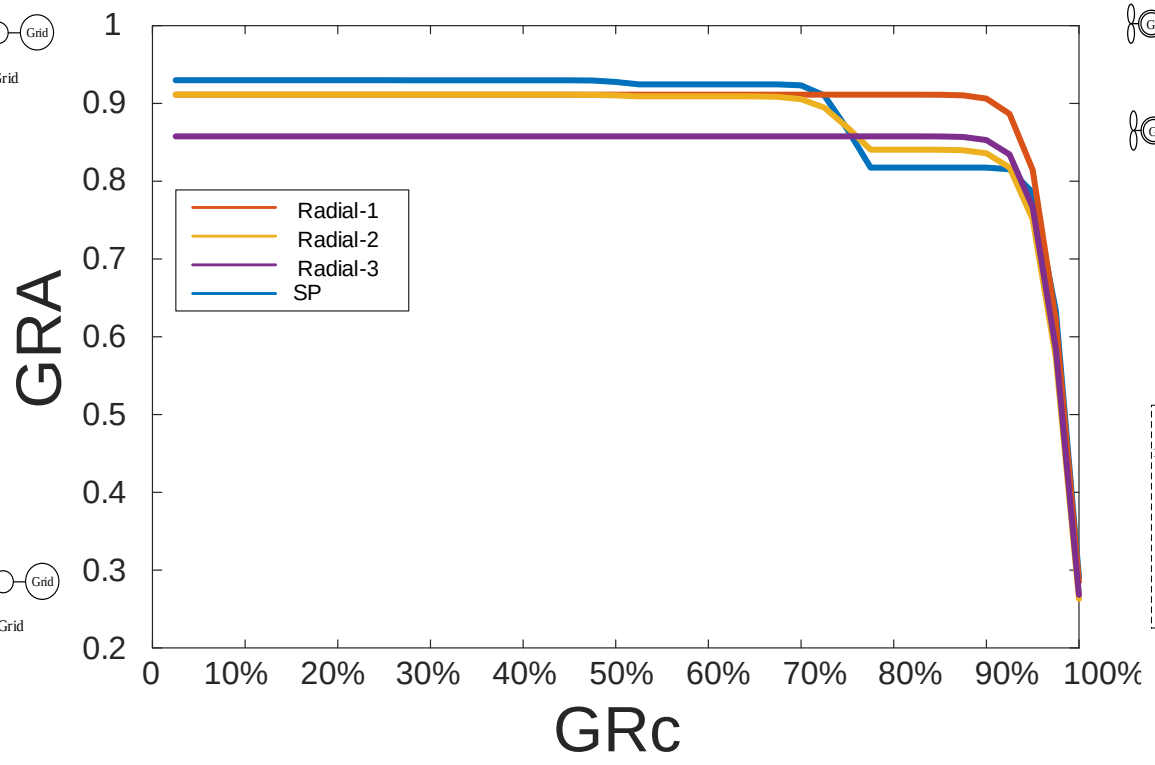
DC Collection System Options for OWF

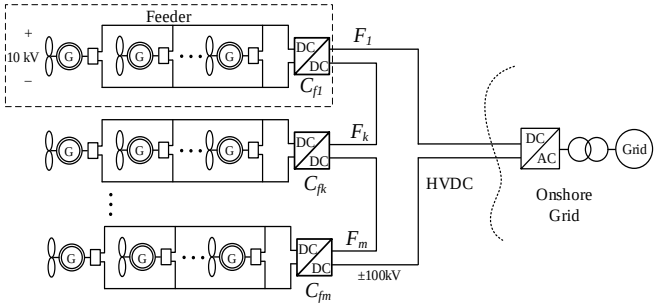


Radial-1

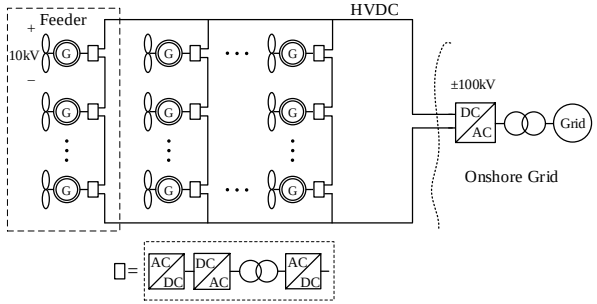


Radial-2





Radial-3



SP Topology

2. MVdc Converter Topology Selection

Work based on:

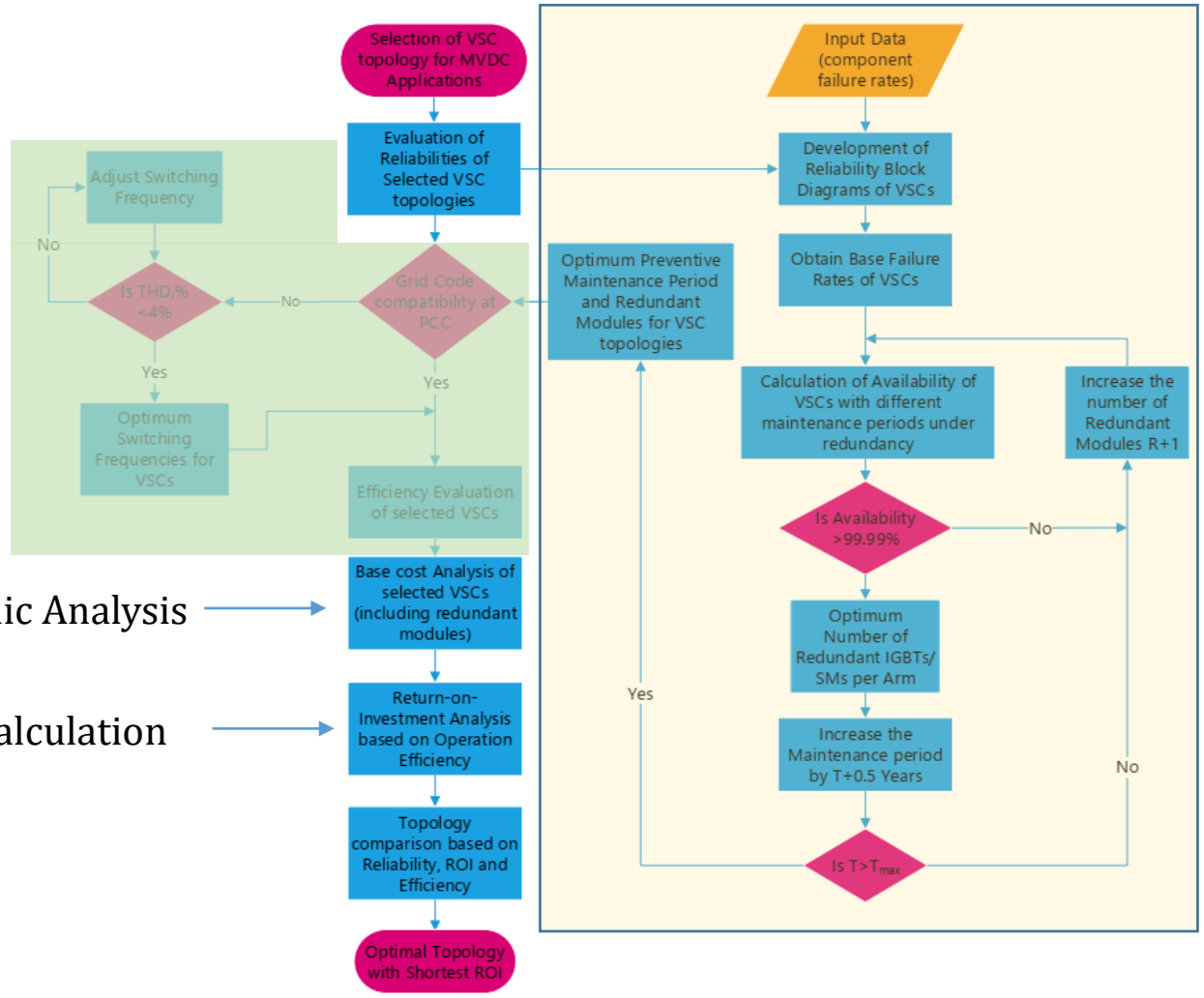
G. Abeynayake, G. Li, T. Joseph, J. Liang and W. Ming, "Reliability and Cost-oriented Analysis, Comparison and Selection of Multi-level MVdc Converters," in *IEEE Transactions on Power Delivery*, Jan 2021 *(Early Access) DOI: 10.1109/TPWRD.2021.3051531*

MVdc Converter Topology Selection

Efficiency calculation based on thermal look-up tables and mission-profile

Economic Analysis

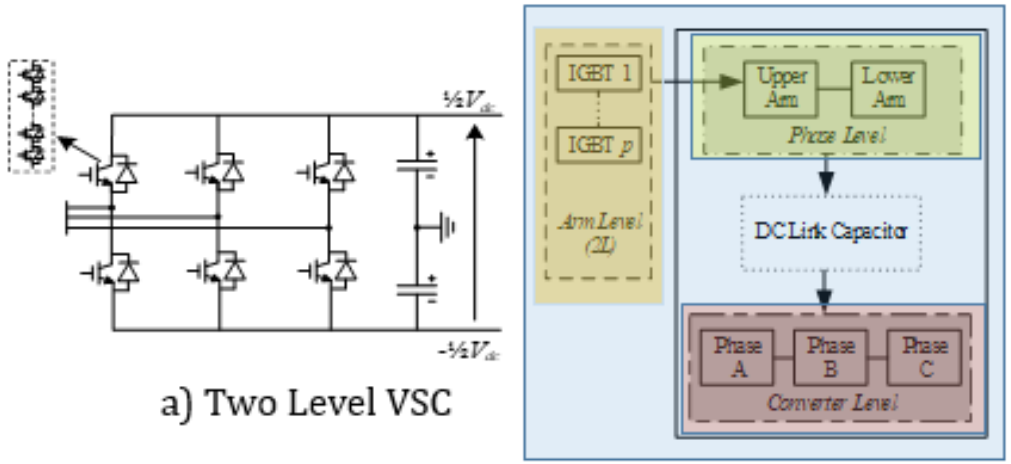
ROI Calculation



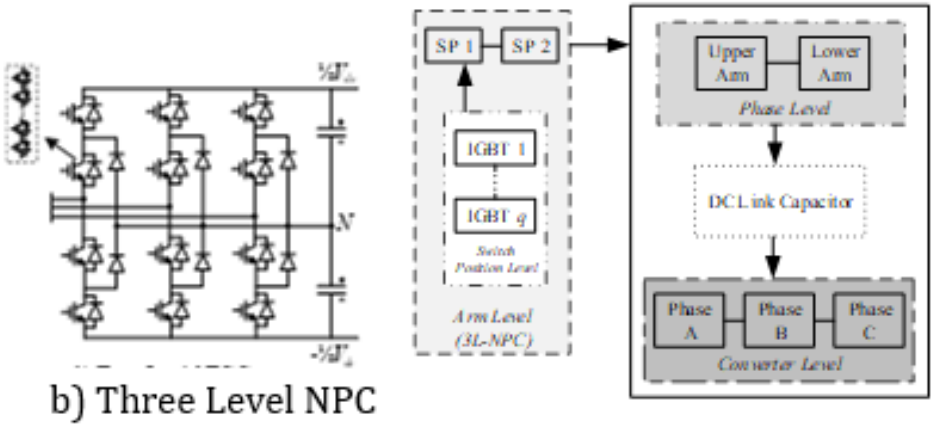
Identification of Optimal Number of Redundant Modules with different preventive maintenance intervals.

Topology Selection Flow Diagram

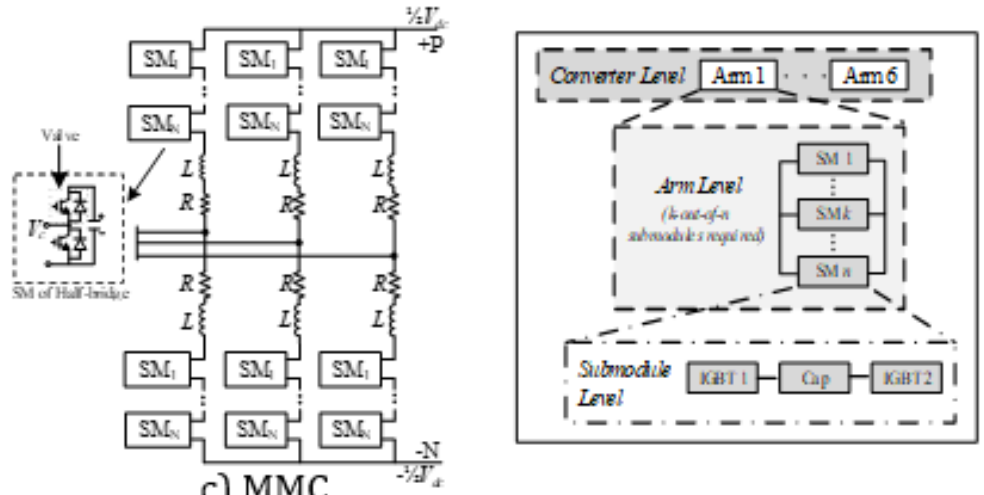
MVDC Converter Reliability Modelling



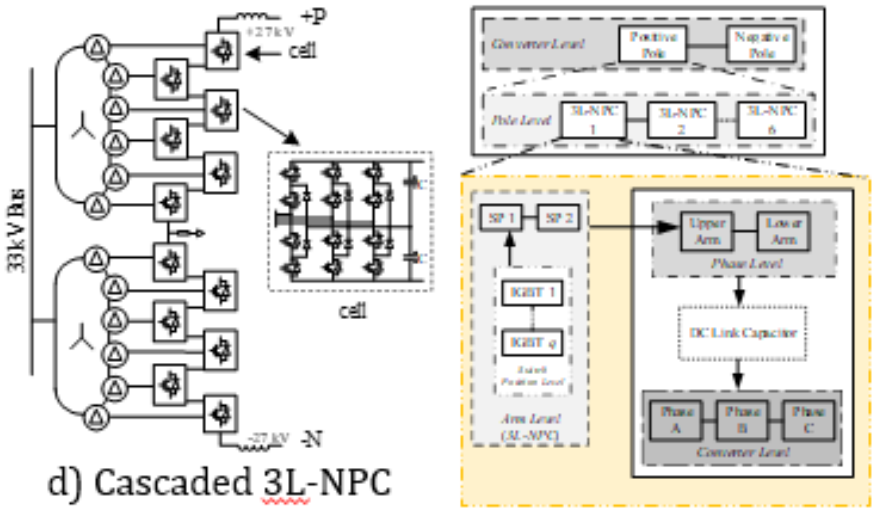
a) Two Level VSC



b) Three Level NPC

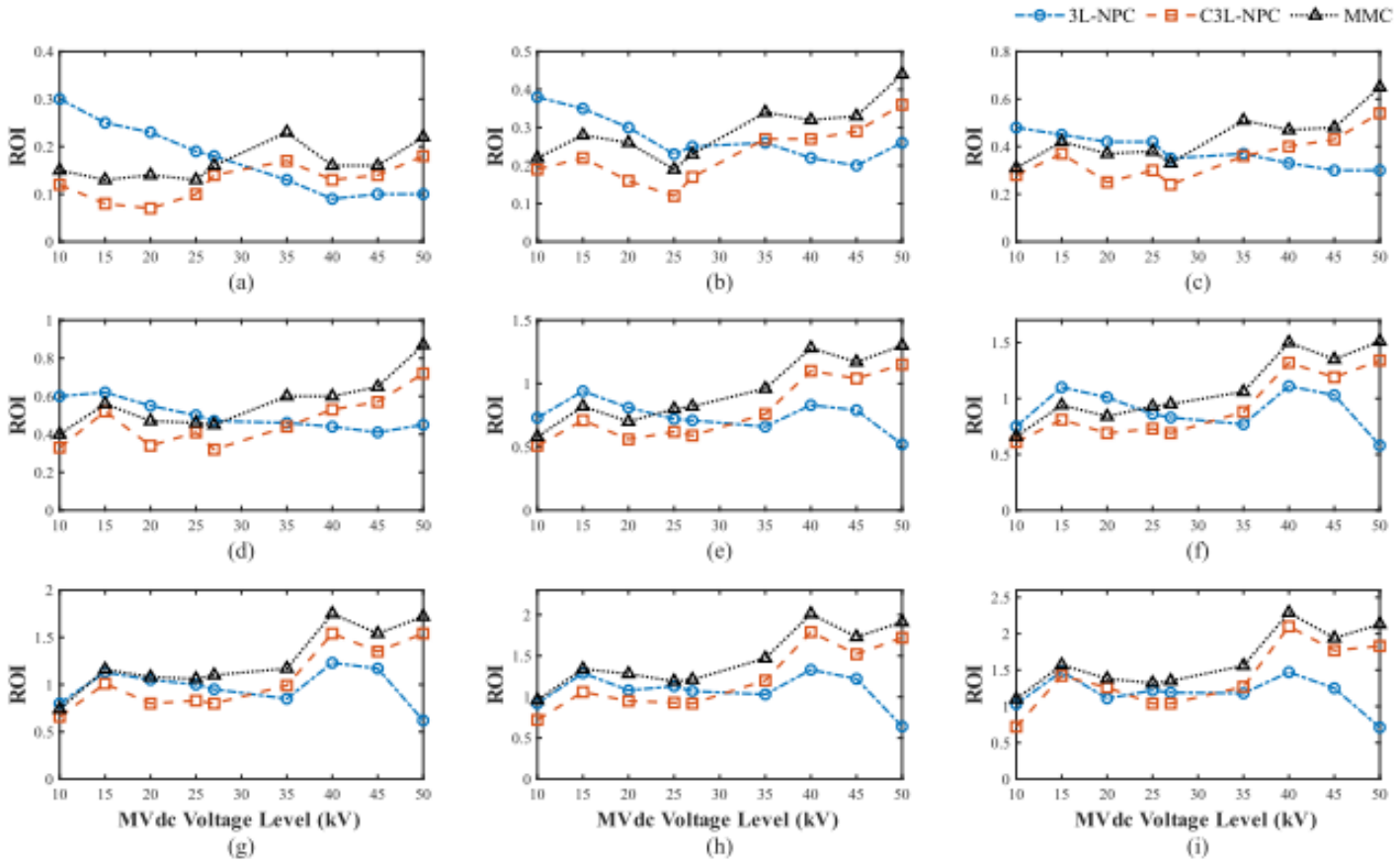


c) MMC

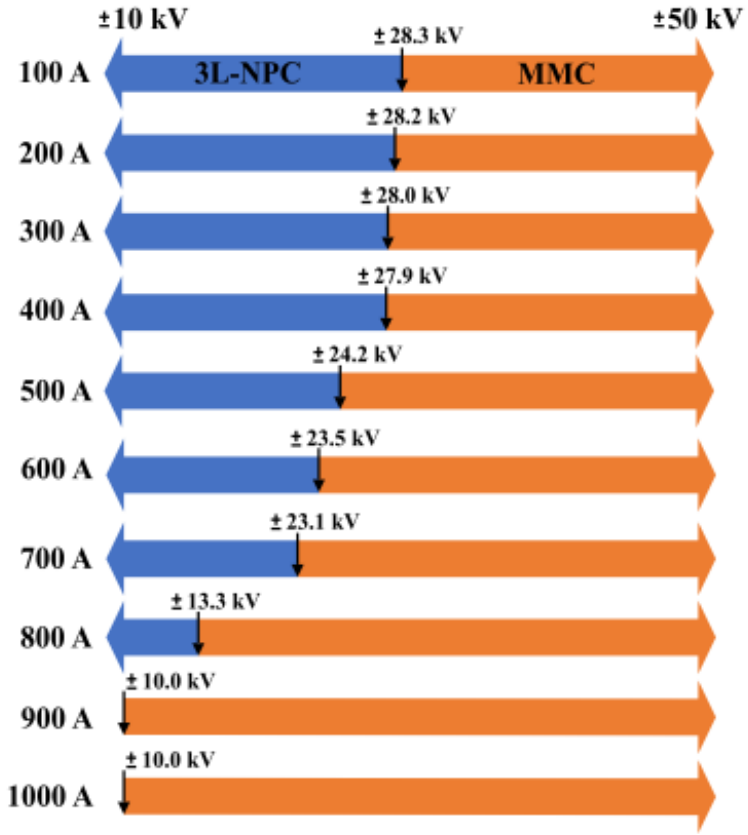


d) Cascaded 3L-NPC

ROI Analysis for whole MVdc Spectrum



Variation of ROI with Change of Rated Current (from 100A-1kA) at Different MVdc Voltage Levels



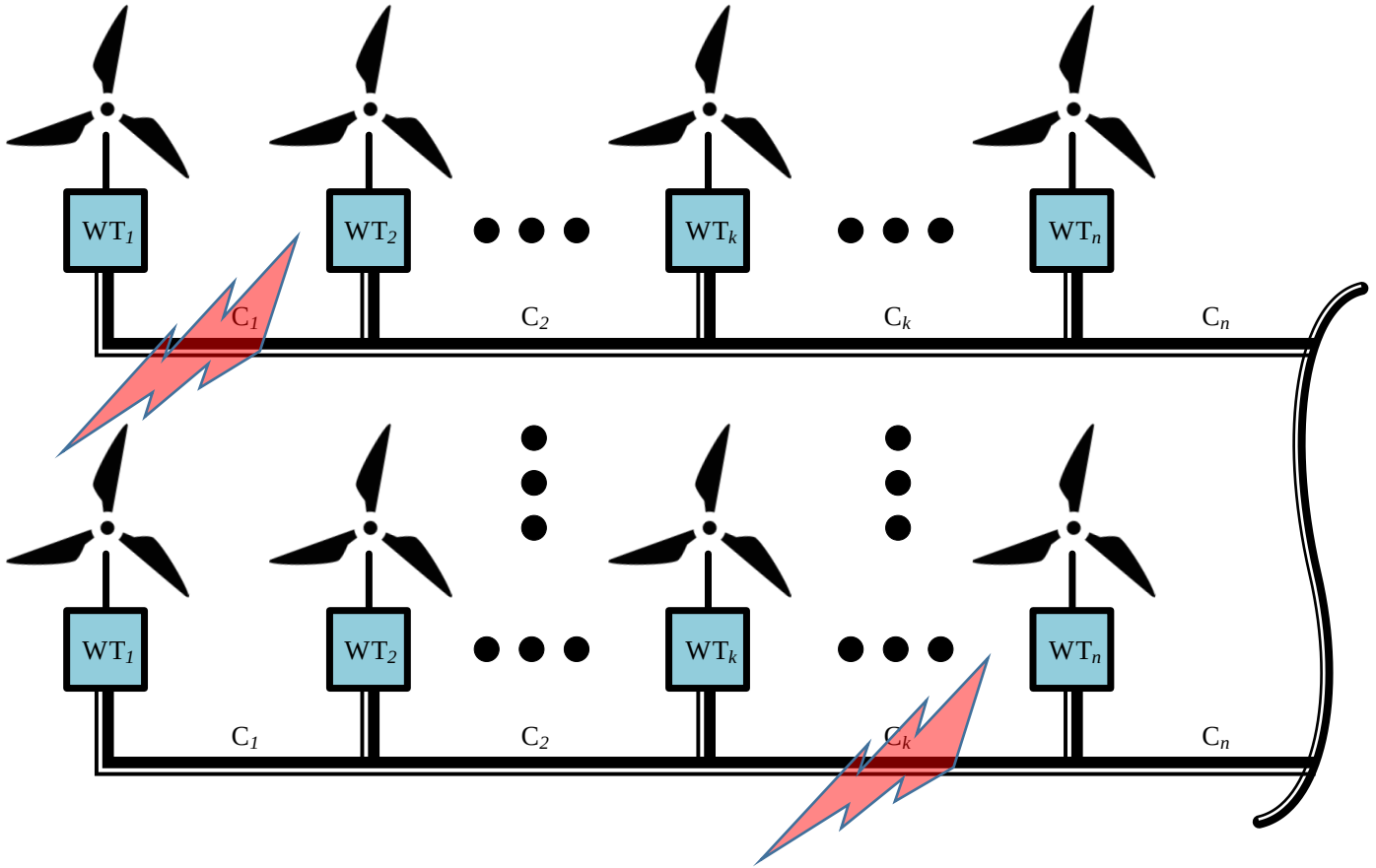
Variation of Voltage Crossover points with the Change of Rated Currents

3. Impact of the Collection System Reliability in Availability Assessment of Offshore Wind Farms

Work based on the submitted manuscript on ***"Analytical Model for Availability Assessment of Large-Scale Offshore Wind Farms including their Collector System"*** *to IEEE Transactions on Sustainable Energy authored by* Gayan Abeynayake, Tom Van Acker, Dirk Van Hertem, Jun Liang *(Under Revision)*

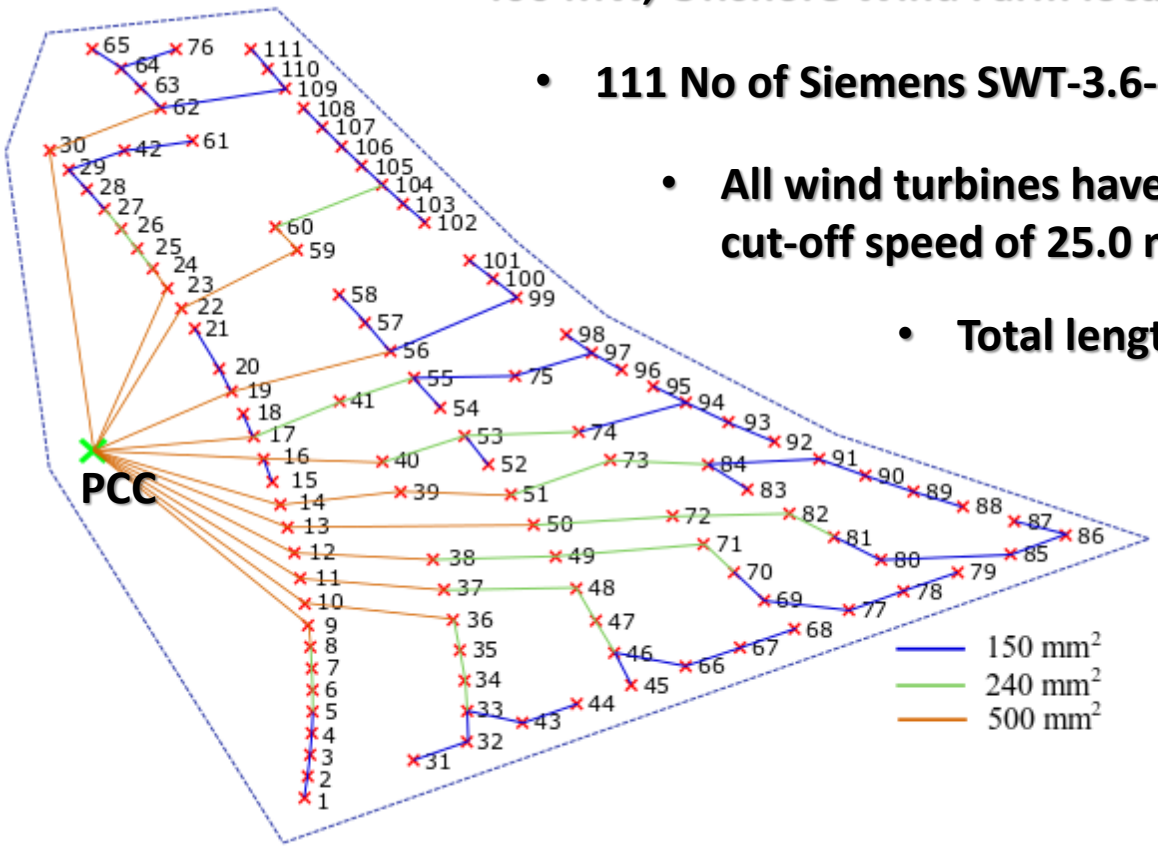
Research Gap

- Compared to WT failure rates, collection system cable failure rates are LOWER
- However, due to higher repair time it cannot simply be neglected.
- **The proposed method based on Universal Generating Function combined with continuous time Markov Chain model is used to answer this question!**

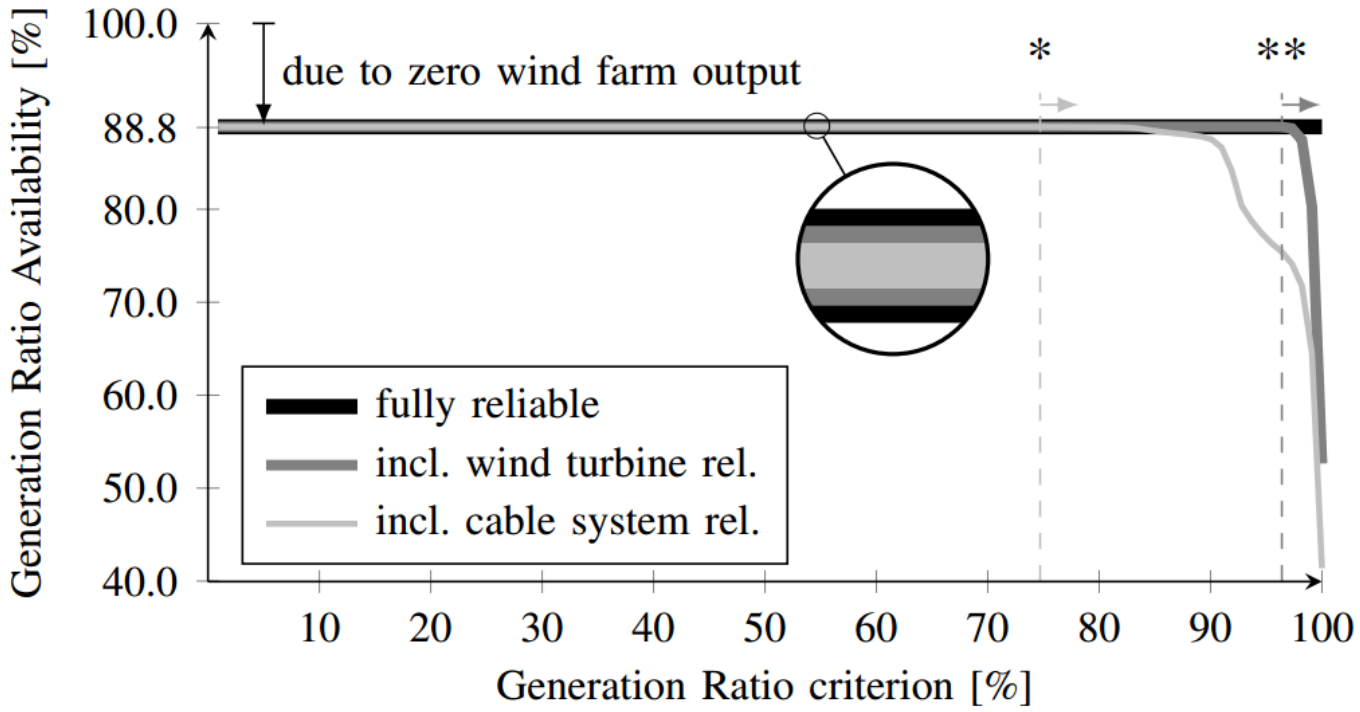


Case Study – Anholt Offshore Wind Farm

- 400 MW, Offshore Wind Farm located between Djursland and Anholt island in Denmark
  - 111 No of Siemens SWT-3.6-120 wind turbines with a rated power of 3.6 MW
    - All wind turbines have a cut-in speed of 3.5 m/s, rated speed of 14.0 m/s, and cut-off speed of 25.0 m/s.
      - Total length of 177 km inter-array cable network



Case Study - GRA



- **Generation Ration Availability (GRA) is an index used to assess the availability of OWFs under stochastic nature of wind speed and component failures[6]**

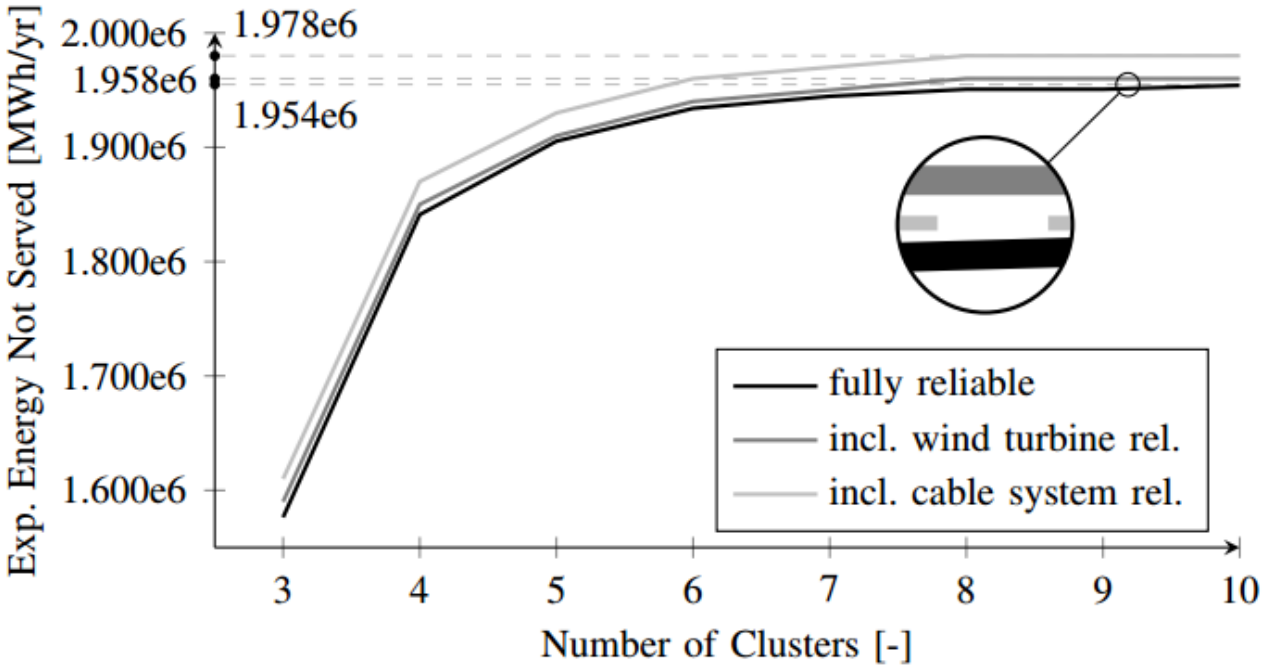
$$\mathrm{GRA}(\mathrm{GRc}) = \sum_{i \in \mathcal{I} \,:\, \mathrm{cnd}_i} \mathrm{GRc} \cdot \omega^{\mathrm{ntw}}.p_i,$$

$$\mathrm{cnd}_i = \omega^{\mathrm{ntw}}.v_i \geq \mathrm{GRc} \cdot \max(\omega^{\mathrm{ntw}}.v)$$

- For a GRc of 95.0 %, the GRA is reduced to 76.3 % (-12.0 %) when considering the collector system reliability.
- The impact of collector system reliability starts from a significantly lower GRc compared to the wind turbine reliability: 74.7 % * and 96.4 % **, respectively

[6] M. Zhao, Z. Chen and F. Blaabjerg, "Generation Ratio Availability Assessment of Electrical Systems for Offshore Wind Farms," in IEEE Trans. on Energy Convers., pp. 755-763, Sept. 2007

Case Study - EENS



$$\text{EENS} = 8760 \cdot \sum_{i \in \mathcal{I}} \omega^{\text{pcc}}.p_i \cdot (\max(\omega^{\text{pcc}}.v) - \omega^{\text{pcc}}.v_i)$$

- Not including the cable network will result in EENS error of 19.89 GWh/yr (1.0 %) which account for 24.05M$ miscalculation over the operating life (20yrs) of the OWF. *

* With a discount rate of 5% and average Danish wholesale electricity price of 36.57 $/MWh

Thank You !

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InnoDC
INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS