A comparison of electrical systems for multi-rotor wind turbines

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1. What Are Multi-rotors?

Multi-rotor wind turbines (MRWT) are an innovative solution to achieving cost effective large scale wind turbines in the range of 20 MW or greater. The idea is to have a large number of small turbines on one support structure instead of one large turbine, circumventing the square cube law and achieving significant savings in material costs for blades and drivetrain components. MRWT's also have a long list of other potential benefits including: further savings due to standardisation, modular design, reduced O&M costs, reduced transport and installation costs, improved control possibilities, reduced loading and increased reliability. Additionally, studies have shown an increase in power for closely clustered turbines compared to stand alone turbines [1,2].

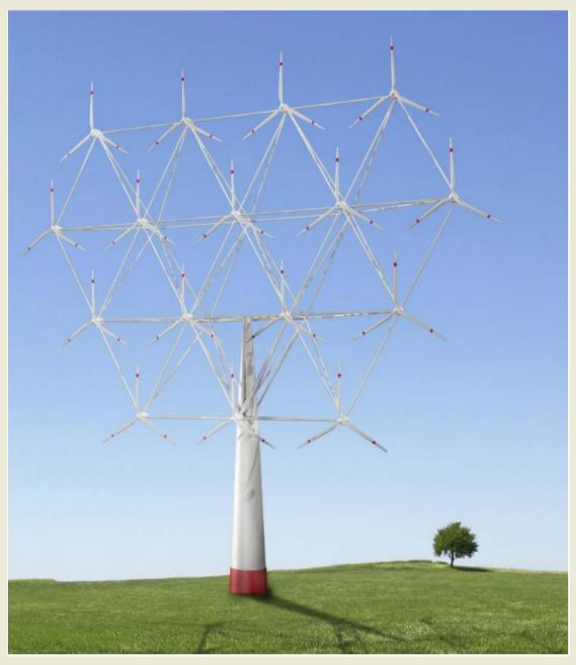
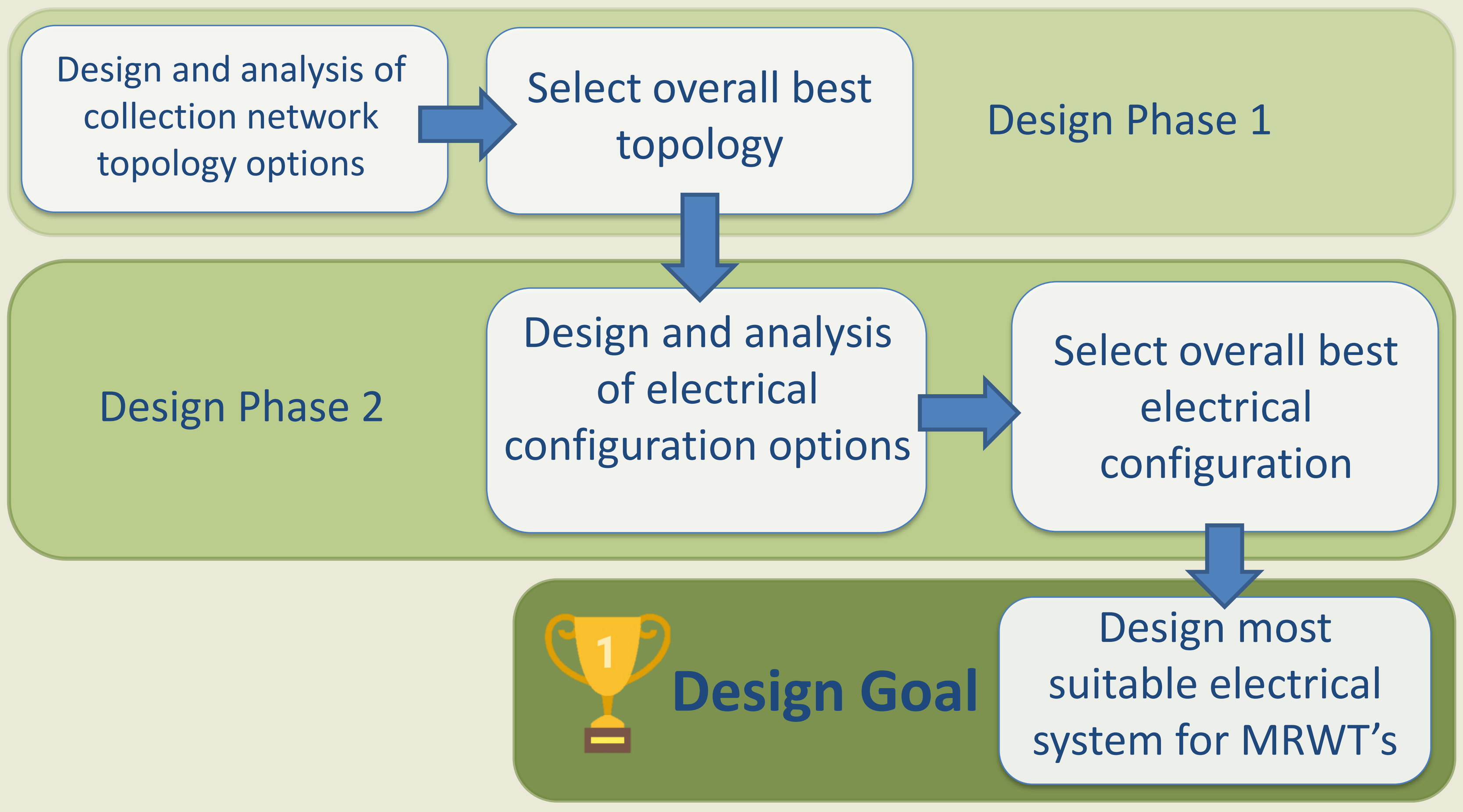


Figure 1: Artistic impression of an MRS turbine

2. Project Outline

Aim: To determine the most suitable electrical system for a 45 rotor MRWT with total rated power of 22.5 MW. The suitability is determined based on four main criteria: capital cost, efficiency, mass, and reliability.

The first design phase focuses on the type of collection network topology; this is how each turbine is connected together electrically. The second design phase looks at different electrical configurations within the best collection network topology; this is different combinations of electrical machines and converters..



3. Design phase 1

Aims

- Minimise cost and mass
- Maximise efficiency, reliability and redundancy

Constraints

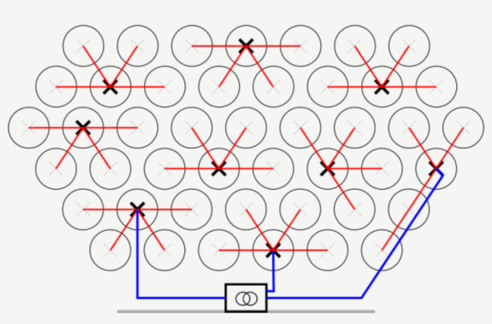
- Each rotor: 40m diameter, 500 kW
- Connect to wider AC collection network
- Independent speed control of rotors
- Components and voltages kept consistent in all topologies

Analysis

- Models developed to estimate mass, cost and losses of each component
- Models based on scaling relationships from academia and commercial datasheets
- Losses calculated for each component over entire range of operational wind speeds

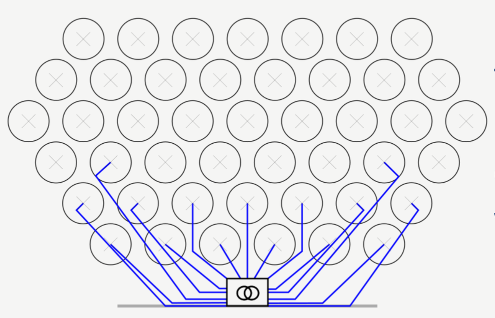
Proposed Collection Topologies

Cluster



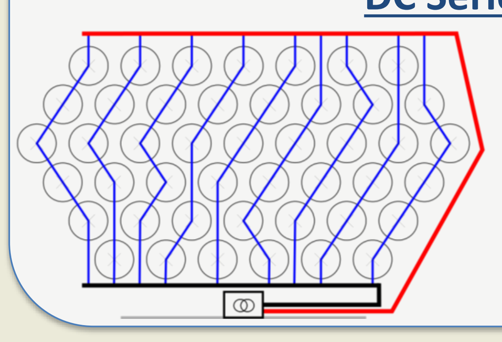
Both AC and DC topologies proposed. Clusters of 5 turbines share a transformer (AC) or DC-DC converter (DC) to step up voltage.

Star



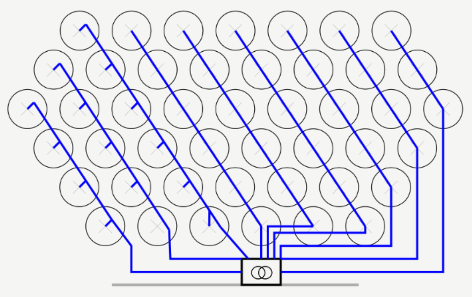
Both AC and DC topologies proposed. Each rotor has its own cable. Medium voltage generators used.

DC Series



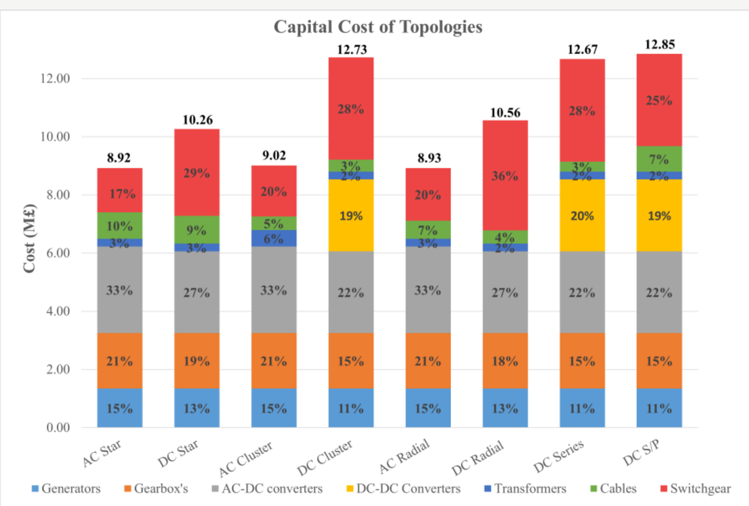
DC output generators connected together in series to increase voltage without transformer or DC-DC converter.

Radial



Both AC and DC topologies proposed. Turbines connected together in strings. Similar to most offshore wind farms.

Results



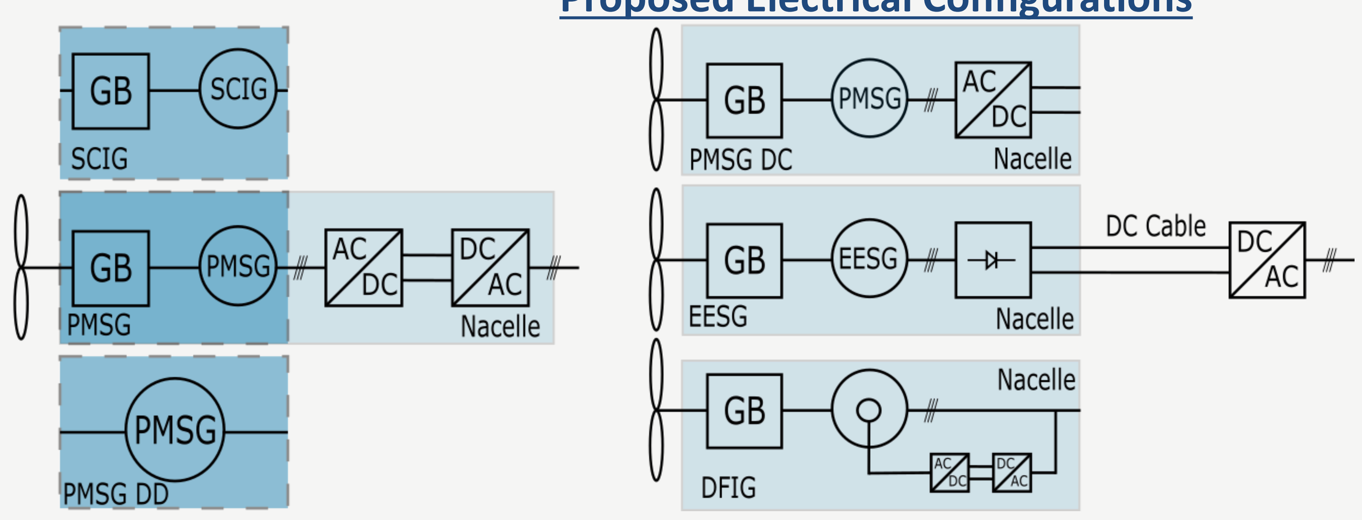
The figure to the left shows the capital cost of the proposed topologies and how each component contributes to the total cost. Similar results are obtained for the mass of each topology and the losses of each topology.

Topology	Cap. Cost	Efficiency	LCOE	Total Mass	Mass per Nacelle	Component count	Reliability
AC Radial	-	-	-	-	-	-	-
DC Radial	X	✓	X	✓	✓	✓	✓
AC Star	-	X	-	✓	✓✓	✓	✓✓
DC Star	X	X	X	✓	✓✓	✓✓	✓✓✓
AC Cluster	-	XX	-	X	XX	X	X
DC Cluster	XX	XX	XX	-	✓	✓	✓
DC Series	XX	XX	XX	-	✓	✓	X
DC S/P	XX	XX	XX	X	X	-	XX

To the right is a comparison of how each topology performs in a variety of categories. Overall the star topologies perform the best, and are taken forward to design phase two to explore different electrical configurations within the star topology.

4. Design phase 2

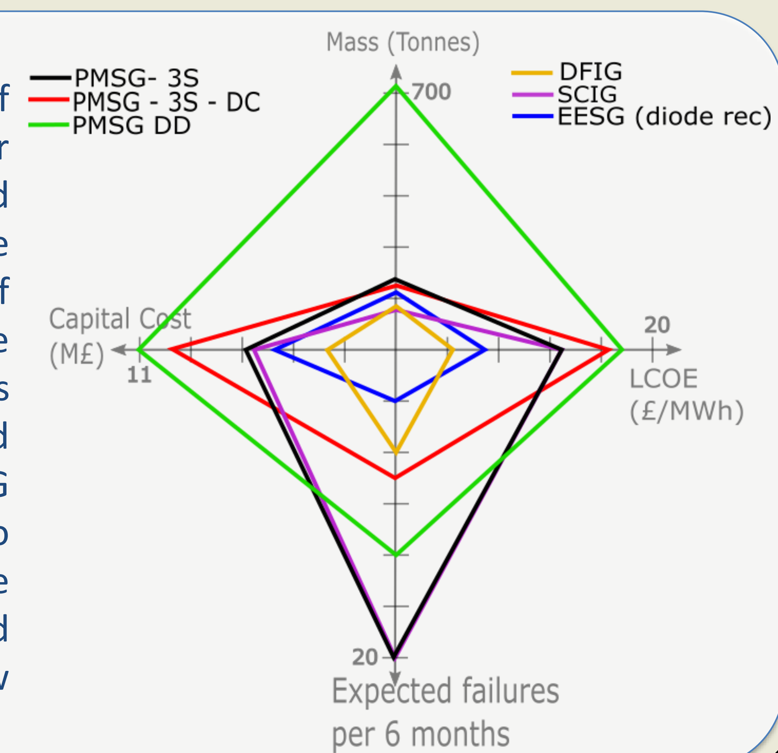
Proposed Electrical Configurations



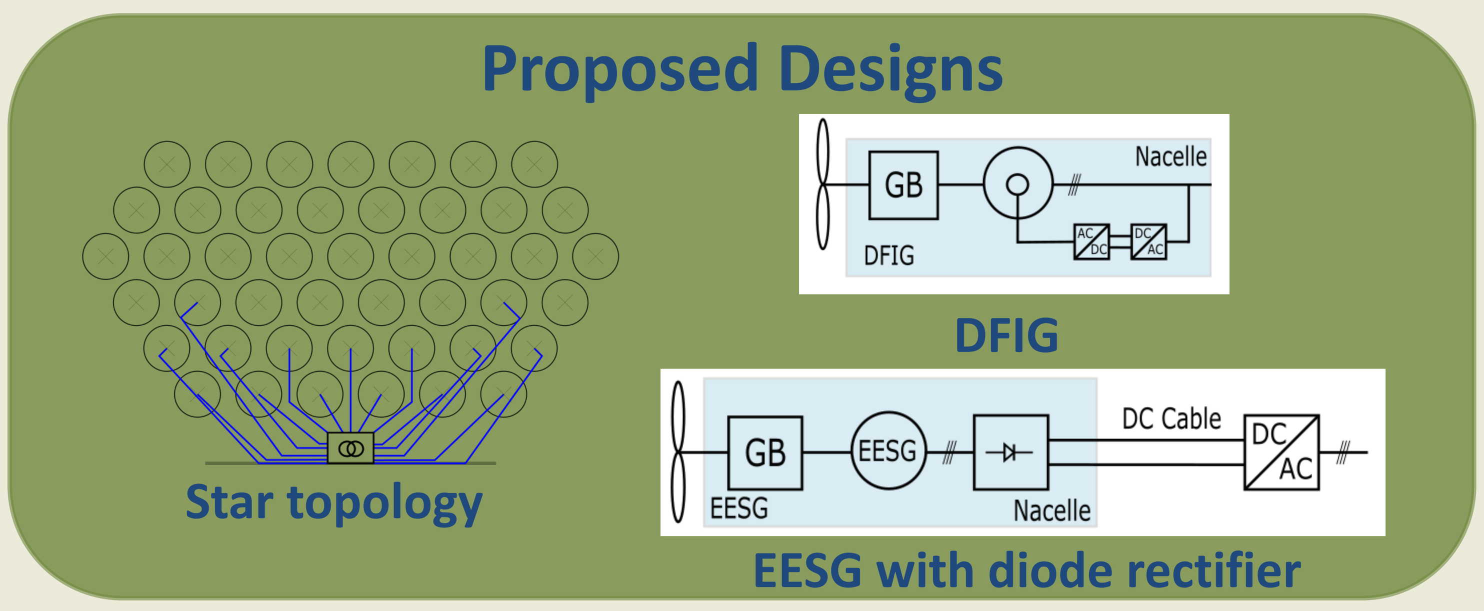
Six configurations are considered and analysed using the same models as in design phase one. A simple analysis of the lost energy due to expected failures is also included. Three configurations use back-to-back IGBT based voltage source converters (VSC); a permanent magnet synchronous generator (PMSG) with three stage gearbox, a direct drive PMSG and a squirrel cage induction generator with a three stage gearbox. There is also a PMSG with gearbox DC configuration, a configuration based on doubly fed induction generators (DFIG) and a configuration that utilises an electrically excited synchronous generator (EESG) with variable DC source on the rotor and a diode rectifier.

Results

The radar plot to the right summarises the results of design phase 2. The more compact the shape, the better overall performance that configuration has. A levelised cost of energy calculation was performed and included the capital cost of the electrical equipment and the gearbox of each system divided by the net present value of the expected electricity produced over a 20 year lifespan. This also includes a reduction of electricity due to the expected amount of failures experienced by each system. The DFIG configuration and the EESG configuration are shown to have the best overall performance. They have among the lowest capital cost and LCOE, among the lowest mass and have the two best reliabilities which is shown by their low expected failures.



5. Conclusions



The results from this analysis show that the most suitable type of collection network topology is the star type. In this topology, each turbine is connected to the step up transformer via its own cable, which results in excellent redundancy within the system. The star topology also has low capital cost and LCOE (of the electrical equipment) and low mass resulting in the best overall suitability for MRWT applications. Six electrical configurations were analyzed and the two most promising configurations are the DFIG configuration and the EESG configuration that utilized a diode rectifier. These two configurations have low capital cost, low LCOE, low mass, and crucially they both have low expected failures. Both of these configuration will be looked at further in future work. The EESG with a diode rectifier is of significant interest as it will have the following additional benefits: low nacelle mass in each turbine due to the utilization of diode rectifier, low expected failure specifically at the nacelle level due to the utilization of diode rectifier – the most failure prone component is the VSC which is located at the base of the array and therefore is easily accessible. The DFIG configuration benefits from vast operational experience within the wind industry.

[1] P. Jamieson et al., INNWIND Deliverable 1 . 3 3: Innovative Turbine Concepts - Multi-Rotor System," Tech. Rep. August, 2015. [2] Y. Ohya et al, Power Augmentation of Shrouded Wind Turbines in a Multirotor System," Journal of Energy Resources Technology, vol. 139, no. 5, p. 051202, 2017.

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