Comparison of Electrical Topologies for Multi-rotor System Wind Turbines

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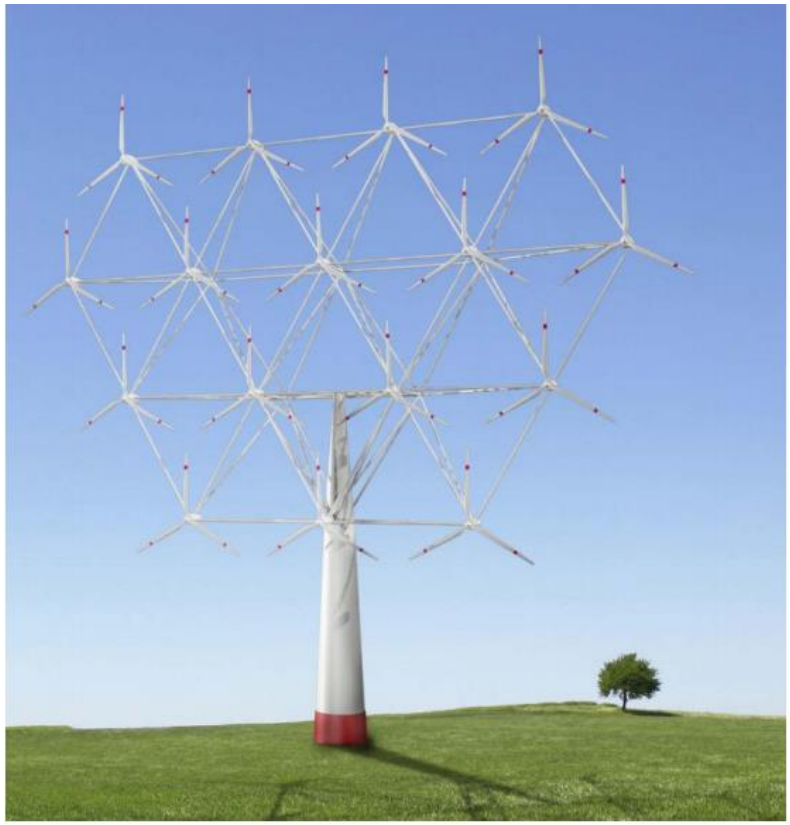
Introduction

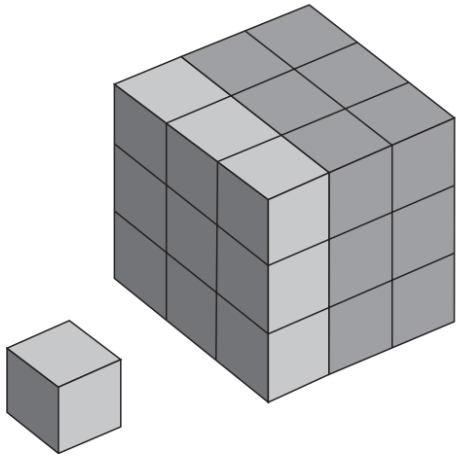
What are Multi-rotor Wind Turbines?

Large number of small wind turbines on one support structure.
Cost effective solution to 15+MW wind turbines



$$\text{Area} \propto \text{Power}$$

$$\text{Volume} \propto \text{Material cost}$$



Multi-rotor Pros & Cons

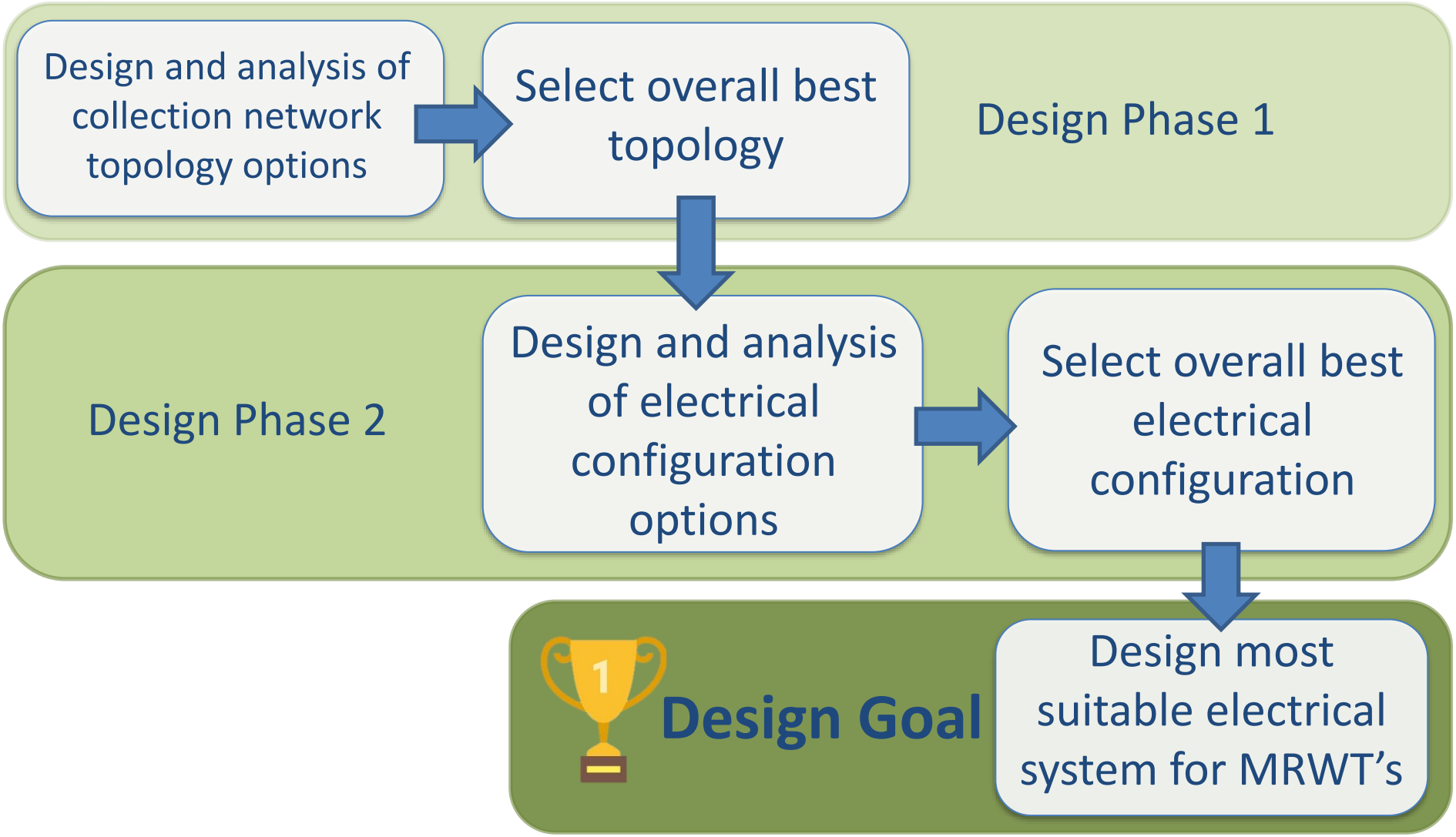
Benefits

- ✓ Reduced levelised cost of energy (LCOE) due to:
  - ✓ Reduced material costs in blades/drive train
  - ✓ Savings due to standardisation
  - ✓ Significant reduction in installation and transport costs
  - ✓ Significant reduction in O&M costs
- ✓ Reduced loading
- ✓ Load averaging
- ✓ Power gains due to clustering of rotors
- ✓ Increased control possibilities
- ✓ Built in redundancy

Drawbacks

- × Large number of components
- × More complex support structure
- × Possible dynamic effects of associated with multiple rotors

Design project outline



Considerations for electrical system

Minimise mass

- Reduce complexity and cost of support structure
- Nacelle mass more important

Minimise cost

- Don't outweigh other cost savings
- Decrease LCOE

Maximise Efficiency

- Reduce losses
- Decrease LCOE

Maximise Reliability

- Reduce component count
- Improve failure rates
- Take advantage of built in redundancy

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Design and analysis of collection network topology options

Select overall best topology

Design Phase 1

Design Phase 2

Design and analysis of electrical configuration options

Select overall best electrical configuration

Design Goal

Design most suitable electrical system for MRWT's

Topology Design

Design Constraints

- 45 rotor MRWT (500kW, 40m diameter)
- Provide AC power to collection network
- Each rotor must have independent speed control

Design Topologies

- Gather power from all turbines
- Based on offshore wind farm collection network designs
- Components kept consistent to focus on type of topology

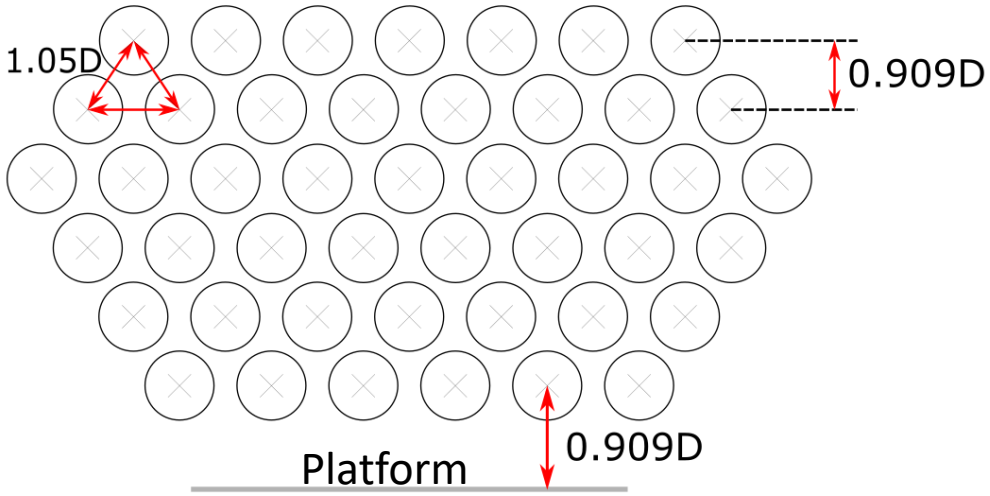
Cost, mass & loss models

- Models developed to estimate mass, cost and losses of each component in system
- Based on scaling relationships, academic literature and commercial datasheets

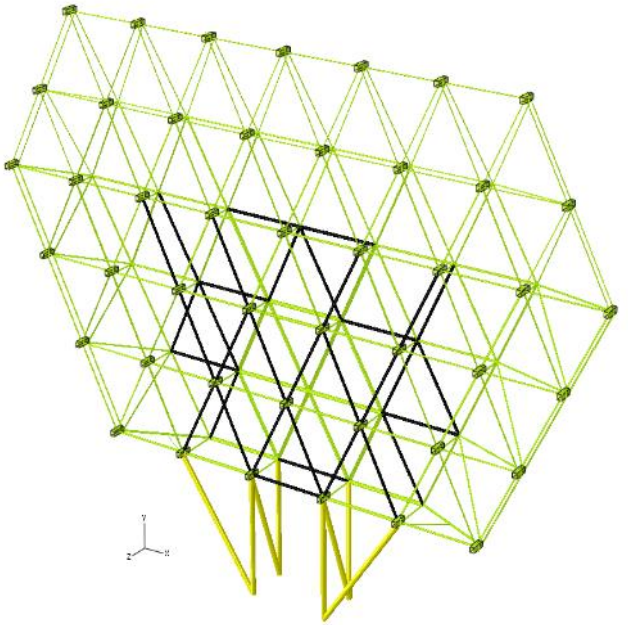
Determine suitability

- Based on the four criteria
- Best performing topologies move onto phase 2.

Layout



Layout and spacing of 45 rotor MRS



Support structure suggested in INNWIND.EU project

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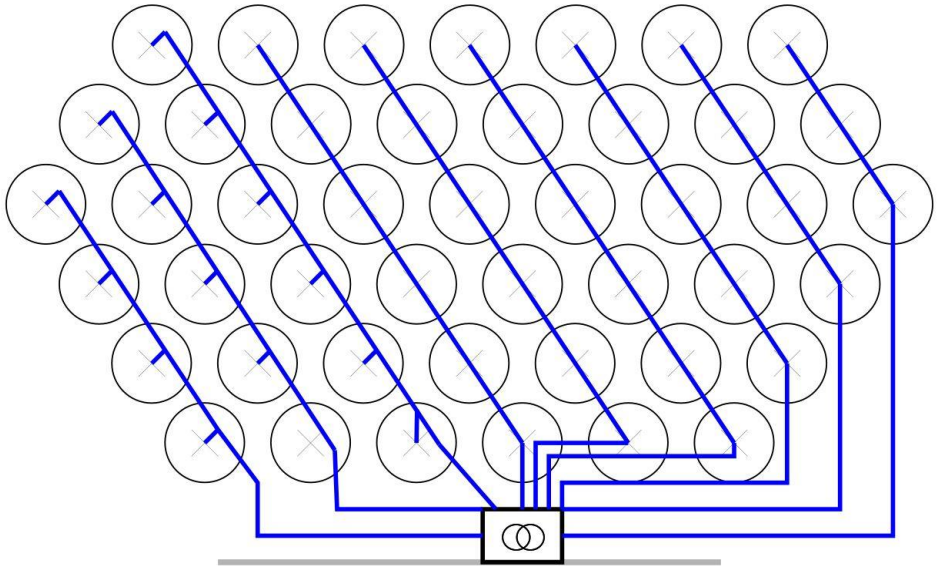
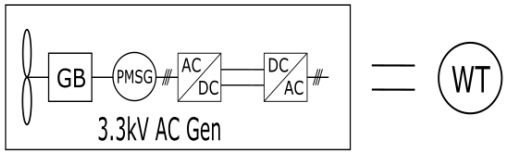
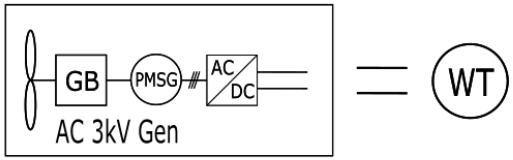
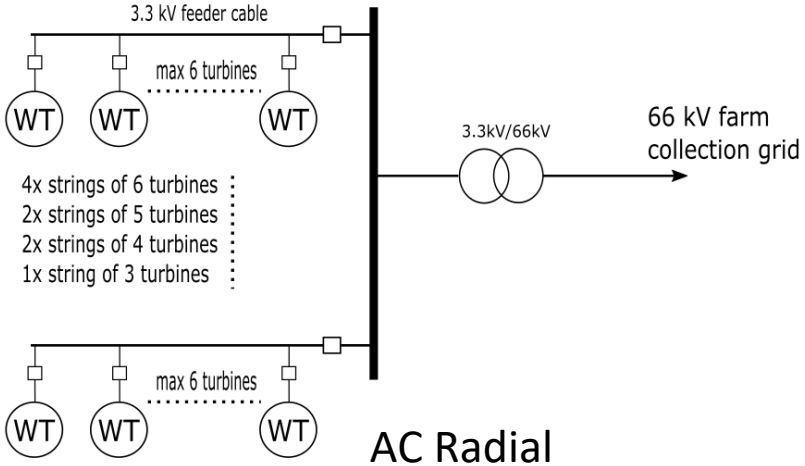
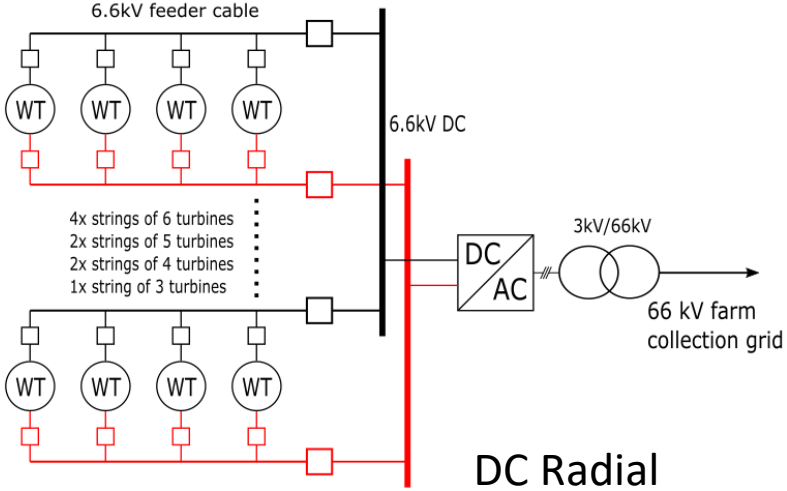








AC Radial



DC Radial

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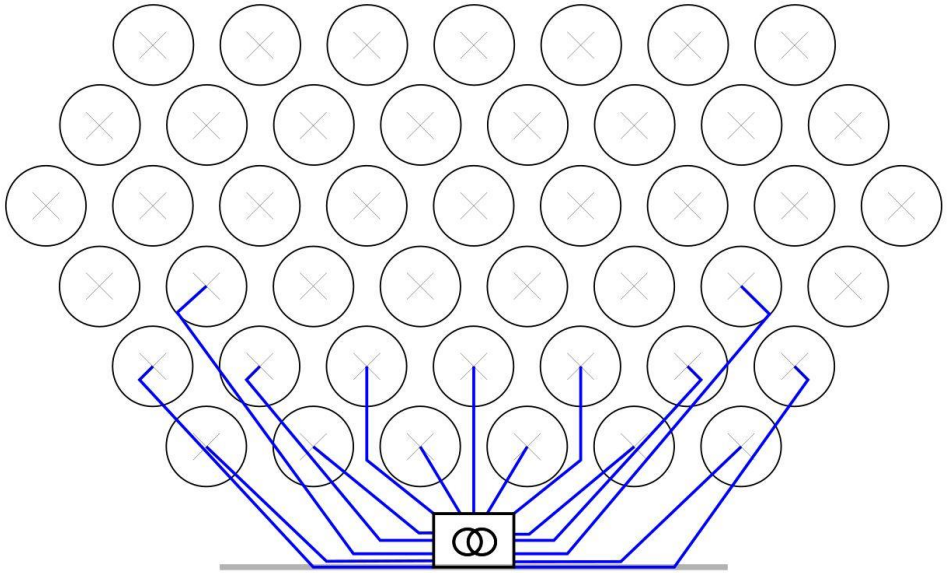
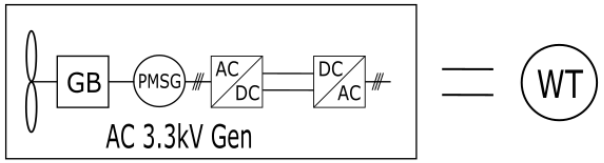
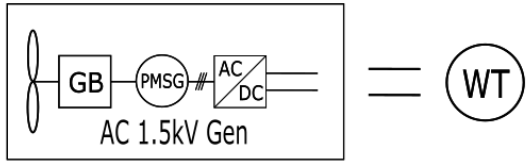
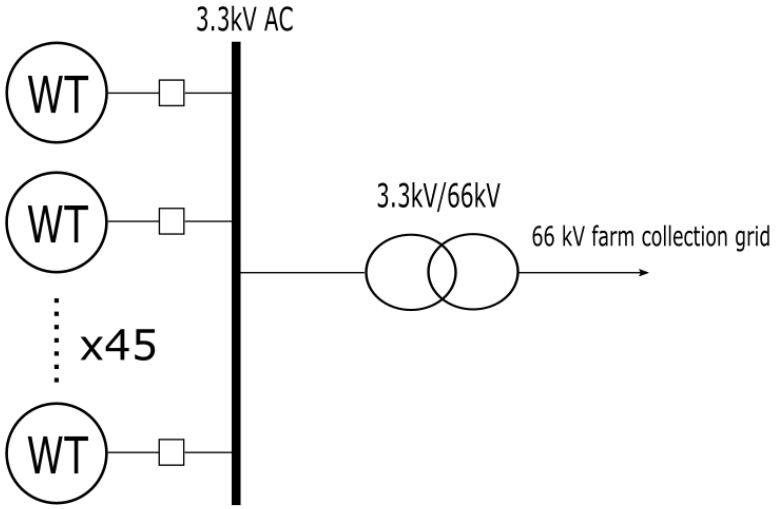
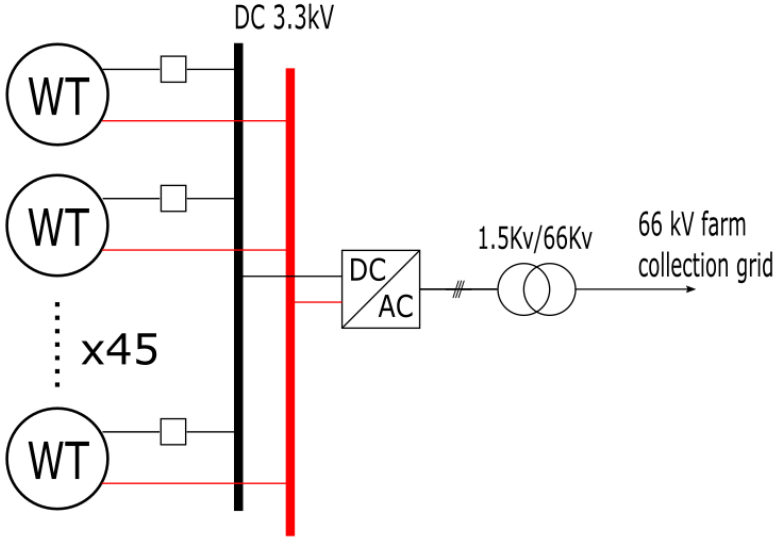








AC Star



DC Star

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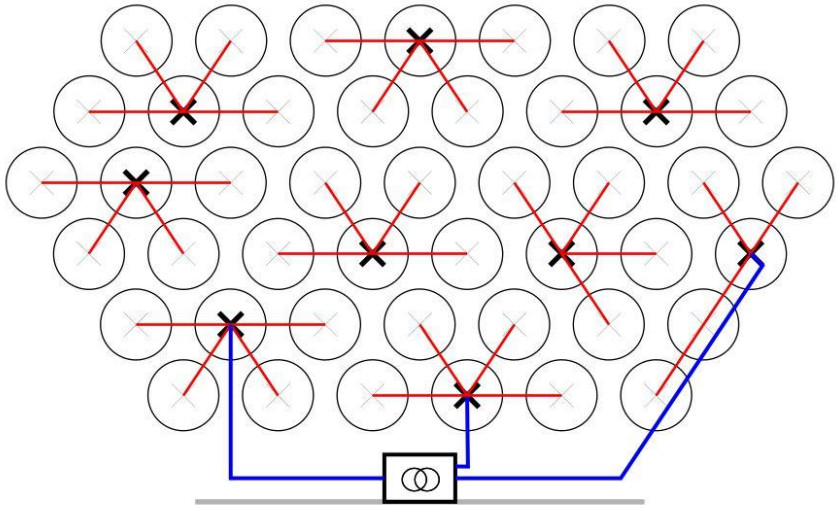
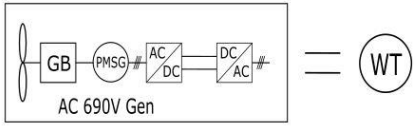
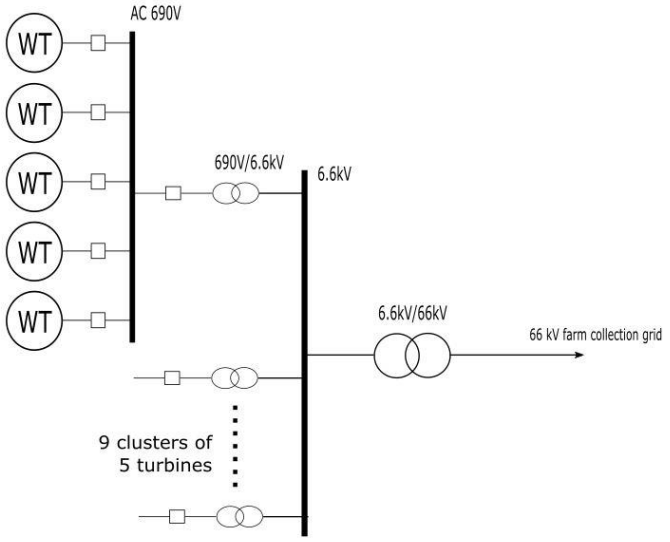
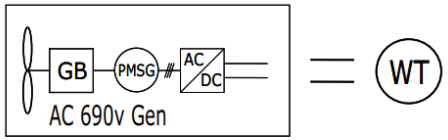
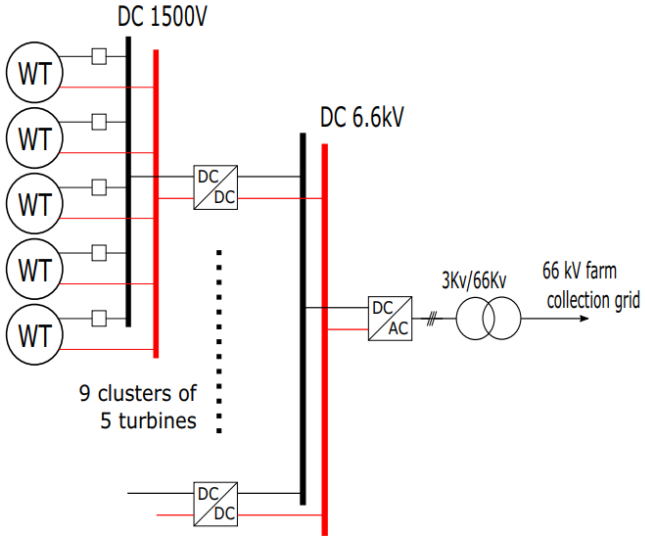




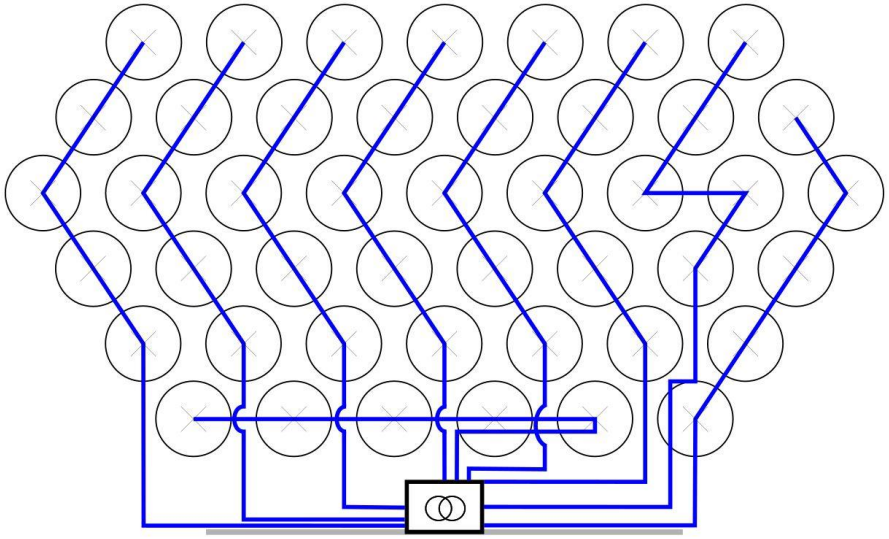


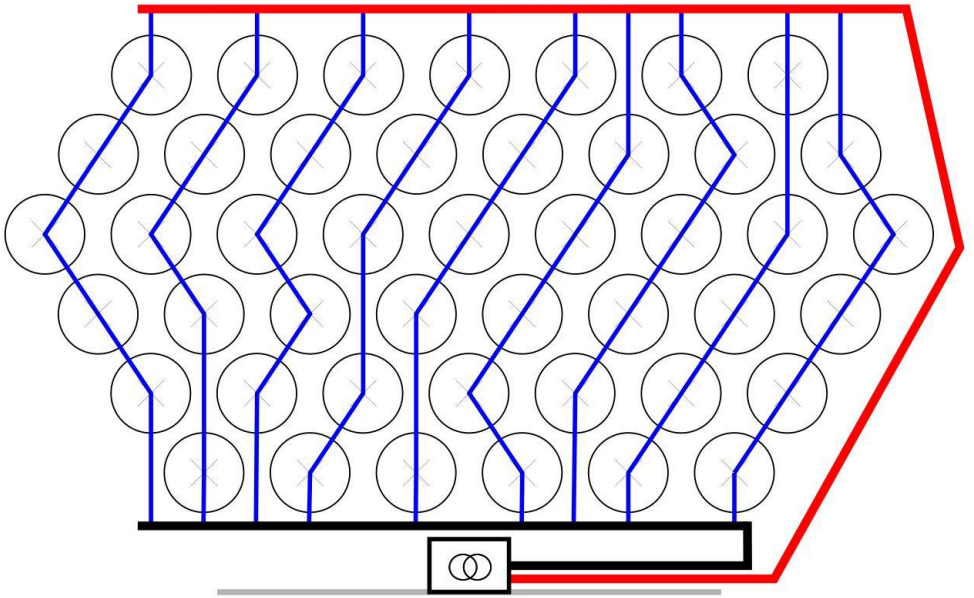
AC Cluster

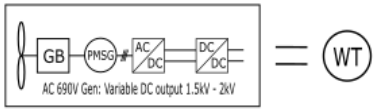


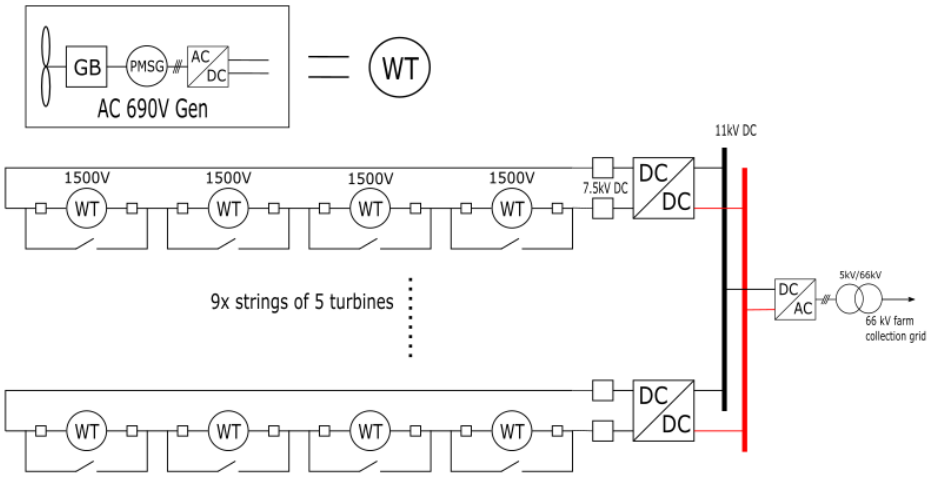


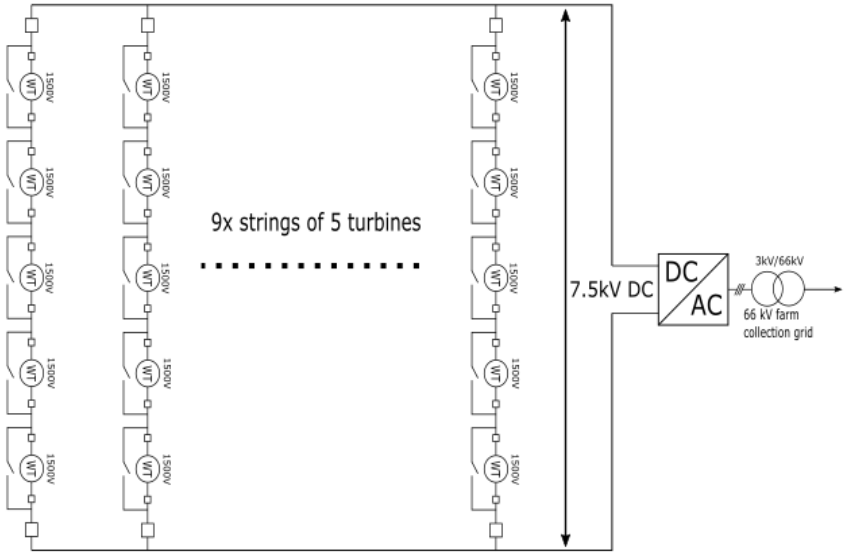
DC Cluster









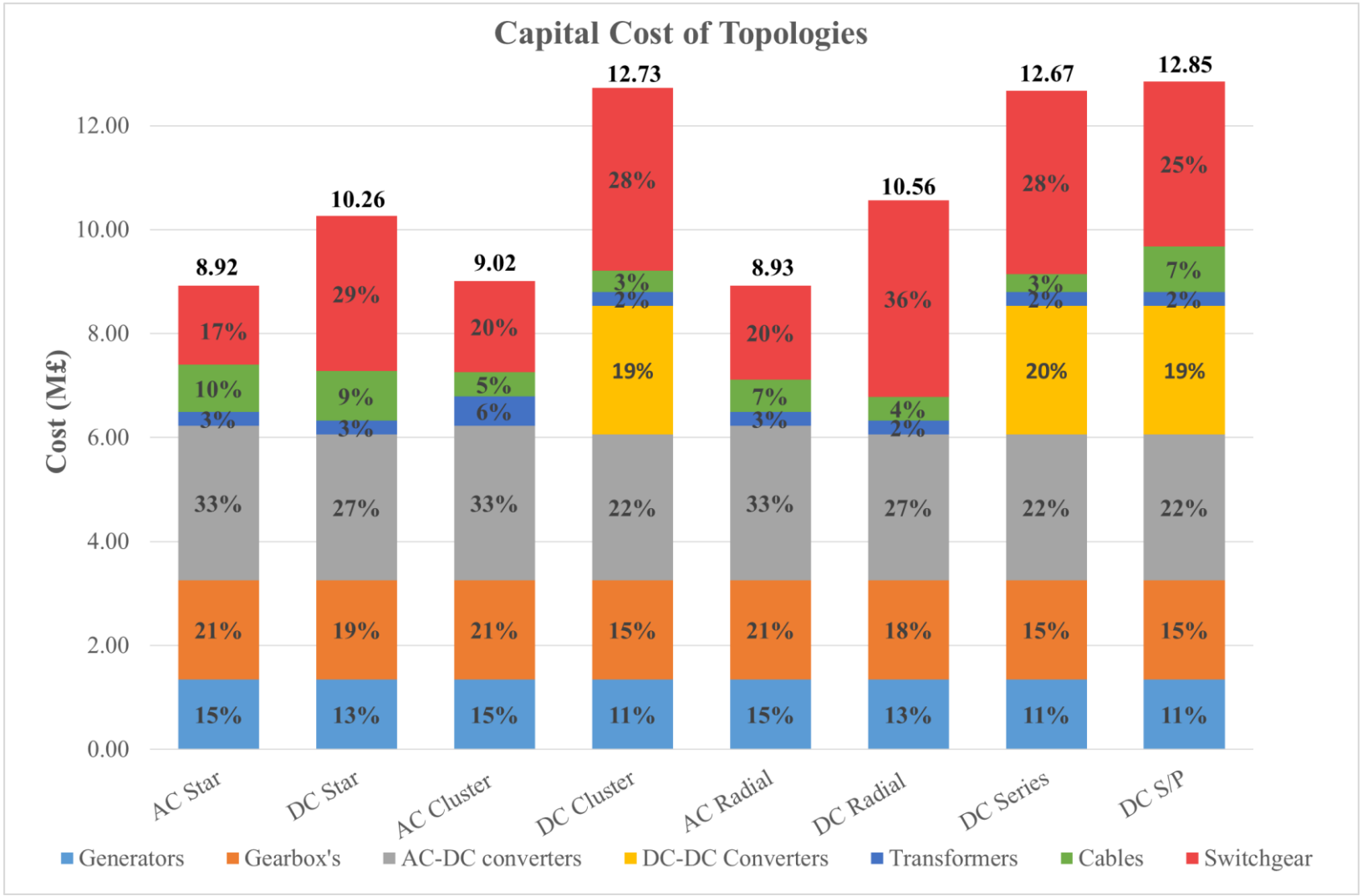


DC Series

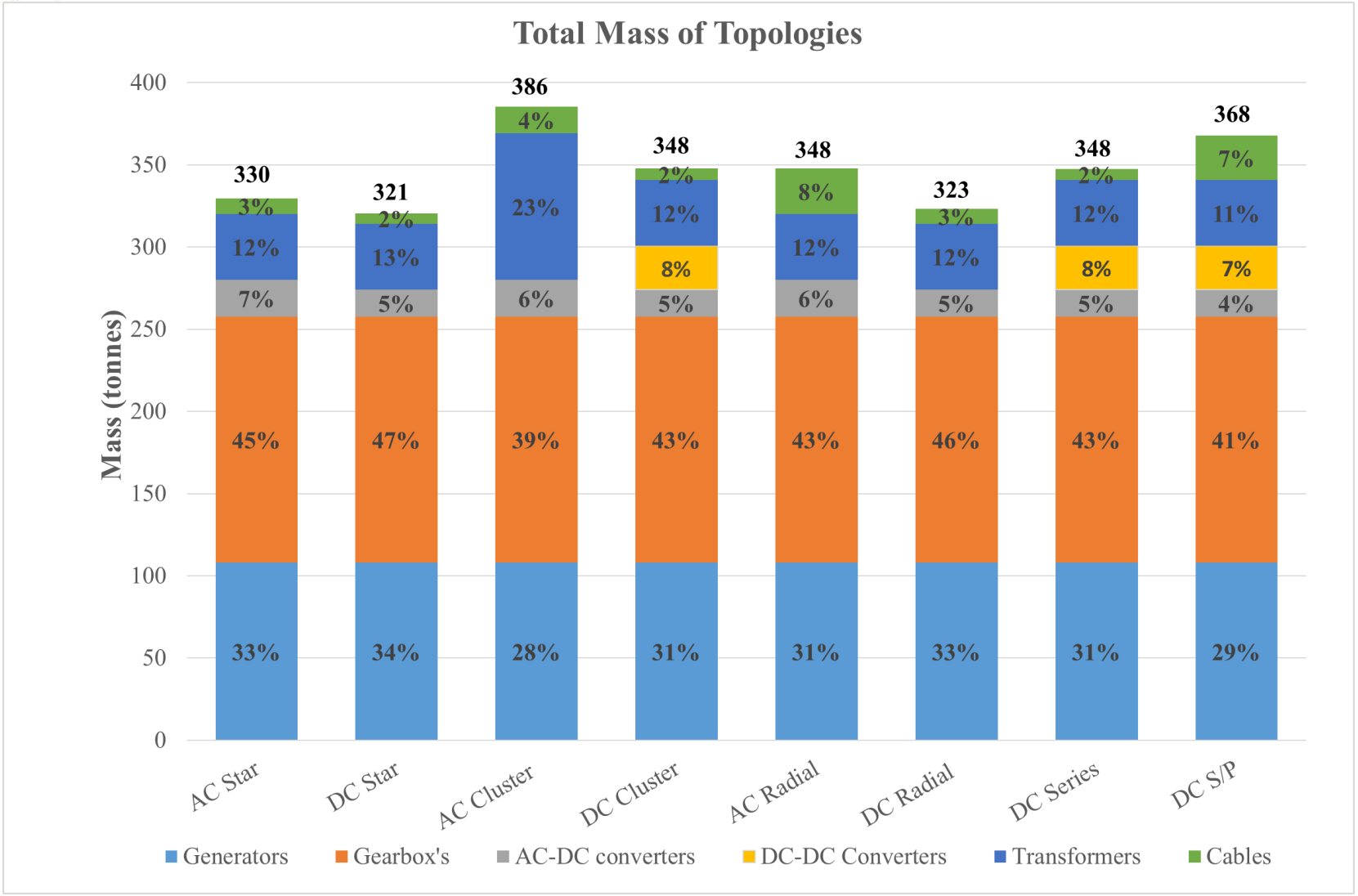
DC Series/parallel

Results

Topology capital cost

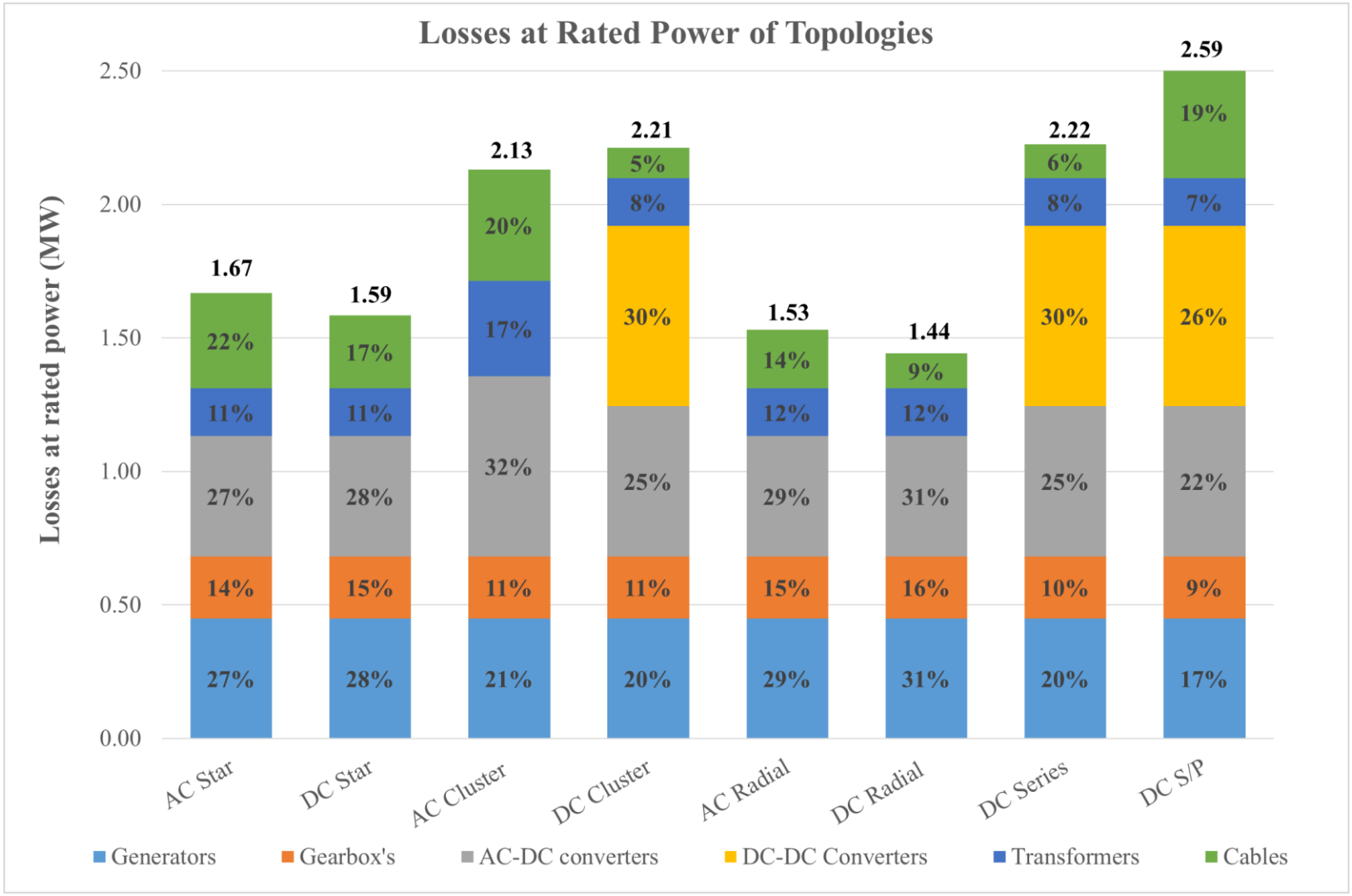


Results
Topology total mass



Results

Topology losses at rated power



Results
Comparison

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	-	X X	-	X	X X	X	X
DC Cluster	X X	X X	X X	-	✓	✓	✓
DC Series	X X	X X	X X	-	✓	✓	X
DC S/P	X X	X X	X X	X	X	-	X X

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Design and analysis of collection network topology options

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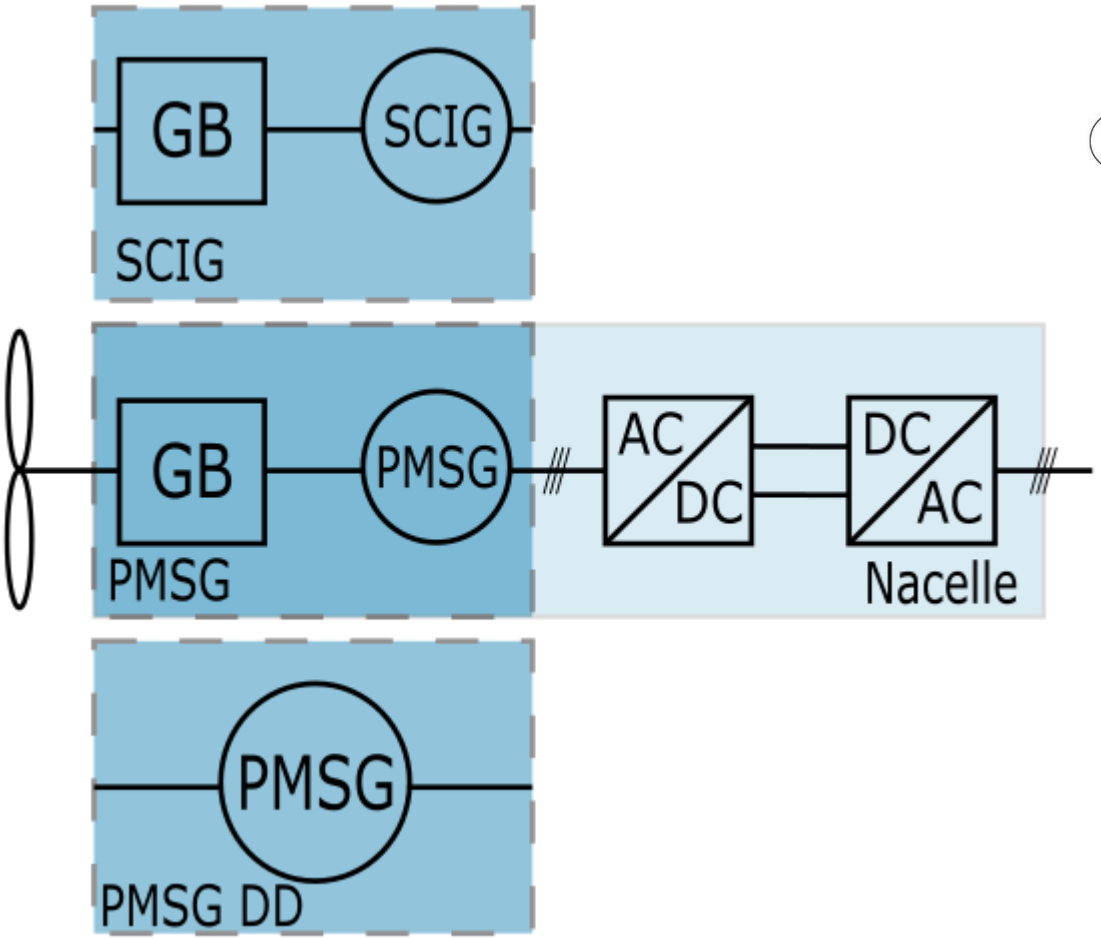
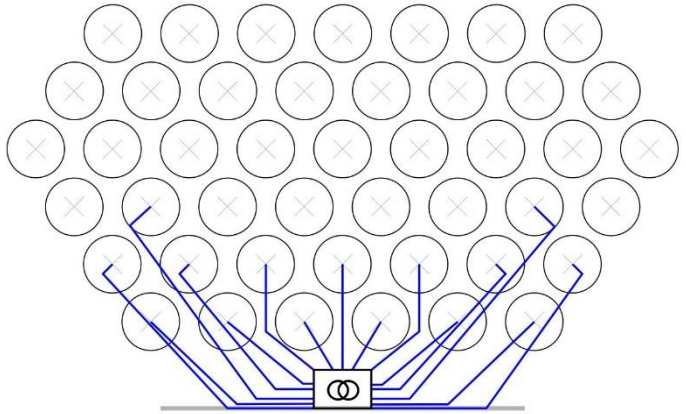
Design Goal

Design most suitable electrical system for MRWT's

Component Selection

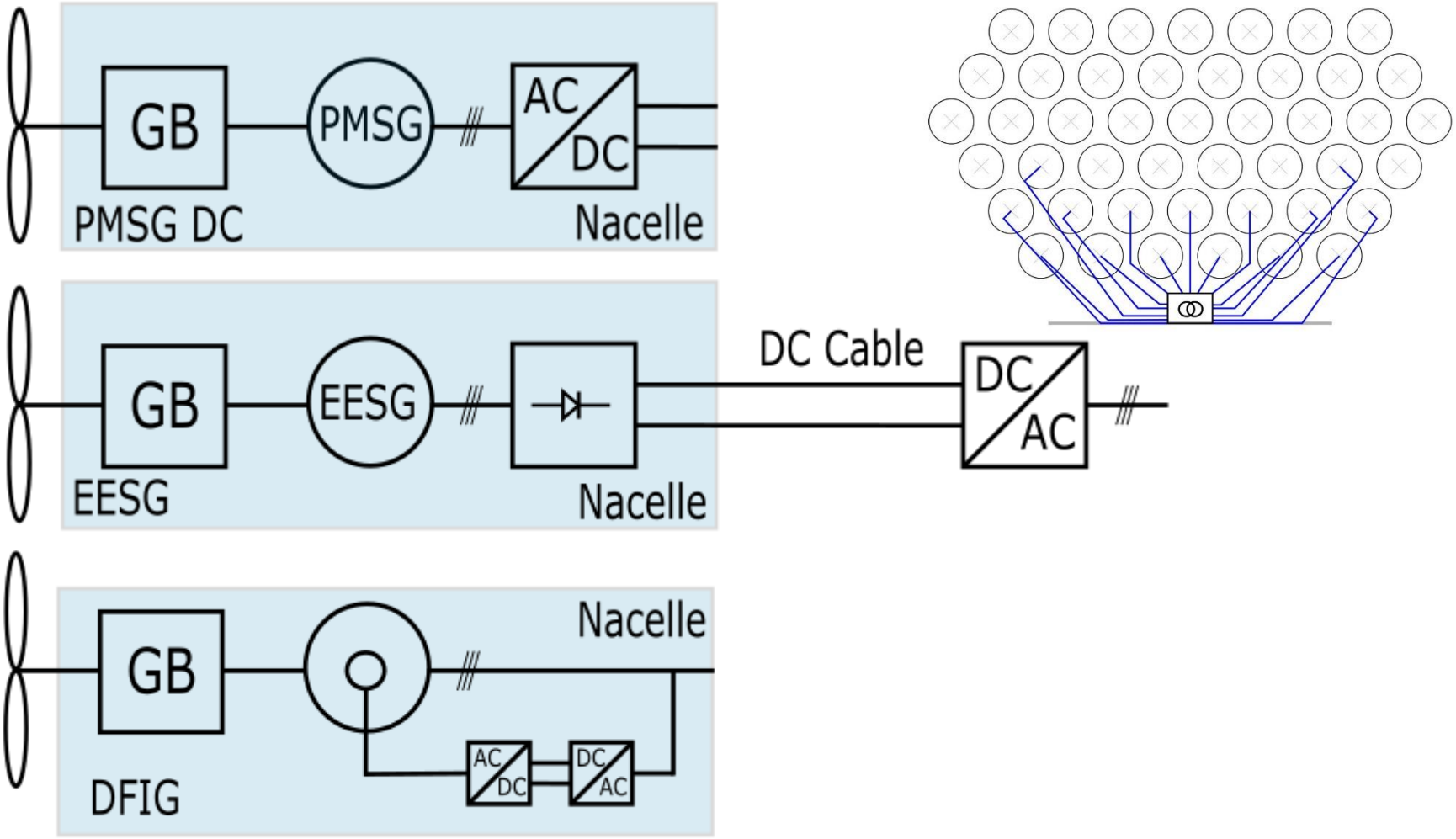
For star topology





Component Selection

For star topology



Quantifying failures

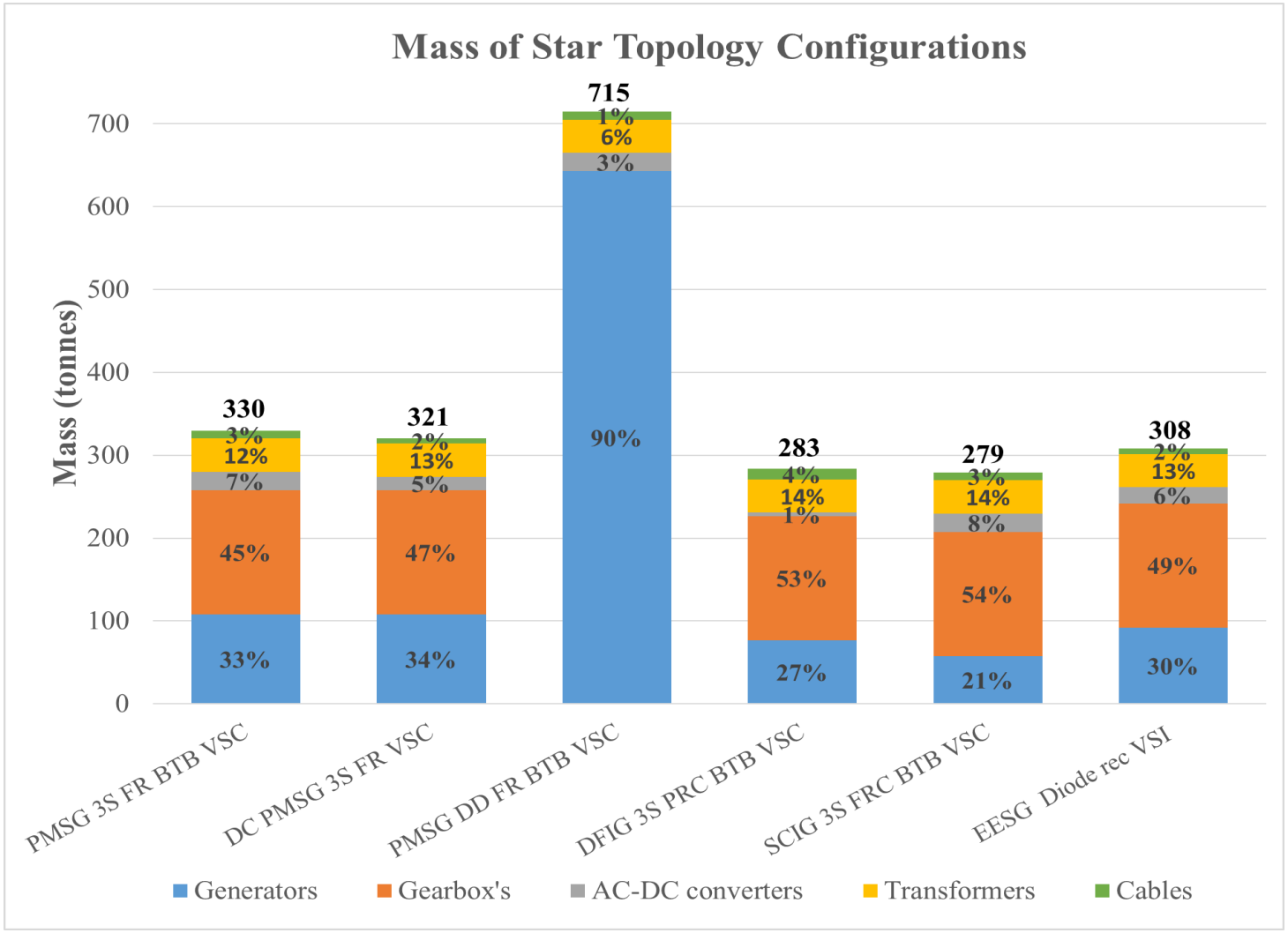
- Assume constant failure rates for each component
- Assume a fixed service period of 6 months
- How many failures will each configuration have in 6 months?
- How much will this cost in lost revenue?

Failure rates of configurations [failures/year/turbine]

Configuration	Generator	Gearbox	Converters	Total failure rate	Failures per 6 months
PMSG	0.076	0.18	0.632	0.888	20
PMSG DC	0.076	0.18	0.316	0.572	13
PMSG DD	0.076		0.632	0.708	16
DFIG	0.123	0.18	0.235	0.538	12
SCIG	0.062	0.18	0.632	0.874	20
EESG	0.123	0.18	0.11	0.413	10

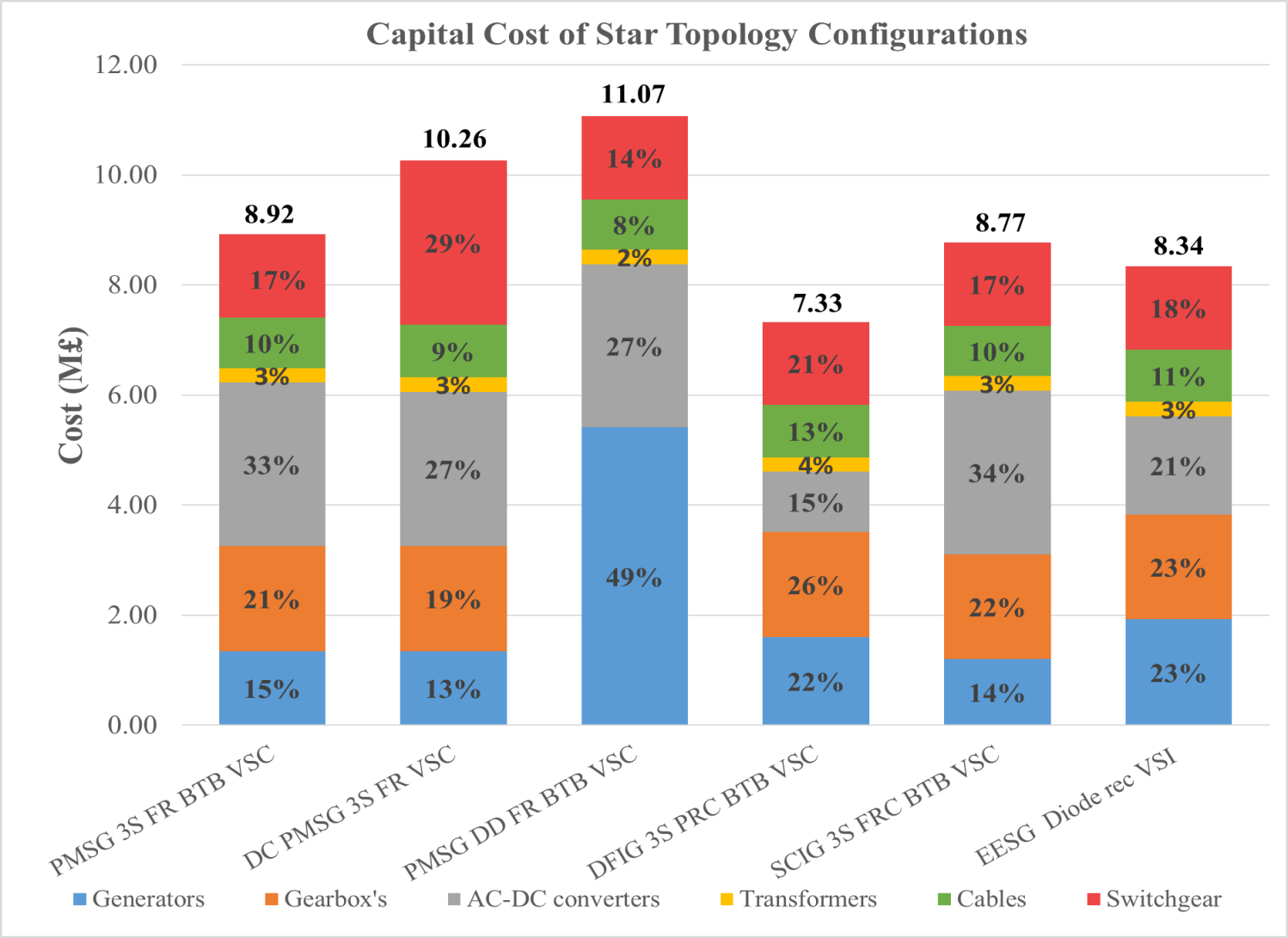
Results

Total mass of star options



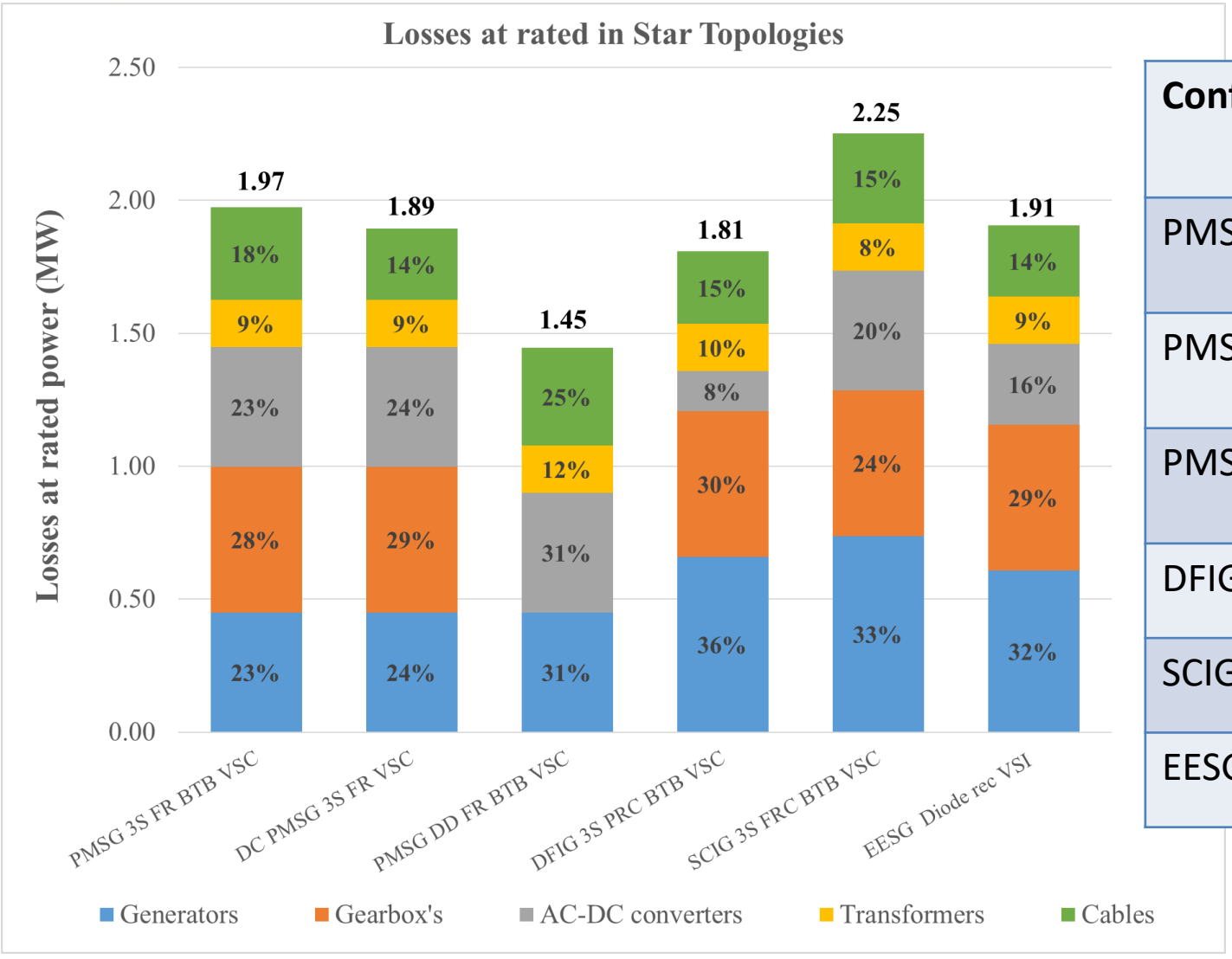
Results

Capital cost of star options



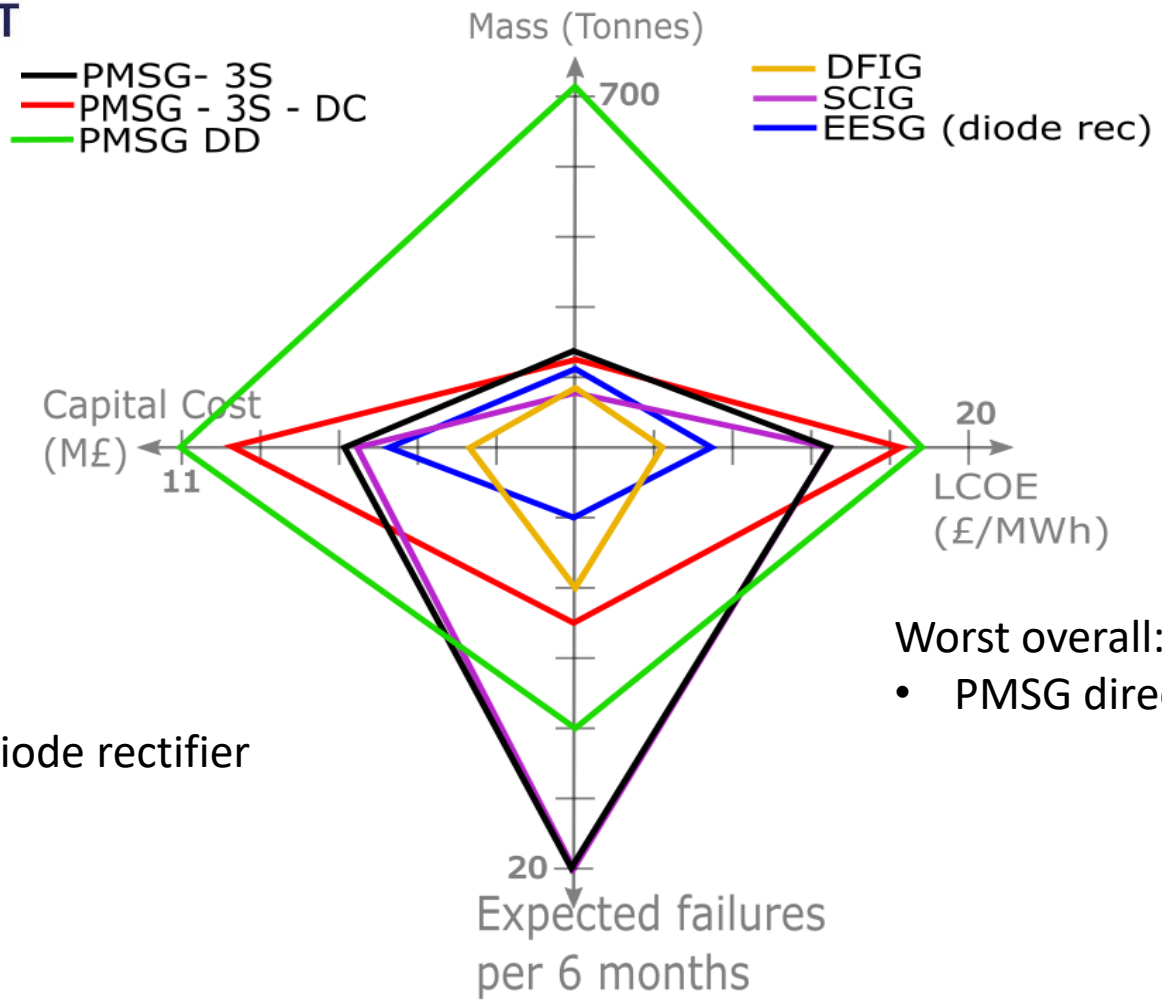
Results

Losses and LCOE of star options



Configuration	LCOE (£/MWh)
PMSG 3S	16.55
PMSG DC	18.31
PMSG DD	18.75
DFIG	12.19
SCIG	16.60
EESG	13.60

Results
Radar Plot



Best overall:

- DFIG
- EESG with diode rectifier

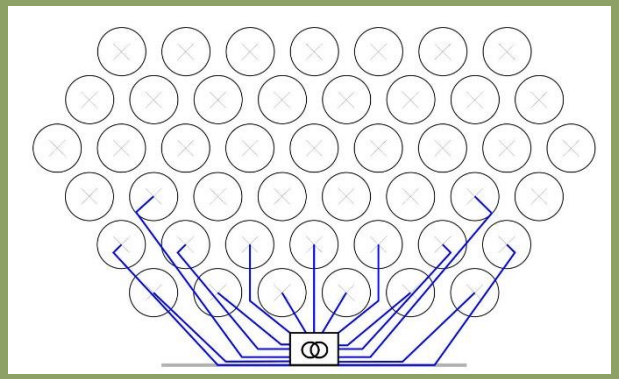
Worst overall:

- PMSG direct drive

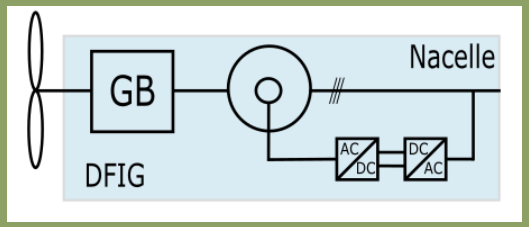
Conclusions

- Star topology is most suitable for MRWT's
  - High redundancy
  - Low cost and mass
- Either DFIG or EESG with diode rectifier is best configuration
  - Both will be explored further in future work

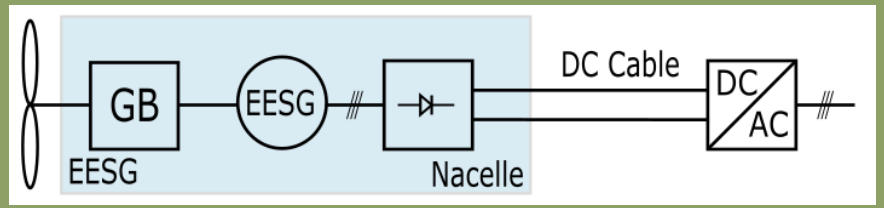
Design Goal



Star topology



DFIG



EESG with diode rectifier

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Thanks for listening

Any questions?

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