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Large scale offshore wind energy systems the multi-rotor solution

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Abstract

A 20 MW, multi-rotor system (MRS) has been designed within the European project, Innwind. Since the start of offshore deployment, the motive in up-scaling of the conventional single turbine concept is to reduce cost of energy through have fewer maintenance sites, fewer foundations and reduced extent of electrical interconnections per installed megawatt of wind farm capacity.

For the established single turbine concept, this potential upscaling advantage is offset by increased cost per rated MW in the wind turbine itself (the square-cube law effect) and the need for demanding new technology development to mitigate this.

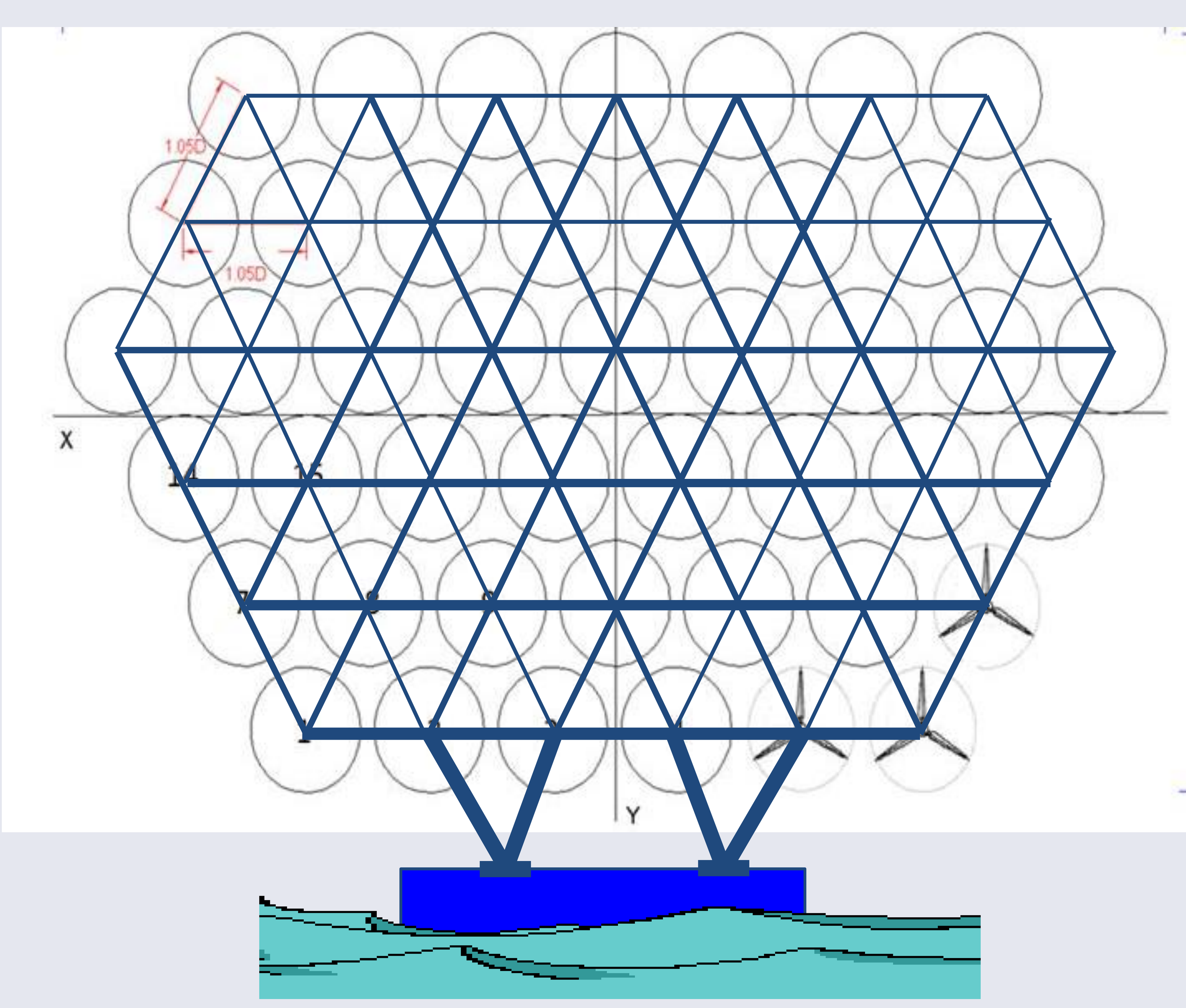
The MRS can be up-scaled without fundamental difficulty or new demands on turbine technology development to unit capacities of 20 MW or more. The Innwind work indicates that compared to an equivalent single turbine, the MRS would appear to have major advantages in reduced, better distributed loading, in reduced system mass, in increased energy capture in relation to total swept area, and in reduced turbine capital cost.

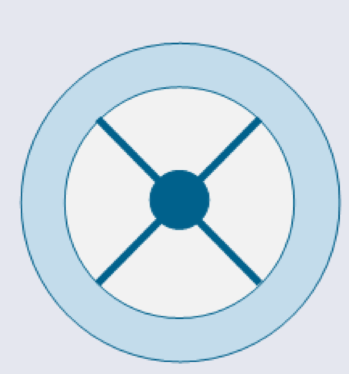
Using a cost of energy model developed independently within the Innwind project, a 30% reduction (Innwind reference value 107€/MWh) in LCOE of the MRS was predicted.

Objectives

The Innwind project objective was to evaluate a variety of innovative wind turbine component or system concepts that may lead to reduced cost of energy in offshore deployment.

Methods





A 20 MW MRS comprising 45 rotors each rated at 444 kW

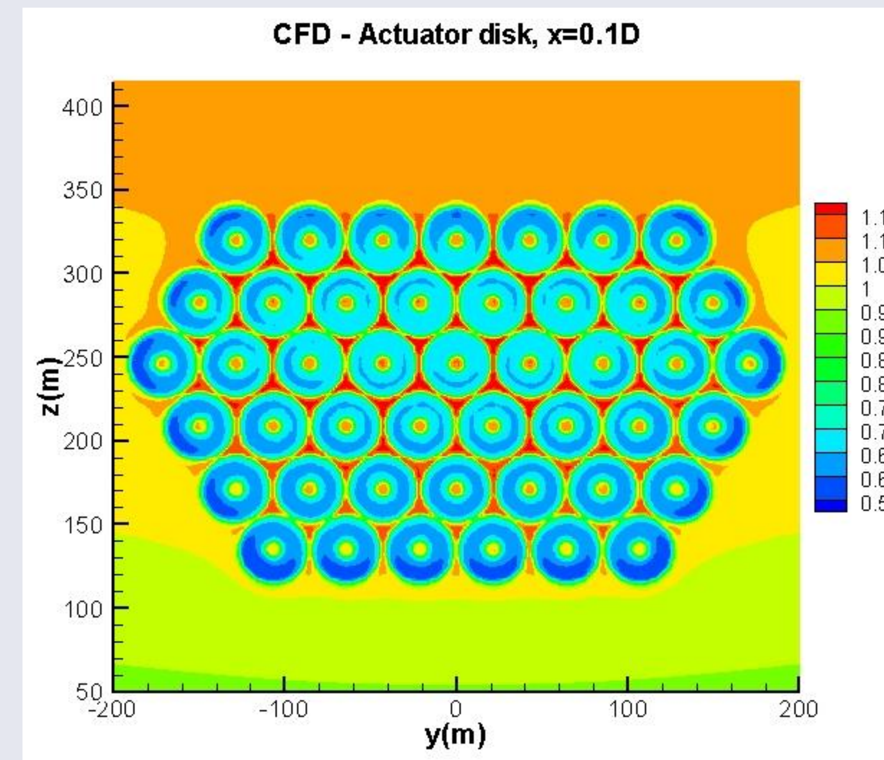
The system concept [1], operation and control, design load prediction was conducted by University of Strathclyde (UoS) using Bladed software further developed by DNV GL to accommodate 45 rotors.

Turbine support structure design was developed by CRES (numerical optimization problem in Mathematica where a similar implementation of the CRES-Frame structural tests has been programmed) for tube member selection and total weight minimisation. Barge type floaters (rectangular, doughnut, disc and 4 interconnected cylindrical floaters) were also designed by CRES primarily for hydrostatic stability.

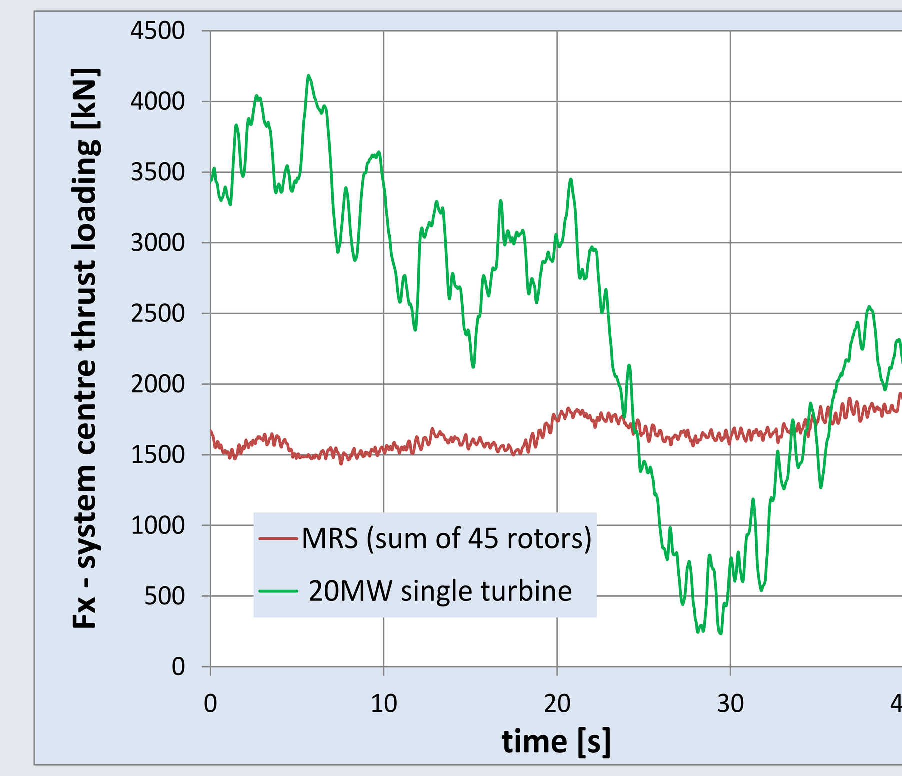
Aerodynamic evaluation using CFD and vortex particle methods [2] was undertaken by NTUA

Using a model for levelised cost of energy (LCOE), based on the NREL model but adapted for innovative systems and developed independently in another task within Innwind [3], comparisons in LCOE were made with an advanced 10 MW design, also developed within Innwind, specifically as a baseline for such purposes.

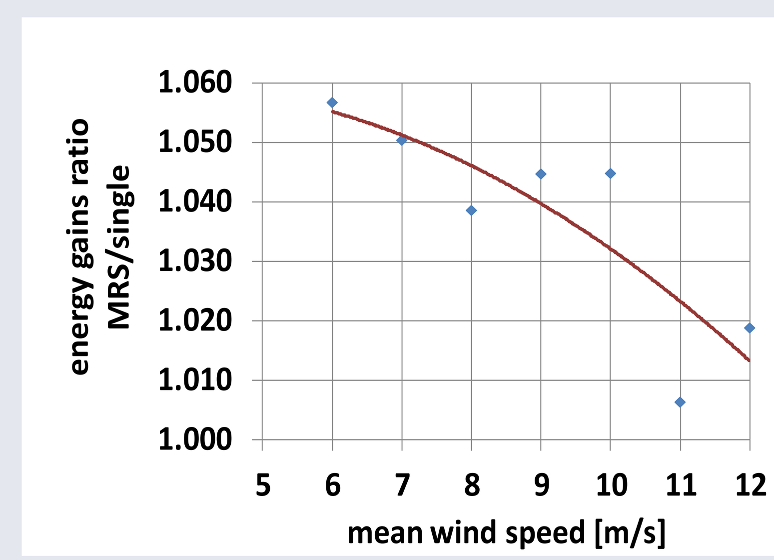
Results



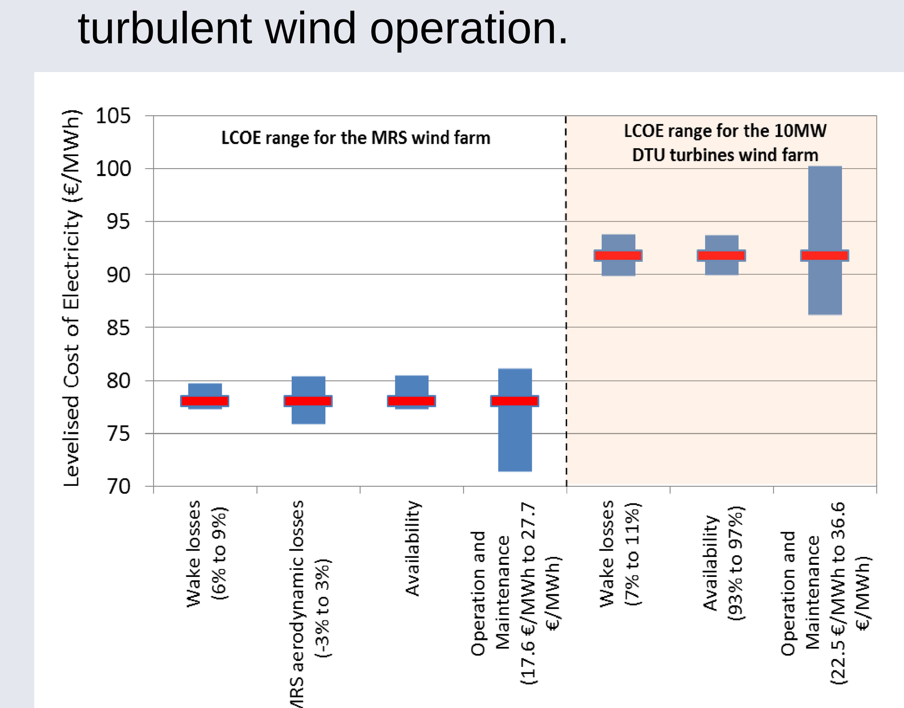
CFD (above) and vortex (inviscid) simulations of a 45 rotor array by NTUA indicated 8% power gain (3% with 7 rotor array)

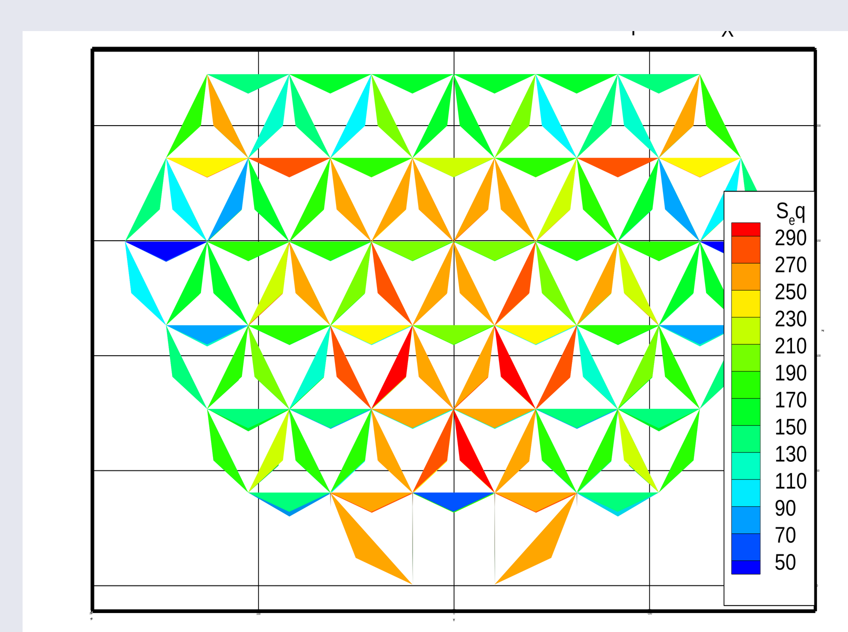


Very large reductions especially in fatigue loads due to randomization of blade position and rotor speed in turbulent wind operation.



An additional mechanism of energy gain with the MRS arises from better spatial and temporal response to turbulence from a set of small rotors.





Stress (Mpa) in DLC 6.2 (extreme storm).

Structure mass with optimised tube selection ~ 3000t which compares well with 3500t for a single turbine tower for a 20 MW system (based on the UPWIND project design) with same total swept area

Comparison of 20MW MRS windfarm with one based on 10 MW reference turbines. Sensitivities were examined of LCOE to assumptions regarding:

- Wake loss
- Aerodynamic loss
- Availability
- O&M
- Turbine cost multiplier
- Turbine cost
- MRS structure cost (modelled as jacket cost)
- MRS power rating in relation to rotor diameter

A summary LCOE evaluation of a related 90 rotor 40 MW MRS indicated a similar range of LCOE to the 20 MW design.

Conclusions

A 30% reduction (Innwind reference value 107€/MWh) in LCOE of the MRS was predicted (neither best nor worse scenarios). Sensitivity studies also indicated a 40 MW unit should be cost effective. Turbine technology is de-risked and market implementation can be faster. Consider by comparison development costs and impact of a serial fault in turbines of 10 MW rating. With unit production of the rotors being in greater volume (factor of 10 to 20) unit reliability should increase. Single turbine faults compromise only a few % of capacity and can be ignored avoiding unscheduled maintenance in challenging sea states.

References

1. *Jamieson,P, "Innovation in Wind Turbine Design", Wiley and Sons Ltd., August 2011.* Journal Article, *Name of Journal*
2. *Voutsinas, S.G., 2006 "Vortex Methods in Aeronautics: How to make things work", Int. Journal of Computational Fluid Dynamics, Vol 20, No 1.*
3. *P. Chaviaropoulos et al., "PI-based assessment of innovative concepts (methodology)", Innwind.EU Deliverable 1.23, April 2014.*