EPSRC

Engineering and Physical Sciences Research Council

University of Strathclyde Engineering

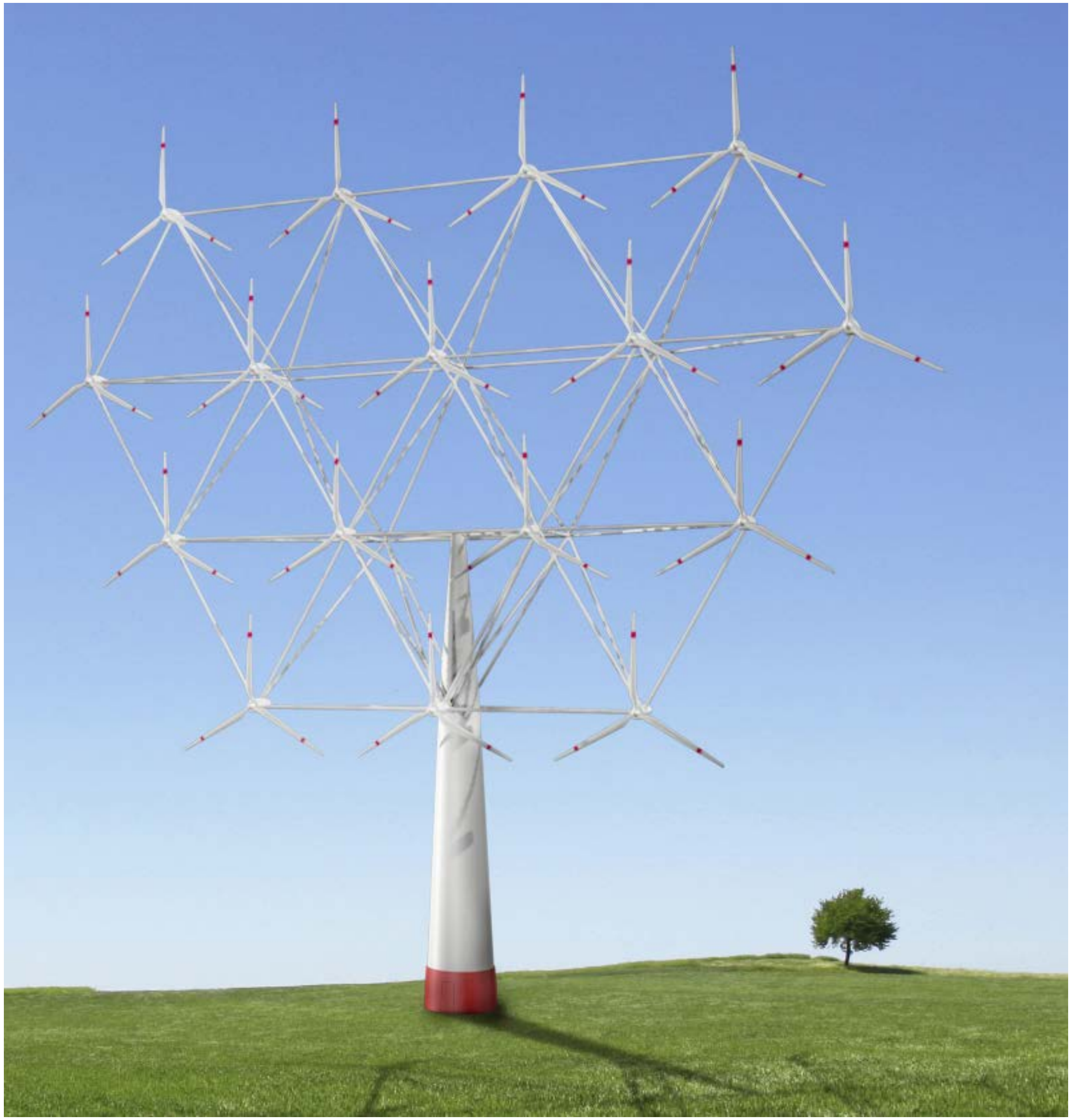
Multi Rotor Systems for Large Unit Capacities Offshore

EERA Deepwind January 2014

Design of Multi Rotor System

OWES

5MW system comprising 16, 312 kW wind turbines



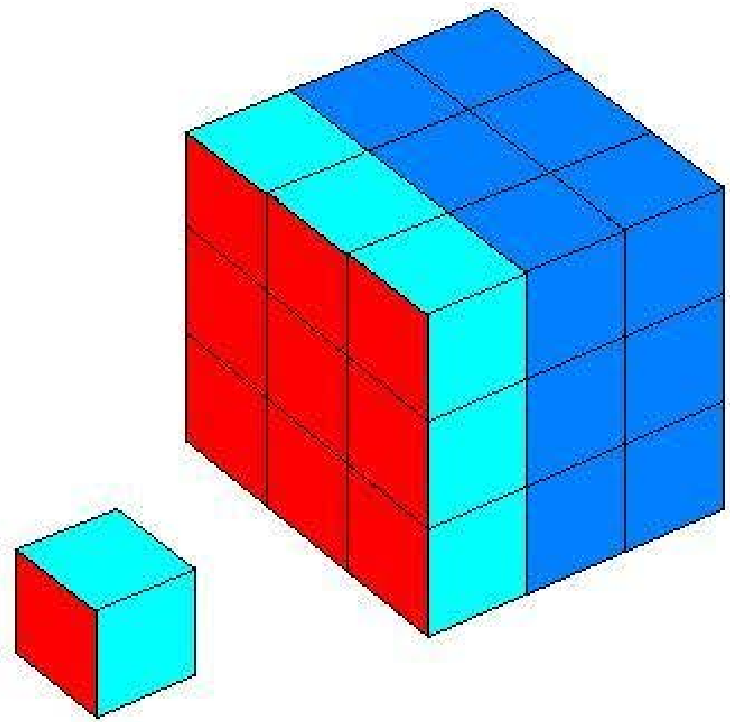
The Case for Multi Rotor Systems

- **Scaling laws** – total rotors and drive trains of the multi rotor system will   have much less weight and cost of blades, hub and drive train of a single equivalent turbine

- **Standardisation** – systems larger than 20 MW will be realised with more rotors not larger rotors. Thus there is opportunity to gain very substantial cost and reliability advantages of standardisation of rotor and drive train components in stable serial production at a size comfortably within industry experience

- **Maintenance** – the multi-rotor system will have in effect almost no unscheduled maintenance. Single turbine faults will usually compromise only a few percent of capacity, reducing urgency to find favourable weather windows for remedial action.

Why Multi-Rotors?



National Geographic
1976

The Multi-Rotor Argument

Equal area: $D^2 = nd^2$

Mass of large rotor: $M = kD^3$

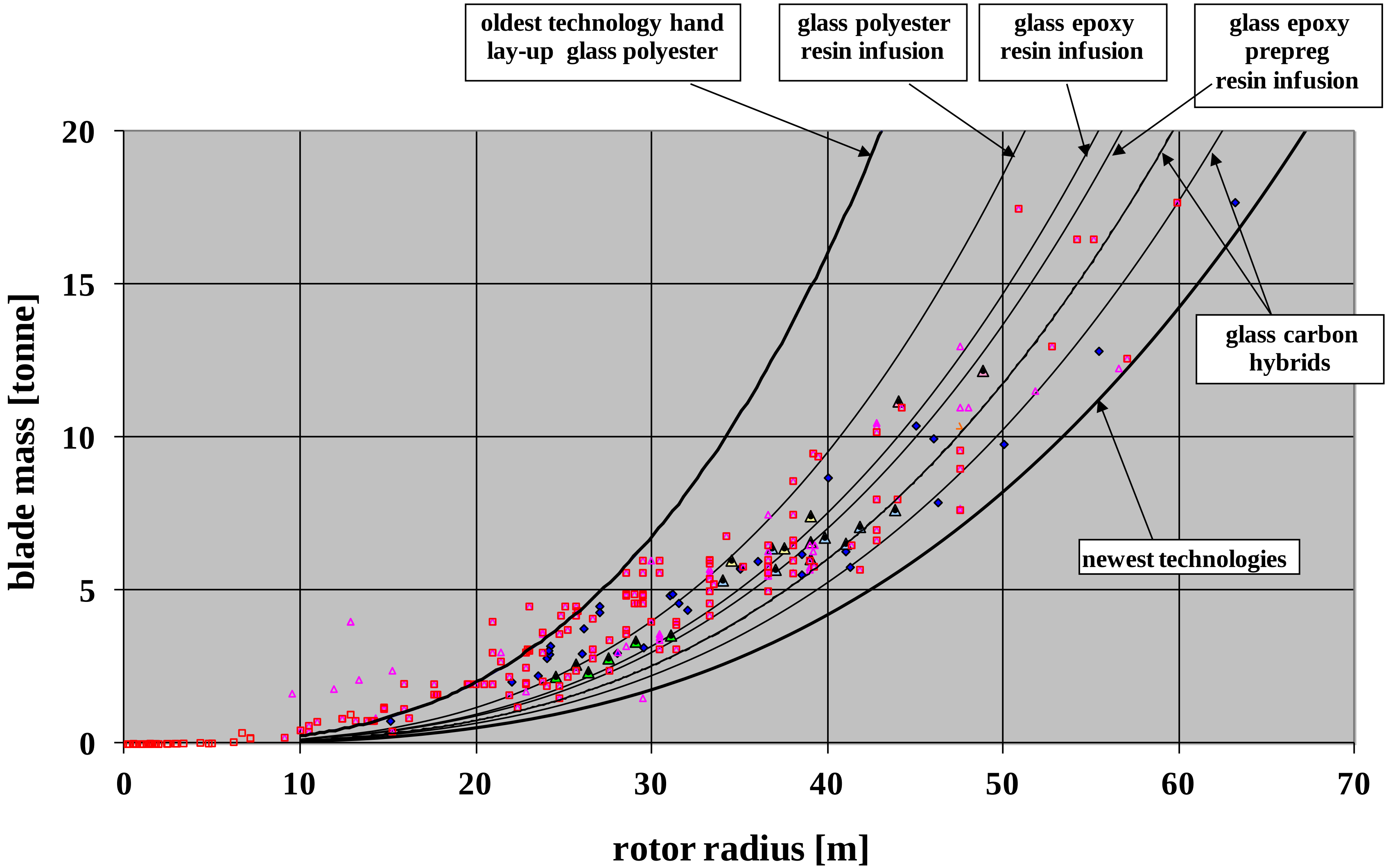
Mass of small rotor: $m = kd^3$

The mass ratio is: $R = n\left\{\dfrac{d}{D}\right\}^3$

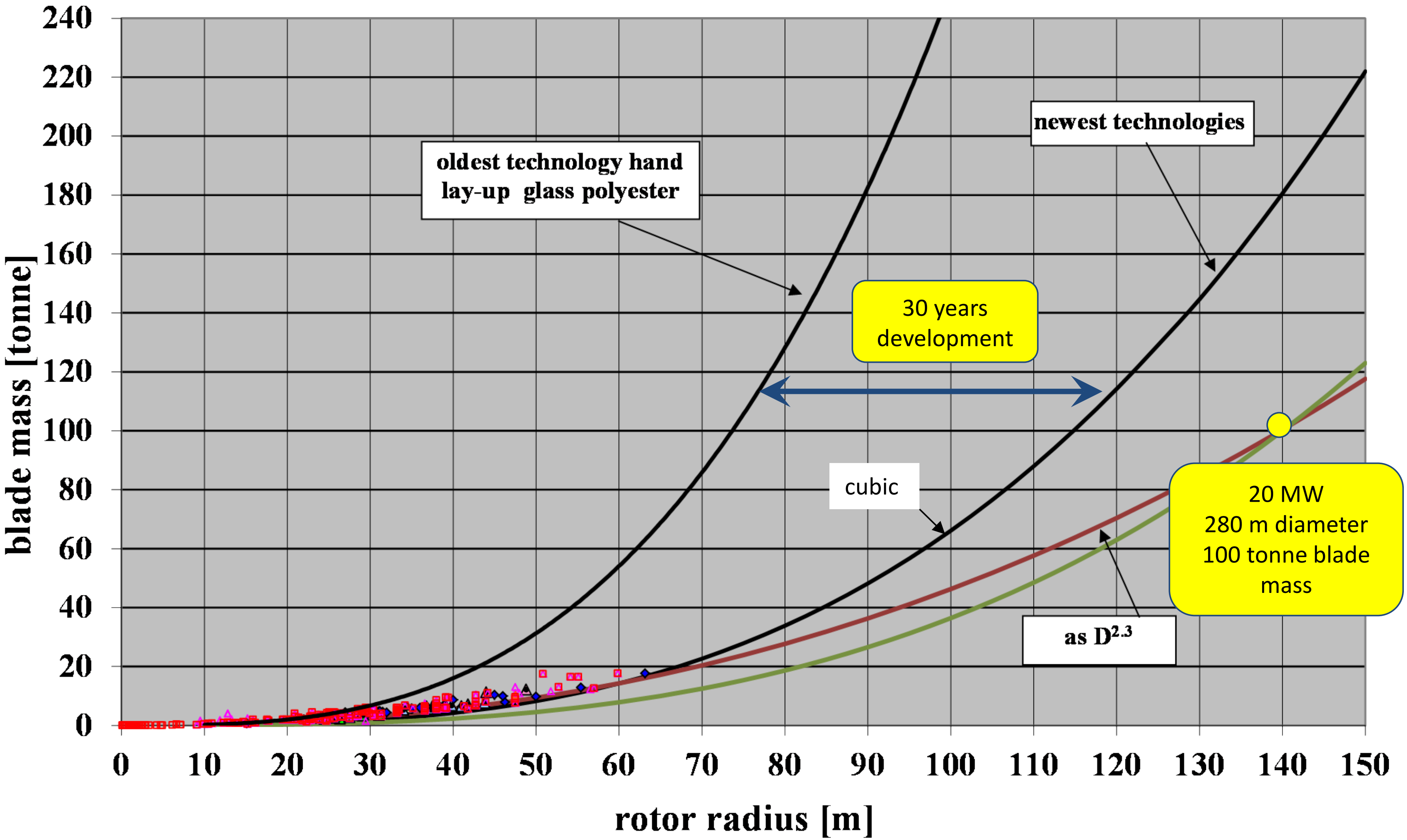
100 rotor, multi-rotor system has 1/10th of weight and cost of rotors and drive trains compared to a single equivalent large rotor!

$$R = \frac{nm}{M} = \frac{1}{\sqrt{n}}$$

Upscaling Challenges



Upscaling Challenges



Upscaling the easy way!

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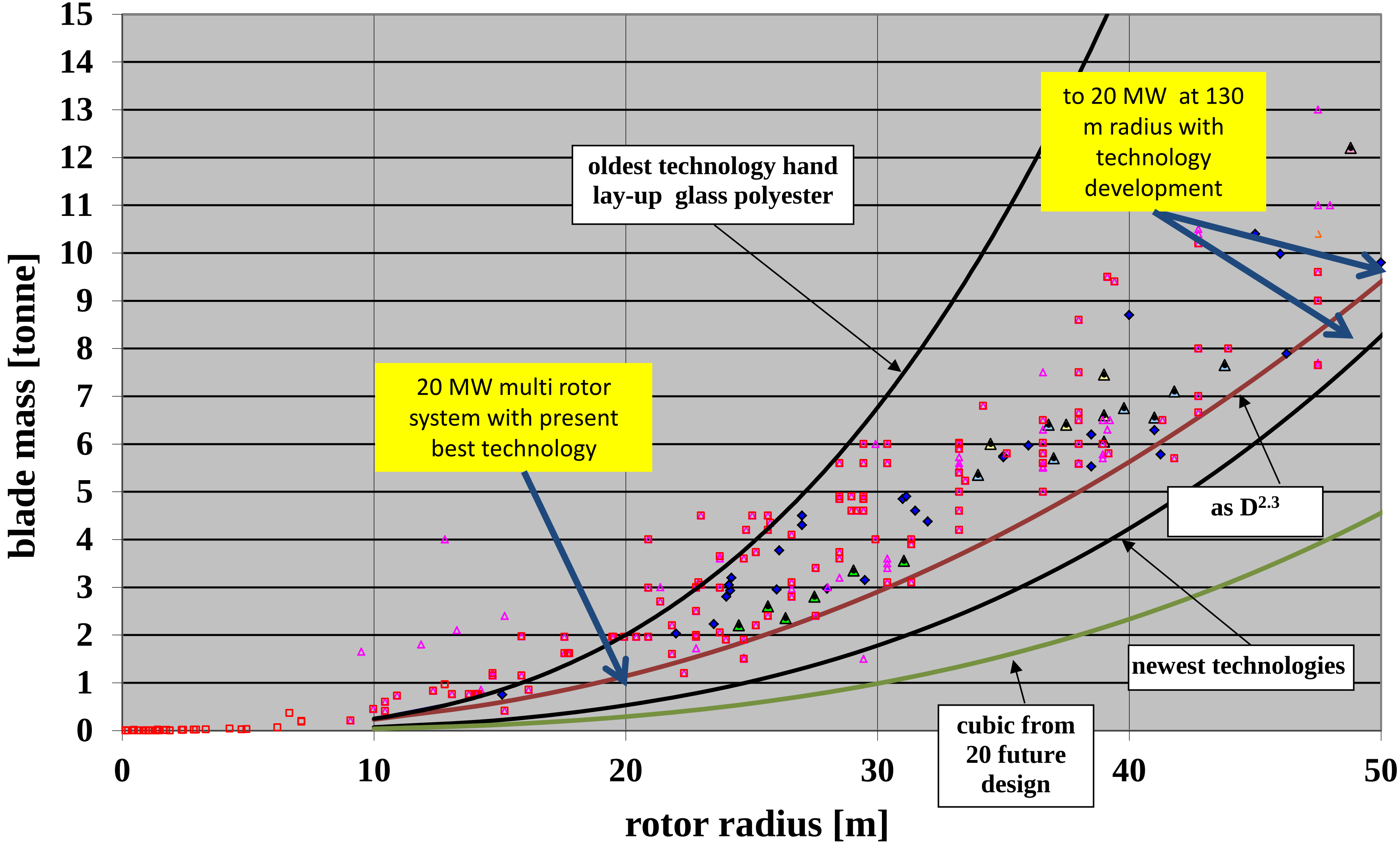

Design of Multi Rotor System

- Define multi rotor system layout
- Create a system model to determine design driving loads
- Define a reduced set of load cases
- Conduct load calculations

The main objective in modeling multi rotor system loads is to facilitate the development of a suitable design of support structure (CRES). When candidate support structures have evolved, the overall aerodynamic interference of structure and rotors will be assessed (NTUA).

Innwind.eu - Partners Roles

SU - Technical coordination, concept design, load calculation using:

GLGH - Bladed for 45 rotors.

CRES – support structure and yaw system design

NTUA – validation of aerodynamics: rotor interaction, structure blockage.

Multi Rotor System Definition

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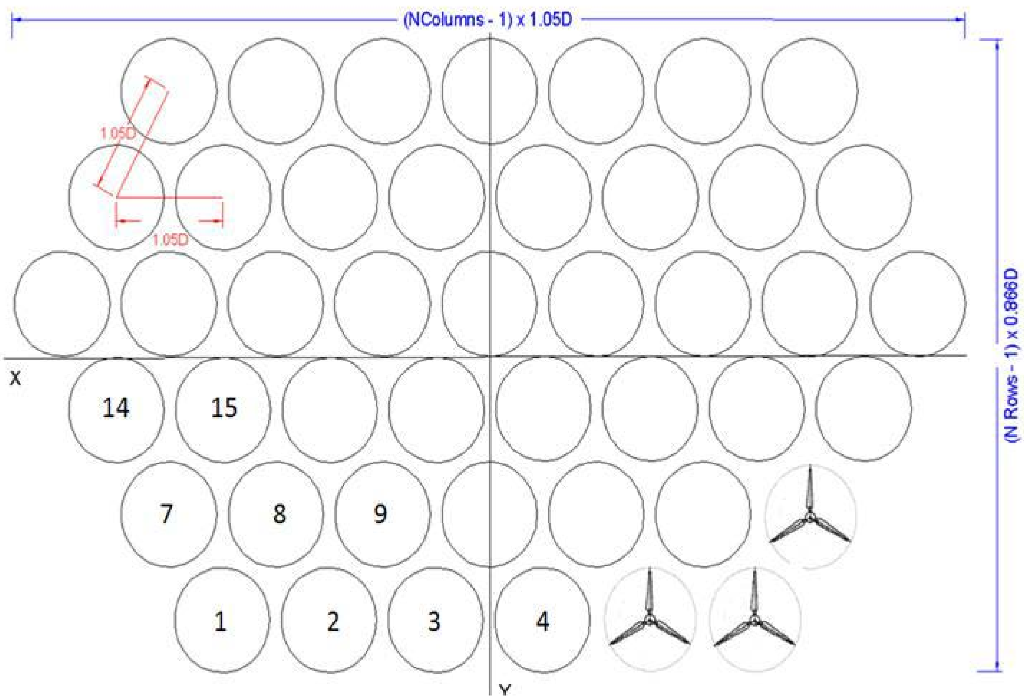
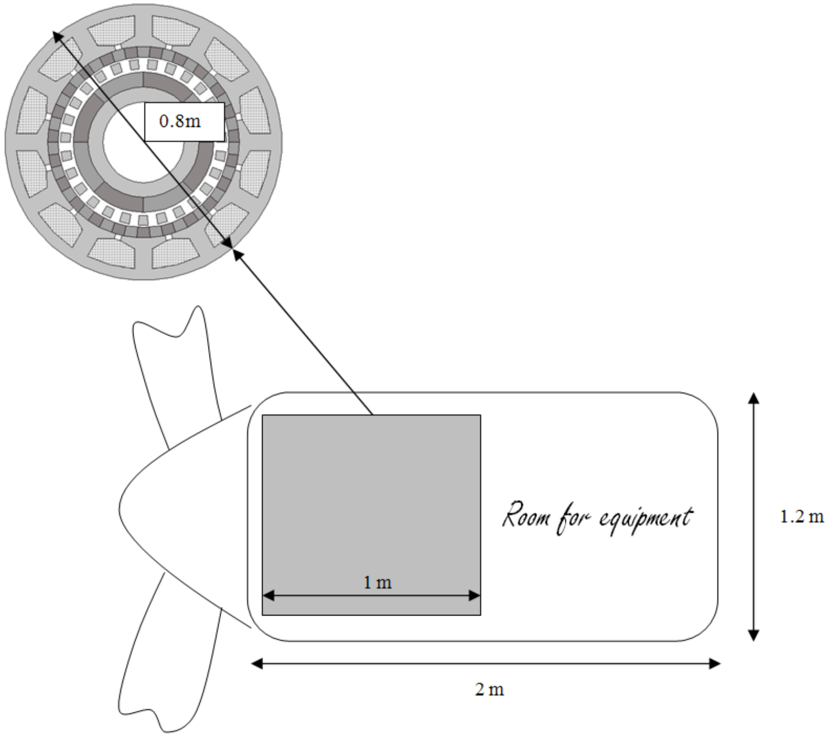
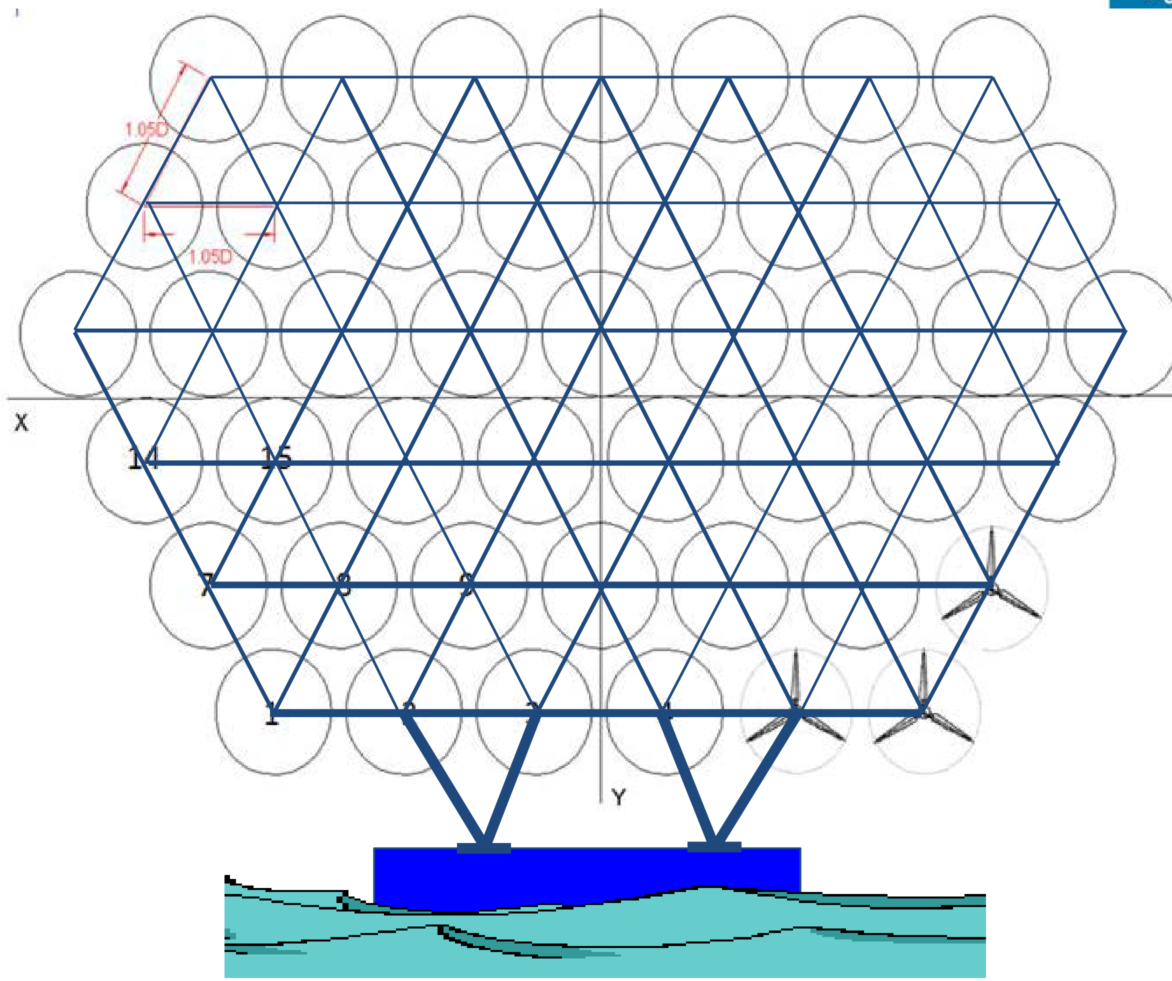
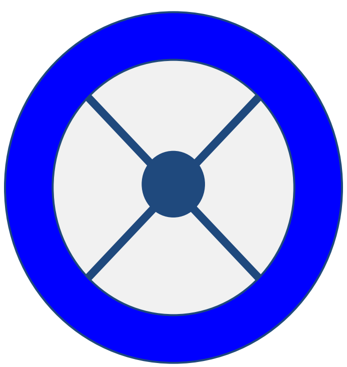




- 45 rotors each of 41 m diameter and of 444 kW rated output power comprising a net rated capacity of 20 MW
- Rotors on a triangular lattice arrangement with minimum spacing of 5% of diameter
- Variable speed, pitch regulated with direct drive PMG power conversion

Multi rotor system concept





Reduced load case set

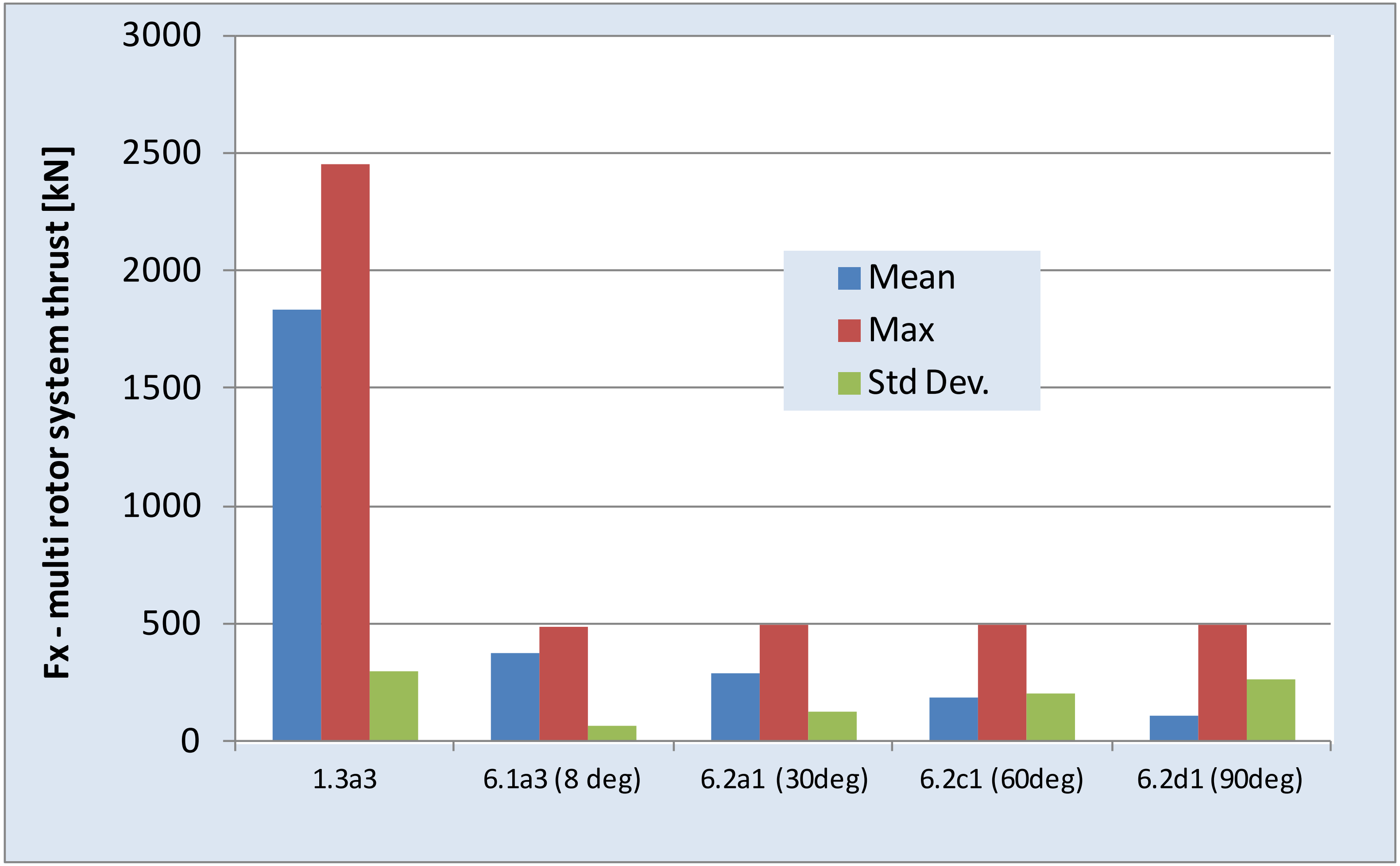
- Loads prediction using GH Bladed adapted for 45 rotors on a single structure

- Design load cases (DLC) and load calculations broadly in conformance with IEC 61400-1 (2005) and GL2003

  a) 1.2 fatigue loads – normal turbulence model (NTM)
  b) 1.3 ultimate loads –extreme turbulence model (ETM)
  c) 6.1 ultimate loads idling in 50 year gust
  d) 6.2 ultimate loads idling with grid loss in 50 year gust (large yaw errors considered but reduced safety factor compared to 6.1)

- A few other load cases are being considered – fault cases affecting a single rotor are considered unimportant for the multi-rotor system design

Ultimate loads comparison – rotor thrust loading



Rotor Centre Thrust – DLC 1.3 a3

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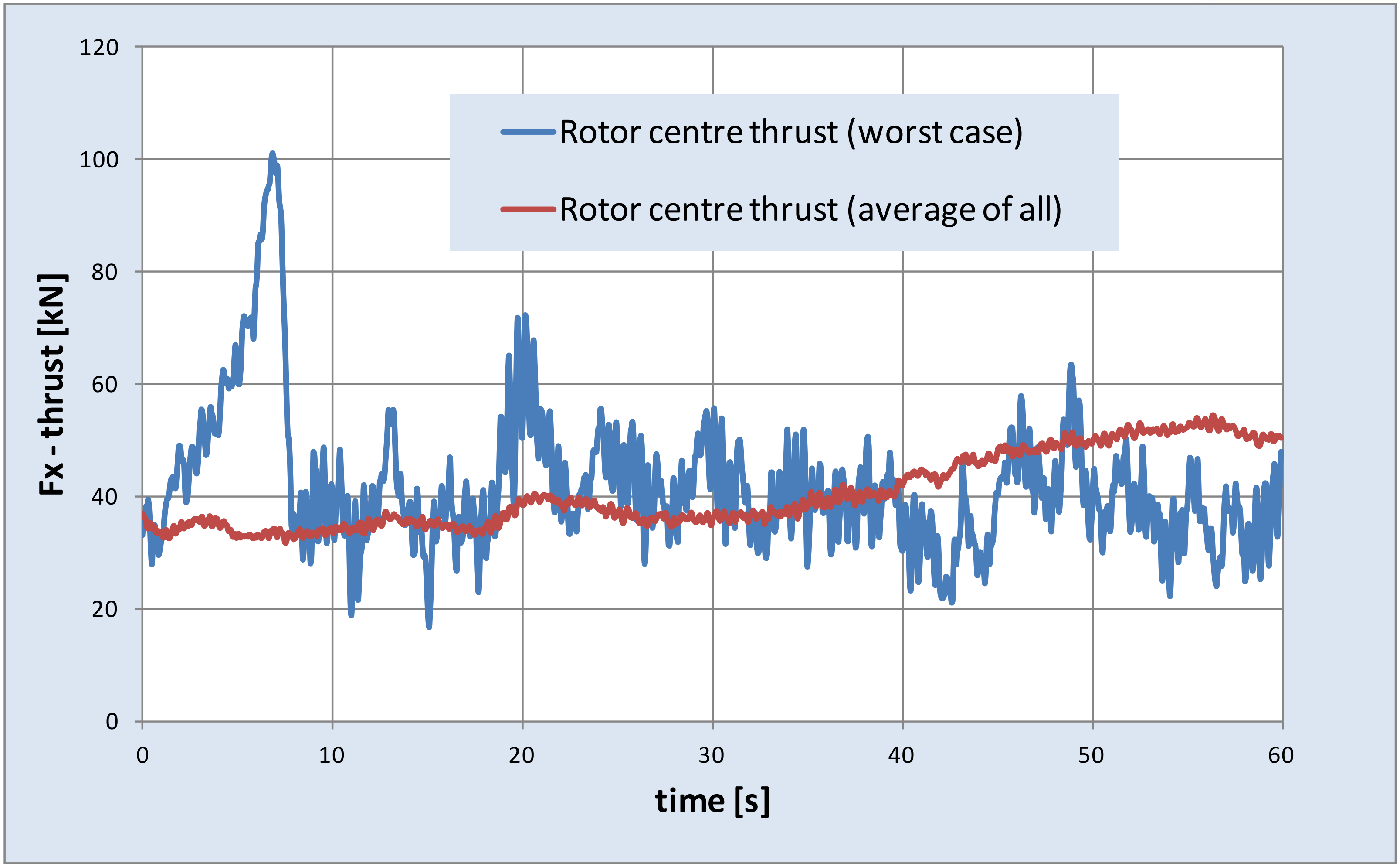
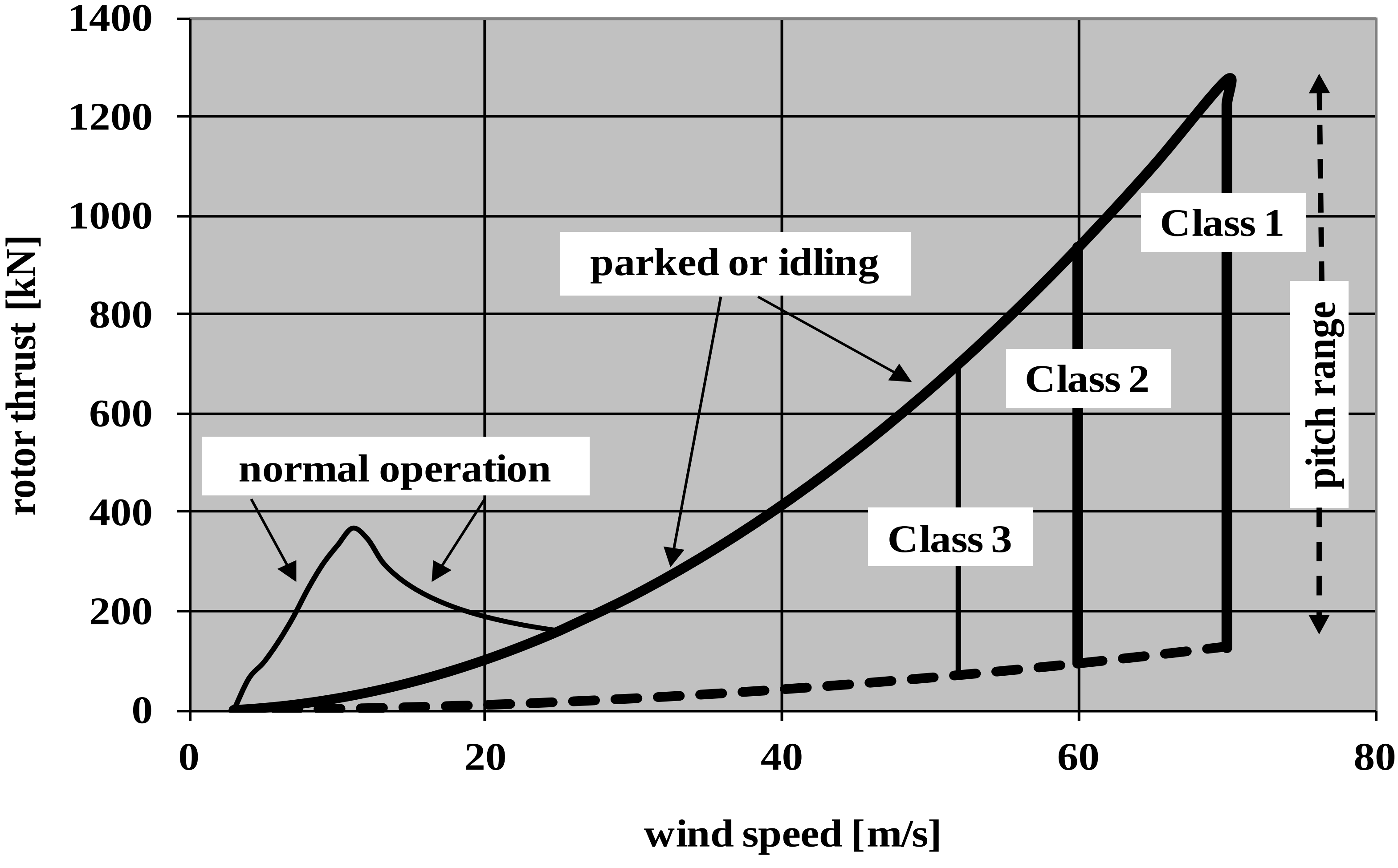
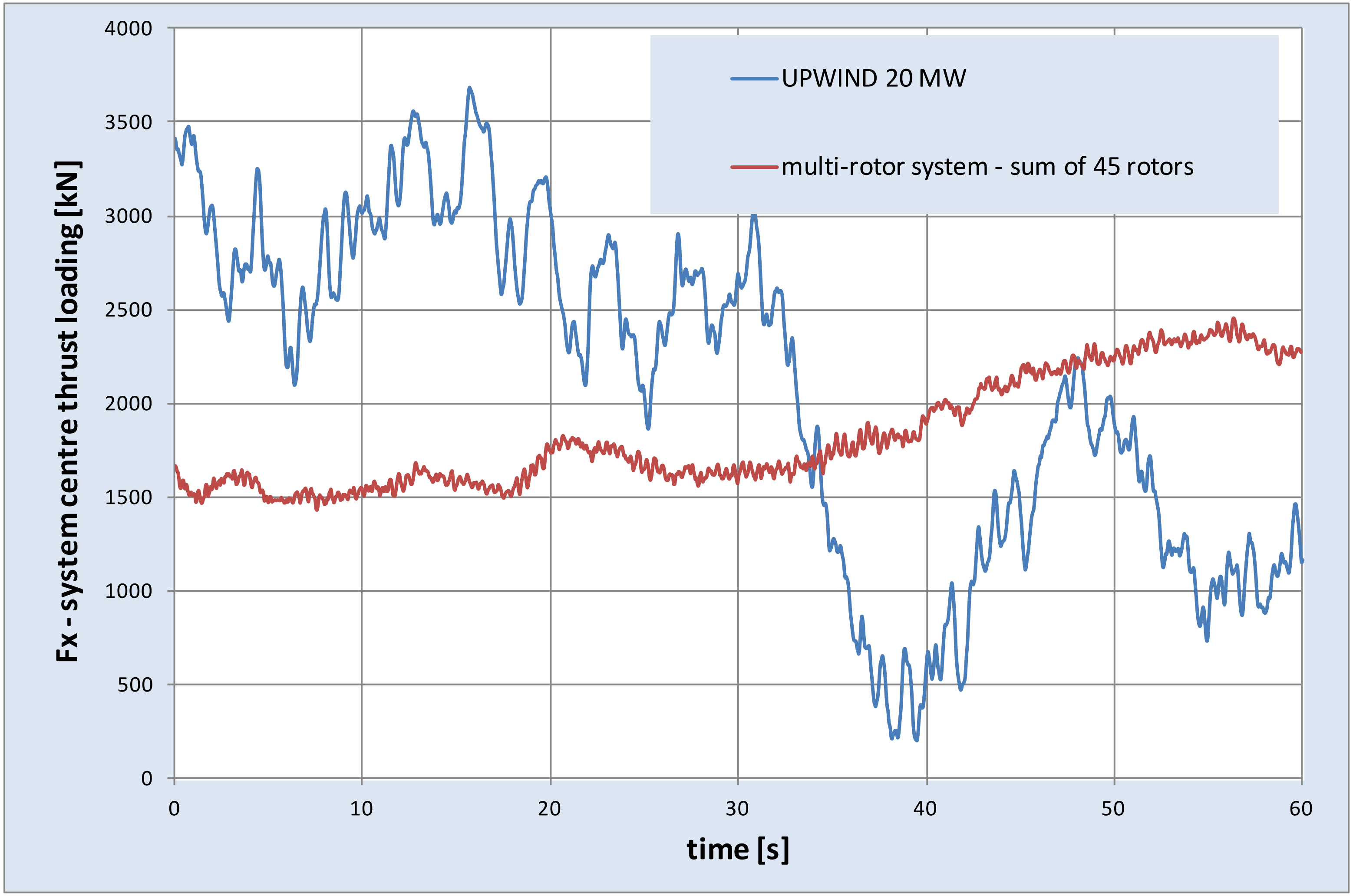


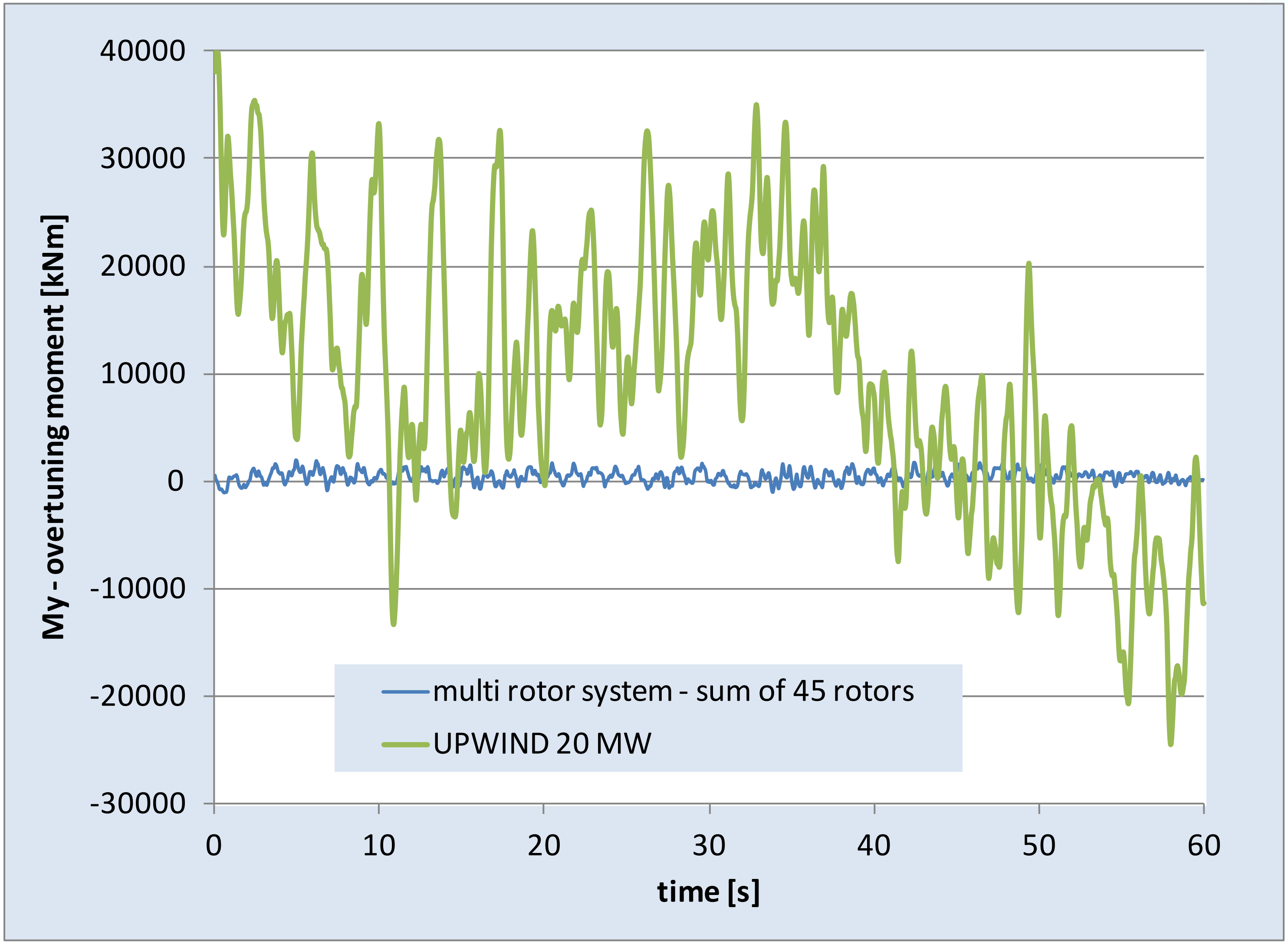
Ultimate loads comparison – rotor thrust loading



Comparison with 20 MW single rotor



Comparison with 20 MW single rotor



Multi rotor system loads summary comments

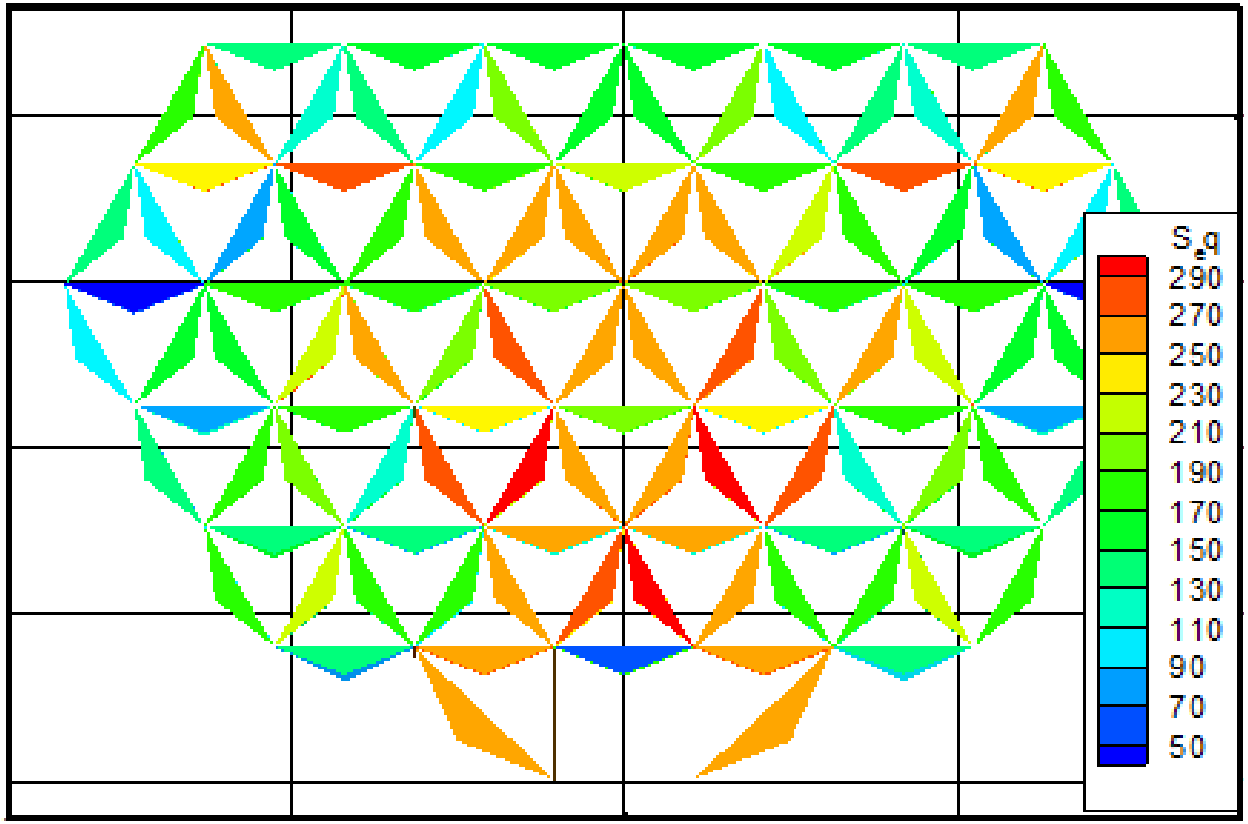
- **ULTIMATE LOADING** - DLC 1.3 in the sub case of operation in turbulent wind around rated wind speed leads to maximum ultimate thrust loading on the multi rotor system

- **FAULTS** - In the multi-rotor system each individual rotor is assumed to be designed in compliance with IEC, Class 1A. Thus fault cases such as blade stuck in pitch or pitch runaway fault may result in design driving loads for the individual rotor. It is assumed however that single rotor fault cases will have no significant impact on design driving loads of the multi rotor support structure

- **DYNAMIC LOADS** - The random blade azimuth relationships between the rotors of a multi rotor system appear to result in very large reductions in dynamic loading of the support structure as compared to large single rotors of equivalent net capacity

- **FURTHER COMPARISONS** - More extensive load comparisons will be made with 2 X 10 MW DTU reference turbines and 4 x 5 MW commercial wind turbines as the 20 MW single turbine is very speculative technology at present.

Structure Optimisation – stress distribution (CRES)



Tube stress [Mpa] for designing extreme load IEC Class 1

Structure mass within 3000 t

Structure Mass Comparisons

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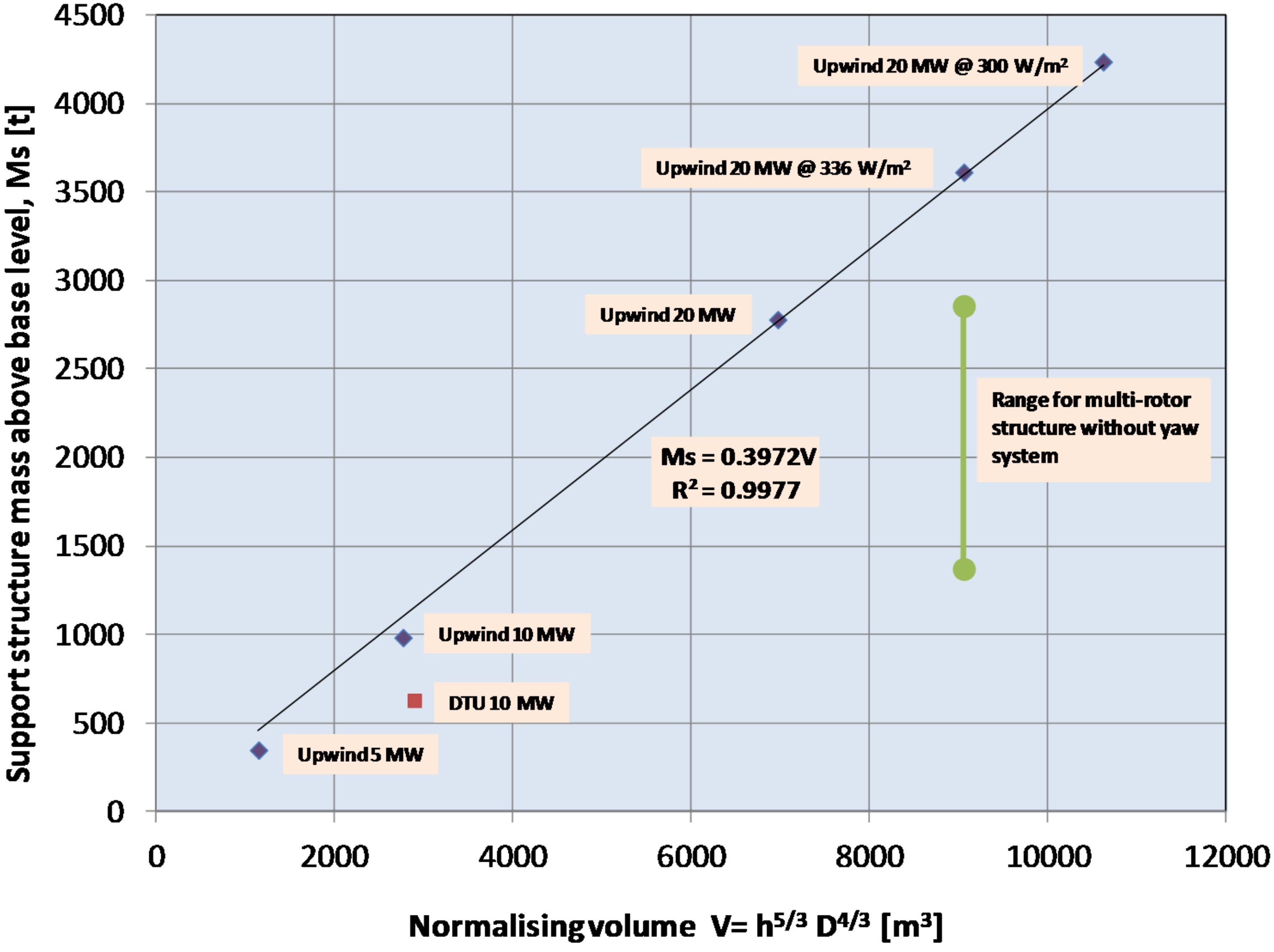
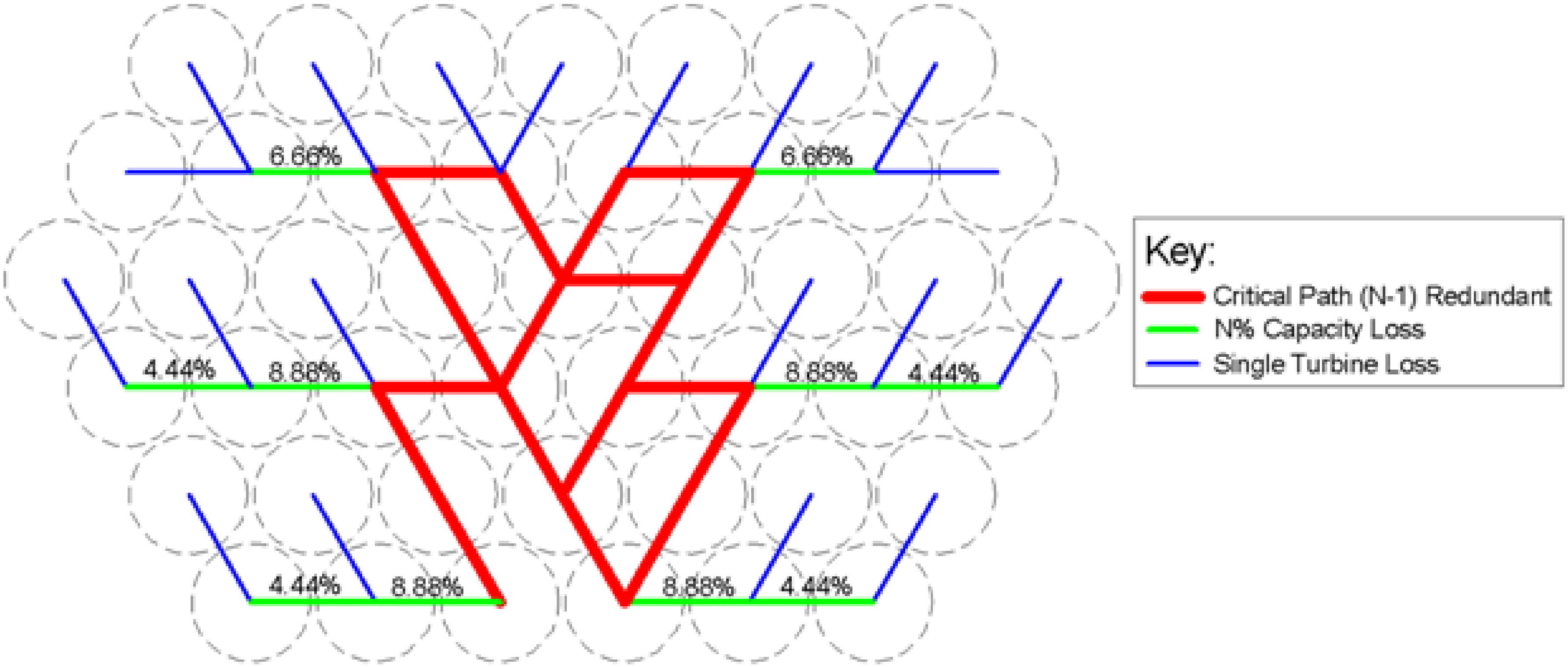
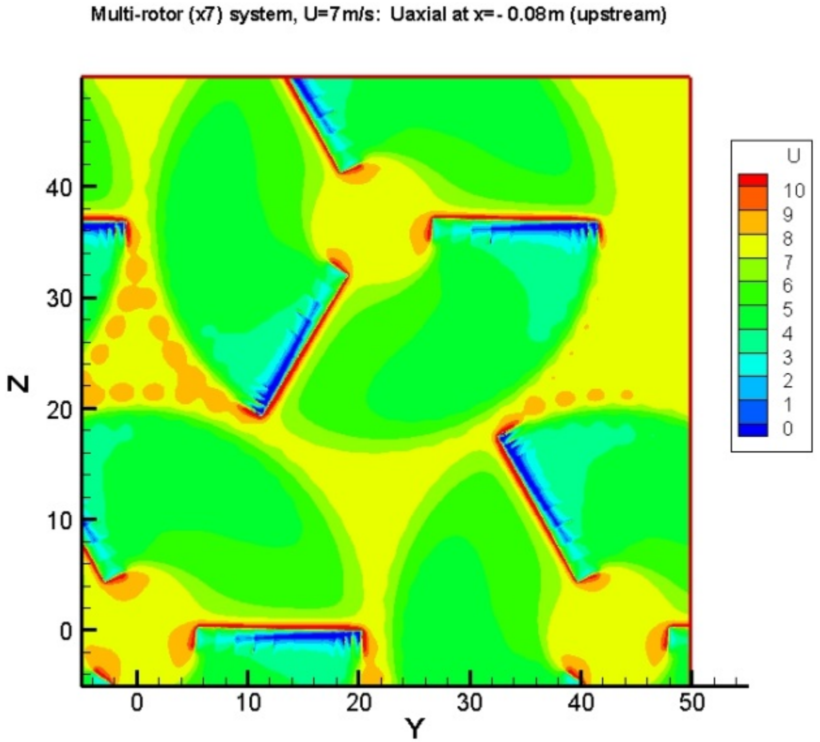
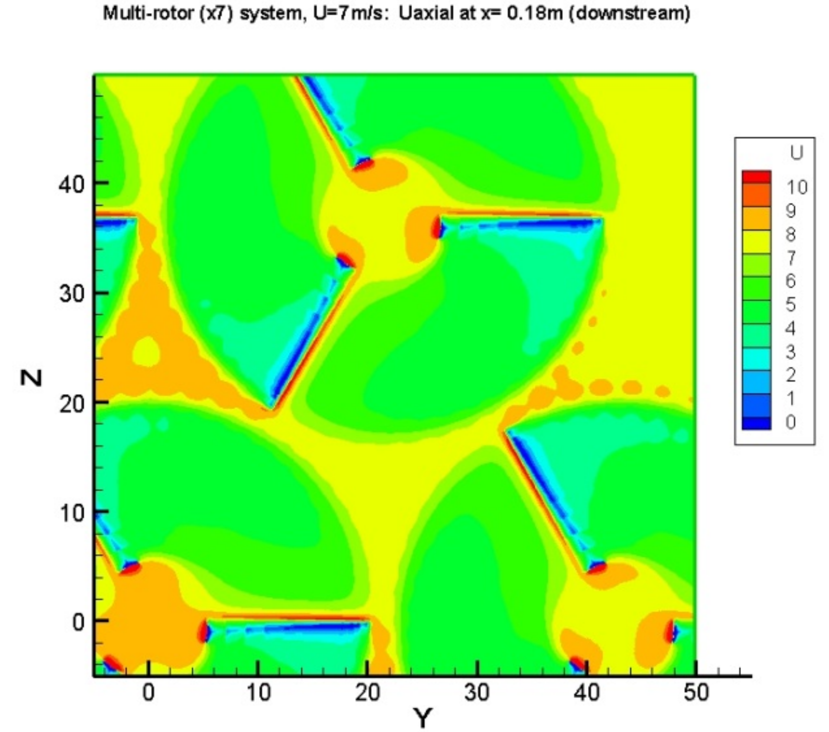


Electrical design – turbine interconnection



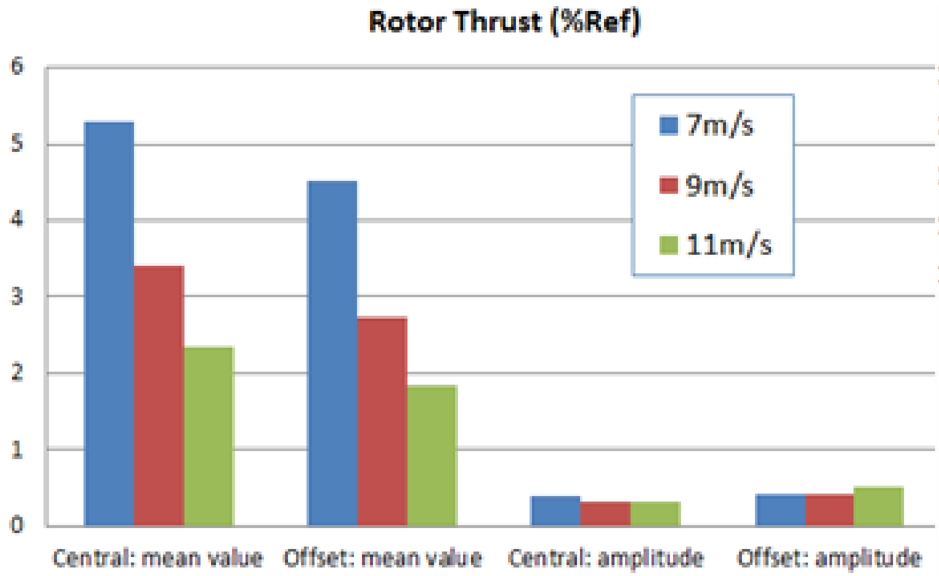
Aerodynamic evaluation of a 7 rotor set (NTUA)

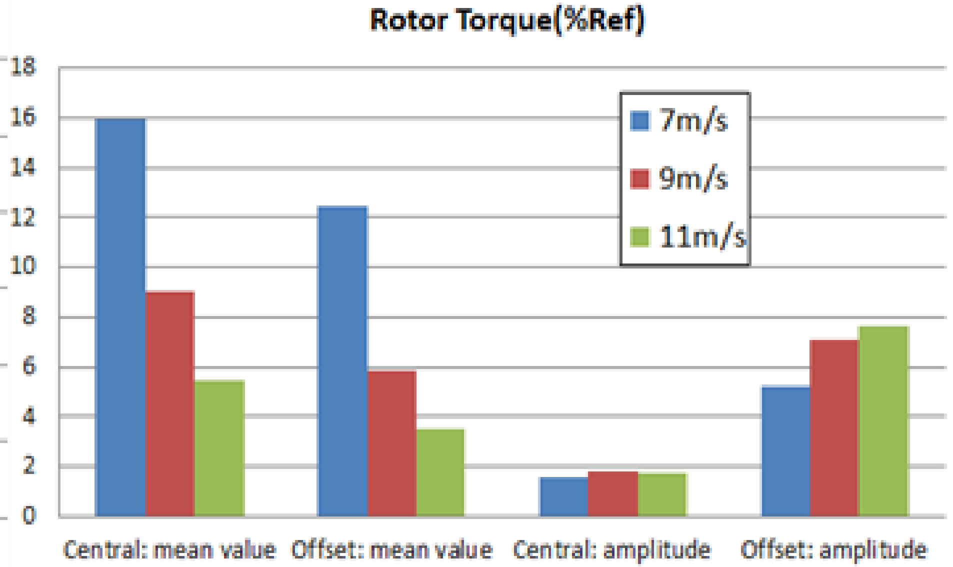




Snapshots of axial flow contours upstream and downstream a 7 rotor system operating at 7m/s wind speed.

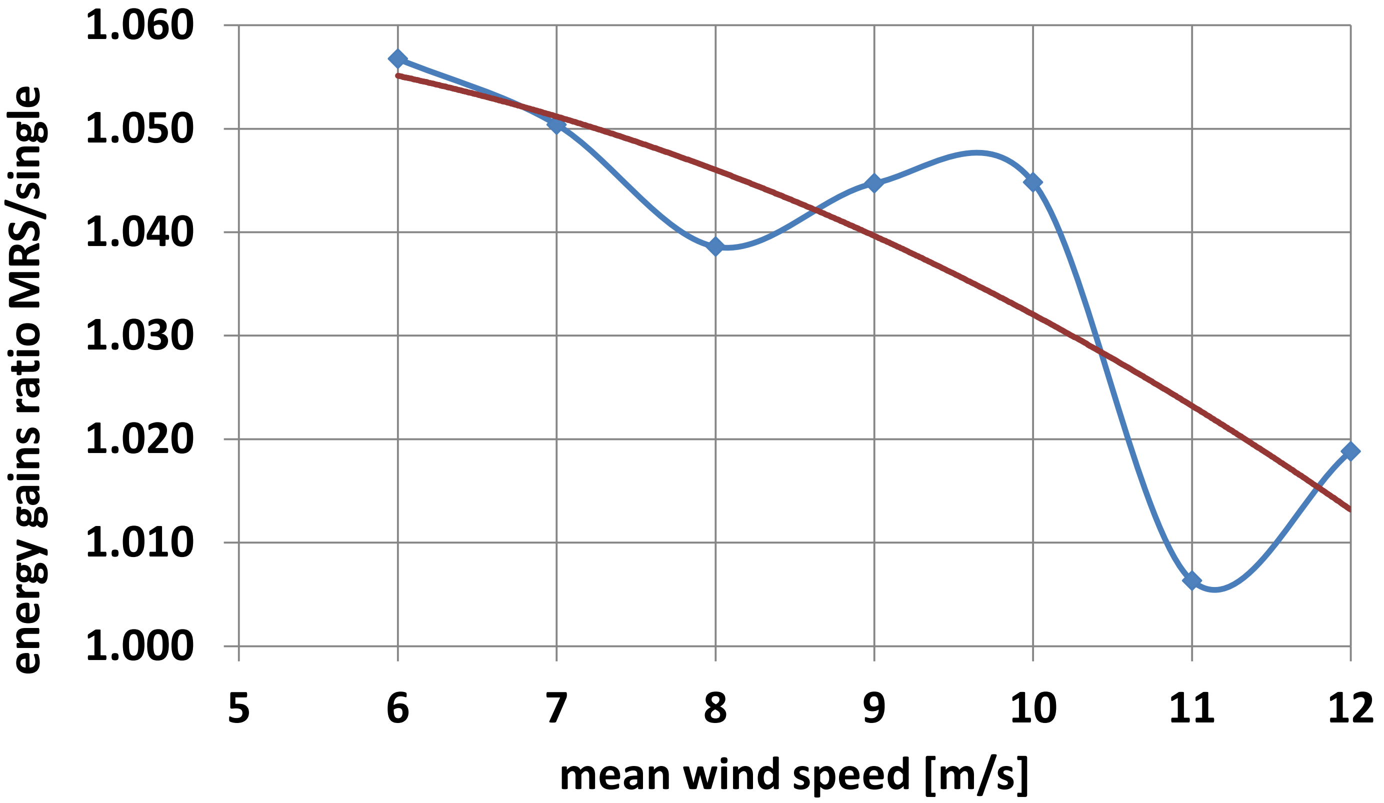
Aerodynamic evaluation – 7 rotor set





Increase in rotor thrust and torque as % of the (reference) isolated rotor performance at three wind speeds for the 7 rotor configuration. The mean values and amplitudes are provided separately for the central and offset rotors

Energy Capture Comparison



This is based on dynamic power predictions using Bladed for both single rotor and multi rotor system, 600 second record with 3 turbulence seeds and results averaged. The ratio is the ratio of the gains of each over steady state at the mean wind speed of the record.

Status and conclusions January 2014

- Concept design well developed
- Load specification and calculations near completion
- Much reduced structure loading from rotors compared to an equivalent single turbine
- Optimised support structure mass is determined as ~ 2700t, somewhat less than an equivalent single 20 MW turbine ~ 3500t
- Aerodynamic evaluation in progress
- Energy capture evaluation in progress