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Energy Yield for Collocated Offshore Wind and Tidal Stream Farms

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OFFSHORE WIND
2030
90TWhr/yr
30-60m (depth)

TIDAL STREAM
2030+
20TWhr/yr
(potential)
30-60m (depth)

HYBRID WIND + TIDAL
Reduced €/MW? capacity
Shared Support
Shared Infrastructure

Background

As part of a wider project to investigate possible cost reduction from offshore marine renewable energy, a model for energy resource assessment of co-located wind and tidal stream turbines has been developed. Time variation of supply from the farm and variation of mean loads on the support structure are presented for the combined deployment to inform viability.

Wind Farm Modelling

- Farm power matrix (Fig. 1) obtained using AWS OpenWind eddy viscosity wake model [1] .
- Power and Thrust curves taken from Vestas 3MW wind turbine.
- 10m wind resource data from UK Met Office Unified model, 2007 [2] extrapolated to hub height .

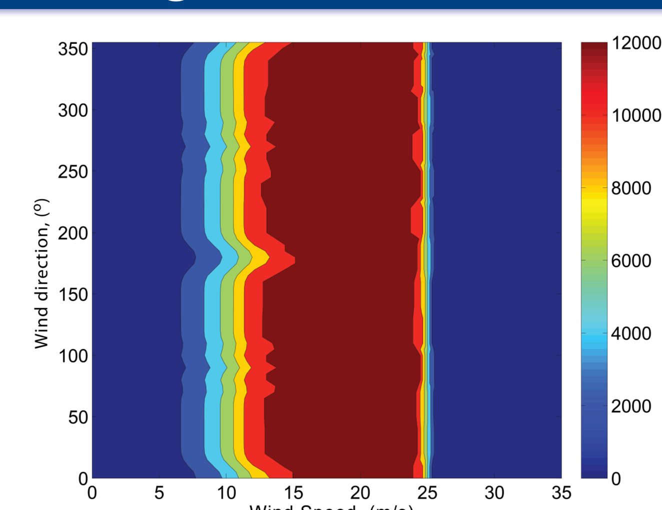


Fig. 1 – Wind farm power matrix for 4 No. 3MW turbines, as arranged in Fig. 5.

Tidal Array Modelling

A self-similar depth-average wake superposition method [3] is employed. The method predicts transverse streamwise velocity profiles (Fig. 2), across the projected area of downstream turbines to within 2%. Flow velocity incident to downstream rotors spanning the wake and bypass flow is less well predicted due to transverse velocity shear.

Energy yield is calculated using mid-depth current and heading data from FOAM [4] to obtain a power time series (Fig. 3).

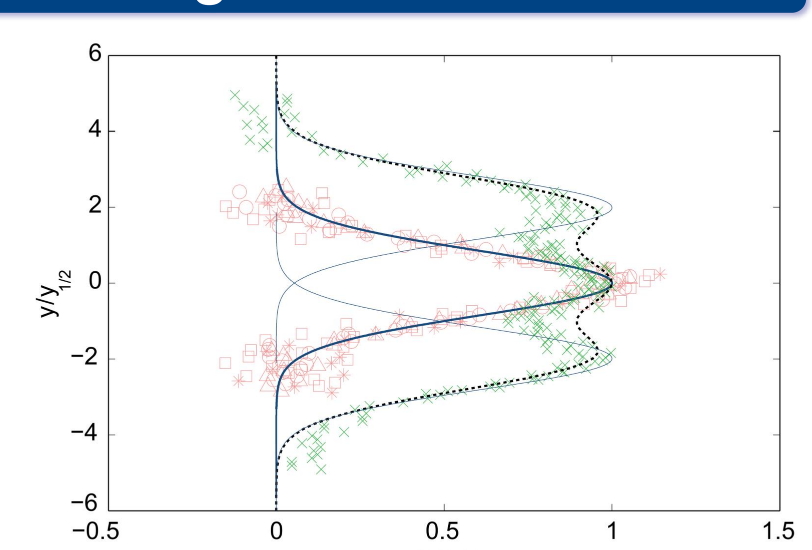


Fig. 2– Transverse profiles of stream-wise velocity for 1 and 3 discs.

- Experimental data for a single disc wake (x=4D, 6D, 8D, 10D)
- Least-squares fit Gaussian profile to single wake data.
- Single wakes at 1.5D y-spacing.
- Experimental wake data for 3 discs, x=6D.
- Superposed wake profile of 3discs, x=6D.

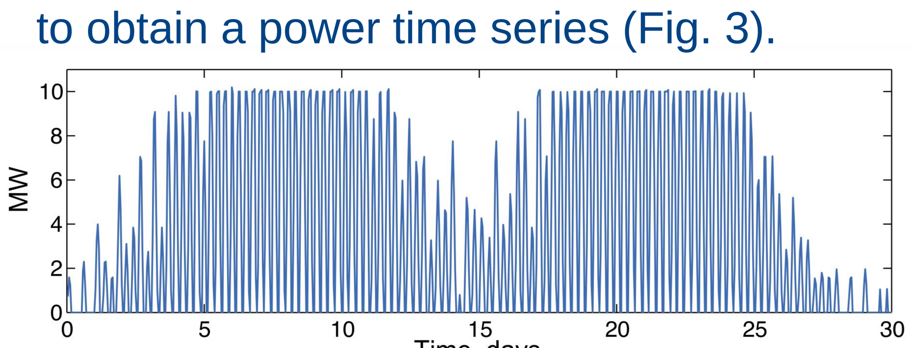


Fig. 3 – Tidal power time-series.

Tidal Yaw Control Strategy

The influence of alternative yaw control strategies on tidal farm energy yield is considered. The approaches considered are: Fixed, Slack-tide and Continuous yaw (Fig. 4).

Fixed Yaw (e.g. OpenHydro)

Slack-tide Yaw (e.g. Alstom/GE)

Continuous Yaw (e.g. Tidal Energy Ltd.)

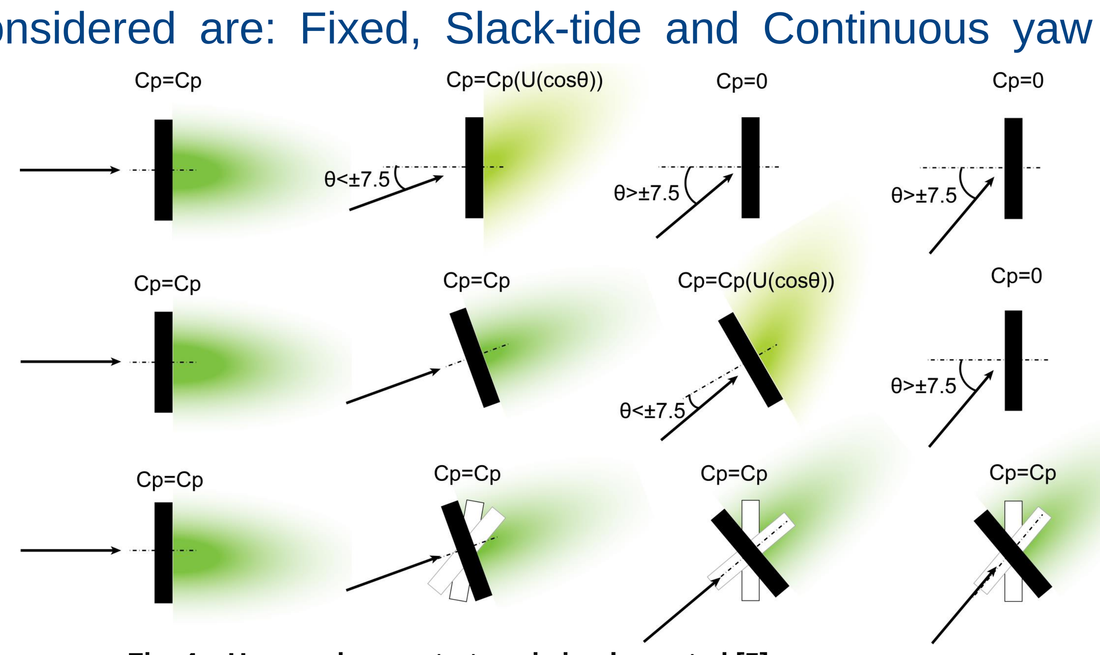


Fig. 4 – How each yaw strategy is implemented [5].

Energy yield for each approach is compared (Table 1) for a small array of 2 rows 5 No. 1MW tidal turbines. The relatively low capacity factors (compared to 0.35 typically for offshore wind[6]) are due to the tidal current being below cut-in speed for over 45% of the time. The continuous yaw system generates 25% more yield than the fixed system. However, the slack tide system only yields 3% less than the continuous and so may offer a suitable compromise, although discrepancies may differ for layouts optimised for a given strategy.

	Fixed	Slack-tide	Continuous
Annual Yield (GWh)	17.79	21.64	22.30
Capacity Factor	0.203	0.242	0.262
(summer-winter)	(0.247 – 0.138)	(0.205 – 0.272)	(0.226 – 0.291)

Table. 1 – Comparison of energy yield and capacity factor with yaw strategy.

Combined Energy Yield Assessment - MeyGen

4 No. 3MW wind turbines are co-located with a rectilinear array of 20 No. 1MW tidal turbines over an area approx. 1100m x 360m (Fig. 5).

Combined Annual Yield = 96.4 GWh

Wind Yield = 48.9 GWh

Tidal Yield = 47.5 GWh

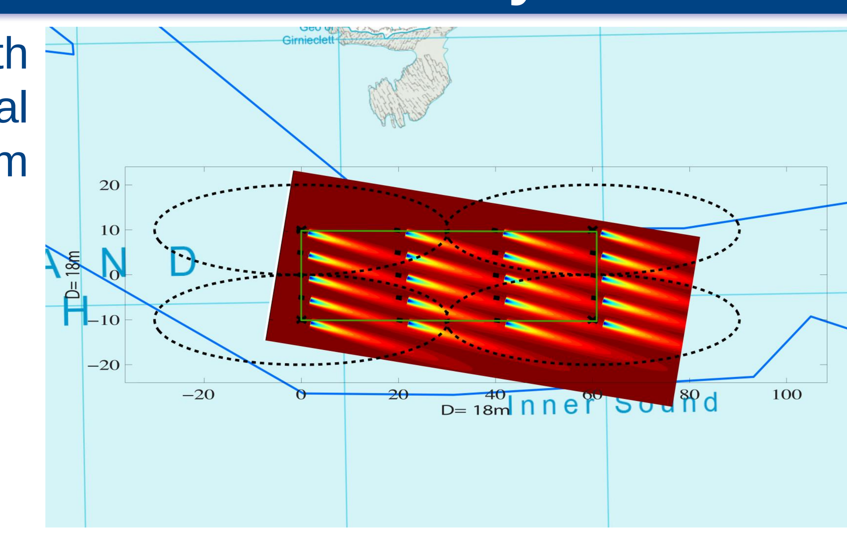


Fig. 5 – Idealised layout of co-located site, showing velocity deficit field for tidal turbines and relative wind spacing (---).

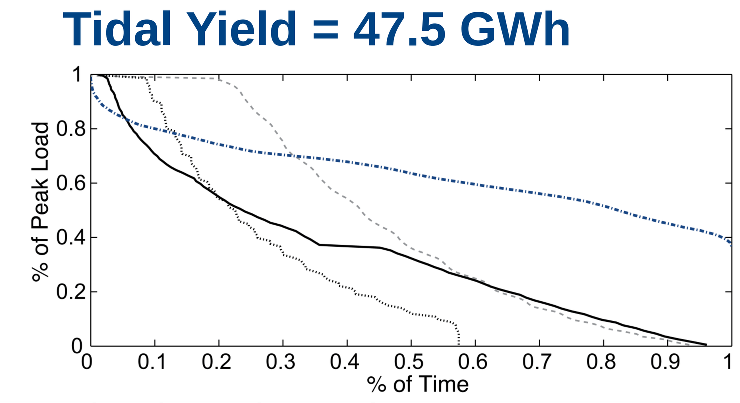


Fig. 6a) – Load Demand Curve

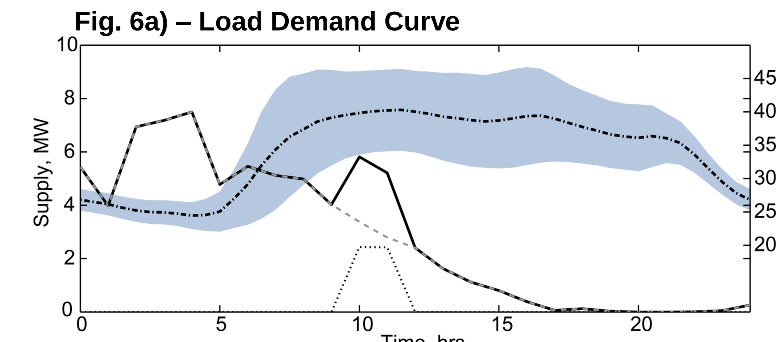


Fig. 6b) – Supply vs. demand for a Summer neap tide.

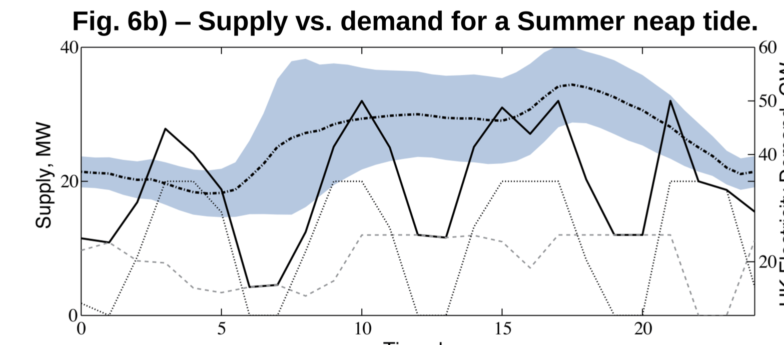


Fig. 6c) – Supply vs. demand for a Winter spring tide.

Wind — Tidal — Combined — UK Electricity Demand — ± 2σ

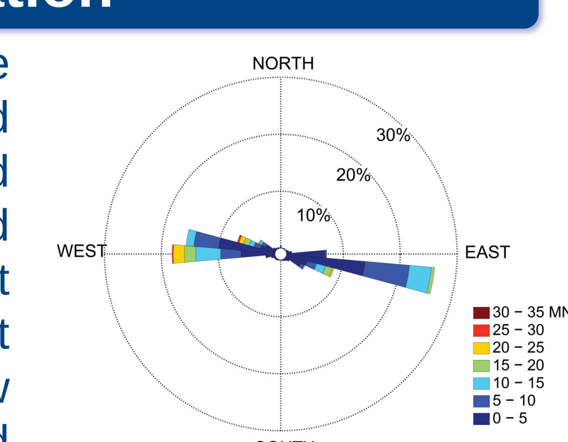
Ideally the LDC (Fig. 6a) of supply would follow the electricity demand. Due to the high cut-in speed of the tidal turbines, over 40% of the time is spent producing zero load, resulting in a steep curve for the tidal-only system. In this case, addition of wind helps flatten the profile, increasing supply for a higher percentage of time.

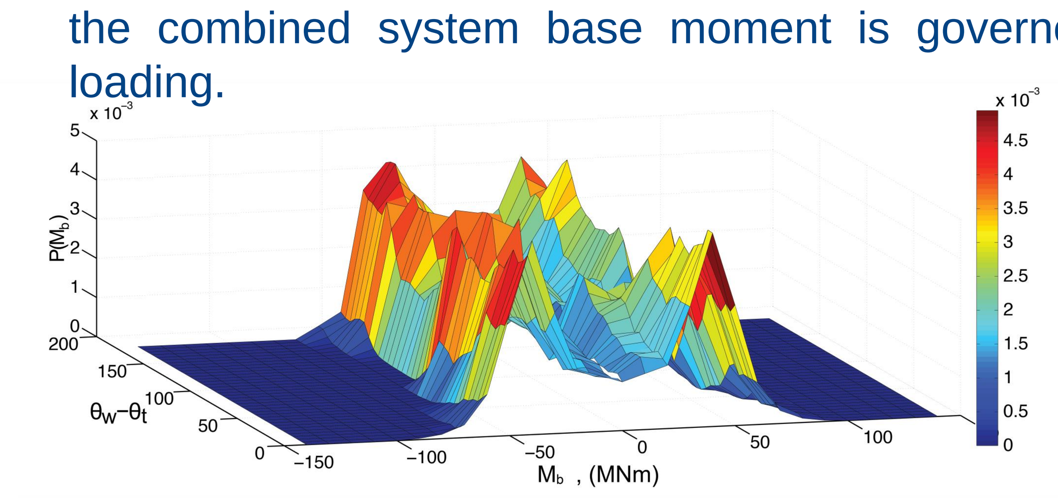
The time variation of supply from the tidal array during a neap tide is not correlated with demand (Fig. 6b). For the example day shown, supply from the wind turbines also tails off as demand increases over hours 7-9 of the day.

However, during a spring tide and windy day, the combined supply magnitude is much greater and regularly meets the demand curve (Fig. 6c). Phasing of the tides means that the supply peaks move by approx. 1 hr, daily.

Support Structure Load Variation

Support structure loading due to a wind turbine, tidal turbine and drag on the tower is considered. Maximum combined load occurs on the 4th row of the array, when wind and current are aligned at 275º. For turbines operating at rated speeds, net horizontal loading of the tidal turbine support structure is 28% greater than on the wind turbine support structure, but the base moment is 76% less. Fig. 7 & 8 show the combined system base moment is governed by wind loading.





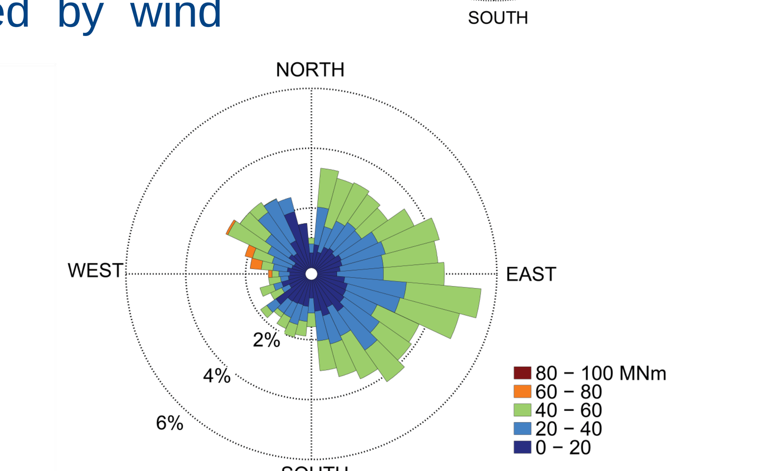


Fig. 8 – Probability distribution of combined system overturning moment. **Fig. 7 – Base moment for tidal only (top), wind-only (bottom).**

Summary & Future Work

- Slack-tide yaw strategy offers a compromise between energy yield and mechanical complexity.
- Combined supply repeatedly meets electrical demand during a spring tide but during a neap tide will be almost entirely dependent on wind.
- Wind loads govern the bending moment of the combined support structure.
- Validity of superposition for yawed turbines & the effect of support structure on array wake interaction and individual device loading will be assessed experimentally.
- Design load characterisation and investigating possible shared electrical infrastructure will help to establish approximate LCOE.

References

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6. DECC (2014) Digest of UK Energy Statistics (DUKES) Chapter 6: Renewable sources of energy