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Multi-rotor tidal stream turbine fence performance and operation

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Abstract

An embedded Reynolds-Averaged Navier-Stokes blade element actuator disk model is used to investigate the performance of a closely spaced cross-stream fence of four turbines. The flow characteristics of such fences are found to be dependent on both the local turbine scale flow problem and the array in channel flow scale problem. The mean fence power is found to be less than that predicted for a single turbine with the same local blockage ratio (ratio of turbine swept area to surrounding flow passage area), but greater than that for a single turbine based on the global blockage ratio of the fence (ratio of total fence swept area to the cross-sectional area of the channel). Cross-fence variation in turbine performance is observed as a result of the differing resistance to bypass flow acceleration around the inboard and outboard turbines and depends on the operating condition of the turbines. Reducing turbine thrust, such as by changing the rotational speed of the turbine or by employing a pitch-to-feather power capping mechanism reduces turbine-turbine interactions and turbine performance becomes more uniform across the fence. An approximately 6% increase in the mean fence power can be achieved if a cross-fence differential blade pitch strategy is employed to maximise the lift to drag ratio along the majority of the blade span of each of the turbine blades.

Keywords: Tidal stream turbines, Tidal turbine fence, Power capping, Blockage effect

The importance of the blockage ratio, B_L, the ratio of rotor swept area to the cross-sectional area of the surrounding flow passage, was demonstrated for tidal stream turbines by Garrett and Cummins [2]. Analysing idealised turbines, it was shown that the peak power coefficient increases by a factor of $(1 - B_L)^{-2}$ above the Lanchester Betz limit, $C_{P,max} = 16/27$, established for an actuator disk in a unconfined flow field. Subsequent work has extended this model to the case of a long fence of actuator disks occupying part of a much larger channel, showing that inter-turbine interference can still result in theoretical performance improvements beyond the Lanchester Betz limit, even when the turbines occupy only a small fraction of the channel cross section [7, 10]. The theoretical power coefficient limit increases as a consequence of a streamwise static pressure (head) difference developing in the flow passage as a result of momentum extraction by the actuator disk and mass conservation requirements. The static pressure difference that can be supported in the flow passage increases with the blockage ratio, and thus the increase in maximum power coefficient is achieved at higher thrust levels and lower through-disk flow speeds.

Exploiting the theoretically achievable performance improvements due to blockage ratio with real rotors requires that turbines are specifically designed to sustain the required higher levels of thrust predicted in the analytic models. Two methods by which this can be achieved is increasing the rotational speed of the rotor, or increasing blade solidity in order to increase the generated forces. Cavitation inception concerns at high rotational speeds have restricted the former approach, whereas the latter approach requires blade redesign. Schluntz and Willden [9] investigated computationally the effect of the blockage ratio on the rotor design and performance of tidal stream rotors in an infinitely long fence using Reynolds-Averaged Navier-Stokes (RANS) embedded blade element actuator disk simulations. It was found that required rotor solidity increased and blade pitch angle decreased as the rotors were designed for higher levels of blockage.

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