Yaw Control for 20MW Offshore Floating Multi Rotor System

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Introduction

Large scale offshore wind turbines of up to 20MW offer substantial reductions in cost due to minimising the number of offshore foundations required per unit of power produced. Multi rotor systems (MRS) offer an innovative solution for turbines of such scale. With development at an early stage assessing the feasibility of such machines is of the upmost importance

There are many fundamental reasons as well as recently produced insight through simulation as to why MRS produces a compelling case for turbines of the 20MW scale. MRS will have less weight in comparison to turbines of fewer rotors resulting in a reduction in the cost. Analysis based on scaling with similarity [1] shows that the ratio of mass of a set of small rotors to that of a single rotor, with the same swept area and therefore power, is $\frac{1}{\sqrt{n}}$ where n is the number of rotors. A similar argument holds for the power train. It is estimated that the levelised cost of energy (LCOE) for the MRS is 15% less than two 10MW DTU reference wind turbines (RWT) [2].

MRS will also benefit from standardisation. The rotors and other components become cheaper through mass production. With the rotors already much smaller than the largest produced by industry currently, the making of components will become more efficient, result in a reduction in cost and increase in reliability.

MRS has benefits in maintenance costs due to their rarely being need for unscheduled maintenance. Faults in singular turbines will not reduce power output by a significant amount and so the loss is deemed acceptable until suitable weather conditions arise so that the fault may be fixed.

Recent simulations also indicate potential benefit for both power production and loading on the turbine. It is hypothesised that the MRS will have benefits in power production as smaller rotors will have a more complete spatial coverage over a swept area [2]. Smaller rotors in theory can also respond faster and so extract high frequency energy from the turbulent wind field. Initial test at TI of around 5-6% at wind speed 9m/s indicate ~2% gains in energy. Gains in power are also predicted through the aerodynamic interaction of the rotors. Using CFD and vortex models an 8% power gain is predicted due to acceleration between rotors. Due the rotors all running at slightly different speeds in turbulent wind an averaging effect is noted whereby structure loads are reduced.

This paper shows the feasibility of a novel yaw mechanism which manipulates the thrust of the rotors of an MRS. A model is built for an MRS that contains all the necessary detail to demonstrate a yaw mechanism for a 20MW MRS. A yaw controller is then designed which demonstrates this mechanism is capable of constricting yaw error.

Approach

A rotor design has been established with 45 rotors of 444KW set in a plane attached to a steel structure seen in figure 1. Structural considerations of the design can be seen in [3]. Each rotor is spaced $1.05D$, where D is the diameter, with the rotors arranged to avoid a high centre of thrust.

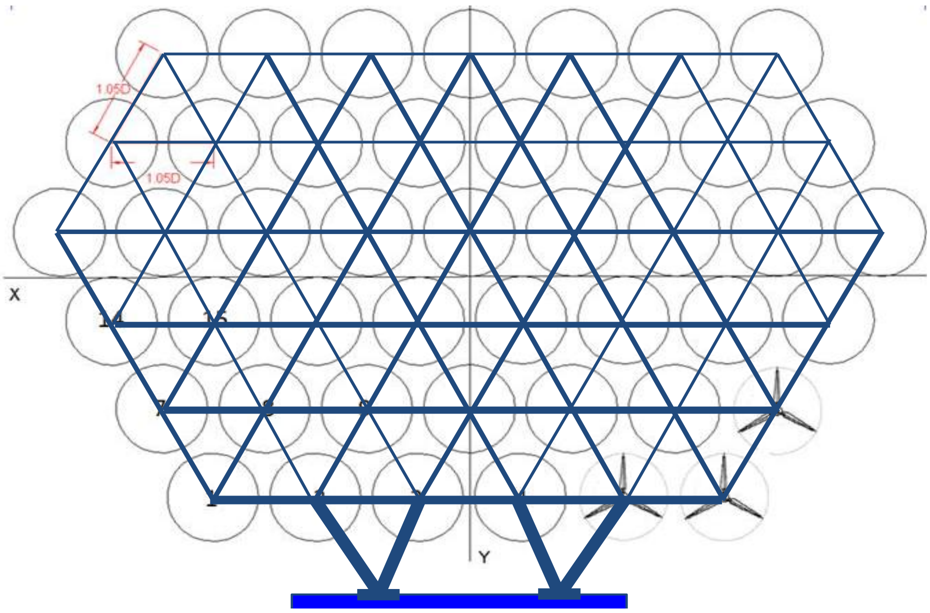

Figure 1

The rotor and power conversion system (RPC) is modelled as a lumped parameter model in Simulink with enough detail as to be fit for control purposes. Figure 2 shows the dynamic relationship of the model. Each RPC contains a fully enveloped controller (FEC) which maximises the power output of the turbine in below rated controllers and maintains rated power above rated. The FEC also work to reduce loads.

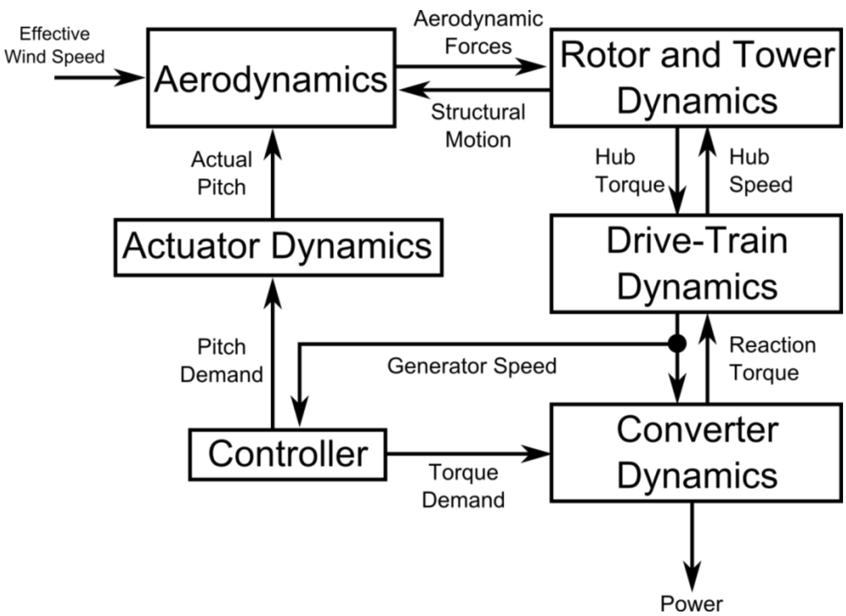

Figure 2

The mass and moment of inertia for the full structure have been calculated with yaw dynamics approximated using a second order dynamic system:

$$\frac{\varphi}{M} = \frac{1}{J_{yaw}s^2 + B_{yaw}s}$$

J_{yaw} is the inertia of the system, B_{Yaw} is the damping, M is the moment about the y axis, and φ is the error in yaw angle (assuming a constant wind direction). Damping losses are approximated to be 1% of the torque.

As seen in figure 2 each rotor requires an effective wind speed time series. A turbulent field of point wind speeds is first generated using the Sandia method. Each point wind speed is then converted into an effective wind speed using a technique described in [4]. A clustering of the rotors is then performed in order simplify the creation and tuning of the control strategy and also to reduce computational time so that the model will progress faster. Figure 3 shows the clustering of the rotors.

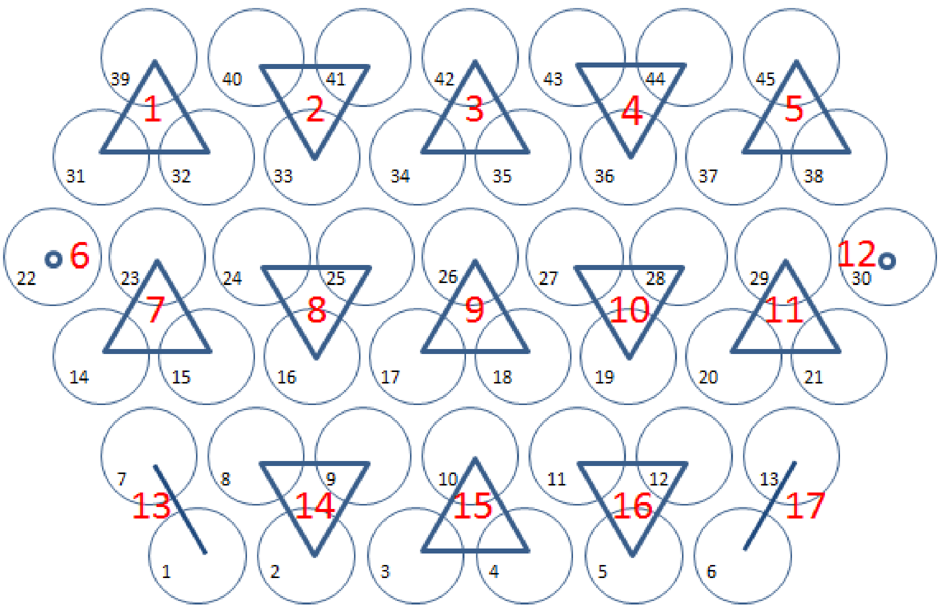

Figure 3

The effective wind speed for each rotor in a cluster is then averaged. This is then fed through the RPC model. The relevant variables such as the thrust and power can then be found by multiplying by the number of rotors in the cluster.

Controlling the thrust of the rotors is done using similar techniques to those developed for wind farm control [5]. The hierarchical structure of the control can be seen in figure 4. The MRS controller modifies the set-points for each 444kW RPC via a Power Adjusting Controller (PAC) on each RPC system. By modifying the set points of each rotor it is possible to control the thrust of each RPC and therefore yaw the MRS. The MRS controller is comprised of two separate controllers. The aggregate controller is responsible for estimating the reduction in power, ΔP, required for a sub-set of rotors to output the required thrust so that the total yaw moment will correct the yaw error. Each rotor will contribute equally. On the same time-scale the dispatch controller assigns a change in power specific to each RPC depending on the state of each system. At a slower time scale the dispatch controller also works to maximise power.

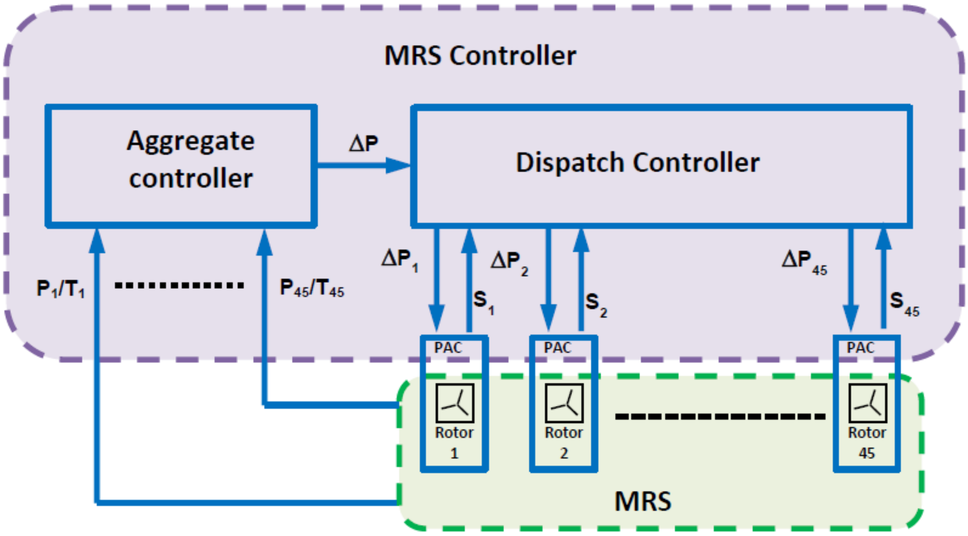

Figure 4

Main Body

The model is first left to run with no additional controller other than the FECs. The resultant yaw angle can be seen in figure 5. The MRS is fixed for the first 100 seconds in order that transients will not affect the behaviour of the model. Clearly when left, the yaw error of the MRS continues to rise.

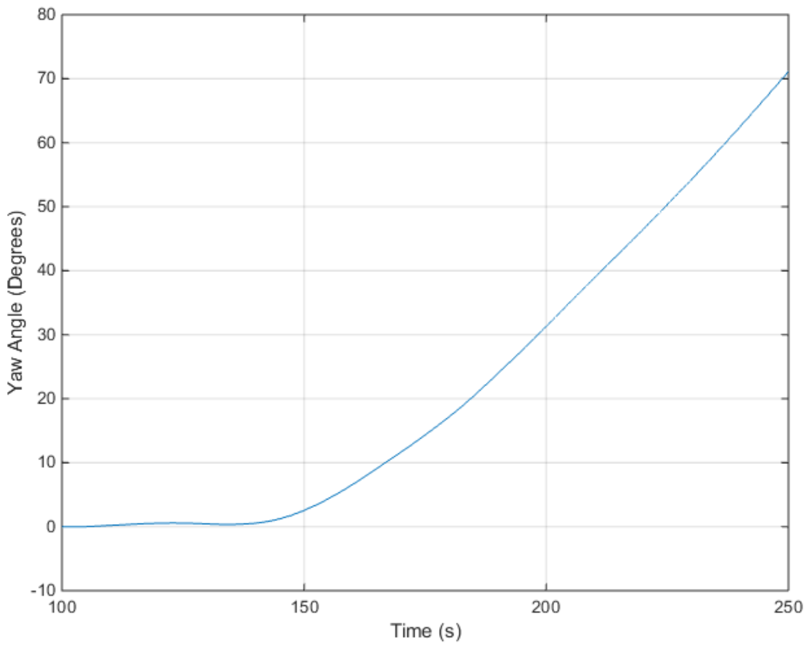

Figure 5

A yaw controller is designed whereby the power, and therefore thrust, of the rotors on one side of the yaw axis is reduced if the yaw error is negative. Where the yaw error is positive, the thrust of the rotors on the opposite side of the yaw axis is reduced.

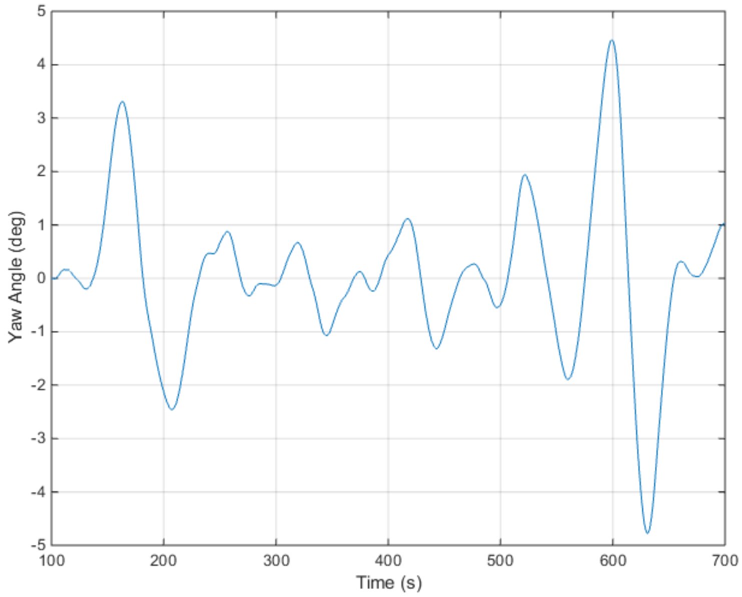

Figure 6

Figure 6 shows that the yaw error over the same period of time using the yaw controller. The yaw error is now constricted to within +/-5 degrees. The power and yaw rate were also measured. As expected the power is reduced where the yaw error is large. The yaw rate is seen in figure 7 and peaks at 0.4 degrees per second.

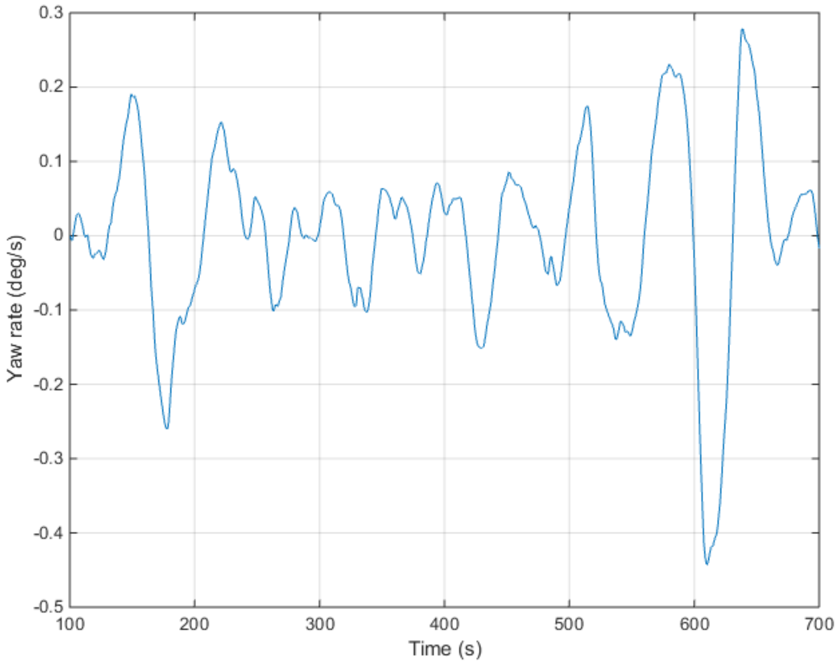

Figure 7

Conclusion

With an MRS model constructed which enabled testing for a yaw controller, it was possible to constrict the yaw error. The thrust from the 45 rotor design was sufficient for the structure to yaw and maintain the yaw error to within a few degrees. With the yaw rate at a suitably fast rate the feasibility for this yaw mechanism was demonstrated.

Learning Objectives

Evaluate the feasibility of altering the thrust of the rotors on an MRS in order to yaw the system.

References

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