Investigation and Assessment of the Benefits For Power Systems From Wind Farm Control

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Introduction

As wind power increases its share of grid penetration, especially through large offshore arrays with capacities into hundreds of megawatts, there are increased requirements on wind farms to provide ancillary services, such as frequency support. The aim of my PhD is to research the benefits for power systems from wind farm control by designing discretised models with short time steps in order to model abnormal operating conditions using Strathfarm.

Strathfarm

Strathfarm is a program which has been developed by Lindsey Amos to model the behaviour of wind farms in a computationally straightforward manner with the goal of being able to use it on a standard desktop PC. At present it can simulate 100 turbines in this way at near real time. The focus of my research so far has been looking at curtailing the total power output of the wind farms. This is done through the use of a PI controller which operates on the difference between the desired power output and the sum of the power generated across all of the turbines.

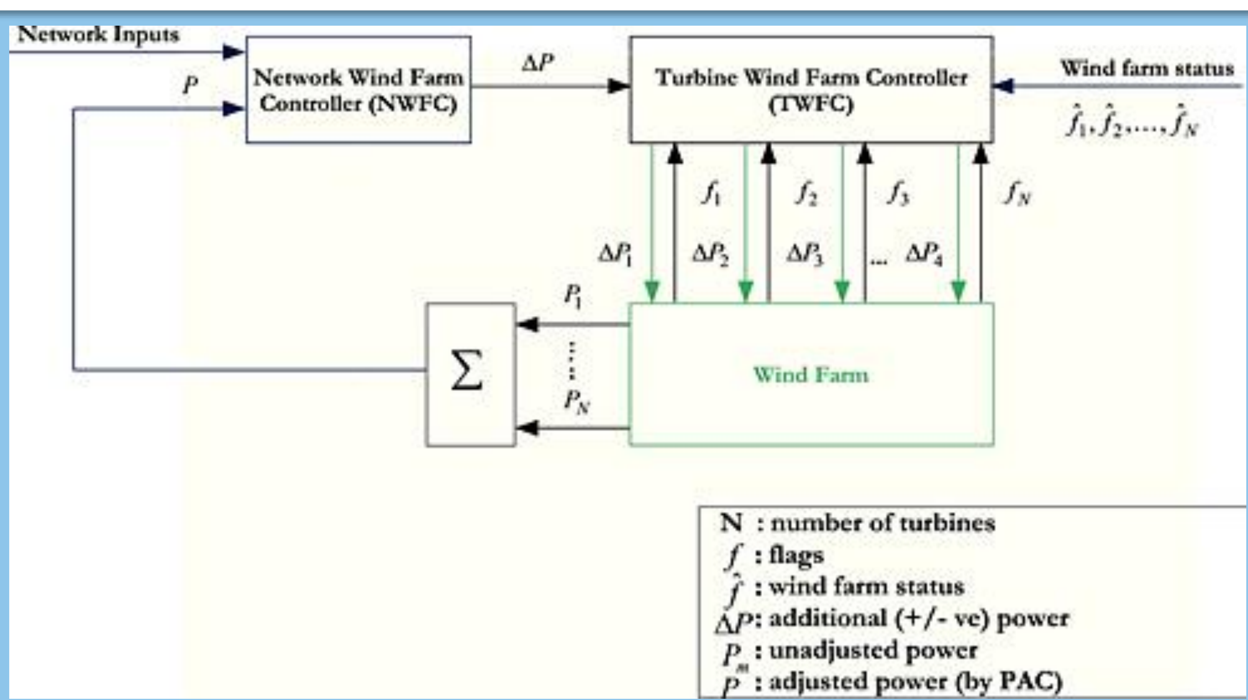

Figure 1. The control structure used in Strathfarm. Edited from (Hur & Leithead 2015).

Wind Farm Controller

The wind farm controller distributes the required change in power output across the wind farm based on information about each turbine which is sent back to the controller through a series of flags. In addition to this, the flag information is used in the anti-windup for the wind farm controller as there are limits to how much curtailment a turbine can safely perform which is indicated by its operational flag and also limits to how quickly the level of curtailment can be changed.

Flag colour	f_i
Green	3
Amber	1
Red	0

$$\Delta P_i = \frac{\Delta P f_i}{\sum_{i=1}^{N_T} f_i}$$

The requested curtailment of each turbine (ΔP_i) is found by multiplying the total requested curtailment (ΔP) by the ratio of the individual turbine's flag value(f_i) to the sum of the flag values across all the turbines ($\sum_{i=1}^{N_T} f_i$).

Curtailment

The power output of the wind farm can be curtailed to a requested output, at times briefly providing more than the uncurtailed power output by using the inertia of the rotors. When more power is requested from a wind turbine than its uncurtailed output it decreases its generator speed whilst increasing generator torque. If this happens for too long the turbine's position in the torque-speed plane will begin to exceed the flag limits. In order to prevent the power output from having a large dip the requested power output in the controller is reduced by multiplying it by the sum of the operational flags of all the turbines divided by the maximum sum of the flags.

$$\Delta P = k_p(Q(t)P_d(t) - P(t)) + k_i \int (Q(t)P_d(t) - P(t))dt$$

$$Q(t) = \frac{\sum_{i=1}^{N_T} f_i(t)}{N_T f_{max}(t)}$$

These equations are the ones used in the wind farm controller to curtail power output where K_p is the proportional gain K_i is the integral gain P_d is the requested power output and P is the total power output from the wind farm.

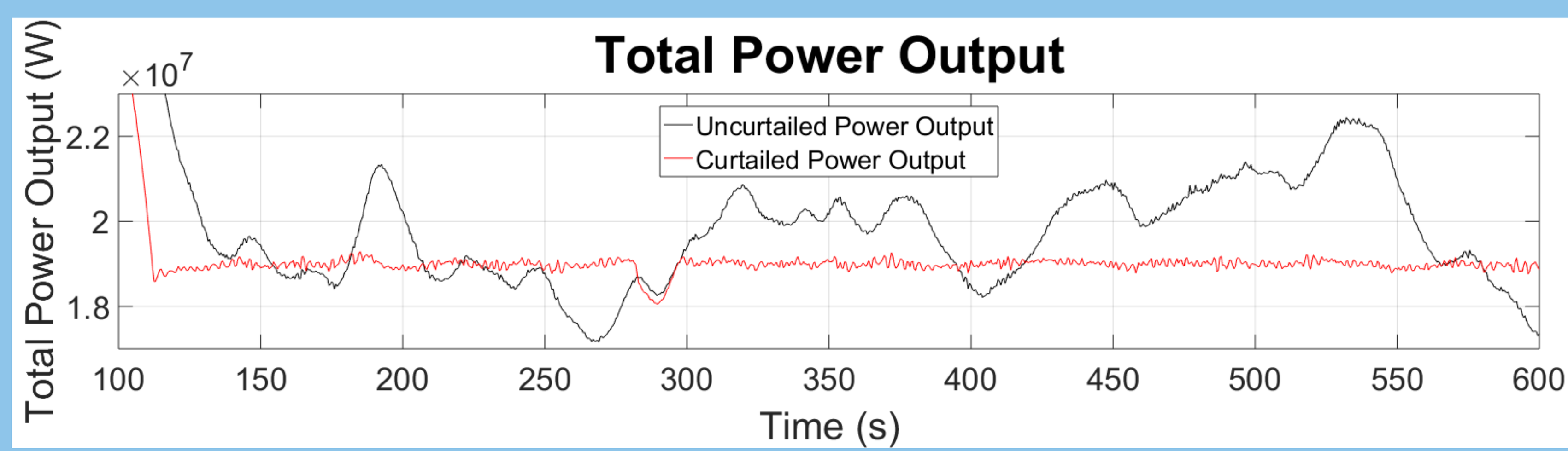

Figure 2. The power output of a wind farm containing ten 5MW turbines in a wind field with a mean wind speed of 8.5 m/s and a turbulence intensity of 5%.

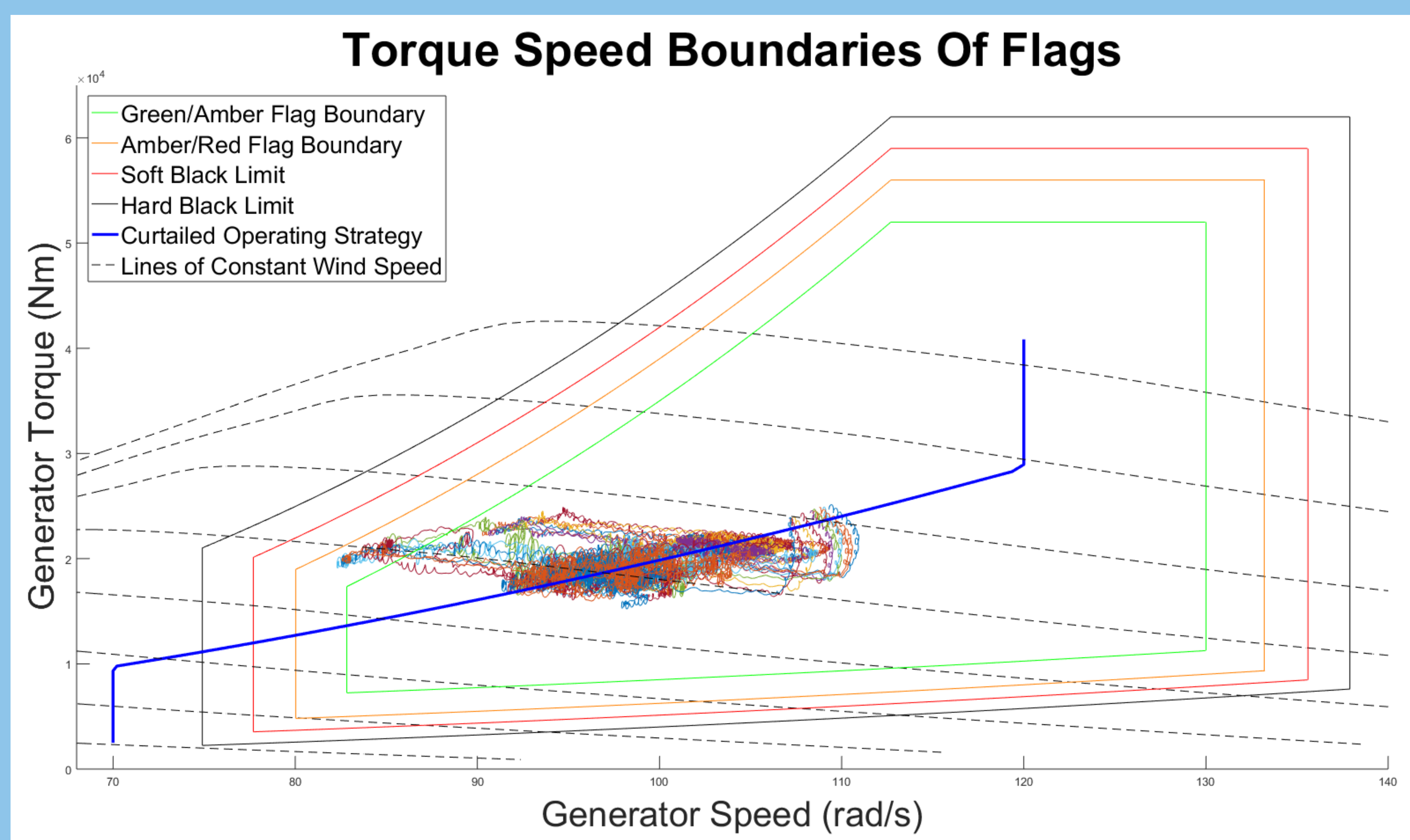

Figure 3. The boundaries between the flags, the curtailed operational strategy at zero curtailment and the estimated generator torques and generator speeds of the curtailment in seen in Figure (2).

Future Work

- Designing a power system model for implementation within Strathfarm which will switch between long and short discretised steps depending on whether the power system has either normal or abnormal conditions.
- Investigating the impact of ancillary services on loadings in wind farms.
- Investigating the capability of wind farm and wind turbine control to improve fault ride through from the perspective of the wind farm and the power system.
- Refining the design of the wind farm controller in respect to the above.

References

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Knudsen, T., Bak, T. and Svenstrup, M. (2014). *Survey of wind farm control-power and fatigue optimization.* Wind Energy, 18(8), pp.1333-1351.
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futureWind & Marine 2018