A comparison of curtailment strategies for reducing lifetime damage equivalent loads across a windfarm

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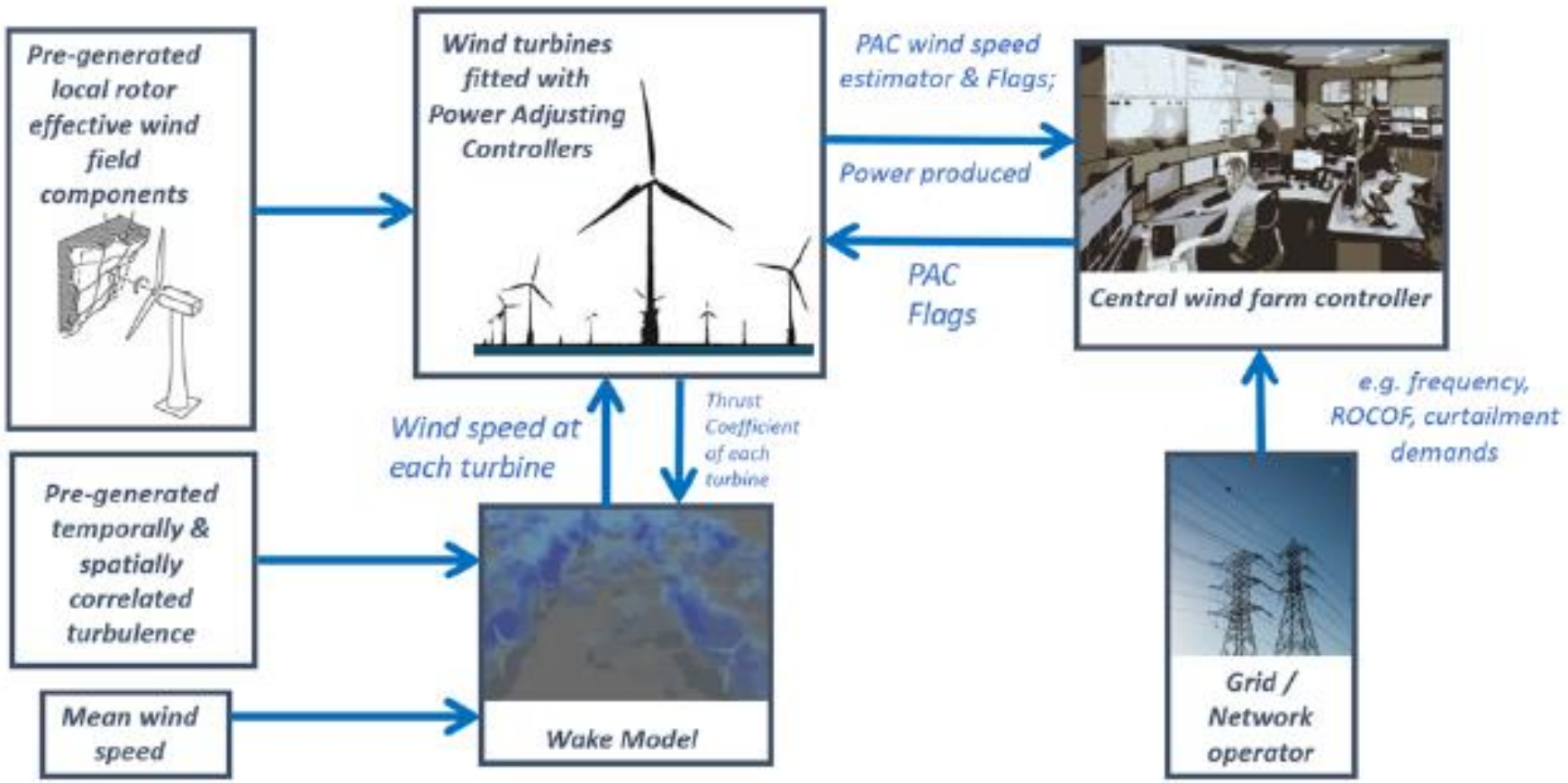
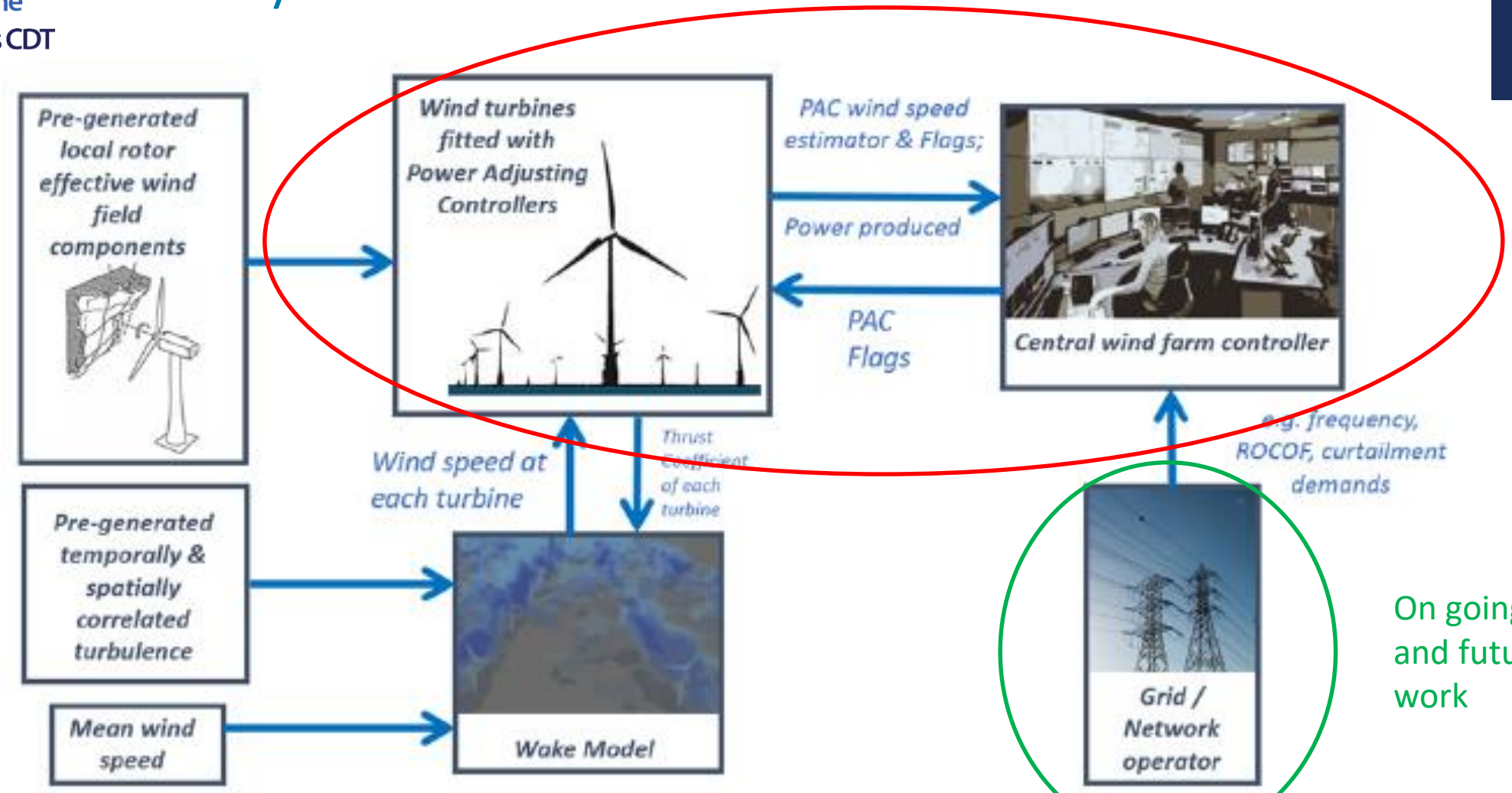
SgurrControl

Strathfarm



- University of Strathclyde's in-house wind farm modelling software
- Developed by Lindsey Amos, combining years of research from the CDT and industrial control centre
- Can accurately model up to 100 wind turbines in real time.

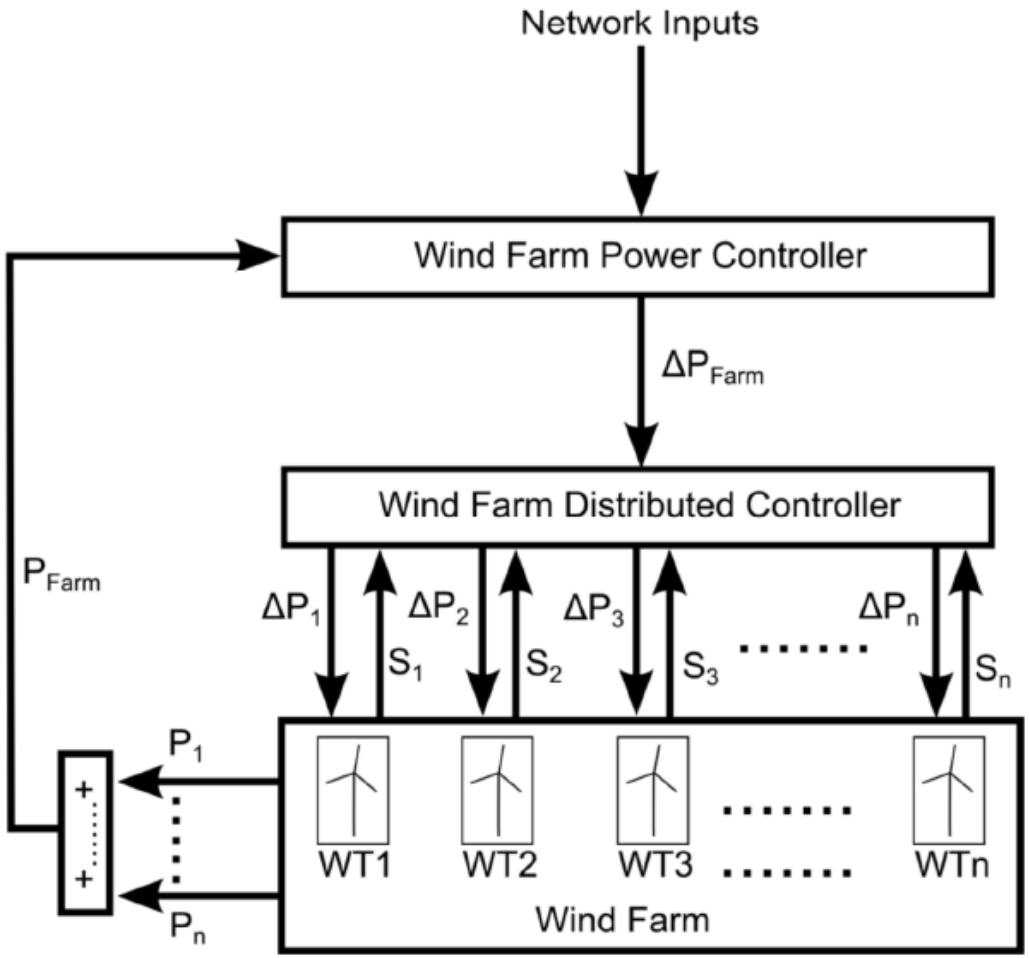
My contribution and research



Research so far

On going and future work

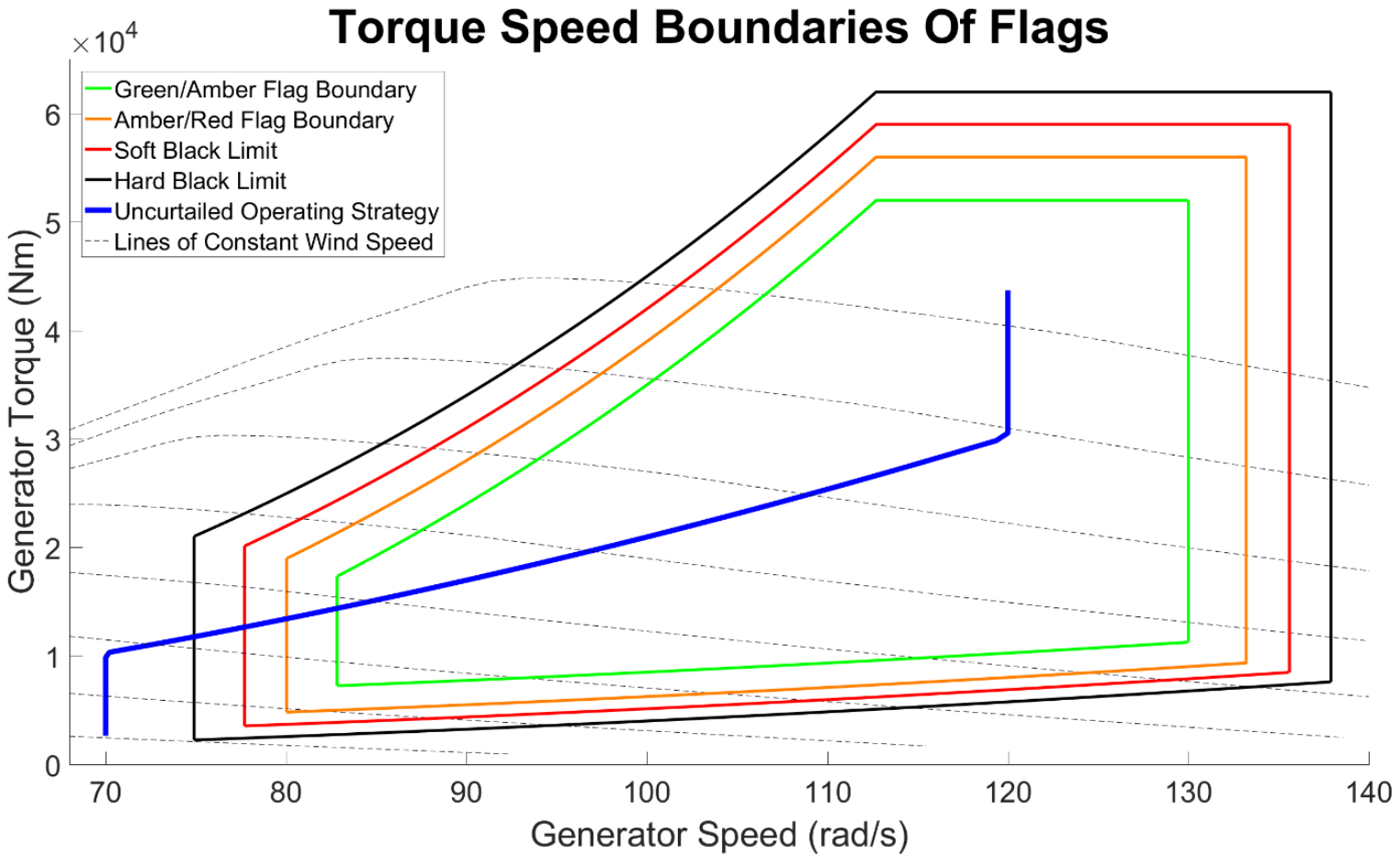
Strathfarm – Wind Farm Controller



- Wind farm power output follows a requested set-point by allocating reductions in power to wind turbines
- A Power Adjusting Controller (PAC) is used in each wind turbine as it can reduce the turbine power output by a requested amount
- The PACs also feed operational information to the farm level controller for use in the process of curtailment allocation.

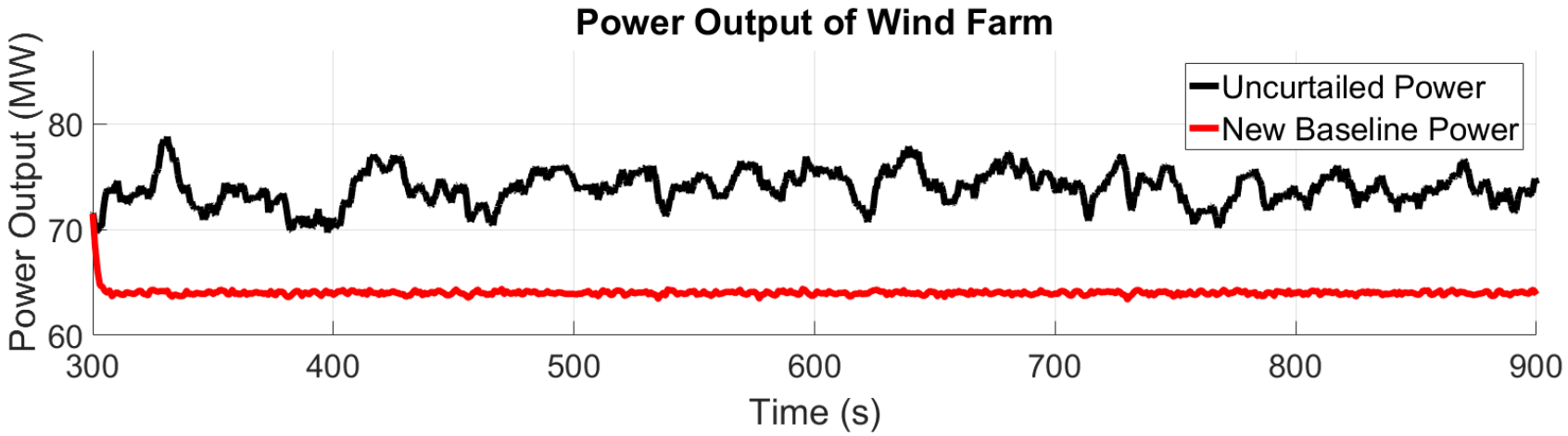
ΔP_n – *The requested curtailment by turbine*
S_n – *The flags from the PACs*
P_n – *The power from each turbine*
P_{Farm} – *The total power from the farm*
ΔP_{Farm} – *The requested curtailment across the farm*

Traffic light Flags



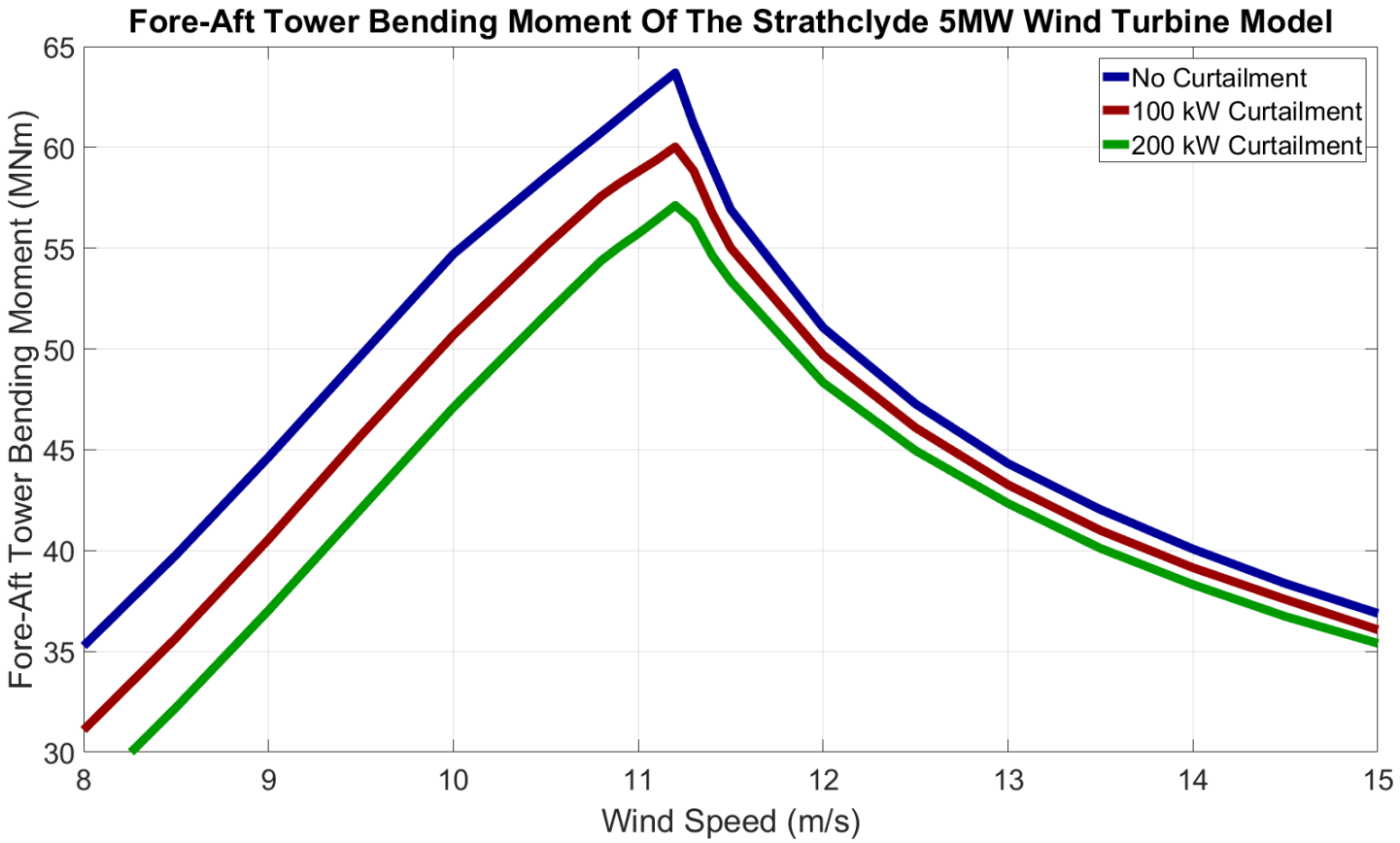
- Traffic light flags are used so that the WFC knows about the operation of each turbine while also allowing the control of the turbines to be decentralised
- The flags are used as a simple way to distribute curtailment across a wind farm

Set-point power



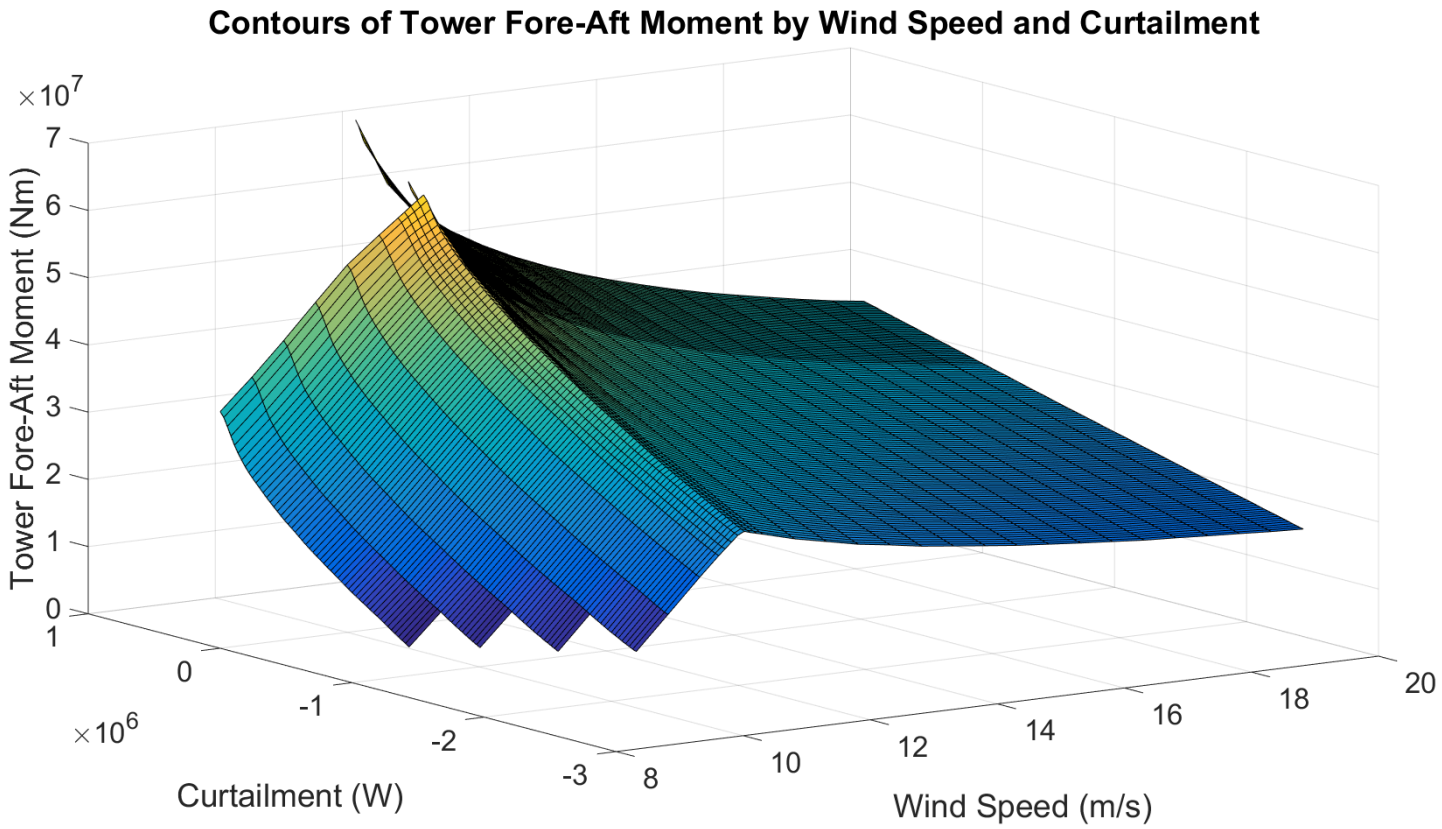
- As grid codes become stricter and there is more wind in power systems curtailment is increasingly required
- Achieved in Strathfarm through wind farm controller
- PI controller used to maintain farm level power set-point
- Anti-windup at farm and turbine level to ensure set-point tracking
- Curtailment is allocated across the farm to avoid any turbine being requested to deliver a power output which cannot be achieved.

Static loads



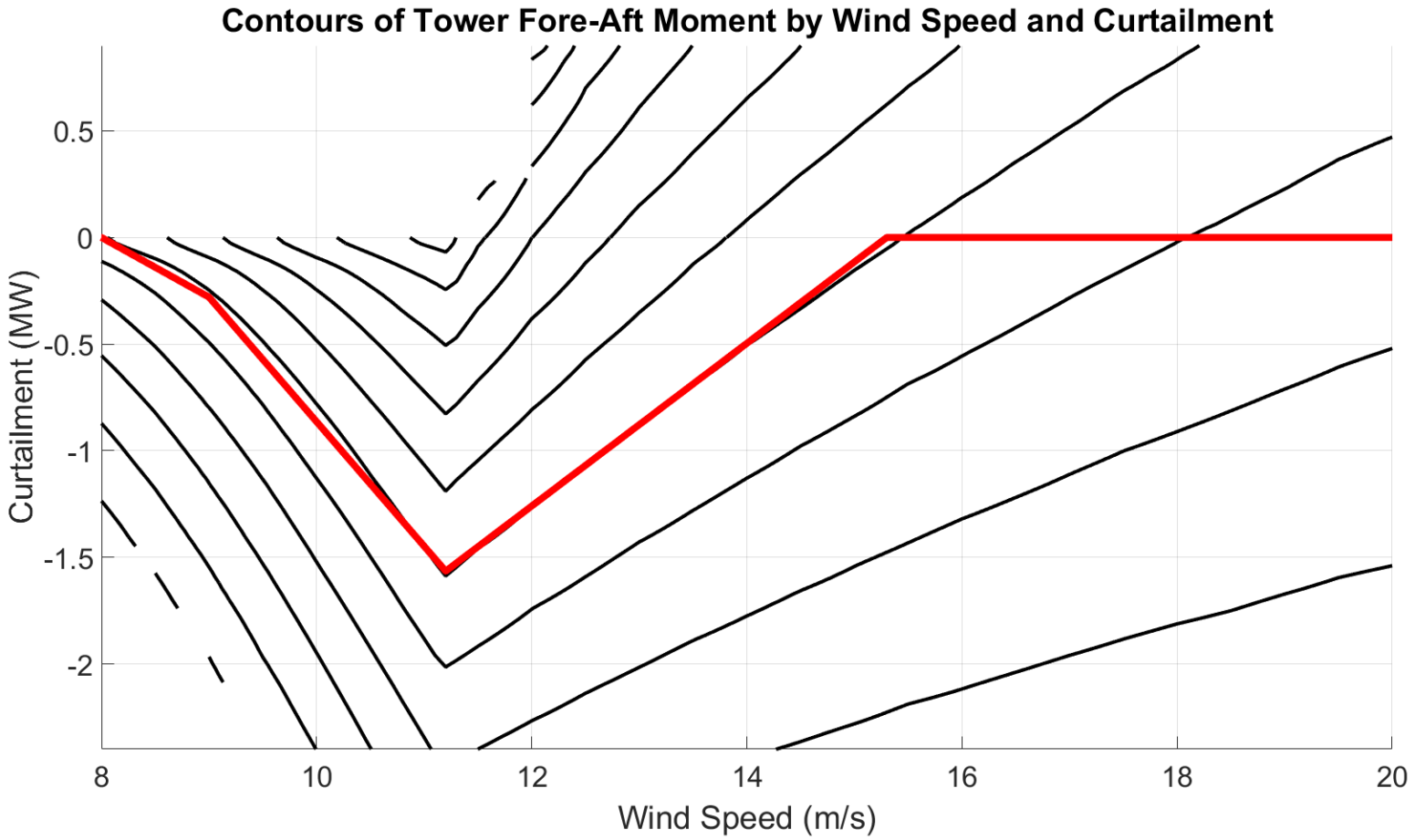
- Moments are the product of a force and a distance
- Highest static loads are at rated wind speed
- Above rated the reduction is due to the pitching of the blades
- When the PAC curtails by pitching there is a similar profile

Static loads with curtailment



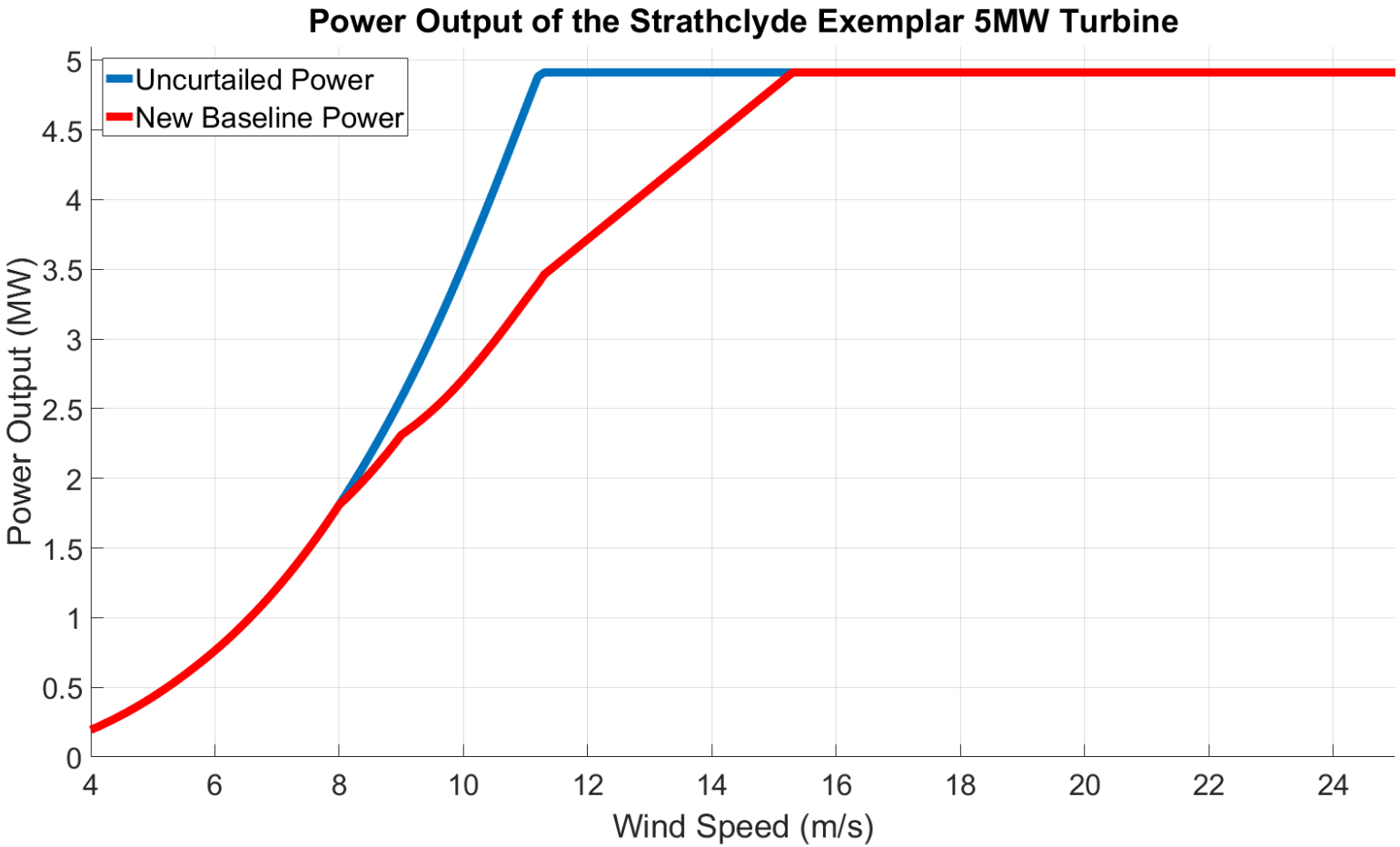
- Fatigue is caused by changes in bending moments
- Damage equivalent loads (DELs) calculated with standard Miner's rule approach
- DELs are comparable to fatigue.
- In a wind turbine's uncurtailed operation the bending moment varies considerably.
- Large variation in bending moments in normal operation near rated.

New curtailment approach

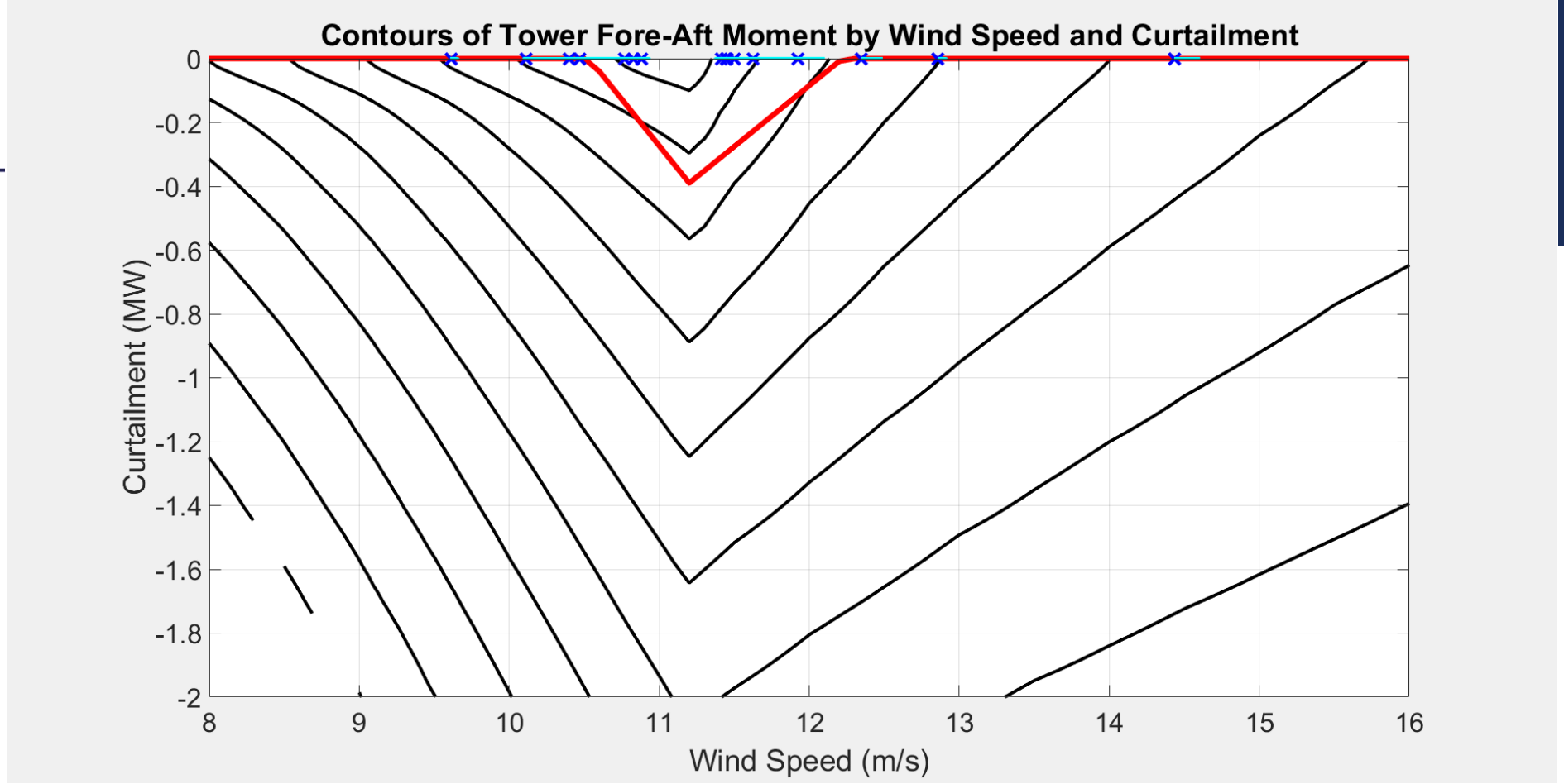


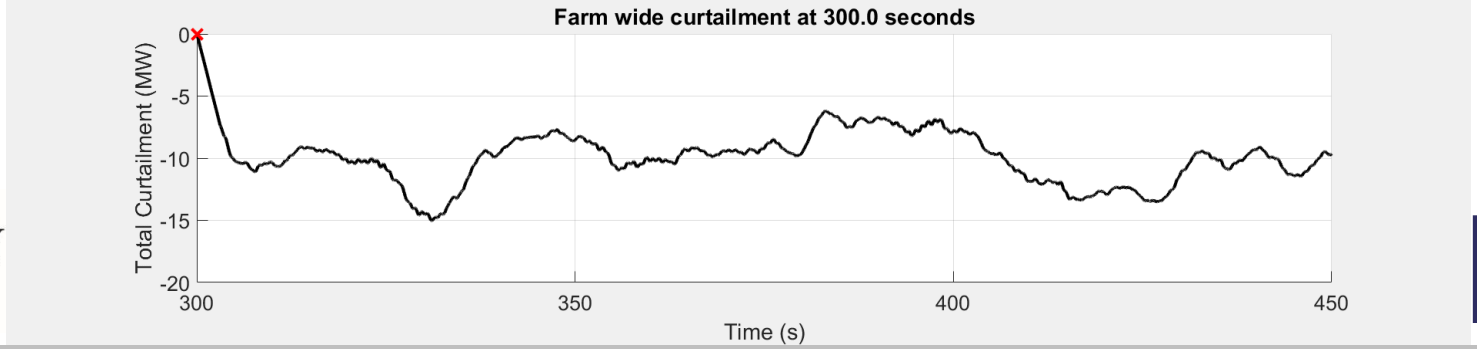
- New baseline for each wind turbine is set by wind farm controller.
- Follows a contour of static bending moments between 8 and 15 m/s
- Curtailment is then equally allocated with limits to prevent positive curtailment.

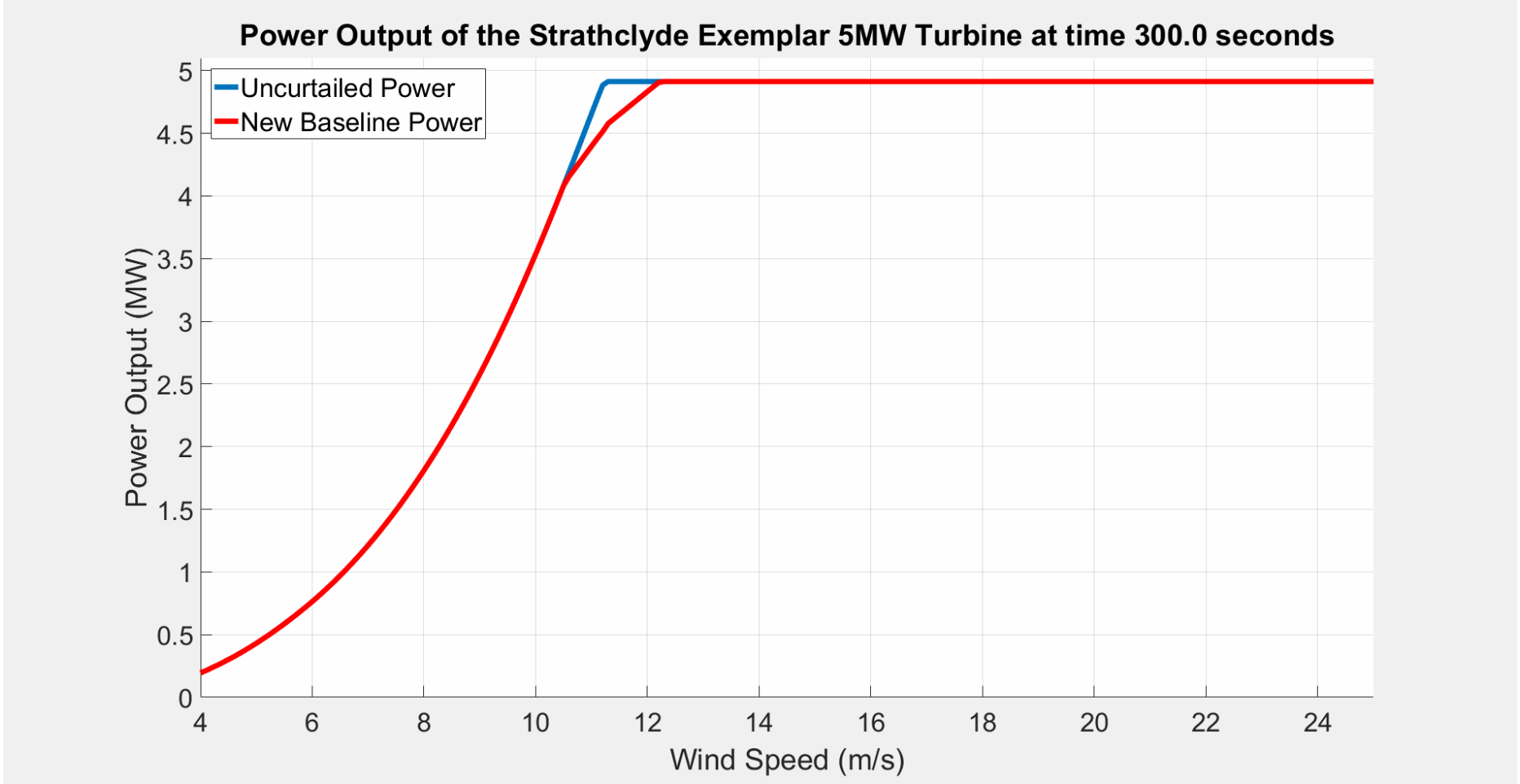
New baseline power curve

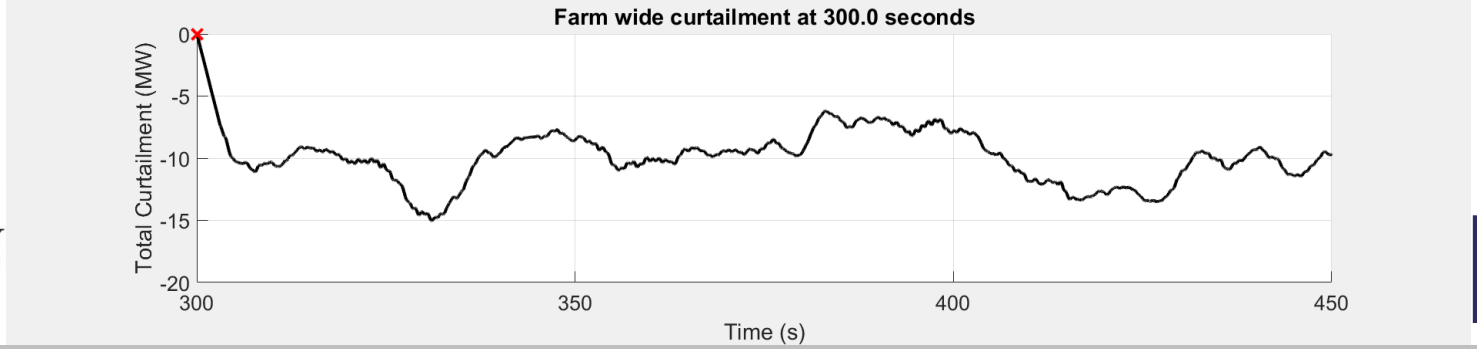


- Allocates curtailment using estimated wind speed from PACs
- Avoids the highest tower bending moments leading to reduced damage equivalent loads


Contours of Tower Fore-Aft Moment by Wind Speed and Curtailment
Curtailment (MW)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
8
9
10
11
12
13
14
15
16
Wind Speed (m/s)


Farm wide curtailment at 300.0 seconds
Total Curtailment (MW)
0
-5
-10
-15
-20
300
350
400
450
Time (s)


Power Output of the Strathclyde Exemplar 5MW Turbine at time 300.0 seconds
Uncurtailed Power
New Baseline Power
Power Output (MW)
Wind Speed (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
4
6
8
10
12
14
16
18
20
22
24

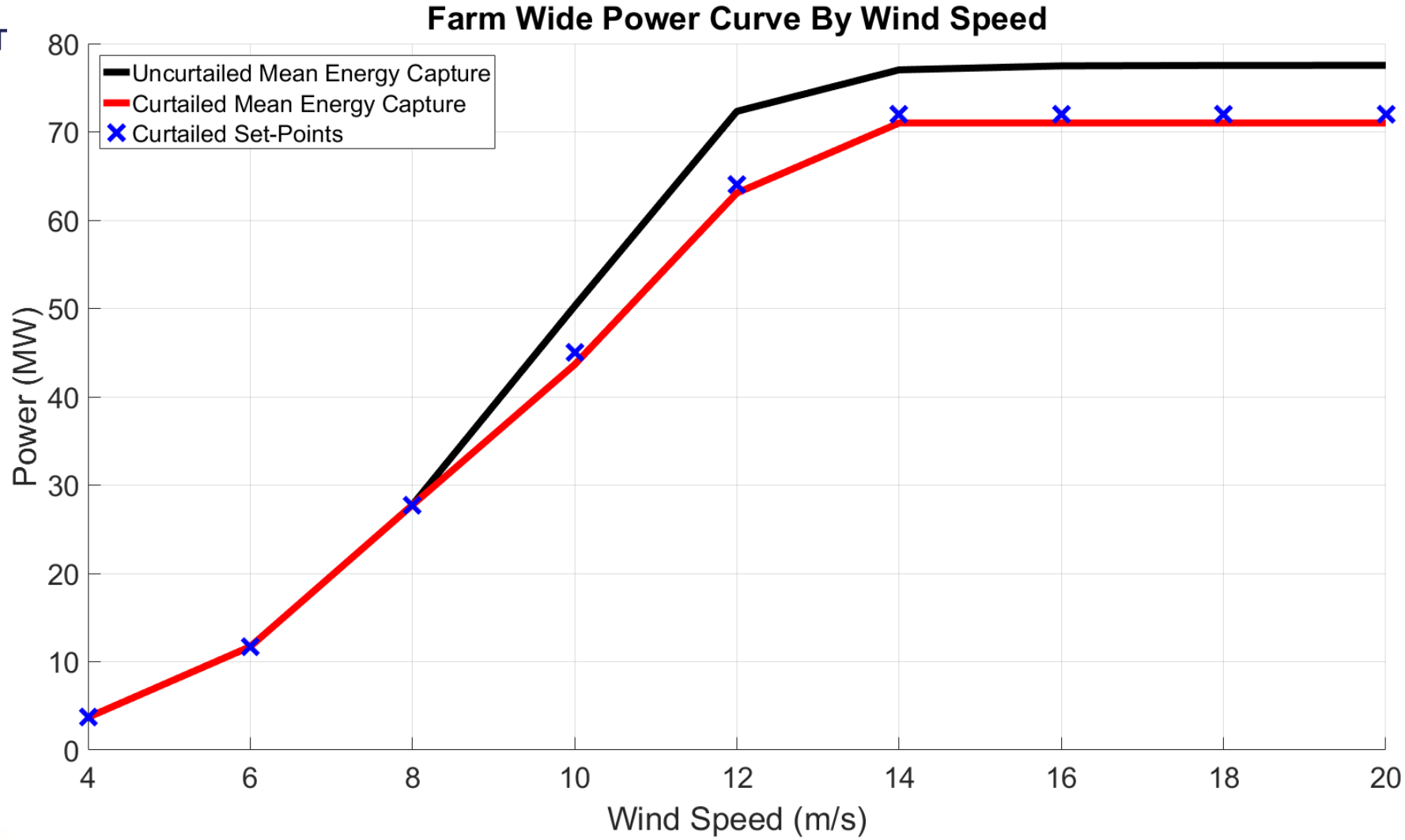

Farm wide curtailment at 300.0 seconds
Total Curtailment (MW)
Time (s)
0
-5
-10
-15
-20
300
350
400
450

Validation

- For the validation simulations a wind farm of 16 turbines, in a 4x4 square was used
- Simulations were run for 900 seconds with the WFC active for 600 seconds.
- The turbines were spaced 1000m (8 Diameters) apart.
- To prove the accuracy of these results simulations were conducted over an extensive range of parameters:
  - Mean wind speeds 4 to 24 m/s at intervals of 2 m/s
  - A, B and C classes of turbulence used (12%, 14% and 16%)
  - Wind angles to farm of 0, 15, 30 and 45 degrees (8 symmetries)
  - Each combination was independently repeated 6 times.

In total 792 windfields were used and over 1TB of data was generated!

Farm Power curve



Validated results

Results were calculated by weighing the simulations against a Weibull Distribution with a mean wind speed of 10 m/s.

Due to the curtailment there was a 6% reduction in energy capture.

Strategy	Tower Fore-Aft DEL Reduction
Equal Curtailment	5.50%
Power Estimation Curtailment	6.14%
New Baseline Curtailment	12.25%

Strategy	Out-of-Plane Blade DEL Reduction
Equal Curtailment	4.36%
Power Estimation Curtailment	5.36%
New Baseline Curtailment	12.22%

Current and future research

- Development of a power system model in Strathfarm
- Modelling faults in Strathfarm
- Strategies for primary response below rated
- Second author on “Distributed control of wind farm power set points to minimise fatigue loads”
- Publication of WFC strategy validation

Thank you for listening!

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futureWind
2020
&
Marine