Wind Farm Control

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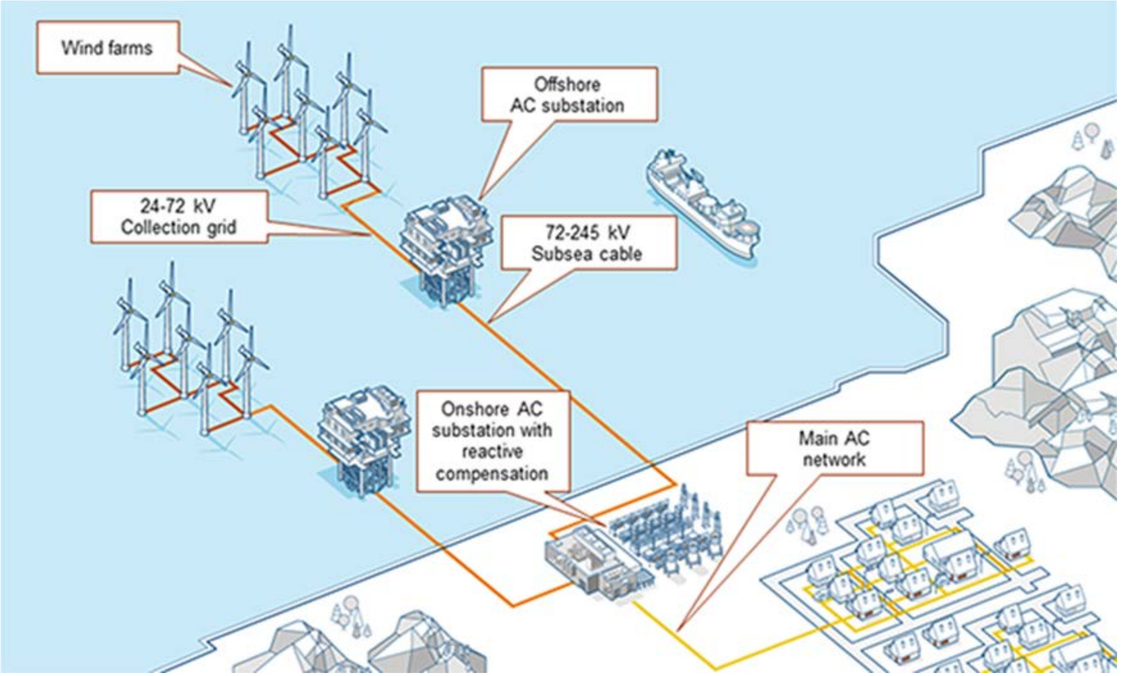
General Purpose Farm Controller

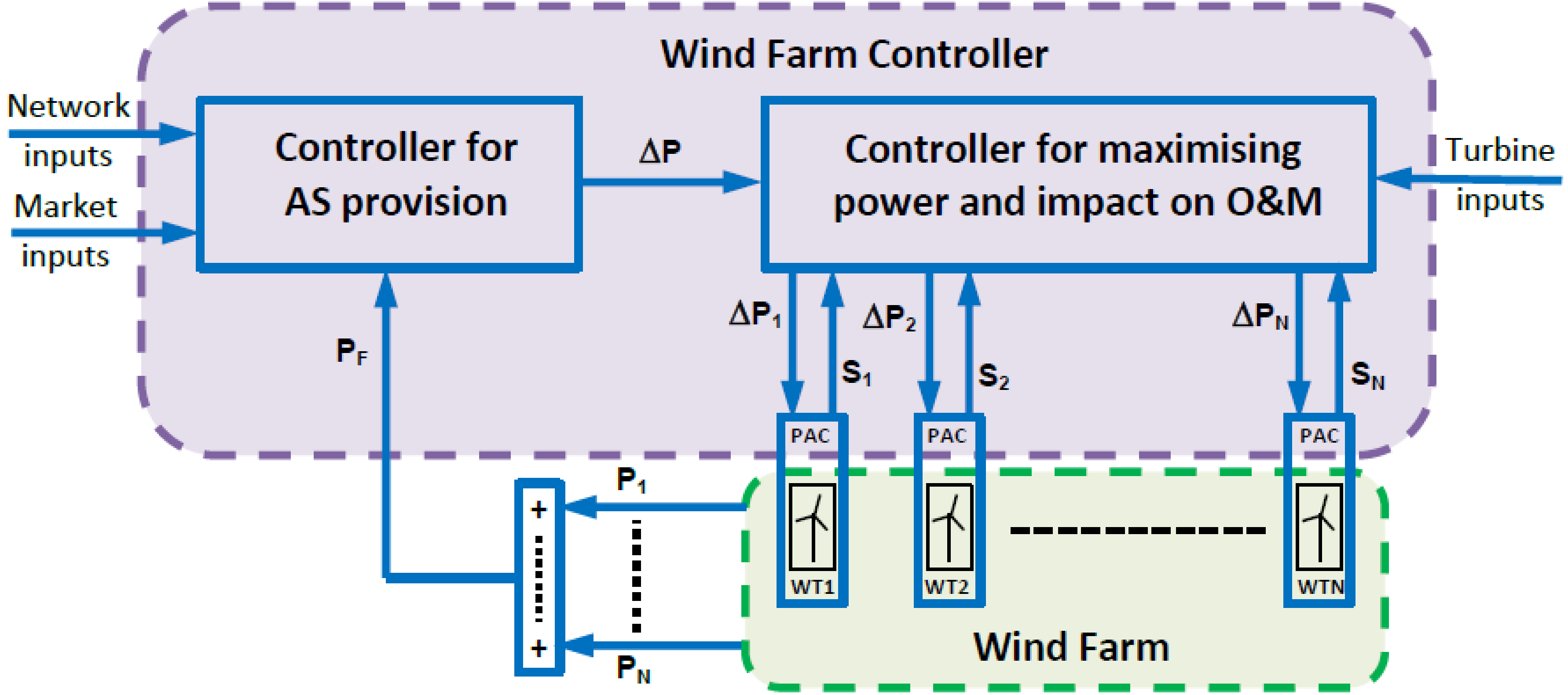


General Purpose Farm Controller

A generic wind farm controller architecture has been adopted with the following attributes.

- It is hierarchical, decentralised and scalable.
- Top layer responds to grid requirements to determine an adjustment in the power output from the wind farm.
- It may operate open-loop, eg to reduce the power output by a fixed amount, or closed-loop, e.g to curtail the output from the farm to a fixed power level. The latter feedback is based on feedback of the total farm output.
- Second layer determines change in power required from each turbine.
- Bottom layer is a generic interface to each turbine, the PAC.
- The only feedback permitted from each turbine to the first and second layers are flags containing information on the state of the turbines and an estimate of the local wind speed.

General Purpose Farm Controller



General Purpose Farm Controller

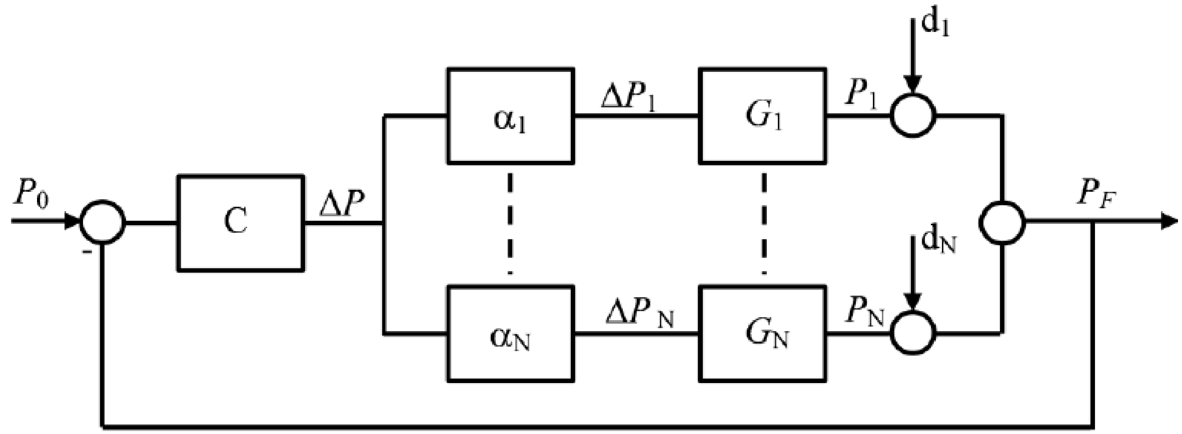
This hierarchical structure of the wind farm controller ensures that the turbine controllers are not compromised

- The wind speed estimation is sufficiently good not to be influenced by the state of the turbine
- The use of flags avoids the introduction of feedbacks based on the state of the turbine
- The farm level feedback acting on the total power introduces feedback round a single turbine but weakened by the inverse in the number of turbines

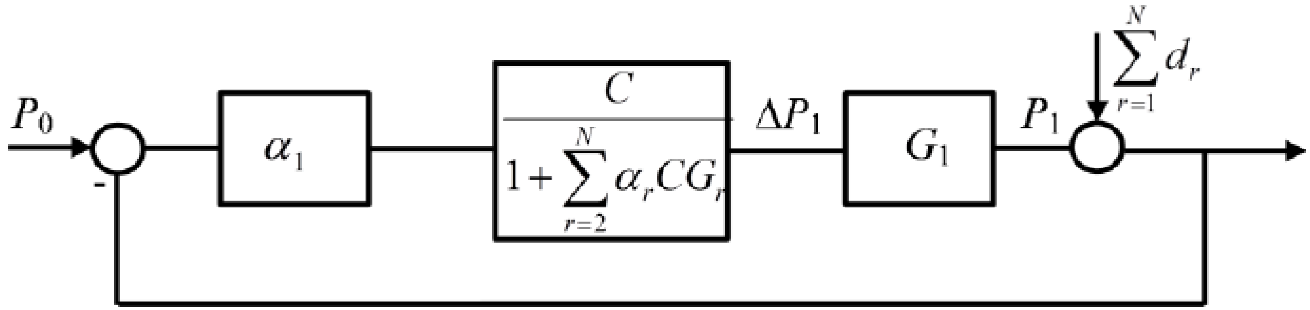
Tight control at the wind farm level can, thus, be achieved with very weak control of each turbine.

General Purpose Farm Controller

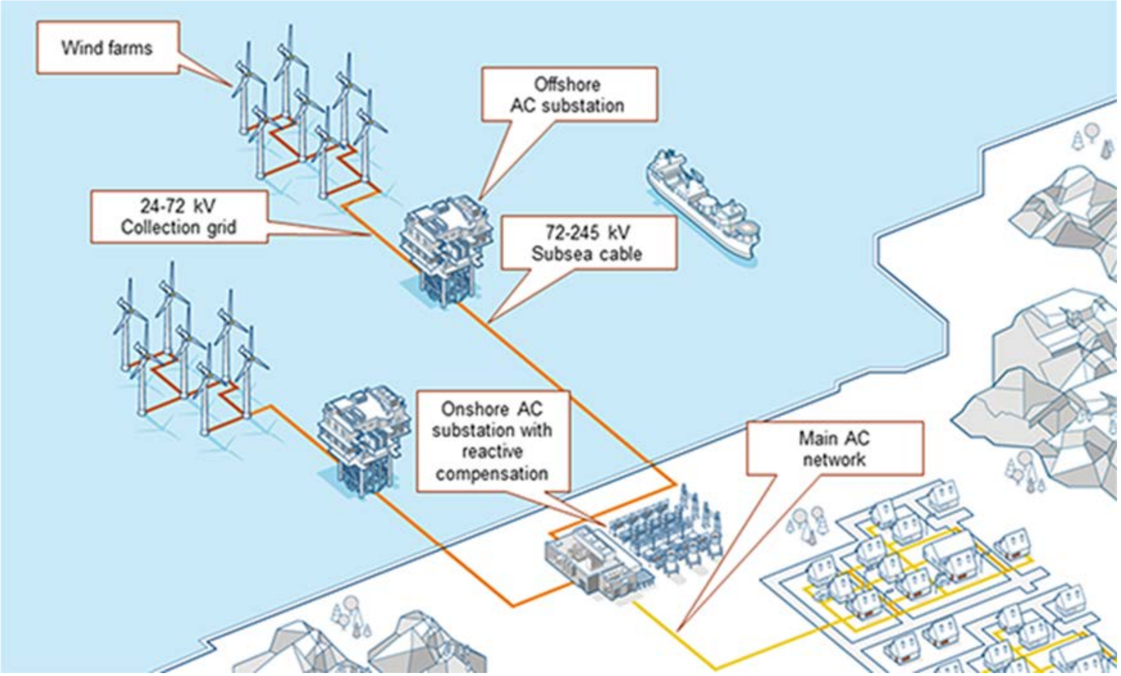
Simplified top layer feedback loop



Feedback loop for single turbine



Power Adjusting Controller (PAC)



Power Adjusting Controller (PAC)

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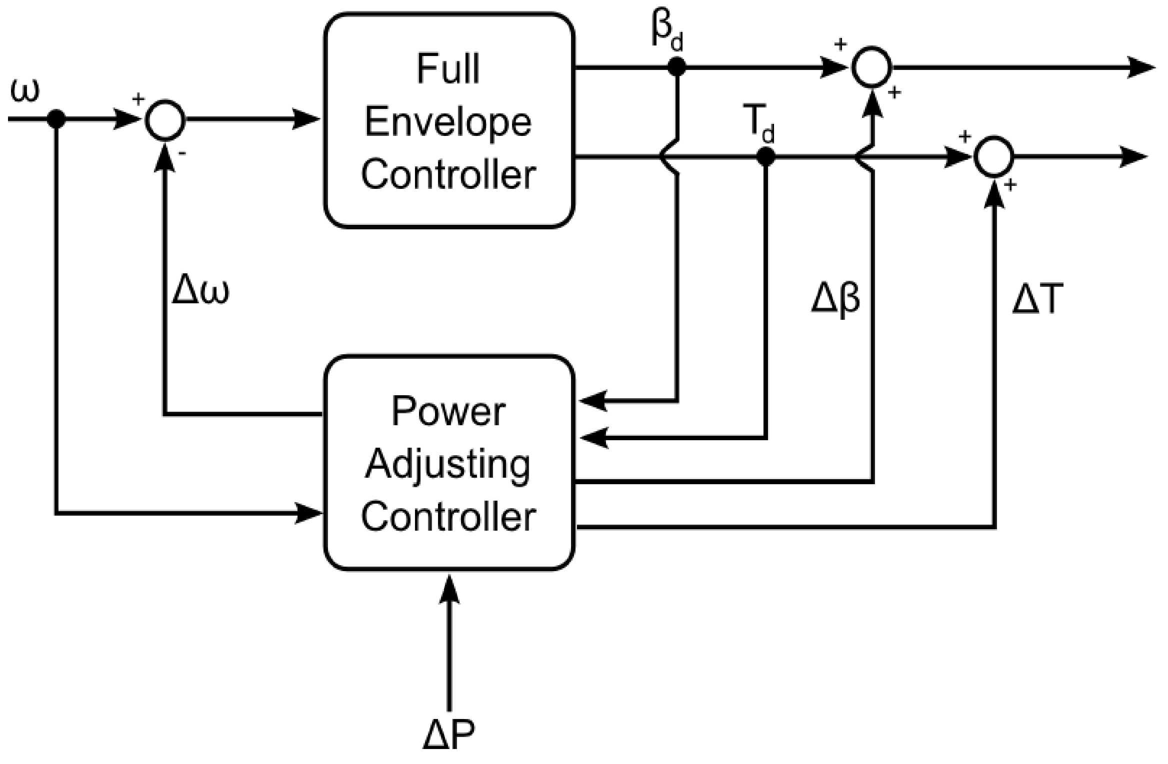
The PAC has the following attributes.

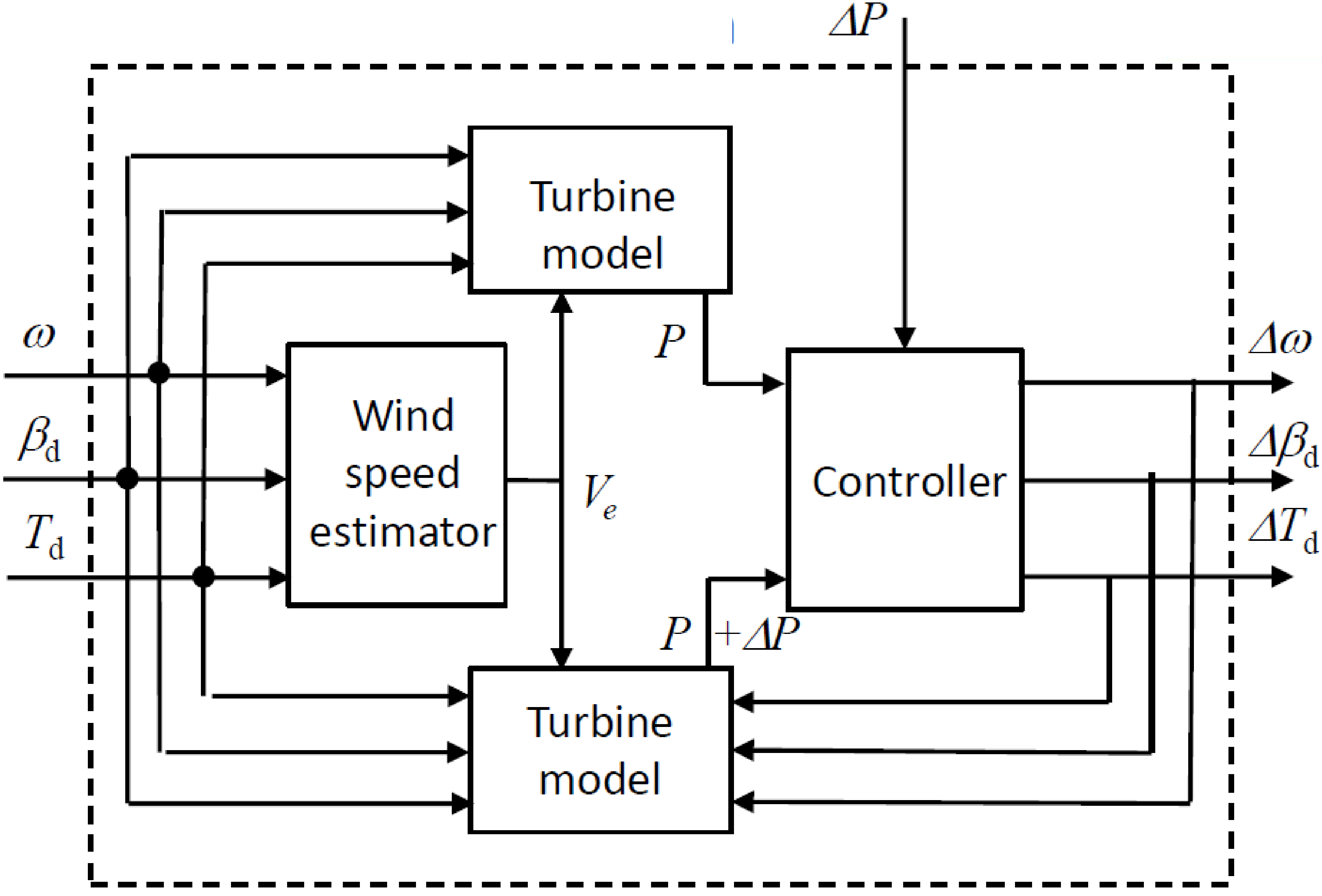
- The PAC does not compromise the turbine controller since it is essentially feed forward in nature
- It can be interpreted as changing the set point or operational strategy of the wind turbine albeit in a continuous and dynamic manner.
- The turbine is kept within a safe operating region through the use of the flags
- The change in output power from the turbine matches very accurately the change in power requested
- Response of the turbine to the requested change can be very fast.
- Very little information about the turbine is required. No information is required on turbine dynamics or the turbine controller.
- It is easily retrofitted.

Power Adjusting Controller (PAC)

PAC jackets full envelope controller

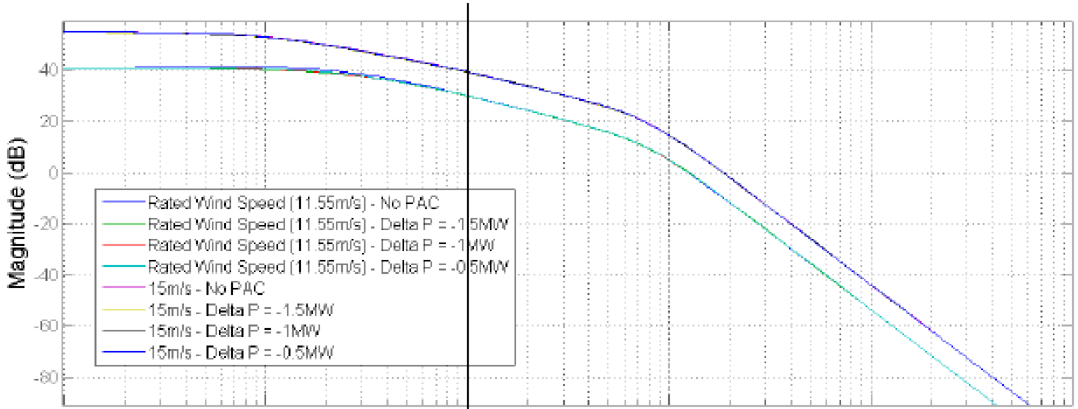


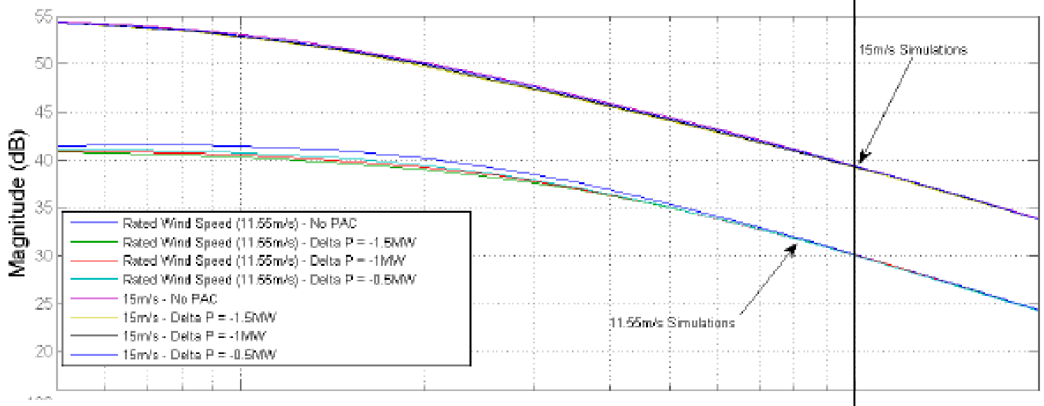
Power Adjusting Controller (PAC)



Power Adjusting Controller (PAC)

Transmittance from pitch demand to generator speed with/without PAC



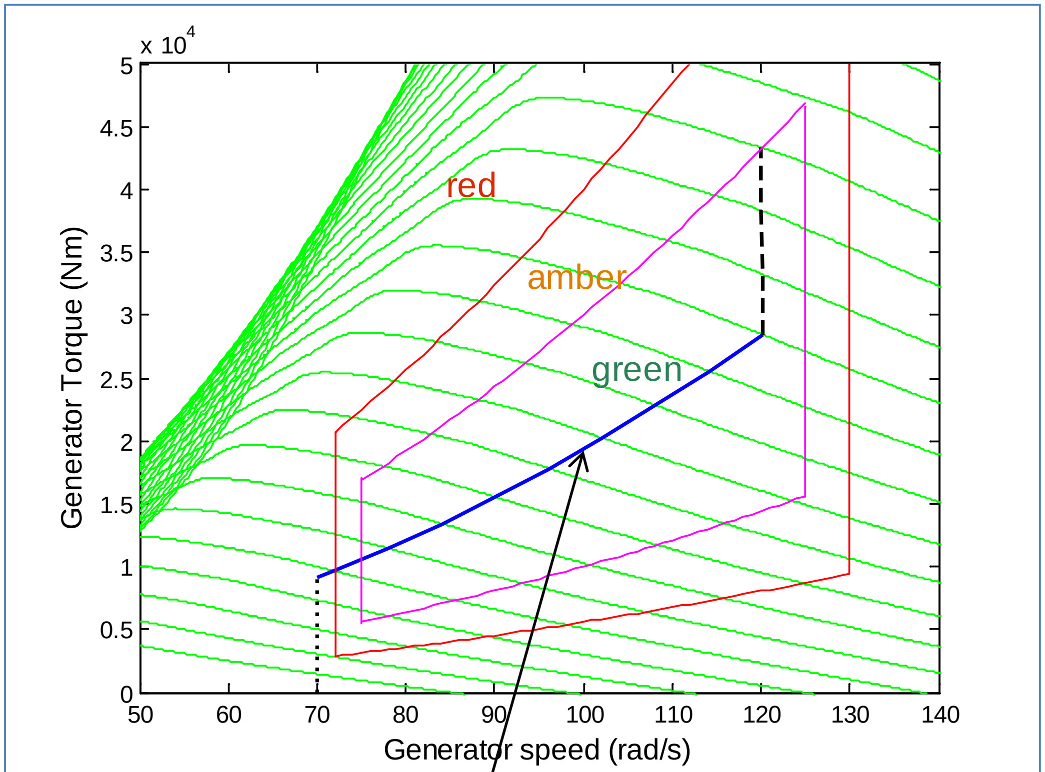


1rad/s

- 5MW turbine
- Wind speeds of 11.5 and 15m/s
- ΔP of 0.5, 1.0 and 1.5MW

- Maximum difference is -0.2dB
- So PAC acts as feedforward

Power Adjusting Controller (PAC)

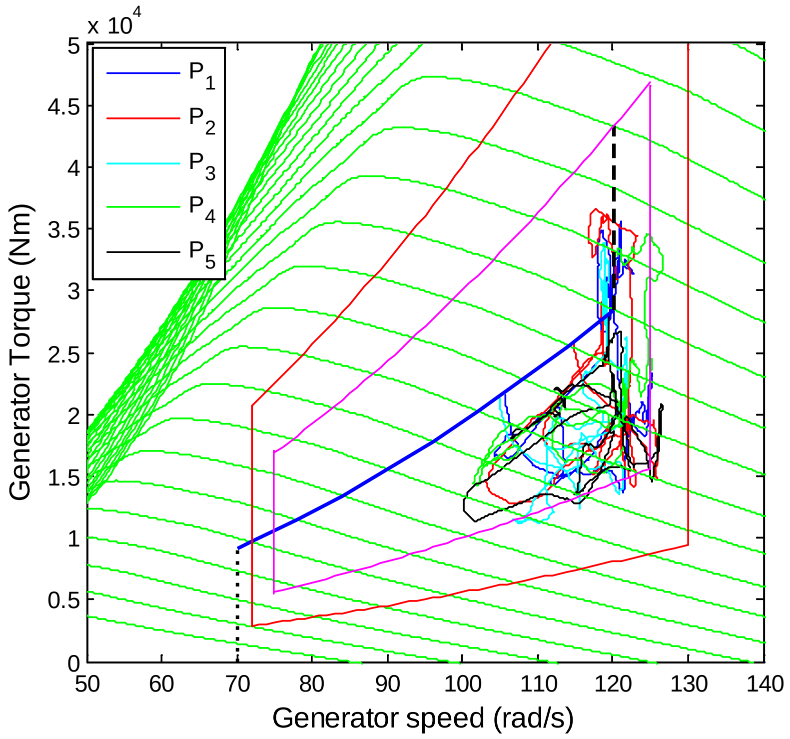


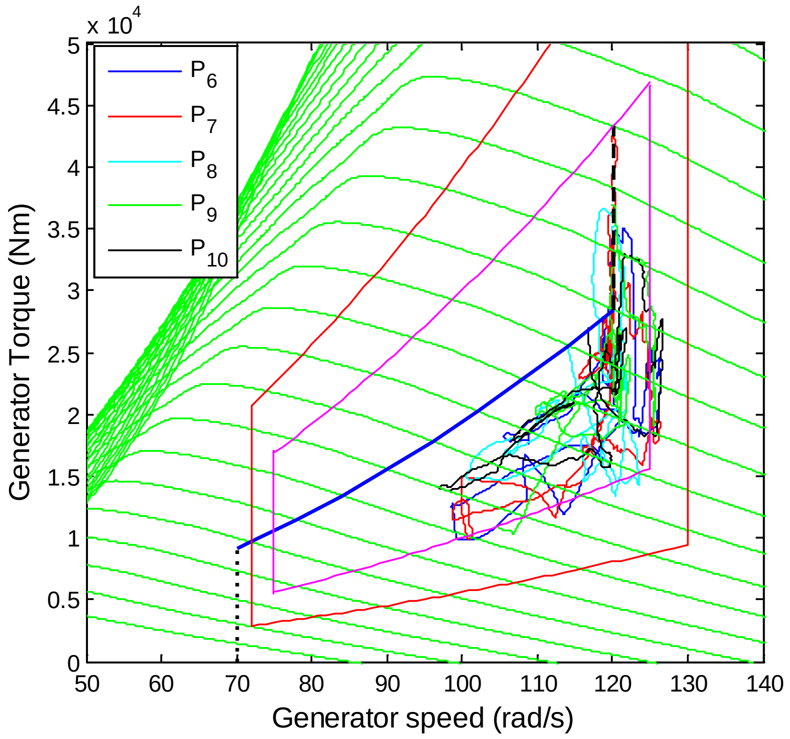
Normal operating strategy

- Flexibility of operation achieved by continuously varying the operating strategy
- The operating strategy curve has been replaced by a region.
- Traffic light system used to keep within safe operating region

Power Adjusting Controller (PAC)

- Individual turbine behaviour
- Traffic light boundaries constrain operational state

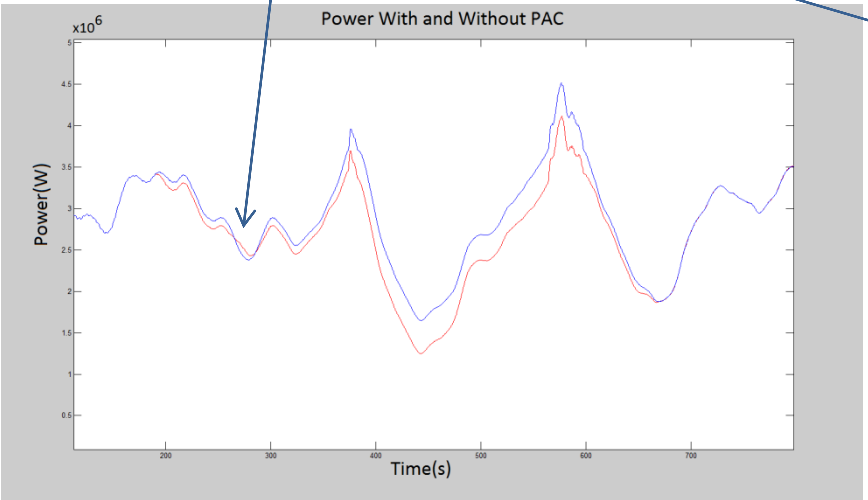




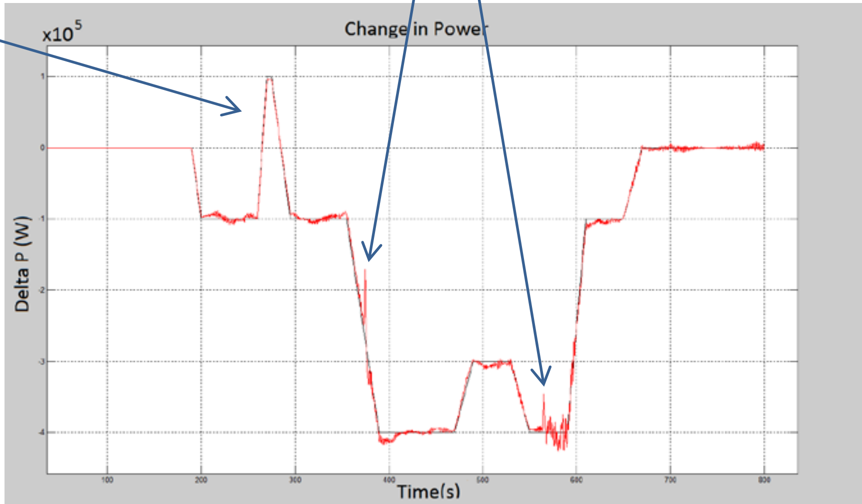
Power Adjusting Controller (PAC)

Increase in output power

Full envelope controller mode switch



Power output with/without PAC

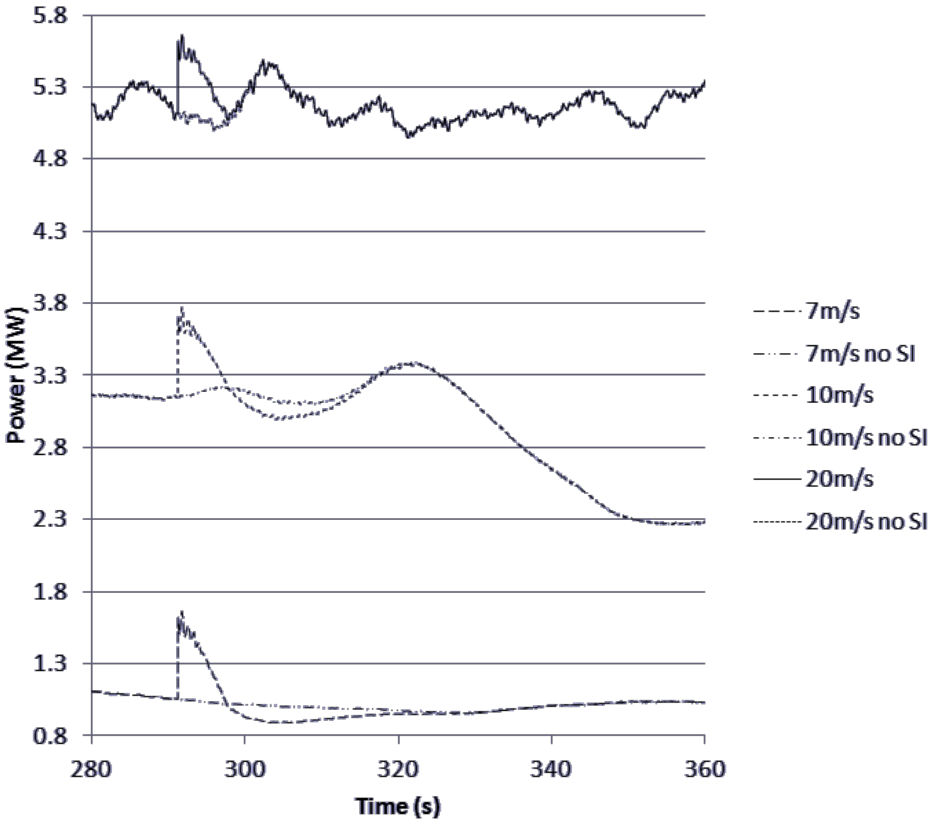


Difference in output with/without PAC

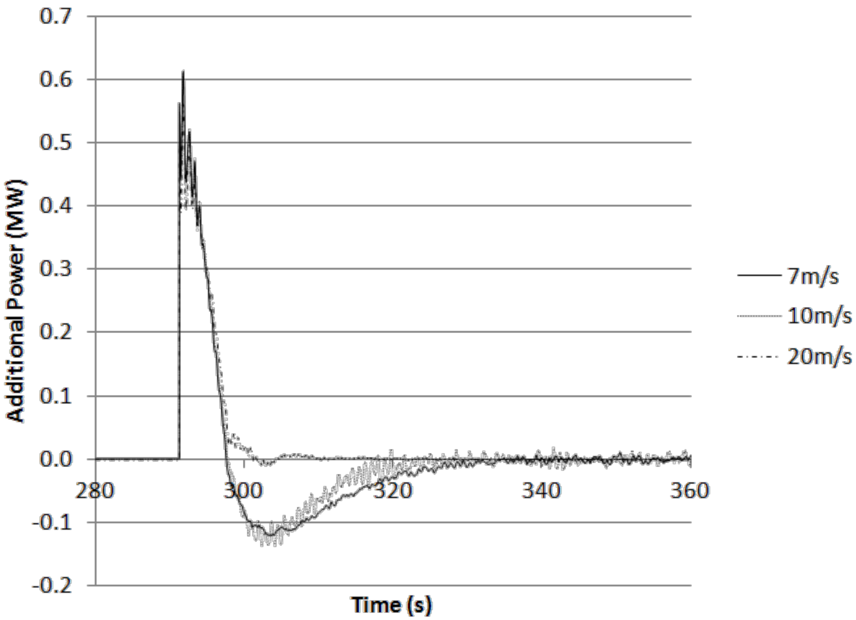
- 5MW wind turbine in 9m/s mean wind speed

Power Adjusting Controller (PAC)

Provision of synthetic inertia

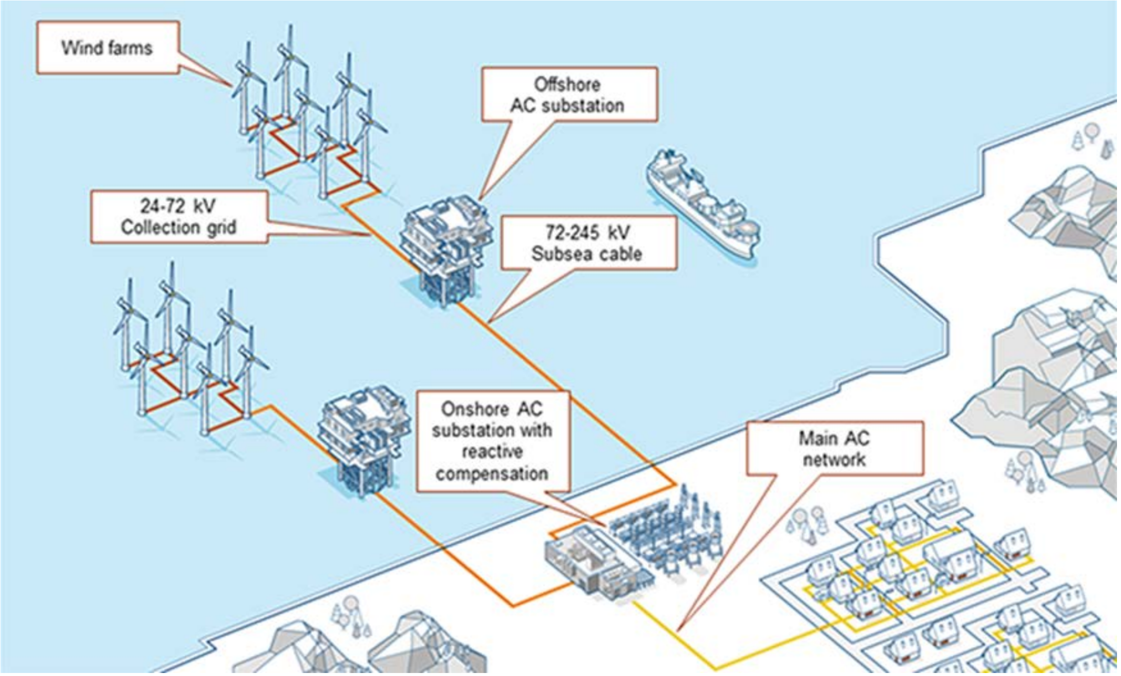


Absolute power outputs



Relative power outputs

Applications



Applications

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Ancillary Services

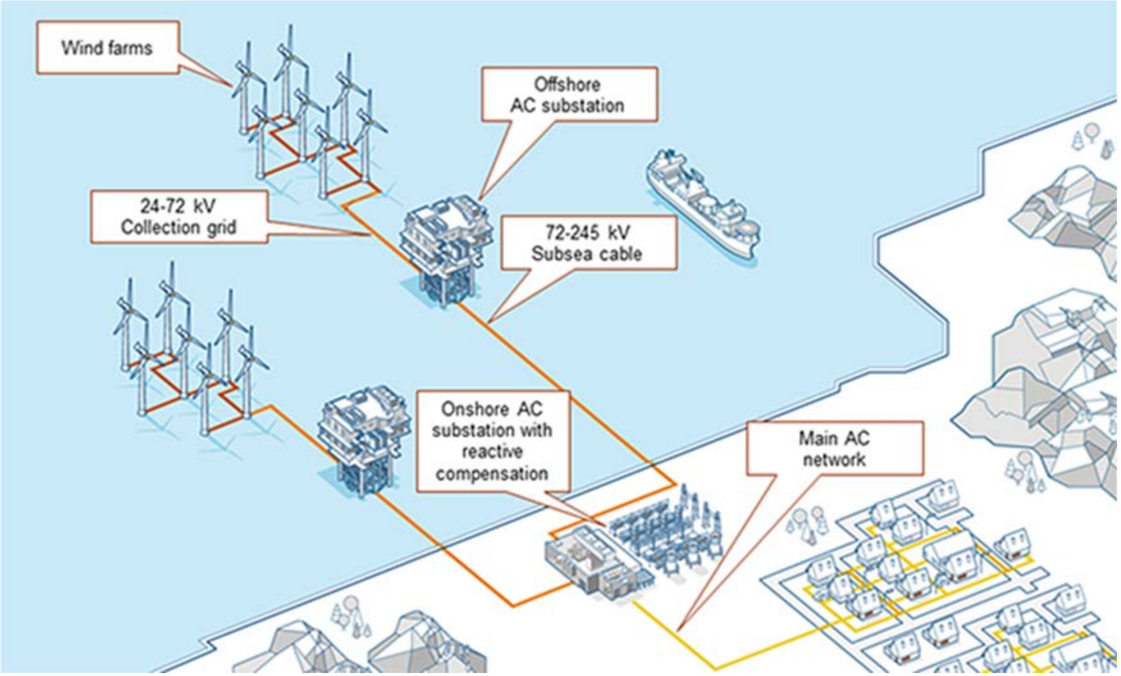
- Delivery of full range of ancillary services at the wind farm level has been demonstrated
  - Curtailment, droop control and synthetic inertia, etc
- No recourse to modifying turbine's converter or controller
- Advantages compared to single turbine provision of AS
  - Turbines can compensate each other
  - Only very weak feedback round turbines required
- No significant increase observed but more detailed assessment required
- Issues related to communications delays and grid frequency measurement addressed by Generator-Response Following concept
- Lab based demonstration of GRF being conducted

Applications

Power optimisation and minimisation of loads

- Extent of benefits not clear
- More detailed assessment required
- Need a suitable wind simulation tool – **StrathFarm**

Wind Farm Simulation Tool



Wind Farm Simulation Tool

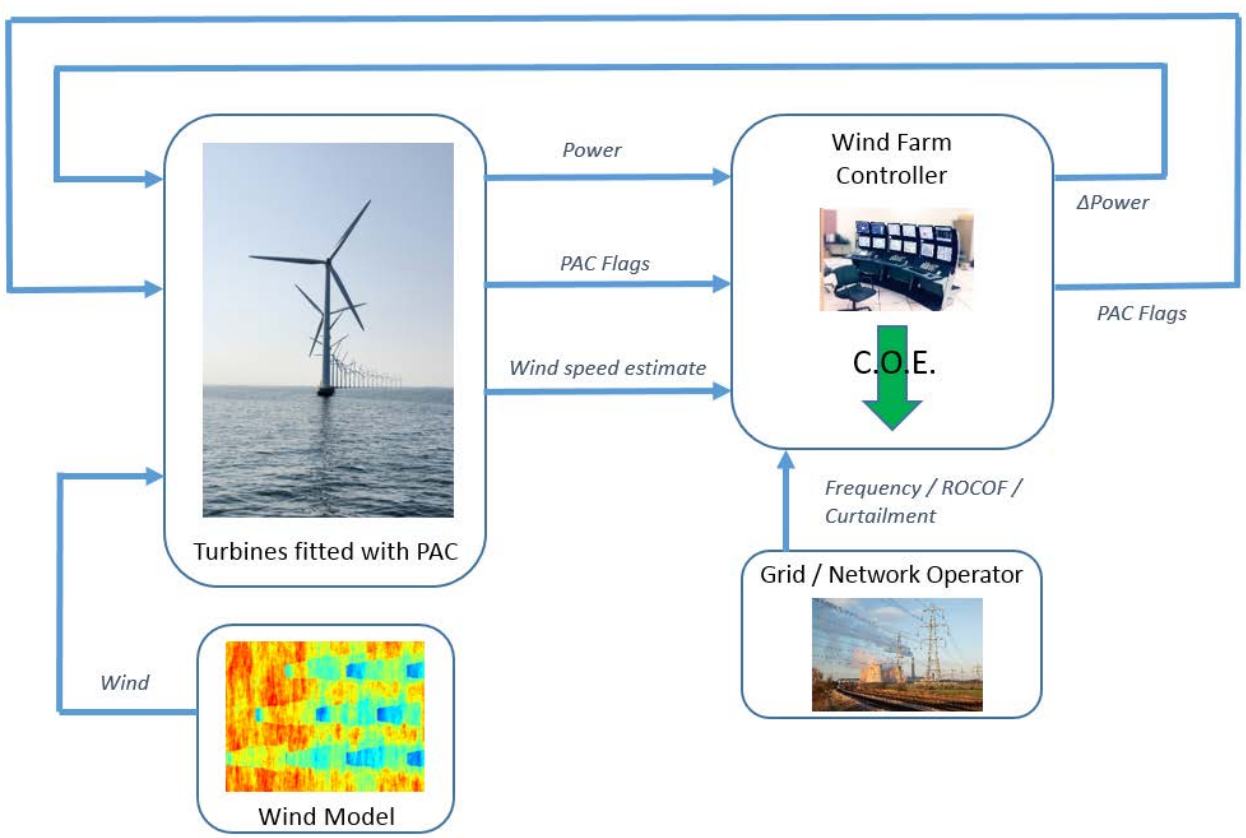
An analysis and design wind farm model and simulation tool is required with the following requirements

- Model wakes and wake interactions
- Model turbines in sufficient detail that tower, blade and drive-train loads are sufficiently accurate to estimate the impact of turbine and farm controllers on loads.
- Include commercial standard turbine controllers.
- Include wind farm controller and interface to turbine controllers.
- Very fast simulation of large wind farms; run in real time with 100 turbines on a standard PC.
- Flexibility of choice of farm layout, turbines & controllers and wind conditions direction, mean wind speed and turbulence intensity.

All above requirements have been met by StrathFarm

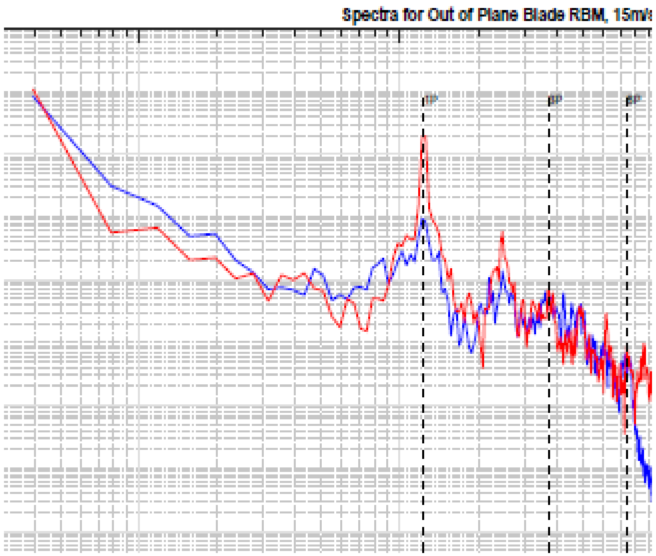
Wind Farm Simulation Tool

- **StrathFarm**

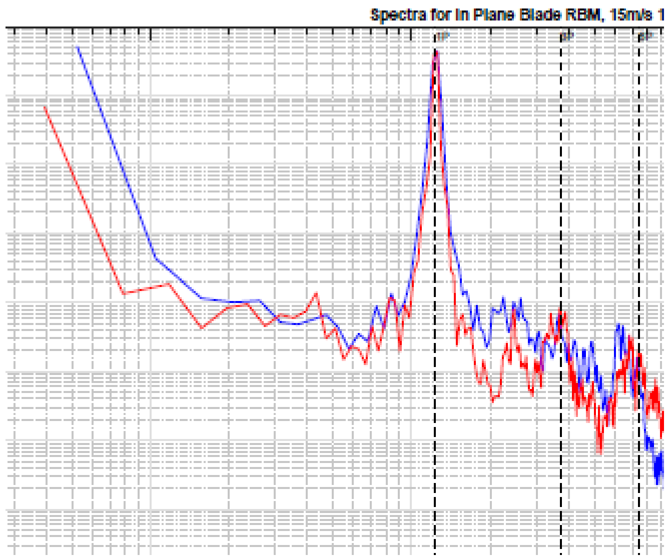


Wind Farm Simulation Tool

- Comparison of blade RBMs to Bladed (———) at 15m/s



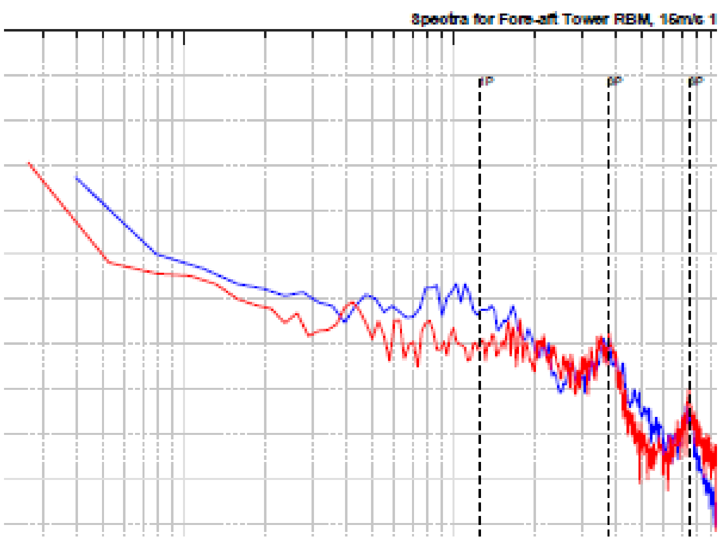
Out-of-plane blade RBM



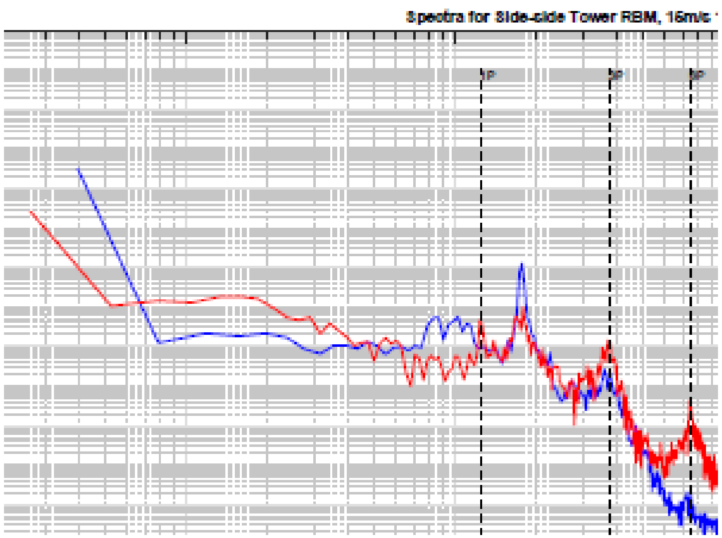
In-plane blade RBM

Wind Farm Simulation Tool

- Comparison of tower loads to Bladed (——) at 15m/s



Fore-and-aft tower RBM



Side-to-side, tower RBM

Wind Farm Simulation Tool

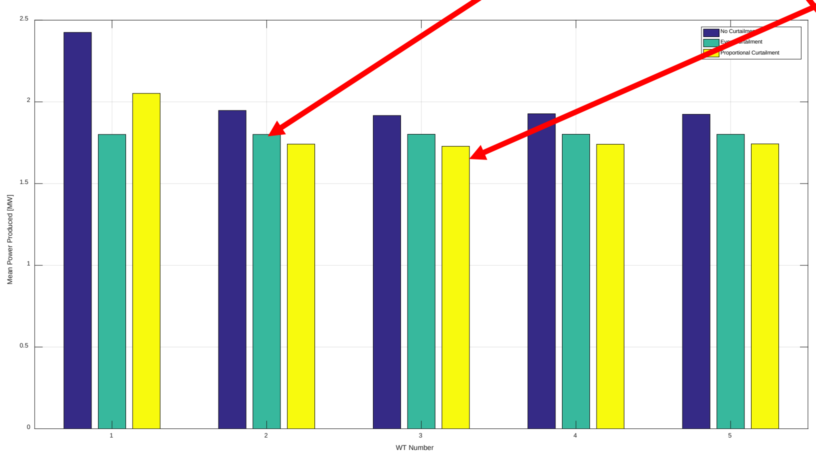
The generic controller architecture has been tested

Example

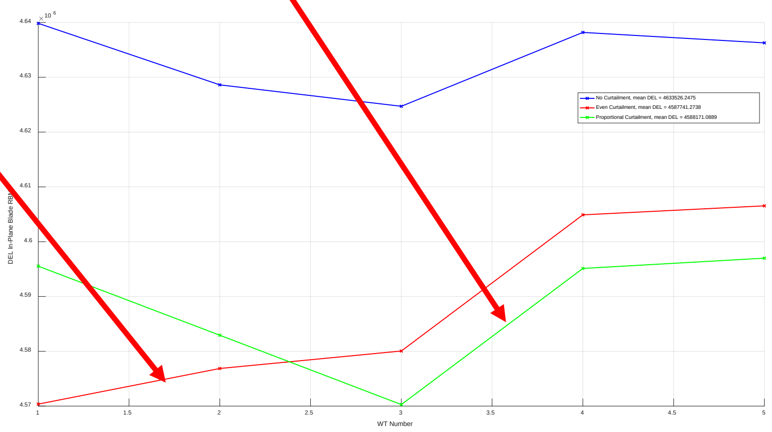
- 5x5MW turbines curtailed to 9MW
- Mean wind speed 9m/s, TI 2%

Strategy 1

Strategy 2



Average power

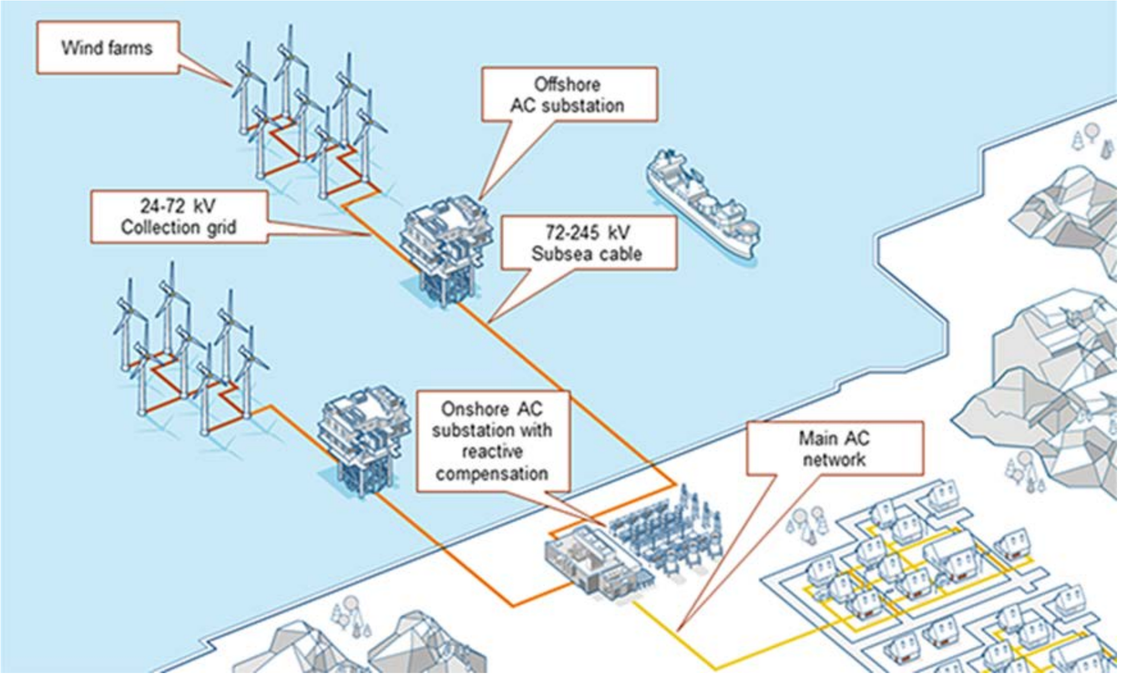


DEL tower fore-aft RBM

Wind Farm Simulation Tool

- Next steps
  - Enhance its batch processing capability
  - Add power systems aspects to cater for grid events
  - Improve the modelling of wakes

Conclusion


Wind farms
Offshore AC substation
24-72 kV Collection grid
72-245 kV Subsea cable
Onshore AC substation with reactive compensation
Main AC network

Conclusion

- A general purpose controller architecture has been developed and demonstrated to be very effective.
- It's hierarchical, decentralised and scalable
- A fast wind farm simulation tool has been developed for wind farm control design studies
- Capable of simulating 100 turbines in real time on a standard PC

Acknowledgements

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