TWIND Summer School

Wind Turbine and Wind Farm Control

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CATAPULT Offshore Renewable Energy

Agenda

- Wind Farm Control
  - Wind Power Plant Control
  - Wind Farm Flow Control
- Wind Turbine Control
  - X
  - Y
  - Grid/Power Control
- Converter Control

Wind Farm Control: Overview

Wind Power Plants (WPP) – encompass the turbines and balance of plant equipment – serve the grid code

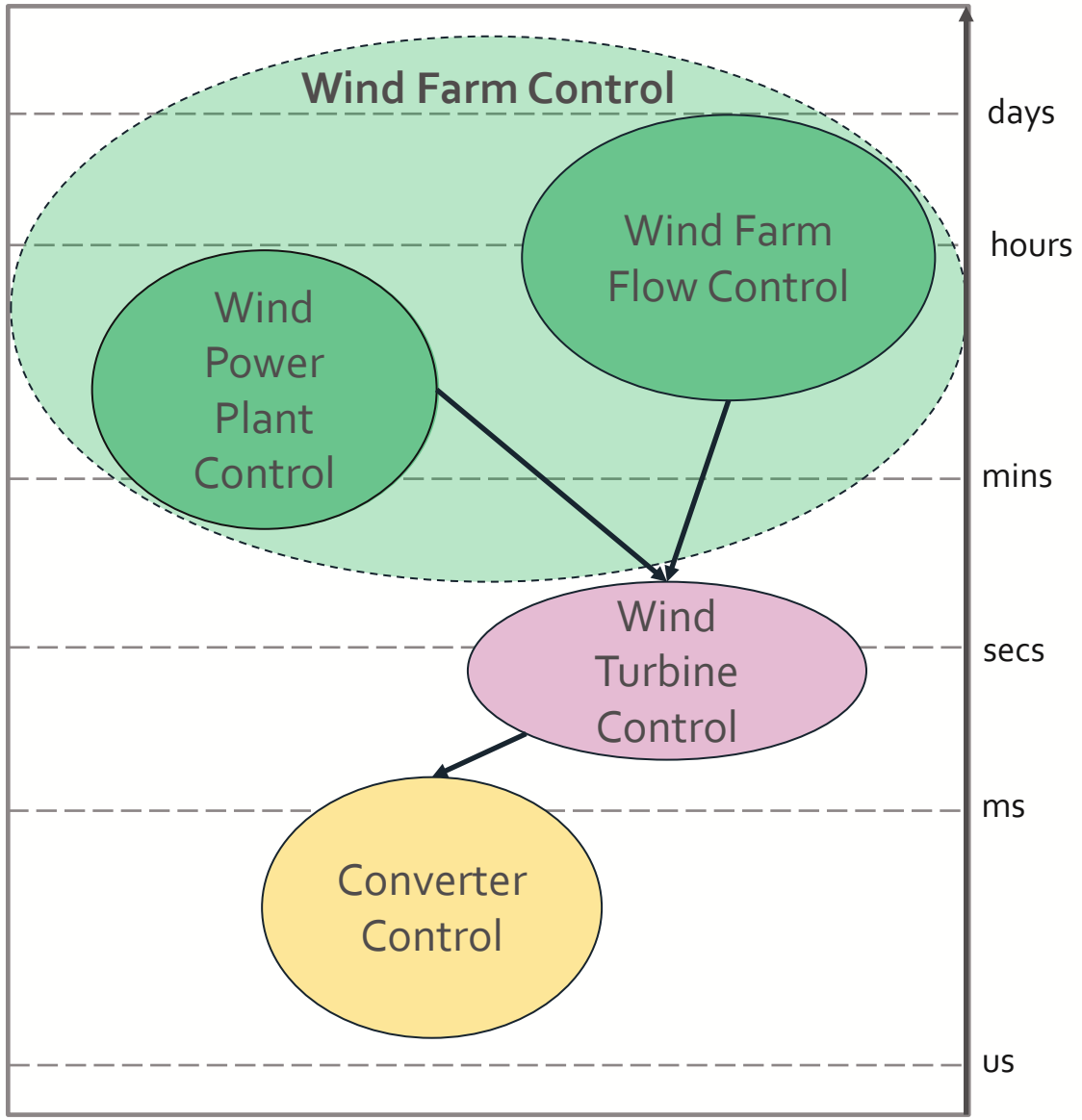
Wind Power Plant Control (WPPC) – well established and designed to comply with local grid codes and grid integration

Wind Farm Flow Control (WFFC) – Recent development aimed at maximising power extraction and/or load alleviation on wind turbines

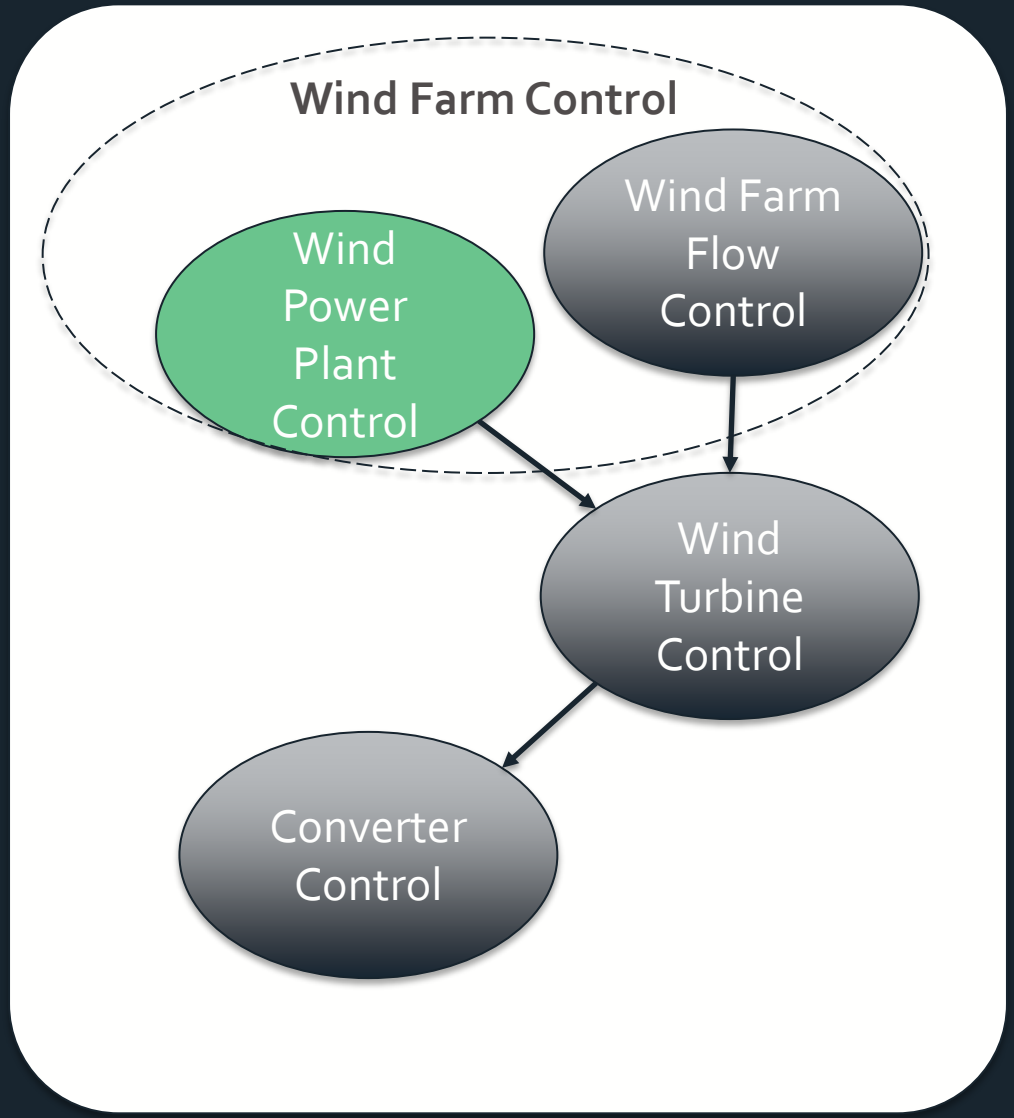
Wind Farm Control (WFC) – Umbrella term for WFFC and WPPC to coordinate operation

of wind turbines within a WPP to serve a common goal

Wind Turbine Control (WTC) – central controller of on each turbine. It controls



Wind Power Plant Control



Wind Power Plant Control

WPPC concerns the coordination of the WPP's turbines to meet its:

1. Grid Code Requirements

A Grid Code details all the technical requirements which must be complied with in order to connect to or use the electric grid. This includes mandatory ancillary services such as limited frequency and reactive power support as well as fault ride through capabilities.

2. Electricity Market Commitments

Energy generators bid into the energy markets to sell their electricity. These include long-term contracts, forward and future markets, day ahead, intraday and balancing markets. The markets are driven by supply and demand so prices can fluctuate significantly.

3. Ancillary Service Market Commitments

Ancillary markets allow generators to sell additional services to help maintain a stable grid. These can be frequency based – to provide additional power on short notice (ms – mins), voltage based – provision of additional reactive power or black start – the ability to restart the grid in case of a complete blackout.

THE GRID CODE

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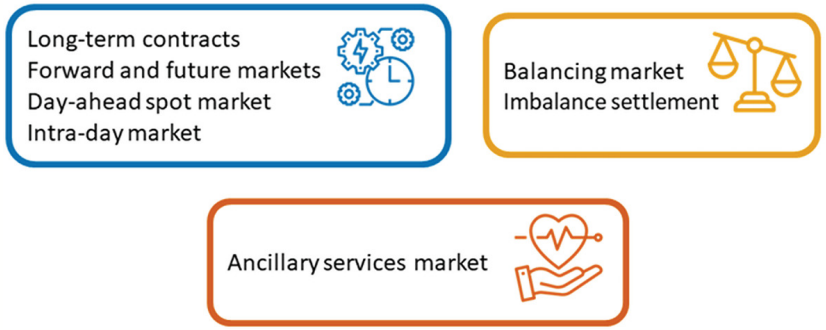
26 November 2020



Wind Power Plant Control

- Higher penetration of Variable Renewable Energy (VRE) generators is expected to lead to greater variation in market prices and lower average prices
- Subsidies for offshore wind will come to an end
- Additional revenue streams through for example ancillary service provision will be of more interest – move from maximum power generation to maximum revenue generation.
- To balance the grid new ancillary service products will be created/available for WPPs:
    - Black start
    - Inertia support
    - Fast Frequency Response (FFR)
    - Harmonic suppression

WPP control will have increasingly complex interactions and requiring more comprehensive testing to ensure that all

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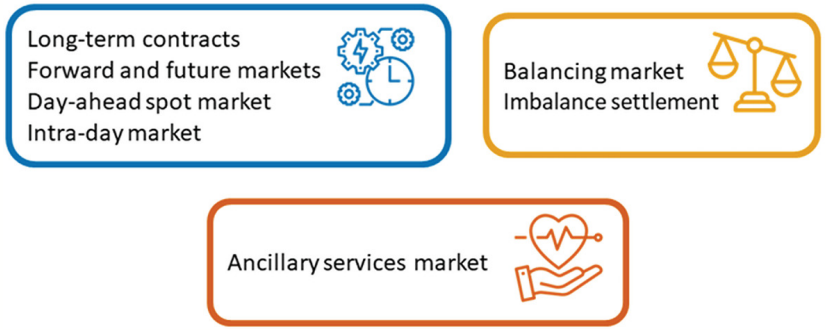
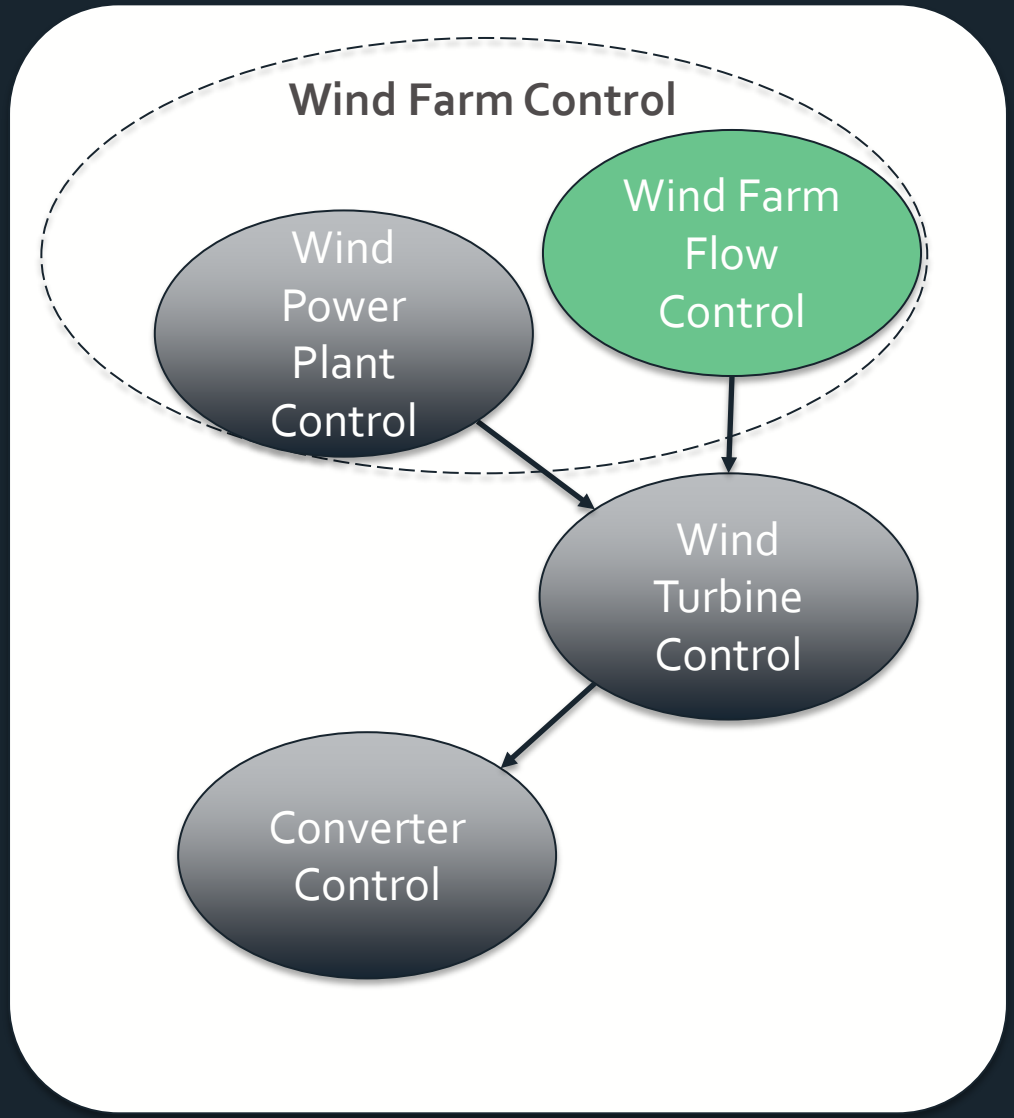


Wind Farm Flow Control

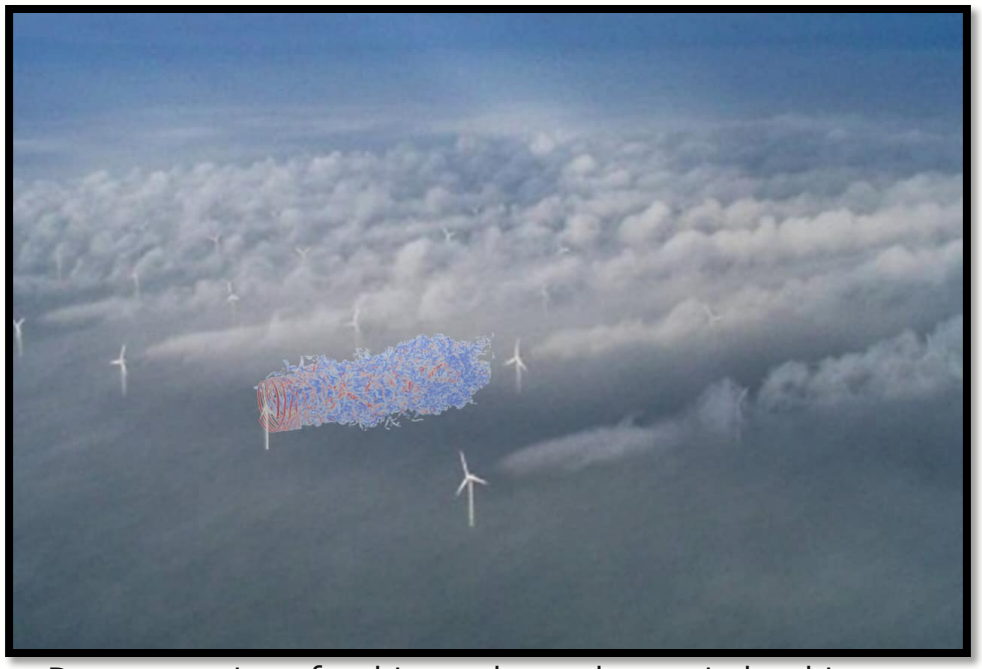


Wind Farm Flow Control (WFFC)

Coordinated control of individual turbines in a wind power plant to mitigate the impact of the interactions between individual turbines and wind flow. WFFC is used to maximise the overall wind farm power production or reduce structural loads. WFFC techniques include:

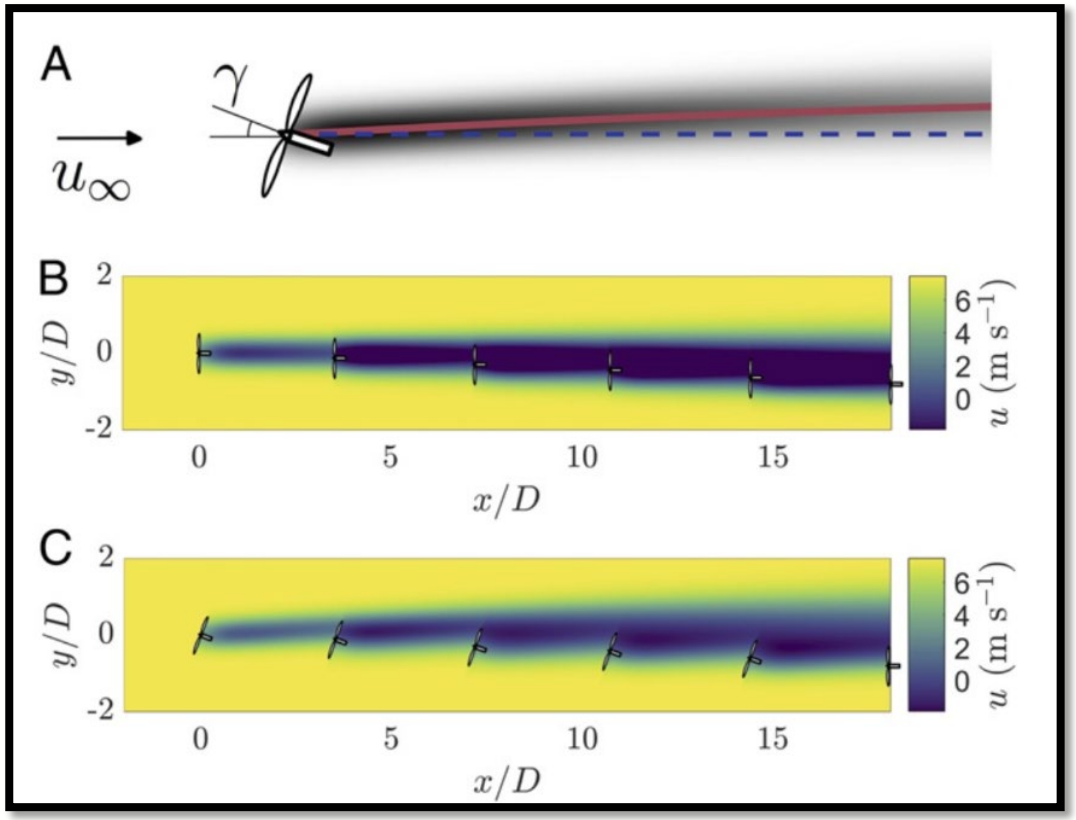
- Axial induction control
- Wake steering/redirection/deflection
- Wake mixing control
- Turbine repositioning

WFFC interacts with the WTC to achieve its control goals

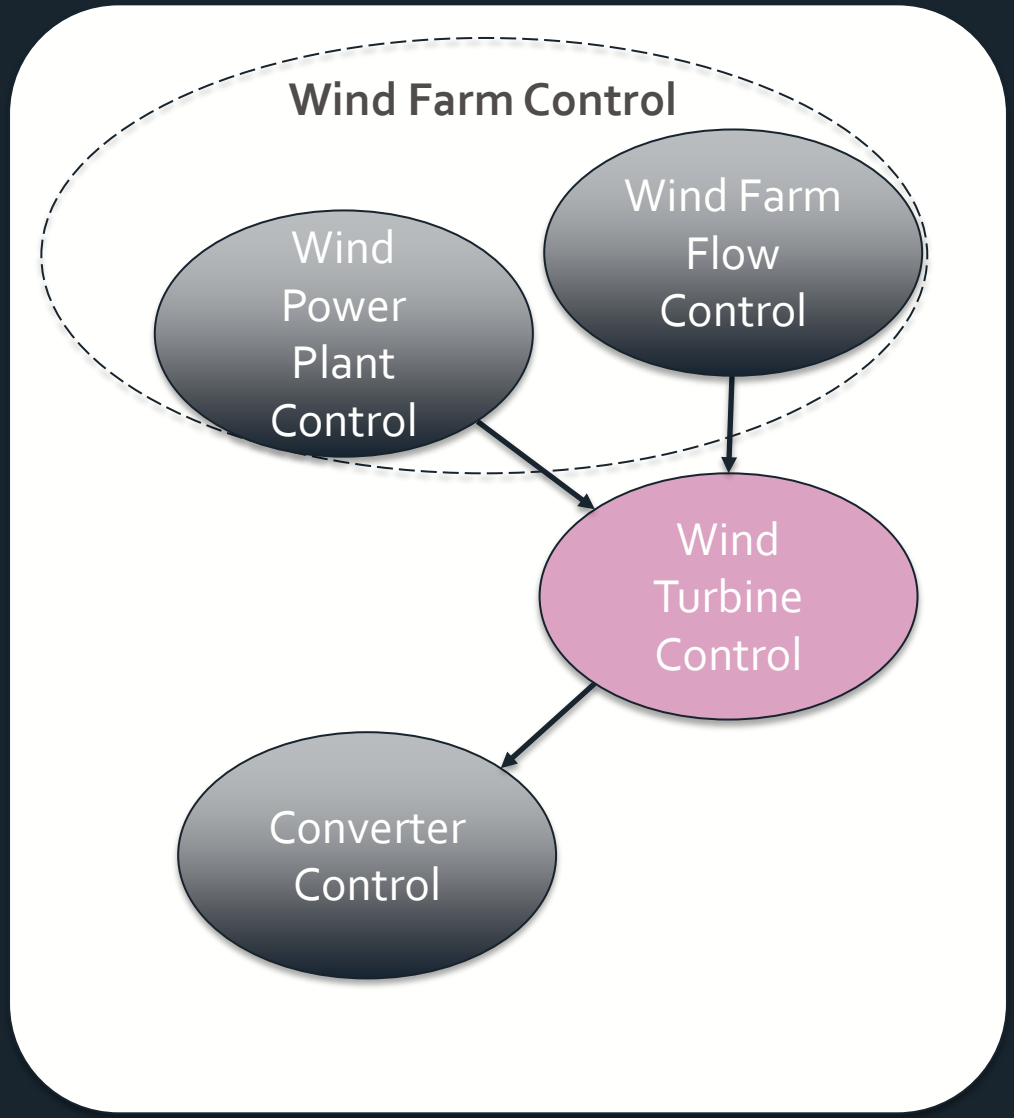


Demonstration of turbine wake on down wind turbines

Example of Wake steering



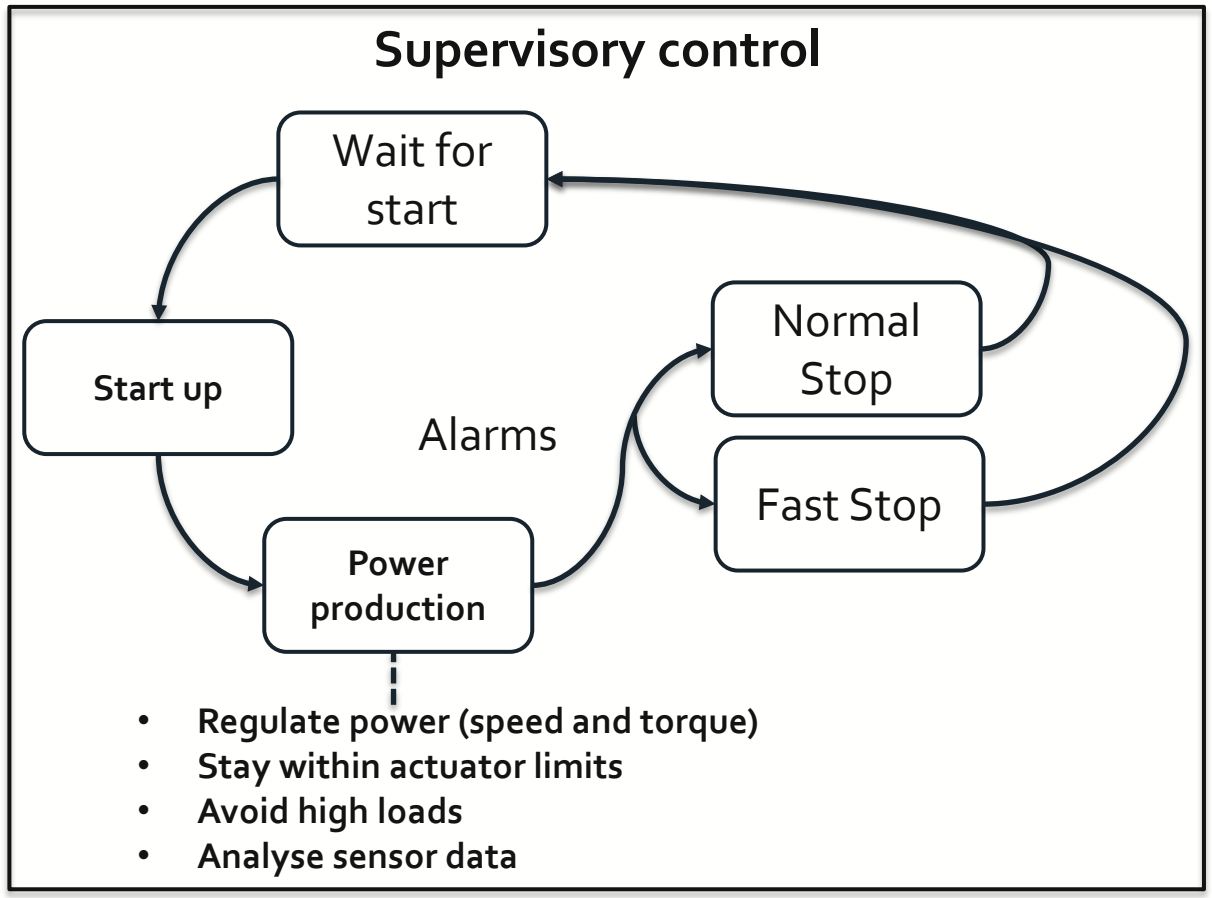
Wind Turbine Control

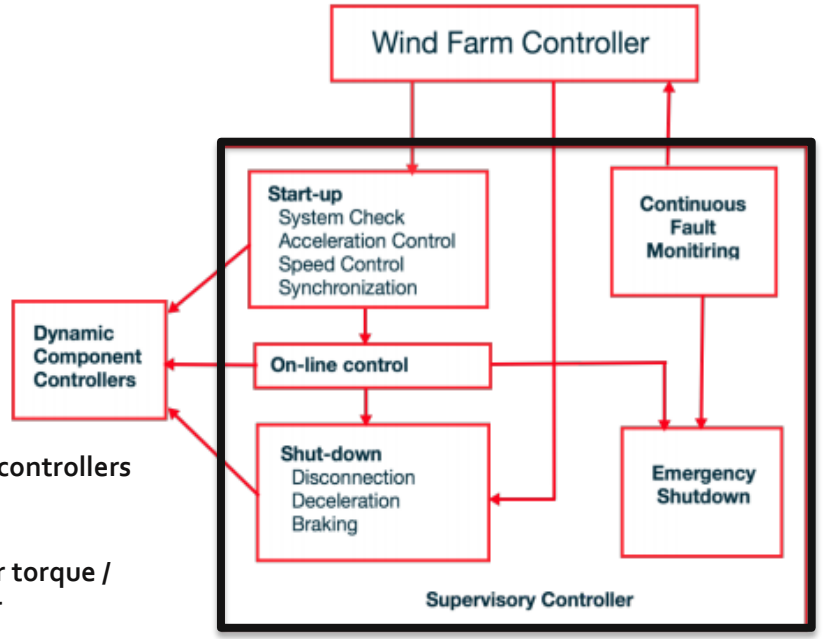


Wind Turbine Control (WTC)

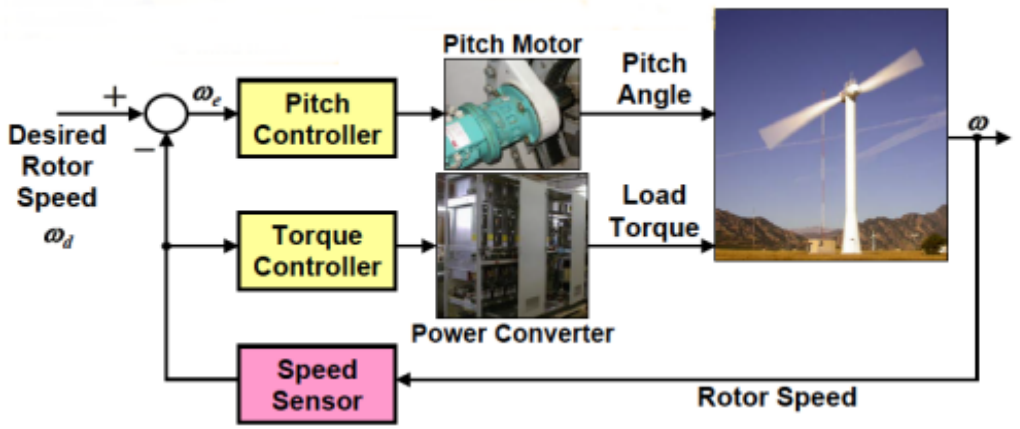
Wind turbine Supervisory controller is responsible for turbine's:

- **Energy capture**
- **Load reduction**
- **Safety and protection**
- **Other constraints: e.g. low noise operation**



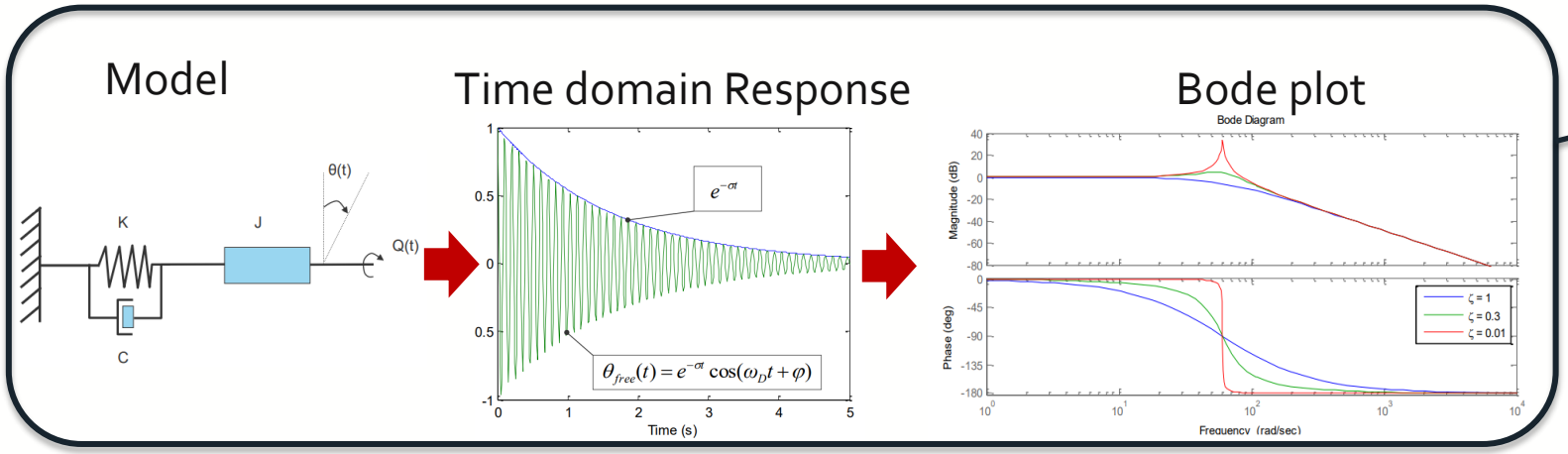


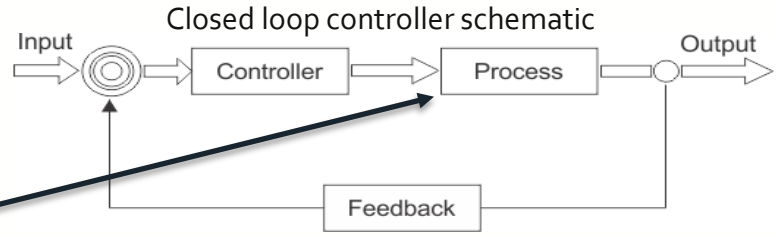
Sub-system controllers
- Pitch
- Yaw
- Generator torque /
- Converter
- etc



Load Reduction strategies

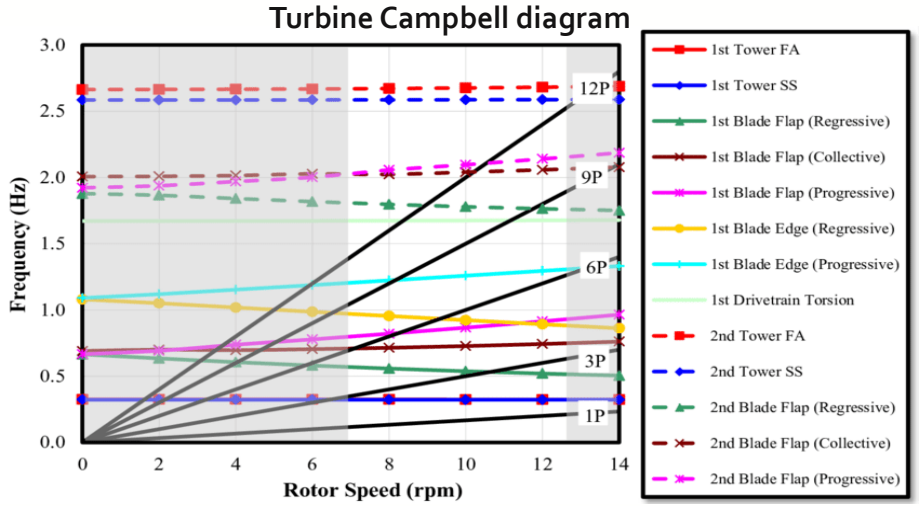
Controller is designed using a dynamic model which represents turbine behavior





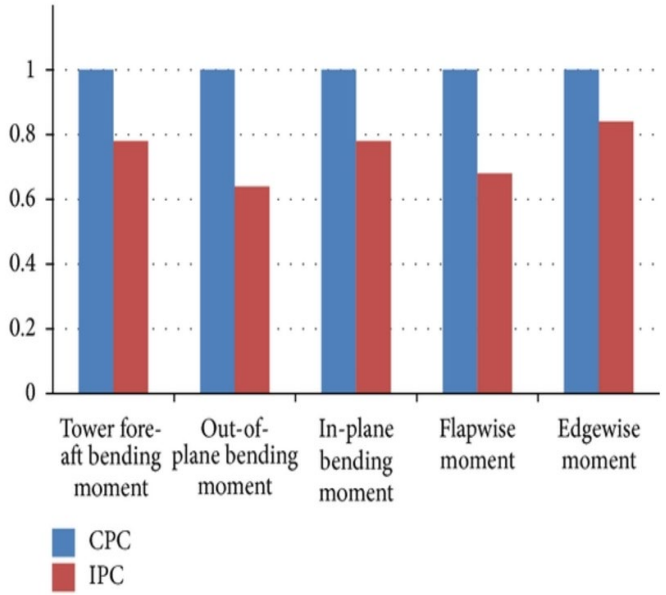
Resonance elimination

- Resonance occurs when turbine operational modes (Black lines) intersect component natural frequencies (coloured lines)
- Controller applies filters (e.g. Notch filter, low-pass filters) to eliminate resonance points by avoiding specific rotational speeds



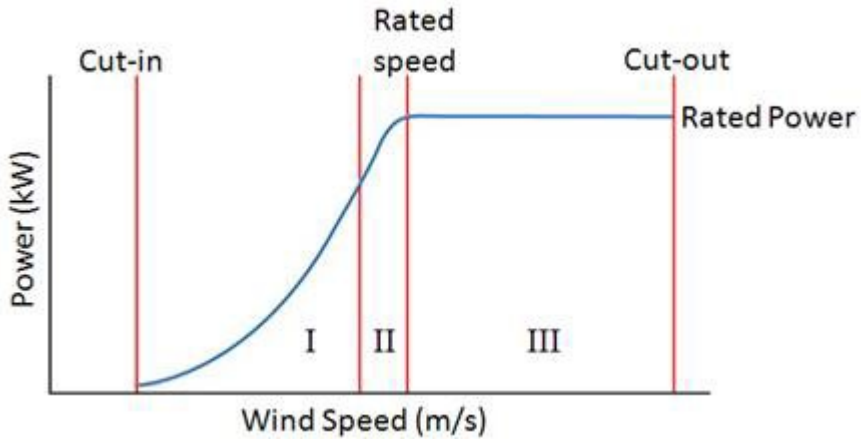
Structural load reduction

Modern Multi – Megawatt offshore wind turbines utilize Individual pitch control to reduce turbine structural loads



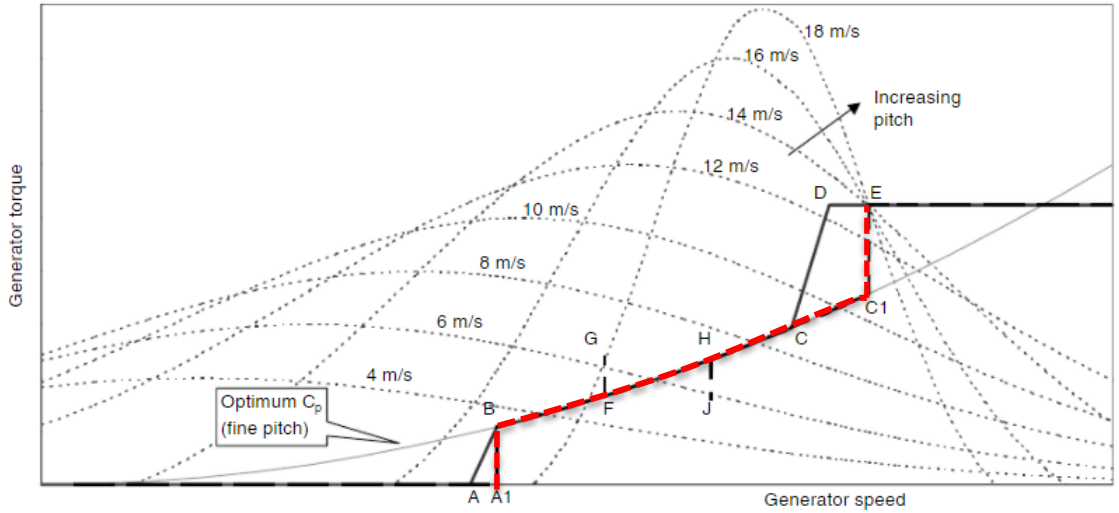
Power production control strategy

- **Seek the highest efficiency of operation that maximizes the coefficient of power, Cp**
- **Ensure safe operation under all wind conditions**
- **Controller algorithms**
  - **Proportional Integral Derivative (PID) controller (most popular)**
  - Advanced controllers
    - Fuzzy logic controller
    - Neural network Controller
    - LQG controller
    - Model predictive control (MPC)

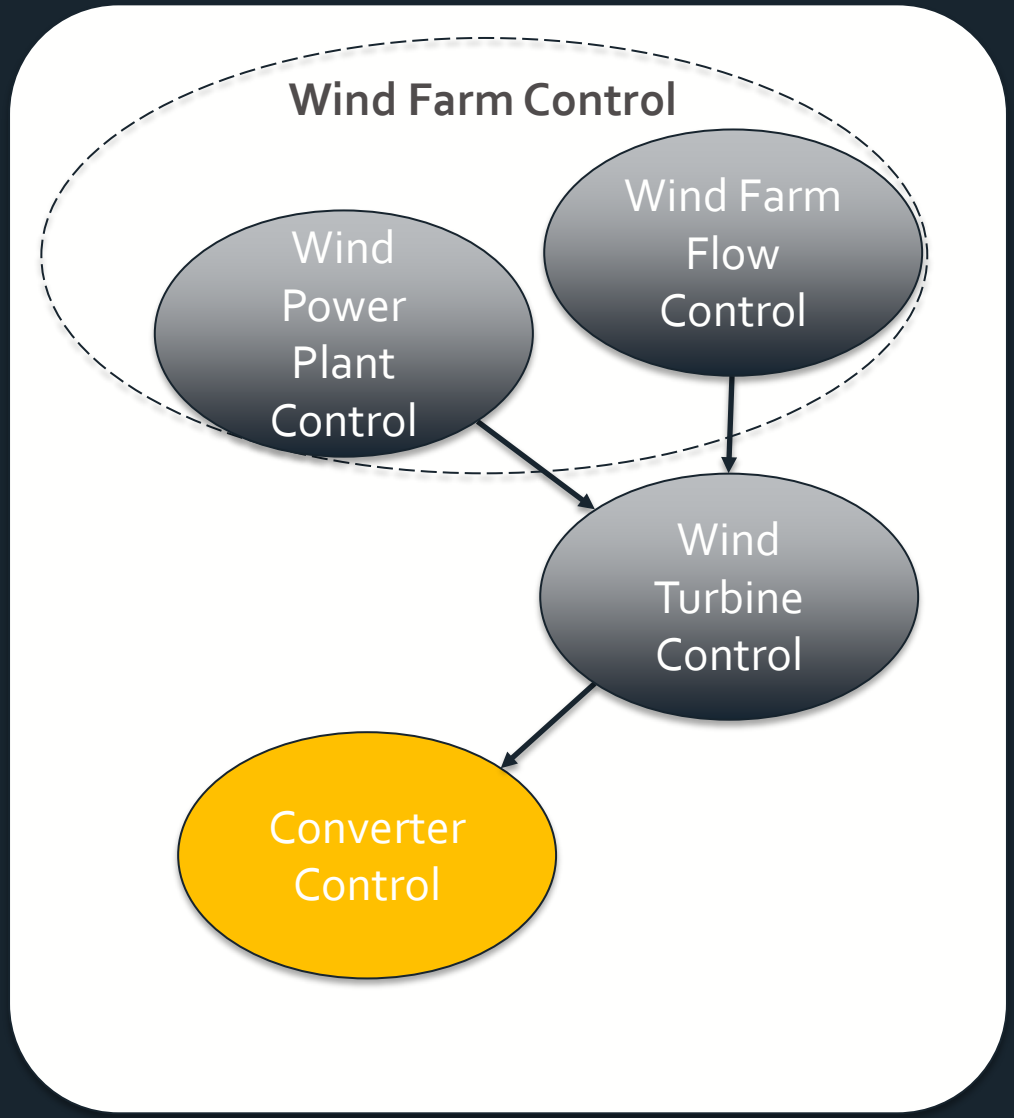


Wind turbine Power is controlled through :

- **Torque Control**
  - Generator torque control (Converter current)
- **Speed Control**
  - Aerodynamic Torque Control
    - Stall Regulation
    - Pitch regulation
  - Generator speed control (Converter voltage)



Converter Control



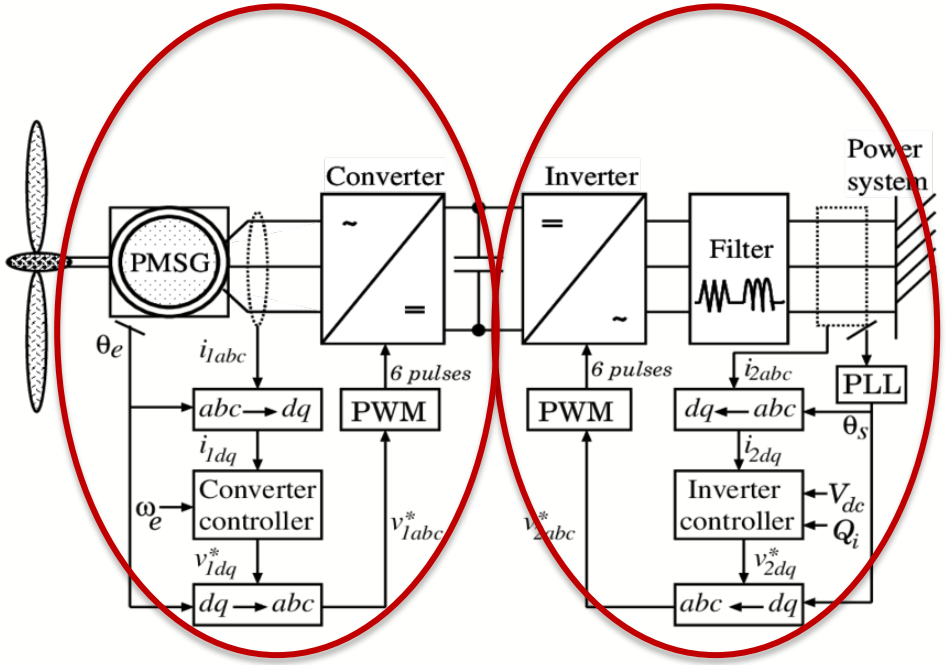
Converter Control

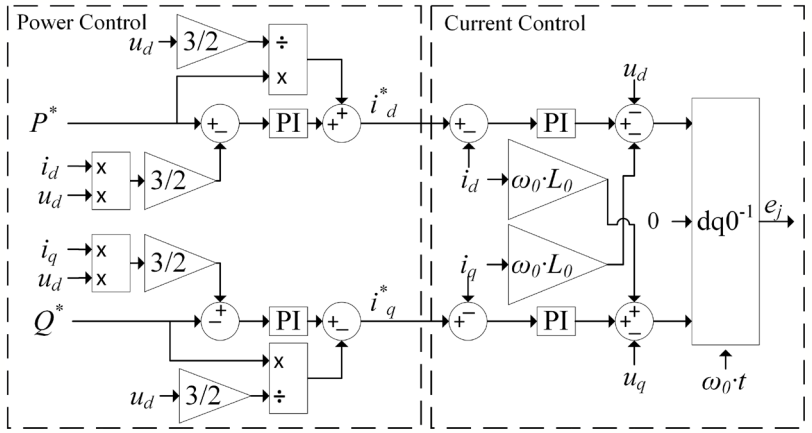
The modern offshore wind turbines have 2 power converters – the drive converter and the grid side converter.

The primary function of both converter controllers is to realise the outcome of the turbine control.

The converter control monitors the measurement point, performs a parks transform and compares this to the reference provided by the WTC. PI controllers then seek to minimise the error between the reference value and set point values

Drive Converter Grid Side Converter





Conclusion

- **Wind Farm Control (WFC)** is an umbrella term for **Wind Power Plant Control (WPPC)** and **Wind Farm Flow Control (WFFC)**
- **WPPC** has been around for some time and is responsible for ensuring the WPP complies to the grid code. In the coming years it will get more complicated as WPPs are requested to do more
- **WFFC** is newer and is responsible for maximising power output / load alleviation
- Both WFFC and WPPC feed signals to the individual **Wind Turbine Control (WTC)** which actually enacts the desired set points.
- **WTC** is also responsible for energy production, load reduction and safety of individual turbines. WTC is a supervisory control which interacts with sub-system controller such as the pitch or yaw controller.
- The **Converter Control** is responsible for realising the voltage and current (Real and Reactive Power) setpoints determined by the WTC

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