Hierarchy and complexity in control of large offshore wind power plant clusters

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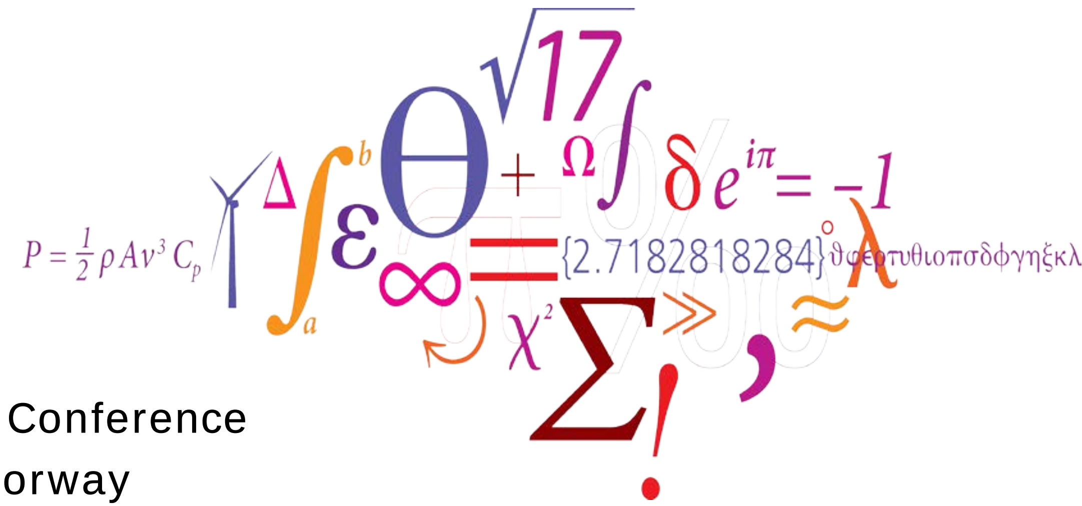

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Outline

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- What is a Cluster ?
  - Aim of a Cluster
- Control Hierarchies in an offshore Wind Power Plant (OWPP) cluster
- State-of-the-art literature in control of large OWPPs
- Control Architectures for large OWPP clusters
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- Summary

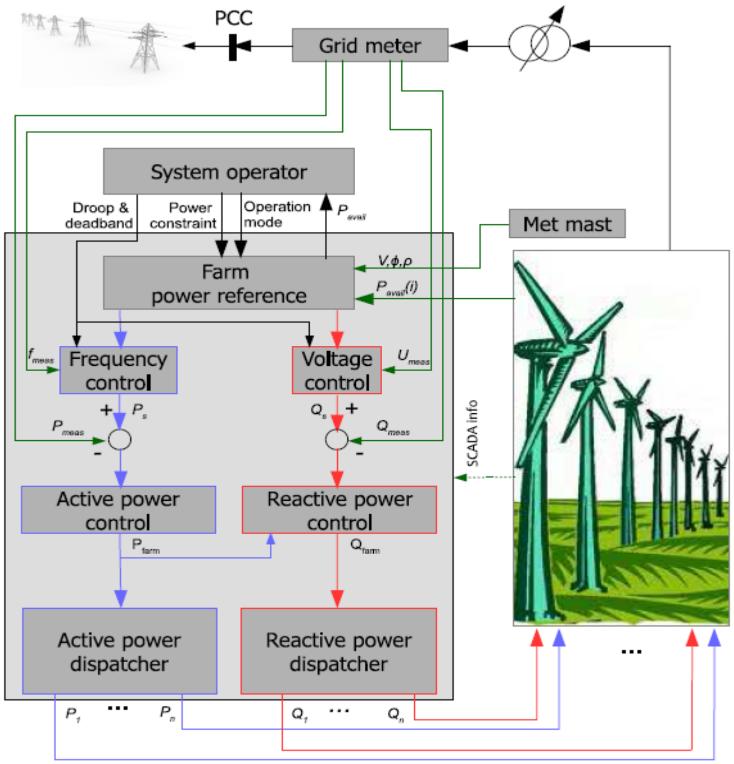
Control Objectives in WPPs

Wind Farm Active Power Control

- Maximize wind power extraction
- Gradient control, balance reserve, frequency control
- Minimize fatigue loads due to wakes

Frequency Control

- Provides primary frequency control by adding a P-demand component to the reference farm power, based on measured frequency
- It is in cascade with active power control



Wind Farm Reactive Power Control

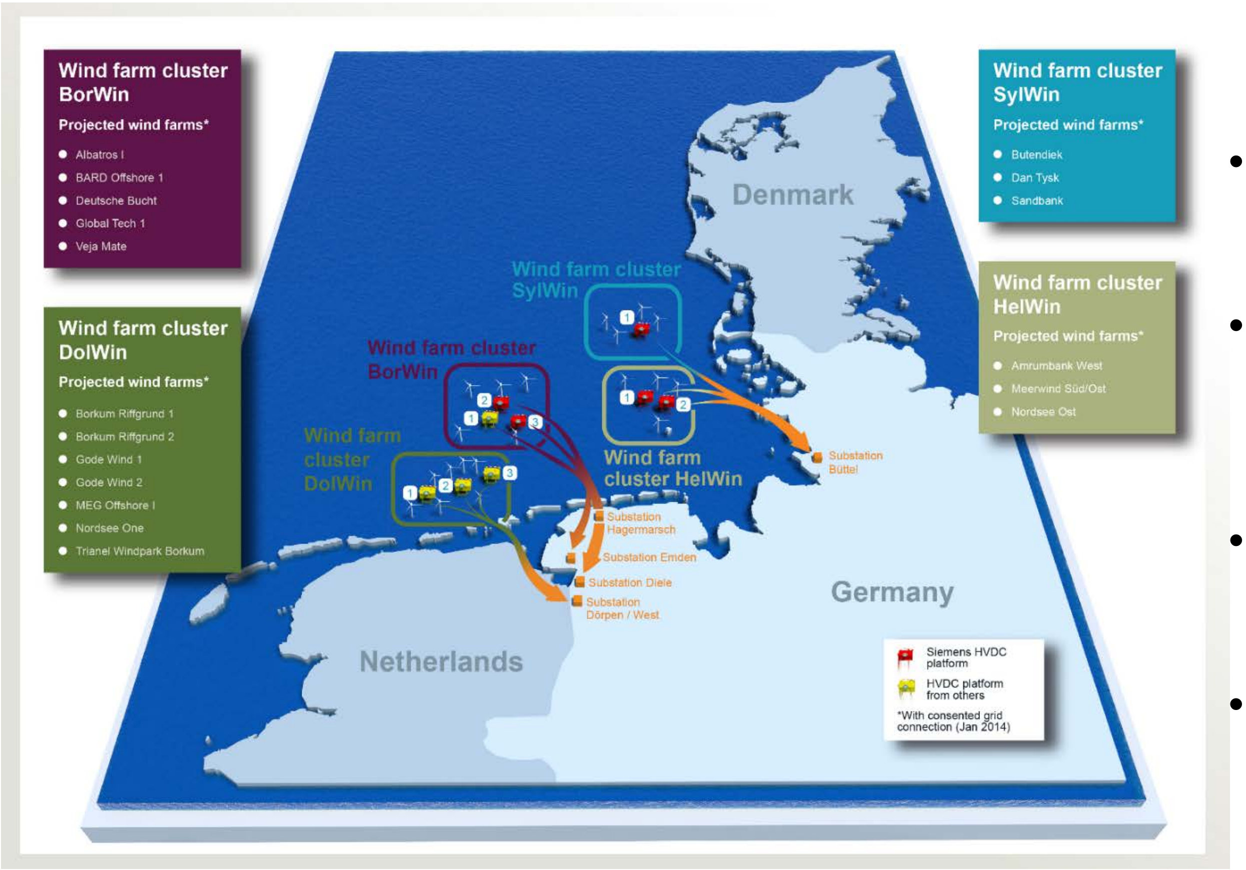
- Voltage regulation in the collection and transmission grid
- Improve power factor at the PCC
- Minimize losses and optimize transmission capacity

Voltage Control

- Voltage support to the operator by adding a Q-demand component to the reference farm power
- HVDC converter and tap changers also assist in voltage control

What is a Cluster ?

- Multiple WPPs existing in close proximity aggregated to form a 'Cluster'
- Individual WPPs could be owned by same or separate owners



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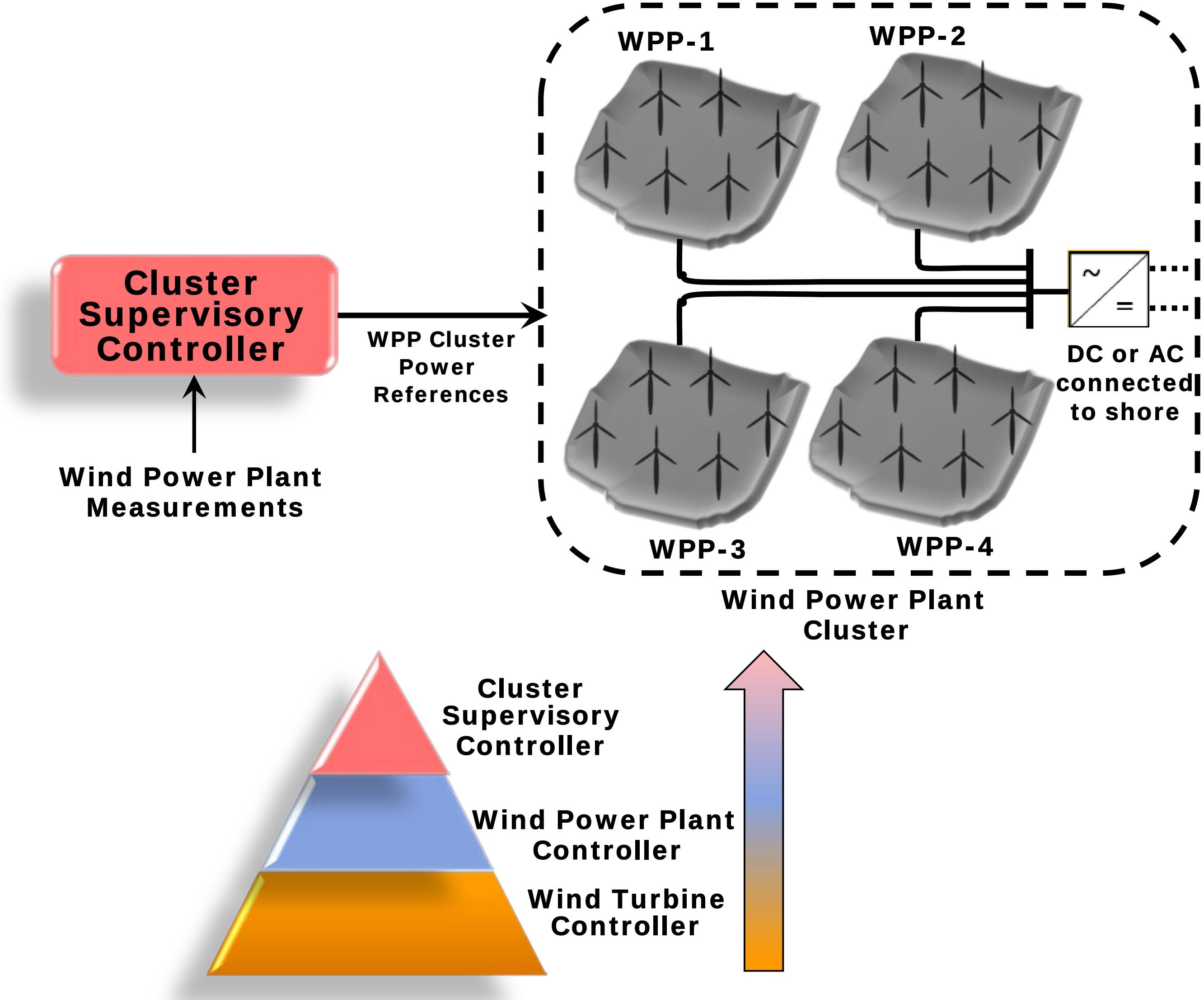
Aim of a Cluster ?

- Increased controllability to better fulfil the TSO requirements
- Sharing of electrical infrastructure (e.g., HVDC converter, export cable etc.)
- Increase the accuracy of wind power feed-in forecast
- Support the coordination between TSOs, dispatch centers, wind power producers and energy markets

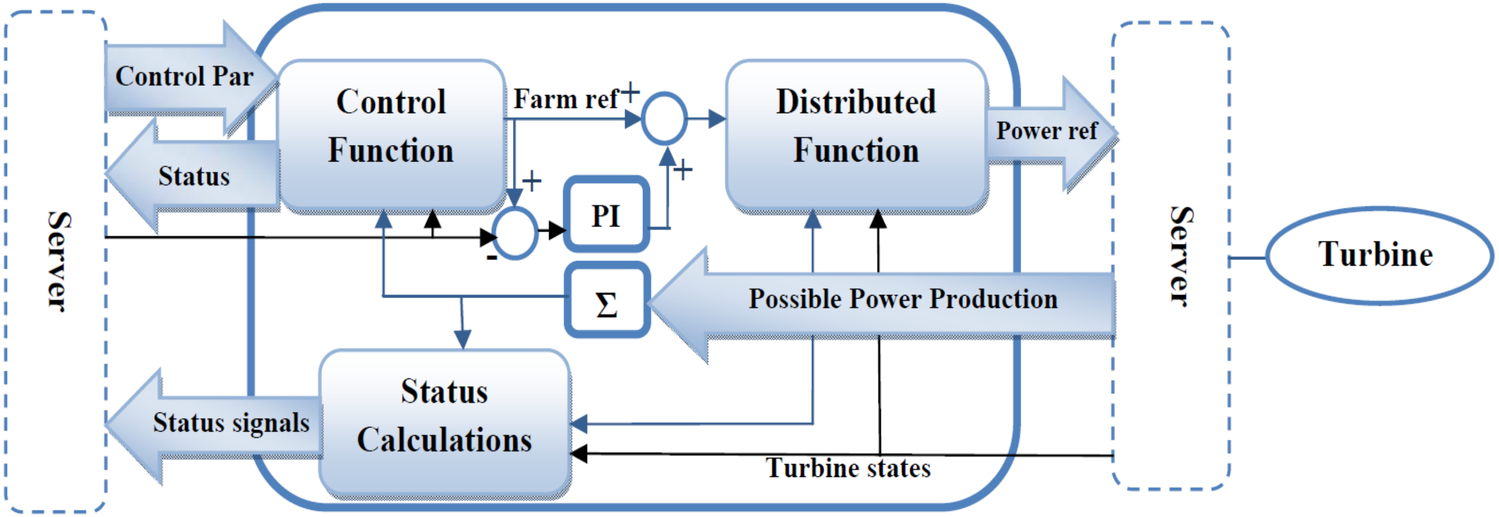
Control Hierarchies in a WPP cluster



Control Hierarchy

State-of-the-art literature in control of large OWPPs

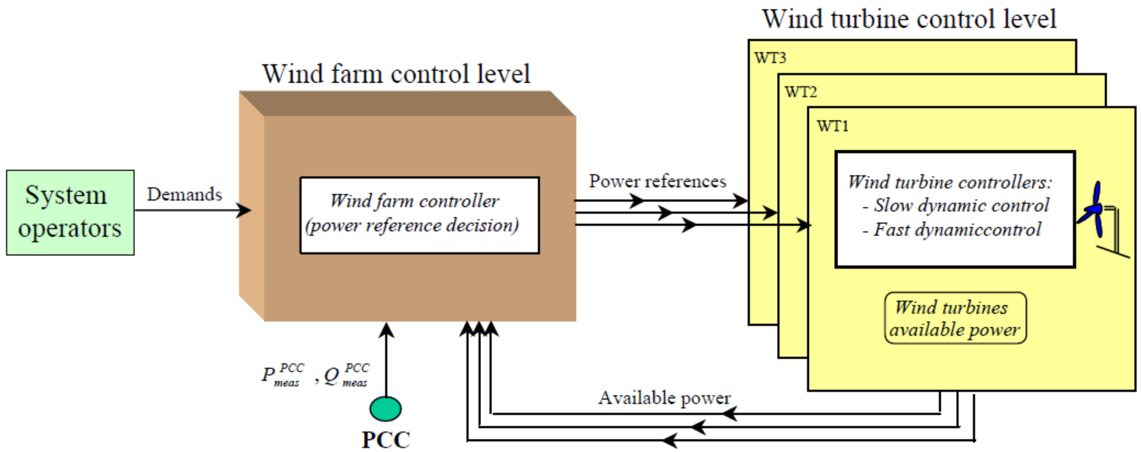
Horns Rev Wind Farm Controller

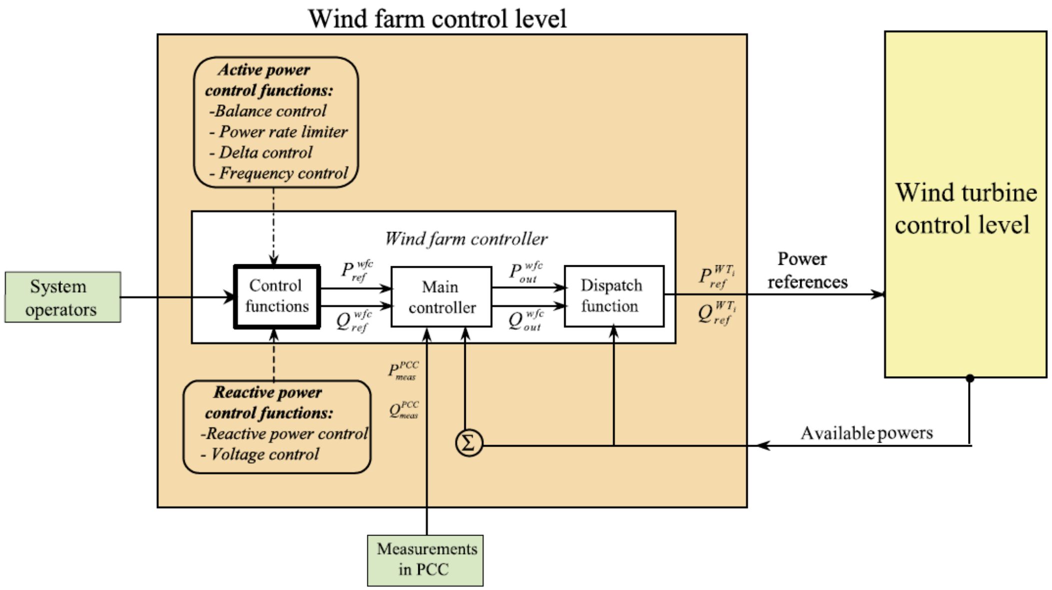


- Advanced Control functions providing power (both active and reactive) reference for the wind farm
- Distribution functions converting the farm level power reference to set points for the individual turbines
- PI controller to ensure correct power production

State-of-the-art literature in control of large OWPPs

Wind Farm Hierarchical Control System

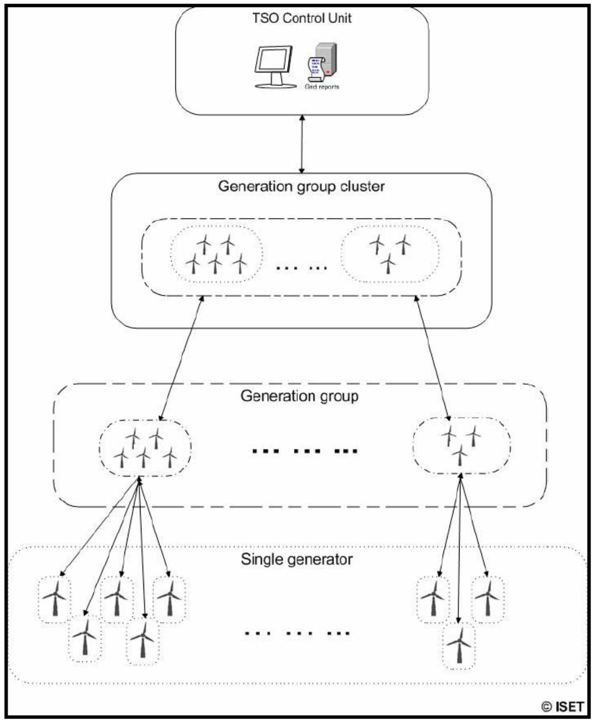


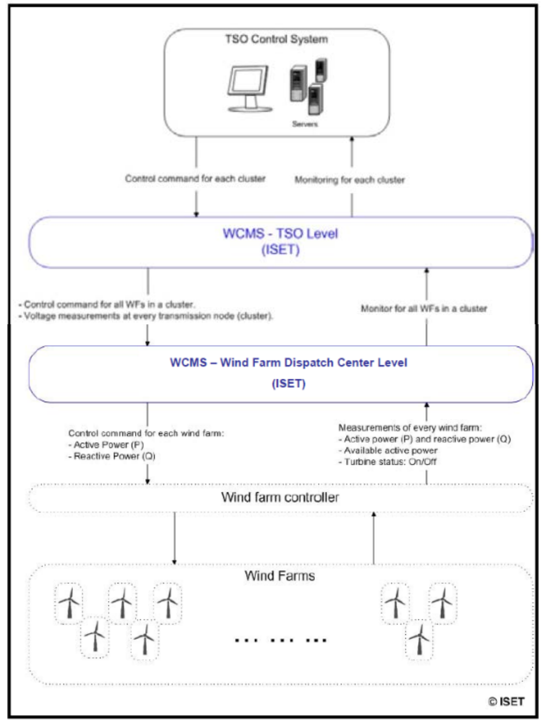


- A central WF controller to generate reference signals (active and reactive power) for each local WT controller
- Fault ride through capability is existing at the WT controller level rather than the WPP.
- The local WT controller is built-up with a hierarchical structure
- The WF control level consists of two control loops

State-of-the-art literature in control of large OWPPs

Wind Farm Cluster Management System



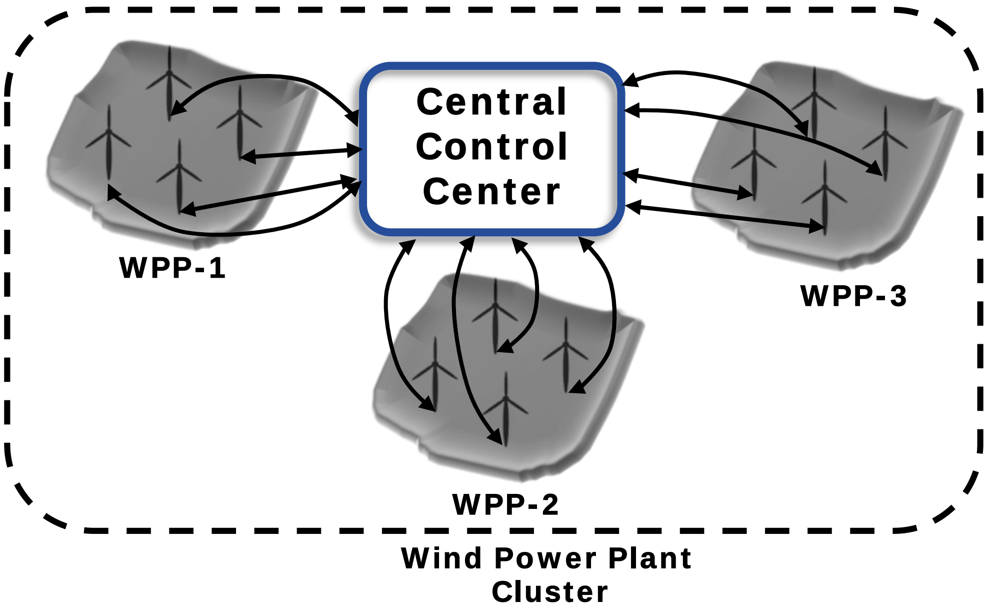


- WPPs are grouped in 'clusters' aggregated physically
- Controlled from an 'upper' level in the hierarchy
- WCMS makes use of WF control strategies and wind energy forecast technologies
- The architecture, consists of two layers, namely the 'TSO layer' and the 'dispatch layer'

Control Architectures for large OWPP clusters

Centralized Control

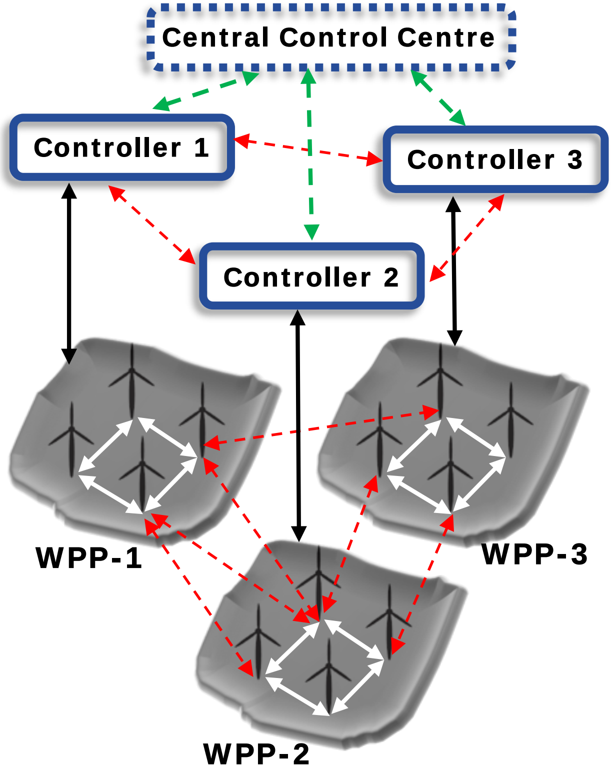
- All the information available about the system is centralized at one location.
- The controllers monitor and coordinate the operation of each turbine
- Challenge
  - Heavy computational burden to process the information
  - Vulnerable to loss or corruption and interruption of information



Control Architectures for large OWPP clusters

Distributed Control

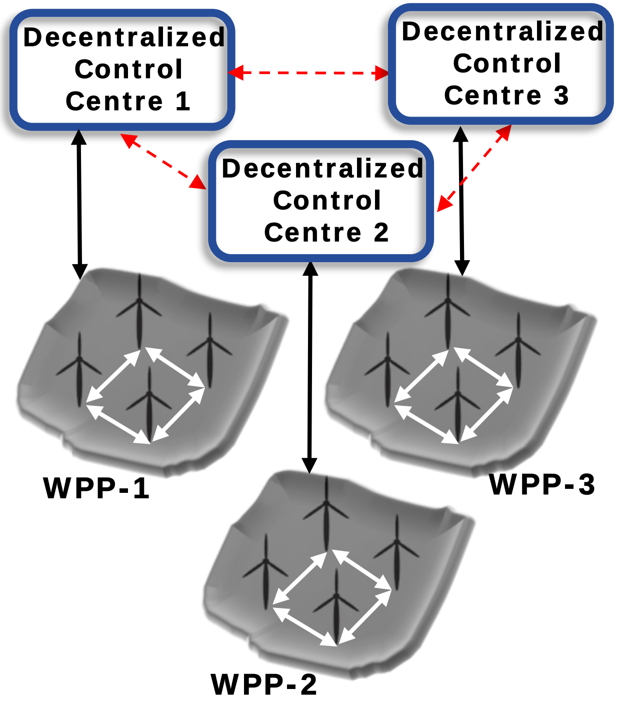
- The turbines talk to each other in order to agree on a global outcome
- Consists of a number of local controllers with capability of communication between them
- Data may be processed locally or remote-controlled by a central controller
- Improves cybersecurity and resilience of the network with respect to failure
- Challenges
  - Proper design of a distributed algorithm
  - Reliability of the communication network
  - Coordination of the agents to achieve the desired power regulation



Control Architectures for large OWPP clusters

Decentralized Control

- Overall plant is controlled by several independent controllers
- Local regulators are designed to operate in an independent fashion
- Information could be shared between the local decentralized control centres
- Challenge
  - Strong interactions between regulators can even prevent one from achieving stability



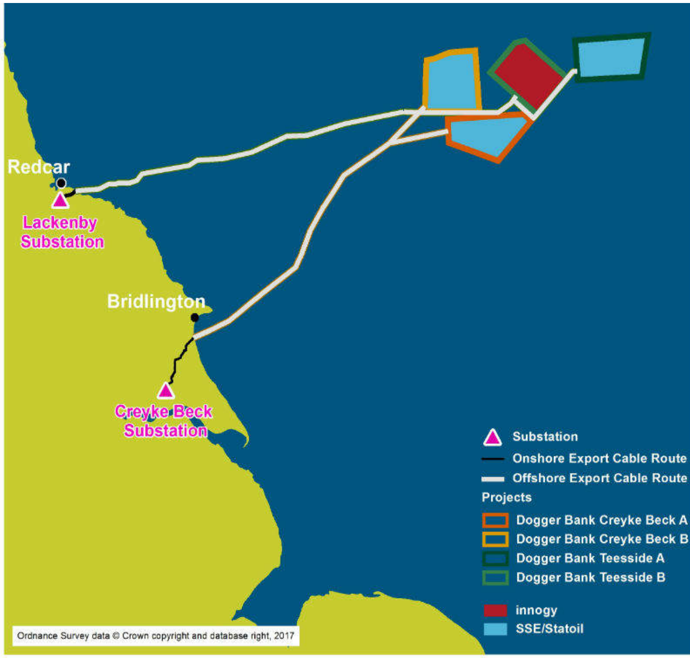
Control complexities in large offshore WPP clusters

- **Control Coordination**
- **Communication Requirements**
- **Control during transients**
- **Assets owned by different operators**

Case Study: Dogger Bank

Communication Requirements

Mode of Communication							
Case 1		**Case 2**		**Case 3**		**Case 4**	
Serial – 120 WTs *Parallel – 4 WPPs*		*Serial – 480 WTs* *Parallel – 0*		*Parallel – 120 WTs* *Serial – 4 WPPs*		*Parallel – 480 WTs* *Serial – 0*	
Action	*Delay (ms)*	*Action*	*Delay (ms)*	*Action*	*Delay (ms)*	*Action*	*Delay (ms)*
Send to WT1 Read Inverter1	500	Send to WT1 Read Inverter1	500	Send to WPP1 Read WPP1	500	Send to WT1 Read Inverter1	500
Send to WT2 Read Inverter2	1000	Send to WT2 Read Inverter2	1000	Send to WPP2 Read WPP2	1000	Send to WT2 Read Inverter2	500
……. …….	….. …..	……. …….	….. …..	……. …….	….. …..	……. …….	….. …..
Send to WT120 Read Inverter120	$6*10^4$	Send to WT480 Read Inverter480	24*10 4	Send to WPP4 Read WPP4	2000	Send to WT480 Read Inverter480	500



- For big OWPP clusters with large number of assets, the cumulative delays can be high
- The delays will increase if more signals are required to be transmitted for every WT
- Delays like measurement filter delay, scada computation delay etc., can further make the response of the system slower

Summary

- Sharing of responsibility can make the system more resilient and reduce the high computational demand
- Distributed control approaches offer the capability to distribute the computational burden
- With the existing industrial practises and communication standards the delays can reach very high values for large OWPP clusters with hundreds of assets
- Appropriate techniques must be implemented in the controller to solve the communication delay related issues.

Thank you

Questions & Discussions

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