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

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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
  - Centralized
  - Distributed
  - Decentralized
- Control complexities
- Case Study: Dogger Bank
- 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

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

- Cluster Supervisory Controller
- Wind Power Plant Measurements

Wind Turbine

WPP Cluster Power References

WPP-1, WPP-2, WPP-3, WPP-4

Wind Power Plant Cluster

DC or AC connected to shore

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

<table>
<thead>
<tr>
<th>Mode of Communication</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
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</thead>
<tbody>
<tr>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
</tr>
<tr>
<td>Serial – 120 WTs</td>
<td>500</td>
<td>Serial – 480 WTs</td>
<td>500</td>
<td>Serial – 120 WTs</td>
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<tr>
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<td>Parallel – 0</td>
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<td>Parallel – 4 WPPs</td>
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<tr>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
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<td>Send to WT1</td>
<td>500</td>
<td>Send to WT1</td>
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<tr>
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<td>Read Inverter1</td>
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<td>Read Inverter1</td>
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<tr>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
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<tr>
<td>Send to WT2</td>
<td>1000</td>
<td>Send to WT2</td>
<td>1000</td>
<td>Send to WT2</td>
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<tr>
<td>Read Inverter2</td>
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<td>Read Inverter2</td>
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<td>Read Inverter2</td>
</tr>
<tr>
<td>Action</td>
<td>Delay (ms)</td>
<td>Action</td>
<td>Delay (ms)</td>
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<tr>
<td>Action</td>
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<td>Action</td>
<td>Delay (ms)</td>
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</tr>
<tr>
<td>Send to WT120</td>
<td>6*10^4</td>
<td>Send to WT480</td>
<td>24*10^4</td>
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<tr>
<td>Read Inverter120</td>
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<td>Read Inverter480</td>
<td></td>
<td>Read Inverter480</td>
</tr>
</tbody>
</table>

- 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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