Cluster Control of Offshore Wind Power Plants Connected to a Common HVDC Station

Ömer Göksu¹, Jayachandra N. Sakamuri¹, C. Andrea Rapp², Poul Sørensen¹, Kamran Sharifabadi³
¹DTU Wind Energy, ²Halvorsen Power System AS, ³Statoil ASA

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DTU Wind Energy
Department of Wind Energy
Outline

• Offshore Wind Power Plant (WPP) Clusters
• Generic benchmark layout with 3 WPPs
• ENTSO-E Generator and HVDC requirements
• IEC 61400-27 Wind Turbine and WPP control models

• Offshore AC Grid Voltage Control
  – **Problem:** Uncontrolled reactive power flow between WPPs and HVDC
  – **Proposal:** Droop control at each WPP

• Power Oscillation Damping (POD) with the Offshore WPP Cluster
  – **Problem:** Unsynchronized active power from the WPPs
  – **Proposal:** Coordinated closed loop cluster regulator at the HVDC

• Conclusion
Cluster connected WPPs to common HVDC examples from the North Sea

Clusters due to distance between the WPPs, combination of different WT models, WT / HVDC manufacturers
Cluster connected WPPs to common HVDC: a generic benchmark layout with individual WPP controllers.

Cluster with individual WPP controllers (plus offshore cluster controller); promising for future installations at the North Sea and UK.

In this study, operation of WPP OLTC and shunt reactors are omitted to observe pure converter response.
ENTSO-E Grid Code Requirements

Network Code on Requirements for Grid Connection Applicable to all Generators (NC-RfG)

Final Draft: June 2015

Network code on requirements for grid connection of HVDC systems and DC-connected power park modules (NC-HVDC)

Final Draft: October 2015

Offshore AC Grid Voltage Control by HVDC station
(WPPs are considered to contribute to voltage control)

POD by HVDC stations
(DC-connected WPPs may potentially contribute to POD)
IEC 61400-27-1 Wind Turbine Models

- RMS models for dynamic response of
  - Type 1, Type 2, Type 3, and Type 4A/B (with full/partial chopper)
- Being validated by wind turbine manufacturers (IEC working group)

- Local fast voltage control at WT terminals
- Active power control (deloaded operation)
- Fault ride-through functions

Type 4B is utilized in this study
Voltage control with droop compensation ($K_{q\text{droop}}$)

$$V_{\text{WPPref-compensated}} = V_{\text{WPPref}} - Q_{\text{WPPactual}} \cdot K_{q\text{droop}}$$

WPP voltage reference is modified with the actual $Q$ of the WPP
Offshore AC Grid Voltage Control: via Local Voltage Control by the WPPs

**Problem:** Uncontrolled reactive power flow between WPPs and HVDC
HVDC injects & WPPs absorb $Q \rightarrow$ Increase of losses

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e.g.
The $Q$ flow is as above for 0 to 0.75pu
$P$ generation from WPPs
(equal $P$ generation is assumed for WPPs)
Equal Sharing of Reactive Power between Converters – via droop

**Proposal:** Droop control at the WPPs (tuning is based on load flow analysis)

![Graphs showing Q-dispatch for different Kdroop values.](image)

From HVDC&A to B&C

From A&B&C to HVDC

Harmonized behaviour!
POD at the onshore by active power: Active power modulation by the OWPPs

Oscillation is sensed by the onshore HVDC
Required P modulation signal is sent to offshore HVDC

Question: How to realize P modulation by the WPP cluster? Open loop or closed loop?
POD at the onshore by active power: Active power modulation by the OWPPs

Open loop dispatch:
Comm. Delay and WPP dynamics are compensated

But compensation is imperfect with mismatch!!

Closed loop cluster control:
Regulation based on total P feedback at the HVDC

Dispatch based on WPPs P generation feedback
**POD at the onshore grid by active power:**
Closed loop cluster regulator at the Off-HVDC

**Problem:** Uncoordinated open loop P references to the WPPs
→ unsynchronized response from the WPPs → Ineffective POD !!

**Proposal:** Closed loop regulation and weighted dispatch to the WPPs
→ synchronized response from the WPPs → Effective POD !!

The closed loop cluster controller can realize the reference to a great extent!
Conclusion

- IEC 61400-27-1 models can be utilized in DC-connected offshore WPP studies

- Offshore AC Grid Voltage Control
  - Droop sharing between WPPs helps to improve reactive power flow
  - Better utilized converter capacities

- POD can be potentially provided by closed loop cluster control
  - Coordination helps to mitigate communication sourced insufficiencies

- DC-connected offshore WPPs can contribute to ancillary services
  - Cluster controller is needed for effective support

- Future work;
  - Voltage control settings optimization based on active power losses
  - Adaptive control design for POD cluster controller
  - Frequency support with cluster controller
References


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Jayachandra N. Sakamuri, DTU Wind Energy, RISØ, jays@dtu.dk

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