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

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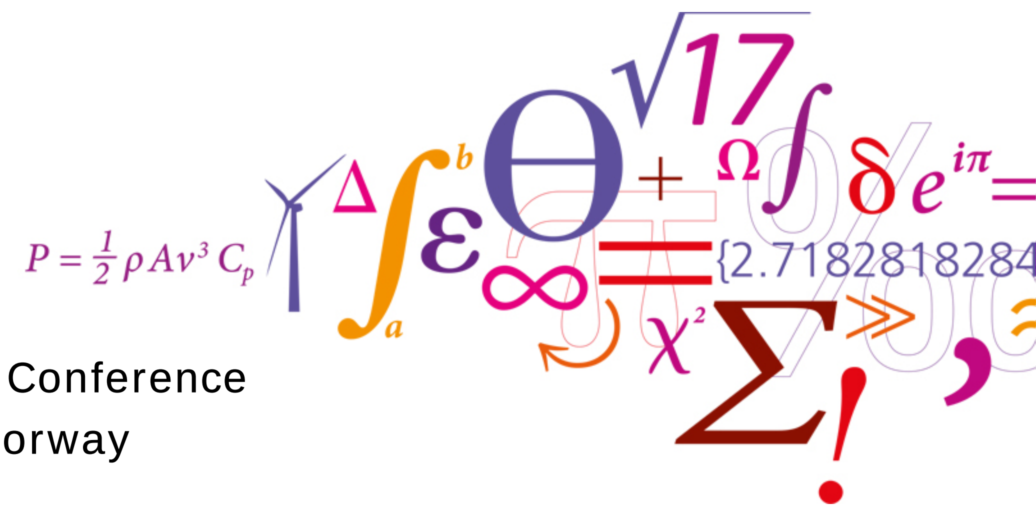


EERA DeepWind'2016
13th Deep Sea Offshore Wind R&D Conference
20-22 January 2016, Trondheim, Norway

DTU Wind Energy
Department of Wind Energy

Outline

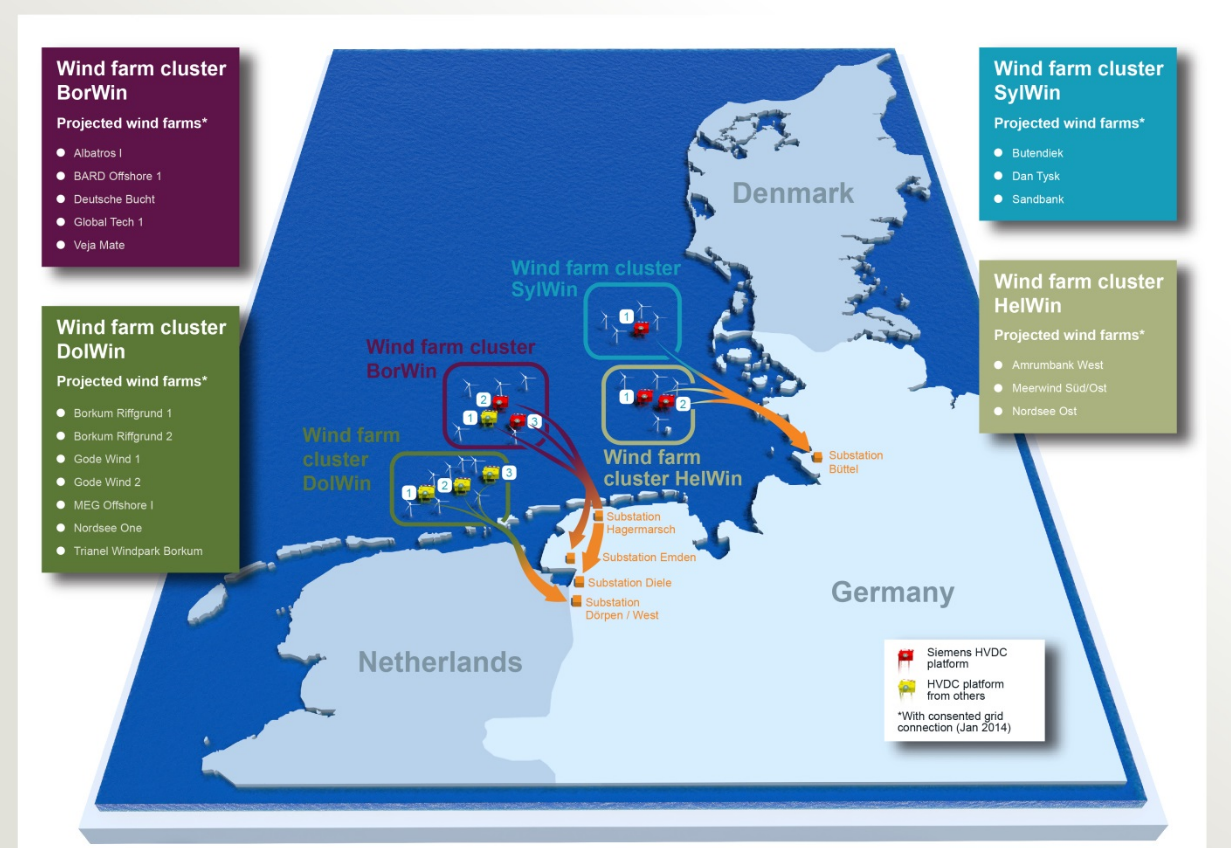
- Offshore Wind Power Plant (WPP) Clusters
- Generic benchmark layout with 3 WPPs
- ENTSO-E Generator and HVDC requirements
- IEC 61400-27 Wind Turbine and WPP control models

- 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

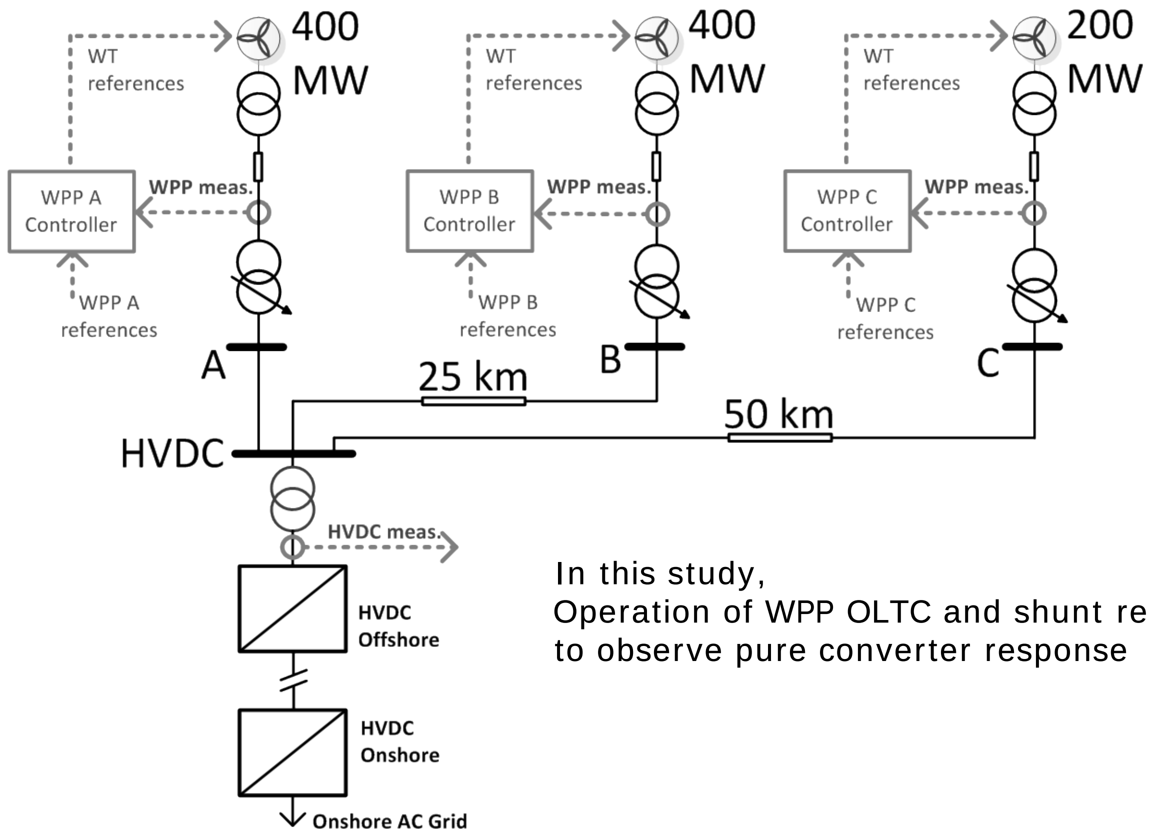
Cluster connected WPPs to common HVDC examples from the North Sea



[http://www.siemens.com/press/pool/de/pressebilder/2013/photonews/300dpi/PN201312/PN201312-10e_300dpi.jpg]

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



In this study,
Operation of WPP OLTC and shunt reactors are omitted to observe pure converter response

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

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

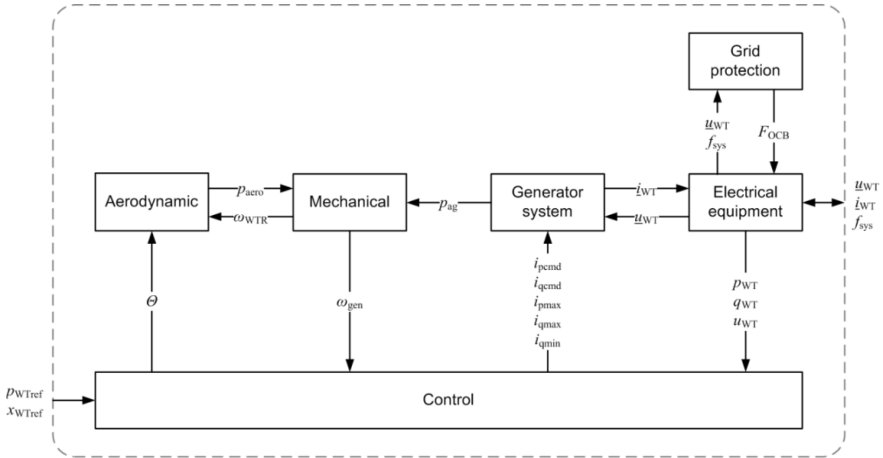
Offshore AC Grid Voltage Control by HVDC station
(WPPs are considered to contribute to voltage control)

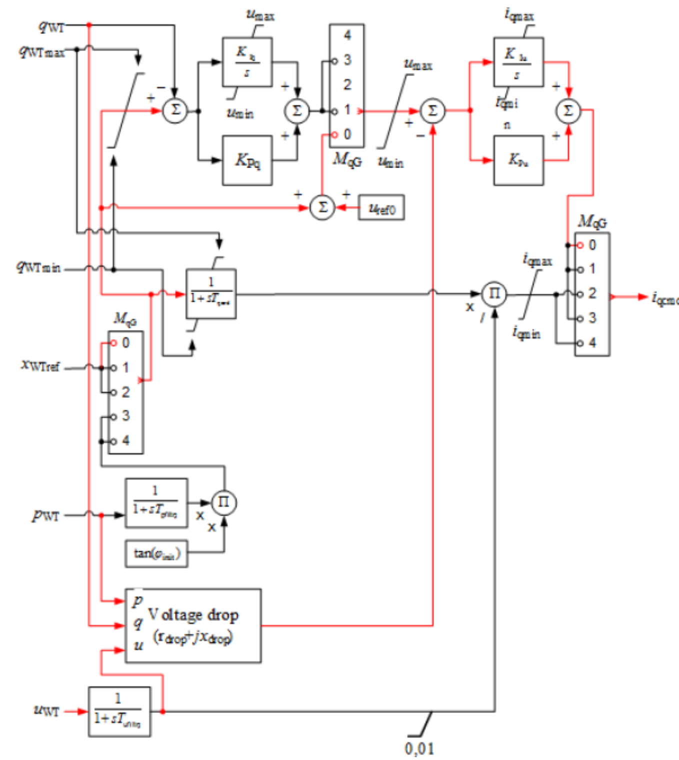
POD by HVDC stations
(DC-connected WPPs may potentially contribute to POD)

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)





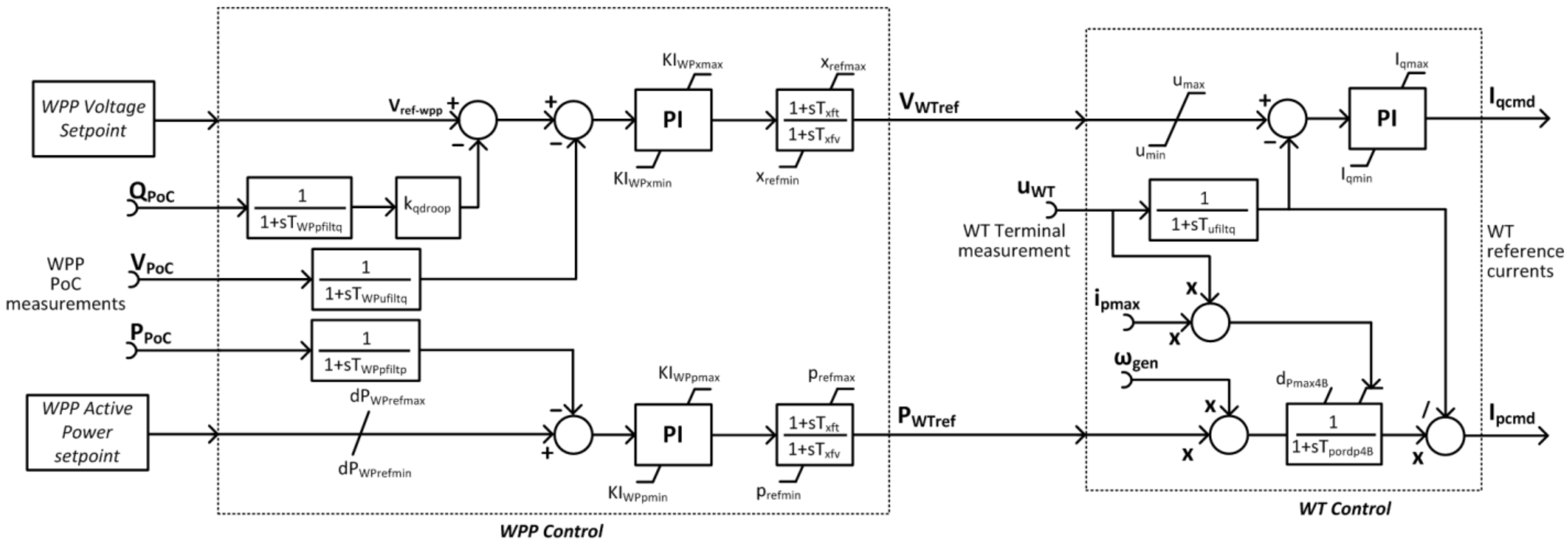
- Local fast voltage control at WT terminals
- Active power control (deloaded operation)
- Fault ride-through functions

Type 4B is utilized in this study

IEC Wind Power Plant Voltage Control

<u>Reactive Power Options:</u> Power factor / **voltage** / reactive power / U(Q) Static control

WPP closed loop active power control (deloaded operation)



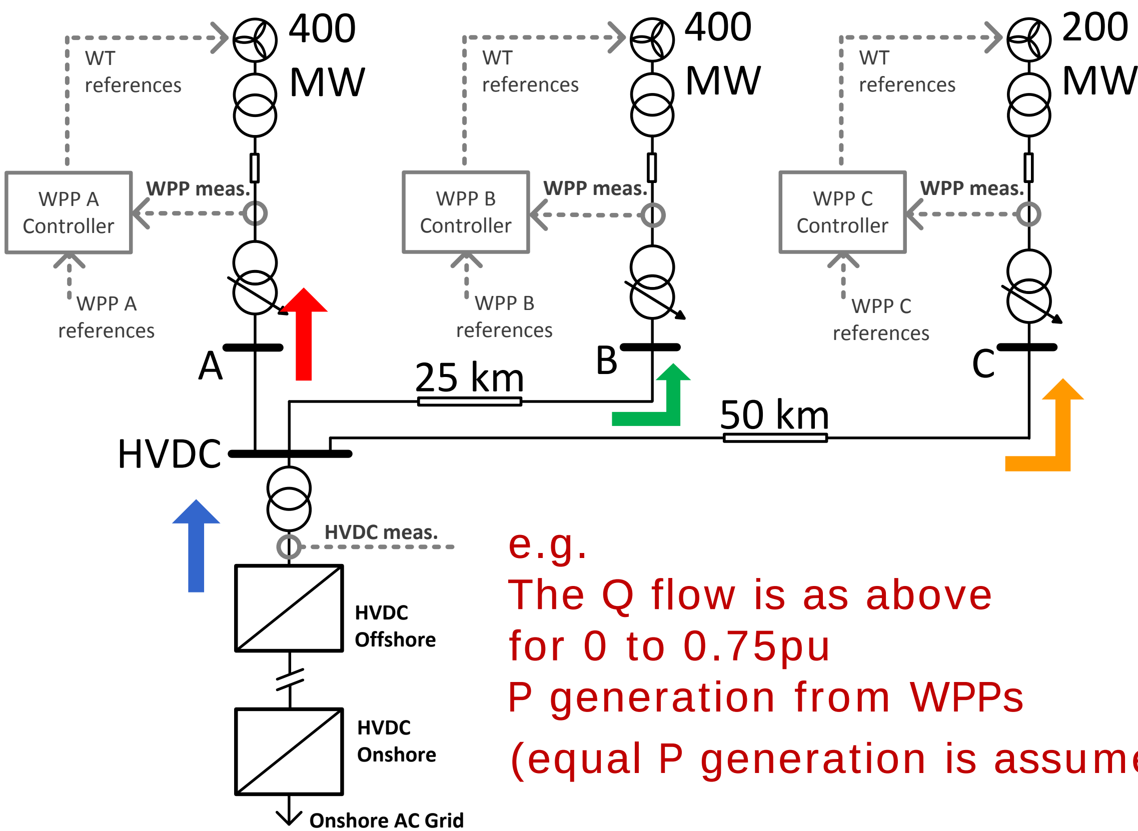
Voltage control with droop compensation (K_{qdroop})

$$V_{WPPref-compensated} = V_{WPPref} - Q_{WPPactual} \cdot K_{qdroop}$$

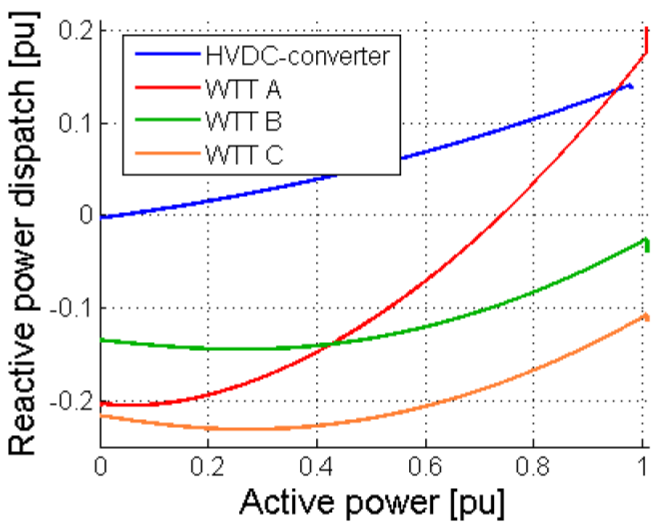
WPP voltage reference is modified with the actual Q of the WPP

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 → Increase of losses

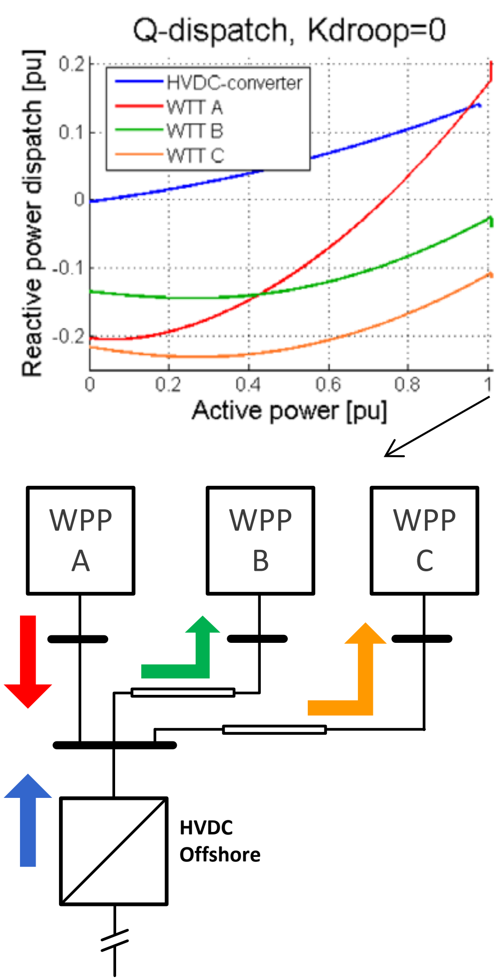


e.g.
The Q flow is as above
for 0 to 0.75pu
P generation from WPPs
(equal P generation is assumed for WPPs)

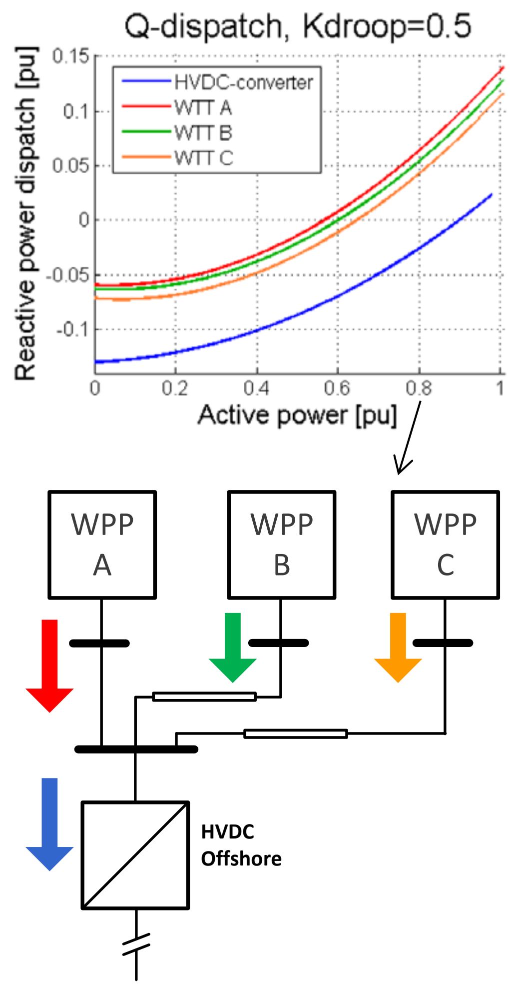


Equal Sharing of Reactive Power between Converters – via droop

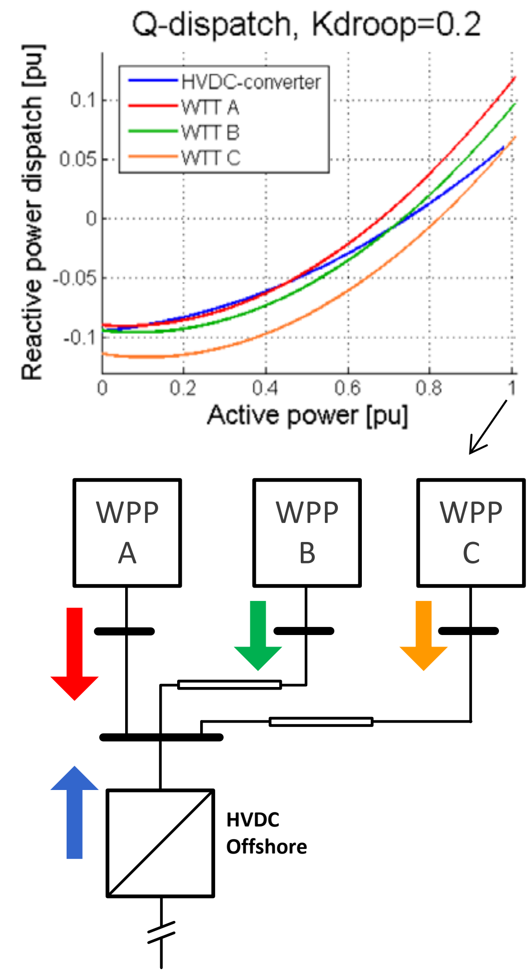
Proposal: Droop control at the WPPs (tuning is based on load flow analysis)



From HVDC&A to B&C



From A&B&C to HVDC



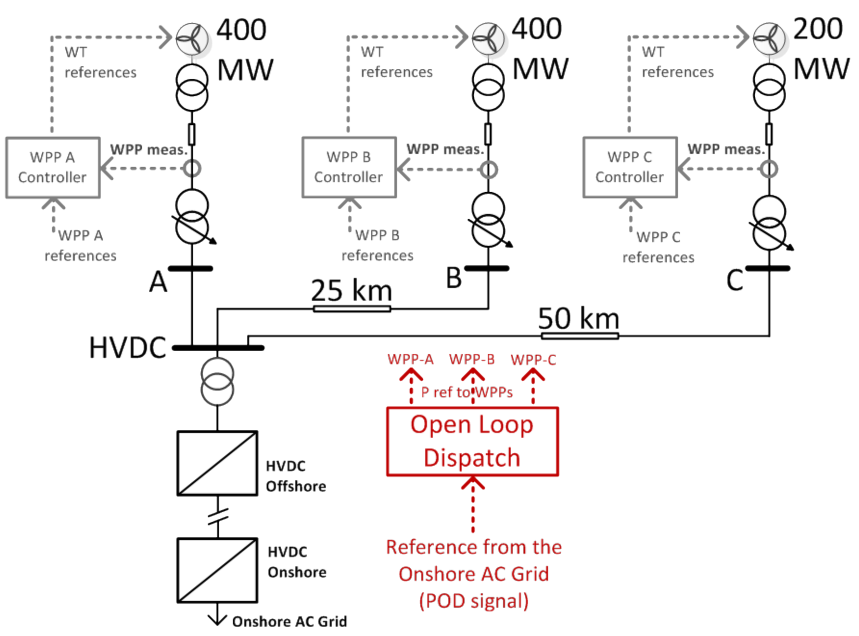
Harmonized behaviour !

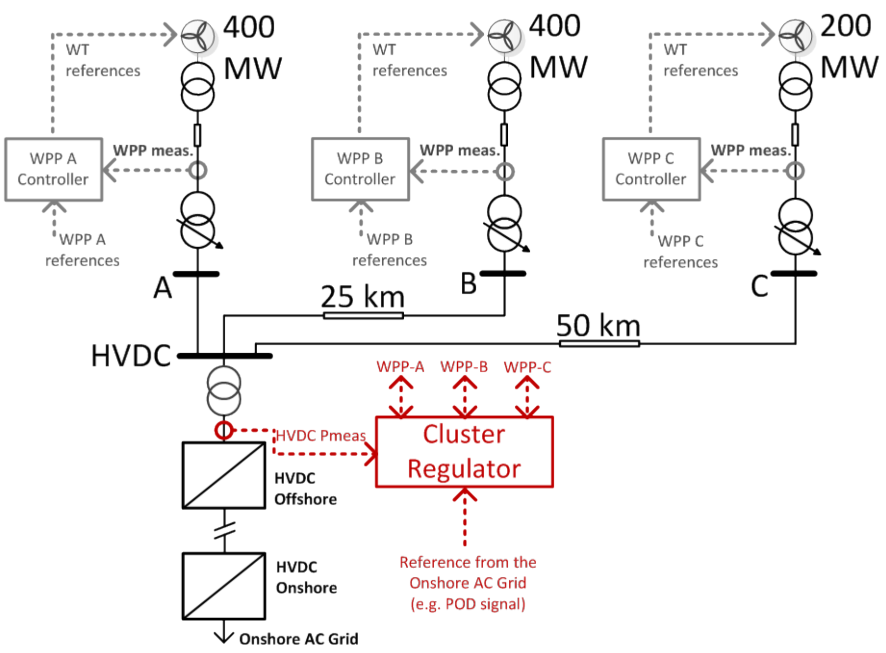
POD at the onshore by active power: Active power modulation by the OWPPs

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?



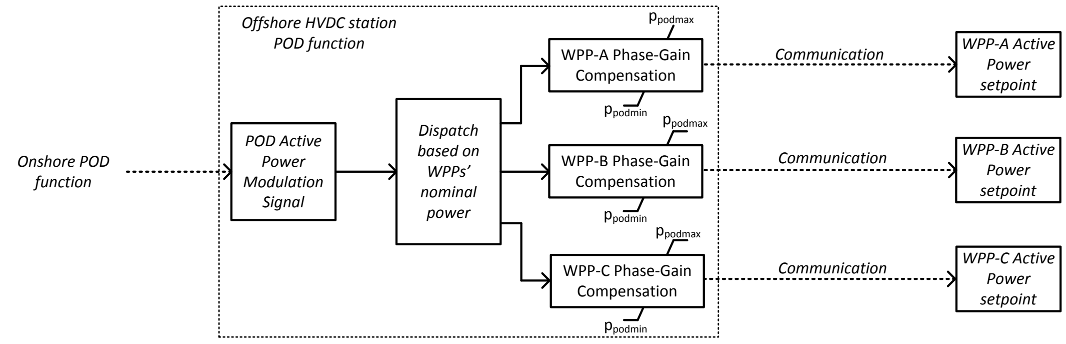


POD at the onshore by active power: Active power modulation by the OWPPs

Open loop dispatch:

Comm. Delay and WPP dynamics are compensated

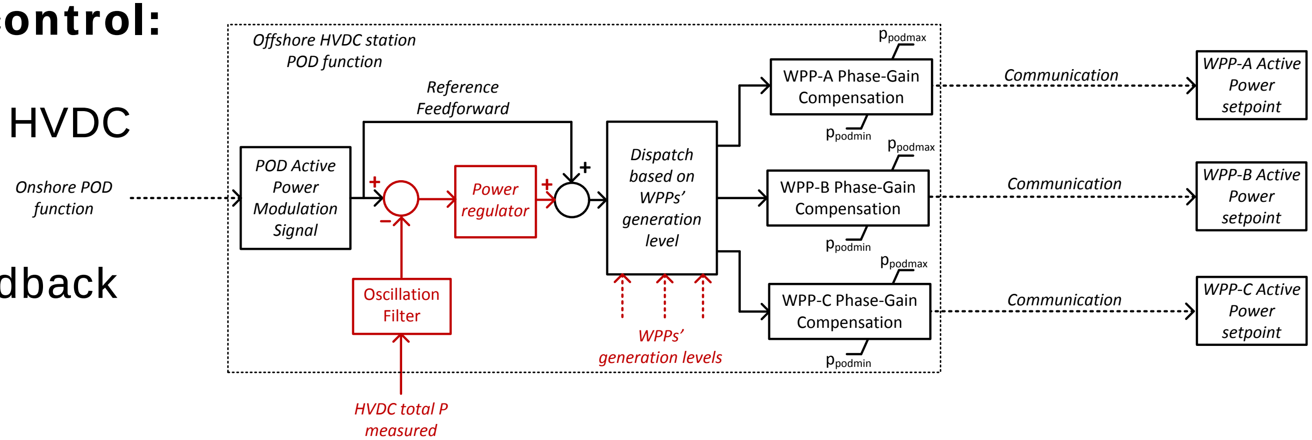
But compensation is imperfect with mismatch!!



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

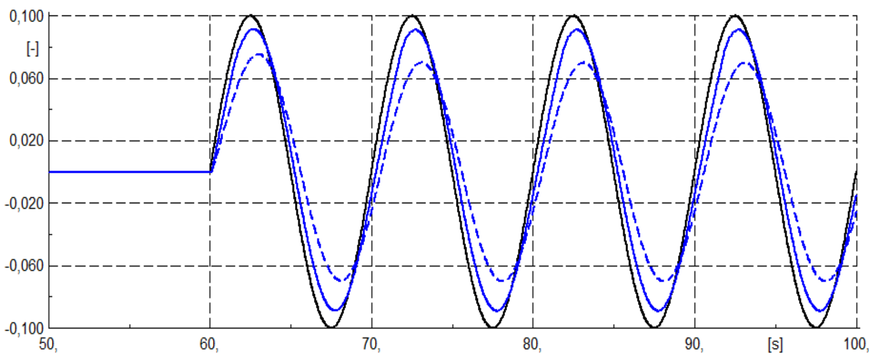
Problem: Uncoordinated open loop P references to the WPPs
→ unsynchronized response from the WPPs → Ineffective POD !!

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

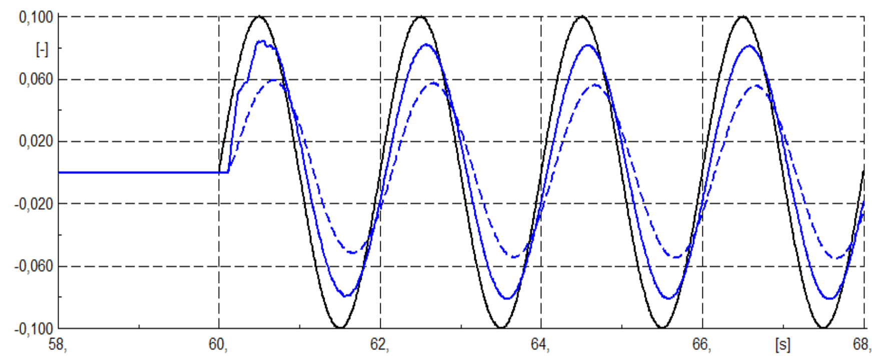
P reference to the Off-HVDC

Off-HVDC measured P with open loop dispatch

Off-HVDC measured P with closed loop cluster control



0.1 Hz P modulation



0.5 Hz P modulation

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

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THANKS !

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This work was supported in part by People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement no. 317221, project title MEDOW.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of Statoil ASA or Halvorsen Power System AS.