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Reducing Rapid Wind Farm Power Fluctuations Using the Modular Multilevel Converter

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Outcomes of the paper

Objective

- *To Develop a tool to smooth the rapid power fluctuations of wind farms with MMC.*

Problem description

Offshore wind farms integration

Problem description

There are three power fluctuations types that are linked with the wind variability:

1. Long-term $\longrightarrow$ seasonal variations.
2. Short-term $\longrightarrow$ time scale of minutes to few hours.
3. Rapid changes $\longrightarrow$ fast variations (wind gusts, tower shadow, ...).

Problem description

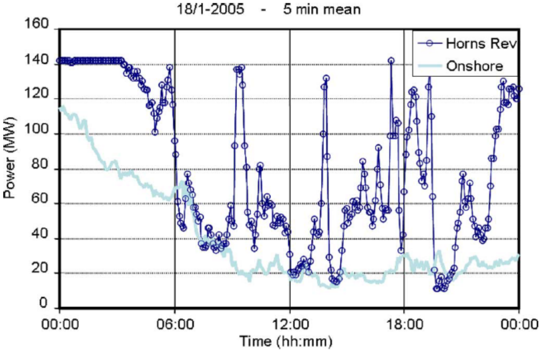


Fig. 1. Power generation of Horns Rev offshore wind farm and onshore wind turbines on January 18, 2005.

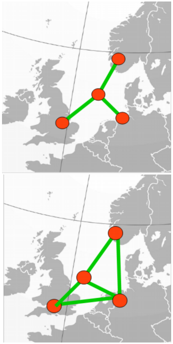
P. Sorensen et. al., Power fluctuations from large wind farms, IEEE Trans. on Power Systems, vol 22, no. 3, 2007

Problem description

Since short-term and rapid changes are difficult to predict, energy storage solutions are being proposed to smooth the variations out.

Problem description

Multiterminal HVDC grid for wind farms integration.



Network Topologies North Sea MTDC

- Radial
- Mesh or Ring

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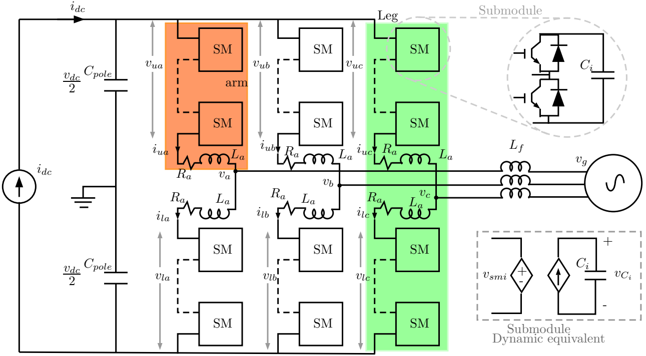
Capability of an MMC to store energy (W)



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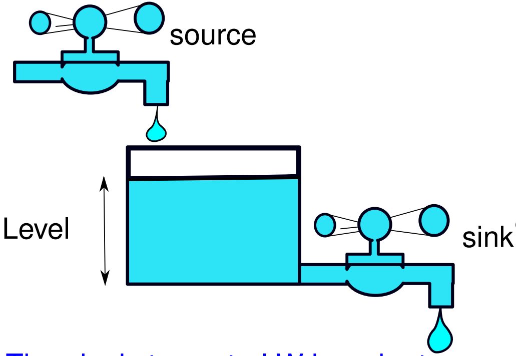
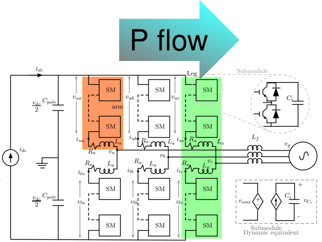
The aim is to control W in order to smooth the fast power fluctuation.

Capability of an MMC to store energy (W)





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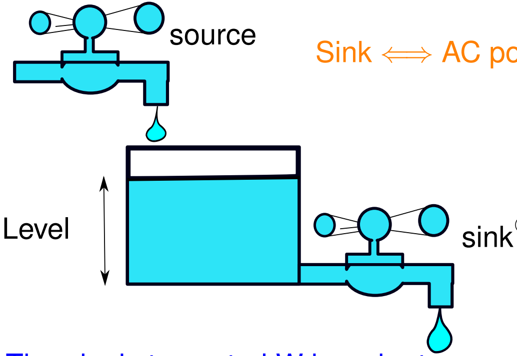
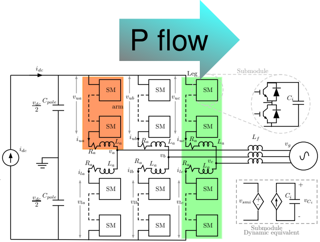


Sink $\Longleftrightarrow$ AC power MMC



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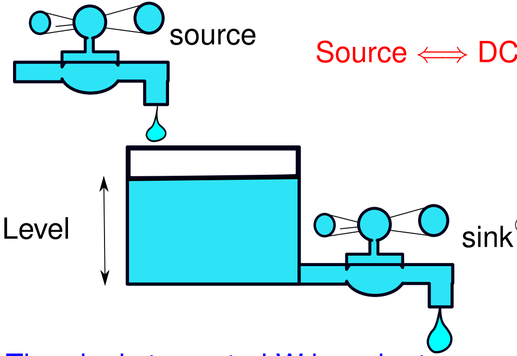
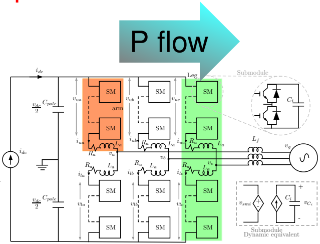
Capability of an MMC to store energy (W)

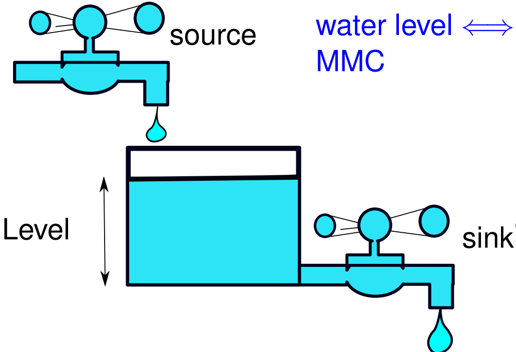


Source $\Longleftrightarrow$ DC power MMC

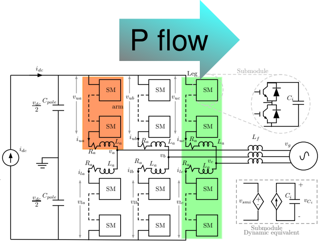


The aim is to control W in order to smooth the fast power fluctuation.

Capability of an MMC to store energy (W)



water level $\Longleftrightarrow$ energy storage capability MMC



The aim is to control W in order to smooth the fast power fluctuation.

Capability of an MMC to store energy (W)

Arm energy dynamics:

$$\frac{dW}{dt} = \frac{1}{3C}\left(P_{dc} - P_{ac}\right) \tag{1}$$

W: Arm energy
C: equivalent arm capacitor
P_{dc}: DC power
P_{ac}: AC power
The aim is to control W in order to smooth the fast power fluctuation.

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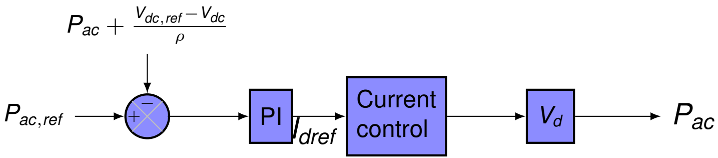
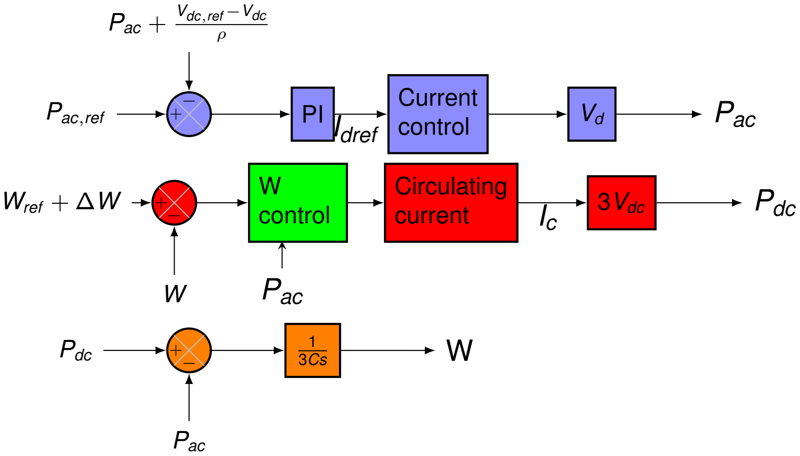
Energy control scheme



Energy control scheme



Energy control

We use a Non-linear control for W.

$$I_{c,ref} = \frac{1}{u_c}\left(\frac{d(W_{ref} + \Delta W)}{dt} + P_{ac} - K(W_{ref} + \Delta W - W)\right) \tag{2}$$

K: virtual gain.

Energy control

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$$I_{c,ref} = \frac{1}{u_c}\left(\frac{d(W_{ref} + \Delta W)}{dt} + P_{ac} - K(W_{ref} + \Delta W - W)\right) \quad (2)$$

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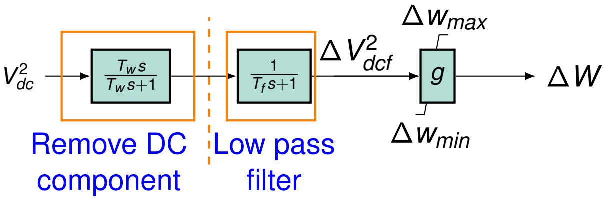

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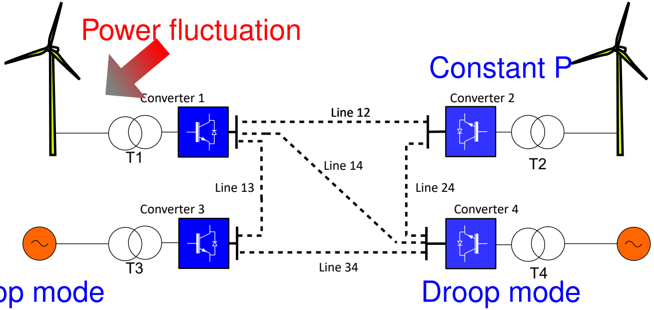
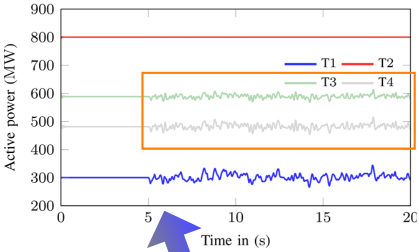
Simulation

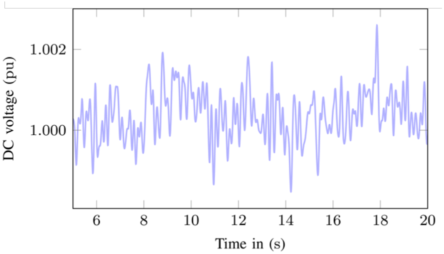
Test system



W. Leterme, et al., A new HVDC grid test system for HVDC grid dynamics and protection studies in EMTP-type software, in 11th IET International Conference on AC and DC Power Transmission, 2015.

Simulation

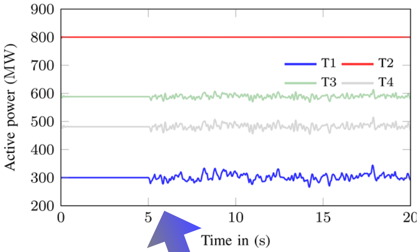


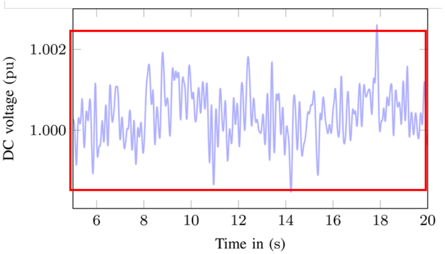


Start $\Delta P_1 = \pm 10MW$

Fluctuation of Power 3 and 4

Simulation

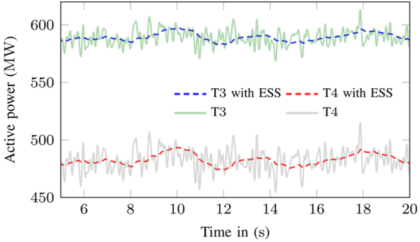


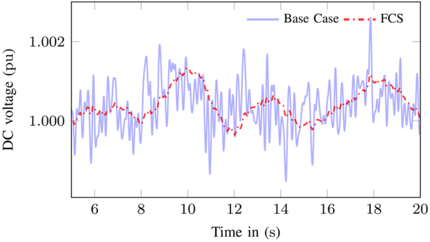


Start $\Delta P_1 = \pm 10 MW$ → Fluctuation of DC voltage

Simulation

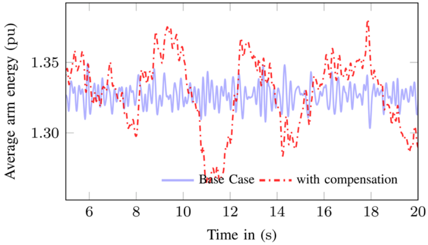
When smoothening function is enabled the active powers and dc voltage show improvements



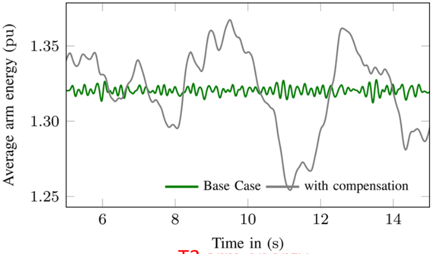


Simulation

- The arm energy $\rightarrow$ larger variation (ΔW enabled).
- The method is distributed.
  Onshore converters (3 and 4) $\Longleftrightarrow$ arm energy variation.



T1 arm energy

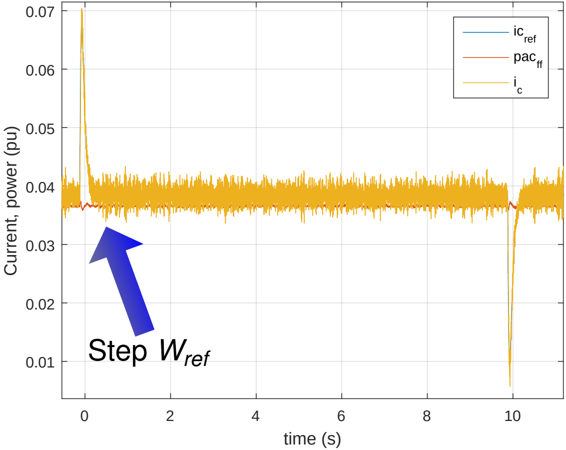


T3 arm energy

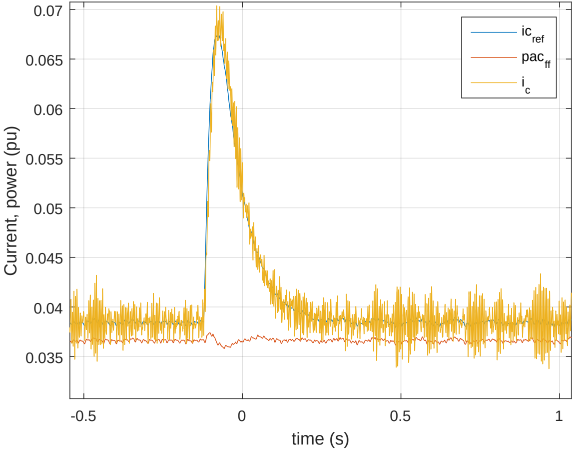
National Smart Grid Laboratory (Norway)

Rated power:
60 KVA
Number of sub-modules:
18 sm
AC voltage:
400 V
DC voltage:
700 V

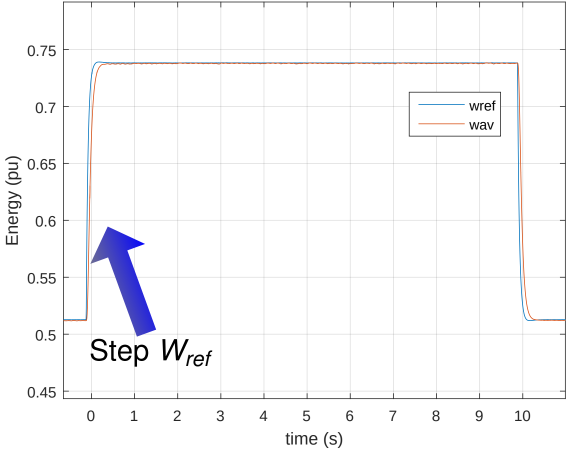
National Smart Grid Laboratory (Norway)



National Smart Grid Laboratory (Norway)



National Smart Grid Laboratory (Norway)



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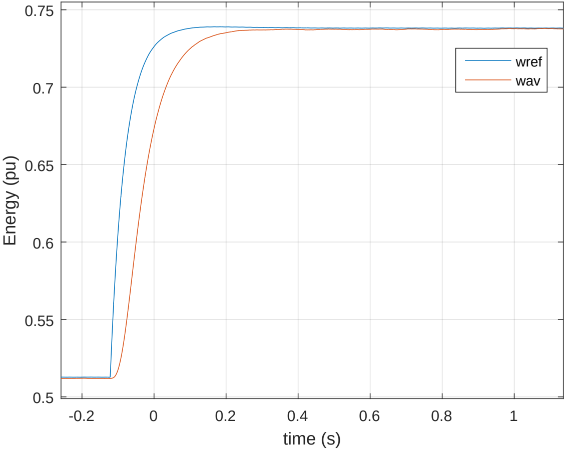

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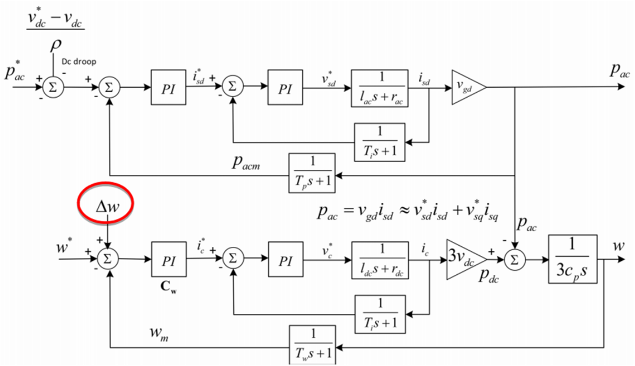
Conclusions

- We developed an energy controller that helps to exploit the energy storage capability of the MMC.
- We validated the energy control technique in the laboratory.
- Fast power fluctuations from wind farms can be compensated applying such controller to the MMCs of the HVDC grid.

Thank you!

Questions

Full scheme



C. D. Barker, R. S. Whitehouse, A. G. Adamczyk, and G. G. Soto, “Low frequency active power oscillation damping using a MMC-VSC HVDC link,” in *13th IET International Conference on AC and DC Power Transmission (ACDC 2017)*, 2017,

A. A. Taffese, E. Tedeschi, and E. de Jong, “A control scheme for utilizing energy storage of the modular multilevel converter for power oscillation damping,” in *2017 IEEE 18th Workshop on Control and Modeling for Power Electronics (COMPEL)*, 2017