Comparison of Inertial Frequency Response Techniques in Offshore Wind Farms based on Permanent Magnet Synchronous Generators

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Introduction

- Offshore Wind Farms (OWF) based on variable speed wind turbines (VSWT) will replace conventional generation.
- Reduction of overall system inertia
- 2 techniques to increase the overall inertia are compared and implemented through an experimental platform based on a 3-terminal VSC-HVDC scheme.

Why Inertia Frequency Response?

- The first seconds after a power unbalance are the most critical in terms of frequency response.

- Solution: **Inertia response from generators.**

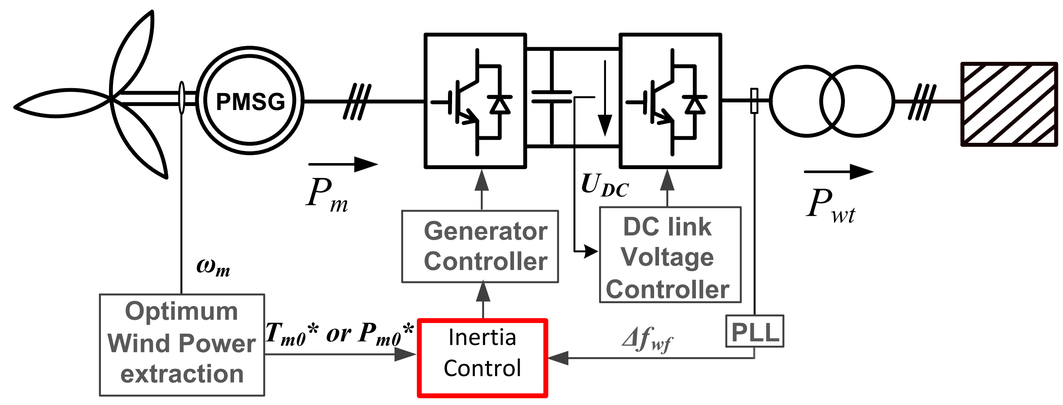
- Fast extraction of kinetic energy from rotational mass that provides automatic response when a frequency deviation is detected.

Inertia Control in PMSG-VSWT

-Problem: VSWT are insensible to frequency variations.

-Solution: **additional control** to equip the Wind Turbines with **synthetic inertia.**

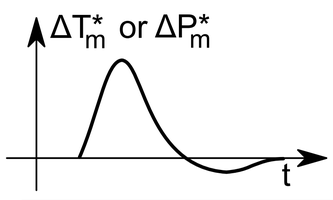
- PMSG-VSWT **control scheme** with inertia control.



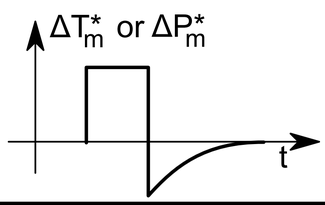
Comparison of Inertia Control Techniques

Existing techniques

Inertia coupling (IC) [1]



Step response (SR) [2]

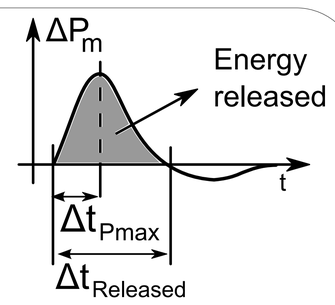


4 cases to compare

Inertia coupling	Step response
Torque (ΔT_m^*)	Torque(ΔT_m^*)
Power (ΔP_m^*)	Power (ΔP_m^*)

Basis of comparison

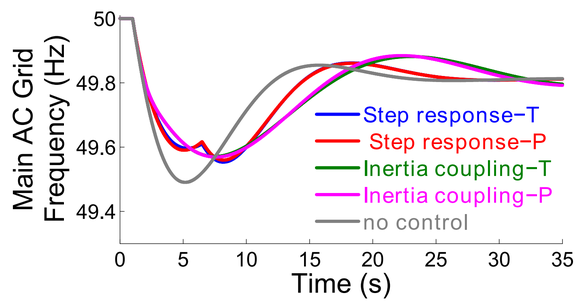
- Same **energy released**
- Same **time the energy is released**
- Same **time to reach maximum power**
- Same power unbalance in AC grid



Results of comparison

Test system: Offshore Wind Farm directly connected to the Main Grid

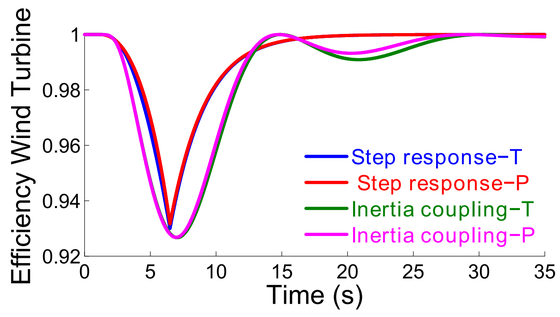
- **AC grid frequency**



- **Rate of Change of Frequency**

Cases	RoCoF (Hz/s) [0s-0.5s]	RoCoF (Hz/s) [0.5s-1s]
Step Response-T	**0.2238**	0.1728
Step Response-P	**0.2180**	0.1744
Inertia Coupling-T	0.2328	**0.1664**
Inertia Coupling-P	0.2328	**0.1664**
No control	0.2418	0.2136

- **Efficiency:** $ef = {C_p}/{C_{p,opt}}$

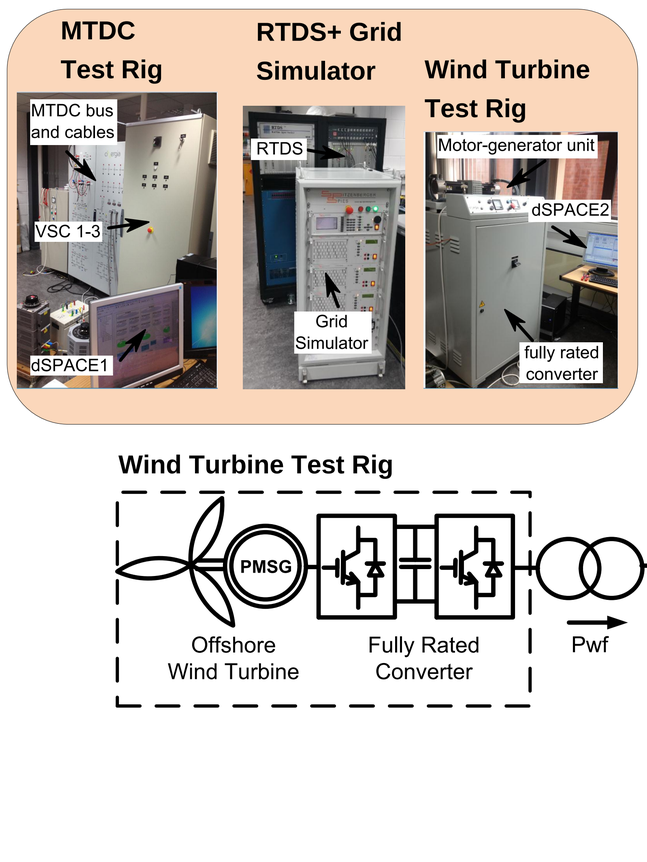


- **Energy loss:** $E_{loss} = \int_0^{t_{\Delta P=0}} P_{wf}(1-ef)dt$

Energy released: 1.85 pu

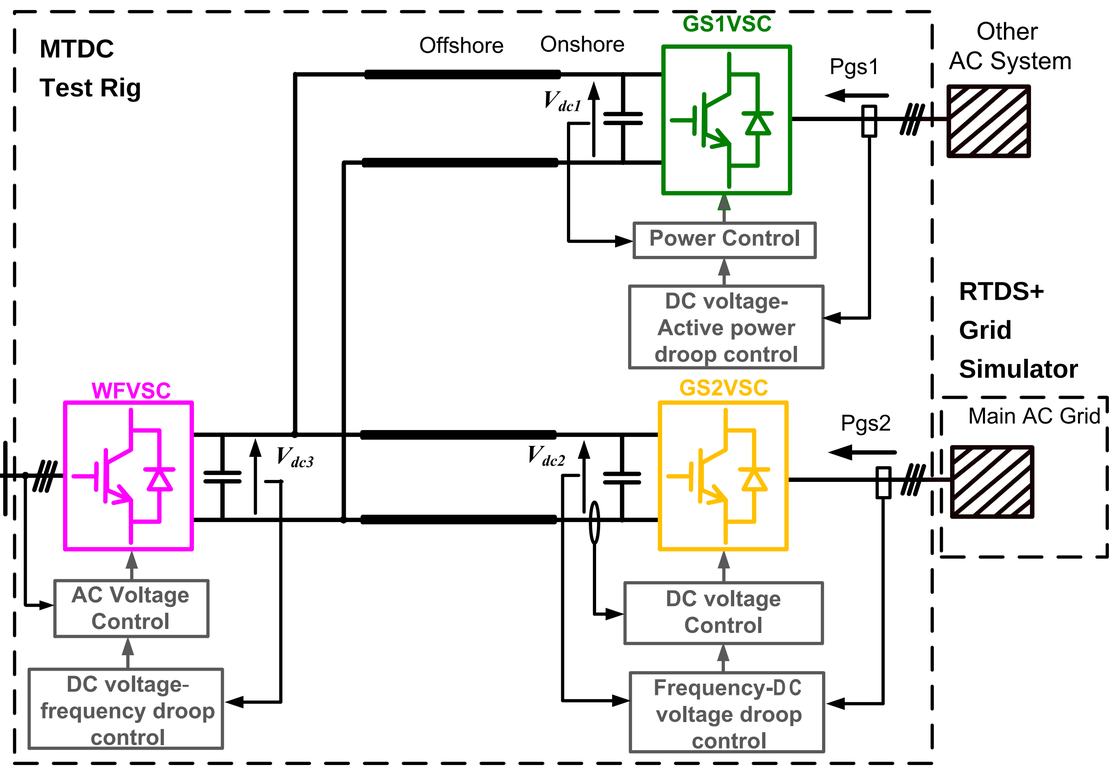
Cases	E_{loss} (pu)	E_{lost}/E_{rel} (%)
Step Response-T	**0.2419**	**13.29**
Step Response-P	**0.229**	**12.38**
Inertia Coupling-T	0.4194	22.67
Inertia Coupling-P	0.3942	21.31

Experimental Implementation of the Inertial Control Techniques: 3-terminal DC grid



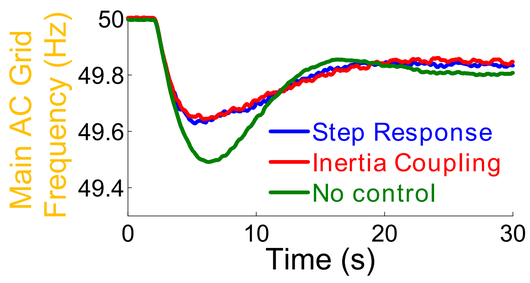
Test system

- Only inertial control based on torque is considered.



Results

- **Main AC grid frequency**



- **Main AC grid RoCoF**

Cases	RoCoF (Hz/s) [0s-0.5s]	RoCoF (Hz/s) [0.5s-1s]
Step Response-T	0.1506	0.2148
Inertia Coupling-T	0.1556	**0.1960**
No control	**0.1490**	0.2190

- **Energy loss in OWF**

Energy released: 0.8 pu

Cases	E_{loss} (pu)	E_{lost}/E_{rel} (%)
Step Response-T	**0.2062**	**25.77**
Inertia Coupling-T	0.3047	38.08

Conclusions

- Comparison Inertia Coupling vs Step Response:
  - No significant differences using torque or power as a reference.
  - Similar frequency response, but Step Response shows a 2nd frequency drop.
  - Step response has better efficiency than Inertia Coupling.
- Similar results in a 3-terminal VSC-HVDC scheme.
- Power losses of the MTDC grid and Control response delay in the VSCs reduce the inertia response contribution.

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