Study Committee B4

DC Systems and Power Electronics

11146

Offshore Grid Forming Control in Parallel VSC HVDC Bipole Systems

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Motivation

Increased interest in offshore wind potential requires more investigation into the dynamic stability and performance of offshore wind collector systems that use HVDC technology to transmit power to multiple onshore load centers.

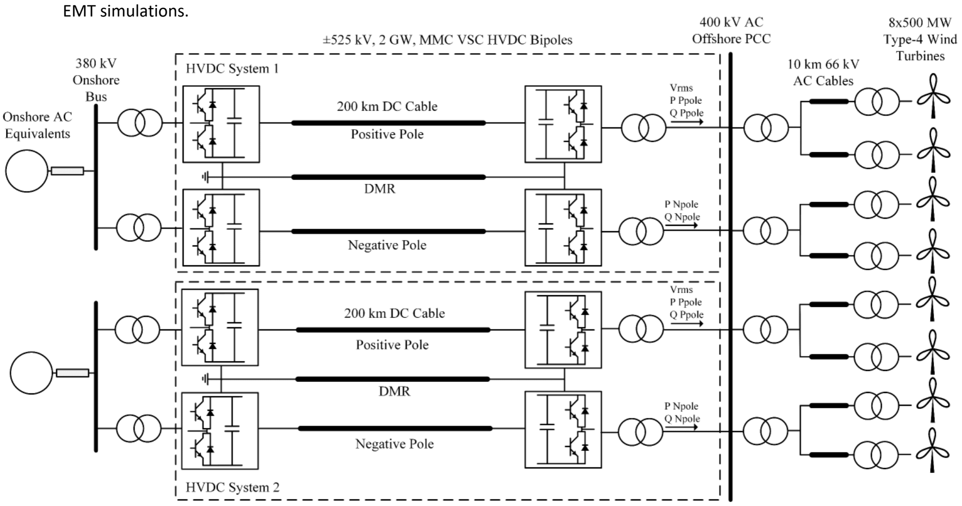
The objective of the study is to:

- Regulate the voltage and frequency of an offshore bus using parallel half-bridge VSC HVDC bipoles.
- Test a novel grid forming control scheme through EMT simulations.

Characteristics of Offshore Grids

Offshore grids have unique dynamic characteristics compared to traditional onshore grids:

- Lack of inertia as wind turbines are decoupled by the inverter in type-4 systems.
- HVDC terminals are effectively connected to constant PQ sources as the wind plant PPCs determine their power output.
- Lack of damping from conventional loads.



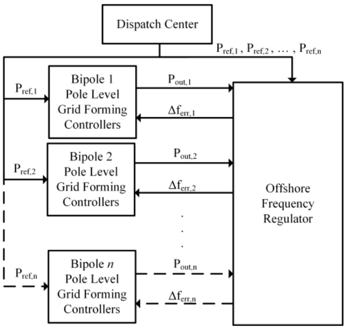
Challenges

The characteristics of offshore grids and parallel operation of tightly-couple HVDC systems pose unique challenges for grid forming control:

- Fighting of parallel frequency controllers results in power circulation between poles.
- AC voltage and frequency are highly coupled, making independent control of active/reactive power difficult.
- HVDC terminals operate in power sinking mode which limits their flexibility to regulate frequency.
- IGBTs require high short-term transient current capability to support the grid voltage during faults while also sinking active power.

Grid Forming Control Concept

- A grid forming control concept is implemented which uses a master offshore frequency regulator in conjunction with pole-level grid forming controllers.



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Offshore Frequency Regulator

- Coordinates active power distribution between parallel HVDC systems through a droop control scheme.
- Calculates the frequency error at the PCC and issues a new power order to each HVDC converter based on their relative droop setting.

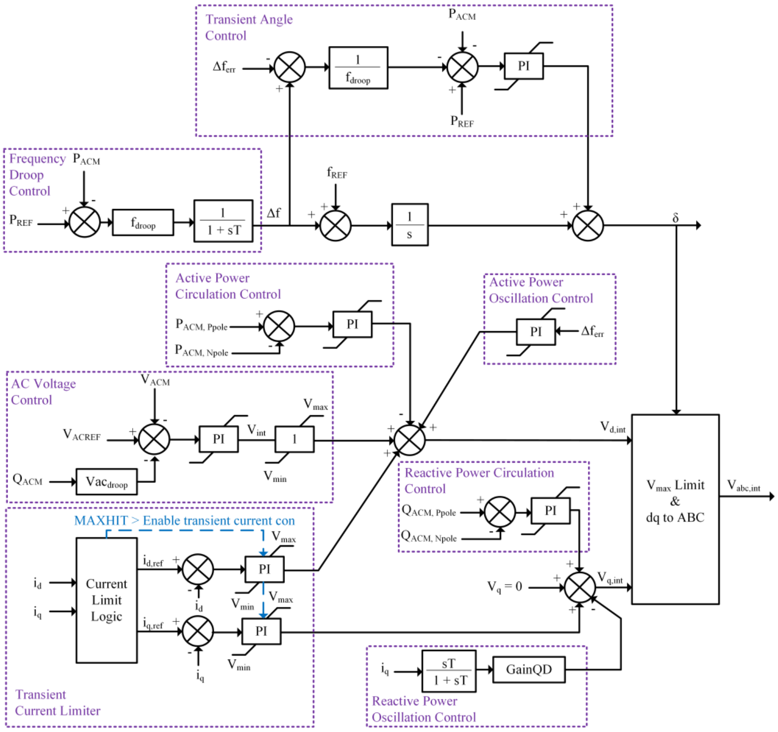
Test System

- 400 kV offshore bus.
- Two ±525 kV, 2 GW, half-bridge, VSC HVDC bipoles with identical parameters.
- 200 km DC cables.
- 8 arrays of type-4 wind turbines with an aggregate capacity of 500 MW each, connected through 10 km 66 kV AC cables.
- Wind plant PPCs configured for constant PQ control.

Pole Controller

Defines the converter's internal voltage magnitude and angle. Various control branches are included to resolve challenges:

- Frequency droop control modulates the frequency order based on the error between measured active power output and reference.
- Transient angle control is used to quickly modulate the internal angle when there is a sudden power change in the offshore grid.
- Reactive power droop is used to coordinate AC voltage regulation between the parallel converters.
- Power circulation control used to eliminate power circulation between positive and negative poles of the same bipole.
- Power oscillation control used to damp out power oscillations between parallel bipoles.
- Transient current limiter used to maintain the converter current within IGBT limits.



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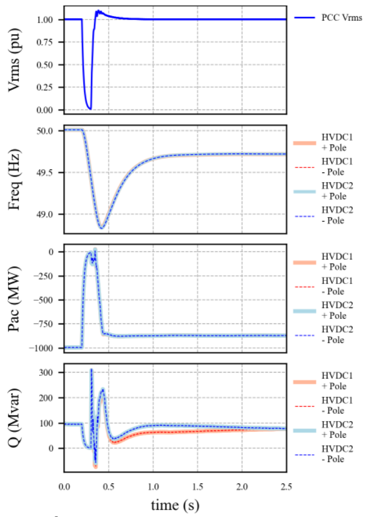
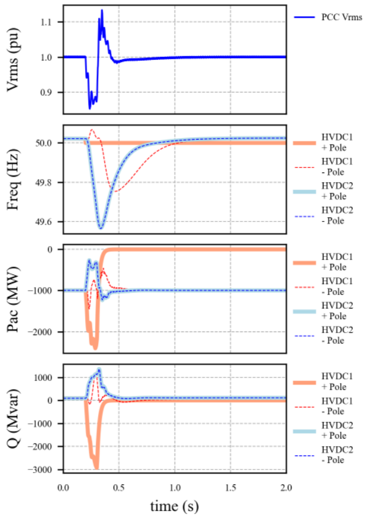
AC Fault

- Bolted 100 ms 3ph-g fault at the PCC and cross-trip of 500 MW of wind generation.



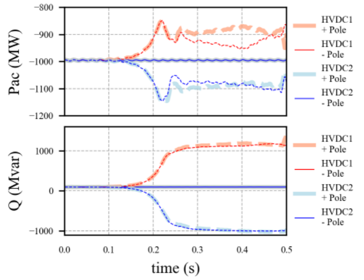
DC Fault

- Pole-to-ground fault on the positive pole of HVDC system 1 is applied and cross-trip of 1 GW of wind generation.



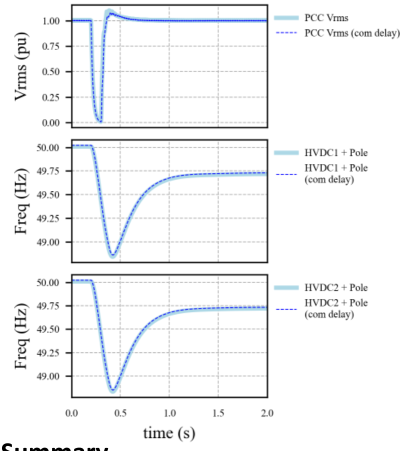
Offshore Instability

- No disturbance test with power oscillation control branches deactivated illustrates how the controller mitigates an instability in the offshore system.



Communication Delay

- AC fault repeated with 20 ms communication delay between master controller and HVDC system 2.



Summary

- A novel offshore grid forming control concept is presented and tested using EMT simulations to assess small-signal and large-signal stability.
- Disturbances include DC faults, AC faults at the PCC, HVDC converters and wind plants, as well as step changes to control reference setpoints.
- Studies show that the concept maintains the offshore frequency stability and power balance.
- This control concept can be utilized in many offshore HVDC systems around the world.