EERA DeepWind'2014
Trondheim, Norway, 23 January 2014

Operation of Power Electronic Converters in Offshore Wind Farms as Virtual Synchronous Machines

Salvatore D'Arco[*]
salvatore.darco@sintef.no

Jon Are Suul[*†]
Jon.A.Suul@sintef.no

[*]SINTEF Energy Research, Norway
[†]Norwegian University of Science and Technology, Norway

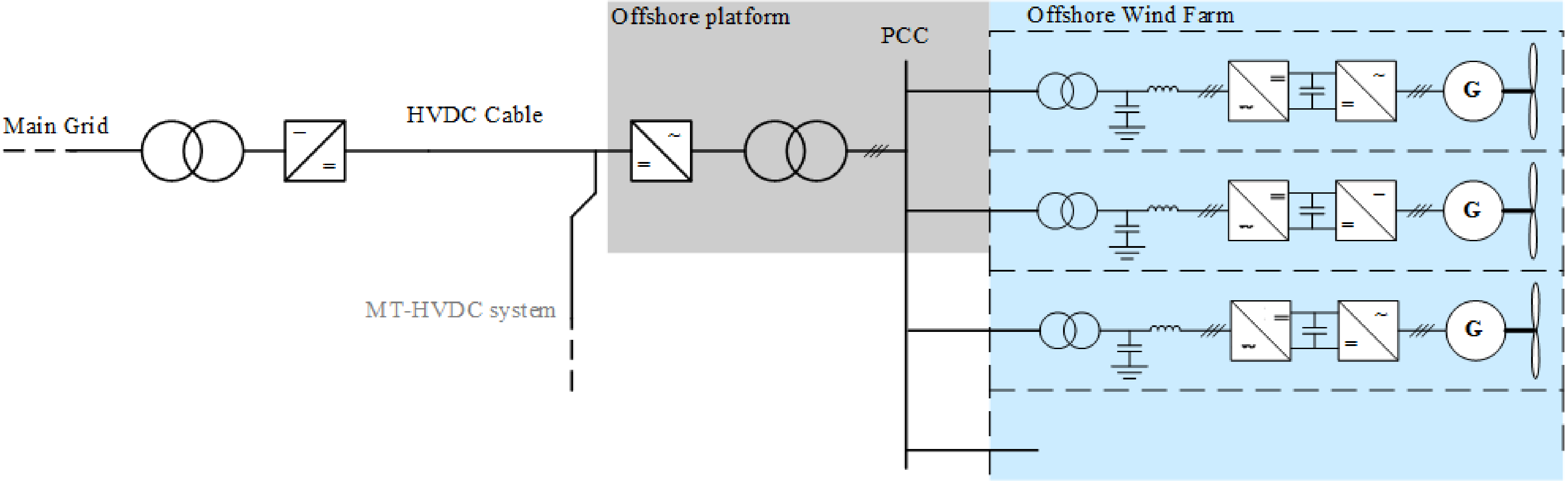
NTNU SINTEF

Outline

- Power Electronics Converters in Offshore Wind Farms
- Introduction to Virtual Synchronous Machines (VSM)
  - Implementation
  - Comparison to other inertia emulation schemes
- VSM application in HVDC-connected Offshore Wind Farms
- Conclusions

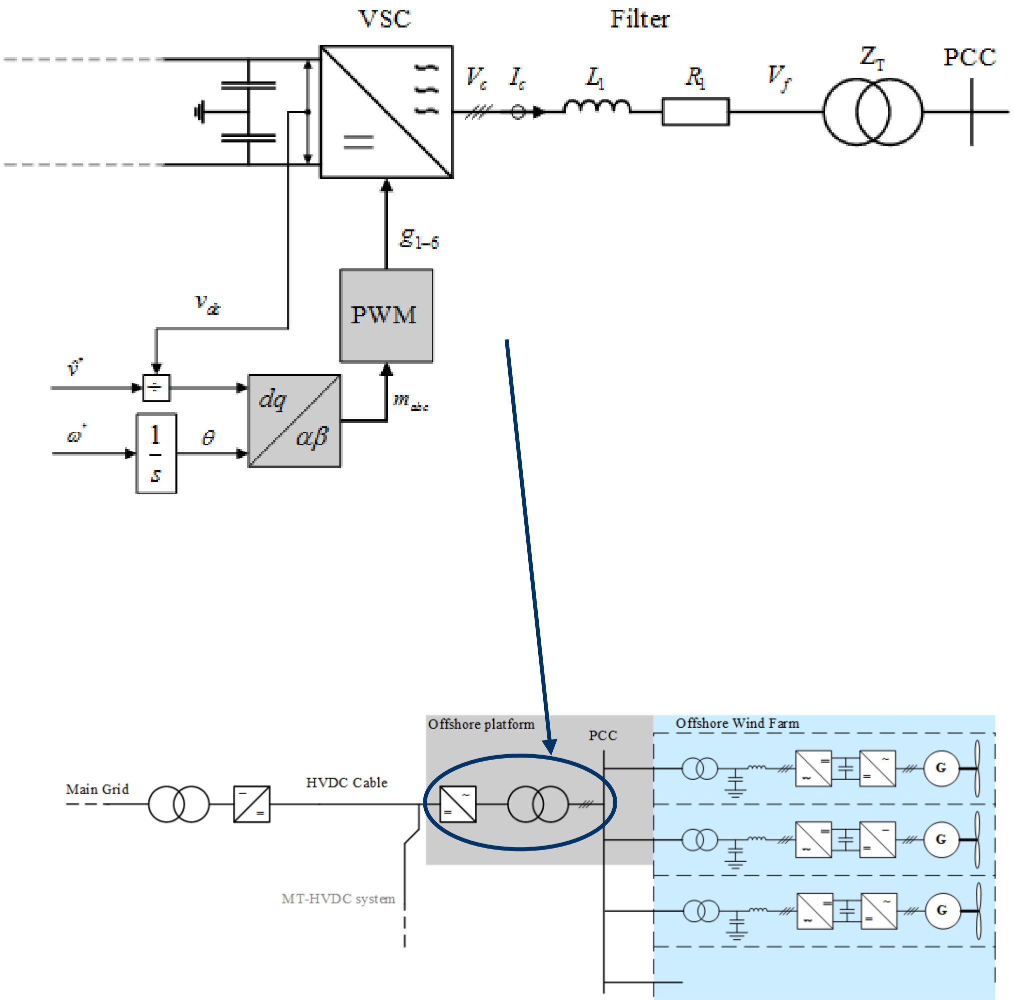
HVDC Connected Offshore Wind Farms

- Long distances to shore
  - Point-to-point HVDC connection to shore
    - Grid side and offshore HVDC converters
  - Internal AC collection grid with converter interface to wind turbines
    - Full-scale back-to-back converter
    - Doubly Fed Induction Generators – rotor converter

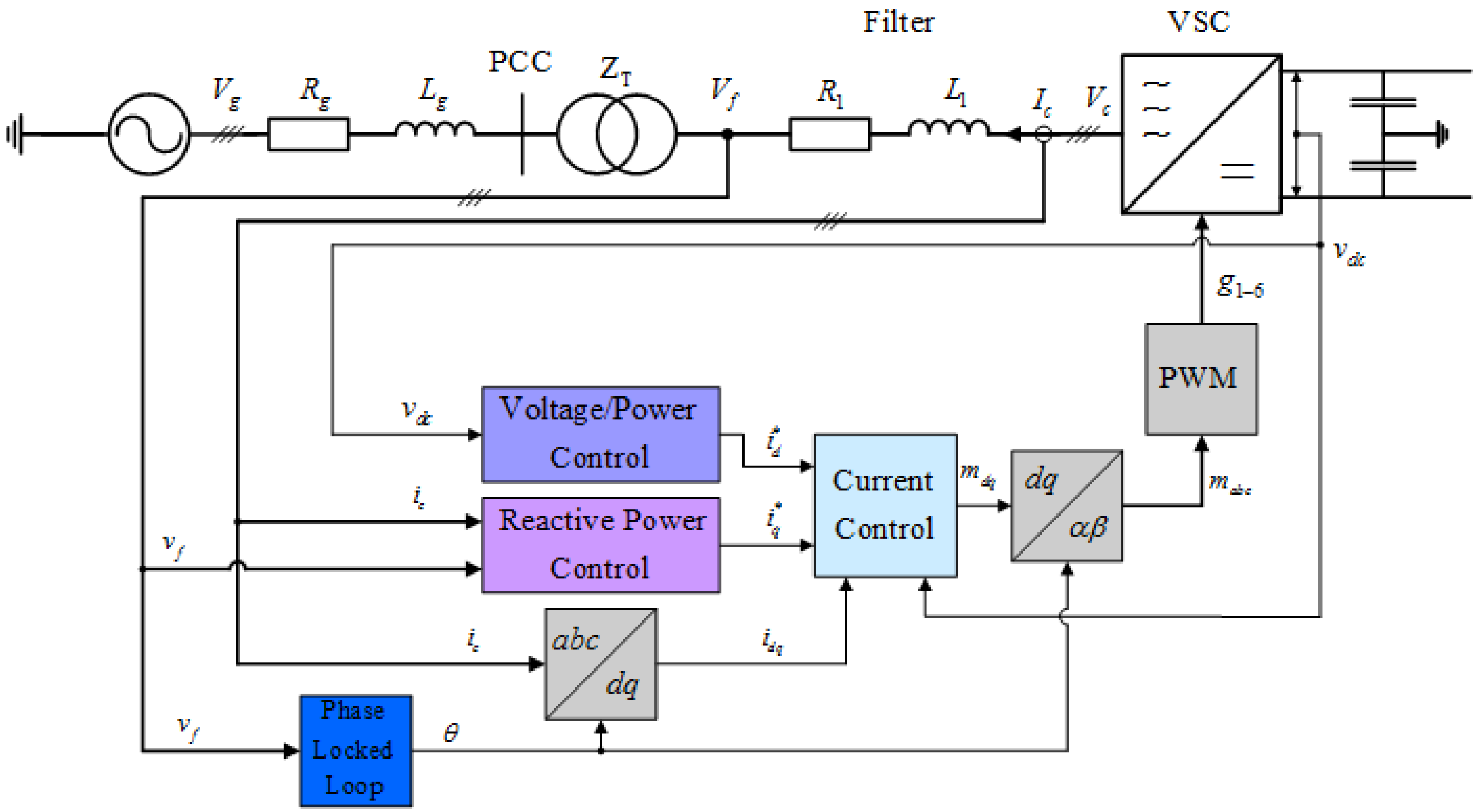


Conventional HVDC Control – Offshore

- Offshore Wind Farm converter:
  - Operates as a frequency master
    - Determines voltage and frequency of local AC collection grid
  - Wind turbine converters are synchronized to the voltage generated by the HVDC converter
- No physical inertia in the offshore grid



Conventional HVDC Control – Onshore



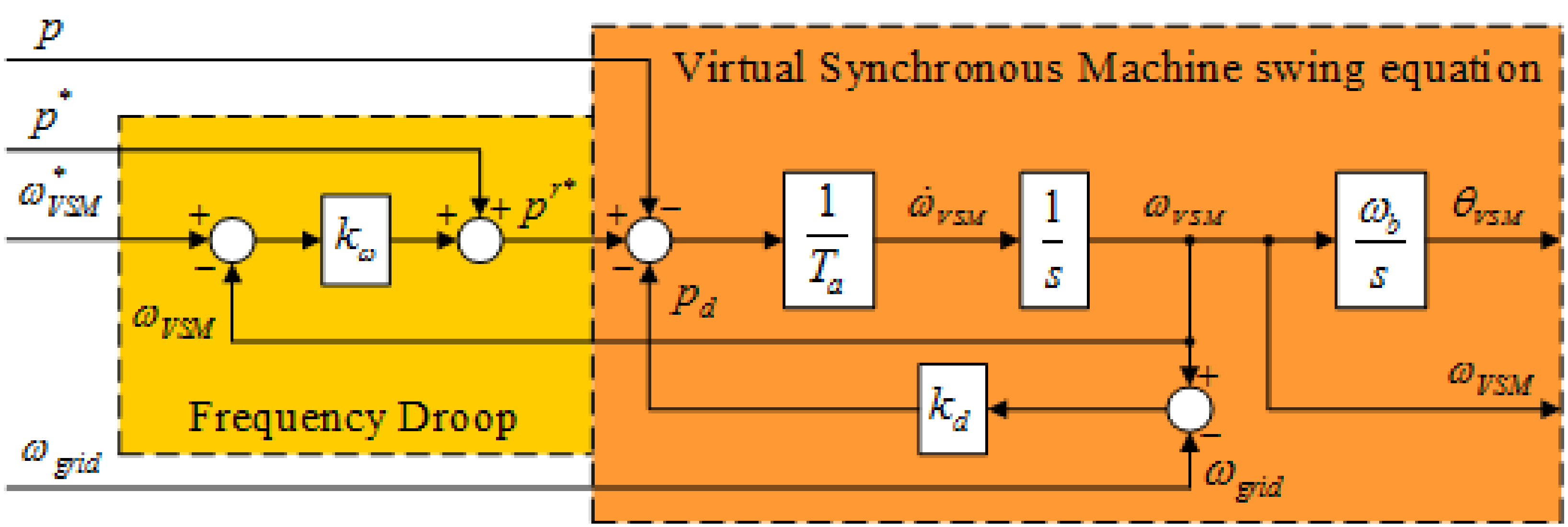
- Synchronized to onshore power system by Phase Locked Loop (PLL)
  - Depends on a relatively strong grid with rotating inertia
- Islanded operation or black-start requires change of control system

Virtual Synchronous Machines

- Power Electronic converters controlled to emulate traditional synchronous machines
  - Emulates inertia and damping
  - Parameters are not limited by physical design constraints
- Will operate in the grid in a similar way as traditional Synchronous Machines
  - Self-synchronization by power-balance effect
    - Does not depend on PLL
  - Allows for stand alone and/or parallel operation as well as connection to a strong grid
- Several possible implementations

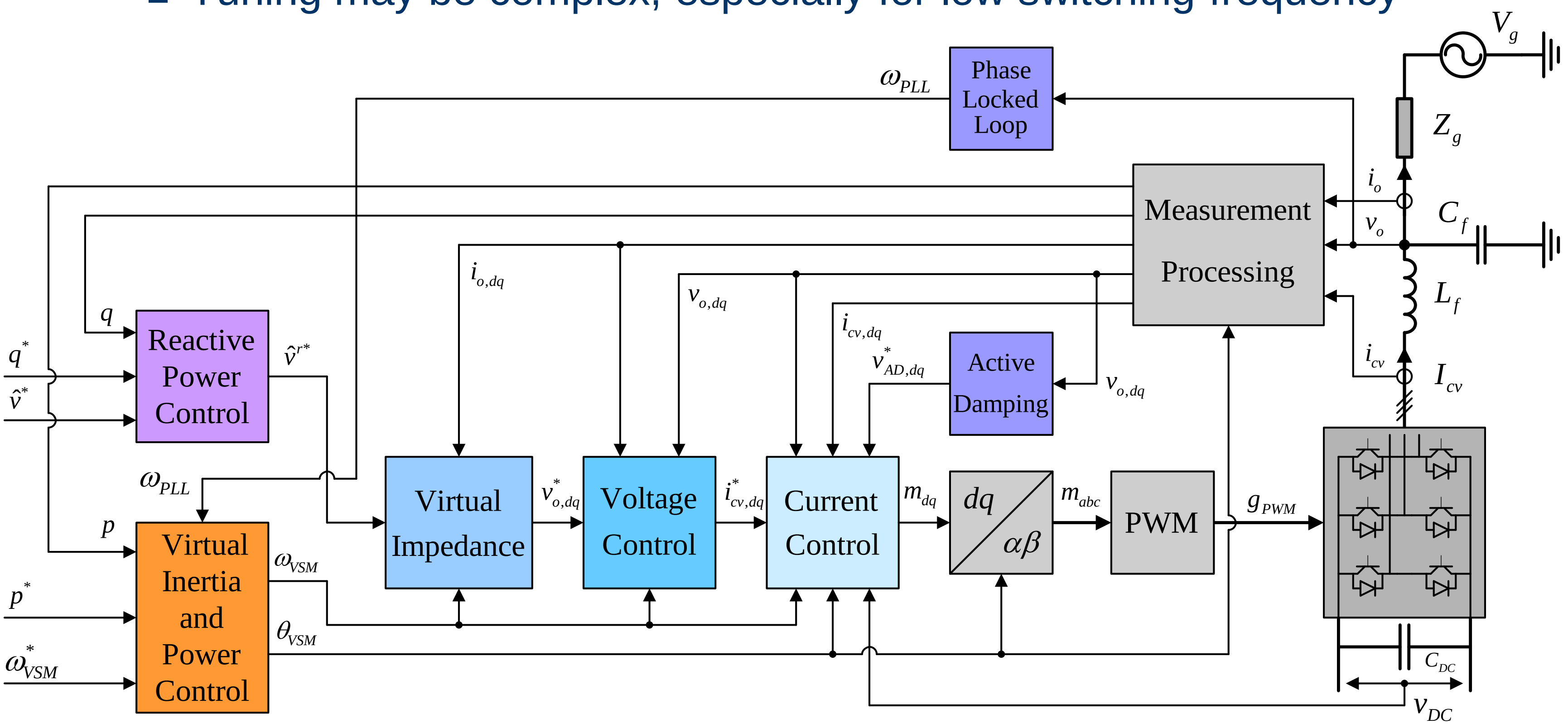
VSM Implementation

- Based on synchronous machine swing equation
  - Reduced order approximation of the inertia and damping of a traditional synchronous machine
  - Provides a frequency and phase angle reference that can be used to control the converter
- Reactive power controller can provide voltage amplitude reference



Overview of VSM-based control scheme

- Inertia emulation and reactive power control gives phase angle references and voltage amplitude reference
  - Used for cascaded voltage and current controllers
    - Protections and controller saturations can be explicitly included
    - Tuning may be complex, especially for low switching frequency



VSM and Inertia Emulation

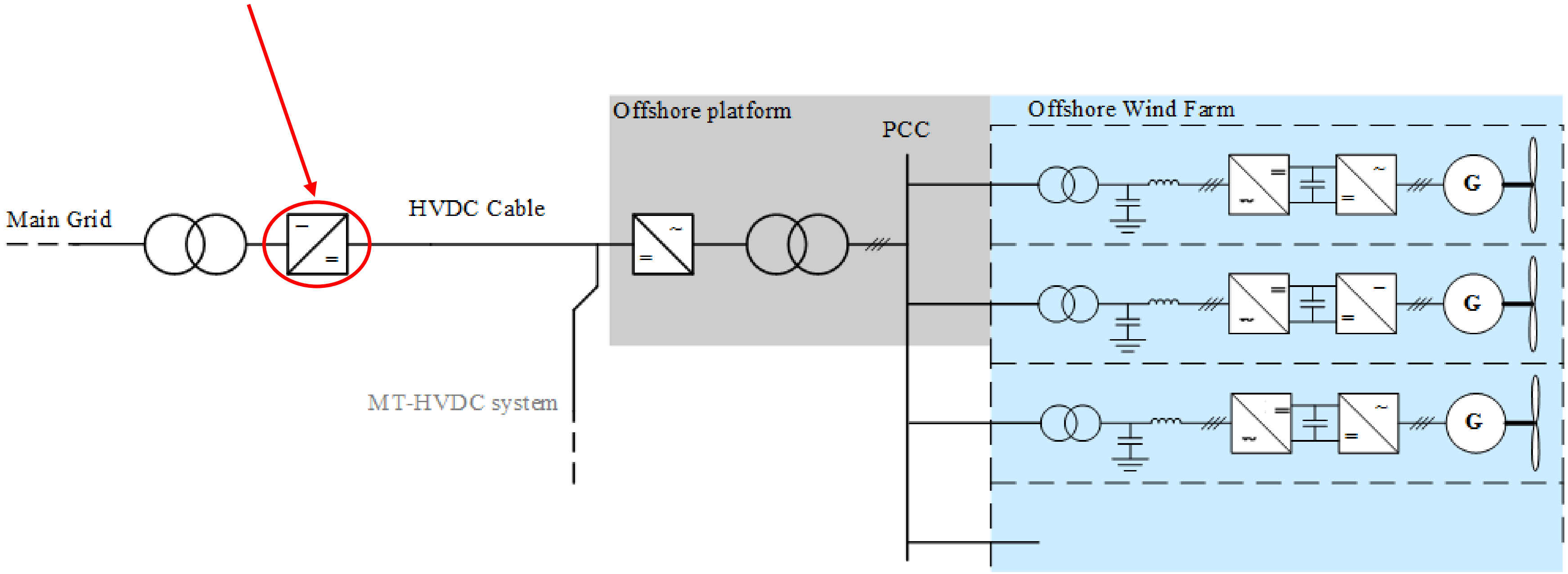
- Inertia emulation is becoming a possible requirement for modern wind farms
  - Most implementations are based on sensing of the grid frequency

$$\Delta P = k_H \frac{df_{grid}}{dt}$$

  - Will contribute to improve power system dynamic response and stability but depends on a stable grid frequency detection
    - Usually based on frequency tracking by PLL or similar techniques
    - Depends on dominant presence of traditional synchronous machines
  - There is no real inertia emulated in the control system
    - Only the power response of an equivalent inertia is emulated
- A Virtual Synchronous Machine can provide the same virtual inertia without depending on a strong grid
- The energy requirements for Inertia Emulation is the same

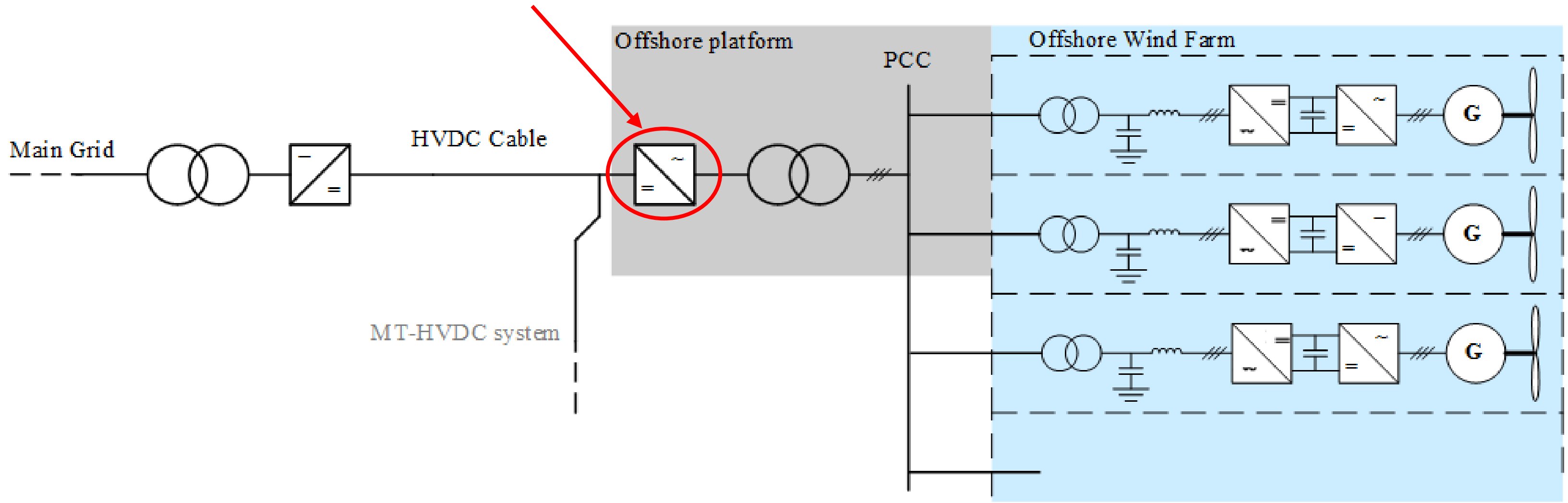
VSM applications in offshore wind farms - I

- Grid side HVDC Converter
  - Providing Virtual Inertia and damping to the AC system
  - Allows for stand-alone and black-start capability with the same control system as for grid connected operation

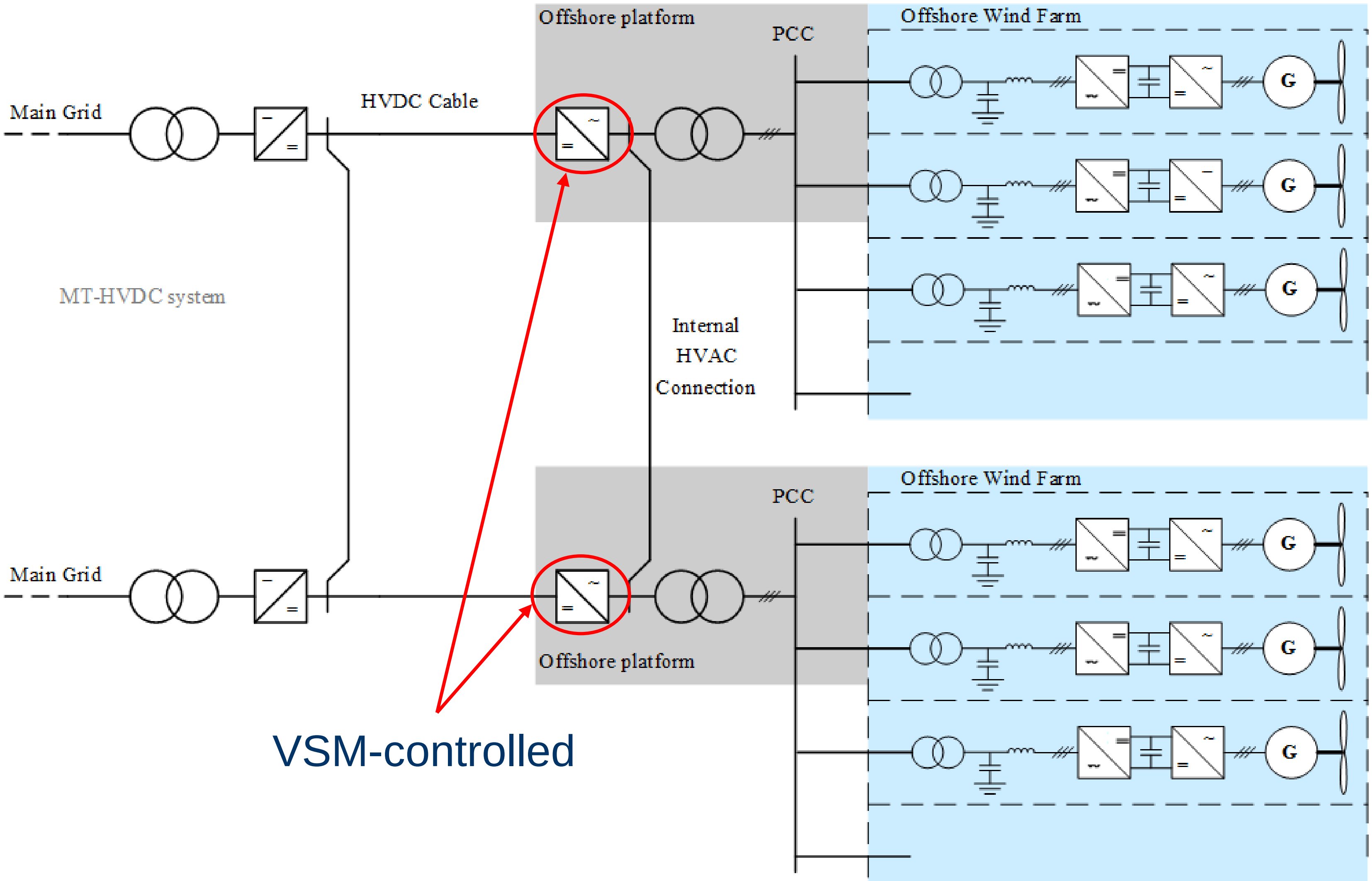


VSM applications in offshore wind farms - II

- Offshore HVDC Converter
  - VSM provides frequency and voltage regulation
    - Wind turbine converters will synchronize to the virtual inertia of the VSM
  - Allows for simple parallel connection and load sharing
    - Wind farms with multiple HVDC connections

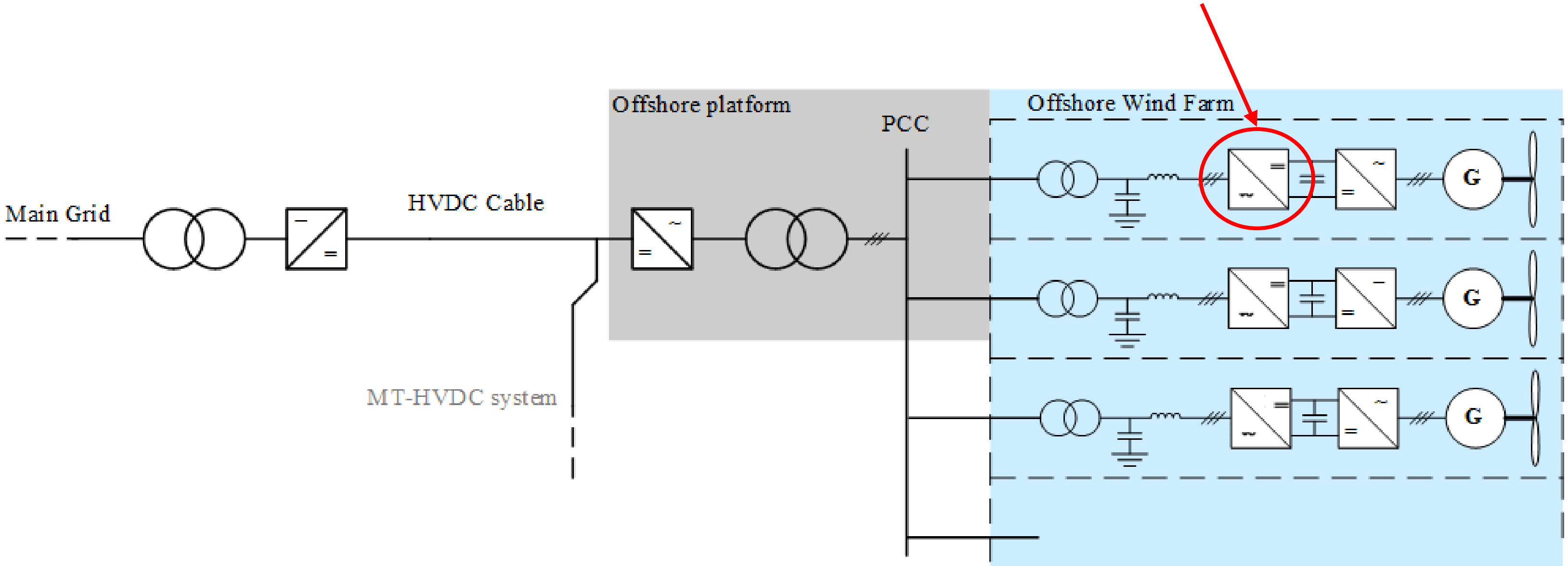


Wind farm with multiple HVDC connections



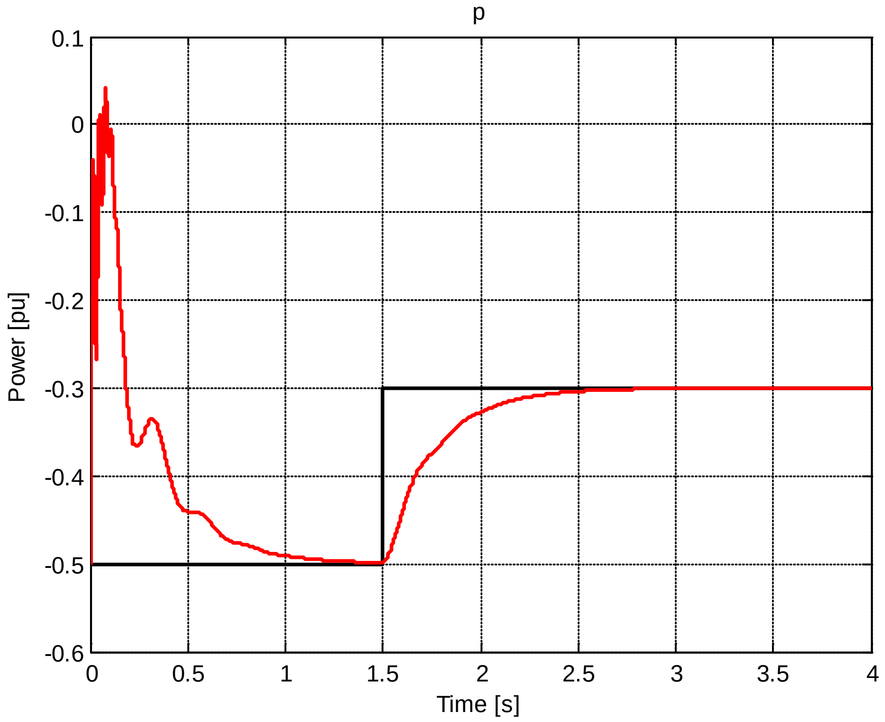
VSM applications in offshore wind farms - IIi

- Each wind turbine converter can be controlled like a VSM
  - Equivalent to large number of synchronous generators operated in parallel
  - Not a preferable solution in short term



Simulation example

- VSM in a HVDC configuration
- Simulation starting from perturbed initial condition
  - First second shows transient response with perturbed initial conditions of the system states
- Step of power reference at 1.5 s
  - No fast transients are excited
- Smooth over-damped response
  - Significantly more damped response than for a traditional synchronous machine
  - Damping coefficient can be higher than for design of a practical machine



Conclusions

- The Virtual Synchronous Machines is a new and promising concept for control of power electronic converters in power systems
  - Emulation of inertia and damping are common to all VSM implementations
  - Based on the same self synchronization effect as a traditional Synchronous Machine and do not depend on PLL
  - Does not have the same limitations of applicability as simple schemes for inertia emulation
- Relevant applications in offshore wind farms
  - Virtual Inertia in grid-side HVDC stations
  - Control of HVDC stations in isolated AC collection grids
    - Simple parallel operation of multiple converter stations
    - The same control can be used for various operation modes

Questions?

This work was supported by the project:

Power Electronics for Reliable and Energy Efficient Renewable Energy Systems - "Offshore Power Electronics" http://sintef.no/OPE

Classification of VSM Implementations

	Voltage vector reference Direct PWM	Voltage vector reference Cascaded Control	Current vector reference	Power Reference
Full order SM model.	Possible	Possible	VISMA	Not relevant
Reduced order SM model	VISMA	Possible	VISMA	Not relevant
Swing Equation	Syncronverter	In literature	In literature	Not relevant
Inertia emulation with power from grid voltage.	Not relevant	Not relevant	Possible	EU VSYNC project