INTRODUCTION TO THE "HVDC INERTIA PROVISION" RESEARCH PROJECT

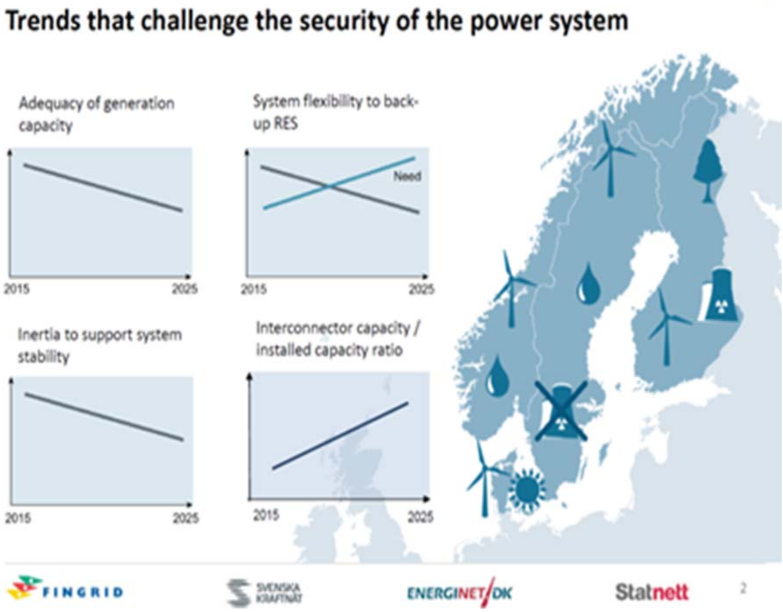
Jon Are Suul, SINTEF Energy Research

Key project information

- Competence-building project for industry supported by the Research Council of Norway (RCN)
  - Project duration: 2017-2022
  - Total budget of 20 MNOK (2M€)
- Industry partners: Statnett, Equinor, Elia and RTE
- Research partners: SINTEF Energy Research, KU Leuven (PhD), CentraleLille (PhD) and NTNU (post.doc)

Background when starting the project

- Near future for the Nordic / European power system:
  - Dominant presence of HVDC interconnectors
  - Increasing share of converter interfaced generation (wind, PV, etc.)
- Standard control of HVDC and converter interfaced generation does not inherently provide inertia
- Periods of low inertia and reduced stability margins during operation with low load and high import

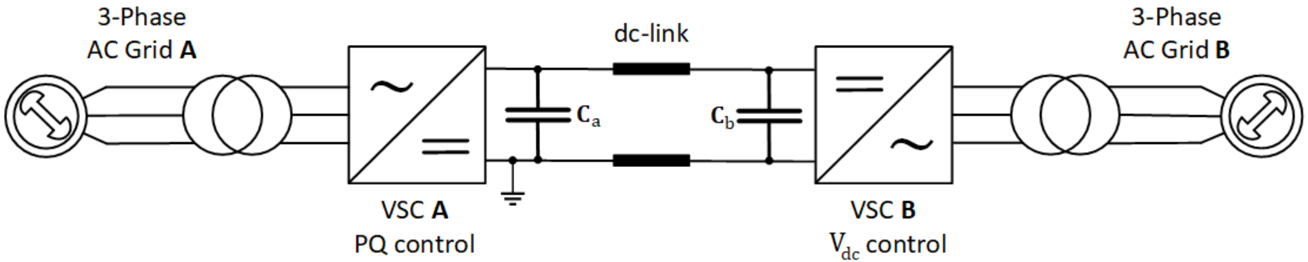


Auke Lont, CEO Statnett
Roundtable of Nordic Energy Stakeholders
Oslo, 1 December 2015

Why Virtual inertia from HVDC converters?

- Main motivations
  - High power rating from a single unit
    - Comparable size and influence on local grid as traditional large generation plants
  - High controllability of Modular Multilevel Converters (MMC)-based HVDC terminals
  - Typically customized design and control

- Challenges
  - Current limitations and energy availability for providing inertial response
  - Conflict between inertia emulation and dc voltage control
  - Need for energy storage for providing grid forming functionality without other dispatchable sources



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Project Objectives

Primary objective:

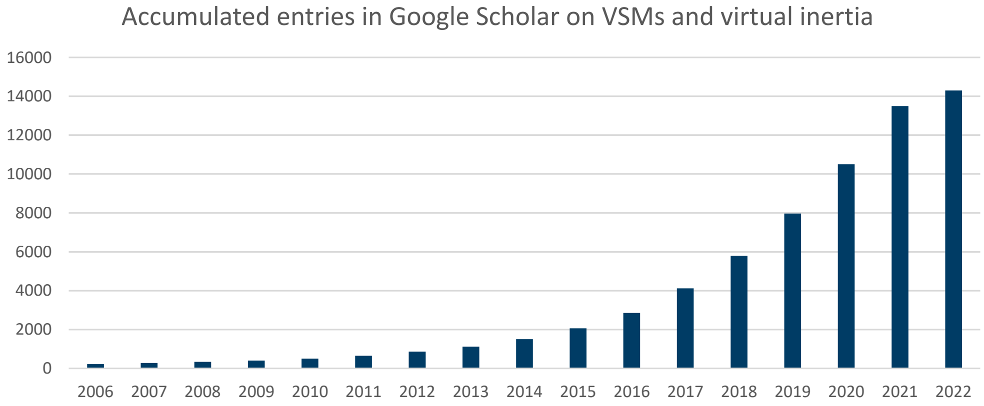
- ***Develop new methods and tools for enabling HVDC interconnectors to improve system stability by delivering inertia support, and by this contributing to future stable and secure operation of the European power systems with an increased share of renewables.***

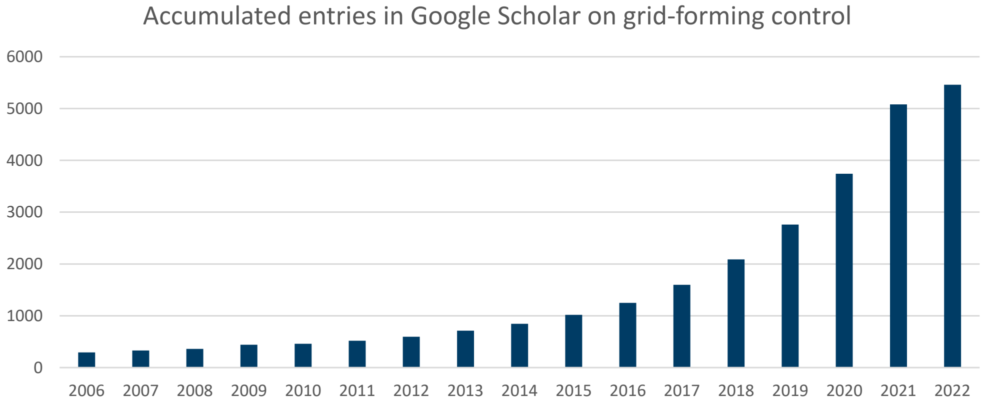
Secondary objectives:

1. Quantify the potential technical and economic benefits and implications of operating HVDC interconnectors for inertia support from a transmission system perspective.
2. Define and analyse suitable strategies for providing virtual inertia from HVDC terminals by acting on external reference signals or by dedicated internal control strategies.
3. Develop new techniques and tools for accurately assessing small- and large-signal stability in large-scale power systems with inertia support from HVDC transmission schemes.
4. Demonstrate virtual inertia control in a laboratory environment, targeting a TRL of 4/5.

What has happened?

- Rapid growth in academic research and publication on virtual inertia and Virtual Synchronous Machines (VSMs)
  - From a limited field of research to a mainstream research activity
- Widespread introduction of the term "grid-forming" control
- Increasing attention from TSOs, power producers and manufacturers
  - Dedicated studies, working groups and scenario definitions
  - Demonstration projects and pilot installations combined with energy storage
- Emerging grid code requirements



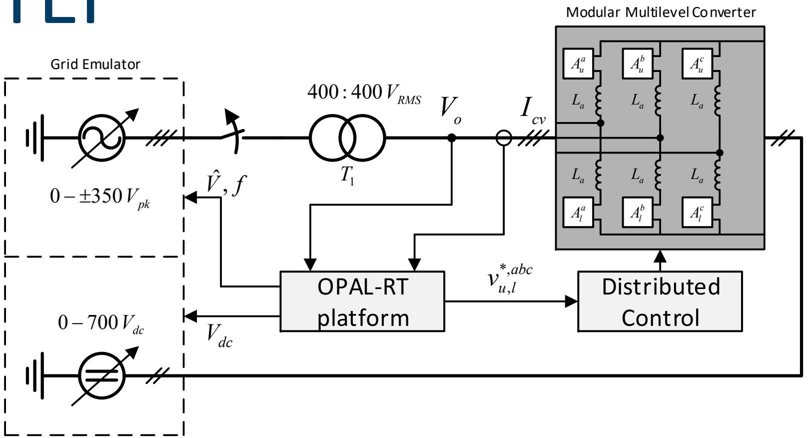


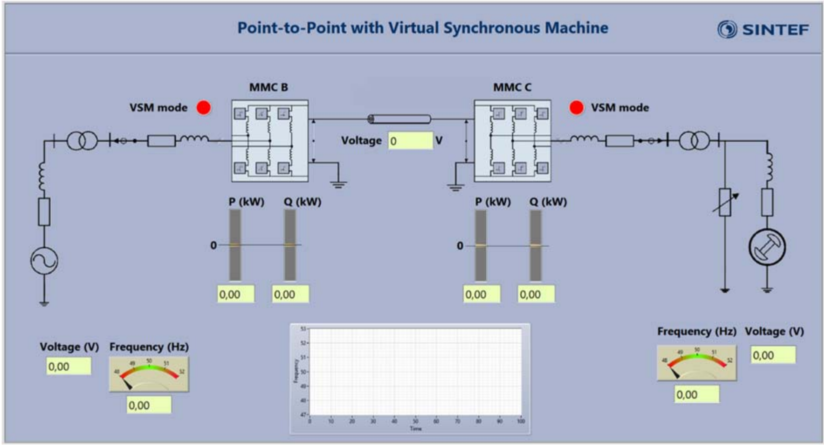
Main research activities in the project

- Power system operation with declining inertia
  - Virtual inertia as ancillary service (KU Leuven)
  - Impact from placement of virtual inertia in power systems (SINTEF)
- Control strategies and analysis of individual converter units
  - Analysis and implementation of "grid-forming" converters (CentraleLille)
  - Evaluation of Virtual Synchronous Machine-based control and grid-following virtual inertia (SINTEF)
  - Adaptations for operation under unbalanced conditions (SINTEF)
- Power system analysis
  - Development of methods and tools for small-signal analysis (SINTEF)
  - Methods for numerical analysis and large signal stability assessment (NTNU)

Experimental testing at SINTEF

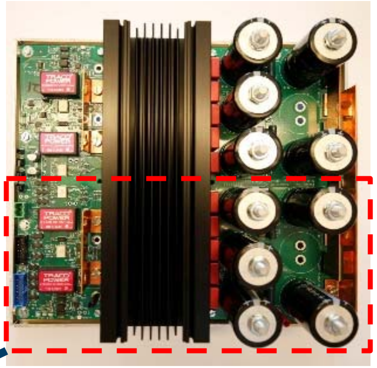
- Based on Modular Multilevel Converter (MMC) prototypes
- Control system testing by OPAL-RT platform used for rapid prototyping
- Power-Hardware-in-the-Loop (P-HiL) testing for assessment of operation in relevant system conditions
  - Real-time implementation of Nordic 44-bus system model

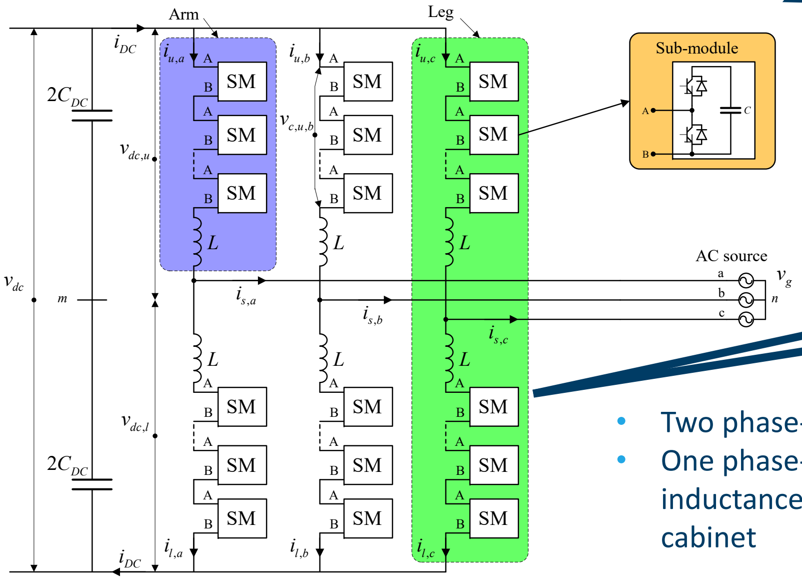




Experimental setups

- 3 MMC prototypes
  - 6 half-bridge sub-modules per arm
  - 18 half-bridge sub-modules per arm
  - 12 full-bridge sub-modules per arm





- Two phase-legs in one cabinet
- One phase-leg and arm inductances in the other cabinet

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Summary and outlook

- The project will be closed by the end of 2022
- Examples of key results will be shown in the following presentations
- Expected increasing industrial interest in virtual inertia and grid-forming functionality from power converters
  - Increasing pace of product development and implementation
- Some identified remaining challenges
  - Protection of "grid-forming" converters
  - Optimal placement and utilization of power system resources
  - Analysis and stability assessment of systems with low physical inertia and high share of power electronics

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