Shahab Karrari, **Mathias Noe, Joern Geisbuesch**
Karlsruhe Institute of Technology (KIT), Institute of Technical Physics (ITEP), Eggenstein-Leopoldshafen, Germany.

Karlsruher Institut für Technologie

IRED 2018
International Conference on Integration of Renewable and Distributed Energy Resources

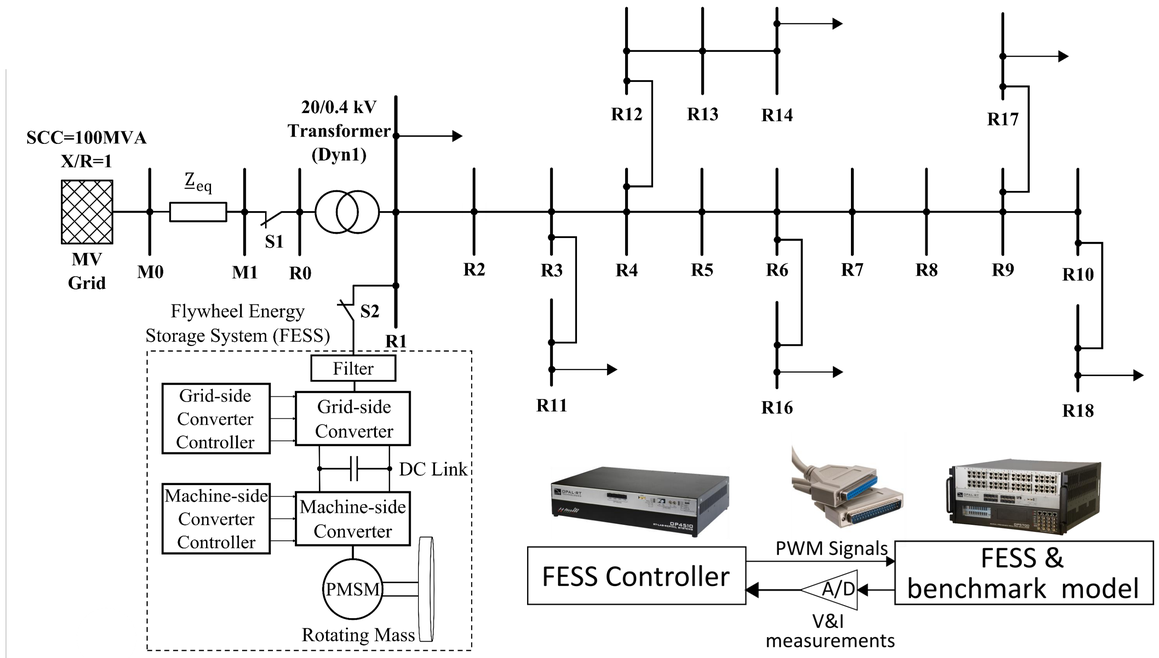
HIGH-SPEED FLYWHEEL ENERGY STORAGE SYSTEMS (FESS) FOR FREQUENCY AND VOLTAGE SUPPORT IN LOW VOLTAGE DISTRIBUTION GRIDS

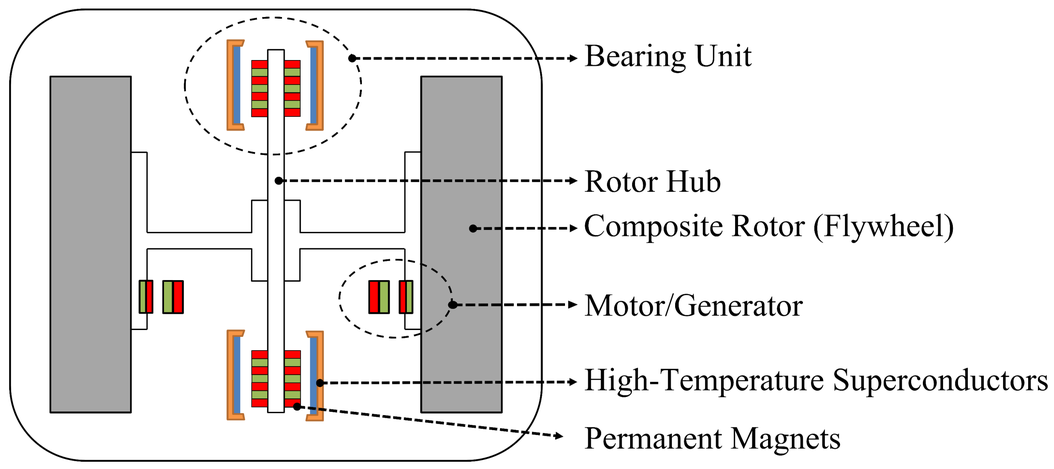
A real-time simulation for Power Hardware-in-the-Loop (P/HIL) testing

Motivation

A high penetration level of renewables and Distribution Energy Resources (DER) has adverse effects on the power quality in low voltage distribution networks. This issue is further escalated with the introduction of e-mobility infrastructure at this voltage level. Energy storage systems with high power density such as Flywheel Energy Storage Systems (FESS) can help to improve power quality measures by

- voltage regulation
- frequency regulation
- unbalanced load compensation
- harmonic compensation



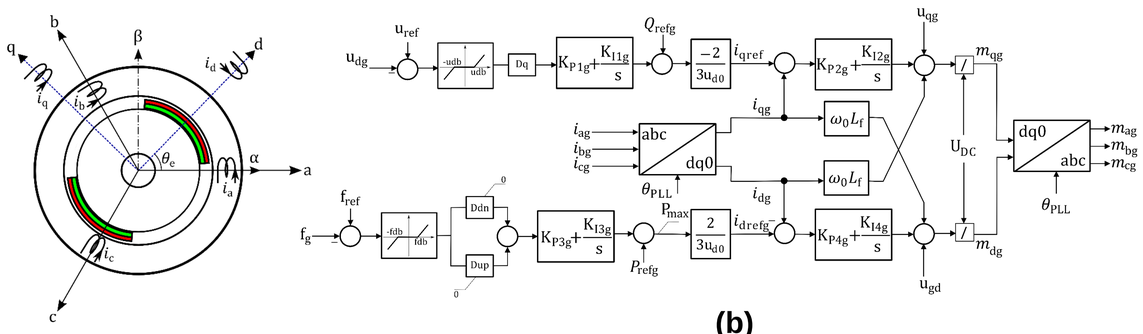


New-generation high-speed FESS

The new-generation high-speed FESS with High-Temperature Superconductor (HTS) bearings is superior to its earlier types with lower self-discharge rates (as low as 0.1% per hour, including the idle power [1]), higher speed and therefore higher energy contents, and lower maintenance.

The advantages of using a FESS are:

- High power density (up to 2 kW per liter)
- Extremely fast cycling characteristics
- Long lifetime (more than 20 years)
- High controllability
- Not sensitive to ambient temperature
- Environmental friendly



$$u_{dm} = r_s i_{dm} + L_d \frac{di_{dm}}{dt} - \omega_e L_q i_{qm}$$

$$u_{qm} = r_s i_{qm} + L_q \frac{di_{qm}}{dt} + \omega_e L_d i_{dm} + \omega_e \psi_f$$

$$T_e = \frac{3}{2} n_p (i_{dm} i_{qm} (L_d - L_q) + \psi_f i_{qm})$$

$$J \frac{d\omega_m}{dt} = n_p (T_e - D\omega_m)$$

$$\omega_m = \frac{d\theta_m}{dt} = \frac{\omega_e}{n_p}$$

Modeling

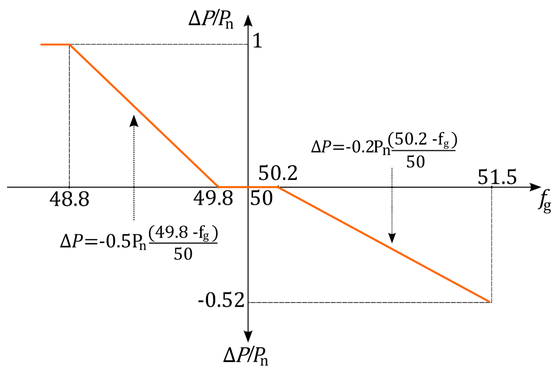
Modeling and real-time simulation of each component of the FESS, including:

- Interior Permanent Magnet Synchronous Machines (PMSM) **(a)**
- Grid-side Converter Controller **(b)**
- Machine-side Converter Controller **(c)**
- Three-level Voltage Source Converters (VSC)
- Phase-locked Loop (PLL)
- Filters

[1] M. Strasik *et al.*, "An overview of Boeing flywheel energy storage systems with high-temperature superconducting bearings," *Superconductor Science and Technology*, vol. 23, no. 3, p. 34021, 2010.

[2] CIGRE, "Technical Brochure 575: Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources," 2014.

Controller parameters are set to comply with the German grid code **VDE-AR-N 4105**:2017-07.



Rea-time simulation results

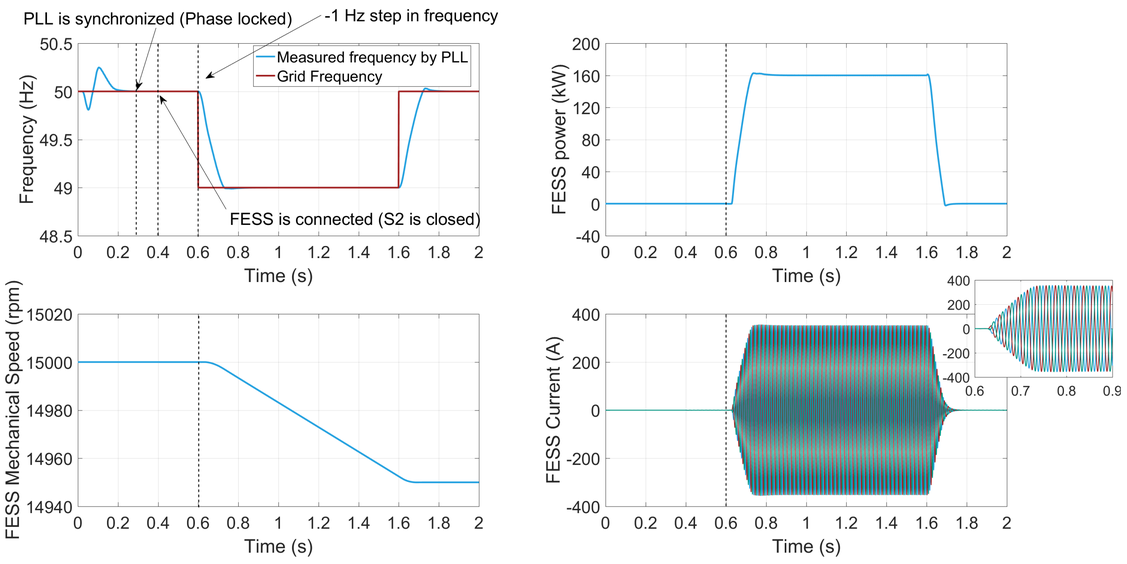
In this work, a FESS with superconducting bearings has been simulated in real-time with appropriate controllers for voltage regulation and frequency support. The FESS and the benchmark grid is simulated in one real-time simulator, while the controllers exchange signals in a Hardware-in-the-Loop (HIL) testing platform

A Benchmark grid based on the CIGRE European LV distribution network benchmark has been implemented in real-time [2].

- Simulation hardware: Opal-RT's OP5600
- Simulation software: RT-LAB
- Simulation step: 20 µs

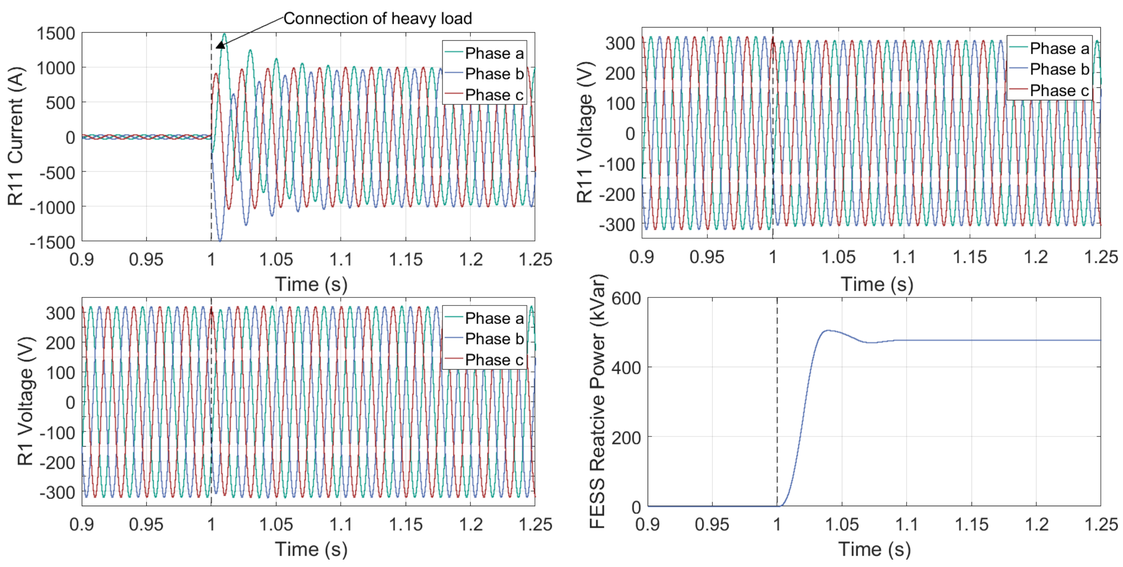
Case 1: frequency support

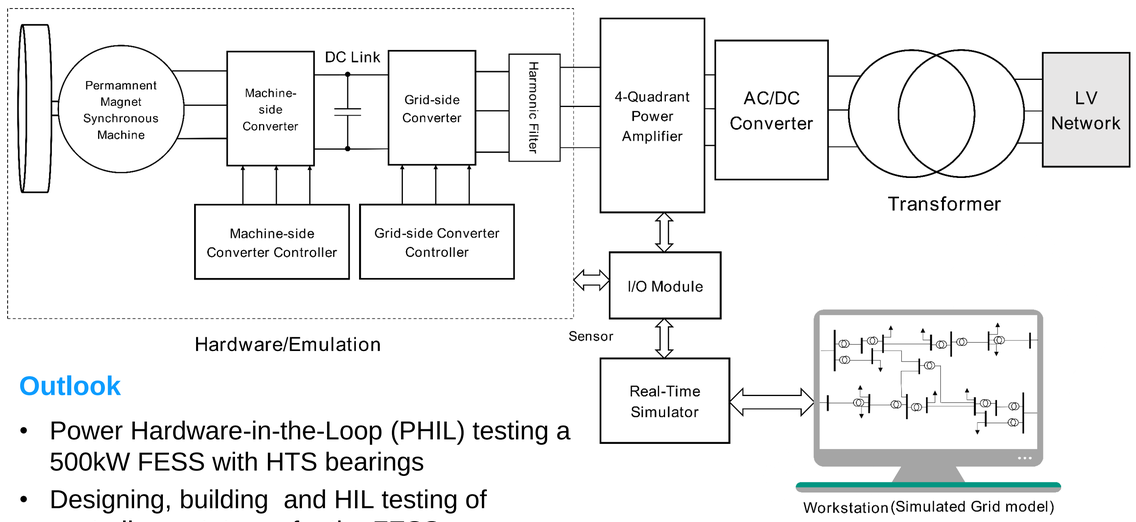
FESS response to -1Hz step change in frequency has been simulated. The FESS injects 160kW to the grid according to the grid code (for a 500 kW FESS).



Case 2: voltage support

A voltage drop due to the connection of a heavy load at bus R11 has been simulated. The FESS reacts by injecting reactive power to the grid.





Outlook

- Power Hardware-in-the-Loop (PHIL) testing a 500kW FESS with HTS bearings
- Designing, building and HIL testing of controller prototypes for the FESS
- Coordinated voltage control with PV systems.