Contribution ID: **482** Type: **Poster**

Sat-Mo-Po.09-01: Energy Cycle Efficiency of Superconducting Magnetic Energy Storage

Saturday 5 July 2025 09:30 (1h 45m)

Superconducting magnetic energy storage (SMES) is a promising candidate for electric power compensation. The target applications of SMES are widely covered with voltage sag, instant shortage, power stabilization, frequency control, load fluctuation, and load leveling. High-temperature superconductors are expected to reduce refrigeration energy requirements for superconducting coils. Particularly, REBCO tapes are strong candidates for high-field magnets because they keep a higher critical current density in a high magnetic field range. In addition, the Hastelloy substrate of the REBCO tapes can be used as support structures for electromagnetic forces. Reversible stress with a 99% critical current recovery is from 610 to 1410 MPa. However, the winding configuration of superconducting coils should be optimized to enhance the stress limit caused by electromagnetic forces.

Based on the virial theorem, the force-balanced coils (FBCs) can balance the electromagnetic forces through a helically wound configuration and minimize the required mass of support structures for energy storage. When the allowable stress and the mass density of the support structure are 400 MPa and 8000 kg/m3, SMES with a conventional coil configuration, such as a solenoid and toroidal field coils, stores the magnetic energy up to 25 to 50 kJ/kg. The FBCs can enhance the theoretical limit of the stored energy up to 50 to 100 kJ/kg. For reference, the theoretical limits of capacitors and flywheels are 25 kJ/kg and 42 kJ/kg. Therefore, SMES with the FBCs'configuration can realize the weight saving of the energy storage system.

This work discusses the theoretical energy cycle efficiency of SMES with the FBCs'configuration. The energy cycle efficiency is defined as the ratio of the output energy to the input energy. In SMES, the input energy should include the energy consumption of cooling systems. The radiative heat loss, the thermal conduction loss from a pair of current leads, and the AC loss in the superconducting coils mainly determine the cooling power.

On the other hand, the ampere-meters of superconductors and the coil surface are a function of the stored energy and the maximum magnetic field. The radiation heat loss is calculated from the coil surface. The AC loss is evaluated by the ampere-meters of superconductors and the operating current density due to the stress limit based on the virial theorem.

Based on the scaling law, the authors show the theoretical energy cycle efficiency determined by the stored energy, the maximum magnetic field, the mass of structures, the ampere-meters of superconductors, the cooling temperature, and cooling power and explore the potentiality of the FBCs as SMES coils. From the energy cycle efficiency viewpoint, the authors examine the feasible target application of SMES depending on the cooling temperature and the type of superconductors, such as NbTi, MgB2, and REBCO, compared to other energy storage systems.

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Session Classification: Sat-Mo-Po.09 - Energy Storage/SMES, Levitation and Magnetic Bearings