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Technologies for Energy Storage
Flywheels and Super Conducting Magnetic Energy Storage

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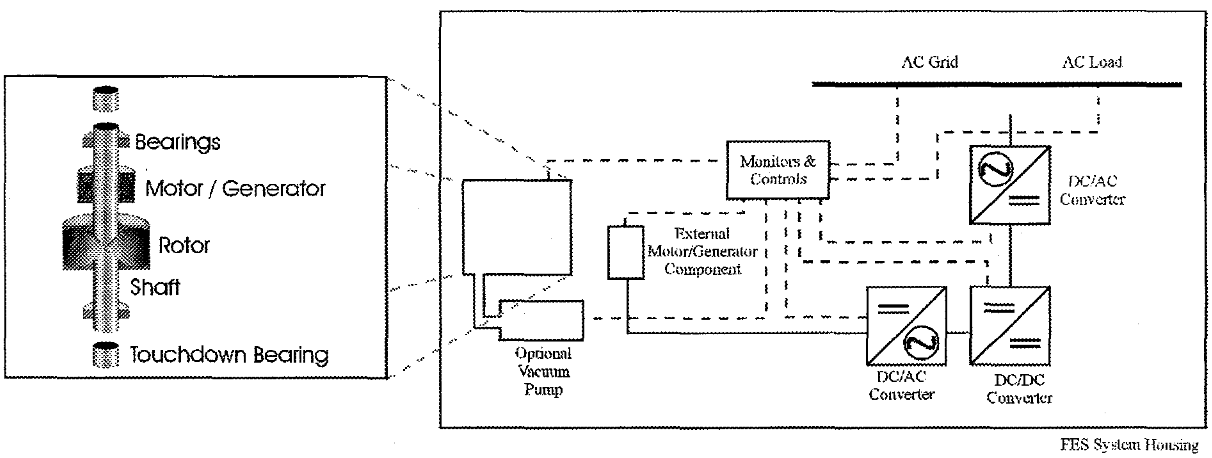
Flywheels

A flywheel is an electromechanical storage system in which energy is stored in the kinetic energy of a rotating mass. Flywheel systems under development include those with steel flywheel rotors and resin/glass or resin/carbon-fiber composite rotors. The mechanics of energy storage in a flywheel system are common to both steel- and composite-rotor flywheels. In both systems, the momentum of the rotating rotor stores energy. The rotor contains a motor/generator that converts energy between electrical and mechanical forms. In both types of systems, the rotor operates in a vacuum and spins on bearings to reduce friction and increase efficiency. Steel-rotor systems rely mostly on the mass of the rotor to store energy while composite flywheels rely mostly on speed.

During charging, an electric current flows through the motor increasing the speed of the flywheel. During discharge, the generator produces current flow out of the system slowing the wheel down. Figure 1 shows the basic characteristics of a Flywheel system.



a) Flywheel Rotor Assembly **b) FES System**

Figure 1. **Blowup of a Rotor Assembly and FES System in Parallel Grid-Connected Configuration.W for 5 seconds**

Steel flywheel systems are currently being marketed in the US and Germany and can be connected in parallel to provide greater power if required. Sizes range from 40kW to 1.6MW for times of 5-120 seconds. At this time sales are limited but growing. The suppliers of the composite type flywheel systems are currently in the prototype stages of development.

Flywheel systems offer several potential advantages. FES systems, as their developers envision them, will have exceptionally long service lives and low life-cycle costs as a result of minimal O&M requirements. FES systems are compact and self-contained allowing them to be placed in tight quarters, and they contain no hazardous chemicals nor do they produce flammable gasses.

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As with any new technology, challenges to widespread commercial use exist. Containment is an issue for all rotating energy equipment, and FES developers must address this concern with selection of sites, containment design, material selection or by thorough testing and rating of their devices.

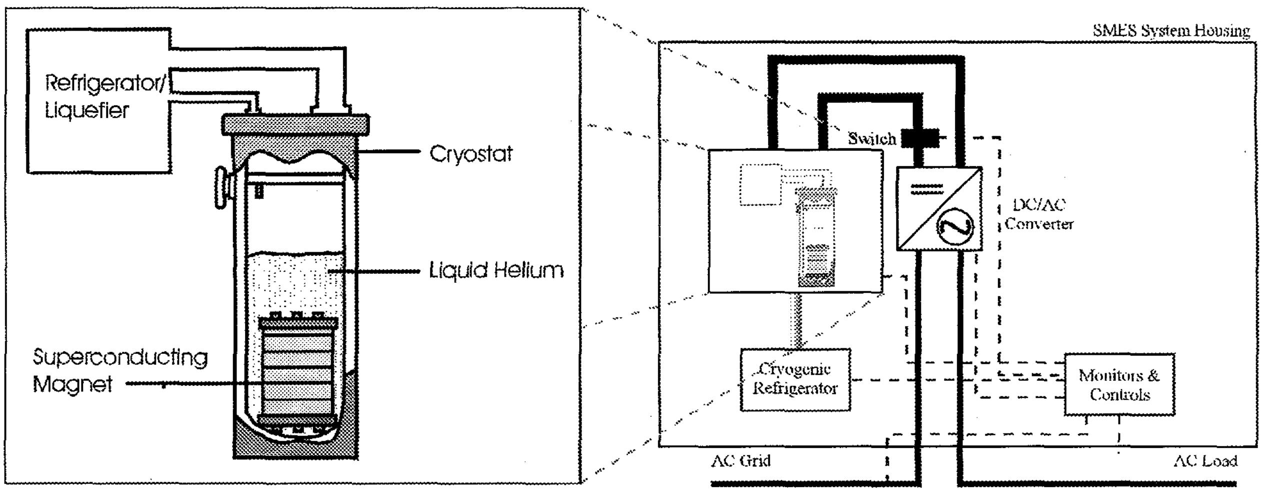
Flywheel developers use a variety of materials and processing methods that produce rotors that perform well at a wide range of rotor speeds. Materials and processing R&D are critical issues in the development of flywheels with energy capacities appropriate to the mid- and long-term goals for flywheel systems. At present, developers are exploring monolithic metallic rotors for low-speed operation and low-density, high-strength composite rotors that operate at very high speeds. These two classes of devices represent two sets of R&D needs. Common to both types of rotors is the need for highly efficient, low maintenance, long life bearings. Both mechanical and magnetic bearing systems are being pursued.

For rotors made of monolithic materials areas of necessary research include bearing improvement and integration with traditional electrochemical UPS devices. For composite rotors, areas of necessary research include improved manufacturing processes, understanding fatigue of the composites, chemical degradation mechanisms of the composites and the effects of degradation phenomenon on the performance and service life of the rotor and the components around it. (For example, will out-gassing from the rotor matrix in the vacuum chamber make vacuum pumps a requirement for systems that include composite rotors?). Significant numbers of "spin-tests" are planned so that flywheel developers will be able to accurately predict the performance and service life of composite rotors in commercial flywheel systems. R&D of health-monitoring technologies for composite rotors (similar to health monitoring of airplane wings) would help researchers develop the necessary performance and service life data. Cost reduction is a goal of all flywheel systems. All of these activities will promote necessary standards for manufacturing, qualifying, testing, and operating FES devices. These types of standards will be essential for commercial systems with composite rotors to gain widespread acceptance in the electric power industry.

SMES

A Superconducting Magnetic Energy Store is an energy storage device that stores electrical energy in a magnet field without conversion to chemical or mechanical forms. In SMES, a coil of superconducting wire allows a direct electrical current to flow through it with virtually no loss. This current creates the magnetic field that stores the energy. On discharge, switches tap the circulating current and release it to serve a load. To remain superconductive, the SMES coil must operate at cryogenic temperatures. Therefore, SMES devices require cryogenic refrigerators and related subsystems in addition to the solid-state power conditioning devices, monitors, controls, climate controls, utility and user interface equipment, safety devices and transportation features.

SMES systems for power quality applications are available from two vendors in the United States: American Superconductor Corporation (ASC) and Intermagnetics General Corporation (IGC). Both systems, as shown in Figure 2a consist of Low Temperature Superconducting coils that operate in liquid helium at a temperature of 4 K (–269°C). The devices use High Temperature Superconducting leads as an interface to copper conductors that are used outside of the cryostat of the SMES. Because the HTS leads operate at higher temperature than LTS materials, they improve system thermal efficiency and electrical performance at the cryogenic/ambient interface. Figure 2b illustrates a SMES unit connected in series with the electric grid and an AC load.



a) Cutaway of Cryostat & Coil **b) SMES System**

Figure 2. Blowup of SMES Cryostat and Coil and SMES System in Series Grid-Connected Configuration.

Most SMES units fielded to date provide 1MW for 1 second and can be paralleled for more power. These early units have been used in power quality applications to correct voltage sags and dips at industrial facilities in the US and Africa. A new application is being installed by a US utility to stabilize a large, ring transmission network. Six units, each capable of providing 2MW, will be installed at substations to stabilize oscillations in the transmission network.

SMES systems have several advantages. A SMES coil has the ability to release large quantities of power within a fraction of a cycle, and then fully recharge in just minutes. This quick, high-power response is very efficient and economical. SMES manufacturers cite controllability and reliability and no degradation in performance over the life of the system as prime advantages of SMES systems. SMES systems are compact, self-contained, and highly mobile; a single semitrailer or equivalent space can deliver megawatts of power. It can be kept at remote locations. Also, SMES units contain no hazardous chemicals and produce no flammable gases. The estimated life of a typical system is at least 20 years.

The technical challenges to SMES include: SMES devices produce large magnetic fields requiring stay out zones and careful component design; they have the potential to rapidly pressurize their cryostats if their coils go normal (become non-superconducting). These issues are well understood and managed safely. For small SMES systems, the issues are designing the conductor to minimize parasitic losses from the air conditioning and refrigeration (including HTS leads and coil) systems, and designing the PCS to minimize costs. Because coil characteristics drive PCS requirements, coil and PCS advances will greatly affect each other. The main business challenge for this new technology lies in the enhancement and full commercialization of smaller systems and the development of systems with greater energy capacity at affordable cost.

Reference

A Summary of the State of the Art of SMES, FES and CAES, Taylor, et. al., SAND99-1854, 1999