High-speed, low-cost flywheels for energy storage in sustainable power systems with distributed generation

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The need and obligation to develop sustainable power supplies worldwide, is coupled to environmentally friendly and sustainable energy storage. This is particularly important in distributed generation not connected to the grid, for example in rural electrification programs in developing countries. These storage technologies also have the potential to impact the sustainability of power systems in developed countries, particularly with the increasing interest in wind, solar and other advanced distributed sources. Other areas of application relate to transportation and micro-grids in developing countries.

Economic power supplies to rural areas in South Africa, often takes the form of Photovoltaic cells connected to a lead-acid battery. The battery lifetime is about two years and the efficiency is 70% or less. There are serious environmental problems associated with the use of lead acid batteries, particularly in the developing countries where the recycling infrastructure is minimal or nonexistent. The availability of high strength fibre composites, low cost rare earth magnets and micro-electronics makes it possible to produce a durable, non-polluting, cost effective battery. These materials are readily available in South Africa, including the magnetizers for the magnets and the machine tools for prototyping or production.

This paper covers the technical aspects of an electromechanical battery. A permanent magnet motor-generator is incorporated in a composite flywheel, running at high speed in a vacuum containment to minimize air friction losses. The flywheel is to be suspended on cascaded, Teflon coated, high-speed roller bearings. A composite flywheel requires a simple containment to sustain the vacuum for the moving parts, since most of the energy is dissipated in the fracture process in case of catastrophic failure. A 3-phase, switch mode bridge converter, driven by a bipolar pulse width modulation board, achieves the variable speed control for the flywheel and the control of the DC bus voltage. The target storage capacity is 250 W-h with a power rating of 40 W.

An outside rotor design is used to maximize the inertia and hence energy storage capability. The rotation is around the vertical axis to minimize the required containment. It is envisaged that the flywheel will be buried underground, to further minimize containment requirements.

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Because of the high speed, a 2-pole design is desirable. However to minimize iron losses, an iron-less stator is used. This requires either extremely thick magnets on the rotor to provide the necessary flux density, or a method for providing the flux density with multiple magnets. A Halbach array allows multiple magnets to be used in a 2-pole configuration. This reduces the machine costs because of the use of multiple small magnets.

Two passive magnetic bearings are used to suspend the shaft radially, which is mounted vertically. The advantage of this is that an external power supply with associated control circuitry is not required. This reduces the complexity and the costs. The entire assembly is suspended on a teflon ball on a steel plate for axial support. This provides a low coefficient of friction bearing, with measurements verifying the design calculations.

The overall system consists of a bi-directional dc-dc converter operating from the solar panel bus and connected to the PM motor/generator through an inverter with freewheeling diodes. The freewheeling diodes provide an uncontrolled rectifier bridge from the generator to the solar panel bus, with power flow controlled by the dc-dc converter. As the panel output reduces, the dc-dc converter allows the PM machine to generate power back into the solar panel dc bus, using the freewheeling diodes of the inverter as an uncontrolled rectifier. A simple micro-controller is used to control the entire system.

The presentation will explain the schematics of the magnetic bearings, control diagram, power electronics and motor/generator. The overall operation will be described and the future direction of the project discussed.

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