A pulse-width modulated buck-boost converter has been designed to interface a 500WH inertial energy storage system operating from 70 to 140VDC to a constant bus of 150VDC. Implementation of hysteresis feedback control provides excellent voltage regulation. The design is based on a 300WH, 94% WH efficient prototype and is currently being optimized to yield 97% overall WH efficiency.

The feasibility of utilizing inertial energy storage flywheels in spacecraft power applications as an alternative to electrochemical energy storage is currently being examined. Electrochemical systems consisting of nickel-cadmium or nickel-hydrogen batteries typically have low cyclical lifetimes, on the order of five years for a lower earth orbit (LEO), limited reliability due to their series construction, and low useful energy densities (about 7 to 14 WH/kg). Various aspects of the inertial energy storage system's performance seem promising. The development of interference assembled composite material flywheels, magnetic suspension bearings, and permanent magnet, ironless armature, brushless DC motor/generators has led to the design of a shaftless flywheel system that offers particular advantages, especially in LEO satellite applications. These include competitive useful energy density figures (greater than 20 WH/kg) at accompanying high rotational speeds, and maintenance free operation at a greatly extended cycle lifetime (20-30 years). The system is also potentially very energy efficient with dual applications in attitude control. (1)

In a LEO application, a spacecraft power system is characterized by a 90-minute sun-shadow cycle. The flywheel motor is powered by the solar array bus for 60-minutes and spins up the flywheel which stores the kinetic energy. This stored energy is then converted to electrical energy by the generator to power the spacecraft for the 30-minute eclipse. As the energy is used, the flywheel spins down. The voltage appearing at the motor/generator terminal is proportional to the flywheel speed. The 500WH inertial energy storage system has been designed for a 75% depth of discharge, which represents a speed change of 2:1.

The feasibility of utilizing any inertial energy storage sub-system, consisting of magnetically suspended flywheels in spacecraft power applications is largely a function of its efficiency. The design goal for the 500WH inertial energy storage system has been set at 80% round-trip efficiency to prove it competitive with the current electrochemical sub-systems typically yielding 70% round-trip efficiency.

Because advancing spacecraft technology is creating a demand for higher spacecraft bus voltages than the typical 28V used today, the 500WH inertial energy storage sub-system is required to interface with a spacecraft bus of 150VDC. This was a spacecraft bus voltage under consideration by Space Station. The flywheel and motor/generator for the 500WH system has been designed for a voltage varying from 70 to 140VDC in both charge and discharge mode. Of course, power conditioning is required in order for the flywheel to interface with a constant spacecraft bus voltage of 150VDC in both modes. (2)

Currently, the electronic circuitry needed for suspension, commutation, and power flow are packaged externally to the flywheel motor/generator. The most convenient approach to power conditioning is to insert a bidirectional power converter between the flywheel motor/generator terminals and solar array bus. This converter could utilize any appropriate technology. So far, pulse-width modulation, resonant converter, and quasi-resonant converter technologies have been considered for this application. A circuit utilizing pulse-width modulation and designed to perform the voltage boost from 70/140V input up to 150V, in a 300WH application has been designed and built (Figure 1). It was found to have a nominal efficiency of 94%. Because of the
promising results of this baseline approach, the circuit is currently being redesigned to yield the required 97% efficiency for the 500WH application. Simple modifications have been made to the current circuitry, such as a reduction of the operating frequency to reduce switching losses, that have increased the efficiency significantly. Although challenging, this goal is reasonable.

The bidirectional feature required for this application can be accomplished by the addition, to the boost topology under consideration, of a switching transistor in parallel with the existing commutating diode and a commutating diode in parallel with the existing main switching transistor. Since the baseline approach uses a power FET for the switching transistor, the intrinsic diode internal to the power FET could serve the function of a commutating diode, but would be severely stressed. Therefore, the current design will consist of separate boost and buck topology circuits for accomplishing the bidirectional feature (Figure 2). Both circuits will share the input and output capacitors and the main output voltage control circuit (Figure 3).

Since this type of regulation is achieved independently to the commutations of the six switches in the permanent magnet, motor/generator, additional energy losses are incurred, and for this reason may not be the most advantageous. Another approach under consideration for future work is to utilize the existing motor/generator commutation switches to perform the required voltage regulation function. This technique should improve the round-trip efficiency over that of the baseline approach, even with the additional expense of the more complex control circuitry and additional energy storage components (inductors and capacitors) that are needed. Circuit designs utilizing state-of-the-art motor control integrated circuit chips for pulse-width modulation of the commutation switches in the motor mode are currently available. Conditioning for the generating mode of the flywheel represents a new design challenge since this type of energy storage has not been used for this application. Therefore the majority of the work accomplished to date emphasizes this mode.
Figure 3 Voltage Controller Circuit

REFERENCES
