

DC Power Management with a High Performance Flywheel

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ABSTRACT

Power management systems using flywheel energy storage may be tailored to serve a variety of applications. These applications include ridethrough, energy storage in hybrid propulsion systems, trackside power management, and providing pulsed power in defense applications. In many of these applications a flywheel connected to a DC bus will source or sink current in response to either behavior of the bus as monitored by the flywheel controller or in response to explicit commands from the application.



AFS Trinity M3A Flywheel Power System (two units)

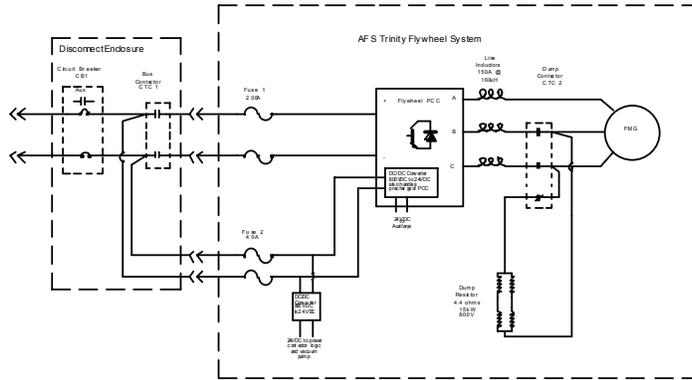
With development-stage flywheel systems emerging as competitive products, development emphasis has changed from a focus on flywheels as a collection of enabling technologies to that of a power management solution for critical systems. Flexibility inherent in the integral power electronics and control system allows a flywheel system to be optimized for a range of diverse applications.

This article discusses the operating characteristics of a 100 kW flywheel system used for stationary power management applications. The test configuration includes a DC supply, resistive loads, and two 100kW flywheels connected to the DC bus in parallel. Operating strategy and the performance of the flywheel system as it implements this strategy are covered.

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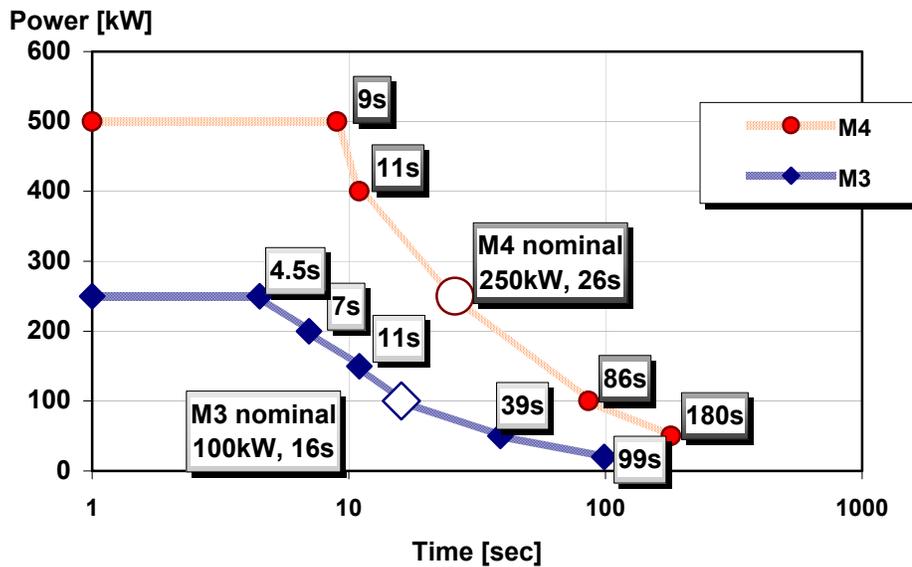
SYSTEM DESCRIPTION

The AFS Trinity M3A FPS is a DC connected power management system. The energy storage element is composite rotor incorporating a permanent magnet motor generator with a total rotor weight of 86 lbs. The variable speed, variable voltage flywheel interfaces with a DC bus through an IGBT inverter.



M3A Flywheel Power System

Also included within the system are a pre-charge circuit and a dump resistor which brings the flywheel to rest in the event of a system fault.



M3 and M4 System Performance

The M3 and future M4 systems are characterized by the duration for which they can discharge at full power.

The nominal rating of the M3 system is 100 kW for 16 seconds although it may also source or sink power at over 200 kW for shorter intervals.

Some of the interesting features of the AFS Trinity flywheel include a high charge rate (equal to discharge rate) and a high duty factor. These features permit the use of this system in power management applications where regenerative energy will be absorbed at a high rate. The nominal thermal design of the system permits operation in thermal equilibrium for continuous repetition of the following charge-discharge cycle:

Full power charge:	15 seconds
Dwell:	15 seconds
Full power discharge:	15 seconds
Dwell:	15 seconds

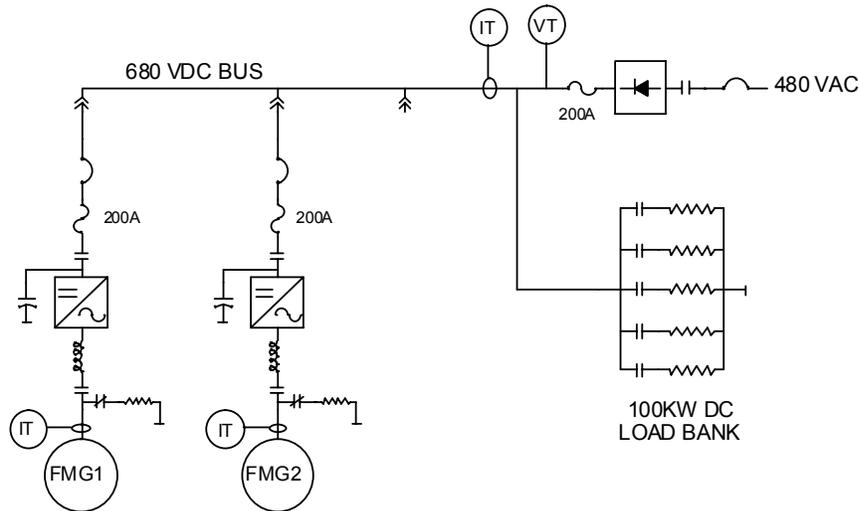
Since full power charge and discharge times equal the dwell times in this cycle, this is referred to as having a 50% duty factor.

The measured efficiency for the conversion of electrical energy on the DC bus to kinetic energy stored in the flywheel rotor is 95% at a 50% state of charge at full rated power. This value of 95% is both a mean value and a weighted average value. Efficiency at high speed (high state of charge) is higher while efficiency at a low state of charge is lower. For a cycle covering the entire charge range, net energy storage efficiency evaluated at the DC bus is about 90% at full power.

The state of charge and availability of the flywheel are always accurately known and cycle to cycle repeatability is perfect. The design cycle life is in excess of 10^6 cycles and testing to date has demonstrated 40,000 cycles without degradation.

SYSTEM TESTING

The basic development test setup includes a DC supply, resistive loads, and two 100kW flywheels connected to the DC bus in parallel.



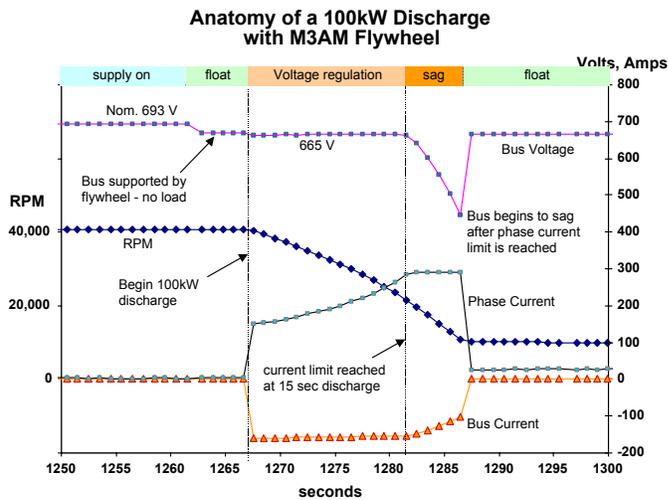
Test Configuration

This configuration allows evaluation of the operation of parallel units using multiple control strategies. Loads may be sequenced manually or automatically. A range of other sources and loads may be connected.

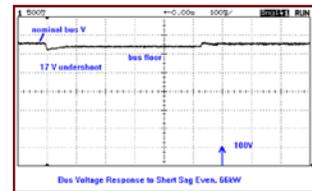
The usual control approach implements two different strategies with regulation of bus voltage having first priority and regulation of the state of charge of the flywheel having second priority. Upon startup, the system observes DC bus voltage. If the bus voltage is within a defined range, the flywheel accelerates to a nominal operating speed or state of charge. The system continues to observe bus voltage. When bus voltage drops below a user defined setpoint, the system discharges to maintain the bus voltage at the level of the lower setpoint. Conversely, when bus voltage exceeds a user defined setpoint, the system absorbs power and charges while holding the bus at the level of the upper setpoint. When the bus voltage is floating between setpoints, the flywheel charges or discharges to return to nominal operating speed. As the flywheel returns to nominal speed, this action alters the DC bus.

All of the parameters that define this process are settable by the user through a keypad interface. These include but are not limited to: upper and lower bus voltage setpoints, nominal operating speed/state of charge, and charge/discharge rate during float.

The following charts show typical data from system testing.



High Power Discharge (Exceeding Rated Storage)



Transient Response

Data for the high power discharge show the response of the system to load conditions that exceed the rating of the system. In this instance, the flywheel maintains DC bus voltage at the lower setpoint level of 665 VDC until the lower speed limit for 100 kW operation is reached. By design, for the M3 rotor this occurs after about 15 seconds at 100 kW. At this point the mode of operation of the system changes from bus voltage regulation to phase current regulation. The system continues to operate in this condition until either the load is removed, the source is restored, or the flywheel is decelerated almost to a complete stop. In the example here, the load is removed and the flywheel system continues to regulate DC bus voltage.

Also of interest is the transient response of the system. For operation with a bus voltage in the range of 550 - 800 VDC, a step change in load on or off causes an undershoot or overshoot of 10 - 25 VDC. The recovery time for voltage regulation after a step change in load is 10 - 30 ms.