Theory of Operation: Low Speed Flywheel

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Objective

This paper will review the concept and operation of a flywheel system used as a direct current (DC) energy source in three-phase uninterruptible power supply (UPS) applications in place of chemical batteries or other short term energy storage technologies.

Overview

Over the last decade, the power quality market has seen the emergence of several new energy storage technologies that address immediate delivery of energy to critical loads following the interruption of utility power. These alternatives to traditional electrochemical batteries include such exotic technologies as ultra-capacitors, super-cooled electromagnets and quick-start engines augmented by hydraulic or pneumatic energy storage. More recently, the industry has seen the reintroduction of one of the oldest energy storage technologies – the flywheel. Modern flywheels take many different forms, ranging from high-tech composite wheels that rotate at ultrahigh speeds to the more traditional steel wheels that couple with existing rotating machines.

Figure 1: Decommissioned Industrial Flywheel

SIMPLICITY

Flywheels seem to have inherent appeal as an alternative to traditional energy storage technologies. Part of this appeal is due to the sheer simplicity of storing kinetic energy in a spinning mass. For decades, most engines have used this concept to smooth their operation. Prior to the development of cost-effective power conversion electronics, the primary method of limiting power interruptions to critical loads was by adding inertia to a motor-generator set feeding a load. Over the last twenty years or so, the promise of a compact, safe, environmentally benign, low-maintenance, long-lasting and predictable source of energy has intrigued inventors and investors alike for applications such as electric vehicles, utility load-leveling and satellite control.

The flywheel has regained consideration as a viable means of supporting a critical load during main power interruption. This is due to the low capital expense and extended run time now available from many systems as well as continued customer dissatisfaction with traditional electrochemical energy storage. Interestingly, continuing advances in the power electronics field, which initially provided an alternative to original flywheels used for “blip” protection, have now enabled some flywheel designs to deliver a cost-effective alternative to the power quality market.

FLYWHEEL 101

The concept behind traditional flywheels is really quite simple. Objects in motion continue in motion unless acted upon by an outside force. Synchronous machines can ride-through short power interruptions by using the mass of the rotors to "flywheel" through these periods. In the case of a motor-generator (M-G), the rotors act as flywheels. Physics allows us to change kinetic rotational energy into electrical energy. In the case of a M-G, a given operating speed (say 1800 rpm) produces a corresponding output frequency, say 60 Hz. As the M-G slows, the frequency declines proportionately. However, if the M-G is a power conditioner, the load must be able to tolerate a decreasing frequency during ride-through. The larger the rotors, the less speed they have to give up for a given electrical load. However, there are practical limitations to the size of an M-G for ride-through applications. At some point, the electrical losses of turning an oversized rotor make it unattractive.

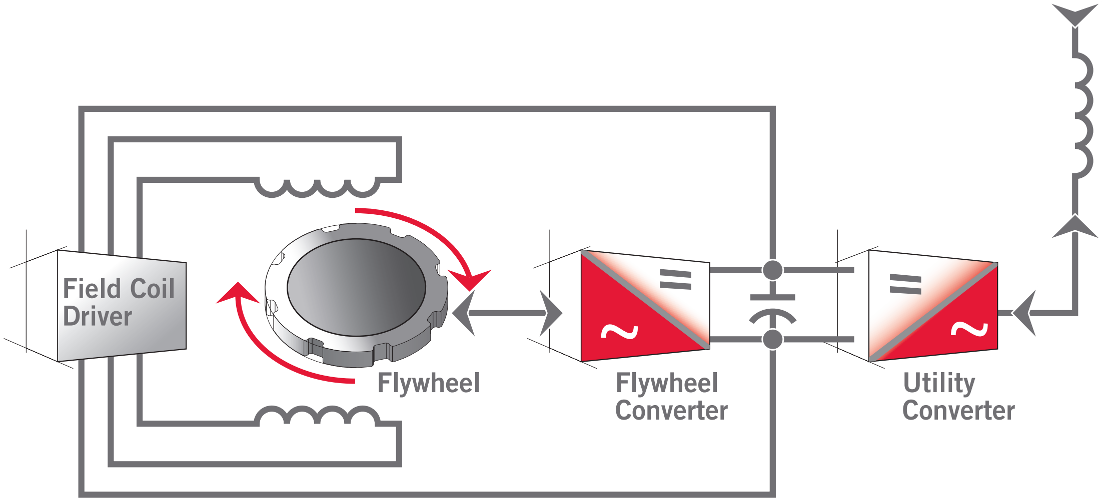

Figure 2: Simplified One Line Diagram

The alternative is to add additional mass with a flywheel, which can be mounted on the same shaft as the motor and generator in order to increase the ride-through time before electrical frequency diminishes to unacceptable levels (0.1 to 0.5 seconds). Again, there are limitations. After the ride-through is over, we must put back the kinetic energy we removed from the mass (rotational speed) the same way we recharge a battery. The problem when the system is a synchronous M-G is that the reacceleration current might be ten times the normal full load current, which in most applications is unacceptable. As a result, the cost of over-sizing the service and the cost of bracing for the high available fault current has ruled out flywheels that ride-through much more than 350 milliseconds – until now.

CLEANSOURCE® DC FLYWHEEL

The CleanSource DC flywheel is configured as a two terminal DC power storage system and is a functional replacement for a bank of chemical batteries used with three-phase UPS systems. Like a chemical battery bank, it receives recharge and float power from the two terminal UPS DC bus and returns power to the same DC bus whenever the bus voltage drops below a programmable threshold level.

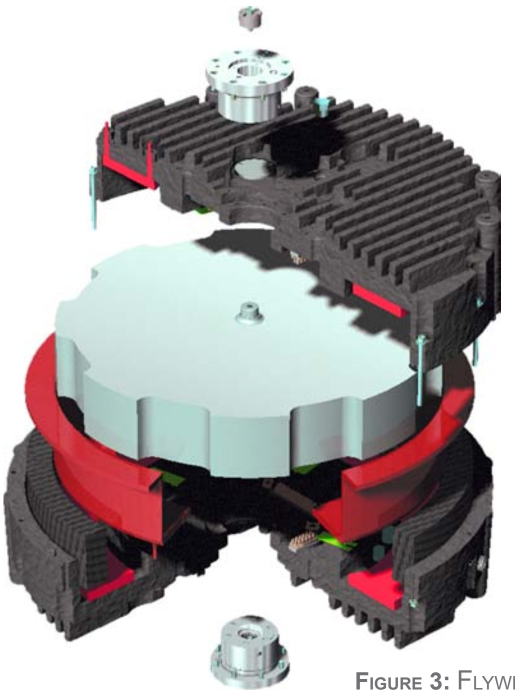

Figure 3: Flywheel Assembly

The heart of the CleanSource DC flywheel is a 14" high, 32" diameter integrated motor/generator/flywheel system that is capable of storing and delivering up to 250kW of power to the DC bus of a UPS. CleanSource DC flywheel stores energy as angular momentum in a single-piece forged 4340 steel rotor rotating in a rough vacuum.

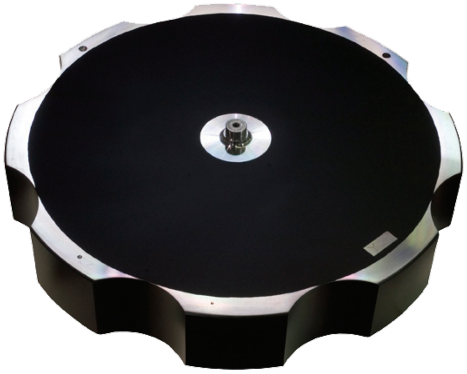

Figure 4: Forged 4340 Steel Rotor

The motor, generator and energy storage functions are all performed by the same stator and rotor structure. There are no permanent magnets or brushes nor are there coils or magnets on the rotor. Optical sensors control the motoring commutation. A magnetic bearing that is integral with the motor-generator field coil structure supports most of the rotor weight. This enables the mechanical bearings to be optimally loaded and greatly extends bearing life. When the UPS battery charger is connected and turned on, the system begins to draw power from the charger to accelerate the rotor. When the flywheel reaches its "fully charged" speed, it enters a mode comparable to a chemical battery's "float" state, in which a small amount of power is drawn from the UPS battery charger to maintain constant rotation.

Once the flywheel is above its minimum discharge speed (about 1/2 of its "fully charged" speed), it is capable of supporting the DC bus in case of a main power interruption. In the event of a utility outage, the AC output bus of the UPS provides a protected source of power for the controller. Whenever the controller senses the DC bus voltage has fallen below a preset minimum, motoring is disabled. A closed loop field control is used to raise the generator output voltage so the bidirectional insulated gate bipolar transistor (IGBT) converter boosts the flywheel DC output to maintain constant voltage, independent of rotor speed. When the power to the UPS rectifier is restored, either by a standby generator or utility power, the double-conversion UPS rectifier brings the DC bus back to its normal value and the flywheel automatically resumes charging.

Figure 5: Example of an integrated flywheel UPS system

CONCLUSION

Flywheel technology is certainly a viable alternative to incumbent energy storage technologies. It alleviates the reliability, lifespan, maintenance and safety issues associated with batteries. Its primary use is in data center applications by bridging power from main utility to standby generator. However, there are a multitude of other applications in which the technology lends itself well as a glitch protection system, particularly in industrial applications where short ride-through is required to avoid hours or days of lost production due to sudden interruptions in operation.

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