Start It Up: Flywheel Energy Storage Efficiency

By Michelle Dunn, Conroe ISD Academy of Science and Technology

Abstract

The purpose of this project was to construct and test an off-grid photovoltaic (PV) system in which the power from a solar array could be stored in a rechargeable battery and a flywheel motor generator assembly. The mechanical flywheel energy storage system would in turn effectively power a 12-volt DC appliance.

The voltage and current of different steel flywheel thicknesses were measured versus time for two different load settings on a 12-volt DC fan. The energy efficiencies of the system for each flywheel size were then calculated by integrating the power versus time scatter plots.

The off-grid PV system was found to be functional in storing and discharging power, especially during quick discharges. Although not the most efficient method of energy storage, this apparatus shows great promise for energy storage when further tested and improved.

Introduction

Currently the United States is struggling with an outdated and problematic electric power grid that fails to meet high demand and to integrate renewable energy sources. A cheaper, less harmful, and easier to maintain energy storage device, the flywheel, may be able to replace the battery banks currently used at energy storage sites such as in solar and wind farms, for regenerative braking systems for railways, and as voltage fluctuation buffers on oil rigs.

An alternative power storage system for a photovoltaic (PV) system instead of batteries is a flywheel, which uses stored kinetic energy created by electrical energy to provide power. Using a flywheel instead of a battery has advantages: a large and quick discharge, no dependency on temperature or environmental factors, no emissions, and no memory effect. Flywheel systems can provide power when there is not enough power being made or none at all, can store excess energy, and can operate in uninterruptible power supplies.

The goal of this project was to demonstrate the viability of a flywheel system to successfully store and discharge electrical energy. By constructing an off-grid photovoltaic (PV) system in which the power of a single-crystalline array was stored in a rechargeable battery and a flywheel, the mechanical flywheel energy storage system could then be used to power a 12-volt DC appliance.

Procedure

The first step involved assembling the photovoltaic system and charging the battery as well as connecting the system using appropriate wiring and connectors. Refer to Figure 1 below for the circuit layout.

A 10-watt mono-crystalline solar panel was placed on a cookbook stand at an angle of 60 degrees for optimum sunlight during the fall and winter. The solar panel was connected to a 7-amp charge controller to prevent overcharging the battery, with the charge controller connected to a 12-volt 8 AH sealed lead acid battery placed in a vented battery box. Two three-way switches were connected via a labeled terminal (B in Diagram 1) to control the direction of current.

The flywheel motor assembly was connected to the common terminal on the second switch. The assembly consisted of a miniature 12-volt DC motor permanently attached to a 0.25-in. thick, 6-in. diameter, steel base plate, upon which three removable steel plates, each 6-in. in diameter of

Michelle Dunn is a member of the Class of 2012 of the Conroe ISD (TX) Academy of Science and Technology. Inquiries regarding her research may be sent to scaffery@conroeisd.net.

varied thickness (0.25-in., 0.50-in., and 0.75-in.), could be attached. A metal squirrel cage surrounded the flywheel motor assembly to serve as a safety shield in case the plate became off balance on the motor axis and spun off.

The load (a 12-volt "Tornado" fan) was connected by using a 4-socket car adapter. Initially it was planned to use a 60-watt light bulb as the load. However, due to voltage spikes from the flywheel motor assembly being rejected by the AC-DC inverter, the load was changed to a 12-volt DC fan.

All components were connected to a common ground wiring system and mounted onto a wooden mounting/display board. 14-gauge insulated copper electrical wiring (max. 32 amps) and wire connectors were used for connections. A video camera, camera, digital multimeter, and timer were used to record data. Microsoft Excel and Logger Pro were utilized for data analysis.

In terms of safety, a certified electrical engineer approved the design. The battery was never opened and the voltage and current of both the battery and solar panel were constantly monitored. Generous size estimations and insulated tools were used as well. Additionally, gloves and safety glasses were worn during testing.

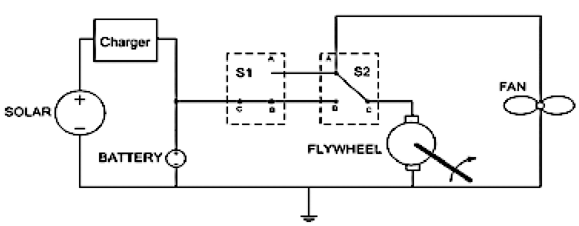

Figure 1 - Schematic Drawing of DC Load System

Testing

For each test, a check from the battery directly to the load (fan) was made initially to ensure proper connections. The video camera was set to record the timer and multimeter readings during the tests.

The flywheel was charged from the battery for 30 seconds based on when the current would generally plateau. After 30 seconds, the switches were reset to allow the flywheel to discharge to the fan. Each flywheel size (base plate only, base plate plus 0.25-in. plate, base plate plus 0.50-in. plate, and base plate plus 0.75-in. plate. Three trials were made for each test to prevent bias. During both charge and discharge, the following measurements were made (see Figure 1 for locations of measurements):

Voltage vs. time for no, low, and high settings on the fan. The multimeter leads were placed on common (S1) and ground (S2).

Current vs. time for low and high setting on fan. The multimeter leads were placed on common (S1) and B (S2) during charging, then common (S1) and A (S2) during discharging.

After each trial, once the flywheel had stopped spinning the switch wire from the battery was disconnected and covered with electrical tape. Photographs of the set-up were taken and observations were recorded. Throughout testing, all system components were routinely checked for safety.

Results

After all the tests were completed, the videos were watched and data collected in Microsoft Excel. The averages of the three trials for test each were calculated. Then a scatter plot was made to show the voltage for no load, the voltage and current for low load, and the voltage and current for high load versus time for each plate.

Refer to Figure 2 for the 0.25-in. plate example. The voltage and current values were multiplied to make a second scatter plot showing the calculated power used and produced by the flywheel during both low and high load cases. Refer to Figure 3.

Vernier Logger Pro was used to calculate the integral (area under the curve) of the power versus time curves to determine the measured flywheel energy input and output for both the low and high power cases for each flywheel size. The theoretical energy stored in the flywheel for each flywheel mass was then calculated by utilizing the

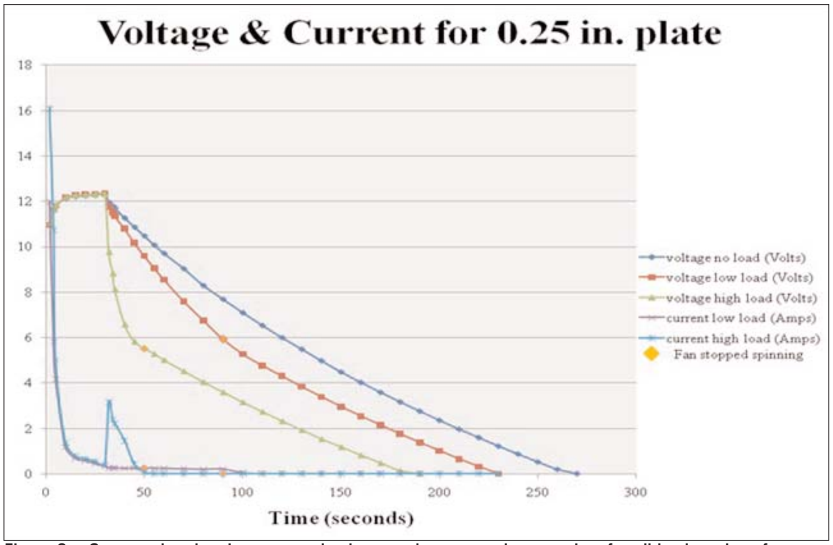

Figure 2 – Scatter plot showing averaged voltage and current values vs. time for all load settings for 0.25 in. plate

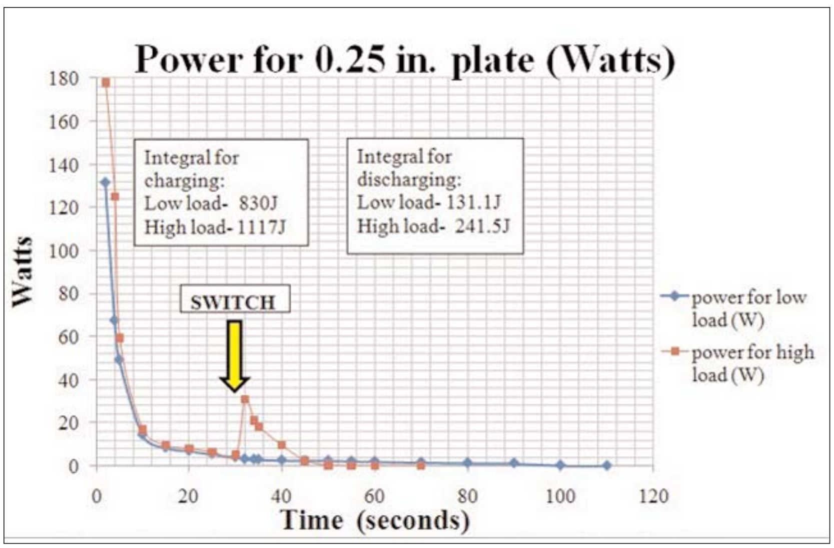

Figure 3 – Scatter plot of calculated power curve for low and high load for 0.25 in. plate

Flywheel Efficiency	Base plate		0.25 in. plate		0.5 in. plate		0.75 in. plate	
	Low	High	Low	High	Low	High	Low	High
Measured Energy Imput	534.4J	521.4J	830.4J	1117J	1348J	915.9J	1792J	1759J
Measured Energy Output	14.4J	35.92J	131.4J	241.5J	36.20J	113.5J	192.9J	333.2J
Theoretical Stored Energy	173.1J	173.1J	346.2J	346.2J	519.4J	519.4J	692.5J	692.5J
Charge Efficiency	32.39%	33.20%	41.69%	30.99%	38.53%	56.71%	38.64%	39.37%
Discharge Efficiency	8.319%	20.75%	37.95%	69.76%	6.970%	21.85%	27.86%	48.12%
Overall Efficiency	2.695%	6.889%	15.82%	21.62%	2.685%	12.39%	10.76%	18.94%

Table 1 – Calculated Efficiences

flywheel energy equation, $E = mr^2\omega^2/4$, where E is energy in joules, m is mass in kilograms, r is radius in meters, and ω is angular velocity in radians.

Since a direct relationship was found between increasing flywheel thickness and flywheel spinning time, it was assumed for each flywheel size that the motor reached an optimal speed of 361 radians per second. Therefore the energy stored could be calculated with the known values of flywheel mass and radius.

To calculate the measured energy input, the theoretical stored energy was divided by the integral of the charging time period. To calculate the measured energy output, the integral of the discharging time period was divided by the theoretical stored energy. To calculate the overall efficiency, the integral for the discharging period was divided by the integral for the charging period.

To assess the validity of the methods used in the experiment, a correlation coefficient was calculated using Microsoft Excel for the averaged sets of power calculations from the three voltage and current trials for the low and high loads of each flywheel size.

Since the correlation coefficients for the averaged sets of power calculations of the different loads for each flywheel size ranged between .97 and .99, the methods used in the tests were consistent.

As shown in Table 1 (Calculated Efficiencies), the 0.25 in. plate was found to be most efficient, possibly due to the particular weight and stress load that the 0.25 in. plate had on the motor/generator. The high load case for each flywheel size was found to be more efficient than the low load, confirming that flywheels are effective for quick and powerful discharges.

Discussion

Improvements for this project relate to efficiency and application. Measuring the motor speed and the voltage and current ratings for the low and high load settings on the fan would validate the assumed motor speed and provide further information on the load specifics for the different tests. In addition, the system had inefficiencies, with energy lost due to general air resistance, the motor bearings, the flywheel being slightly off balance and vibrating, as well as in the wiring, connections, switches, and with overestimated sizing calculations.

Reducing flywheel energy loss and attempting to power the flywheel directly from the solar panel and lessening the dependence on the battery would be the main goal of a continuation of this project. Improvements of the flywheel motor assembly would include enclosing it to reduce air resistance, incorporating magnetic bearings, and improving the balance of the flywheel on the shaft.

Other improvements include using different flywheel materials/shapes/designs, having a more appropriate (e.g., faster) motor/generator, using an oscilloscope for more accurate current and voltage readings, and being able to power AC loads using an inverter (to convert DC to AC current) and an RC Snubber circuit (to smooth out voltage spikes coming off of flywheel motor assembly).

An application for this project would be for people to start using off-grid photovoltaic systems to power their homes or private businesses. More research into improving energy storage systems such as the flywheel would help bridge this transition. Cooperation is the critical instigator to get the wheel spinning.

Conclusions

Modernization of the American electric grid requires the integration of renewable energy resources, a smarter grid, financial incentives, and consideration of commercializing new technologies while maintaining currently used energy sources (oil and natural gas). Comparing breakthrough innovations with the present energy sources, such as by analyzing the liability of the flywheel energy storage system over deep cycle rechargeable batteries, would determine the amount of confidence that should be put into integrating newer technologies into the electric power grid of the United States.

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