Flywheel Energy Storage (FES): Exploring Alternative Use Cases

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Abstract

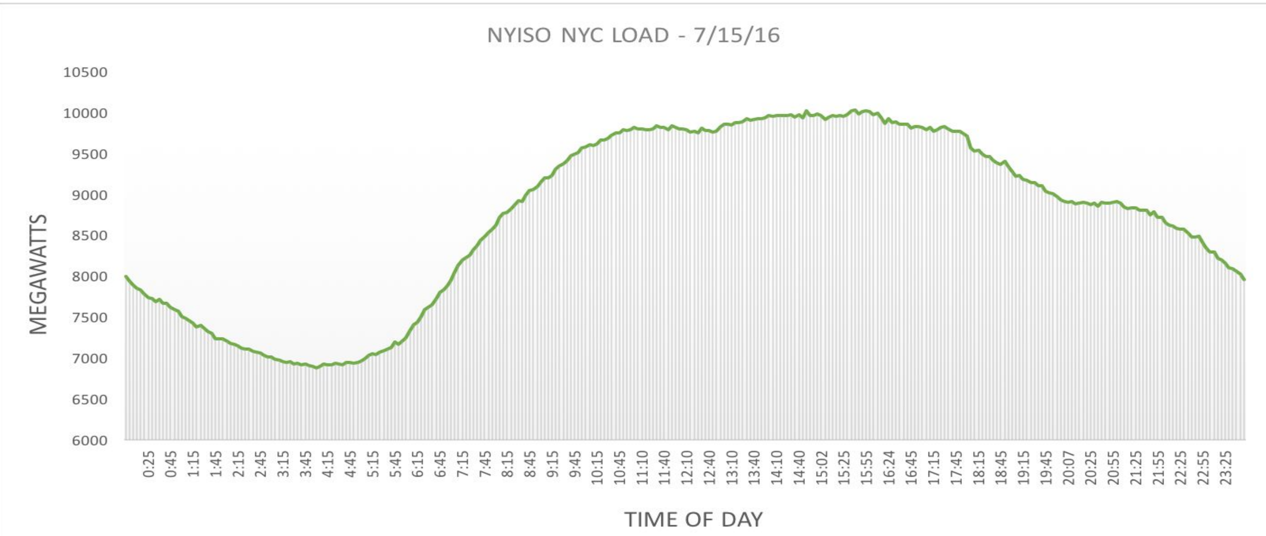
Each day, utilities struggle to delicately balance generation supply and consumer demand in electricity markets. Current market structures are highly inefficient, with costly power plants supplying power over overly congested transmission lines. Adding renewable energy sources to the grid only increases the complexity of the problem, because they create energy intermittently.. Recently, chemical batteries have been hailed as a potential solution to this problem, because they can lower peak consumption as the energy demand spikes - a process known as **peak shaving**. However, a more environmentally friendly option for peak shaving is a **flywheel: a mechanical battery that stores kinetic energy that can be released as electricity**. Although the flywheel is a **net consumer** of energy, it can also save money for both the consumer (and utility) by spinning up when electricity is at its cheapest and releasing the energy when the energy prices start to rise. Flywheels are typically used for frequency regulation; however, in this senior design capstone, we explored a use case for peak shifting and demand shaving in a commercial setting on the New York City electrical grid and engineered a proof of concept prototype. We used data analysis and real time electricity pricing to show that a **100 kW system of flywheels installed in the basement of a commercial building can induce monthly cost savings of up to $500**, based on our July 2016 model.

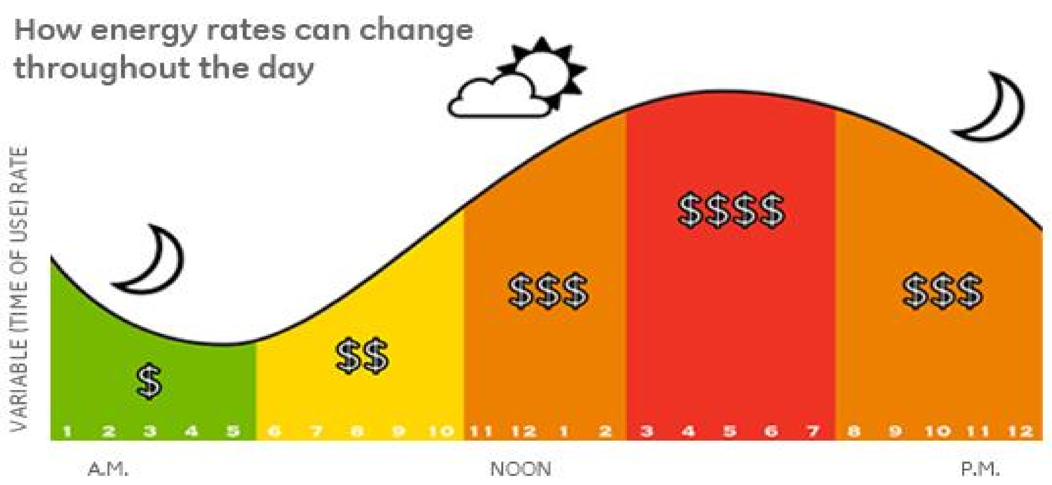
Problem Background

Energy Storage Tech. - Batteries vs. Flywheels

Category	Lead-Acid	Li-Ion	Flywheel
Discharge Efficiency	85%	85%	90-93 %
Typical Storage Time	Minutes/Short Term/Days	Minutes/Short Term/Days	Minutes/Short Term
Max Cycle #	500-1000	1,000-10,000	20,000+
Estimated Lifespan	5-15 years	5-15 years	20+ years
Ecological Source Materials	Toxic	Toxic, Rare Earth Minerals	Standard, recyclable

Market Forces - Typical Daily Load and Cost Profiles





- Electricity prices shift due to a variety of factors: fuel costs, weather, wire congestion, and grid failures
- NY PSC estimates that "the **top 100 hours of demand cost New York's ratepayers as much as $1.2-1.7 billion** annually."
- When consumption is high and lines are congested, utilities charge a **demand charge (kW)** to cover the cost of their peaking plants and monetize the stress such demand has on the grid (transmission and distribution)

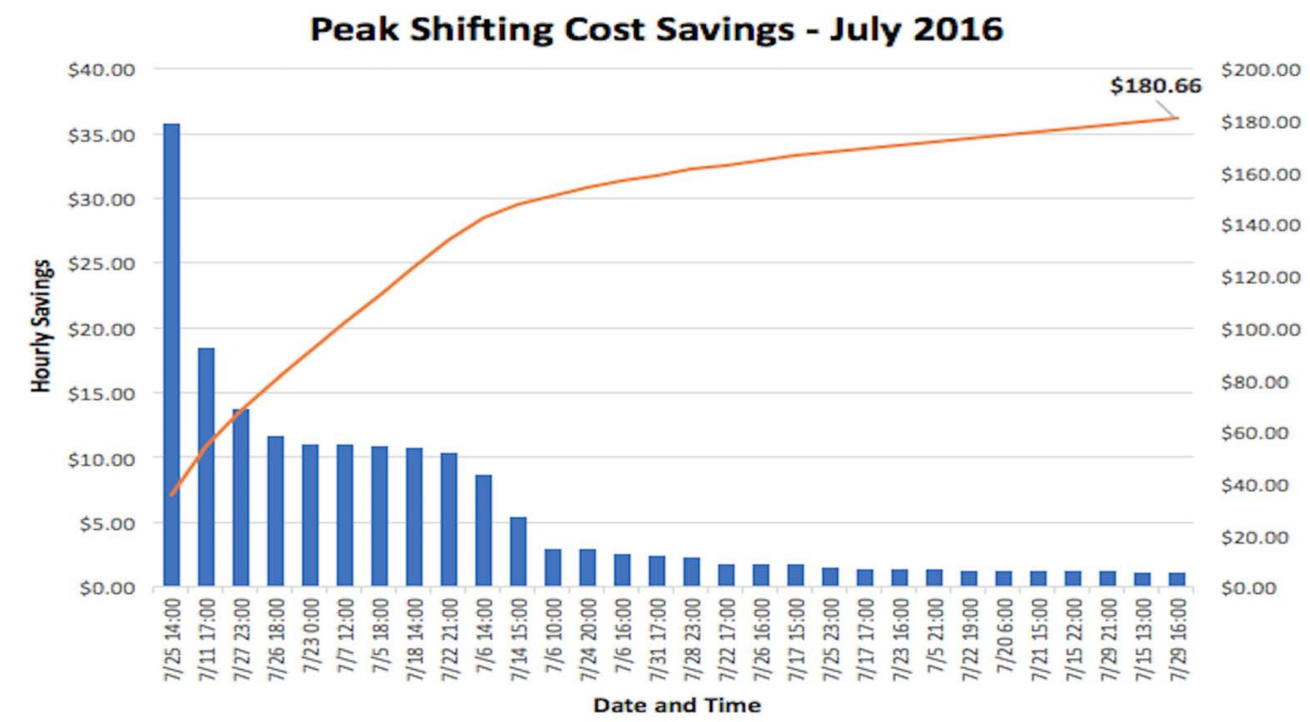
Energy Market Modeling

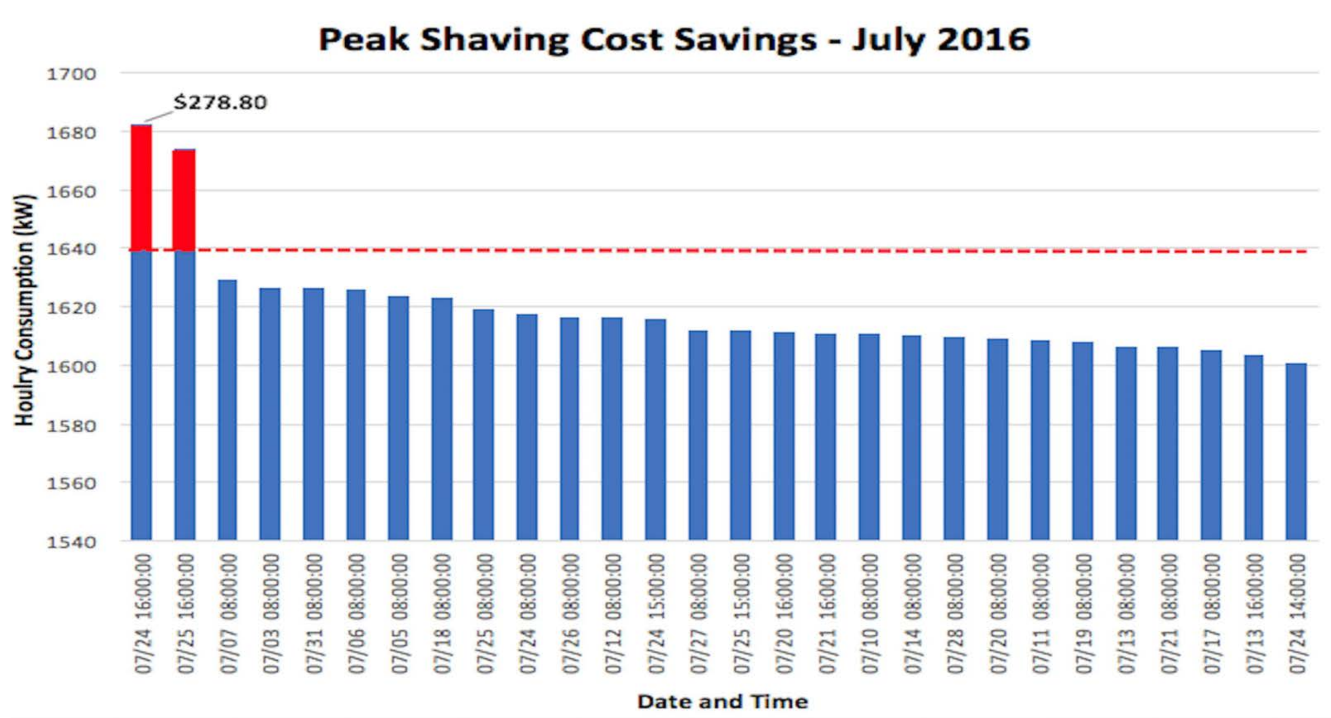
Our FES use case: commercial building in NYC

Demand Charge: Greatest rate of electricity used in any half-hour period during monthly billing cycle (measured in kW)

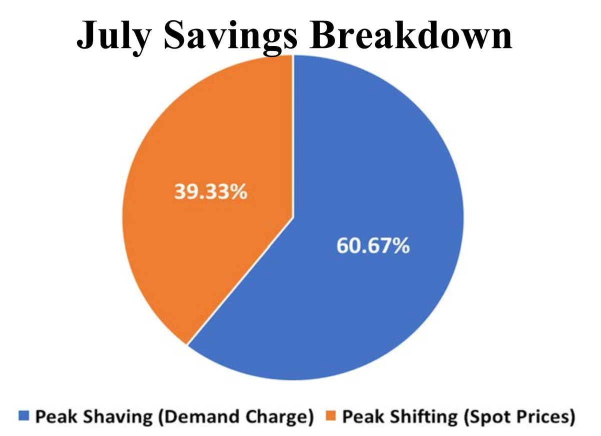
Flat Rate (FRP): Regardless of major electricity price fluctuations, customers pay a predetermined rate for kwh's consumed

Voluntary Time of Use (VTUP): Customers are charged the market spot price for electricity, which varies greatly over the course of the day to push better consumer behaviors (Running the washing machine at night).





Model Metrics
- 100 kW system
- 85% round trip efficiency
- Peak shifting: 30 cycles
- Consumption cap: 1,640 kWh



Savings

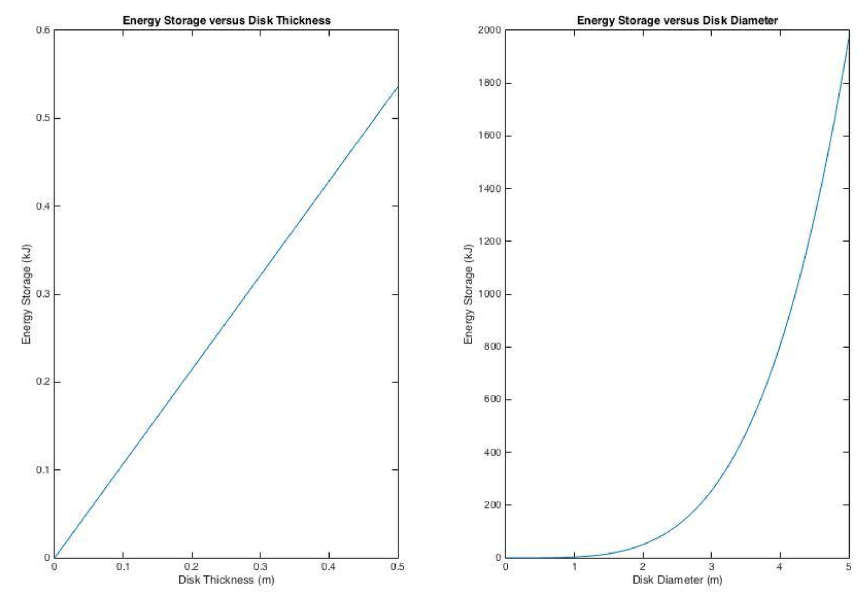
Peak Shifting: $278.70

Peak Shaving: $180.66

Total: $458.38*

Flywheel Theory

Inputs: diameter, motor wattage, motor RPM, disk thickness, efficiency, density of material

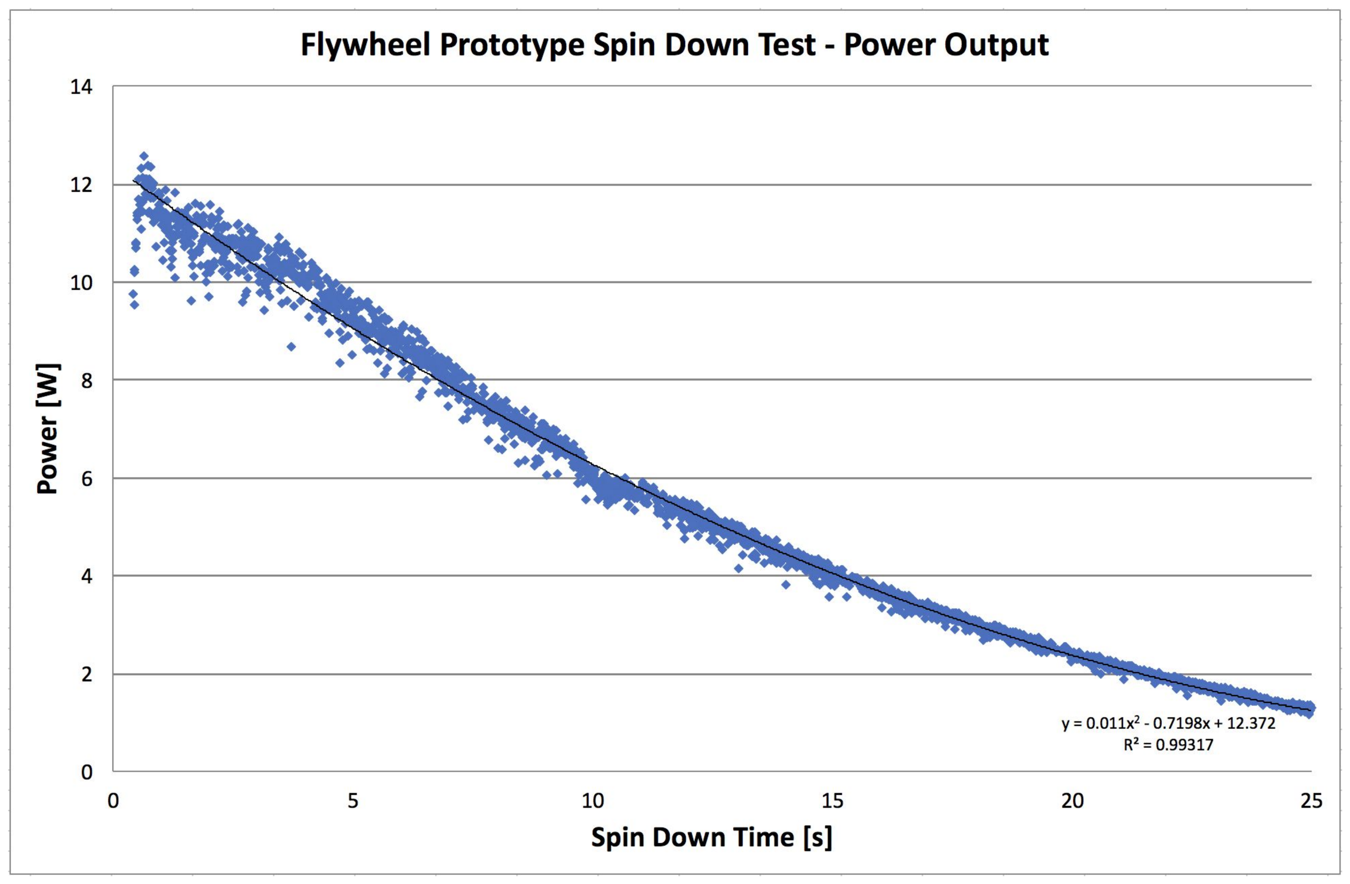


$$KE_{rotational} = \frac{1}{2} I \omega^2 \qquad I_{disk} = \frac{1}{2} m r^2$$

*Graphs assume 100% efficiency, ours is 16%

Prototype Design and Results

	Design Objective	Test Results
Spin-up time	< 1 minute	12.5 seconds
Max Shaft Displacement	0-0.5 inches	0.24 inches
Safety Factor	20+	100+
Cost	< $1500	$925
Model Efficiency	40%	29.3%



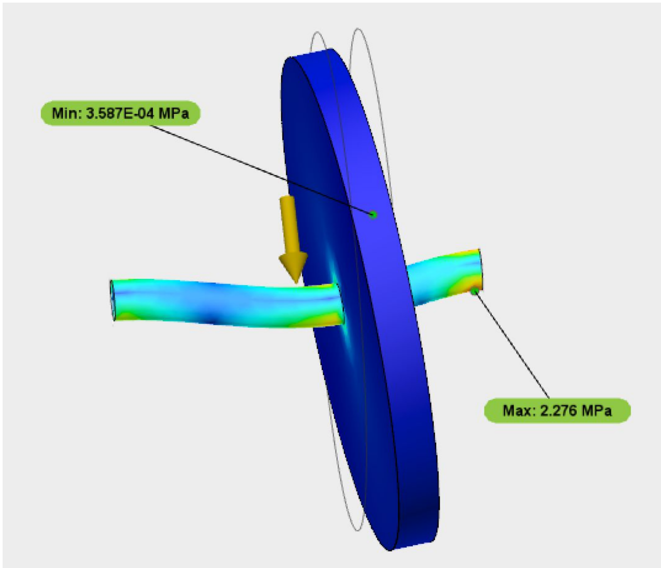


Figure A: Fusion360 Simulation of Static Stresses on shaft in Prototype

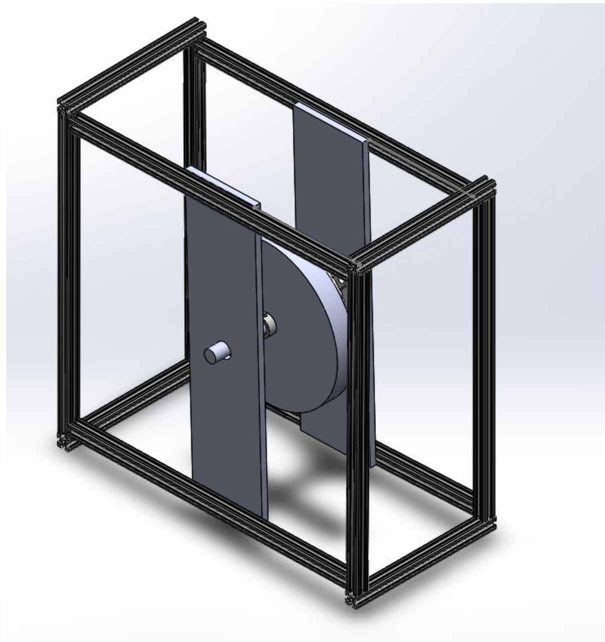


Figure B: CAD Model created in SolidWorks of the finalized flywheel prototype rotor and frame assembly

Impact and Conclusion

- Flywheels are a **proven technology** for large scale (utility) and small scale (hybrid cars), our use case of commercial building is in between
- As renewable energy generation continues to increase, clean energy storage will be able to offset demand from fossil fuel plants and reduce total greenhouse gas emissions; **flywheels can help with renewables integration**
- Buildings can save money by charging FES system before spikes and discharging the electricity to avoid paying high real time prices