Flywheel Energy Storage (FES) as a Method for Peak Demand Shifting

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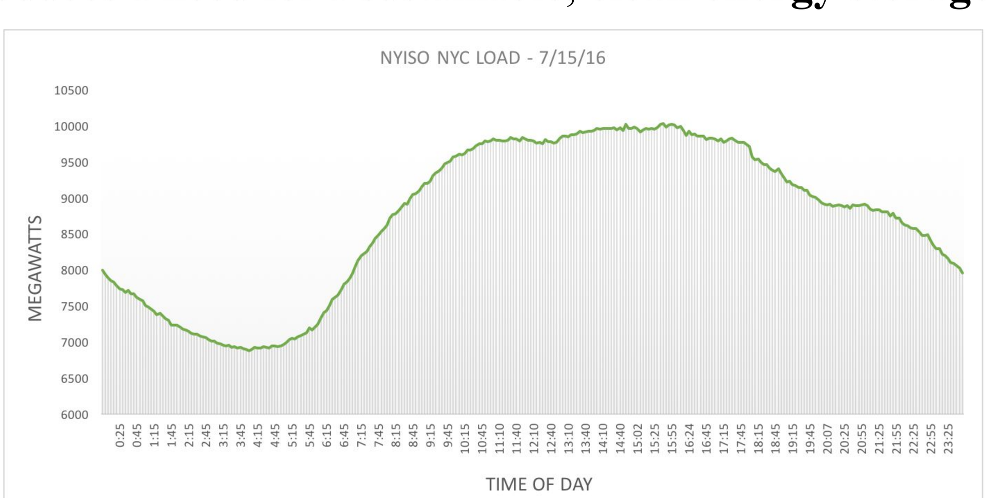
Abstract

Each day, utilities face the issue of having to turn on and off power sources in order to meet energy demand. This operation is incredibly costly and potentially wasteful if the grid has more energy than needed. Adding renewable energy sources to the grid only increases the complexity of the problem, because they create energy intermittently and unpredictably. Recently, chemical batteries have been hailed as a potential solution to this problem, because they can turn on as the grid demand spikes - this is called **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 save money for both the consumer (and utility) by spinning up when electricity is at its cheapest and then releasing the energy when the energy starts to spike and becomes more expensive. In this senior design capstone, we designed a flywheel for a commercial setting on the New York City electrical grid, and engineered a proof of concept prototype. We also used data analysis and real time electricity pricing data to show that a **200 kW system of flywheels installed in the basement of a commercial building can induce monthly cost savings of up to $700**, based on our model for July 2016. Furthermore, these flywheel systems could be coupled with renewables to assist with renewables integration and yield environmental benefits.

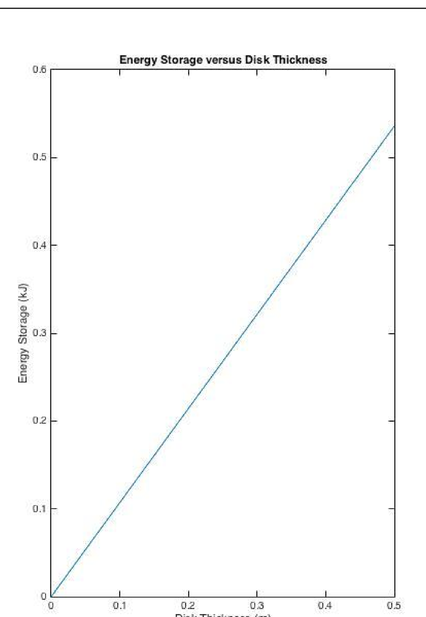
Problem Background

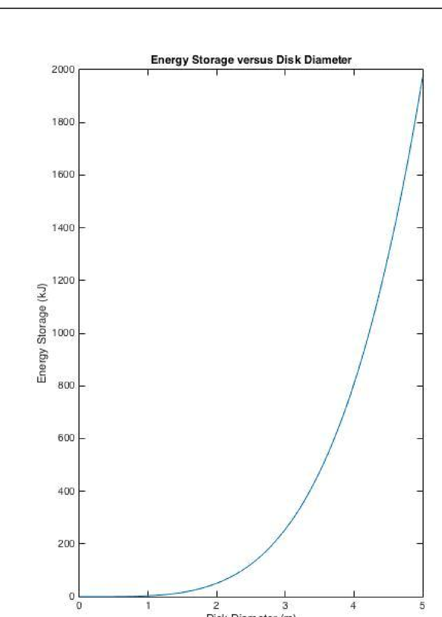
Energy storage
- Chemical batteries require toxic chemicals and rare earth metals but also have ecologically toxic effects associated with their disposal
- They are expensive and unsustainable, lasting for 200-2,000 cycles
- This introduces a need for a sustainable, **clean energy storage** alternative



Need for Peak Shaving, Demand Reductions
- Electricity consumption increases exponentially to peaks around 3 to 5 PM
- Electricity prices can fluctuate due to a variety of factors: fuel costs, weather, transmission congestion, and unexpected grid failures
- When electricity consumption is high, utilities may charge their customers a **demand charge** to cover the cost of their peaking plants and monetize the stress of such levels of consumption on the grid

Flywheel Theory





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

$$KE_{rotational} = \frac{1}{2} I \omega^2$$

$$I_{disk} = \frac{1}{2} m r^2$$

*Graphs assume 100% efficiency

Energy Market Modeling

Modeled cost savings come from price differentials and demand charge reductions

- **Demand Charge** = (real time price) - (day ahead agreed upon price)
- **Peak Shaving** = Reducing energy usage during times of high grid load
- Modeling Methodology:
  - DOE building load projections → modelled NYC large office monthly electricity usage
  - NYISO zonal pricing data → determined that pricing variability in NYC is greatest in July, optimal month for maximizing savings
- While the system modeled was too small to receive subsidies, larger storage units can qualify for financial incentives from state governments and utilities

FES Formulas

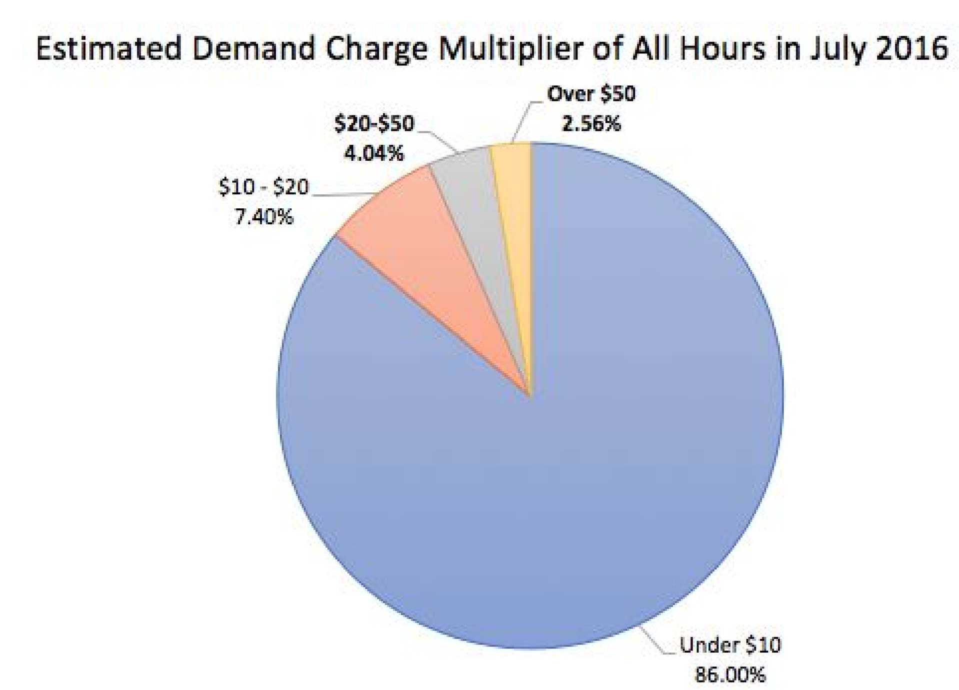
No FES Price : $(RTP_0)(EO)$

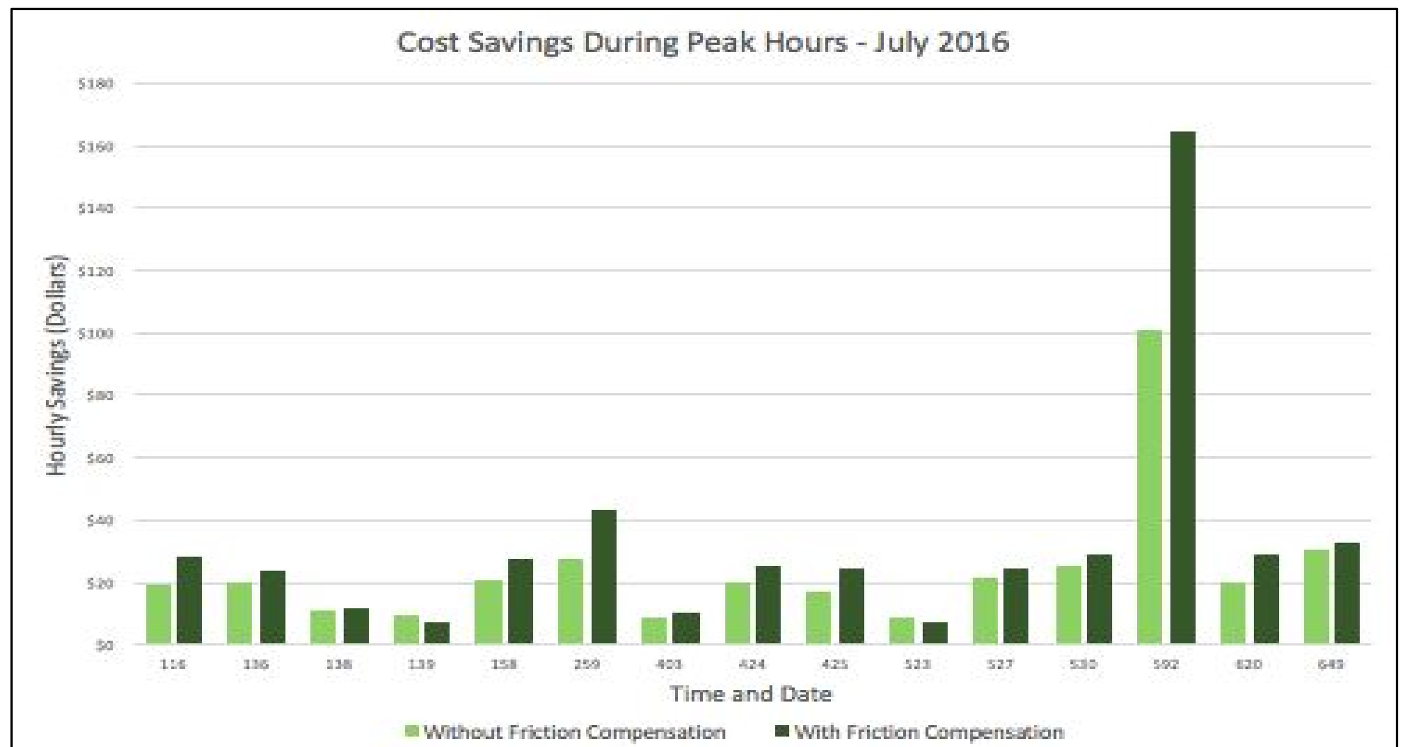
FES Version A Price : $(RTP_1)(EO(1-FL)^{charge\ hours}) + (EO - EO(1-FL)^{charge\ hours})(RTP_0)$

FES Version B Price : $(RTP_1)((\frac{EO}{(1-FL)})^{charge\ hours})$

Savings = No FES Price - min (Version A, Version B)

Key
EO : Electrical output
FL : Frictional loss
RTP: Real time price
Version A : Charged to EO, discharge lower due to friction
Version B : Discharged at EO, charged higher to compensate for friction

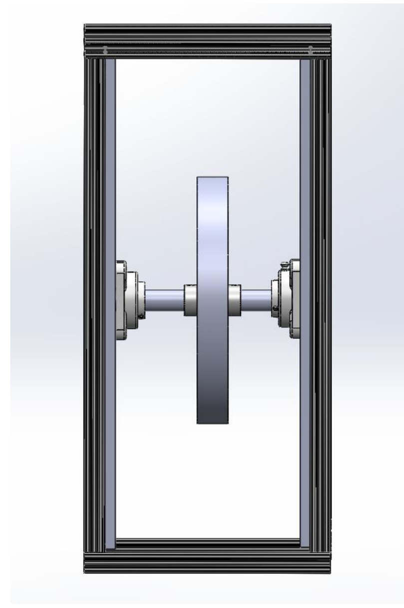


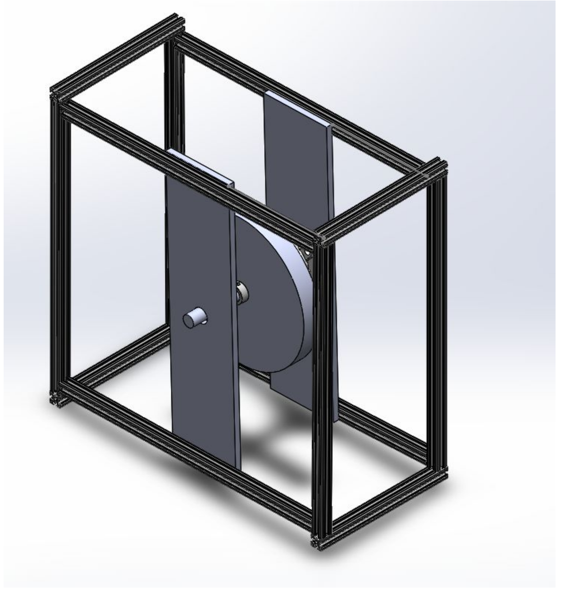


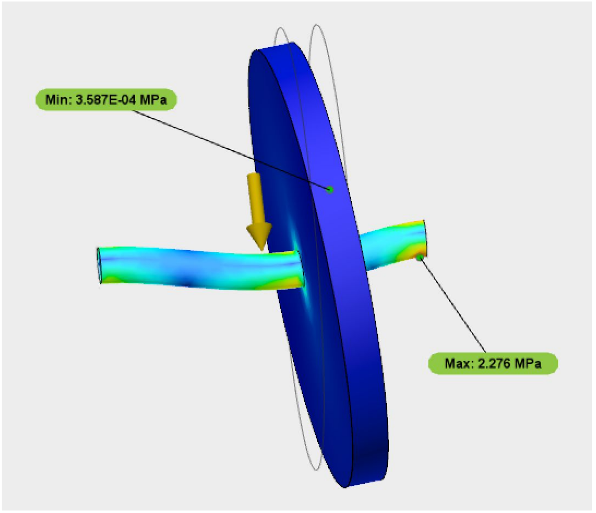
Prototype Design

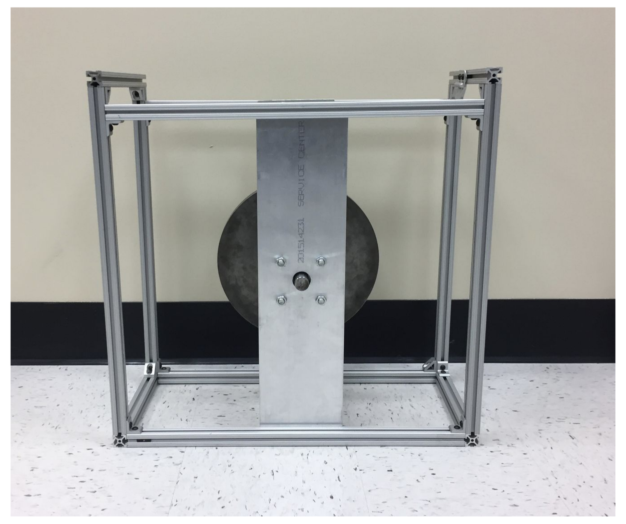
	Design Objective	Design Specs
Energy Stored	1-2 Wh	2.37 Wh
Spin-up time	< 1 minute	12.5 seconds
Max Shaft Displacement	0-0.5 inches	0.24 inches
Safety Factor	20+	100+
Budget	$1000-1500	$815

- Steel flywheel disk (12 inch diameter, 1 inch thick, 33 lbs)
- Aluminum 8020 T-Slot square frame with custom bearing mounts
- Solid 1 inch diameter steel shaft with keyway
- Flange-mounted ultra-low friction ball bearings
- Brushed 24VDC, 3000rpm, 2.4 Full Load Amps, 159 in-oz starting torque motor-generator used for spin up and energy draw









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
- Easily sourced and recycled, flywheels offer an environmentally friendly alternative to chemical batteries
- 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 avoid the sudden spikes in real time price of electricity by loading up a FES system during the hours preceding these spikes and discharging the electricity to avoid paying exorbitantly high real time prices