Powering Remote Islands Using Renewable Energy

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Abstract

Motivation: The current method for powering remote island communities, which relies on shipping in diesel fuel from the mainland, is both expensive and unsustainable. Renewable energy is a promising alternative and improving methods for generation and storage would make it a more viable option.

Challenge: Renewable energy output is often inconsistent, and periods of peak production do not align with periods of peak demand.

Vision: Use a MATLAB simulation to determine the most effective methods for meeting energy demand.

Goals:

- Determine the optimal split between redox flow and lithium-ion batteries for storing energy generated by tidal and solar power
- Determine the optimal balance between solar and tidal power needed to meet the demand of a simulated island community
- Minimize the levelized cost of energy (LCOE)

Results: Using a hybrid energy storage system (HESS) with redox flow and lithium-ion batteries to store energy generated using tidal and solar power, the LCOE was reduced to 9.6 ¢/kWh, 20% less than the national average of 12 ¢/kWh.

Experimental Methods

Optimization Methods:

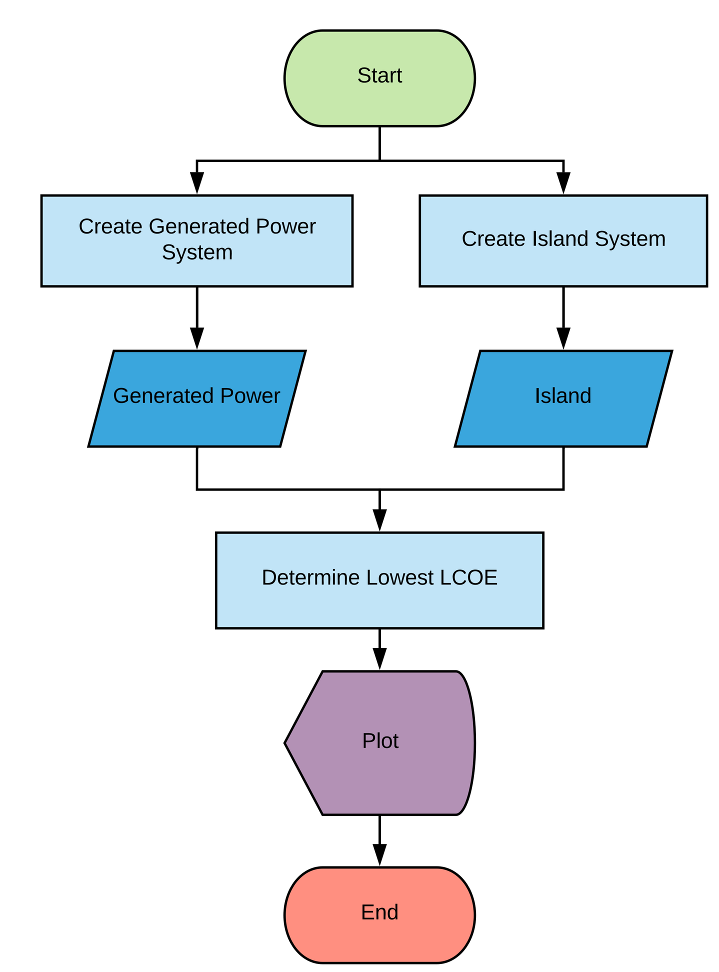
- Attempted Constrained Gradient Descent Optimization
- Exhaustive Search
- Genetic Algorithm
- Pattern Search

Figure 3: Battery Inputs

LiB Cost of Energy	220 $/kWh
LiB Cost of Power	0 $/kW
LiB Life Cycle	4,000 Total Charges
Flow Cost of Energy	30 $/kWh
Flow Cost of Power	1,000 $/kW
Flow Life Cycle	12,000 Charge and Dischage Switches

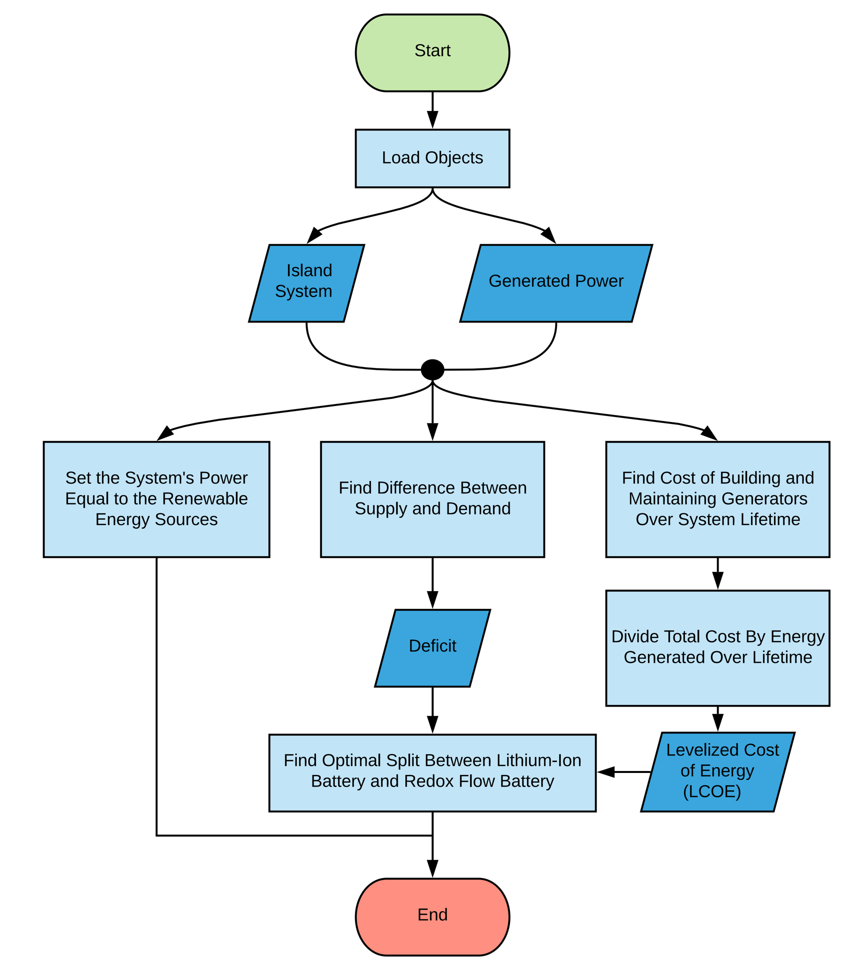
MATLAB Flow Charts

Figure 4: Main



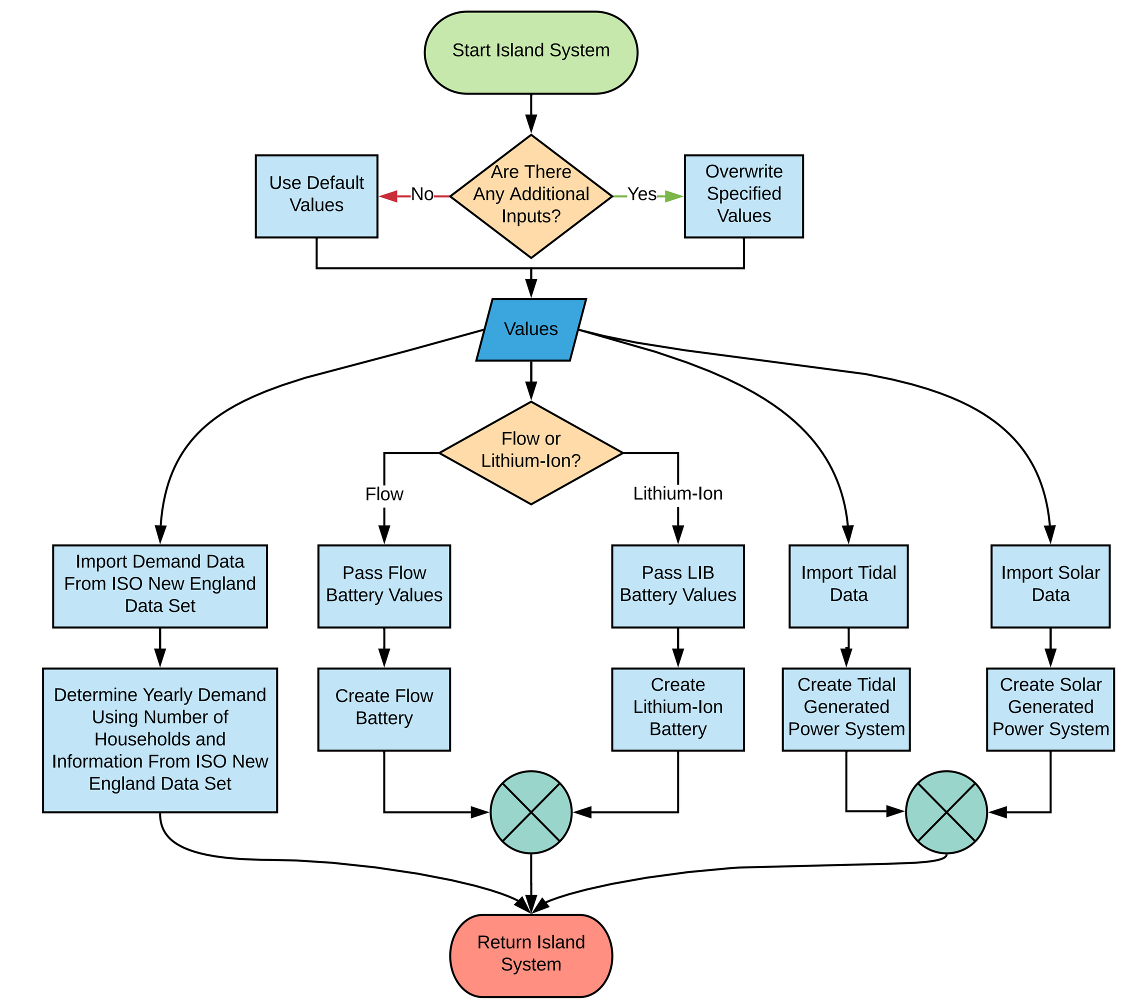
Calls functions to plot lowest LCOE

Figure 5: HESS Optimization Function



Function used to optimize split between lithium-ion and redox flow batteries

Figure 6: Island System



Model of simulated island system

Background

An ideal energy storage system effectively bridges the difference between supply and demand while also minimizing the levelized cost of energy (LCOE), a measure of the lifetime costs of building and maintaining a generator divided by its energy production. The two main energy storage technologies examined in this project are flow and lithium-ion batteries.

Vanadium Redox Flow Battery	Lithium Ion Battery
Less Efficient than LiB	High Efficiency
Medium Energy Density	High Energy Density
State Switching Causes Increased Degredation	Degrads Quickly When Fully Charged and Discharged
Negligible Self-Discharge	Low Self-Discharge Rate
Scales Up Well	Low Maintenance

Figure 1: Battery Comparison

As a result of their differing characteristics, flow batteries are ideal for storage, while lithium-ion batteries are best-suited for delivering power. In order to optimize the LCOE, a hybrid energy storage system in which flow batteries store excess energy and transfer that energy to the lithium-ion batteries to rapidly charge and discharge is most effective.

Tidal Power	Solar Power
Harnesses Energy From the Tides	Harnesses Energy From the Sun
Highly Consistent and Predictable	Inconsistent due to Seasonal Variation
Very Efficient	Less Efficient than Tidal Energy
Less Scalable	Highly Modular, Thus Easily Scalable

Figure 2: Power Generation Comparison

Different forms of power generation (solar vs. tidal) are also taken into consideration.

Results

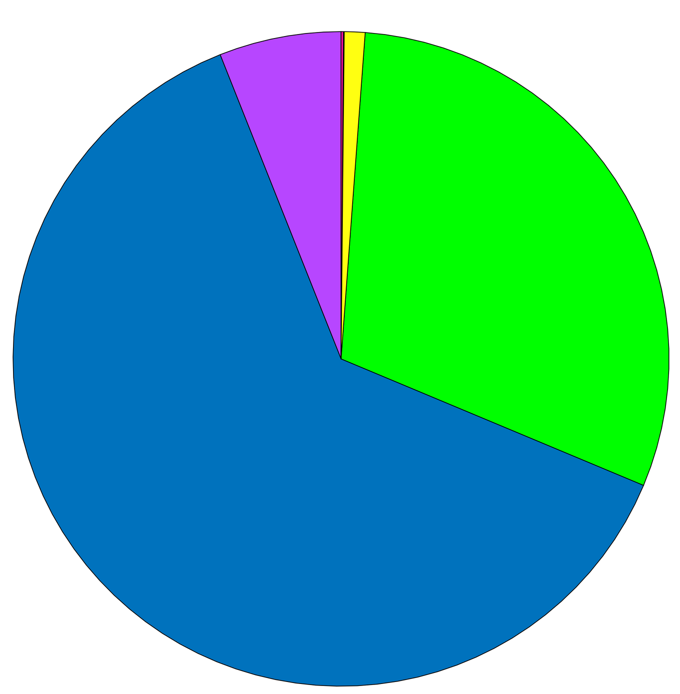


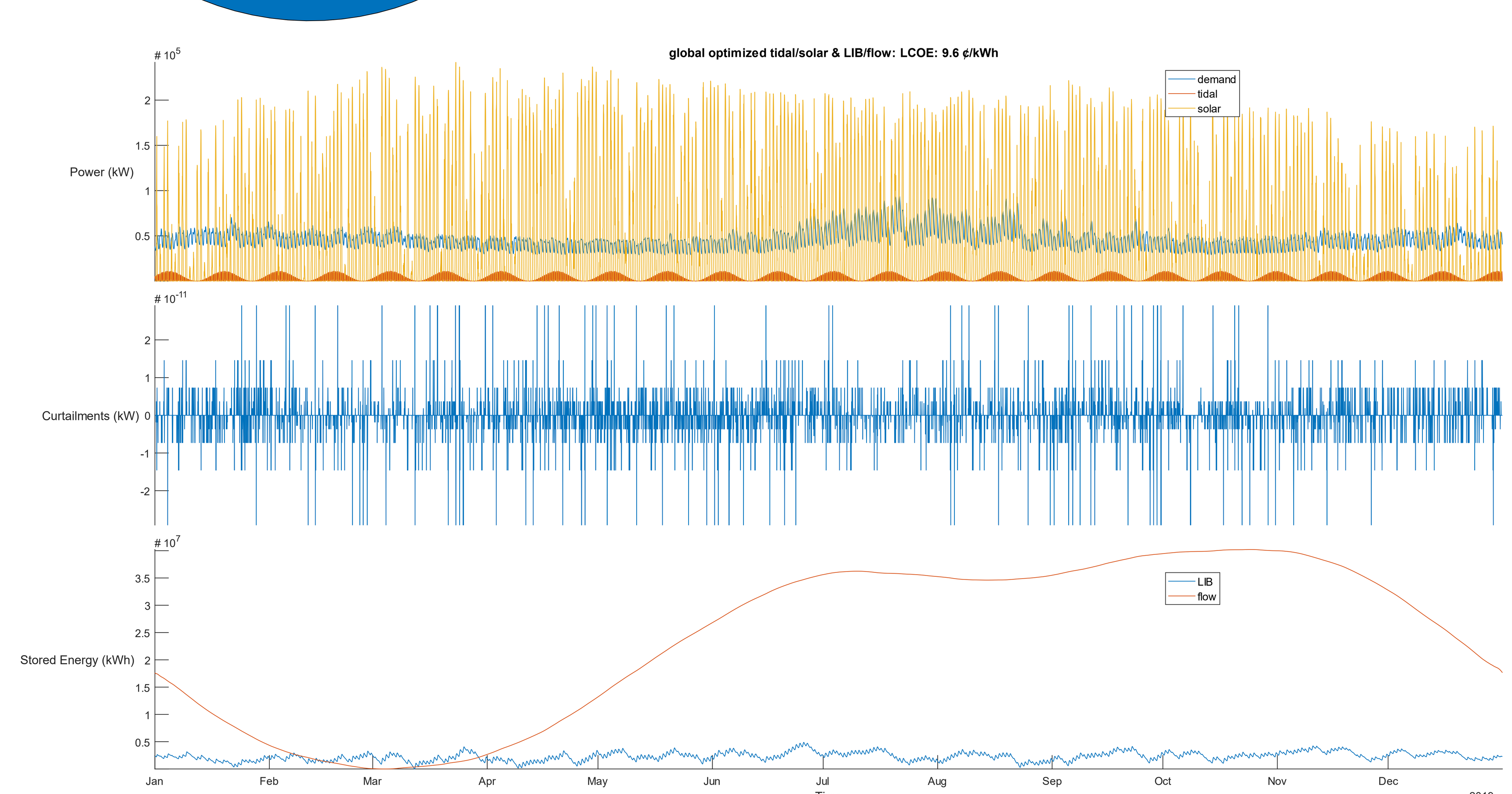
Figure 7: Global Optimized Tidal/Solar and Lithium-Ion/Flow LCOE: 9.6 ¢/kWh (Chart)

Legend:

- Solar: 6.0 ¢/kWh
- Tidal: 0.6 ¢/kWh
- LIB: 2.9 ¢/kWh
- Flow: 0.1 ¢/kWh

	Flow	LIB
Tidal	26.7 ¢/kWh	12.3 ¢/kWh
Solar	19.2 ¢/kWh	9.6 ¢/kWh

Figure 9: LCOE Comparison



MATLAB Graphs

Figure 8: Global Optimized Tidal/Solar and Lithium-Ion/Flow LCOE: 9.6 ¢/kWh (Graph)

Legend:

- Top - Power (kW): Demand, Tidal, Solar
- Middle - Curtailments (kW)
- Bottom - Stored Energy (kWh): LIB, Flow

Generated Power: 276 MW
Tidal : 11 MW
Solar: 265 MW

Conclusion

After experimenting with different optimization methods—including a constrained gradient descent optimization, an exhaustive search, MATLAB's genetic algorithm, and pattern search—it was determined that pattern search is the most effective optimization method. Using the pattern search global optimization function, the LCOE for the overall system was reduced to 9.6 ¢/kWh, which is approximately 20% less than the national average of 12 ¢ kWh . This was done using a lag of 863 hours and 96% solar energy. Lag is a moving average of curtailments and was used to determine how to divide energy storage between the flow and lithium ion batteries. Future research might include exploring other sources of renewable energy as well as different energy storage techniques.

References

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MATLAB Global Optimization Toolbox 2020a, The MathWorks, Inc., Natick, Massachusetts, United States.

Acknowledgements

Department of Civil and Environmental Engineering
Professor Michael Kane, *Assistant Professor*
Jonathan Cohen, *Undergraduate Candidate*
Kris Govertsen, *Ph.D. Candidate*
Department of STEM
Claire Duggan, *Director of Programs and Operations, Center for STEM Education*
Salima Amiji and Natasha Zaarour, *YSP Coordinators*
Nicholas Fuchs, *Project Implementation Coordinator*