Control of Smart Energy Microgrids with Predictive Edge Intelligence

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ABSTRACT

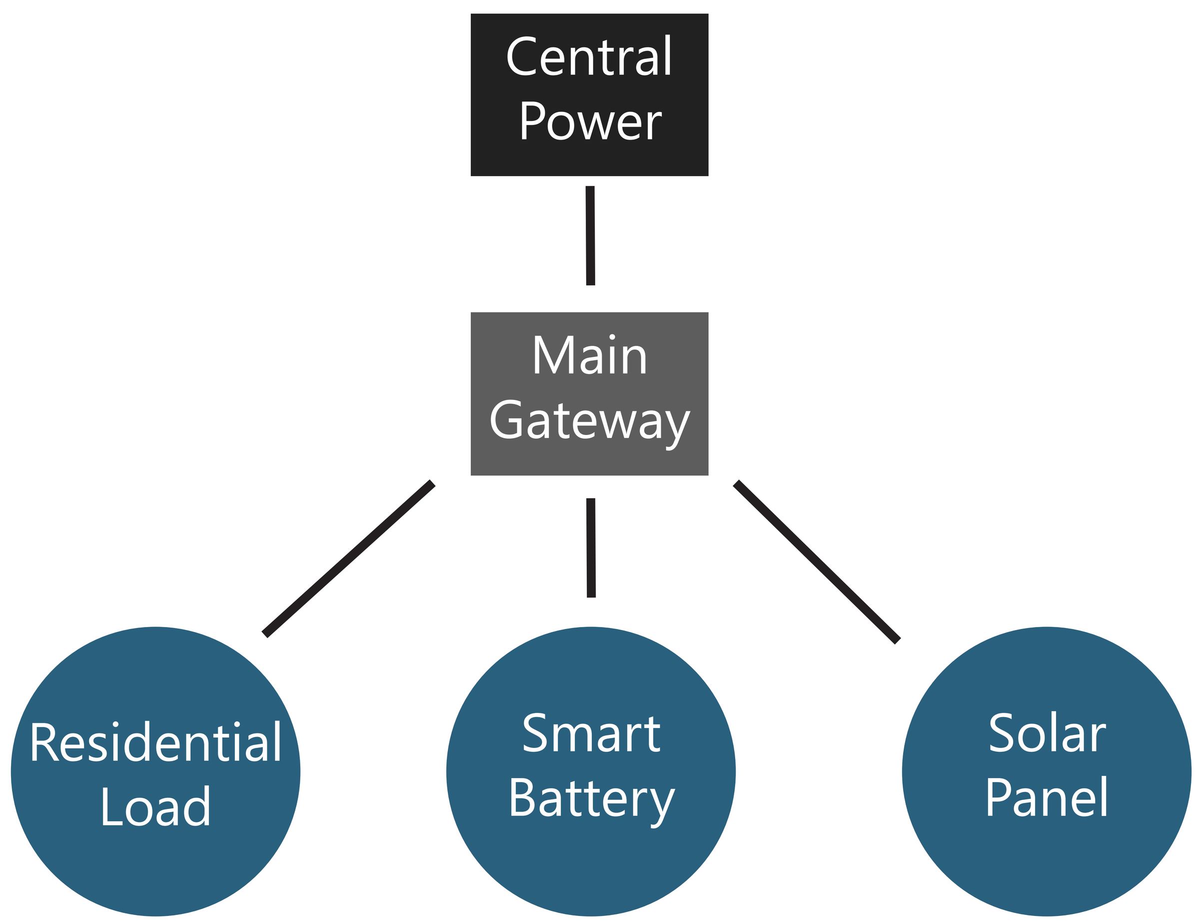
Small-scale renewable energy inherently produces variable levels of power, so an accompanying battery can help supply a more consistent amount of electricity based on the needs of the local grid. This project investigates how computational edge intelligence can be used to provide energy stability in a small-scale microgrid with a smart battery, solar panel, and time-varying load. Gateways between hierarchical levels on the grid set demand-based pricing signals that incentivize stability. These pricing signals are passed to the edge devices, where predictive AI adjusts usage to maximize profit. The smart battery is trained using adaptive dynamic programming, leveraging actor-critic neural networks to address the real-time computation needs for this application. The hedgehog method is used to find optimal solutions in conjunction with synthetic annealing. For this experimental setup, the battery was able to successfully learn behavior that increases stability in the grid.

FRACTAL GRID ARCHITECTURE

The electric grid in the United States was designed for the resources of the mid-twentieth century, relying on unlimited fossil fuels with centralized control. As renewable energy generation has become more prominent, the grid has struggled to adapt to these distributed and variable energy sources. Furthermore, the technology developed for renewable energy storage is more promising at a small-scale. As more generation and storage devices are introduced, the current centralized grid control system will quickly be overwhelmed by complexity.

Instead, a new system of smart microgrids would allow for dynamic stability through localized control at fractal levels of the grid. This model has been proposed in the project "Fractal Graph Framework for an Evolving Grid Architecture" by Introspective Systems, funded by the Department of Energy. Different levels in the grid communicate through pricing signals set by gateways at each junction. The edge devices use locally and temporally learned intelligent algorithms to control their own operations deciding on when it is most advantageous to consume or supply power to the greater grid. These distributed systems with grid edge intelligence leverage computational models to promote stable renewable energy adoption, localized resilience after natural disasters, and increased security against physical and cyber-attacks.

EXPERIMENTAL SETUP



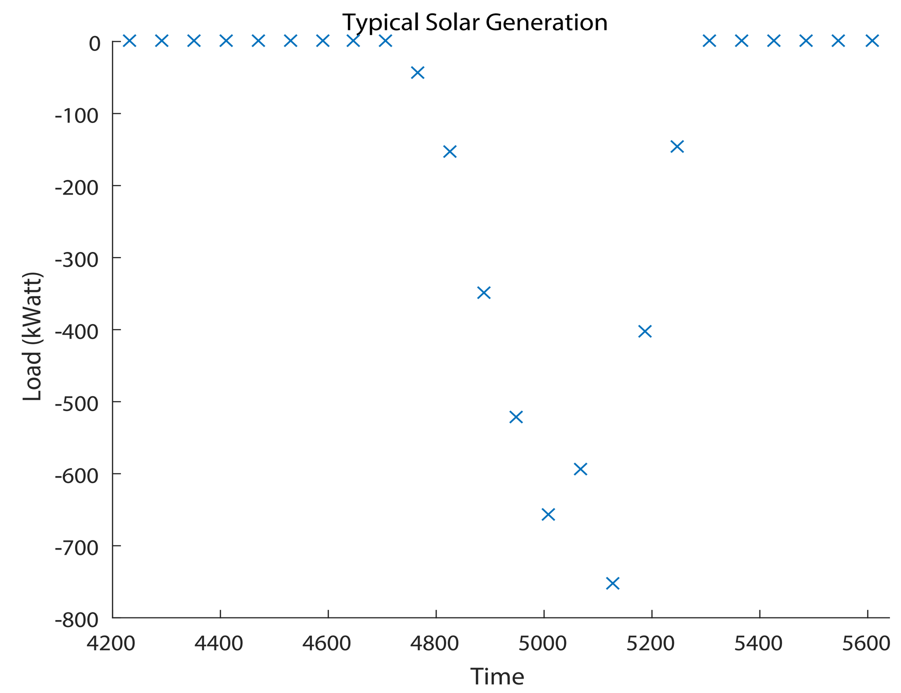
The smart battery was developed using a system with a solar panel, battery, and residential load connected to a gateway, which sets the pricing signals. The house load was determined from a typical house load curve, and the solar panel output was given from a solar API. Pricing signals are set by the gateway based on the instantaneous load and the prices of local generation and central power.

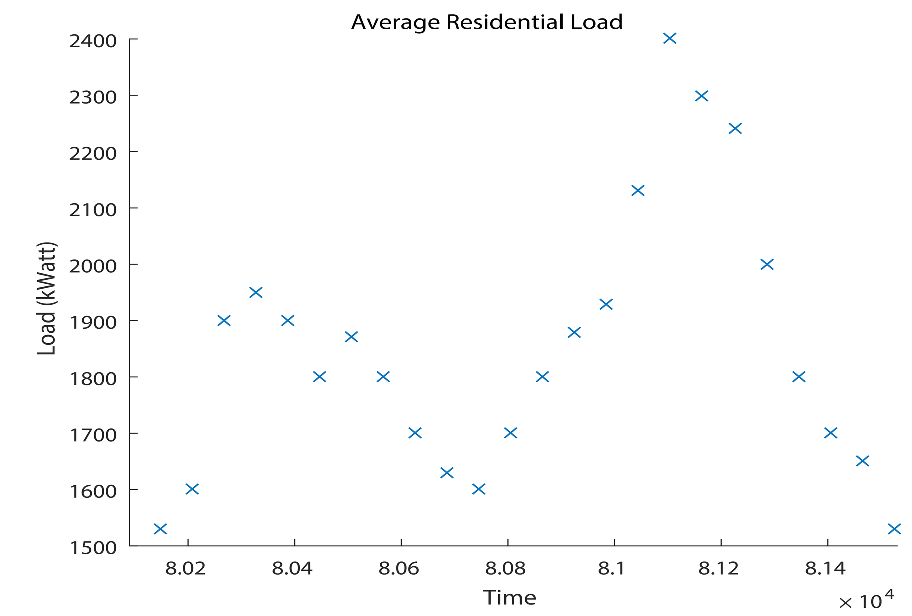
SMART BATTERY ALGORITHM

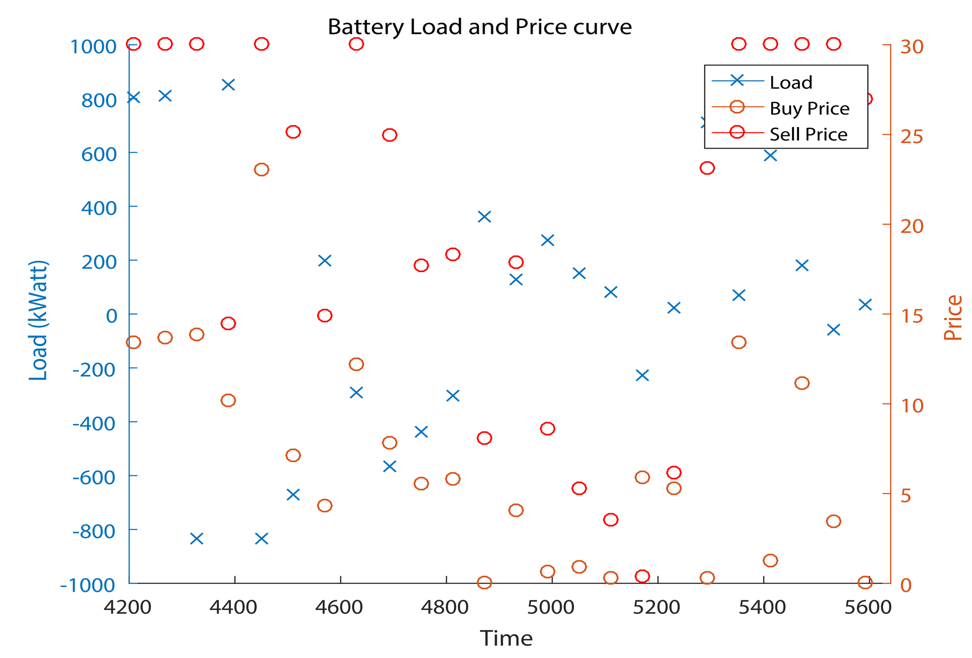
The battery in this system controls the charging and discharging rates using adaptive dynamic programming based on the instantaneous state of the system, considering pricing signals from the gateway, the battery charge level, and the time of day. A pair of actor-critic neural networks are used to make a decision based on the state, and evaluate the outcome according to a utility function. This utility function rewards charging and discharging to promote overall grid stability and reduce fluctuations in power. An approximation for the optimal value of the non-linear utility function is found using synthetic annealing with the hedgehod method. The actor-critic pair are trained in tempo over the course of the simulation, resulting in improved performance over time.

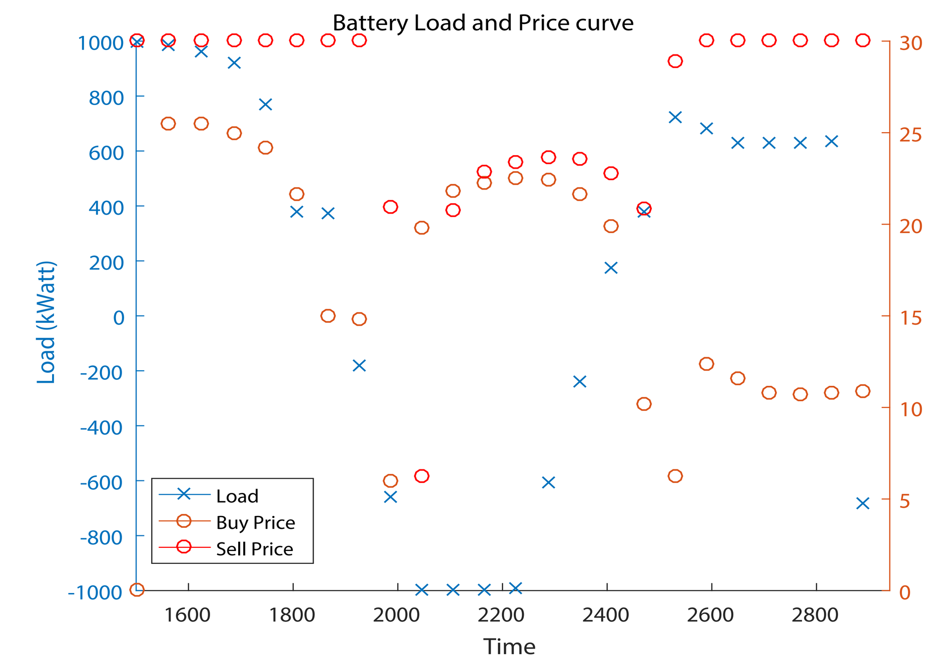
TRAINING RESULTS

The follow graphs show sample load curves for the solar generation and residential load in this simulation, followed by the battery load and generation in comparison to the buy and sell prices.









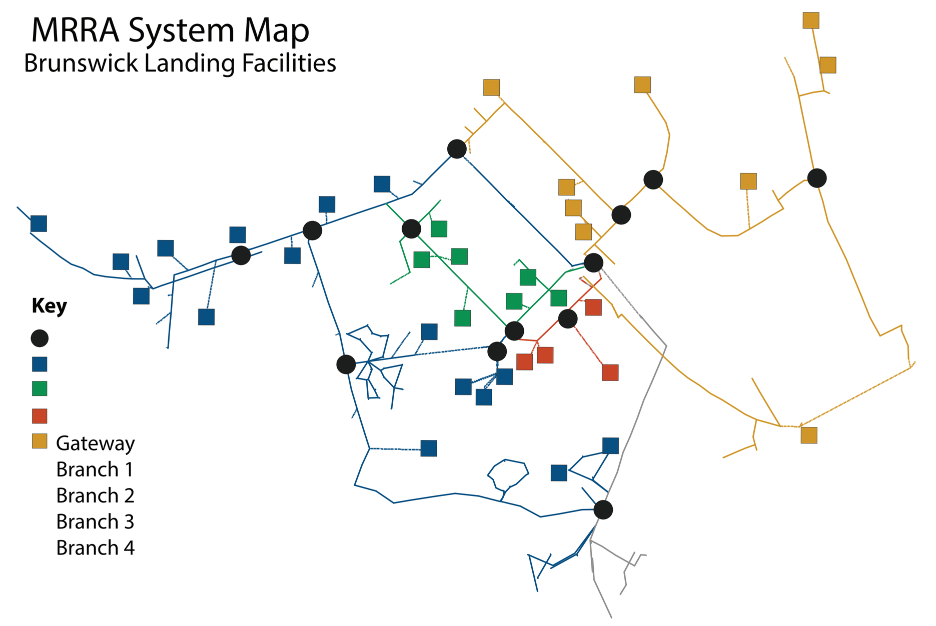
Over the course of the simulation , the battery effectively learns smart behavior, such as charging during the day when prices are low due to increased solar generation, and discharging in the evening when residential energy demand is higher. This has the effect of balancing the load to the grid, as evidenced by more stable pricing signals from the gateway.

DISCUSSION

In the case of a smart solar and battery system, communication through pricing signals encourages the battery to charge up when there is an access of solar power, then sell energy back to the grid during times of peak load. The machine learning method with adaptive dynamic programming using actor-critic neural networks is successful in training a smart battery to respond to pricing signals to provide stability in the electric grid. This battery is able to learn from the system in real time, and adapt to the behavior of other devices on the grid through purely pricing information, indicating that this algorithm is successful for balancing the load in the context of this microgrid. The same algorithm showed similar behavior when used with different combinations of devices in other microgrid configurations.

IMPLICATIONS

This use case can be expanded to more advanced systems as well. Introspective Systems is continuing research on the project "Fractal Graph Framework for an Evolving Grid Architecture" using the Brunswick Landing's Renewable Energy Center 4 MW Microgrid as a test-bed. The electrical grid of this project is shown below.



When stable microgrids are connected to other grids, the distributed, collaborative swarm intelligence will lead to emergent stable behavior throughout the grid. As more smart microgrids are adopted, this system allows for natural integration into the overall grid, without increasing computational complexity. Furthermore, a system made up of multiple microgrids allows for localized power usage, which enables the grid to be more resilient if natural disasters threaten sections of the grid.

ACKNOWLEDGEMENTS

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