Optimizing Community Scale Energy Systems
Executive Summary
December 2 ,2016

Introduction

Residential electricity transactions often occur on a simplified, flat-rate market that insulates customers from wholesale price signals and rate structures that would reward them for altering their consumption patterns. In addition, residential appliances, including air conditioning units, are relatively inefficient compared to larger systems. These shortcomings can be addressed by aggregating the energy use of a residential neighborhood and connecting it to a central utility plant. A central utility plant with a generator, battery, chiller, and other equipment can improve the energy efficiency of a neighborhood, allow it to operate more flexibly, and help it participate in market rate structures that reward this flexibility. This project discusses the development of a model that simulates this community energy strategy. The results of this model show that this strategy can provide an economic benefit to the neighborhood depending on the set of equipment being installed in the plant.

Methods

To estimate how a central utility plant could reduce the cost of providing energy for a community, a hypothetical community is constructed based on electricity demand data collected from Pecan St. These data were taken from 123 homes and then scaled to approximate a community of 4000 homes. In a baseline case, the community's electricity demand is met by electricity purchases with a time-of-use rate. The time of use rate was taken from Austin Energy and includes a rate for energy [$/kWh] and a rate for peak monthly demand [$/kW] that both vary depending on the month and time of day.

All variations on the baseline include a power generating station that can be used to meet community demand or to sell electricity on the day-ahead wholesale market to offset community electricity costs. Electricity sales are also subject to demand charges based on the peak power sold to the grid. The fuel consumption for the generator is a linear function of the power output of the generator. The generator model also includes a minimum up and down time as is common in unit-commitment dispatch optimization problems. In addition to the generator, our analysis considered the following variations:

- An additional 2.5 MW of solar capacity where hourly solar production is also based on solar panel production data from the set of 123 Pecan St. homes
- Centralized battery storage with 10 MWh of capacity and a maximum power transfer of 2.5 MW
- A centralized chilling station to meet community air conditioning demand where AC demand is based on data from the set of 123 Pecan St. homes and is disaggregated from total electricity demand

Different combinations of the listed variations were considered, including a variation with both solar and battery storage and a variation that included centralized solar, battery, and chilling. The objective of this optimization analysis is to minimize the cost of purchasing fuel and electricity and running the equipment offset by electricity sales to the grid. Some of the major constraints used in this optimization analysis include the following:

- The net power generated by the central utility is the sum of electricity generated by the power plant and solar panels and difference of electricity discharged and stored by the battery
- Power cannot be purchased and sold within the same hour
- The difference between community electricity demand and electricity generated by the central utility is sold to the grid

The annual operating cost was then added to the annual cost of financing the central utility equipment to determine whether such investments would reduce the cost of providing energy to the community.

Results

The Community Energy System problem was modeled in Pyomo and solved using CPLEX. The problem was solved for a variety of equipment configurations, e.g. a utility plant consisting of a generator, battery, chiller plant, and solar array versus a utility plant consisting only of a generator. For each scenario, the solver minimized an objective value representing operating costs for the entire year. In a post-processing step, capital costs for each equipment configuration were annualized and added to objective values to compute an overall annual cost.

Baseline capital costs were $6.2M for a 6MW generator, $3.5M for a 10 MWh battery, $9.0M for a 2.5 MW solar array, and $23.8M for a mechanical chiller and construction of a neighborhood cooling loop. For configurations without a chiller, a cost of $9.2M was included to account for residential A/C condensers. With a chiller present, residential condenser equipment is excluded. The annualized cost of capital equipment was calculated using a 6% interest rate, although this value was later varied to check the sensitivity of the results. Total costs for five utility plant configurations are shown in Figure 1.

Figure 1 shows that multiple configurations of neighborhood utility plants can significantly reduce operating expenses relative to the baseline scenario. This reduction is possible because 1) making electricity with the generator is often cheaper than buying electricity, 2) selling excess electricity earns profit for the community, 3) the battery (when present) helps mitigate power flow in/out of the utility plant, which limits demand changes, and 4) a mechanical chiller is more efficient than residential A/C units, so less electricity is consumed overall. However, the operating cost savings are largely offset by the annualized cost of capital.

In Figure 1, the operating cost of the Generator+Battery configuration is less than the Generator+Battery+Solar configuration. Because solar panels produce electricity at zero cost, this was an unexpected result. The result indicates that, although the scheduling of equipment for each configuration was optimized, there is a need to optimize the size of each piece of equipment (solar, battery, generator, etc) relative to each other. In this case, it appears that the battery is not large enough to mitigate the increased power flows from the solar array, resulting in increased demand charges.

Conclusions and Future Work

Initial analysis shows that there is technical and economic potential for a community utility plant to serve energy demands while reducing overall cost to the neighborhood. The model built for this project can be easily adapted to include other equipment. Notably, configurations with thermal storage should be included for analysis. As mentioned in the preceding paragraph, there is an optimal size for each piece of equipment depending on the configuration of the utility plant. For example, the optimal size of the battery depends on whether or not a chiller plant is present, and vice versa. Expanding the optimization methodology to consider this problem will increase the value of the results. Because optimally sizing each piece of equipment will increase solution time, heuristical approaches might be necessary. Finally, the current model is deterministic in terms of electricity demand and wholesale electricity prices. Including stochastic events in both demand and wholesale prices will more accurately quantify how a neighborhood utility plant would perform in practice.

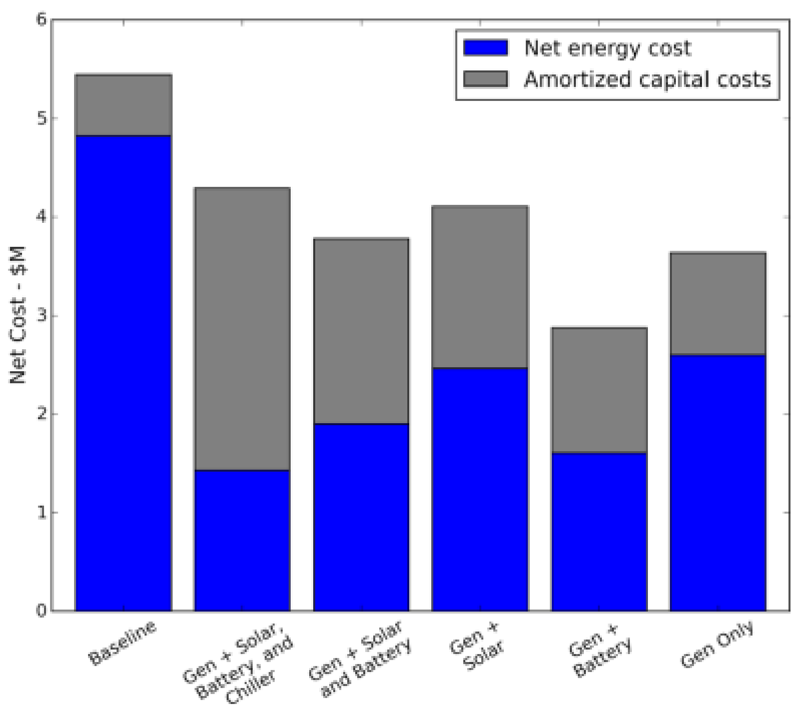

Figure 1: Total annual cost (operating + capital) for a neighborhood utility plant in five distinct configurations. Costs are compared to a baseline scenario where electricity is purchased and residential A/C compressor capital costs are included.