

A TECHNO-ECONOMIC MODEL TO ASSESS OPTIMAL DISTRIBUTED ENERGY RESOURCE INVESTMENTS IN THE RESIDENTIAL ELECTRICITY SECTOR

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Overview

Growing population, changing climate, and rising economic activities have led to a global increase in electricity demand. Maintaining the balance between supply and this increasing demand often necessitates the usage of old and inefficient generators that are not environmentally friendly and increased investment in expensive generation, transmission and distribution infrastructure. Distributed energy resources (DERs), like solar photovoltaic panels and onsite energy storage systems, can help offset a portion of this demand while simultaneously reducing harmful emissions. DERs additionally provide a variety of value streams including reliability, power quality, congestion management, voltage support, energy arbitrage, real time price dispatch, and demand charge reduction. However, high capital and installation costs remain one of the major disadvantages associated with onsite solar and storage. Investment tax credits, rebates and net metering programs offered by some utilities can help reduce the economic burden of DER investments.

This paper develops a framework to evaluate when it is a good economic decision for the residential customer to invest in DERs based on three different electricity rate structures: 1) constant electricity rates, 2) real time pricing (RTP) structure, and 3) time-of-use (TOU) rates. The framework is demonstrated using empirical electricity consumption data and residential rates from Austin Energy, the municipal electric utility in Austin, Texas.

Methods

A linear optimization model is developed using R to minimize costs incurred by a residential customer and is solved using the 'rglpk' linear programming package. The objective function includes cost of power bought from the grid, capital and operations and maintenance (O&M) costs for solar panels and energy storage systems (ESSs), capital cost for control infrastructure (thermostats, water temperature controller, etc.), rebates availed by the customer, and incentives received for solar generation. The objective function is minimized subject to several constraints including load constraints, distribution grid power transfer capability, energy conservation surrounding the solar panels and the ESSs, charging and discharging limits for the ESSs, and limits on energy capacity of the ESSs during the time period of analysis. Heating, ventilating and air-conditioning (HVAC) systems, electric water heaters (EWHs), electric vehicles (EVs) and pool pumps are some of the highest energy-consuming (but controllable) devices used in the residential sector. Thus the optimization model also includes a one-parameter thermal model for the HVAC and EWH, and charging models for the EV, and pool pump. The customer is able to specify bounds for the room and water temperature, and temporal limits for EV and pool pump charging. Three scenarios are evaluated: 1) a home with solar and ESS, 2) a home with solar but no ESS, and 3) a home with no solar or ESS. Electricity charges to the customer and overall expenditure, including amortized capital and O&M costs for the DERs as well as federal, state, and utility level rebates, are quantified. Cumulative power flows among the solar panel, ESS and the home are also highlighted in addition to the energy consumption and operational level of each shiftable end-use appliance.

Results

For a home with all four controllable end-use appliances considered in this study, it is observed that the electricity bill is lowest for a customer with both solar and ESS for all pricing scenarios. The overall expenditure varies for the different rates - Scenario 2 with solar but no ESS produces the lowest cumulative cost for the constant rate while Scenario 3 with no solar or ESS is cheapest with the real time and time-of-use pricing structure for the summer peak day. This trend shows that the capital costs for DERs, and particularly ESSs, need to decrease further to make them economically viable for a residential customer with high energy consumption. For a flat rate, the ESS is charged solely from the solar panels while for the real time and time-of-use pricing structures, the ESS charges both from the grid and the solar panel on the summer day. The model also solves for the operational level of each appliance. The levels of the HVAC, EWH, EV, and pool pump for the time-of-use rate are shown in Figure 1.

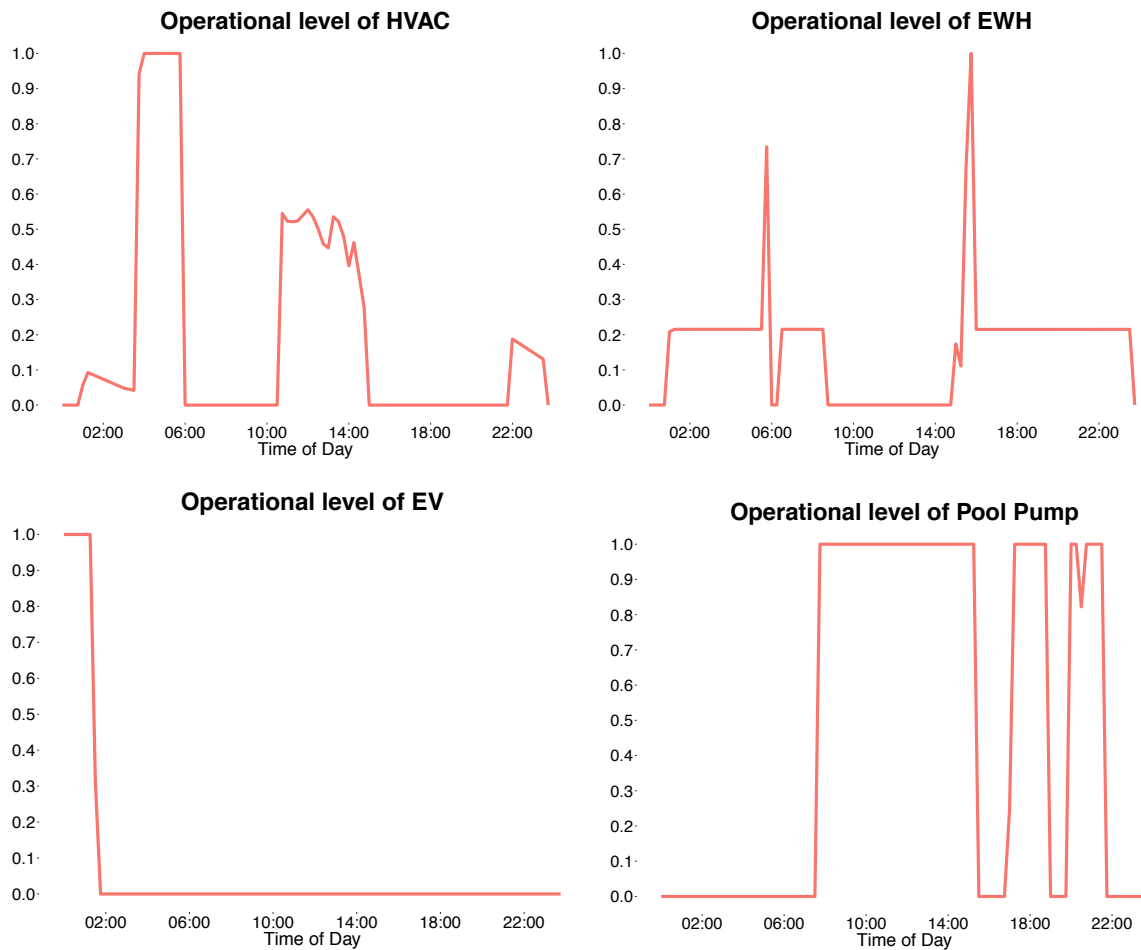


Figure 1: The model solves for the operational level of a 3.5 kW HVAC system, 4.5 kW EWH, 6.6 kW EV battery and 1.1 kW pool pump on the summer peak day of 2017 for a time-of-use rate

Conclusions

Solar panels and energy storage systems are still very expensive at the present day. Studies have shown that the capital and installation costs for solar panels and lithium-ion batteries have decreased by 61% and 82% respectively between 2010 and 2017 [1, 2], although solar panels have experienced a higher cumulative historical decline in prices. As the costs for DER assets continue to fall, an increasing number of customers will decide on whether or not to invest in local generation and storage. This study establishes a framework for quantifying the economic value of DER investment for different pricing structures. Future work will include performing sensitivity analyses based on different ownership frameworks (utility-owned, third party owned and customer owned solar and ESS) and various control methodologies for DERs (utility control, third party aggregator control, autonomous control).

References

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