Energy Management in Smart Houses with Batteries, Renewable Energy and Context Awareness

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Residential energy consumption accounts for around 40% of the overall energy consumption in the US, with tens of millions of individual consumers. This large scale consumption creates a promising opportunity to save energy, and in turn, reduce the total cost of energy for consumers. In this work, we focus on how residences can automate and control their energy consumption in an efficient way. This automation is achieved through monitoring and management, which are enabled by advances in smart grid technologies such as smart metering, sensor deployment, and communication methods. In addition, in this study, we consider smart battery usage and leverage context awareness along with renewable energy integration.

Using batteries is a well-known method to take advantage of the diurnal patterns of the energy consumption profile of a house and variable electricity prices. These devices can store energy when it is cheap and provide the stored energy when the price is higher. Several studies have previously addressed this idea and formulated optimization problems to solve for the best battery characteristics to minimize the total cost of energy. Although these studies account for battery properties in their formulations, they do not model the non-linear behavior of the batteries. These properties, including the depth and rate of battery discharge, are affected highly by the battery type. We first define a battery configuration study and then formulate the problem of selecting the best battery configuration in order to minimize the total cost of energy. This study leverages our previous work, where we introduce an accurate battery lifetime model and validate the model against real measurements, with an average error less than 5%.

We begin our analysis by investigating the case of two-tier time of use electricity pricing, which consists of a high and low energy price. For this case, we assume that there is no renewable energy integration. We formulate the problem with electricity pricing dynamics and non-linear battery behavior, and obtain a feasibility control inequality that can test if a battery configuration is profitable. The inequality we obtain is simple and easy to apply. We verify the outcomes of this inequality with a simulation study using real house energy consumption profiles from MIT REDD dataset. We use multiple battery types for our analysis and show that up to 43% energy cost savings is possible with battery usage. However, without specific battery configurations, these savings can be reduced or even eliminated altogether. Our next steps in this topic include the analysis of different pricing dynamics, other than two-level pricing, and the investigation of how the results and the framework would change with renewable energy integration and its variable nature. More specifically, we want to answer the following questions: 1) which pricing mechanism makes the battery usage more profitable? 2) how does the renewable energy integration and its variable nature have an impact on the best battery configuration?

We further consider the impact of context awareness in the home. The advent of smart metering, non-intrusive load monitoring (NILM), and the prevalence of mobile and stationary sensing provides the ability to determine energy consumption in the home and occupant behavior. This data can, in turn, be used to modify the behavior of energy consumers in the home. We investigate these scenarios through a series of case studies involving both internal and external sensed data, demonstrating up to a 50% reduction in grid consumption. Internal variables such as user occupancy and appliance output data enables prediction of future energy consumption, which in turn can enable home automation. External variables such as temperature and solar irradiance can be used to control the behavior of heating and cooling (HVAC) appliances. Both can be used to better understand, predict, and react to user and environmental behavior in the home, and consequently, control energy consumption and cost.