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Managing Smart Grids Using Price Responsive Smart Buildings

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Abstract

The market is a tool used to efficiently allocate resources. Energy markets have been used to allocate generation and transmission resources at the level of the transmission and distribution system, with significant innovation on these markets occurring since deregulation in the 1990s. The advent of the Smart Grid and Smart Building have enabled these innovations to be brought to the level of the retail electricity market, where even individual buildings will be able to adjust their consumption based on price signals from the market. This paper gives a review of the development of energy markets and the technologies of the Smart Grid and Smart Building that are enabling their participation in the market at the edge of the grid. The OpenADR communication protocol is examined as a means of communicating price information between the load and the utility. Finally, a hardware-in-the-loop Smart Building test setup is described. This test setup is used to compare the performance of baseline and price responsive controls, with a power reduction of 60% achieved during a period of peak consumption and grid congestion corresponding to a large price surge.

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1. Introduction

A cavalcade of new technologies has produced new opportunities in generation, distribution, and consumption of power which fall under the broad heading of Smart Grid, and in time these technologies have extended into Smart Buildings. These technologies produce potential for reductions in power consumption, or cheaper generation, or reduced grid congestion, among other benefits. In this paper, these new technologies will be combined with energy

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market concepts to demonstrate how these potential benefits can be realized. In particular, this paper will demonstrate how smart buildings and the smart grid can be used to reduce congestion on the grid during periods of peak loading.

The group of technologies that has arisen in the last fifteen years include distributed generation, particularly residential and commercial PV installations, local energy storage, high speed wireless communications networks, distributed and cloud computing, and machine learning-based automation technologies. Distributed generation and energy storage resources have driven a change from centrally controlled and operated power systems to a more diffuse control with bidirectional power flows [1]. This has created the need for high speed communication to collect data and dispense commands. This collection of networks and computational techniques clusters together under the umbrella of the Smart Grid [2]. Ranging from simple technologies, such as smart meters that can enable export to the grid, up to highly complex systems, such as virtual power plants that can coordinate the deployment of resources over a wide geographical area, the Smart Grid provides the framework for control of these new distributed resources.

Smart Buildings combine existing building automation systems with technologies like smart meters and machine learning to provide control of energy consumption within a building [3-4]. Just as the Smart Grid facilitates coordination of distributed generation resources on the edge of the grid, it can also be leveraged to coordinate the operation of Smart Buildings to provide grid services. Programs like demand response, which previously were mostly implemented in large loads like industrial sites, may be extended to small commercial and even residential buildings using the communication infrastructure built for the Smart Grid. The Smart Building can then use technologies like machine learning to find ways to manage its energy via load shedding while minimizing the disruption to the inhabitants of the building.

Electricity markets have long been used to coordinate resources on the grid. They provide coordination for resource scheduling, pricing, transmission capacity reservation, and congestion management [5]. Major innovations since deregulation in the mid-1990's include energy tagging and locational pricing [6]. Such markets have not typically been applied at the retail level, however. Instead, retail customers have a flat rate for electricity. This decouples the consumption of power from the price of power, giving rise to inefficiencies in the use and distribution of power at the point of consumption [7]. The Smart Grid communications framework provides a method to implement these markets at the retail level on the edge of the grid, and research is underway to implement market concepts such as energy tagging at this local level [6, 8].

This paper presents the implementation of a Smart Building that receives the price of electricity over the Smart Grid communication infrastructure. Section 2 will describe the OpenADR communication protocols used to communicate price information. Section 3 will describe the hardware-in-the-loop (HIL) test bed used to implement the Smart Building controls as well as the building, weather, and price models used for the test. Section 4 will present the building energy consumption for the baseline and price-responsive cases.

2. OpenADR and Price Responsive Load Control

OpenADR was developed by the Demand Response Research Center of the Lawrence Berkeley National Laboratory in 2002 [9]. It is intended as a communication interface to send demand response information between the grid and load resources. The standard specifies data models in XML files which are sent over the HTTP or XMPP transport protocols, which can be accessed using a standard internet connection. The standard also specifies cyber security measures.

The OpenADR protocol classifies components as Virtual Top Nodes (VTNs), which initiate demand response requests, and Virtual End Nodes (VENs), which implement those requests. In a typical configuration the VTN might be a server operated by the electric utility and the VEN might be an individual building. The specification does allow hierarchical data flow, so a more complex system might have an aggregator as an intermediary. The aggregator acts as a VEN for the utility server, but is a VTN from the perspective of the individual loads that are aggregated by it.

OpenADR provides a simple version of the standard, OpenADR 2.0a, and a version with a greater number of features, OpenADR 2.0b. One key difference is the type of event signals that can be sent using the protocol. Table 1 provides a list of all of the EiEvent signal types available in the OpenADR standard. OpenADR 2.0a uses only the Simple Levels signal type, which can be used to communicate the start or end of a previously agreed event. The actions required in these events might be pre-programmed, such as turning off a particular set of loads, or could be implemented as pre-agreed energy shedding target.