Demo Abstract: Distributed Control of a Swarm of Buildings Connected to a Smart Grid

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1 Introduction

Energy-efficient control mechanisms are necessary to manage the ever increasing energy demand. Recently several tools for building energy consumption control have been proposed for small (e.g. homes) [8] and large (e.g. offices) buildings [3][6][1]. The mechanism each tool uses is different, e.g. HVAC control [3] and appliance rescheduling [8], but they share the goal of improving consumption of the buildings with respect to a given cost function. Some examples of cost functions are reduced energy consumption, reduced electricity bill, lower peak power, and increased ancillary service participation. The tools however do not capture the impacts of their control actions on the grid. These actions can lead to supply/demand imbalance and voltage/frequency deviation and thus, threaten grid stability. Utilities can take protective actions against those who cause instability by increasing electricity price or even momentarily disconnecting them from the grid. The effects of these protective actions can be so severe that the savings obtained by building management tools might disappear.

The demo illustrates a method for measuring the effects of individual building management tools on the grid and provides this information to the tools and, where warranted, to the building operators to help find corrective actions. By using a simulation tool, we can forecast any possible instability event before it happens and warn each tool if their actions are likely to affect negatively the grid. The simulation tool is an OpenDSS-based grid simulator, called Smart Grid Swarm Simulator (S^2Sim). S^2Sim simulates the grid dynamics (power, voltage) and interfaces to multiple tools to provide a large and realistic view of the grid. S^2Sim communicates with each tool periodically, obtains their status and provides feedback with a price signal as a way to adjust energy consumption. The demo also shows how independent building control tools align in the grid, how their actions trigger protective actions of the utility and how these actions impact the comfort level in each building.

2 The tool set

Each separate building control tool connects to S^2Sim as an external client. These tools can be building simulators and control optimization packages with complex mathematical models or sensors monitoring and streaming real-time building power consumption data. S^2Sim does not know the internal details of the clients. It has the capability of two-way communicating with clients, time-synchronizing them and providing them with pricing and regulation signals to mimic the behavior of a utility. The power flow calculation is performed using OpenDSS [5], a widely used open source power flow simulator. S^2Sim uses the consumption information provided by the clients to create a consumption map of a selected virtual circuit, representing a neighborhood, microgrid or even a city. S^2Sim feeds the consumption information into OpenDSS to calculate the power flow solution and extracts stability related information. This information is then fed back into the controller that mimics a utility and provides real-time pricing and regulation signals to guide the client consumptions. The resulting system becomes a large closed-loop control.

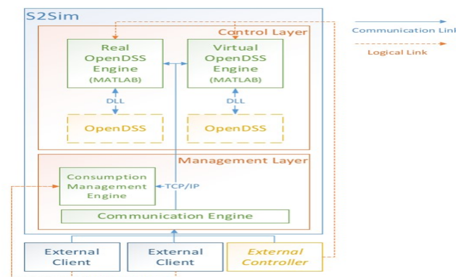

Figure 1. The communication structure in S^2Sim

S^2Sim is highly modular and extensible. The controller providing the utility functionality can be replaced by another tool, where the communication is handled over the well-defined messaging protocol. Client communication is handled over TCP/IP, enabling parallel computing and the co-simulation of proprietary solutions, where the source code is not publicly available. The system structure along with external clients and the controller is shown in Figure 1.

The building control clients that are coordinated and interfaced by S^2Sim are described below.

HomeSim: HomeSim [8] is a modular energy simulation platform that provides an analysis of the individual houses' leaf nodes - the appliances, sources, and energy storage devices. HomeSim is replicated and connected to the grid simulator S^2Sim to represent the impact of the independent residences found in the real grid. Similarly, grid-level availability and pricing changes result in individual responses from each instance, allowing a better analysis of distributed, grid-aware energy management algorithms.

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SDH_HVAC: The Sutardja Dai Hall (SDH) HVAC client utilizes an optimal control algorithm presented in [3] that provides a mathematical framework for HVAC operation of commercial buildings. The framework assumes Time-Of-Use (TOU) pricing for electricity consumption, time-varying reward rate for up and down flexibility, and comfort zone constraints. SDH_HVAC computes the energy demand as well as the flexibility of HVAC systems to be used as a source of frequency regulation for the smart grid. In the demo, we also use the contractual framework that is presented in [3] that demonstrates how buildings and grid should interact. The ensuing interaction between the utility and the building operator would be through flexibility power signals sent from the utility to the building operator to be tracked.

Bancroft_HVAC: The Bancroft_HVAC client simulates a commercial building HVAC system controlled by a Model Predictive Control (MPC) scheme synthesized by automatically generating control signals that satisfy finite and infinite horizon Signal Temporal Logic (STL) properties [6]. The building is modeled as a resistor-capacitor circuit with n nodes, m of which are rooms and the remaining $n-m$ walls. An STL property in our tool is to maintain a minimum comfortable temperature whenever the room is occupied, while minimizing the cost of heating based on the observed prices.

MLE+/EnergyPlus: EnergyPlus is a high-fidelity building energy simulator that is supported by the U.S. Department of Energy. It can simulate complete building energy systems including HVAC, lighting, and chillers. MLE+ [1] is an open-source Matlab / Simulink toolbox for co-simulation pf contrellers with EnergyPlus. The MLE+/EnergyPlus client simulates multiple realistic building of different types (e.g. office buildings and hospitals) in EnergyPlus with Demand Response (DR) controllers in Matlab, which connect to S^2Sim via the open-source toolbox MLS^2Sim [4].

Beyster Battery Bank: The Beyster Battery Bank is a DR system deployed in an office environment at the University of Michigan. The system consists of a circuit panel meter and several plug loads optionally supplied by a dispatchable battery bank. The battery bank consists of seven uninterruptible power supplies (UPSs), each instrumented with a modified ACme board [2] that switches the UPS between power mains and battery backup. If the price goes above a certain level, the battery bank is "dispatched" – the ACme boards are actuated, switching to battery backup. The UPSs are reconnected to mains if the price drops or if the max allowable battery time is exceeded.

Scaife Hall: As part of the Sensor Andrew [7] project at CMU, various subsystems in the Scaife Hall building on campus are being made accessible for real-time monitoring and control. This includes access to circuit and plug-level electricity usage, chilled water and steam flow rate with temperature, rooftop air handlers, HVAC set points and schedules as well as per-room environmental sensing. Both live and historical sensor data can be fed into S^2Sim in order to generate pricing signals based on simulated grid dynamics. These pricing signals can then be evaluated against user context sensed within the building to select unnoticeable actions for load shedding. For example, room-level fan controllers and lights can be disabled in unoccupied regions.

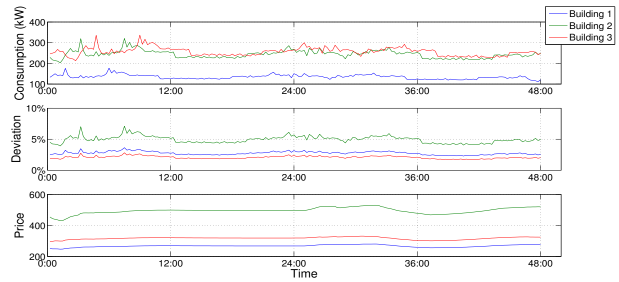

Figure 2. Power-vol. deviation-price for 3 buildings

3 The Demo

A simple S^2Sim simulation is performed on a small portion of the UC-San Diego university campus circuit with three office buildings for 48 hours. Figure 2 shows the sensed consumptions of the three buildings and how their consumptions are reflected differently into voltage deviations due to different circuit connections and different voltage levels. The power levels and deviation levels are then processed by the controller to generate individual price signals which show the response of the utility to the voltage deviation values. The grid dynamics frequently changes due to the consumption of each building, proving the necessity of coordination among different building management tools. In the demo, we present the communication among the clients mentioned above via S^2Sim, how they affect the grid and the response to the price signals they receive. In this demo, we show that a control policy based on coordination among buildings achieve better performance than individual control actions.

4 Acknowledgments

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