GreenSwitch: The Home Extension

Abstract

1. **Instruction**

The cost of electricity is increasing. In the past 25 years, the price of residential electricity has increased about 30%. [1] With more appliance used in resident home, the demand of electricity has increased almost 50% over 20 years. [2] According to the US Department of Energy (DOE), buildings accounted for about 38.9% of US primary energy consumption in 2006, 74% of which is electrical energy [3]. This electrical usage is roughly divided equally between residential and commercial buildings. Consequently, several efforts by the DOE and the research community [5] have begun to analyze energy use within buildings to identify the dominant energy loads. Recent research shows that depending on the special use modality of the building, the dominant electricity consumers can be lighting, computing infrastructure, or what is most often the case, heating ventilation and air-conditioning systems collectively referred to as HVAC [4, 5].

The simplest way to cut electricity bill is to use less electricity. But this way has negative impact on the quality of daily life. The other problem is that consumers have to continuously monitor market price change and operate their appliance to reduce electricity cost. Usually consumers do not know the specification of appliances. So the task is challenging.

To address these problems, we propose GreenSwitch, an intelligent system that determines when and how much to store low-cost energy for use during high-cost periods, when to use solar power or grid power and when to turn on or turn off appliance to achieve lowest electricity cost without disrupting daily life.

Several companies have recently announced plans to build “green” datacenters, i.e. datacenters partially or completely powered by renewable energy. For example, Apple is building a 20MW solar array for its North Carolina datacenter [6]. McGraw-Hill has recently completed a 14MW solar array for its datacenter [7]. Our idea is that why don’t we use this approach to build a “green” home house. These home houses will either generate their own renewable energy like using solar energy or draw it directly from an existing nearby plant. However, solar energy is intermittent, which requires approaches for tackling the energy supply variability. One approach is to use batteries and/or the electrical grid as a backup for the renewable energy. It may also be possible to adapt the workload to match the renewable energy supply. For highest benefits, green home house operators must intelligently manage their workloads and the sources of energy at their disposal. We model this cost-minimization problem as a linear optimization.

1. **Related work**

The way of reducing home electricity cost has been well studied in the research literature. Parasol and GreenSwitch: Managing Datacenters Powered by Renewable Energy quantified, based on the real datacenter experimental evaluations, the tradeoffs of building a solar and/or wind powered datacenter in the future. Specifically, it discussed the space requirements and the capital cost of these technologies. This idea also can apply in resident home. It demonstrated Parasol, a solar powered micro datacenter. The authors introduced the infrastructure, hardware, software components of Parasol, with quite a few details. It also presented GreenSwitch, the core part of the system to manage workload and energy source. The authors explained in detail how GreenSwitch works, and how to mathematically model each part of the system, as well as the objectives. Finally, the paper gave a couple of experimental results and evaluations.

Reference [2], propose SmartCharge, an intelligent charging and discharging system that determines when and how much to store low-cost energy for use during high-cost periods based on expectations of future demand. They designed SmartCharge in detailed infrastructure, outline the linear optimization problem, and evaluate it in both simulation, using power data from real homes and existing market-based residential pricing plans, and with a small-scale prototype using a home UPS system and a few household appliances.

1. Initial Approach

3.1 GreenSwitch: the Home Extension

In [1], Goiri et al. demonstrated the central real time control system, GreenSwitch, as their core system to make benefit out of renewable energy plant investment with solar and/or wind power. Rather than controlling the massive data center, part of the contribution in this project is to adapt GreenSwitch so that it will be able to manage workload and energy source in homes/buildings, which leads to GreenSwitch: the Home Extension.

The solver of original GreenSwitch was mainly based on linear programming (LP). Linear programming is a well-developed area, and the algorithms are available to solve various problems. Because of this general technique, as well as the whole GreenSwitch architecture, future researchers are able to reuse this system without significant modification; only the configuring part and the mathematical modeling of specific optimization problems are needed to be changed.

We now discuss about the modeling of LP in home appliances. In [2], Barker et al. showed that a typical home has the following appliances: a central air conditioning (A/C) or separate window A/C units or HVAC unit, an electric dryer and washing machine, heat recovery ventilation (HRV) unit, dishwasher, refrigerator, and freezer. In addition, the building also has a solar panel, generating power and feeding into the home’s grid supply. To model LP, we need to model both objectives and constraints. Note that in [1], the solver part of GreenSwitch is essentially the design and implementation of LP.

The objectives of the solver should also be similar to the original GreenSwitch; the solver should provide an optimized workload schedule and energy source schedule, under which it should minimize the total electricity cost in a certain range of time.

The deferrable and non-deferrable workload determination, however, is an interesting problem. Since traditional non-deferrable workload refers to time critical system tasks such as hard real time systems, very few of these home appliances has to be treated like so. However, some systems, such as HVAC, does need to be turned on and off once the sensor senses the values outside certain defined range. Yet even if such system fails to start or finish its job before its deadline, there is no severe harm happening. In fact, this boundary between deferrable and non-deferrable is highly vague and also depended on particular custom needs. Thus in our system we give customers the power to choose which one can be deferred and the relevant deadlines.

As for the constraints modeling, it is system specific with an entirely different set of parameters and equations. But based on certain common senses, such as total offered energy should be equal to or greater than the total requested energy, it should be straightforward to implement. The configuring part of GreenSwitch is rather a bunch of actuators which adjust different appliances according to the commands from the solver. The setting up highly depends on the physical limitations and saturation areas of these actuators. For now, we just assume that every appliance under control can be delayed indefinitely, every energy source can be activated/deactivated and the maximum amount can also be changed.

3.2 Dataset

Researchers from University of Massachusetts Amherst Computer Science department made publicly available numerous data sets in [2] for enabling research in sustainable homes. The dataset came from a variety of different sources, including, electricity usage at the mains panel, each circuit, and plug load. Additionally, the data also came from multiple weather, motion, door, wall switch, and thermostat sensors, as well as electricity generation data from solar panels and wind turbines. We observe 6 types of data as follows:

• Electricity at the Mains Panel: average real and apparent power every second for the home and each circuit at the mains panel.

• Electricity at Outlets: real power usage at intervals from home’s plug loads.

• Wall Switch Events: on-off-dim events at wall switches.

• Average electricity generation from solar panels and micro wind turbines every five seconds.

• Thermostat Events, Motion Events and Door Events: a variety of events relating to energy consumption, including motion sensors, door/trigger sensors, and thermostat sensors.

• Weather Station Data: environmental data provided by the weather sensors every minute both inside and outside the home.

With the data provided by the team, the following work can be done:

Cost Optimization: 1st, Use the weather data to predict the aggregate consumption for homes; 2nd, quantify the potential for savings based on the today’s electricity market pricing plans.

Demand Flattening: Use a Least Slack First (LSF) to schedule loads in ascending order of their remaining time without affecting their objective. In addition, use home electricity data, plug load and circuit data for eight background loads, and the team’s temperature and humidity data from the weather sensors to evaluate LSF’s potential for demand flattening.

Load Monitoring: Use AutoMeter to resolve a home’s electricity usage into several parts each second with low resolution data, from Insteon wall switch events and iMeter plug loads.

Renewable Prediction: Predict future renewable generation using weather forecasts from the National Weather Service.

NILM: Although Non-intrusive load monitoring (NILM) focuses on large scale scenarios, commonly greater than 100 loads, there are still many relatively low-power loads, like less than 50 W. Low power loads is a common characteristic of homes. By the analysis of the team’s data, we find it useful in developing and evaluating new disaggregation algorithms for electricity data.

1. Reference

[1] Electric Power Annual 2010. Technical report, U.S. Energy Information Administration, November 2011

[2] Aditya Mishra, David Irwin, Prashant Shenoy, and Jim Kurose, SmartCharge: Cutting the Electricity Bill in Smart Homes with Energy Storage

[6] Data Center Knowledge. Apple Plans 20MW of Solar Power for iDataCenter, 2012. http://www.datacenterknowledge.com/archives/2012/02/20/apple-plans-20mw-of-solar-power-for-idatacenter

[7] Data Center Knowledge. Data Centers Scale Up Their Solar Power, 2012, http://www.datacenterknowledge.com/archives/2012/05/14/data-centers-scale-up-their-solar-power/