Study Feasibility of Making Smart Office Buildings (Case Study: Power Energy Control)

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Abstract: The main purpose of this study is study the feasibility of making smart office buildings, especially in Germany and Italy, with the focus on power energy control. In an attempt to overcome the defects of quiescent power shutdown system, smart quiescent power control system has been developed. However, due to its higher investment costs, feasibility evaluation must be conducted. Energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. The evolution of the electricity grid towards the smart network is kind of energy sources in smart office buildings: a combination of local power generation, battery storage and controllable loads can greatly increase the energetic self-sufficiency of a smart office buildings, enabling it to maximize the self-consumption of electricity, thus taking advantage of control their electrical building loads and time-variable tariffs to achieve economic savings. The performance is compared to the optimal energy usage scheduling, which would be obtained assuming the exact knowledge of the future energy production and consumption trends. In addition, sensitivity analysis is carried out to quantify accuracy of estimates.

[Pirooz Jafari, Payam Mohebbi. **Study Feasibility of Making Smart Office Buildings (Case Study: Power Energy Control).** *Nat Sci* 2016;14(9):64-69]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 10. doi:10.7537/marsnsj140916.10.

Keywords: Smart Office Buildings, Power Energy Control, Electricity Grid

1. Introduction

Smart office building technology typically delivering energy savings and maintenance efficiencies. In large office buildings with centralized building automation systems, relatively inexpensive devices can be connected to the building control panel to enable a smart office building management system to extract and analyze real-time equipment and system performance data and use it to fine-tune building performance.

In smaller office buildings that do not have centralized smart systems, the availability of affordable wireless sensors combined with this new smart building technology makes it possible to deploy a building automation system. Making installation of a smart building management system much more affordable.

The smart grid concept is not only revolutionizing the electricity grid infrastructure, but also incentivizing awareness of a more sustainable energy utilization: “green” solutions for residential and commercial buildings have been investigated with the aim of increasing the diffusion of renewable energy sources. However, the inherently intermittent production patterns of renewables increase the unpredictability of the overall power availability, thus raising power balancing issues in the management of the smart office buildings.

Smart building systems are more energy-efficient than legacy systems, but can also reduce operational risks, improve building performance and enable more accurate capital planning. Concurrently, the “smart office building” paradigm aims at improving the energy efficiency and occupant’s quality of living by integrating intelligent control mechanisms enabled by information and communication technologies (ICT). The goal of such systems is the optimization of the building operation by integrating information about the users’ preferences and activities, ambient conditions and electricity supply availability. In particular, demand-response interactions make it possible to equalize the load experienced by the grid by lowering the consumption in the case of power production scarcity or by increasing power absorption when production exceeds demand. To do so, the smart building must include distributed generation plants, storage capabilities and controllable electrical loads. Each smart office building can be managed by a dedicated control system, which schedules the charge/discharge cycles of the storage bank and the runtime of the power loads, in case they exhibit some malleability: several management policies have been investigated, mostly aimed at the minimization of the operational costs in the presence of time-variable energy tariffs.

A smart office architecture in which the energy usage of an office equipped with a photovoltaic plant, a storage bank and a set of loads (either non-deferrable or deferrable) is controlled by means of an energy manager, which makes decisions based on energy production and consumption forecasting algorithms and exploits the following peculiarities of the smart office ecosystem:

- Heating, cooling and lighting consumption can be forecasted according to the utilization schedules of the rooms (e.g., the usage of conference rooms is mostly pre-planned by means of a booking mechanism; the occupation of offices depends on the traveling and time-off patterns of the employees);
- Deferrable loads, such as the battery recharge of laptops and mobile devices, can be planned according to the periods in which the devices are plugged in at the working stations, which can be declared in advance by the device owners according to their daily working schedule.

In this paper, energy management service (EMS), which can be provided by a specialized third party, by the utility or by the distribution was discussed. The EMS defines the amount of charged/discharged energy in/from the local storage bank, the runtime of controllable loads and the amount of energy to be absorbed/injected into the grid based on the electricity tariffs.

Several optimization methods for the energy and comfort management of both residential and commercial smart buildings have been proposed by the scientific community, with strategies ranging from day-ahead to real-time planning.

A consistent body of recent works has specifically addressed the peculiarities of smart office and smart campus environments. Guan et al. designed a MILP for the minimization of gas and electricity bills of a university campus building equipped with a controllable combined heat-power system, battery storage and a photovoltaic plant.

Barbato et al., which enables the integration of renewable local energy sources, storage banks and controllable loads, and supports demand response with the electricity grid operators.

Guan et al. designed a MILP for the minimization of gas and electricity bills of a university campus building equipped with a controllable combined heat-power system, battery storage and a photovoltaic plant. The program is applied both under the assumption of a deterministic scenario or of a “scenario tree”, where uncertainty about future power usage is taken into account by means of a weighted objective function, including various production/consumption patterns, each one occurring with different probabilities.

Methods for knowledge extraction to automatically infer and adapt rule sets for the management of a smart office (or a generic smart building) are proposed by Gupta et al. [20] and Anjos et al. By analyzing data gathered from electricity meters, sensors and actuators deployed within the office environment and combining them with the users’ preferences, control rules can be dynamically generated, modified and deleted. This enables the system to provide monitoring and control capabilities for the photovoltaic installation, the backup batteries, air condition, blinds, lights, power plugs, window sensors, and humidity, temperature, brightness and power meters.

A hierarchical multiagent control system for a microgrid-integrated smart building is discussed by Wang et al. A particle-swarm optimization method is applied by the main agent for the maximization of the user comfort, whereas additional local agents manage controllable loads, room illumination, and temperature and air quality by means of fuzzy rules.

Measured data and control capabilities are available via different devices and clients, and all information is stored in, or retrieved from, a database. In addition, a rule system at the application layer of the middleware is used to observe the current status and under appropriate conditions to issue commands, e.g., to maintain a defined brightness level.

We observe that many offices nowadays are moving towards cloud-based solutions for their mission-critical systems, such as management software or productivity suites. As a consequence, businesses generally have high availability contracts with Internet service providers and backup solutions. The second major issue is that a centrally-managed EMS leaks private information about the ongoing or scheduled activities in the office. To this end, there is a rich research area discussing how to perform privacy-preserving energy scheduling at the expense of an increase of computation effort or of potential savings. There are a few issues that must be considered before deploying a cloud-based solution. The first issue is that network connectivity issues make the EMS unreachable and, thus, unable to manage the devices.

Employing a cloud-based EMS rather than an on-premises solution is a fundamental design choice of our framework, which enables the implementation of advanced services. Every time epoch, the server application collects the state of charge of the storage devices, the set of devices that can be managed and pushes them to the EMS along with the configuration requests, such as the minimum recharge level that must be guaranteed to the users of the rechargeable devices. Then, the application server enforces the decisions of the EMS by translating them into hard limits on the charge/discharge rate of the battery and on the consumption of deferrable or malleable loads. In our experience, a standard server can optimize the needs of a single smart office in a few seconds, so the server application can receive the answer with very limited latency.

This is especially important when the smart office operates in islanded mode: the server application is responsible of early termination of the islanded mode if the consumption exceeds the available power from the photovoltaic plant plus the storage bank. Since the EMS makes decisions by using predictions of the consumed/produced power, the server application must also ensure that the EMS decisions are feasible and do not result in unwanted outages if the prediction error happens to be large.

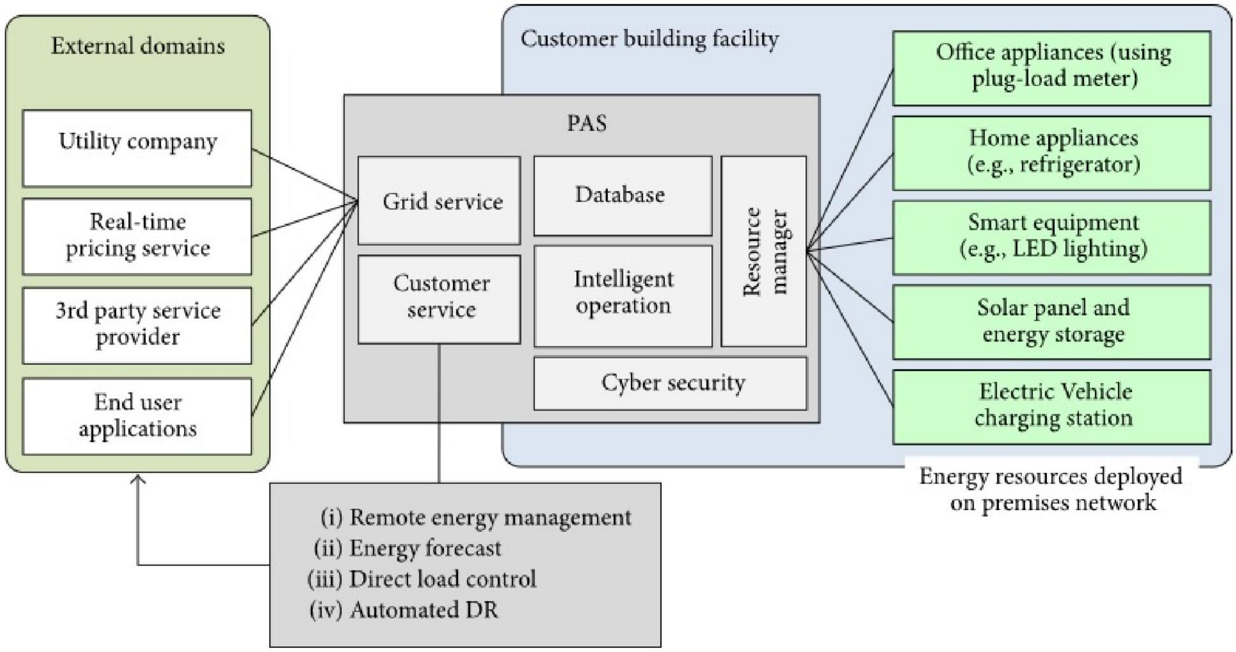

Fig. 1. Interrelationships of a premises network, energy resources, external domains, service providers, and energy services

Consumption Forecast

A triple exponential smoothing model provided were applied to predict the power consumption, since seasonal models are supposed to be a simple but feasible approach for short-term electricity demand. Adequate results have been obtained using a triple exponential smoothing model with parameters, which correspond to the weight of recent data, trend and seasonality, respectively.

The basis for these models are time series, where we use the historical consumption data for the past six same days. If we utilized information from the last successive days, the strong differences between workdays and weekends would distort the forecast values.

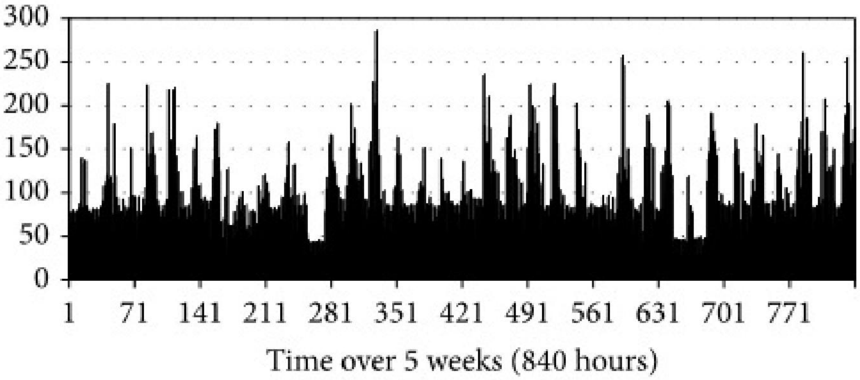

Fig. 2. Demand forecasting of a set of energy loads

Energy Management Algorithm

The energy management algorithm assumes that the optimization horizon is divided into a set of epochs T of fixed duration (e.g., in the order of minutes) and works under the following assumptions:

- The battery of the local storage bank can be charged (possibly with interruptions) with the energy generated by the photovoltaic plant and/or by direct feeding from the electricity grid;
- No more energy than the daily production of the photovoltaic plant can be injected into the grid (this prevents the smart office from getting state incentives for reselling energy bought from the grid);
- The duration of plug-in periods of rechargeable electronic devices is specified by the owners at the moment of plugging in the device. Alternatively, these periods could be enforced by using switchable sockets controlled by the system. The recharge process can possibly experience intermediate interruptions. Recharge is mandatory if the current state of charge of the device battery is below a given threshold specified by the user.

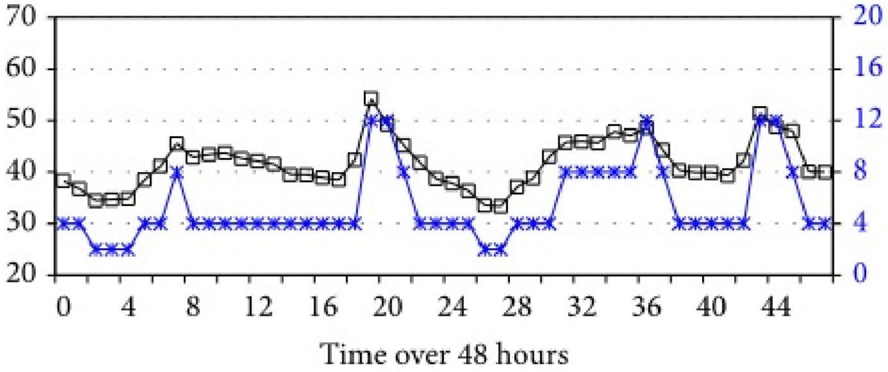

Fig. 3. Smart grid interoperation

Performance Evaluation

To assess the performance of our proposed EMS, we tested it in the Smart Energy Lab. The testbed includes a photovoltaic plant with peak production of 8kWp, a storage bank with capacity of 11kWh and recharge rate of 1kW, a set of non-deferrable appliances (lights, heating/cooling systems, servers and desktop computers) and 54 controllable plugs to which 33 laptops (device battery capacity of 60Wh, recharge rate of 45W) and 33 mobile phones (device battery capacity of 7Wh, recharge rate of 4W) can be connected. Recharge is mandatory until device batteries reach 70% of charge.

The scheduling horizon is a 24-h period divided into 100 epochs of a 20-min duration (though from the theoretical point of view, the duration of an epoch can be arbitrarily defined, most of the state-of-the-art commercialized smart meters use measuring intervals of 20 min). We start considering the minimization of the overall operational costs. The rewards for the recharge of the electronic devices above the mandatory threshold are price incentives corresponding to the daily average electricity price. Note that such incentives do not impact the actual bill, since they appear exclusively in the objective function of the MILP model. The electricity prices vary according to three different tariff types currently applied by an Italian energy provider and reported in Figure 4:

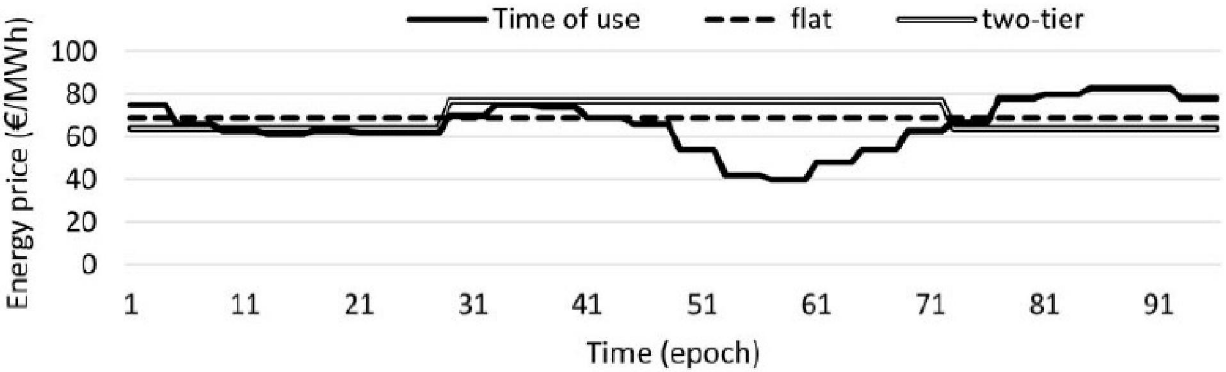

Fig. 4. Time of use and two-tier tariff prices

We now detail the analysis of the numerical results obtained for two reference days (a sunny weekend day and a partially-cloudy working day, respectively), assuming the usage of time-of-use tariffs. The corresponding energy exchanges with the grid obtained by means of the EMS.

It is worth noting that the time-of-use tariff leads to the lowest bills when compared to the other tariff options: in this scenario, due to the high variability of the energy prices, which exhibit hourly changes, the benefits of charging the battery during low-price periods and to discharge it when prices are higher become more evident. In order to leave a sufficient capacity to store the power generated by the solar panels, the storage bank is mostly discharged during the early morning. The battery is also discharged during the evening period, in order to reduce the amount of purchased energy when prices are high However, in the case of the time-of-use tariff, the schedules defined by the EMS lead to the highest bill gap with respect to the optimal ones, since with such a tariff, even small deviations with respect to the optimal schedules, due to inexact forecasts, could result in non-negligible additional expenses.

Conclusion:

This paper describes an energy management system for a smart office environment, which combines forecasting algorithms for the predictions of energy production/consumption trends with an optimizer that schedules the smart building operations according to the forecasted and actual energy utilization patterns, as well as to the current energy prices. Based on the presented results, we believe that the integration of our proposed system is a valid support to achieve nearly-optimal schedules of the smart building operational mode and to ensure significant cost savings.

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6/29/2016