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An interactive building power demand management strategy for facilitating smart grid optimization

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HIGHLIGHTS

- Interactive building power demand management strategy for integrating commercial buildings into smart grid.
- Quantify demand and demand alteration characteristics of commercial buildings to facilitate the smart grid optimization.
- Building thermal storage model is developed for predicting power demand alteration potential.
- Commercial buildings can contribute significantly and effectively in grid power demand management.

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ABSTRACT

With increasing use and integration of renewable energies, power imbalance between supply and demand sides has become one of the most critical issues in developing smart grid. As the major power consumers at demand side, buildings can actually perform as distributed thermal storages to help relieving power imbalance of a grid. However, power demand alteration potentials of buildings and energy information of grids might not be effectively predicted and communicated for interaction and optimization. This paper presents an interactive building power demand management strategy for the interaction of commercial buildings with a smart grid and facilitating the grid optimization. A simplified building thermal storage model is developed for predicting and characterizing power demand alteration potentials of individual buildings together with a model for predicting the normal power demand profiles of buildings. The simulation test results show that commercial buildings can contribute significantly and effectively in power demand management or alterations with building power demand characteristics identified properly.

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1. Introduction

In response to the increasing environmental challenges, depletion of fossil fuels, dramatic growth of power demand, use and integration of renewable energies, and critical risk of blackouts (e.g., USA blackout in 2003, India and Brazil blackouts in 2012), smart grid is considered as a promising solution concerning its improvements and benefits in power reliability, energy efficiency, economics and sustainability [1–3]. In recent years, many efforts have been made on different aspects of smart grid including micro-grid [4], distributed generation and distributed storage [5–8], smart meter [9], information and communication technologies [10], advanced metering infrastructure [11], supervisory control and data acquisition [12], demand response [13,14] and energy management system [15]. By conducting efficient acquisition of energy information and optimal controls of operation, smart grid can achieve a better power reliability and a higher overall energy performance when integrating different energy sources, storages and loads.

Although smart grid researches and applications have involved end-users (e.g., buildings) in the form of demand response (i.e., incentive-based and price-based [16]), but buildings can only conduct their power demand controls in a passive and static means by receiving signals (e.g., electricity prices) and controls (e.g., direct load controls) from the grid. Moreover, the potential of building power demand alteration and the possibility of establishing an interactive operation between buildings and the grid have been rarely studied. Actually, buildings have been becoming the major energy consumers with consuming around 40% of total end-use energy all over the world [17] and over 90% of total electricity in some urban areas, such as Hong Kong [18]. Buildings can help improving energy performance of an electrical grid by shifting loads and reducing peak demands. Previous studies mainly focus on the impacts and benefits of adopting different power demand control strategies under specific electricity prices in buildings

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Nomenclature

A	effective area (m^2)
B	operation energy cost
C	thermal capacitance (J/m^2 K)
COP	coefficient of performance
E	effective storage capacity (kW h)
e	Euler's number
J	objective function
N	number of frequency points
P	power demand or power capacity (kW or MW)
Q	cooling/heating load or heat (kW)
R	thermal resistance (m^2 K/W)
r	electricity price or price rate
T	temperature (°C)
t	time (min or h)
Σ	summation

Greek symbols

τ	time constant (h)
η	storage efficiency (%)
Δ	variation

Superscripts

$'$	associated with interaction process
k	number of iteration

Subscripts

act	actual
bui	building
c	charging
cont	controllable
conv	convective heat
d	discharging
ew	associated with external wall
est	estimated
fr	fresh air
im	associated with building internal mass
i, *in*	inside, indoor air
k	the *k*th data
la	latent heat
o, *out*	outside
rf	roof
rad	radiation
set	associated with temperature set-point reset strategy
sys	associated with HVAC system
shed	sheddable
tot	total
win	window

[19–21]. *However, characterization of power demand alteration potentials of buildings and their collective effect on grid dynamic optimization have rarely been addressed.*

With the development and extensive use of building automation systems, information and communication technologies and grid energy management system, a bidirectional communication between buildings and a grid can be widely established and used for interacting and optimizing the power supply and the demand. It is worth mentioning that, power demands of end-users and electricity prices of the grid are the key information for interaction and optimization between power supply and demand sides [22]. Buildings, as one of the most important participants involved in a smart grid, can provide useful information such as energy behaviors, power demand and the corresponding alteration potentials for grid control and optimization. In fact, smart meters have been successfully applied for residential buildings in many countries collecting detailed energy data [23]. *However, the use of smart meters and power demand alteration potentials in commercial buildings have not been reported and quantified for grid scale interaction and optimization.*

This paper proposes an interactive building power demand management strategy, which includes four main steps: (1) prediction of building power demand, (2) characterization of the building demand alteration potential and associated efficiency degradation, (3) grid dynamic prices accomplishment, and (4) optimization of building power demand control. The interactive strategy quantifies the thermal characteristics and power demand alteration potentials of passive buildings (i.e., buildings without active thermal energy storages) by adopting the building models developed. Simulation case study is conducted for testing the interaction and optimization between a group of commercial buildings and a small-scale smart grid.

2. Basic concept of the interactive strategy

Buildings are the major energy (especially power) consumers today and their shares are still increasing due to the urbanization. Buildings can benefit an electrical grid by relieving the pressure of power imbalance during different energy processes, particularly with the application of energy storages. Compared with traditional grids, smart grids enable a bidirectional operation (i.e., "two-way" connection with power flow and information flow) to improve power reliability and energy performance. A generic interactive framework is proposed in this paper for establishing the bidirectional communication between supply and demand sides of a smart grid, as shown in Fig. 1. Different participants such as power suppliers, deliverers and consumers are involved and connected by an information and data communication network. An information management and control center is employed by the smart grid for data and information collection, reliability and performance analysis, generation management and optimal control. It is worth mentioning that, the bidirectional connection and communication between smart meters and building automation systems of commercial building are more complicated than that in the residential sector. The practical integration of building automation systems and smart metering systems is rare, and no standard or agreed approach exists for such integration. However, there is no technical problem to achieve such integration practically. A generic integration framework, integrating building automation systems and smart metering systems, is therefore proposed for involving commercial buildings in a smart grid.

Commercial buildings and their thermal masses are investigated by considering the availabilities of thermal storage capability, energy information acquisition and control strategy implementation. Fig. 2 illustrates a bidirectional power and information connections of suppliers and consumers (i.e., commercial buildings). Commercial buildings and their thermal masses are considered as thermal storages storing/releasing energy in form of thermal energy. By having power information (e.g., generation capabilities and power demand alteration potentials) and incentive programs (e.g., dynamic prices) of power supply and demand sides, the overall energy performance can be improved with active participant of buildings. It is worth noticing that only simple pricing algorithm and generation capability profile are adopted in this study to test the buildings–grid interactive operation particularly the potentials and effects of buildings.

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