Applied Energy xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Optimal operation of an energy management system for a grid-connected smart building considering photovoltaics' uncertainty and stochastic electric vehicles' driving schedule

Dimitrios Thomas [a,b,*], Olivier Deblecker [a], Christos S. Ioakimidis [b]

[a] *Department of Electrical Engineering, University of Mons, 7000 Bd Dolez 31, Mons, Belgium*
[b] *ERA Chair 'Net-Zero Energy Efficiency on City Districts', Research Institute for Energy, University of Mons, Mons, Belgium*

HIGHLIGHTS

- A mixed integer linear programming building energy management system.
- Photovoltaic uncertainty considered by exploiting real smart-metering data.
- Bidirectional energy trading capabilities of electric vehicles investigated.
- Consideration of a stochastic electric vehicles' driving schedule.
- Prioritization mechanism exploring different system's selling-back to grid capabilities.

ARTICLE INFO

Article history:
Received 28 March 2017
Received in revised form 10 July 2017
Accepted 15 July 2017
Available online xxxx

Keywords:
Energy management system (EMS)
Electric vehicle (EV) to grid (V2G) and vehicle to building (V2G)
Smart building
Photovoltaic (PV) uncertainty
Demand response (DR)
Energy storage system (ESS)

ABSTRACT

The evolution of smart grids enables active end-user participation in energy management systems (EMS) through demand response (DR) strategies. The integration of renewable energy sources (RES), electric vehicles (EVs) and energy storage systems (ESS) provides additional energy and storage options to a microgrid. Factors as RES generation, market prices and EVs' driving schedule determine the benefits of microgrid's operation. In this paper, a mixed-integer linear programming (MILP) framework-based model is provided to investigate the cooperative evaluation of an EMS operation in a building considering: (i) bidirectional energy trading capabilities of an EV fleet arriving at an office building under a stochastic EVs' driving schedule, (ii) the impact of PV uncertainty on EMS operation based on real smart-metering data and comparing it with a deterministic PV production approach and, (iii) the effect of setting different prioritization factors in selling energy back to the grid from the resources on total system's cost. Results confirmed the necessity of the stochastic approach as in all considered case-studies was found that the total expected daily cost for the system was much lower compared to their corresponding deterministic cases. For the base case study, detailed results were provided demonstrating the power flow between the microgrid's components and the grid under both a stochastic and a deterministic approach.

1. Introduction

1.1. Background and motivation

Electricity grids in the near future will have to adopt to the changes in technology, to the values of environment, society and economy. In response to changing requirements, system safety operation, power quality, energy efficiency, cost of supply and environmental protection need to be re-examined in a liberalized market environment. In this transitional period, smart grids refer to the evolution of electricity grids and they can be considered as the "building blocks" of smart grids. Microgrids are organized based on the control capabilities over the main network operation and they are characterized by the presence and operation of DERs, such as microturbines, PV arrays, energy storage devices (batteries, energy capacitors) and controllable loads (e.g., electric vehicles) at distribution level [1]. Microgrids offer new features to electricity industry adding many possibilities for multi-stage electrical power

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* Corresponding author at: Site Epargne (56, rue de l'Epargne – n°4, B7), 7000 Mons, Belgium.
E-mail address: Dimitrios.THOMAS@umons.ac.be (D. Thomas).

http://dx.doi.org/10.1016/j.apenergy.2017.07.035
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Please cite this article in press as: Thomas D et al. Optimal operation of an energy management system for a grid-connected smart building considering photovoltaics' uncertainty and stochastic electric vehicles' driving schedule. Appl Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.07.035

Nomenclature

Abbreviations

DER	distributed energy resources
PV	photovoltaic
ESS	energy storage system
RES	renewable energy sources
DR	demand response
EMS	energy management system
EV	electric vehicles
PEV	plug - in electric vehicles
V2B	vehicle to building
V2G	vehicle to grid
G2V	grid to vehicles
MILP	mixed - integer linear programming
MV	medium voltage
LV	low voltage

Indices

T	index for hour, t = 1, 2, . . . , T
I	index for EV, i = 1, 2, . . . ,I
ω	index for PV generation scenario, $\omega = 1, 2, \ldots, \Omega$

Sets

T	number of time slots for the considered time horizon
I	number of EVs
Ω	number of scenarios for PV generation

Parameters

$\eta^{ESS,ch}$	charging ESS efficiency
$\eta^{EV,ch}$	charging EV efficiency
$CR^{ESS,\min}$	minimum ESS charging rate [kW per time interval]
$CR^{ESS,\max}$	maximum ESS charging rate [kW per time interval]
$DR^{ESS,\min}$	minimum ESS discharging rate [kW per time interval]
$DR^{ESS,\max}$	maximum ESS discharging rate [kW per time interval]
$CR^{EV,\min}$	minimum EV charging rate [kW per time interval]
$CR^{EV,\max}$	maximum EV charging rate [kW per time interval]
$DR^{EV,\min}$	minimum EV discharging rate [kW per time interval]
$DR^{EV,\max}$	maximum EV discharging rate [kW per time interval]
$\eta^{ESS,disch}$	discharging ESS efficiency
$\eta^{EV,disch}$	discharging EV efficiency
E_1	Maximum power that can be requested from the grid [kW]
E_2	Maximum power that can be injected back to the grid [kW]
P_t^{build}	Building power demand [kW]
$P_{t,\omega}^{PV,gen}$	PV generation for scenario ω at time t [kW]
$SoE^{ESS,init}$	initial ESS state of energy [kW h]
$SoE^{ESS,\min}$	minimum ESS state of energy [kW h]
$SoE^{ESS,\max}$	nominal ESS capacity [kW h]
$SoE_i^{EV,arr}$	state of energy of the *i*-th EV when arriving [kW h]
$SoE_i^{EV,dep}$	State of energy of the *i*-th EV when departing [kW h]
$SoE^{EV,\min}$	minimum state of energy of EV [kW h]
$SoE^{EV,\max}$	nominal EV battery capacity [kW h]
T_i^{arr}	arrival time of the *i*-th EV to the building
T_i^{dep}	Departure time of the *i*-th EV from the building
ΔT	number of time intervals in 1 h period
ε_t^{buy}	day - ahead electricity price at time t [cents/kW h]
ε_t^{sell}	day - ahead electricity price of energy sold to the grid at time t [cents/kW h]
λ_{PV}	priority parameter for PV
λ_{EV}	priority parameter for EVs
λ_{ESS}	priority parameter for ESS
$\pi_{t,\omega}$	probability of PV scenario ω occuring at time t

Variables

$p_{t,\omega}^{ESS,ch}$	ESS charging power [kW]
$p_{t,\omega}^{ESS,disch}$	ESS discharging power [kW]
$p_{t,\omega}^{ESS,inj}$	power from the ESS injected to the grid [kW]
$p_{t,\omega}^{ESS,build}$	power from the ESS used to cover building load [kW]
$p_{t,\omega}^{PV,inj}$	power from the PV injected to the grid [kW]
$p_{t,\omega}^{PV,build}$	power from the PV used to cover building load [kW]
$p_{t,\omega}^{PV,stored}$	power from the PV stored to ESS [kW]
$p_{i,t,\omega}^{EV,ch}$	charging power of the *i*-th EV [kW]
$p_{i,t,\omega}^{EV,disch}$	discharging power of the *i*-th EV [kW]
$p_{i,t,\omega}^{EV,inj}$	power of the *i*-th EV injected to the grid [kW]
$p_{i,t,\omega}^{EV,build}$	power of the *i*-th EV used to cover building load [kW]
$p_{t,\omega}^{grid,req}$	power requested from the grid [kW]
$p_{t,\omega}^{grid,inj}$	total power injected to the grid [kW]
$soe_{t,\omega}^{ESS}$	ESS state of energy [kW h]
$soe_{i,t,\omega}^{EV}$	state of energy of the *i*-th EV [kW h]
$\xi_{t,\omega}$	binary variable: 1 if ESS is charging during time t, 0 otherwise
$\sigma_{i,t,\omega}$	binary variable: 1 if the *i*-th EV is charging during time t, 0 otherwise
$u_{t,\omega}$	binary variable: 1 if grid is supplying power during time t, 0 otherwise

grid operation, control and management. Some of these new features include advanced smart metering, demand-side management systems and communication infrastructure providing real-time information for all system variables [2,3].

A microgrid can be considered an aggregation concept in which both demand-side and supply-side resources in distribution grids can participate. From a customers' point of view, microgrids can potentially decrease the cost of energy supply by using the new features previously mentioned, providing at the same time both thermal and electricity needs. On the other hand, from the grid's operator point of view, a microgrid can be characterized as a controlled entity within the power system operated as a single aggregated load. The grid operator may send emergency signals to the microgrid(s) requesting an increase/decrease of its power supply/demand depending on the network's needs in each time period incentivizing thus end users to meet these requests via economic rewards.

Buildings have become major energy consumers over the world as they consume around 40% of total end-use energy [4]. Thus, energy efficiency improvement in buildings is critical for reducing emissions and for mitigating the carbon footprint. Smart technologies in buildings are considered crucial on the roadmap in terms of increasing energy efficiency, integration of RES and reduction of pollutants emissions and bringing the smart buildings concept to the fore [5]. A key notion related to smart buildings is DR management. Basically, DR "is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utilities load shape" [6]. The concept of smart buildings can be beneficial to microgrids in a way that the bidirectional energy and data flow

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