Energy Conversion and Management 74 (2013) 209–222

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

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

Efficient energy consumption and operation management in a smart building with microgrid

Di Zhang [a], Nilay Shah [b], Lazaros G. Papageorgiou [a,*]

[a] Centre for Process Systems Engineering, Department of Chemical Engineering, UCL (University College London), Torrington Place, London WC1E 7JE, UK
[b] Centre for Process Systems Engineering, Imperial College London, London SW7 2BY, UK

ARTICLE INFO

Article history:
Received 18 February 2013
Accepted 23 April 2013

Keywords:
Planning/scheduling
Smart building
Microgrid
Mixed integer linear programming
Optimisation
Real-time pricing

ABSTRACT

Microgrid works as a local energy provider for domestic buildings to reduce energy expenses and gas emissions by utilising distributed energy resources (DERs). The rapid advances in computing and communication capabilities enable the concept smart buildings become possible. Most energy-consuming household tasks do not need to be performed at specific times but rather within a preferred time. If these types of tasks can be coordinated among multiple homes so that they do not all occur at the same time yet still satisfy customers' requirement, the energy cost and power peak demand could be reduced. In this paper, the optimal scheduling of smart homes' energy consumption is studied using a mixed integer linear programming (MILP) approach. In order to minimise a 1-day forecasted energy consumption cost, DER operation and electricity-consumption household tasks are scheduled based on real-time electricity pricing, electricity task time window and forecasted renewable energy output. Peak demand charge scheme is also adopted to reduce the peak demand from grid. Two numerical examples on smart buildings of 30 homes and 90 homes with their own microgrid indicate the possibility of cost savings and electricity consumption scheduling peak reduction through the energy consumption and better management of DER operation.

1. Introduction

Due to the increase of energy demand and rising global emissions of greenhouse gases, the current centralised generation system is challenged. The future electricity distribution system will be integrated, intelligent and better known as smart grid, which includes advanced digital metres, distribution automation, communication systems and distributed energy resources. The desired smart grid functionalities include self-healing, optimising asset utilisation and minimising operations and maintenance expenses [1]. Microgrid is a relatively small-scale localised energy network, which includes loads, network control system and a set of distributed energy resources (DERs), such as generators and energy storage devices. A microgrid can operate in either grid connected or islanded mode[1] when there are external faults and/or to gain economic advantage. A microgrid equipped with intelligent elements from smart grid has been adopted to enable the widespread of DERs and demand response programs in distribution systems [2], which is considered as future smart grid. Microgrid has an economic incentive due to avoiding energy purchases during peak periods and creation of carbon benefits through low-carbon/low-pollutant generation and co-production of heat and power, which has higher energy efficiency. It also provides secure and reliable energy supply during serious blackout period as a back-up energy supplying system.

Several studies have considered how to design the capacity of a microgrid system to minimise the annual cost. Comprehensive review of the research on microgrid technology, the current research projects and the relevant standards is given by [3], in which pilot projects and further research are discussed. The optimal choice of the investment and optimisation of run-time operational schedules is presented for commercial-building microgrids in [4], where electrical storage and thermal storage are integrated in Distributed Energy Resources Customer Adoption Model (DER-CAM). Asano et al. [5] develop a methodology to design the number and capacity of each equipment in a microgrid with combined heat and power (CHP) system considering partial load efficiency of a gas engine and its scale economy are considered to minimise the annual cost. A baseline analysis estimating the economic benefits of microgrids is performed by King and Morgan [6], and the examined results indicate that better overall system efficiency and cost savings can be achieved from a good mix of customer types. A computer program that optimises the equipment arrangement of each building linked to a fuel cell network and the path of the hot-water piping network under the cost minimisation objective has also been developed in [7], where operation plan of each piece of equipment

* Corresponding author. Tel.: +44 20 7679 2563.
E-mail address: l.papageorgiou@ucl.ac.uk (L.G. Papageorgiou).

[1] Islanded mode means no electricity can be obtained from grid.

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.04.038

is considered. Bagherian and Tafreshi [8] present energy management systems and optimal scheduling of microgrid. The optimal decisions, including the use of generators for power and heat production, storage system scheduling, proper load management and local grid power selling and purchasing for next day, are determined by maximising the profit. A generalised formulation to determine the optimal strategy and cost optimisation scheme for a microgrid is shown in [9], accounting for emission cost, start-up costs, operation cost and maintenance costs. Optimal economic operation scheduling of a microgrid in an isolated load area is obtained by mixed integer linear programming (MILP) model in [10], and a Virtual Power Producer (VPP) is used to operate the generation units optimally and the methodology is applied to a real microgrid case study. A short-term DER management methodology in smart grids is presented by [11], which involves as short as 5 min ahead scheduling and the previously obtained schedule is rescheduled accordingly. A Genetic Algorithm (GA) approach is used for optimisation. Hawkes and Leach [12] present a linear programming (LP) model to minimise the cost for the high level system design and corresponding unit commitment of generators and storages within a microgrid. Compared with centralised generation, the sensitivity analysis of results to variations in energy prices indicates a microgrid can offer an economic proposition. This model can provide both the optimal capacities of candidate technologies and the operating schedule.

As the energy consumption by buildings represents 30–40% of the world's primary energy consumption [13], smart planning of energy supply to buildings is important to conserve energy and protect the environment. Basic actions to improve energy efficiency in commercial buildings in operation are presented in [14]. Domestic energy consumption depends on the dwelling physical properties, such as location, design and construction, as well as appliances' efficiency and occupants' behaviour. By changing the living behaviour itself, there can be 10–30% energy consumption reduction [15]. More importantly, the liberalisation of electricity markets results in electricity hourly or half-hourly prices and real-time electricity prices encourage consumers to get involved in searching for optimal power consumption way to save their energy costs [16].

This paper considers a smart residential building with its own microgrid, DER and automation system. Smart building is becoming more attractive and viable in the building industry while meeting both desires of comfort and energy savings. The idea of the smart home originated from the concept of home automation, which provides some common benefits to the end users, including lower energy costs, provision of comfort, security and home-based health care and assistance to elderly or disabled users [17]. Smart homes with automation operations are becoming capable along with the technology development, where heating or lighting can be controlled according to the presence of customers [18]. Particle swarm optimisation (PSO) algorithm is applied to the load balancing problem in smart homes in [19], where the optimal distribution of energy resources is determined by an adapted version of the Binary PSO. A method based on LP techniques is proposed for economic evaluation of microgrids from the consumer's point of view in [20]. Operation of distributed generators and energy storage systems are optimised and power interruption costs together with additional expenses to construct the microgrid itself are involved. Some work has also been done to achieve the energy conservation and management perspectives. A multi-agent system for energy resource scheduling of an islanded power system with microgrid is proposed by [21], with an objective to manage the resources efficiently and obtain the minimum operation cost while satisfying the internal demand. A dynamic decision model is presented by [22] to optimise energy flows in a green building with a hybrid energy system, which involves different renewable energy sources. A fuzzy controller is developed and the Man Machine Interface is integrated with Building Energy Management systems to improve the indoor environmental conditions with minimum energy needs [23]. While in [24], an MILP model is developed for scheduling operations in microgrids connected to the national grid to analyse potential policies. A linear diversity constraint is introduced to maintain diversity in the generation of electricity from multiple resources on the production schedule. An energy management and warning system for resident has been proposed for energy saving in [25], which monitors the power usage and warns the users when the power usage is getting close to the monthly prescribed energy usage levels. The electric power dispatch optimisation problem is solved by the genetic algorithm approach by [26], the proposed model determines the optimum operation of a microgrid for residential application under environmental and economic concerns. However, these scheduling optimisation models only consider operation scheduling based on given energy profile rather than scheduling the energy demand.

Scheduling tasks subject to limited resources is a well known problem in many areas of the process industry and other fields, but there are differences when considering the scheduling of electrical appliances. Different time representations and mathematical models for process scheduling problems are summarised in [27]. Four time representations are presented with strengthened formulations which are compared in different scheduling problems. While short-term and medium-term scheduling of a large-scale industrial continuous plant is addressed in [28]. A systematic framework is proposed there and applied on an industrial continuous plant to utilise the main units efficiently. Maravelias and Sung [29] reviewed the integration of production planning and scheduling problem, while key concepts and advantages/disadvantages of different modelling methods are presented. Sun and Huang [30] reviewed energy optimisation methods for energy management in smart homes, such as fuzzy logics, neural network and evolutionary approaches. Hybrid intelligent control systems for generating control rules is recommended for further study and works considering scheduling of appliance operation time are also included. An MILP based smart residential appliance scheduling framework is proposed in [31], where electricity is solely bought from grid and the tariff is known 24 h in advance. Another work for scheduling the operation of smart appliances is presented by [32], where the savings from energy is maximised by shifting domestic loads with real-time pricing. A peak-load shaving online scheduling framework is proposed by [33], and the power consumption scheduling is developed in a systematic manner by introducing a generic appliance model. Scheduling of both energy generation and loads has been studied for single smart home in recent works. The operation of an Electrical Demand-Side management system is presented by [34], where deferrable and no-deferrable tasks commanded by the user are scheduled for 1 day of a house with PV generation. Kriett and Salani [35] propose a generic mixed integer linear programming model to minimise the operating cost of both electrical and thermal supply and demand in a residential microgrid. A real-time price-based demand response management application is presented by [36] for residential appliances in a single house to determine the optimal operation in the next 5-min time interval by considering future electricity price uncertainties, stochastic optimisation and robust optimisation approaches have been applied. An optimal and automatic residential load commitment framework is proposed by [37] to minimise household payment, which determines on/off status of appliances, charging/discharging of battery storage and plug-in hybrid electric vehicles. Derin and Ferrante [38] develop a model that considers both operation scheduling and electricity consumption tasks order scheduling. But their results indicate relatively high computation time, over 35 min, to schedule only three electricity consumption tasks.