Sustainable Cities and Society 22 (2016) 146–163

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Demand side flexibility: Potentials and building performance implications

K.O. Aduda*, T. Labeodan, W. Zeiler, G. Boxem, Y. Zhao

Building Services Group, Department of Built Environment, Technische Universiteit Eindhoven, Den Dolech 2, 5612 AZ Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 28 December 2015
Received in revised form 13 February 2016
Accepted 17 February 2016
Available online 22 February 2016

Keywords:
Office buildings
Electrical power grids
Demand side flexibility
Indoor air quality
Thermal comfort performance

ABSTRACT

Due to their significant energy demand, buildings are critical in efforts towards attaining the much needed operational flexibility in electrical power grid occasioned by increased decentralized renewable energy integration. In a departure from past studies which are often biased towards power systems performance, this paper presents key building performance implications when used within the context of electricity demand-side management (DSM) programs to provide power systems flexibility services to the smart-grid. Focusing on office buildings and using an average-sized office building as test-bed, their potential as a source of demand-side flexibility in terms of building specific parameters such as power demand, energy consumption, limits of operational flexibilities, systems' response times, indoor comfort, comfort recovery time and availability are evaluated and discussed. Analysis of field study data demonstrates that office buildings could effectively serve as a source of power flexibility. However, variation in indoor air quality and thermal comfort performance across various zones within the building may complicate estimation of demand side flexibility potential, its acceptability and operation at building level. This emphasizes the need of taking into consideration case study based specifics when using buildings to service power flexibility requirement.

1. Introduction

Increased decentralized renewable energy production at the low voltage levels has led to the transformation of electricity supply chain infrastructure and consequently heralded development of smart grids concept. A smart grid is defined as an upgradable electricity network often occurring at the low voltage region of distribution and that is enabled for intelligent control and multi-directional communication between sources, loads and components in such a manner that allows for cooperative and economical energy utilization (Farhangi, 2010; Giordano & Fulli, 2011). The smart grid is about electrical connectivity to active loads and generators within an elaborate demand side management programme effected with the aid of elaborate communication infrastructure, sensor network, automated metering, demand driven control systems and intelligent coordination (Siano, 2014). The emergence of the smart grid concept is partially related to an attempt to solve the challenge posed by integration of renewable energy sources (RES) in form of associated uncertainties (Sartori, Napolitano, & Voss, 2012). Central to this is the suggestion to use additional power flexibility in current electricity power grid as a way of mitigating the uncertainties (Lund, Lindgren, Mikkola, & Salpakari, 2015). The term flexibility is described in power systems engineering as the ability to cost effectively balance electricity supply and demand continually while also maintaining acceptable service quality to connected loads (Ulbig & Andersson, 2015; Cochran et al., 2014). This definition is inclusive of the ability for periodic energy availability to the grid over a defined time, response to random unscheduled load and provision of additional reserves to manage uncertainties arising from inaccurate forecasting or sudden change in the weather (Olsen et al., 2014; Hummon et al., 2014). As illustrated in Fig. 1, flexibility sources in the electrical power grid can be grouped under two categories (Lund et al., 2015; Cochran et al., 2014):

a. Supply side flexibility—in the form of dynamically fast responding conventional power plants, combined heat and power plants, combined gas turbine cycles plant, large scale storage systems, and curtailment of RES power feed-in,
b. Demand side flexibility (DSF)—in the form of services delivered through intelligent integration of connected loads in carefully crafted demand-side management (DSM) programs. Applied to this context, intelligent integration implies adaptation of present

* Corresponding author. Tel.: +31 0 40 247 2039.
E-mail address: k.o.aduda@tue.nl (K.O. Aduda).

http://dx.doi.org/10.1016/j.scs.2016.02.011
2210-6707/

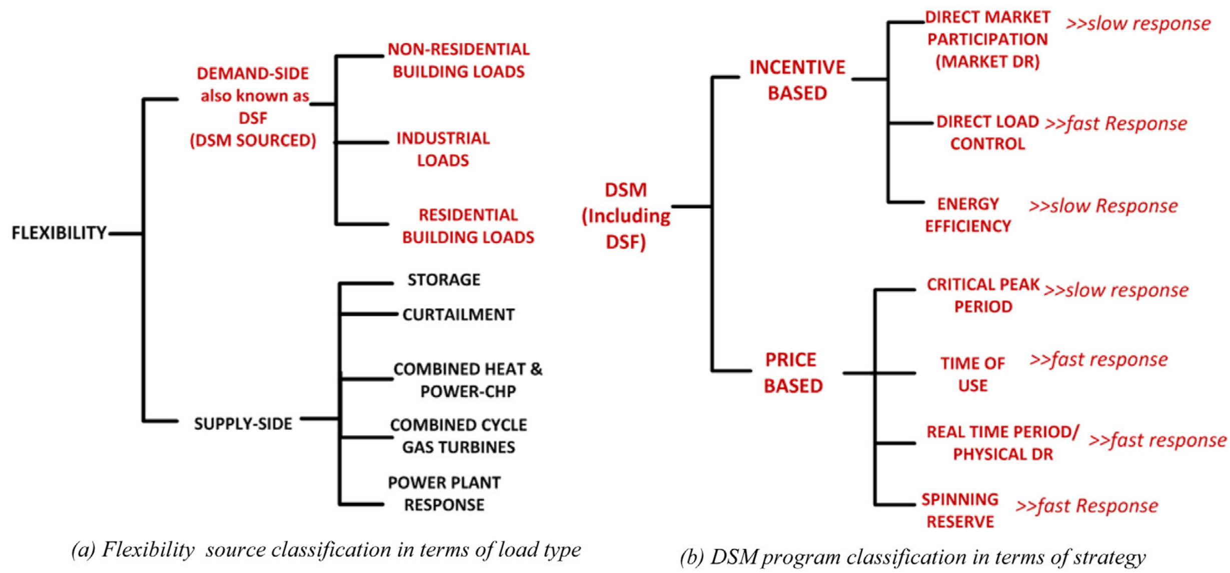

Fig. 1. Flexibility sources in modern electricity power networks.

electricity supply chain infrastructure to improve flexibility, agility, and responsiveness to frequent changes (Vojdani, 2008).

Supply side flexibility in this context refers to dedicated power plants or supply side storage often using fossil fuel and having capacity to make up for the mismatch between electricity generation and consumption by ramping up or down in required time and duration (Cochran et al., 2014). Due to the high cost of operating and maintaining flexibility sources on supply-side and increased localized power networks reliability related issues, emphasis has of recent been focused on alternative cost effective DSF strategies such as demand response and demand driven control measures (Xue, Wang, Yan, & Cui, 2015; Labeodan, Aduda, Boxem, & Zeiler, 2015a). DSF is the ability of demand side installations to respond to power systems requirements for ramping up or down using on-site storage capabilities, increasing or reducing electricity consumption patterns whilst maintaining acceptable indoor comfort bandwidth (Zheng, Meinrenken, & Lackner, 2015; Iwafune, Ikegami, Fonseca, Oozeki, & Ogimoto, 2015). Load classification details for DSF within DSM framework is available in Fig. 1a.

1.1. Demand-side management

DSM is inclusive of all undertakings on the demand side of an energy system undertaken in close collaboration of the consumers and power system utilities in efforts to alter load pattern using incentives, subsidies or cash benefits (Palensky, Member, Dietrich, & Member, 2011).

As shown in Fig. 1b, DSM whether residential, non-residential or industrial based can be classified with respect to strategy employed as either incentive based (also referred to as reliability based) or price based (also referred to as economic based)(Lund et al., 2015; Palensky et al., 2011; Müller et al., 2015). Lund et al. (2015), Palensky et al. (2011) and Müller et al. (2015) all describe incentive type DSM as those generated by deterioration in overall power quality through regulation based services whereas price based DSM are those that are generated by end-user desire to reduce cost of electricity. DSM for residential sector is often centred around load shifting and peak reduction by ensuring that household tasks are undertaken with respect to prevailing electricity prices; these are mostly price based and thrive on existing diversity of tasks and appliances that can be undertaken on rotational basis. On the other hand, non-residential buildings such as offices have fairly fixed schedules with little room for manoeuvre as all the tasks have to be undertaken at the same time. Common office building loads include those dedicated to provision of space cooling, space heating, humidification, ventilation, office appliances' operation and lighting. For office buildings, labour is more productive than energy cost thus making DSM practices more incentive based than price based. Ultimately, DSM involving non-residential systems tends to rely on strategies incorporating storage system use or system inertia use or cooperative energy usage with neighbourhood buildings.

With respect to power system flexibility, useful strategies may be those for incorporating direct market participation, direct load control, real time period and spinning reserve; these generally fall under the category of demand response or demand based control services. Increased depth in the application of DSM especially with regards to the ability for regulation, spinning reserve and differentiation as an energy market service has been possible mainly because of successful innovation and end user incentives involving renewable energy technologies and improvements in information and communication technologies (Siano & Sarno, 2016). As regards this, Siano (2014) envisages that demand response will become crucial for peak load management and frequency regulations with faster response times and as such is a crucial part of smart grid implementations.

1.2. Purpose and scope

Buildings form an essential part of the smart grid due to the significant energy consumed and produced in them. It is reported that buildings (both residential and non-residential) account for between 20 and 40% of the total final energy consumption (Pérez-Lombard, Ortiz, & Pout, 2008); in Europe this figure is reportedly 40% with electricity accounting for over 48% of the total final energy mix (Economidou, Laustsen, Ruyssevelt, & Staniaszek, 2011). By virtue of this, buildings form a potential source of worthwhile DSF.

The purpose of this article is to analyze the performance of office buildings when used within the context of electricity demand-side management (DSM) programs to provide power systems flexibility services to the smart grid. The specific focus is therefore on the performance of office buildings during incentive based DSF activities.