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Demand side flexibility coordination in office buildings: A framework and case study application

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ABSTRACT

The transition from the traditional electrical power grid to the smart grid calls for a paradigm shift to accommodate bi-directional flow of power, information and the use of available useful flexibility between consumers, their buildings, and the grid. As buildings are considered a potential source of demand side flexibility it therefore becomes paramount that measures be put in place to ensure the useful building flexibility is delivered to the smart grid. However, this should be done without compromising the traditional functionality of buildings, which includes safety, thermal comfort and maintaining an acceptable indoor air quality. In this paper, through a systematic review of relevant literature, requirements for coordinating the interaction between building's useful energy flexibility and the grid are outlined. Secondly, based on performance analysis and measurements from an averaged sized test case office building, the useful flexibility for grid services is quantified. Thirdly, an autonomous coordination framework for leveraging the useful demand side flexibility from buildings is proposed.

1. Introduction

In an effort to address the growing demand for energy in a sustainable and environment friendly manner, the last three decades has heralded a global increase in proliferation of renewable energy sources (IRENA, 2015) as well as increased effort to modernize the grid to a smarter and greener grid (Siano, 2014; Tuballa & Abundo, 2016). Smart grids are power networks that intelligently integrate connected entities (end-users, producers, prosumers) using comprehensive information and communication infrastructure (Andreotti et al., 2016; Tuballa & Abundo, 2016).

Specific advantages of the future smart grid include: ability to be greener as a result of renewable energy sources (RES) integration, increased quality of market interactions with connected infrastructure, reduced investments on grid reinforcement, accelerated power outage restoration and dynamic energy balancing to achieve operational efficiency (Farhangi, 2010; El-Hawary, 2014; Slootweg, Member, & Morren, 2011). Demand side management (DSM) is one of the pillar technologies in the development of smart grid and is particularly important for realization of end user energy efficiency, flexible load management and overall cost reduction (Macedo, Galo, Almeida, & Lima, 2015; Zhao & Tang, 2016). However, operation of DSM schemes are greatly affected by physical and informational uncertainties (Mathieu, 2015; Ruiz-Romero, Colmenar-Santos, Gil-Ortego, & Molina-Bonilla, 2013; Sankar, Raj Rajagopalan, Mohajer, & Vincent Poor, 2013). Therefore, the transition to the smart grid requires not only a two way flow of power and information, but also a two way flow of flexibility between the end user and utility supplier (Kolokotsa, 2015).

Power systems flexibility is the ability to continually balance electricity supply and demand with negligible disruption to service for connected loads often in response to variability in RES based generation (Ulbig & Andersson, 2015). Power systems flexibility can be derived from supply-side or demand-side resources (refer to Fig. 1).

Supply side power flexibility uses dedicated conventional power plants or supply side storage to balance mis-match in electricity production and demand within systems' operations guidelines (Cochran et al., 2014). Sources of supply side flexibility include supply side energy storage, power transmission curtailment and dedicated power response plants (Lund, Juuso Lindgren, Mikkola, & Salpakari, 2015).

Demand side flexibility (DSF) refers to the use of demand side installations (such as storage after the traditional power meter and other connected loads) to intelligently balance power demand and available supply without diminishing design intended functionality

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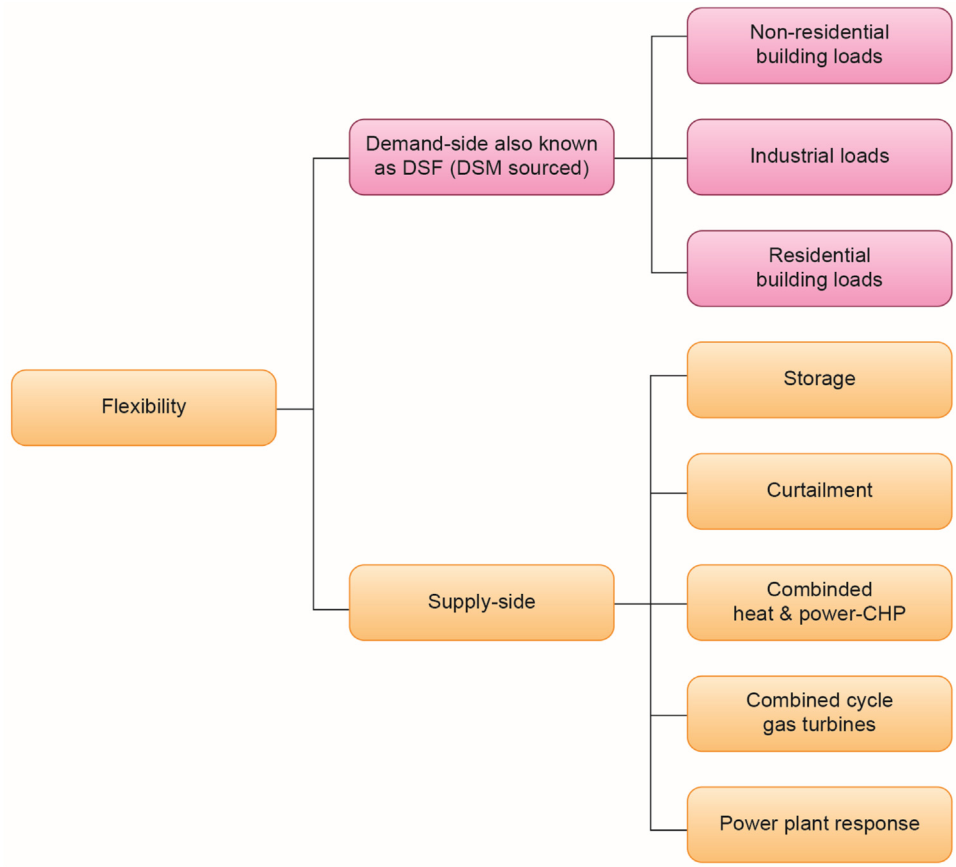

Fig. 1. Domains in power flexibility studies.

(Lund et al., 2015; Ulbig & Andersson, 2015). DSF is currently under the spotlight due to two main benefits associated with it. First, the use of DSF is more cost effective as it forestalls investment in new standby power plants and limits operational expenses for existing ones by improving reliability (Mohagheghi, Stoupis, Wang, & Li, 2010; Xue, Wang, Yan, & Cui, 2015). Second, DSF is associated with resultant high energy sustainability as it allows for greater efficiency of available resources whilst also enabling use of RES (Labeodan, Aduda, Boxem, & Zeiler, 2015; Xue et al., 2015). The interest in DSF will continue to rise as more incidences of power flexibility requirement are expected with increased RES integration in electricity supply chain management (Kondziella & Bruckner, 2016; Lew et al., 2013).

1.1. Importance of office buildings as a power flexibility resource

DSF can be derived from residential buildings, industrial buildings and non-residential buildings (including offices) as shown in Fig. 1. Whilst the flexibility from industrial is significant (Aslam, Soban, Akhtar, & Zaffar, 2015), it is misleading to assume that consumption from both sectors alone would translate proportionately to DSF potential. Realization of DSF from industrial sector must contend with two main challenges. First, industrial processes need continuous and reliable power supply to prevent heavy commercial losses and maintain safety (Noor, Thornhill, Fretheim, & Thorud, 2015); therefore, their co-option as DSF resource requires careful on-site management. Secondly, industrial processes are very complex; for example some occur on real time basis and at times produce energy as a by-product (Ding, Hong, & Li, 2014). Consequently, the use of industrial sector installations as DSF resources becomes equally complex.

The use of residential buildings for power flexibility is also hampered by requirement for elaborate information exchange infrastructure as a result of large number of load entities involved and their associated relatively small size (Hong et al., 2015). As a result, DSF coordination for residential buildings becomes complicated taken that the process is hierarchically structured with stepwise aggregations from local energy contractors, distribution and transmission service operators (Siano, 2014).

The challenges associated with the industrial and residential sectors makes commercial office buildings seem relatively more viable as an alternative source of flexibility of power flexibility (Samad, Koch, & Stluka, 2016; Mathieu, Dyson, & Callaway, 2012). Consequently, with the right strategy non-residential buildings (including offices) appear to be best suited as DSF resources. There are 3 main reasons that make commercial office buildings an important focus for DSF studies. First, buildings in the European Union area and the United States of America account for up to 40% of total primary energy with a significant portion dedicated to heating, ventilation and air condition (HVAC) systems in commercial buildings (Cao, Dai, & Liu, 2016; Lin, Barooah, & Mathieu, 2015). HVAC systems in buildings are useful for DSF services with supply air fan for fast response services (Maasoumy, Rosenberg, Sangiovanni-Vincentelli, & Callaway, 2014) and chillers for both slow and fast response services (Maasoumy et al., 2014). Second, commercial buildings are mostly equipped with automation control systems which makes it easy for implementing additional control algorithms required for DSF actuation (Hao et al., 2014; Lin et al., 2015). Last, commercial buildings mostly have sign high thermal inertia