Building and Environment 118 (2017) 362–376

Contents lists available at ScienceDirect

Building and Environment

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

10 Questions

Ten questions concerning smart districts

Nicholas Good [a,*], Eduardo A. Martínez Ceseña [a], Pierluigi Mancarella [a,b]

[a] School of Electrical and Electronic Engineering, The University of Manchester, Ferranti Building, M13 9PL, Manchester, UK
[b] Department of Electrical and Electronic Engineering, The University of Melbourne, Parkville, Victoria, 3010, Australia

ARTICLE INFO

Article history:
Received 24 January 2017
Received in revised form
21 March 2017
Accepted 23 March 2017
Available online 25 March 2017

Keywords:
Community energy systems
Flexibility
Transactive energy
Multi-energy systems
Smart districts
Energy efficiency
Energy trilemma
Energy quadrilemma
Smart grid

ABSTRACT

As an extension of the 'energy trilemma' of *affordability/sustainability/security* to also include *social acceptance*, the 'energy quadrilemma', is driving multiple and complex developments in energy systems, particularly at the level of distributed energy resources. These, and in particular demand side resources, may have an important role in providing the flexibility required for electricity systems to integrate low carbon technologies, while also increasing the efficiency of the energy system as a whole. This is particularly relevant to resources that are aggregated in districts, for instance through community energy systems, that also adopt various enabling 'smart' technologies, thus becoming 'smart districts' and supporting the transition towards a smart grid. Recognising that the smart district is a relatively new and ill-defined concept, this paper identifies and answers *ten questions* covering relevant physical, commercial, planning and operational aspects of smart districts. In particular, amongst others, we propose a new viewpoint on 'energy efficiency' that is more aligned with the key role of flexibility in future energy systems; criticise the concepts of 'self-sufficient', 'net-zero energy' and 'energy-positive' buildings and districts; discuss how price-driven optimization through 'transactive energy' approaches can deliver whole-system efficiency and flexibility beyond the smart district itself; argue the importance of considering multiple energy vectors in a multi-energy context; and finally specify four requirements for districts to become smart districts.

1. Introduction

Nowadays, there are increasing concerns amongst policy-makers and researchers about how to tackle the 'energy quadrilemma' of affordability, sustainability, security and social acceptance [1]. This is increasing focus on how society might generate, transport and consume energy at lower cost, with reduced emissions and with greater reliability [2], while seamlessly exchanging energy services in transactive environments that incorporate economics and customer preferences and choices [3]. Following a multi-energy perspective [4], these challenges involve all forms of energy, with electricity, gas and heat being particularly common energy vectors. Central to addressing the quadrilemma is adoption of low carbon generation plant, which generates electricity/heat using renewable energy sources, or from nuclear fission. To increase consumption of low carbon energy, and to obtain energy services most efficiently, this growing penetration of renewable energy is being accompanied by general electrification of various services. Examples are substitution between gas and electricity for heating [5] as well as cooling [6], or fuel oil and electricity for transportation [7]. Although welcome, these changes to our energy systems are significant, and are having significant consequences. Specifically: (i) distributed Renewable Energy Sources (RES) generation and new large heating and electric vehicle loads are producing new challenges for electricity network operation [8]; and (ii) significant penetration of intermittent, zero marginal cost RES, and inflexible nuclear is reducing (and reducing certainty on) running hours for traditional fossil-fuel electricity generation, hastening closure of existing plant and discouraging investment in new plant, reducing generation capacity margins and traditional sources of flexibility [9,10]. These challenges are further exacerbated by increasing pressures to reduce public expenditure and consumer bills and to reduce the cost of energy system operation and maintenance (even as demand for investment grows as, in developed countries, much infrastructure approaches its end-of-life, and, in developing countries, demand for energy services grows [11,12]).

* Corresponding author.
E-mail addresses: nicholas.good@manchester.ac.uk (N. Good), eduardo.martinezcesena@manchester.ac.uk (E.A. Martínez Ceseña), pierluigi.mancarella@unimelb.edu.au, p.mancarella@manchester.ac.uk (P. Mancarella).

http://dx.doi.org/10.1016/j.buildenv.2017.03.037

Nomenclature

Acronyms

BSUoS	Balancing Service Use-of-System
CHP	Combined Heat and Power
CM	Capacity Market
COP	Coefficient-Of-Performance
CP	Capacity Payments
DNCM	Distribution Network Constraint Management
DR	Demand Response
DUoS	Distribution Use-of-System
EDNO	Electricity Distribution Network Operator
EDUoS	Electricity Distribution Use-of-System
EHP	Electric Heat Pump
ESO	Environmental and Social Obligation
ETNO	Electricity Transmission Network Operator
ETUoS	Electricity Transmission Use-of-System
EV	Electric Vehicle
GCP	Grid Connection Point
GDUoS	Gas Distribution Use-of-System
GDNO	Gas Distribution Network Operator
GTNO	Gas Transmission Network Operator
GTUoS	Gas Transmission Use-of-System
ICT	Information and Communication Technology
LCI	Low Carbon Incentive
MIP	Minimisation of Imbalance Penalties
NPC	Net Present Cost
NPV	Net Present Value
OPWM	Optimisation of Purchases on the Wholesale Market
OR	Operating Reserve
PV	Photovoltaic
RES	Renewable Energy Sources
SO	System Operator
TES	Thermal Energy Store
UoS	Use-of-System

1.1. Smart energy systems and districts

In order to address these challenges in an economic and efficient manner, the smart grid concept proposes the use of novel Information and Communication Technology (ICT) infrastructure to improve monitoring and control of, and communication between, grid (and grid-edge, e.g., consumer) devices and infrastructure, especially at the consumption side. Development of improved 'smartness' in this way may be a cost effective way of dealing with increasing energy system costs whilst maintaining acceptable levels of reliability. This may be achieved by using improved monitoring capabilities to operate infrastructure closer to limits which may facilitate more efficient use of existing infrastructure and reduce investment needs [13–15]. Smartness can also provide a means to exploit flexible resources from around the energy system, which will be important in any future energy system [16]. In fact, due to the loss of flexibility expected at the generation side, new flexibility from the intelligent operation of the demand-side is of paramount importance to sustain the energy sector. This evolution of the demand side, from passive to active, from consumer to prosumer, and from inflexible and price inelastic to flexible and price elastic, will fundamentally change the role of the demand side in energy system operation. In particular, these developments will result in increasing engagement and interaction of users with energy issues [17]. Combined with increased penetration of distributed generation, flexible consumption devices (such as EVs), and probably storage, and possible economic motivations (see Section 2.3), the stage is set for a new role for the demand-side within smart energy systems. As explored in this work, a significant feature of this new role will, given facilitation by appropriate enablers [18], be a move towards transactive energy approaches, where demand-side parties optimise their energy behaviour in response to economic signals, to minimise overall energy cost whilst also benefiting the energy system [19–21].

Whilst demand-side participation in energy systems does not require coordination amongst actors, or co-location of any set of actors, there are several features of energy systems and of communities which make organisation at the district level, and incorporation of necessary 'smart' features, attractive and natural. This organisation may be conscious, through direct control of technologies (e.g., by an energy service company operating a district heating network or an aggregator controlling heating, ventilation and air conditioning devices to provide power system services to the grid), or may emerge from interaction between individual consumers as they autonomously respond to price signals (from system-level or local markets) or, possibly, trade with each other through distributed, peer-to-peer, markets [22,23]. This work does not consider specific means of coordination, but instead seeks to illuminate the relevant aspects and benefits of this coordination. On the technical side these benefits can include increased local consumption of local electricity generation which will reduce network losses and use of upstream infrastructure. Further, coordination at the district level can enable some distribution of system management tasks (coordinated by system operators through implicit – price – or explicit – quantity – signals). In addition, co-location of actors in districts also enables installation of heat networks, which can significantly increase efficiency of heat delivery and district flexibility [5]. Development of districts may also be considered natural from the social perspective, as spread of practices and technologies have been shown to follow social networks, which are often local [24].

However, despite the steady evolution towards smart districts within smart energy systems, there are still many questions on the subject that need answers. Firstly, given the youth of the concept, there is a lack of clarity on the key features of smart districts. Then, the tension between exploiting district flexibility through price signals (within a transactive-like framework [19,20]) and the protection (through stable prices) traditionally afforded to consumers, raises questions on the role of current/future markets in optimally exploiting of flexibility from smart technologies. The question of how technologies may be optimally exploited also raises the question of how optimisation should be carried out across time (planning/operational), and space (locally/nationally). Considering optimality also naturally raises the question of objectives. In particular, the complexity of smart districts means that the traditional objective of energy efficiency may not be appropriate. Further, methods for planning for other district objectives (net-zero-energy/'energy positive'/100% renewable) should be explored.