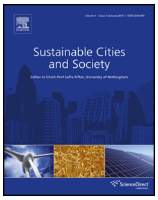
Sustainable Cities and Society 15 (2015) 22–32

Contents lists available at ScienceDirect

Sustainable Cities and Society

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



Towards a regulatory framework for microgrids—The Singapore experience

Carmen Wouters*

School of Energy and Resources, UCL Australia, University College London (UCL), Torrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia

ARTICLE INFO

Article history:
Available online 7 November 2014

Keywords:
Distributed generation
Grid safety
Liberalisation

ABSTRACT

Microgrids are increasingly put forward as key concepts of future energy supply complementing the conventional centralised energy system. This paper describes operational and regulatory microgrid challenges and makes suggestions regarding how to overcome them. Motivated by its unique liberalisation process, state guided growth processes and technology focused economic and sustainable growth ambitions, Singapore is put forward as a case study. An analysis of its legislative framework identified that advanced legislation is already in place regarding the distribution of locally generated cooling. However, a regulatory framework for full energy integrated modern microgrids is still in its infancy. Global lessons learned from the Singapore experience are therefore mainly with regard to utility based microgrids as they might facilitate the set-up of regulatory frameworks and standardisation. Additionally, grid connection codes and standards are needed to ensure safe microgrid operation. Furthermore, microgrids still need a legally defined identity. Here, global best practices are likely to lead the way.

1. Introduction

Energy is a key driver of industrialised societies. Consequently, in order to deliver energy to the consumer, the supply system is required to have high standards with respect to design, operation, safety and cost. The growing global population coupled with the growing global energy demand and climate change issues challenge the current standards and requirements of the energy supply system (Banerjee & Islam, 2011; Blumsack & Fernandez, 2012; International Energy Agency, 2012; Marks, Heims, & Fiebig, 2010). Moreover, the finiteness of conventional energy resources such as oil, coal and gas introduces additional restrictions on the development of the energy supply system (Banerjee & Islam, 2011; International Energy Agency, 2012). As a result, energy supply is an area of extensive research, which focuses on the challenge to achieve secure, safe and sustainable energy for the growing global population at an affordable price (Blumsack & Fernandez, 2012). The development of new technologies, such as centralised renewable energy plants, storage, small-scale decentralised generation units, microgrids and smart grids, is expected to play a major role in a momentous transformation of the conventional energy supply system to a future energy system (Alanne & Saari, 2006; Driesen & Belmans, 2006). Especially decentralised energy generation in the form of small-scale, locally controlled distributed generation (DG) units coupled in a single entity, a microgrid, is of increasing interest to accommodate for the new multidimensional needs of society (Blumsack & Fernandez, 2012).

At the time of writing, research regarding microgrids has mainly been focused on technical and economic aspects. Technical research is concerned with the effects of decentralised generation on the conventional electricity network through amongst others bi-directional electricity flows related to grid safety and islanding. Logenthiran, Srinivasan, and Wong (2008) and Mirsaeidi, Mat Said, Mustafa, Habibuddin, and Ghaffari (2014) for example, respectively carried out research regarding power flow calculations and reviewed the development of innovative protection systems to accommodate for microgrid operation. Economic research is especially concerned with cost benefit analyses, cost optimal design modelling and game-theoretic internal market operation models (Marnay et al., 2007; Mehleri, Sarimveis, Markatos, & Papageorgiou, 2012; Saad, Han, Poor, & Basar, 2012; Weber, Marechal, & Favrat, 2007). Even though such research is advancing the technological and economic barriers, the regulatory framework for microgrids is still lagging behind (Blumsack & Fernandez, 2012). Marnay, Asano, Papathanassiou, and Strbac (2008), Marnay, Zhou, Qu, and Romankiewicz (2012) and Romankiewicz, Qu, Marnay, and Zhou (2013) presented studies of global microgrids together with policy recommendations and existing regulations to enable microgrids. A detailed analysis of the appropriateness of an existing national regulatory framework is however not yet presented to date. The

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* Tel.: +61 8 8110 9960.
E-mail address: carmen.wouters.12@ucl.ac.uk

http://dx.doi.org/10.1016/j.scs.2014.10.007

aim of this paper is to analyse the existing regulatory framework in Singapore regarding several identified microgrid challenges.[1] First, the position of microgrids within the energy system is presented. Second, operational and regulatory microgrid challenges are discussed with future lessons for Singapore based on the interaction between technology and regulation as well as policy recommendations to overcome such barriers in the future. Finally, global lessons are drawn from the Singaporean experience.

2. Microgrids and their place in the future energy system

2.1. The microgrid concept

Today, the microgrid concept has no unique definition since modern microgrids are not standardised in design but tailored to a specific location and to local requirements (Lasseter, 2002; Marnay et al., 2012). The modern microgrid concept, however, is not new when looking at the evolution of the energy supply system to what is today known as the *conventional* centralised energy system since it relates back to the initial development stages of the electrification in industrialised nations (Asmus, 2011; Van Hende & Wouters, 2014). The first 'electricity grids' emerged in the 19th century within countries that were marked through the industrial revolution such as the United States, Western Europe, Chile and Australia (Asmus, 2011; Van Hende & Wouters, 2014). These first grids were decentral isolated direct current based 'micro' grids that were privately owned and operated and served a local consumer base. The local 'micro'grids, based in major load centres, made way for an alternate current long distance interconnected transmission and distribution network at the end of the 19th century when the electricity demand and levels of industrialisation and urbanisation started to grow rapidly (Van Hende & Wouters, 2014). This up scaling of the network led to the centralisation of power plants at the peripheries of load centres. The latter evolution was coupled with a change in electricity regulation from local to State control and centrally controlled monopolies with enlarging central power plants owned and operated by utilities (Asmus, 2011; Van Hende & Wouters, 2014). The energy crisis in the 1970s led to an increase in fossil fuel prices. To counteract the finiteness and dependency on conventional fossil fuels such as coal, oil and gas and the dependency on imported primary energy resources as well as to increase energy security by diversifying the generation portfolio, independent power producers and large-scale renewables, such as wind farms, emerged (Asmus, 2011; Marnay et al., 2008; Romankiewicz et al., 2013; Van Hende & Wouters, 2014). These new technologies were however still set up within the conventional centralised network topology. The 1980s marked the global start of liberalisation of the electricity markets with the introduction of competition forming what is known today as the *conventional* centralised energy system which is still mainly based on fossil fuels (see Section 2.2). Within this liberalisation process two trends created favourable conditions for decentral generation to regain attention (Van Hende & Wouters, 2014). First, the conventional electricity supply structure is under pressure due to amongst others the growing global population coupled with an increasing energy demand and climate issues (Banerjee & Islam, 2011; International Energy Agency, 2012; Marks et al., 2010). Second, full retail contestability of consumers in liberalised electricity markets introduced increased consumer awareness in terms of energy efficient appliances and emissions (Blumsack & Fernandez, 2012). These trends form a catalyst for a change in philosophy regarding the future energy supply structure (Alanne & Saari, 2006; Blumsack & Fernandez, 2012; Driesen & Belmans, 2006; International Energy Agency, 2012; Marks et al., 2010; Marnay et al., 2007, 2008, 2012). Local energy generation and supply close to or at the premises of end-consumers would help to accommodate these trends since local generation can exploit the locally available (renewable) energy resources and can better balance local supply and demand whilst increasing energy supply efficiency (Blumsack & Fernandez, 2012; Marnay et al., 2012). Modern microgrids are here often put forward as key components that balance local supply and demand whilst potentially coupled with the central grid for increased flexibility and reliability (Blumsack & Fernandez, 2012; Marnay et al., 2012).

The modern microgrid concept gained increasing interest in the United States as a possible solution and prevention of black outs after the rolling black outs of 2001 (EPRI, 2011; Van Hende & Wouters, 2014). The Consortium for Electric Reliability Technology Solutions (CERTS) formulated a first definition of a modern microgrid in 1998 (Lasseter, 2002). Also, the European Union showed to be an initiator of microgrid research and developments through its 'More Microgrid' projects starting in the late 1990s (European Union, 2014; Marnay et al., 2012). Modern microgrids are defined on the basis of general characteristics since they are not standardised in design, but tailored to a specific location and local requirements (Lasseter, 2002; Marnay et al., 2012; Romankiewicz et al., 2013). A modern microgrid is a locally controlled entity technically defined through three main requirements; (1) comprising both locally controlled (small-scale) generation units (sources), energy loads (sinks), and possible energy storage units, (2) a potential interconnection with the central electricity grid, either on-grid or islanded, and (3) typically implemented at the low voltage distribution level (Lasseter, 2002; Marks et al., 2010; Marnay et al., 2012; NYSERDA, 2010; Romankiewicz et al., 2013). Microgrids often have a single point of common coupling with the grid and thus present themselves as single entities to the grid (Marnay et al., 2008, 2012). The introduction of decentral generation in the form of small-scale generation units and microgrids, however, introduces grid connection challenges in terms of bi-directional electricity flows, grid protection, islanding procedures, voltage stability and grid safety (Ackermann, Andersson, & Söder, 2001; Blumsack & Fernandez, 2012; Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005).

The modern microgrid concept is thus not new in that it consists of local balancing of energy supply and demand. The modern microgrid, however, is not solely a local provider of electricity but is also a smart and flexible energy supply system providing electricity as well as other services such as heating and cooling to its consumers making use of intelligent communication technology, storage and renewables (Blumsack & Fernandez, 2012; Lasseter, 2002; Marnay et al., 2008). Furthermore, it often complements a connection with the central grid increasing the reliability of its consumers through islanding capabilities (Lasseter, 2002). Microgrids optimise the local supply and demand of energy through small-scale generation units ranging in size from several kW to several MW in installed capacity (Kwee & Quah, 2010; Marnay et al., 2012; Pepermans et al., 2005). These units, key components of a microgrid environment, can be both dispatchable, such as micro combined heat and power (CHP) units, and intermittent, i.e. generation units based on natural resources such as solar and wind (Kwee & Quah, 2010; Marnay et al., 2012; Pepermans et al., 2005). Small-scale generation units are often referred to as DG units and are located close to or at the premises of end-consumers in the grid (Ackermann et al., 2001; Pepermans et al., 2005). The potential of waste heat recovery from local electricity generation for heating and cooling purposes is also an important benefit of microgrids (Lasseter, 2002; Marnay et al., 2008). Note that *thermal* energy supply refers in the

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[1] This paper uses legal sources but does not employ traditional legal methods. Instead, it departs from an engineering perspective to make regulatory recommendations. The author welcomes feedback and suggestions on the method and presented arguments.