Renewable Energy 69 (2014) 260–270

Contents lists available at ScienceDirect

Renewable Energy

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

Review

Comparative analysis of tertiary control systems for smart grids using the Flex Street model

F.N. Claessen [a,d,*], B. Claessens [b], M.P.F. Hommelberg [b], A. Molderink [c], V. Bakker [c], H.A. Toersche [c], M.A. van den Broek [d]

[a] Software Engineering Cluster, Centrum Wiskunde & Informatica, CWI, P.O. Box 94.079, 1090 GB Amsterdam, The Netherlands
[b] Unit Energy Technology, Flemish Institute for Technological Research, VITO NV, Boeretang 200, 2400 Mol, Belgium
[c] Faculty of Computer Science, Mathematics and Electrical Engineering, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
[d] Copernicus Institute for Sustainable Development and Innovation, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 23 November 2012
Accepted 18 March 2014
Available online

Keywords:
Flex Street
Smart grid
Control system
Comparison method
IntelliGator
TRIANA

ABSTRACT

Various smart grid control systems have been developed with different architectures. Comparison helps developers identify their strong and weak points. A three-step analysis method is proposed to facilitate the comparison of independently developed control systems. In the first step, a microgrid model is created describing demand and supply patterns of controllable and non-controllable devices (Flex Street). In the second step, a version of Flex Street is used to design a case, with a given control objective and key performance indicators. In the last step, simulations of different control systems are performed and their results are analysed and compared. The Flex Street model describes a diverse set of households based on realistic data. Furthermore, its bottom-up modelling approach makes it a flexible tool for designing cases. Currently, three cases with peak-shaving objectives are developed based on scenarios of the Dutch residential sector, specifying various penetration rates of renewable and controllable devices.

The proposed method is demonstrated by comparing IntelliGator and TRIANA, two independently developed control systems, on peak reduction, energy efficiency, savings and abated emissions. Results show that IntelliGator—a real-time approach—is proficient in reducing peak demand, while TRIANA—a planning approach—also levels intermediate demand. Both systems yield benefits (€5–54 per household per year) through reduced transport losses and network investments in the distribution network.

© 2014 Published by Elsevier Ltd.

1. Introduction

Future energy scenarios of the Netherlands take into account a shift towards more distributed energy resources (DER), including renewable power technologies [1]. The introduction of technologies such as wind turbines and photovoltaics brings about issues concerning intermittency and overproduction [2,3]. To help mitigate these issues, local demand response (DR) and energy storage may be considered [4].

Integrating the DR and storage solutions requires an energy management system for smart grid control, that can respond to fluctuating demand and supply through direct-load control [5]. Different control architectures have been developed, which exhibit different characteristics (Section 2.1). The evaluation and comparison of control systems is useful for developers, as they can more effectively recognise strong and weak points of their systems. Different methods of evaluation are currently used (Section 2.2).

In our research, a new analysis method is proposed (Section 3) that is able to compare independently developed control systems using the Flex Street model (Section 4). The analysis method is demonstrated by designing three exemplary cases (Section 5) and comparing the IntelliGator and TRIANA control systems (Section 6).

2. Related work

2.1. Control architectures

Architectures of control systems are usually discussed within the context of microgrids, i.e. sections of the low voltage

Abbreviations: COP, coefficient of performance; DBU, daily battery usage; DER, energy resources; DHD, domestic heat demand; DR, demand response; HHD, heating heat demand; KPI, key performance indicators; LV, low voltage; MV, medium voltage; PHEV, plug-in hybrid electric vehicles; PV, photovoltaic; SPF, seasonal performance factor; VITO, Vlaamse Instelling voor Technologisch Onderzoek.

* Corresponding author. Software Engineering Cluster, Centrum Wiskunde & Informatica, CWI, P.O. Box 94.079, 1090 GB Amsterdam, The Netherlands.
E-mail addresses: uu@felixclaessen.nl, cwi@felixclaessen.nl (F.N. Claessen).

http://dx.doi.org/10.1016/j.renene.2014.03.037
0960-1481/© 2014 Published by Elsevier Ltd.

distribution network containing loads as well as DER. Microgrids focus on autonomy by matching supply and demand internally. Achitectures are often designed as a multi-agent system, which fits the characteristics of microgrids as distributed, dynamic, scalable and modular systems [6]. Three levels are discerned in the operation of microgrid control [7,8]. Primary and secondary control are concerned with safeguarding and optimising power quality, respectively.[1] This study focuses on the evaluation of tertiary control systems.

Tertiary control replaces the actions of secondary control by scheduling device dispatch according to some optimisation process (usually economic). This requires communication between local controllers (i.e. devices). A central controller is commonly instituted to create a hierarchical communication topology. However, different governance structures may appear depending on the roles of the controllers [13].

In a hierarchical system, a central controller optimises the scheduling and issues commands to local controllers, thus leading to centralised control. If instead of commands, only requests are sent for a cap on quantity or price, control becomes more decentralised.

In a market system, local controllers compete for resources, while a central controller acts as auctioneer (i.e. mediated trade). Provided that all market participants are perfectly competitive, this leads to decentralised control [14]. When a central controller can (and does) set market prices, this leads to more centralised control.

An alternative governance structure to hierarchies and markets is a co-operative network [15]. Co-operative networks are less guided by a formal structure of authority, depending on reciprocal communication and exchange (i.e. direct trade). This form of governance has also received attention in the context of virtual power plants [16]. The role of a central controller, if any, would be limited to that of a bulletin board listing offers from available devices [17,18].

2.2. Evaluation studies

The most common evaluation methods for individual (tertiary) control systems are case study simulations and field trials; both are usually defined in the context of microgrids. Evaluation studies exist for all three types of control architectures, such as in Refs [19–23] (hierarchy-based), Refs [24–27] (market-based) and Refs [28–30] (network-based). Performance indicators vary considerably, or, in some studies, are absent completely.

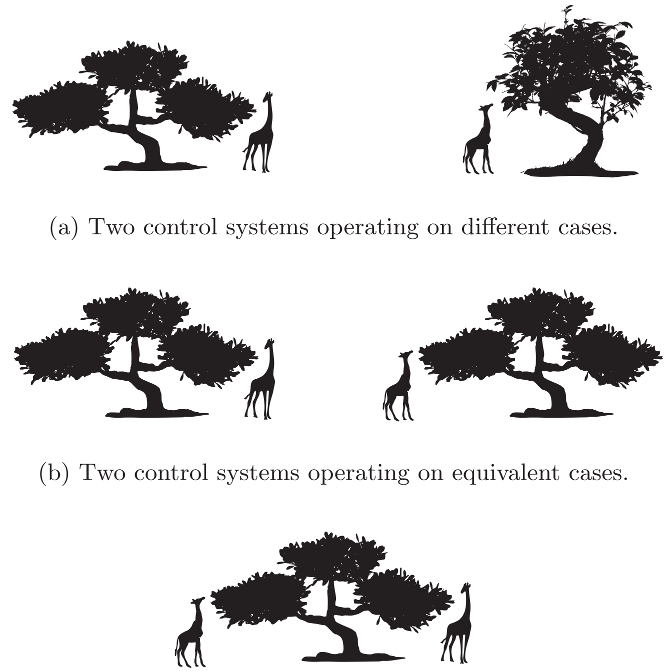
Several studies also provide a comparison of different control systems, all of which using case study simulations. Three different analysis methods are used for these comparisons (Fig. 1):

1. independent simulations of systems operating on different cases, which yields a qualitative comparison (e.g. Ref. [31]);
2. simulations operating on equivalent cases, which gives a quantitative comparison (e.g. Refs. [32,5]); and
3. co-simulations of control systems within the same case, which enables a quantitative assessment of interoperability, competition and emergent properties (e.g. Ref. [33]).

The first two methods are mainly used to evaluate microgrid control, while the third method is used to evaluate virtual power plant control.

Although evaluation studies have made attempts to provide standardised cases, they either show a limited scope (i.e. a small or uniform device population) or have not actually been subjected to multiple control system architectures. The present study implements the second analysis method. However, it is explicitly set up to facilitate the comparison of independently developed control systems. Furthermore, our case study aims to resemble a realistic setting for the operation of smart grid control systems, describing a large and diverse device population.

[1] Different architectures of primary and secondary control are discussed in Refs. [9,10] and [7,11,12], respectively.



(a) Two control systems operating on different cases.

(b) Two control systems operating on equivalent cases.

(c) Two control systems operating on the same case.

Fig. 1. Behavioural comparison methods depicted by giraffes feeding on savannah trees.

3. Analysis method

The proposed method consists of three steps: In the first step, the Flex Street model generates versions of a residential microgrid. In the second step, a case is made by assigning an objective to these microgrids, and defining key performance indicators (KPI) for the control systems. In the final step, different control systems are simulated in a case study, and the output of the simulations is analysed using the KPI.

A clear separation between the assembly of a case and the simulations of developed control systems has two benefits: it enables the use of pre-existing simulation environments (simulators) owned by participating developers, and it facilitates the creation of standardised cases for comparison studies.

4. Flex Street

The Flex Street model represents a microgrid of 400 houses connected to the main gas and electricity grid. The houses are fitted with a selection of distributed energy resources (DER), storage options and controllable loads (Fig. 2). Submodels of all devices are described in Section 4.1–4.3. The majority of devices is modelled in a bottom-up approach to create flexibility in case design. Flex Street currently describes the demand and supply patterns (electricity and heat) of all devices within the microgrid for one year, using a time step of 15 min. Devices were modelled with prognostic

Download English Version:

https://daneshyari.com/en/article/6768281

Download Persian Version:

https://daneshyari.com/article/6768281

Daneshyari.com