ARTICLE IN PRESS

ISA Transactions ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

ISA Transactions

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

Research Article

A robust adaptive load frequency control for micro-grids

Mohammad-Hassan Khooban [a,b,*], Taher Niknam [a], Frede Blaabjerg [b], Pooya Davari [b], Tomislav Dragicevic [b]

[a] Department of Electrical Engineering, Shiraz University of Technology, Shiraz, Iran
[b] Department of Energy Technology, Aalborg University, Aalborg DK-9220, Denmark

ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form
8 May 2016
Accepted 4 July 2016
This paper was recommended for publication by Oscar Camacho.

Keywords:
Adaptive PI control
General Type II Fuzzy Logic
Load frequency control (LFC)
Modified Harmony Search Algorithm (MHSA)
Micro-grids

ABSTRACT

The goal of this study is to introduce a novel robust load frequency control (LFC) strategy for micro-grid (s) (MG(s)) in islanded mode operation. Admittedly, power generators in MG(s) cannot supply steady electric power output and sometimes cause unbalance between supply and demand. Battery energy storage system (BESS) is one of the effective solutions to these problems. Due to the high cost of the BESS, a new idea of Vehicle-to-Grid (V2G) is that a battery of Electric-Vehicle (EV) can be applied as a tantamount large-scale BESS in MG(s). As a result, a new robust control strategy for an islanded micro-grid (MG) is introduced that can consider electric vehicles' (EV(s)) effect. Moreover, in this paper, a new combination of the General Type II Fuzzy Logic Sets (GT2FLS) and the Modified Harmony Search Algorithm (MHSA) technique is applied for adaptive tuning of proportional-integral (PI) controller. Implementing General Type II Fuzzy Systems is computationally expensive. However, using a recently introduced α-plane representation, GT2FLS can be seen as a composition of several Interval Type II Fuzzy Logic Systems (IT2FLS) with a corresponding level of α for each. Real-data from an offshore wind farm in Sweden and solar radiation data in Aberdeen (United Kingdom) was used in order to examine the performance of the proposed novel controller. A comparison is made between the achieved results of Optimal Fuzzy-PI (OFPI) controller and those of Optimal Interval Type II Fuzzy-PI (IT2FPI) controller, which are of most recent advances in the area at hand. The Simulation results prove the successfulness and effectiveness of the proposed controller.

1. Introduction

The entrance of DGs and MGs to the power systems results from some challenges, such as growing demand for energy, environment issues and growing reliability in power systems [1]. The complexity and uncertainty in the system are raised by these new technologies. The increase of reliability of the conventional power systems and the improvement of economic and environmental issues are the factors of the MGs entrance into the power systems [2]. For reducing global warming and increasing the speed of entering the power industry in the deregulated environments, presence of RESs in the MGs is very helpful. MGs are placed in low/medium voltage (LV/MV) levels of distribution networks [3].

Changes in system state parameters and operating conditions are fast especially in an isolated MG with fluctuant renewable sources and EVs. Traditional controllers cannot guarantee to control the system frequency in the presence of V2G and other units [4,5] because it is not optimal for the whole set of operating conditions and configurations. Moreover, generating rate and capacity constraints in the LFC units are not easy to be considered in the controller design [6]. As a consequence, in an isolated MG, a controller that performs robustly over a wide range of system operating conditions is necessary [7]. The load frequency control aims to maintain the power balance in the system such that the frequency deviates from its nominal value to within specified bounds and according to practically acceptable dynamic performance of the system [4,6]. This control strategy may be highly efficient (fuel saving) and economical since it takes advantage of minimum additional equipment and maintenance, etc.

Many controllers, such as conventional PID control [6], intelligent control [8], adaptive control [5], robust control [7], and MPC [4], have been used in order to make the LFC respond better. In [9],

Abbreviations: MG(s), micro-grids; OGT2FLC, optimal General Type-II Fuzzy Logic controller; HS, harmony search; MHSA, Modified Harmony Search Algorithm; IT2FPI, interval type-II fuzzy PI; EV, electric vehicle; GA, genetic algorithm; PSO, particle swarm optimization; PV, photovoltaic; WT, wind turbine; MPC, model predictive control; V2G, vehicle to grid; BESS, battery energy storage system; FESS, flywheel energy storage system; DMS, distribution management system; DG, diesel generator; LFC, load frequency control; FLC, fuzzy logic control; RESs, renewable energy sources; PHEVs, plug-in hybrid electric vehicles; SOC, state of charge; PMUs, phasor measurement units; FC, fuel cell; MFs, membership functions

* Corresponding author.
E-mail addresses: mhk@et.aau.dk, khooban@sutech.ac.ir (M.-H. Khooban).

http://dx.doi.org/10.1016/j.isatra.2016.07.002
0019-0578/© 2016 ISA. Published by Elsevier Ltd. All rights reserved.

coordinated control of blade pitch angle of wind turbine generators and PHEVs is presented for LFC of MG using MPC. In this study, the smoothing of wind power production by pitch angle control is suggested using the MPC method and is in accordance with PHEVs control in order to decrease the number of PHEVs. In [10], in wind diesel hybrid power systems, the control system is based on a PI controller, where the index of the integral square error (ISE) was optimized for the sake of having better PI's parameters. The PI controller could not have good control performance over a wide range of operating conditions because it has been modeled at nominal operating conditions. In [4], in order to show V2G capabilities for frequency regulation and voltage sag reduction using fuzzy logic FL controller, a typical city distribution system was designed. However, this method has many drawbacks because it can show good dynamics merely when some specific membership functions were chosen. Robust H-infinity LFC for hybrid DG system has been studied in [11], the proposed method of which is too complex. In [12], small-signal stability analysis of an autonomous MG with storage system has been conducted. The new hierarchical control architecture for isolated MG is presented in [3]. Since the proposed algorithms based on aforementioned PI controller are not robust, intelligent PID controllers have been lately introduced applying/exerting FL [2,8].

Recently, researchers pay attention to general Type II fuzzy sets and systems because of their ability to deal with uncertainties and disturbances [13–23]. Zadeh in 1975 presented Type II fuzzy sets as an extension of Type I fuzzy sets [18]. Since the calculation of Type II fuzzy logic systems especially IT2FLSs are easy, they have been successfully used in engineering areas. This demonstrates the efficient performance of IT2FLSs in comparison to Type I fuzzy logic systems (T1FLS) when faced with various uncertainties such as dynamic uncertainties, rule uncertainties, external disturbances and noises [19]. Available information for making rules in a fuzzy logic system can be uncertain. Unlike interval Type II fuzzy sets (IT2FS) and Type I fuzzy sets (T1FS), general Type II fuzzy sets can deal with rule uncertainties. In the literature, since the general Type II fuzzy sets and systems are computationally complex, only IT2FLSs have been mainly applied. Liu proposed a useful fast process for computing centroid and type reduction of GT2FLS using a recent plane representation theorem [19]. In [14–18], main concepts of Type II fuzzy sets and systems were well set up. The core concept of centroid for Type II fuzzy sets was expanded by Karnik and Mendel [20]. Furthermore, an algorithm is presented which is called KM algorithm and it is used to compute the centroid of Type II fuzzy sets (T2FSs). A new representation geometric method for general Type II fuzzy sets (GT2FS) is introduced by Coupland and John [21]. But this method is beneficial for standard T2FSs and it is not useful for sets with rotational symmetry. Plane representation, a new method for GT2FSs, is introduced in 2006 by Liu [24] which is beneficial for both computational and theoretical tasks. A GT2FLS is divided into several IT2FLS with the level of for each of them by using plane representation theorem. An independent type reduction for each plane of GT2FLS was proposed by Liu in 2008.

This paper introduces a new adaptive approach using a combination of the GT2FLC logic and MHSA techniques for adaptive tuning of the most common existing PI controller based on LFC in islanded MG(s). According to the online measurements, PI parameters are tuned automatically by applying GT2FLC rules. Considering an optimal performance, the MHSA technique is used online to specify the membership functions' parameters. Unlike the classical tuning methods which are not suitable for providing a useful performance over a wide range of operating conditions, many advantages are offered by the proposed optimal tuning scheme for a MG frequency control with many distributed generations and renewable energy resources. Moreover, this proposed method is not complex in comparison to the above-mentioned methods. The simulation study is performed on a complex MG, including different loads and renewable generation resources to demonstrate the effectiveness of the proposed control scheme, and the superiority of the suggested controller over OFPI controller and OIT2FPI controllers is demonstrated in Section 6 through simulations.

The rest of the paper is organized as follows. In Section 2, the model of MG in isolated mode is defined. Then, in Section 3, the new General Type-II Fuzzy Logic formulation is completely reviewed. In Section 4, a Modified Harmony Search Algorithm is discussed in details. Section 5 shows the advantage of the proposed method in a simple flowchart. A simulation example using a specific isolated MG system under various disturbances is performed to support the functionality of the proposed control scheme in Section 6. Finally, conclusions are drawn in Section 7.

2. Model of isolated micro-grid

2.1. The micro-grid model

Fig. 1 illustrates an MG including distributed loads, low voltage distributed energy resources such as micro-turbines, WTs, PVs, and storage devices such as FESS and BESS [2].

DMS manages the power grid, and MG dispatch system (MGDS) controls the MG operation. Distributed generation resources, EV (s), loads, and PMUs are installed in this MG in order to measure the real-time information of circuit breakers [4].

2.2. Model of the electric vehicle

Using equivalent EV with different inverter capacities can handle the modeling of EVs because there are different numbers of EVs in each EV station. Fig. 2 illustrates the equivalent EV model which can be used for load frequency control [4,24]. The behavior of the battery characteristic of one EV is shown in this model, where the total charging or discharging power in controllable state can be calculated accordingly. As is mentioned, the response to the LFC signal can be limited by the number of controllable EVs and by the EV customers' convenience indicated by the specified SOC. After charging, the EV can respond to the LFC signal only within the energy capacity limit, i.e., MWh limit [4].

$$E_{control}^{min} \le E_{control} \le E_{control}^{max} \quad (1)$$

where $E_{control}$ is the total energy of the controllable EVs, while $E_{control}^{min}$ and $E_{control}^{max}$ are the lower and upper energy capacity limits, respectively. These energy capacity limits are computed from

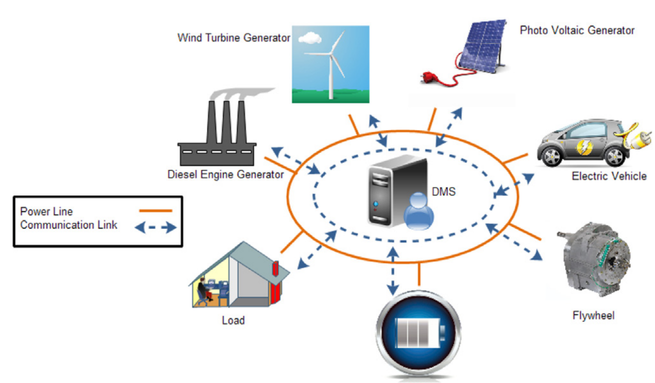

Fig. 1. General scheme of micro-grids.

Please cite this article as: Khooban M-H, et al. A robust adaptive load frequency control for micro-grids. ISA Transactions (2016), http://dx.doi.org/10.1016/j.isatra.2016.07.002