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A new load frequency control strategy for micro-grids with considering electrical vehicles

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ABSTRACT

Owing to the intermittent nature of the renewable energies employed in smart grids, large frequency fluctuations occur when the load frequency control (LFC) capacity is not enough to compensate for the imbalance of generation and demand. This problem may become intensified when the system is working in an island operation mode. Meanwhile, electric vehicles (EVs) are growing in popularity, being used as dispersed energy storage units instead of small batteries in the systems. Accordingly, the vehicle-to-grid (V2G) power control can be applied to compensate for the inadequate LFC capacity and thereby to improve the frequency stability of smart grids, especially in the island operation mode. On the other hand, large scale and complex power systems encounter many different uncertainties. In order to handle these uncertainties, this study proposes a combination of the general type-2 fuzzy logic sets (GT2FLS) and the Modified Harmony Search Algorithm (MHSA) technique, as a novel heuristic algorithm, to adaptively tune the proportional-integral (PI) controller for LFC in islanded MicroGrids (MGs). Although implementing general type-2 fuzzy systems is generally computationally cumbersome, by using a recently introduced plane representation, GT2FLS can be regarded as a combination of several interval type-2 fuzzy logic systems (IT2FLS), each with its own corresponding α level and linguistic rules can directly be incorporated into the controller. This paper further presents a new modified optimization algorithm to tune the scaling factors and the membership functions of general type-2 fuzzy PI (GT2FPI) controller and thereby to minimize the frequency deviations of the MG system against load disturbances more effectively. To evaluate the efficiency of the proposed controller, the obtained results are compared with those of the proportional integral derivative (PID), Fuzzy-PID (FPID), and Interval Type II fuzzy based PI (IT2FPI) controllers, which are the most recent methods applied in this respect. Simulation results demonstrate the perfection and efficacy of proposed controller.

1. Introduction

MGs are believed to be economically viable approaches to supply energy to remote areas in which the wind speed is high enough to be used for electric generation [1–5]. In situations where a diesel unit is also available in the MG, the economic and optimized operation of the resulting hybrid power system relies heavily on the ability of the operator primarily to provide reliable service to the energy consumers of the network. This correspondingly requires that the frequency of the network be held within a limited range so that the consumer's and network's equipment will not get damaged as a result of frequency fluctuations. Moreover, it is highly crucial for the operator to provide a continuous electrical service of high standards. However, frequency variation in the MGs poses a significant challenge on that because MGs tend to demonstrate higher rates of mismatch between generation and demand; on the one hand, renewable energy is uncertain and intermittent, and on the other hand, the power consumption of the isolated community might vary frequently. As a result, applying a proper control strategy is vital to provide the scheduled frequency rate and compensate for the mismatch between power generation and consumption [5].

EV seems to be the future of automotive industry which not only promotes energy saving, but also is environmentally friendly [6,7]. Moreover, EV technology is a promising approach to reduce

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gasoline consumption. Utilizing EVs will also reduce emission of greenhouse gases to a great extent. What further makes the use of EVs highly recommendable is that they can be used as energy storage units in grids. While connected to the grid, EVs exchange power with the power grid bi-directionally, i.e., a charging EV can be regarded as a consumer in the grid [8], while a charged EV can be regarded as a power producer [9]. Statistically speaking, private cars remain idle for almost 95% of a day; thus if EVs are used instead, the EV will be in a charging mode all through this time saving energy. Thus, EVs may be a good solution to improve the stable operation of the isolated MGs because they provide load balance ability and also facilitate the flexible operation of the isolated grid. As mentioned earlier, one main challenge in the use of MGs is the large frequency fluctuation, which occurs due to the integration of renewable energies with intermittent nature into the isolated MG in which the capacity of LFC is not high enough to cope with the mismatch between generation and demand [4].

In power systems, the responsibility of the LFC is to create a power balance in the system so that the system frequency changes only within certain bounds and the reasonably dynamic performance of the system is sustained [4,10]. A proper LFC will increase energy efficiency (and fuel saving) and might, also, reduce the need for further protective equipment and thereby avoid maintenance cost. In order to improve the performance of the LFC, many controllers have been applied in the literature including the conventional PID control, adaptive control [10], intelligent control [11], robust control as well as the Model Predictive approaches [4]. However, in the LFC control of an isolated MG with fluctuating renewable energy sources and EVs, conventional controllers are not optimal for all probable operation conditions and system configurations because the state parameters and the operation status of the system change rapidly; and thus conventional controllers cannot guarantee the well-coordinated control effects of V2G and other units for the system frequency. Moreover, the LFC should also involve several constraints, including the generation capacity and rate constraints, which conventional controllers cannot overcome. Thus, for the LFC in an isolated MG, a controller with robust performance over a wide range of system operation conditions is highly desirable. The key to designing such controllers is to make use of EVs as mobile energy storage units through techniques called V2G methods to overcome the constraints of LFC, especially in isolated grids.

Recently, to design more robust LFCs, several studies in the literature have applied fuzzy logic controllers (FLCs) with various designs, for instance in combination with PIDs [11]. In fact, in developing robust controllers, FLCs are generally known as good options, capable of delivering a desirable performance while encountering uncertainty in the system parameters. However, the problem with the FLCs is that they cannot manage all rule uncertainties in that their membership functions are type-1 fuzzy sets [12–16].

Thus, because General type-2 fuzzy sets and systems can potentially handle uncertainties and disturbances of the system, they have recently become popular among researchers [17,18]. As an extension of type-1 fuzzy sets, type-2 fuzzy sets were first proposed by Zadeh [19]. Ever since, type-2 fuzzy logic systems (particularly IT2FLSs) have been successfully applied in various engineering fields because of their simplicity in calculation. Nonetheless, so far, among the various fuzzy systems, only IT2FLSs have been frequently used in the literature since general type-2 fuzzy sets and systems are known to involve high computational complexity. It has been suggested that IT2FLSs demonstrate a better performance in comparison with the T1FLS in the face of such uncertainties in the system as rule uncertainties, dynamic uncertainties, as well as external noises and disturbances (see Ref. [18]). Nevertheless, unlike IT2FS and T1FS, General type 2 fuzzy sets were found to cope quite effectively with the uncertainties in the available information used to construct FL system rules. Accordingly, Liu has used a recently introduced plane representation theorem to propose a fast process for calculating centroid and reducing type of GT2FLS [20]. Throughout what follows, a review will be provided of some earlier studies on computation centroid and the type reduction of GT2FLSs.

In Refs. [18–21], fundamental concepts of type-2 fuzzy sets and systems are described. The basic concepts of centroid for type-2 fuzzy sets were developed by Karnik and Mendel. They also presented the KM algorithm which defines a procedure for calculating the centroid of type-2 fuzzy sets (T2FSs). Later on, in 2008, a new representation geometric approach for general type-2 fuzzy sets (GT2FS) was proposed by Coupland and John [22]. As an alternative approach to type reduction, the proposed method is suggested to be much faster as it involves much less computation; however, it should be emphasized that their proposed method is effective only with respect to the standard T2FSs and it demonstrates difficulties when sets with rotational symmetry are concerned. In 2006, *plane representation* method for GT2FSs was proposed by Liu. The method is appropriate not only for theoretical tasks, but also for computational ones [20]. Plane representation theorem assumes that the GT2FLS is a combination of several independent planes and thus divides a GT2FLS into several IT2FLSs, each with its own α level. Later in 2008, Liu [20], taking the GT2FLS as a combination of several independent planes, suggested the independent type reduction for each plane of GT2FLS so that one can simply use previously established tools of IT2FLS in the context of GT2FLS, e.g. [18,20,23]. To further simplify the calculation of GT2FLS, in 2011, Zhai and Mendel [24] proposed *Centroid Flow* (CF) algorithm which is a fast method for calculating the centroid of each plane without having to execute iterative algorithm of KM for each plane separately. As the first step in CF algorithm, type reduction is executed for the lowest α-plane; afterwards, the type reduced centroid of the other α-planes is estimated using the derivative of the secondary membership functions. Although CF algorithm is fast, it should be noted that CF estimations may result in values for each α-plane that are different from their theoretical values in some cases, particularly when secondary grades are asymmetric and demonstrate many changes. Thus, in 2012, Zhai and Mendel [24] proposed Enhanced Centroid Flow (ECF) as an improved version of CF algorithm. To obtain centroid of each α-plane, ECF uses an upward and a downward process to improve the accuracy of the process.

Based on the above discussion, the current study proposes a new adaptive control strategy, which involves a combination of the General Type II Fuzzy (GT2FLC) logic and the Modified Harmony Search Algorithm (MHSA) techniques for the adaptive tuning of the most popular existing proportional-integral (PI) based frequency controllers in the MG systems. In the proposed control strategy, the PI parameters are automatically tuned using general type II fuzzy rules, according to the measurements made online. In order to obtain an optimal performance, the MHSA technique is used online to determine the membership function parameters. The proposed optimal tuning scheme offers many benefits for the frequency control of MGs that involve numerous distributed generations and use renewable energy sources. The classical tuning methods, however, may not be applicable in such contexts to provide a desirable performance over such a wide range of operation conditions. The proposed method is quite simple and does not involve any of the complexities of the methods previously reviewed. The suggested control strategy is implemented in the hybrid wind-diesel power system as a case study. Simulation results demonstrate the superiority of the proposed controller over the proportional integral derivative (PID) controller, Fuzzy-PID (FPID) controller and Adaptive Interval Type II fuzzy PI (IT2FPI) controller.

The organization of the paper is as follows. Section 2 elaborates details of the isolated MG with a hybrid wind-diesel system. Section

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