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Integrated frequency and power control of an isolated hybrid power system considering scaling factor based fuzzy classical controller

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ABSTRACT

This paper describes an application of quasi-oppositional harmony search (QOHS) algorithm to design the scaling factor (SF) based fuzzy-classical controller (such as PI/PD/PID) for frequency and power control of an isolated hybrid power system (IHPS). The considered IHPS model is comprised of a wind turbine generator, a diesel engine generator and an energy storage device (such as superconducting magnetic energy storage (SMES), in this case). Traditionally, SF, membership functions and control rules are obtained in fuzzy logic controllers (FLCs) by trial and error method or are obtained based on the experiences of the designers or are optimized by some traditional optimization techniques with some extra computational cost. To overcome all these problems of FLCs, classical controllers have been integrated in this paper with the FLC. QOHS algorithm is applied to simultaneously tune the SFs (the only tunable parameter of FLC), the gains of the classical controllers and the tunable parameters of the SMES device to minimize frequency and power deviations of the studied IHPS system against various load demand and wind change. Different considered controller configurations of the IHPS are SF based FLC (termed as Fuzzy-only), SF based FLC with proportional-integral (PI) (named as Fuzzy-PI) controller, SF based FLC with proportional-derivative (PD) (abbreviated as Fuzzy-PD) controller and SF based FLC with proportional-integral-derivative (PID) (designated as Fuzzy-PID) controller. Simulation results, explicitly, show that the performance of the Fuzzy-PID controller based IHPS is superior to Fuzzy-only, Fuzzy-PI and Fuzzy-PD controller based IHPS configuration in terms of overshoot, settling time and the proposed Fuzzy-PID controller is robust against various wide range of load changes.

1. Introduction

It has been estimated that approximately two billion people, in developing countries, lack grid based electricity service and though who are availing, lack reliable electrical power supply in rural areas. Grid extension in many cases is unrealistic because of distributed populace, irregular geography or the both. So, the main source of power for their basic electrical demand is diesel engine generator (DEG) [1]. However, availing this power supply is not a breezy affair, as it involves cost of transportation and an inventory carrying cost of fuel. On the other hand, there are other complex aspects like crisis related to energy such as depletion of fossil fuel, souring prices of oil, global warming *etc.* Also, other environmental related issues have emerged global concerns. Thus, small standalone renewable energy systems (RESs) have significant opportunities for narrowing the electricity gap in rural parts of the developing world [2].

RESs (like wind, solar, hydro, wave power, biofuels *etc.*) have established their consideration as alternatives of fossil fuels. Solar and wind energy are clean and abundantly available sources of energy in nature. These are, currently, suppling power for several standalone applications extensively. But the solar energy has low energy conversion efficiency to that of the wind energy and is very costly as compared to the wind power. Therefore, wind energy generation has engrossed a lot of confidence [3]. As per the Renewable's 2013 global status report (see [4]), in 2012 only, the operational wind power capacity was nearly 45 GW, thereby, making global operational wind capacity of 283 GW, which is resulting in an increase of 19% growth. Also, the annual growth rate of cumulative wind power capacity in the years 2007–2012 has been averaged to 25%.

The intermittent wind characteristics result in fluctuating frequency and power output from the wind turbine generators (WTGs) [5]. The fluctuating frequency and power, seriously, affect

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the stability and security of the local grid [6]. To overcome all these drawbacks of the WTGs, these are hybridized with DEGs which also make it a self-sufficient off grid power system [7]. This hybridization of two different energy sources together, to form a new power system, is termed as hybrid power system. As the considered system is not integrated with the grid and is working independently, the studied power system of the present work is labeled as isolated hybrid power system (IHPS) [8].

DEG checks in whenever WTG is unable to meet the load demand requirement. Two major conditions that stimulus the fuel ingestion of a DEG are the load for operation and the frequency of switching. At lower load demand, the DEG is inefficient because of high level of friction relative to the load and the efficiency drops further, if it is not running at its operating temperature. The frequency of switching of DEG may be considered effective if it is followed by a long period without further activity. Thus, to overcome these two issues related to the DEGs, an energy storage device (ESD) or very high wind power penetration is required. As the level of wind power penetration is beyond human control, so ESDs have been identified as a favorable approach for adding WTGs with DEG in IHPSs [6]. For this reason, it is necessary to explore the possibilities of combining wind-diesel generators and ESD in order to reduce the running cost per kWh and to increase the reliability of the power supply.

ESDs (such as battery energy storage system, flywheel energy storage system, compressed air energy storage, super capacitor, superconducting magnetic energy storage (SMES) *etc.*) are, universally, considered to store the unconsumed active energy and make it available at the peak-load demand or at low wind speed [9]. The SMES offers fast control and flexibility as it may store the unconsumed active energy and delivers the same at the peak-load demand. Application of SMES, to control frequency and power for IHPS due to load changes, has been presented in [10]. In [11], a robust SMES design for a hybrid wind-diesel power system with a fixed structure and conventional lead/lag compensator has been proposed. With lower order, the stabilizing effect of SMES is guaranteed [11].

Now, the main problem of IHPS is the complexity of the required control technique that may handle the wind speed variations (as the turbine output power is cube of the wind speed) and the load configurations increase the controller responsibilities. Moreover, the DEGs make it worst to be controlled by means of classical controllers. For controlling IHPS, the most common approach is the usage of the classical controllers (like fixed-gain proportional-integral (PI), proportional-derivative (PD) or proportional-integral-derivative (PID) controllers). In process industries, PID controllers are effectively employed for processes with huge time delay and uncertainty. The classical controllers are very tantalizing to load disturbances, parametric variations *etc.* Compensators are, in fact, a closed form solution for linear control problem. A properly designed/tuned compensator/PID controller may offer best results. Thus, the parameters of the controller have to be, continually, improved. These problems of classical controllers have been tried to solve by different techniques like adaptive control [12], sliding-mode control [13], variable structure control [14], automatic generation control [15] *etc.* The designing of classical or adaptive classical controllers relies strictly on the mathematical model of the system. However, it is challenging to develop a precise mathematical model for the considered IHPS due to unknown load variation, unknown and unavoidable parametric variations due to saturation, temperature variations and system disturbances. All these issues result into relatively large overshoots and transient frequency deviation in a closed loop transient response for the studied IHPS model. Some of these problems may be resolved by various controller optimization approaches. In this series of work, soft computing techniques are being extensively used in the literature to tune the gains of the PID controllers[1] properly. The PI, PID controllers are tuned by genetic algorithm (GA) in [16] for a hybrid-power system and the results are compared to those obtained by the application of a conventional PI or PID controller. The improvement in the quality of the power supply has been achieved by utilizing particle swarm optimization (PSO) algorithm by the way of properly tuning of the controller parameters that confirms acceptable limits of the voltage and the frequency deviations [17]. In [18], the PID controller gains of a multi-loop control scheme have been optimized with a hybrid approach that is the combination of differential evolution (DE) with chaotic Zaslavskii mapping. In [19], the foraging behavior of E. coli bacteria has been proposed for the determination of the optimal gains of the PID controller. And, thus, the list of optimization of controllers goes on.

In the recent past, with an aim of overcoming all these control related problems, fuzzy logic controller (FLC) is being extensively used for harvesting wind energy [20]. The mathematical tool for the FLC is the fuzzy set theory, introduced by Zadeh in [21]. As compared to the classical controllers (*i.e.* PI, PD, PID *etc.*) and their adaptive versions, the FLC has some advantages like (a) mathematical model of exact system is not required, (b) nonlinearity or arbitrary complexities are the issues of concern and (c) it is framed on the basis of human logic (*i.e.* linguistic rules) with an IF-THEN general structure. However, the application of FLC has some shortcomings too. There are still no well-defined standards for the (a) shape of membership functions (MFs), (b) number of considered linguistic divisions, (c) rule base pattern, (d) appropriate inference mechanism and (e) defuzzification methodology. Normally, these are selected by trial and error method or experiences of the designers. So, new FLC techniques are highly encouraged for resolving these complications. On that series, a new scaling factor (SF) based FLC configuration has been introduced in this work in order to resolve some of the FLC complications. It has been shown by many contemporary researchers on the same series that the classical controller, when hybridized with FLCs, enhances the closed loop performance by updating the controller parameters [22]. Hence, optimization of the tunable parameters has been carried out in the literature to overcome this problem (see Section A.1 of Appendix Section).

In the recent years, the researchers' pool have very, extensively, used the heuristic optimization techniques in quest of global optimal solution because of their flexibility, versatility and robustness, which has been proven time and again. GA [23], PSO [24], DE [25], bacteria foraging optimization (BFO) [26], gravitational search algorithm [27], seeker optimization algorithm [28], cat swarm optimization [29], cultural algorithms [30] *etc.* have been surfaced in the recent literature and these techniques have been applied to the diversified fields of power systems applications. These methods are excellent in (a) obtaining the global optimum solution and (b) handling discontinuous and non-convex fitness landscape [23–30].

Even with all the advancements in the field of heuristic methodologies, there are, probably, some more opportunities of improve on their ability of searching, converging characteristic and stabilizing aspect of the optimization problem. With this avenue, a new optimization algorithm (termed as harmony search (HS) algorithm) has been floated in the literature [31]. HS has gained the inspiration from the improvisation process of musicians' searching for a perfect state of harmony [31]. In the literature, the researchers have proposed some improved HS variants in order to find out probable global optimal solutions in a reasonable time

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[1] Need for soft computing based controllers for present application is given in Appendix Section (Refer Section A.1).

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