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Fractional order fuzzy control of hybrid power system with renewable generation using chaotic PSO

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ABSTRACT

This paper investigates the operation of a hybrid power system through a novel fuzzy control scheme. The hybrid power system employs various autonomous generation systems like wind turbine, solar photovoltaic, diesel engine, fuel-cell, aqua electrolyzer etc. Other energy storage devices like the battery, flywheel and ultra-capacitor are also present in the network. A novel fractional order (FO) fuzzy control scheme is employed and its parameters are tuned with a particle swarm optimization (PSO) algorithm augmented with two chaotic maps for achieving an improved performance. This FO fuzzy controller shows better performance over the classical PID, and the integer order fuzzy PID controller in both linear and nonlinear operating regimes. The FO fuzzy controller also shows stronger robustness properties against system parameter variation and rate constraint nonlinearity, than that with the other controller structures. The robustness is a highly desirable property in such a scenario since many components of the hybrid power system may be switched on/off or may run at lower/higher power output, at different time instants.

1. Introduction

The increase in energy demand coupled with the rising concerns of global warming, has necessitated the integration of renewable energy technologies like wind and solar energy into the power grid. This has given rise to hybrid distributed energy generation and storage systems [1]. The generation from the wind and solar power plants is stochastic in nature and depend on the weather conditions at any particular time instant. This might result in situations where the electrical load is higher than the generation. Energy storage devices like batteries, flywheels or ultra-capacitors might be coupled with such systems to mitigate this unbalance. They also improve the power quality and decrease the fluctuations in grid frequency [2]. If there is surplus power available from these renewable sources over the demanded load, these storage devices store them for a short period of time and later release them to the grid when the demand load is higher than the generation. For these actions to be performed properly there needs to be a control strategy which coordinates these activities.

Control systems based on fractional calculus [3] are gaining increasing interest in the research community due to its additional flexibility and superior design performance [4,5]. Fractional calculus has spurred recent interest in signal processing [6] and computational intelligence techniques have also been integrated in the design of fractional order control systems [7]. These fractional order intelligent control systems are finding wide applications in process control [8,9], nuclear reactor control [10], chaos synchronization [11] etc. among many others. Fractional calculus has also been integrated with fuzzy logic [12,13] and PSO [14,15] to enhance their performance. Also, computational intelligence based design for fractional order control systems have been found expedient in different power system applications like automatic voltage regulator [16–18], two area load frequency control [19], microgrid frequency control [20] etc. Motivated by the success of such diverse applications of computational intelligence based fractional order control systems, a fractional order fuzzy control scheme is explored in this paper for the case of hybrid power systems. Other approaches towards designing control strategy for these kind of systems include the standard PID controller [21], genetic algorithm based PI/PID controller [22], robust H_∞ controller [23,24] etc.

In this paper, a comparison has been reported between standard PID and fuzzy PID controller to show the advantage of the proposed scheme. Due to the presence of stochastic renewable energy generation components like wind and solar power, there is

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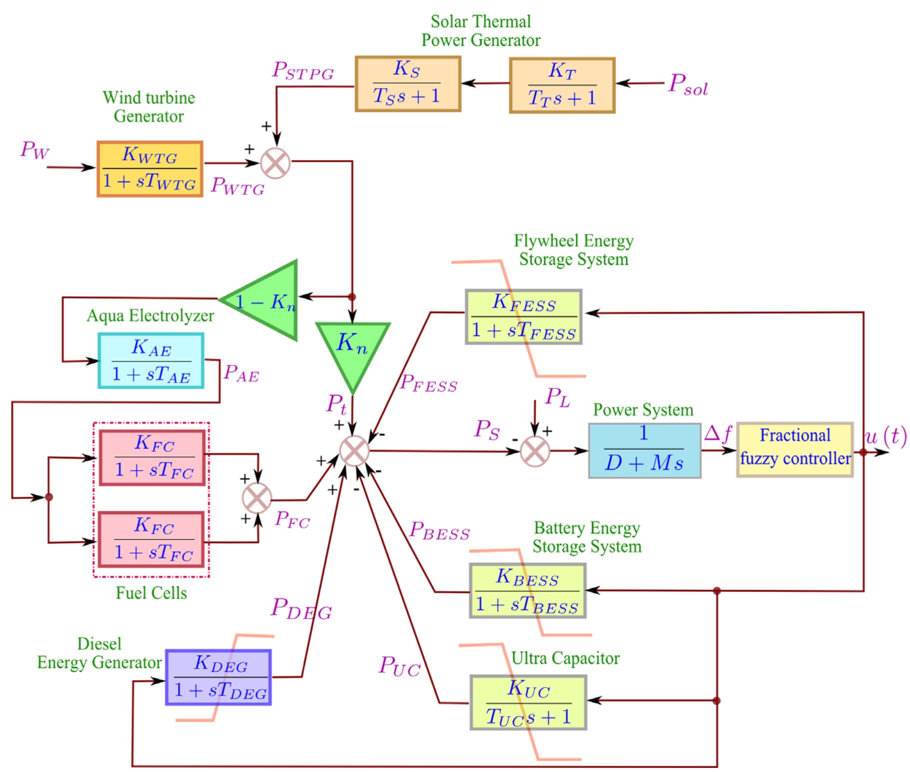

Fig. 1. Schematic of the hybrid power system with rate constraint nonlinearity in energy storage/generation elements.

a continuous variation in grid frequency. This affects the power quality which needs to be kept within limits so that the downstream connected electrical loads do not malfunction. For this purpose a controller is introduced in the loop, which sends a signal to the energy storage systems to absorb/release additional/deficit power from/into the grid respectively. The controller also sends a command to the diesel engine to release high bursts of power into the grid to meet short term load demands. The fractional order fuzzy PID controller [25] is employed for this purpose and is compared with performances achieved by PID and fuzzy PID controller. The schematic of the hybrid power system along with the controller is illustrated in Fig. 1. Another advantage of our proposed control scheme over that reported in [18,19] is that only one centralized controller structure is required for the overall hybrid power system. This removes the necessity of having one controller for each of the power storage units in the feedback path like that reported in [21,22] and eliminates the need for effective tuning of each of the controllers simultaneously, which is cumbersome in practice. The proposed scheme, therefore, reduces cost, additional wiring, maintenance and also the necessity of tuning each of the controllers separately, avoiding any possible performance deterioration due to loop interactions.

The evolutionary and swarm algorithm works well over the classical gradient based methods especially in noisy [26] and dynamic environments [27–29] which are commonly encountered in control system design to handle stochastic fluctuations. In this paper, a chaotic PSO algorithm has been used for determining the controller parameters by optimizing a time domain performance metric (which is noisy) due to the presence of stochastic fluctuations in the wind power generation, solar power generation and the load profile. Other new search and optimization algorithms like the gravitational search algorithm [30] and cat swarm algorithm [31] might also be used to find the controller parameters.

The rest of the paper is organized as follows. Section 2 describes the various components of the hybrid energy system. Section 3 briefly introduces the FO fuzzy controller which keeps the frequency deviation of the power system within allowable range. Section 4 explains two-chaotic map adapted versions of PSO algorithm, along with the objective function for optimization. Section 5 presents the comparison amongst the performances of three controller structures and also their robustness against system parameter variation. The effect of the rate constraint nonlinearity in the feedback elements is explored next in Section 6, followed by discussion on the heuristics and implementation issues in Section 7. The paper ends with the conclusions in Section 8, followed by the references.

Table 1
Nominal parameters of the components of hybrid power system.

Component	Gain (K)	Time constant (T)
Wind turbine generator (WTG)	$K_{WTG}=1$	$T_{WTG}=1.5$
Aqua Electrolyzer (AE)	$K_{AE}=0.002$	$T_{AE}=0.5$
Fuel Cell (FC)	$K_{FC}=0.01$	$T_{FC}=4$
Flywheel energy storage system (FESS)	$K_{FESS}=-0.01$	$T_{FESS}=0.1$
Battery energy storage system (BESS)	$K_{BESS}=-0.003$	$T_{BESS}=0.1$
Ultracapacitor (UC)	$K_{UC}=-0.7$	$T_{UC}=0.9$
Diesel engine generator (DEG)	$K_{DEG}=0.003$	$T_{DEG}=2$
Solar Thermal Power Generation (STPG)	$K_S=1.8$, $K_T=1$	$T_S=1.8$, $T_T=0.3$

2. Description of the hybrid power system with renewable generation

The schematic of the hybrid power system using different modes of energy generation and storage is illustrated in Fig. 1 with its different components described in Table 1.

2.1. Models of various generation subsystems

For small signal analysis, the transfer functions of the WTG, STPG, FC and DEG can be modeled by first order transfer functions