Research article

A novel optimized hybrid fuzzy logic intelligent PID controller for an interconnected multi-area power system with physical constraints and boiler dynamics

A.H. Gomaa Haroun a,b, Yin-ya Li a,*

a School of Automation, Nanjing University of Science and Technology, Nanjing 210094, China
b College of Engineering Sciences, Department of Electrical and Electronics Engineering, Nyala University, South Darfur, Nyala, Sudan

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ABSTRACT

In the fast developing world nowadays, load frequency control (LFC) is considered to be a most significant role for providing the power supply with good quality in the power system. To deliver a reliable power, LFC system requires highly competent and intelligent control technique. Hence, in this article, a novel hybrid fuzzy logic intelligent proportional-integral-derivative (FLPiD) controller has been proposed for LFC of interconnected multi-area power systems. A four-area interconnected thermal power system incorporated with physical constraints and boiler dynamics is considered and the adjustable parameters of the FLPiD controller are optimized using particle swarm optimization (PSO) scheme employing an integral square error (ISE) criterion. The proposed method has been established to enhance the power system performances as well as to reduce the oscillations of uncertainties due to variations in the system parameters and load perturbations. The supremacy of the suggested method is demonstrated by comparing the simulation results with some recently reported heuristic methods such as fuzzy logic proportional-integral (FLPI) and intelligent proportional-integral-derivative (PID) controllers for the same electrical power system. The investigations showed that the FLPiD controller provides a better dynamic performance and outperform compared to the other approaches in terms of the settling time, and minimum undershoots of the frequency as well as tie-line power flow deviations following a perturbation, in addition to perform appropriate settlement of integral absolute error (IAE). Finally, the sensitivity analysis of the plant is inspected by varying the system parameters and operating load conditions from their nominal values. It is observed that the suggested controller based optimization algorithm is robust and perform satisfactorily with the variations in operating load condition, system parameters and load pattern.

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1. Introduction

Modern electrical power system consists of different power system utilities, such as: hydro, thermal, nuclear and gas; these units are coherently interconnected with each other by transmission lines (tie-lines) [1], except nuclear units. Nuclear plants are usually well-kept at base load close to their maximum output without sharing in the Load frequency control (LFC) [2]. The main aims of the interconnected power system utility are: generating, transmitting, and distributing electrical power as economically and consistently as possible while maintaining a continuous supply of the power with an acceptable quality to all consumers [3]. The power system utility will be in an equilibrium point when there is a balance between generated power and the electrical power demand. In interconnected area power systems, if the load perturbation occurred at any area of the system, the frequency related to this area is affected firstly and then the other areas are also affected accordingly through transmission-lines. Thus, each area in a power system has its generation unit which is capable for its own load perturbations and power interchange between the neighboring areas [1,3].

In addition, with the increasing size and complexity of the power system along with the increasing energy demand in recent years, it leads to using soft computing methods that intelligently control the power system network. Sudden perturbations in load and unexpected fault conditions affect the system frequency and tie-line power interchange between the control areas [4,5]. It is impossible to maintain the balances between generation and demand without control [2]. LFC in the power systems is played a most significant role for providing the power supply with good
quality [6]. In view of above, the control technique is needed to cancel the effects of random load changes for maintaining the frequency at nominal value. The main purposes of LFC in an interconnected multi-area power system are to provide the desired real power output from the generator to encounter the variations in load, maintain the frequency of power system close to the nominal value and maintain the tie-lines power between areas [7]. Hence, a control scheme is required, that not only preserves constancy of frequency and desired output power but also to attain zero steady state error and inadvertent scheduled power interchange.

Nowadays, scientists are annoying to develop different control algorithms to explore the best controller for power system problems. Conventional controllers such as PI and PID controllers are widely employed in the power system to handle the LFC problems [8,9], but in general, have some limitations. Literature survey shows that there are several advanced control strategies have been suggested by many researchers over the past decades for LFC scheme [2]. In this regard, many development and research work have been presented such as conventional [10], optimum control [11], active disturbance rejection control (ADRC) [12], Genetic algorithm (GA) [13], Firefly algorithm (FA) [2], etc. which play a vital role in LFC mechanism. Fast dynamic performances, robustness against parameter variations and load changes are obtained by employing ADRC controller, but the authors did not consider the effects of physical constraints [12]. GA has been widely addressed in the literature survey to design LFC mechanism. Meena and Kumar employed the intelligent Genetic algorithm to tune the parameters of fuzzy PID controller in a two-area thermal power system with generation rate constraints [13].

In view of the above, classical controllers are easy tuning parameters with simple architecture, however commonly have more limitations [14]. Furthermore, classical controllers are not robust against the disturbances and system uncertainties; consequently, it may not be appropriate to work under all operating conditions. Hence, sophisticated controllers have been established to improve the transient performances of LFC. It has been asserted by many researchers that the application of FLC improves the transient performance of PID controller and handling the variations in the operating point or in system parameter by online updating of the controller parameters [15,16]. Fuzzy logic controller based conventional PID controllers can be successfully utilized for the nonlinear system, but there are no specific rules to discover appropriate choice of the fuzzy parameters (such as inputs, membership functions, rule base, etc.). In general, these parameters are selected by utilizing certain empirical rules and therefore may not be getting the optimal parameters. Inappropriate selection of the input-output scaling factor may considerably degrade the transient performance of FLC. In [7], the authors utilized hybrid Differential Evolution (DE) and Pattern Search (PS) in multi control area power system to explore the optimum scaling parameters of the fuzzy PI/PID controller, without considering the impact of nonlinearities. A novel nature-inspired technique termed as Multi-Verse Optimizer (MVO) [17], was established in a two-area non-reheat thermal power system with high voltage direct current (HVDC) to optimize the scalar factors of Fuzzy PID, but the authors did not add the effects of non-linearities. In the literature regarding LFC, many researchers ignored the effects of physical constraints and boiler dynamics for simplicity. But these effects might need to be included in the model to achieve a better description of the real-world system.

It is obvious from the past studies that the performance of the power system depends on the controller syntheses and the techniques utilized to tune the controller parameters. Therefore, constructing and implementing anew controller strategy with high performance heuristic optimization methods to real world problems is always welcome. Recently, a new biologically-inspired technique known as particle swarm optimization (PSO) has been highlighted by Kennedy and Eberhart [18]. It is a population technique used to explore the search space of the stated problem. It has been efficaciously set up to handle the nonlinear and non-convex optimization problems. A new technique based on craziness particle swarm optimization (CRAZYPPOSE) has been presented for LFC of a two-area thermal power system with GDB non-linearity [19], to optimize the scaling parameters of PI controller. However, the authors did not add the effects of the GRC and boiler dynamics to the model. A novel nature-inspired technique based on PSO algorithm has been employed in a five-area non-reheat thermal power system [20], to optimize the scaling factors of PID controller, but the authors did not reflect the effects of non-linearities. Modern research confirmed that the PSO is so worthwhile in optimization method and gives high performance results and could be superior to many algorithms [21,22].

In thoughtfulness of previous works aforementioned, a maiden attempt has been made in this article to apply a PSO approach to tune the scaling factors of hybrid fuzzy intelligent PID (FLPiPID) controller for LFC of an interconnected four-area power systems incorporated with physical constraints and boiler dynamics. The proposed approach is developed and subjected to the system model despite the presence of the physical constraints like generation rate constraint (GRC) and governor dead band (GDB) as well as the boiler dynamics; because the neglecting of the physical constraints and boiler dynamics lead to nonrealistic results of the system. The output of fuzzy logic controller (FLC) is multiplied by \( \alpha \) and \( \beta \), which are namely the proportional and integral gains, respectively then combined with the output of the intelligent PID controller to provide the total controller output. Stationary membership functions and rule base are assumed for the FLC mechanism. Input \( (K_p \text{ and } K_i) \) and the output scaling factors \( \alpha \) and \( \beta \) of FLC together with the parameters of the intelligent PID controller \( K_p, K_i \text{ and } K_d \) are optimized via PSO algorithm to minimize the objective function. Regarding above survey, the motivation of the proposed controller addressed in this article, is the simplicity of its structural and can be implemented easily in the practical, as well as considered to be the first time employed in LFC system. The superiority of the suggested controller is confirmed by comparing the simulation results with a lately published article based on the fuzzy logic PI controller for the same system [3]. The obtained results showed that the proposed method outperforms to the
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