Electrical Power and Energy Systems 71 (2015) 254–261

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A new intelligent online fuzzy tuning approach for multi-area load frequency control: Self Adaptive Modified Bat Algorithm

Mohammad Hassan Khooban *, Taher Niknam

Department of Electrical Engineering, Shiraz University of Technology, Iran

ARTICLE INFO

Article history:
Received 11 January 2015
Received in revised form 12 March 2015
Accepted 17 March 2015
Available online 31 March 2015

Keywords:
Online intelligent control
Fuzzy logic control
Load frequency control (LFC)
Self-Adaptive Modified Bat Algorithm (SAMBA)
Automatic Generation Control (AGC)

ABSTRACT

The primary aim of the Automatic Generation Control (AGC) is to maintain system frequency and tie-line interchanges in a predestine limits by regulating the power generation of electrical generators, in case of fluctuations in the system frequency and tie-line loadings. This paper proposes a new online intelligent strategy to realize the control of multi-area load frequency systems. The proposed intelligent strategy is based on a combination of a novel heuristic algorithm named Self-Adaptive Modified Bat Algorithm (SAMBA) and the Fuzzy Logic (FL) which is used to optimally tune parameters of Proportional–Integral (PI) controllers which are the most popular methods in this context. The proposed controller guaranties stability and robustness against uncertainties caused by external disturbances and impermanent dynamics that power systems face. To achieve an optimal performance, the SAMBA simultaneously optimizes the parameters of the proposed controller as well as the input and output membership functions. The control design methodology is applied on four-area interconnected power system, which represents a large-scale power system. To evaluate the efficiency of the proposed controller, the obtained results are compared with those of Proportional Integral Derivative (PID) controller and Optimal Fuzzy PID (OFPID) controller, which are the most recent researches applied to the present problem. Simulation results demonstrate the successfulness and effectiveness of the Online-SAMBA Fuzzy PI (MBFPI) controller and its superiority over conventional approaches.

Introduction

In the field of power system operation and control, AGC plays an important role in ensuring reliability and power quality of the grid. In a large-scale interconnected system, all the generation units work with the same frequency as they are all synchronously connected together. Any abrupt small load perturbation in the different areas will cause the frequency of the areas and the transferred power of the tie-lines to change. In such conditions, fixed gain controllers based on classical control theories are presently utilized to control the load perturbation. Such approaches are ineffective as operation points of the grid changes dramatically during a daily cycle [1–3]; and thus, they may no longer be advisable in all operating conditions. To overcome this issue, variable structure controller [4–6] is offered and many adaptive control approaches have been recommended [7–12] for AGC. For sketching these control approaches, a perfect model is required which has to follow the state of variables and satisfy system constraints. Accordingly, in practical AGC application, it is difficult to apply these adaptive control approaches.

In multi area power systems, if a load variation happens at any one of the areas, the frequency corresponding to this area firstly varies; and then, as perturbation's effects spreads through tie lines, frequency of the other areas changes as well. After a load fluctuation, in order to keep the frequency to the predetermined range, a control system has to be sketched to operate on the setting of the steam entrance valve of the turbine unit. Such controllers must rectify the frequency transients in the system as soon as possible. In these control systems, an integral controller is set as secondary controller. The integrator gain of the secondary controller is set to a value so that a balance is struck between fast transient recovery and low overshoot in dynamic response of the system. Unfortunately, such kind of controller is extremely slow, i.e., it takes a very long time to recover from transients caused by load perturbations.

The PID controller is still the standard tool in industrial automation application according to simple implementation, suitable reliability and easy realization. The main drawback of PID controllers is that their performance is highly dependent on an appropriate tuning of their coefficients [13]. To overcome this issue, one

* Corresponding author.
E-mail addresses: dr.mohammadhassan.khooban@ieee.org, khooban@sutech.ac.ir (M.H. Khooban), taher_nik@yahoo.com (T. Niknam).

http://dx.doi.org/10.1016/j.ijepes.2015.03.017
0142-0615/

can utilize the most well-known tuning method proposed by Ziegler and Nichols (ZN) [14]. However, in practice, tuning parameters of the controller is very complicated in a large portion of the systems as they demonstrate certain features such as nonlinearity and time-variability. Conventional parameter tuning techniques require a mathematical model of system being controlled. Consequently, the common PID parameter tuning methods are not suitable for AGC in power systems as they, and accordingly their model, are constantly changing over time.

With the aid of FL, different alternative, intelligent PID controllers have been recently proposed. Fuzzy logic controller (FLC) is credited with being a suitable method for designing robust controllers that are able to provide a desirable efficiency while facing uncertain parameters. The most important problem related to the FLCs is that they cannot completely be used for the linguistic and numerical uncertainties in variable environmental conditions as they apply accurate fuzzy sets. Fuzzy sets apply the uncertainties related to the FLC inputs and outputs by employing precise and crisp membership functions [15]. Since fuzzy membership functions are completely accurate, all uncertainties are eliminated when the fuzzy membership functions are selected [15,16]. The linguistic and numerical uncertainties in variable environmental conditions make problems in the exact consequent of membership functions over the design procedure.

Recently, FL has been extensively utilized for identification, modeling and control of nonlinear dynamic systems [17,18]. In [19–23], several combinations of control approaches are proposed to improve the performance of fuzzy PI or PID controllers. The procedure of adjusting PID coefficients might be difficult, costly and time consuming [24,25]. Regularly, a proficient gainer tries to control the process by regulating the factors of controller due to error and change rate of error. In this paper, the optimal adjustment is achieved using SAMBA. The original bat algorithm is a promising technique for real-world optimization problems [26]. Compared with original Genetic Algorithm (GA), original bat takes less time for each function evaluation as it does not utilize as many operators as original GA (such as crossover, mutation and selection operator) [27]. Since the bat has a simple and straightforward concept, easy implementation and quick convergence, it has recently attracted lots of attention and wide applications in different fields [28].

In this paper an Online MBA-Based Fuzzy Tuning PI (MBFPI) controller is presented. The proposed framework is simple and does not have complexities of the previously presented methods in the literature. The parameters of input and output membership functions of the fuzzy controller's coefficients are optimized simultaneously by SAMBA. The proposed framework can be easily utilized in the most PI controllers to carry out load frequency control in multi-area power systems. Performance of the proposed controller is evaluated on a test case power system having four interconnected areas. Simulation results demonstrate the superiority of the proposed controller compared to OFPID controller and PID controller.

Four-area test power system

An interconnected four-area [2,3,29–32] power system is utilized to evaluate the performance of the proposed approach in a realistic power system scenario. The interconnected power system consists of four single areas which connected together with power transmission lines called the tie line. Area 1, Area 2 and Area 3 own reheat units and they are completely interconnected to each other. Area 4 is denoted as the area with hydro unit and is only connected to Area 1. Fig. 1 shows a simplified representation of an interconnected system in a general form, including both ring and bus interconnections. The tie line allows electric power to flow between areas and each area feeds its user pool.

A load perturbation in one area affects the frequencies of the areas as well as the power flow of the tie lines. In order to bring the local frequency back to its steady-state point, the control system of each area requires information concerning the transient state of other areas. Such information can be discovered by monitoring output frequency fluctuation of those areas and tie line power fluctuation. Hence, the power flow of the tie line is firstly sensed and then resulting tie line power signal is fed back into corresponding areas. Fig. 2 gives a block diagram depicting the four areas interconnected power system [30]. In the multi-area power system, B_i is the frequency bias setting of i-th area (p.u. MW/Hz), Δf_i is the frequency deviation of i-th area (Hz), T_{ij} is the synchronizing coefficients between i-th and j-th area (p.u. MW/Hz). Moreover, ΔP_i is the load disturbance in i-th area (p.u. MW), $\Delta P_{\text{tie}i}$ is the tie-line power between i-th area and other areas (p.u. MW) and final R_i represents the speed regulation of i-th area (Hz/p.u. MW). The turbine reference power of each area in a conventional system is attempted to be set to its nominal point by an integral controller. The input of the controller of each area is $B_i \Delta f_i + \Delta P_{\text{tie}i}$ ($i = 1, 2, 3, 4$) named area control error (ACE) of the same area. Also, ΔACE is derivation of the control error.

Conventional PID and fuzzy-PID control

Conventional PID control

In common power systems, conventional PID controllers mostly use secondary frequency controls which are generally tuned based on some pre-specified operating points. However, the PID controllers cannot provide the assigned desirable performance when the operating condition of the power system changes. Optimum performance of the controller will be achieved if the PID controller is able to continuously track the changes occurring in the power system. Accordingly, FL can be utilized as an appropriate intelligent approach for online tuning of PI controller parameters [31].

In this paper, the traditional PID controller designed for load frequency control is initially adjusted by a novel heuristic method namely SAMBA. Then, a pure FPI controller is sketched. The obtained results will be compared with the online SAMBA-fuzzy based PI design and a conventional FPID methodology in the next sections. An unabridged study on the classical PI/PID tuning methods like ZN has been submitted in [31–33]. In order to make a fair comparison, parameters of each controller are optimized using the SAMBA algorithm. Accordingly, the PID parameters are obtained as given in Table 1.

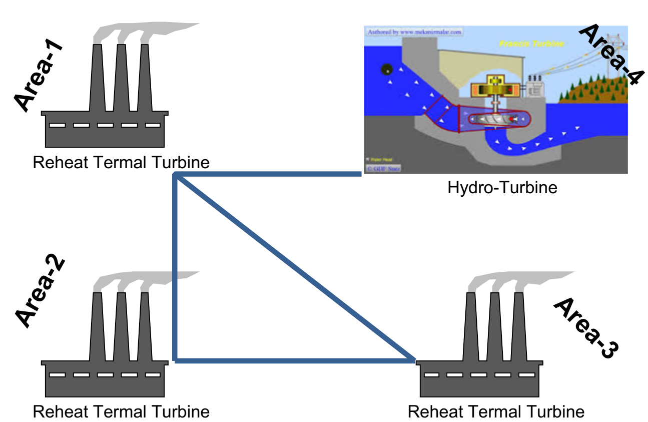

Fig. 1. General scheme of four area interconnected power system.