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Research Article

Design and analysis of tilt integral derivative controller with filter for load frequency control of multi-area interconnected power systems

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ABSTRACT

In this paper, a novel Tilt Integral Derivative controller with Filter (TIDF) is proposed for Load Frequency Control (LFC) of multi-area power systems. Initially, a two-area power system is considered and the parameters of the TIDF controller are optimized using Differential Evolution (DE) algorithm employing an Integral of Time multiplied Absolute Error (ITAE) criterion. The superiority of the proposed approach is demonstrated by comparing the results with some recently published heuristic approaches such as Firefly Algorithm (FA), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) optimized PID controllers for the same interconnected power system. Investigations reveal that proposed TIDF controllers provide better dynamic response compared to PID controller in terms of minimum undershoots and settling times of frequency as well as tie-line power deviations following a disturbance. The proposed approach is also extended to two widely used three area test systems considering nonlinearities such as Generation Rate Constraint (GRC) and Governor Dead Band (GDB). To improve the performance of the system, a Thyristor Controlled Series Compensator (TCSC) is also considered and the performance of TIDF controller in presence of TCSC is investigated. It is observed that system performance improves with the inclusion of TCSC. Finally, sensitivity analysis is carried out to test the robustness of the proposed controller by varying the system parameters, operating condition and load pattern. It is observed that the proposed controllers are robust and perform satisfactorily with variations in operating condition, system parameters and load pattern.

1. Introduction

For satisfactory operation of a power system, the frequency should remain constant. Frequency control ensures constancy of speed of induction motors and synchronous motors. A considerable drop in frequency could result in high magnetizing currents in induction motors and transformers. The wide-spread use of electric clocks and the use of frequency for other timing purposes require accurate maintenance of synchronous time which is proportional to frequency as well as its integral [1]. Under steady-state conditions the total power generated by power stations is equal to the system load and losses. However, the users of the electric power change the loads randomly and momentarily. This results in sudden appearance of generation-load mismatches. The mismatch power enters into/drawn for the rotor thus causing a change generator speed and hence the system frequency. In an interconnected power system, as load demand varies randomly, both area frequency and tie-line power interchange also vary. It is impossible to maintain the balances between generation and load without control. So, a control system is necessary to keep the frequency at the scheduled value. The Load Frequency Control (LFC) loop continuously regulates the active power output of the generator to match the randomly varying load. The objectives of LFC are to minimize the transient deviations in area frequency and tie-line power interchange and to ensure their steady state errors to be zeros [2]. LFC is one of the major issues in electrical power system design/operation and is becoming much more critical recently with growing size, varying structure and complexity in interconnected power system [3,4].

Researchers in the world propose several LFC strategies to maintain the system frequency and tie line flow at their scheduled values during normal operation and also during small perturbations. In [5,6], a critical literature review on LFC of power systems has been presented. It is observed from literature survey that there is scope to design new controller structures to improve the system performance. In [7], the latest research related to intelligent control technologies and applications in various domains have been presented. Practical solutions and novel methods for the recent research problems in many engineering fields have been presented in [8], where the resulting design procedures are emphasized

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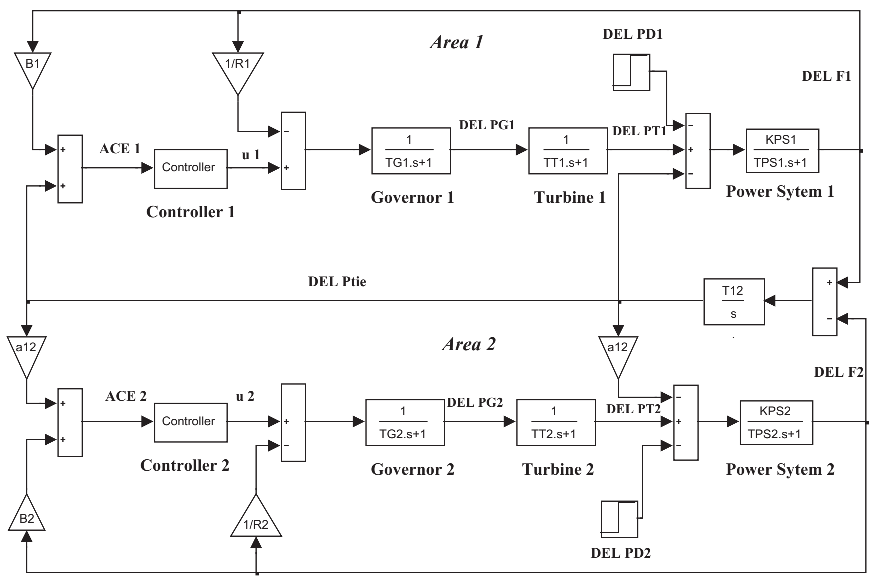

Fig. 1. MATLAB/SIMULINK model of two-area non-reheat thermal system.

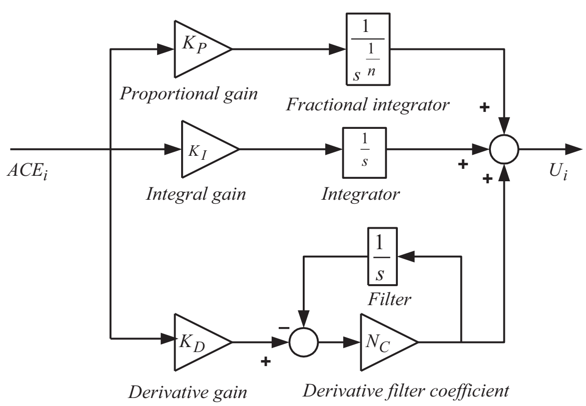

Fig. 2. Structure of TIDF controller.

using MATLAB/SIMULINK software. In [9], soft-computing fundamentals, soft-computing based inductive methodologies/algorithms, and industrial soft-computing applications, as well as multidisciplinary solutions have been presented. In recent times, new artificial intelligence-based approaches have been proposed to optimize the PI/PID controller parameters for LFC system. In [10], several classical controllers structures such as Integral (I), Proportional Integral (PI), Integral Derivative (ID), PID and Integral Double Derivative (IDD) have been applied and their performance has been compared. Several control strategies have been proposed by many researchers over the past decades for LFC of power system such as optimal control [11], model predictive control [12], sliding mode control [13], reinforcement learning [14], neural network [15], fuzzy system theory [16], ANFIS approach [17] and 2- Degree Freedom of Proportional-Integral-Derivative (2-DOF PID) controller [18]. A robust decentralized LFC algorithm was proposed in [19] to regulate the Area Control Error (ACE) in the presence of system uncertainties and external disturbances. In [20], a PID load frequency controller for power systems was presented where the controller parameters are obtained by expanding controller transfer function using Laurent series. Internal Model Control (IMC) is a general design procedure for tuning which optimally meet requirements for stability, performance, and robustness of the control system [21]. However, the main drawback of IMC tuning method is that the process poles are canceled with controller zeros which results in sluggish response to load disturbance. Also, IMC tuning rules are expressed in terms of process model parameters and can be applied after the identification of the process model.

Also different types of optimization algorithm have been proposed in LFC problem to find the optimal parameters of controllers. Recently, Saroj et al. [22] have proposed FA based PID controller for LFC and the superiority of the controller is demonstrated by comparing the results with GA [23], BFOA [23], DE [24], PSO [25], hybrid BFOA-PSO [25], and conventional ZN [23] approaches. A PID controller for LFC is presented in [26] where a filtering technique was proposed to decrease the effects of disturbance and the parameters of controller was obtained employing an Imperialist Competitive Algorithm (ICA). It is clear from literature survey that the performance of the system not only depends on the artificial intelligent techniques employed but also on controller structure.

In a Tilt Integral Derivative (TID) controller, the proportional component of PID controller is replaced with a tilted component having a transfer function $s^{\frac{-1}{n}}$. The resulting transfer function of the TID controller more closely approximates an optimal transfer function, thereby achieving improved feedback controller. The derivative mode of PID controller though improves stability of the system and increases speed of the controller response, produces unreasonable size control inputs to the plant. Also, any noise in the control input signal will result in large plant input signals which often lead to complications in practical applications. The practical solution to these problems is to put a first filter on the derivative term and tune its pole so that the chattering due to the noise does not occur since it attenuates high frequency noise. Surprisingly, in spite of these advantages, TID with derivative Filters (TIDF) controller structures are not attempted for the LFC problems. In view of the above, a maiden attempt has been made in this paper for the application of TIDF controller for LFC of an interconnected power system.

Differential Evolution (DE) is a population-based direct search algorithm for global optimization capable of handling non-differentiable, non-linear and multi-modal objective functions, with few, easily chosen, control parameters [27]. DE uses weighted differences between solution vectors to change the population whereas in other stochastic techniques such as Genetic Algorithm (GA) and Expert Systems (ES), perturbation occurs in accordance with a random quantity. DE employs a greedy selection process with inherent elitist features. Also it has a minimum number of control parameters, which can be tuned effectively [28]. In view of