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Sliding mode based load-frequency control in power systems

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ABSTRACT

The paper presents a new discrete-time sliding mode controller for load-frequency control (LFC) in control areas (CAs) of a power system. As it uses full-state feedback it can be applied for LFC not only in CAs with thermal power plants but also in CAs with hydro power plants, in spite of their non-minimum phase behaviors. To enable full-state feedback we have proposed a state estimation method based on fast sampling of measured output variables, which are frequency, active power flow interchange and generated power from power plants engaged in LFC in the CA. The same estimation method is also used for the estimation of external disturbances in the CA, what additionally improves the overall system behavior. Design of the discrete-time sliding mode controller for LFC with desired behavior is accomplished by using a genetic algorithm. To the best of our knowledge, proposed controller outperforms any of the existing controllers in fulfilling the requirements of LFC. It was thoroughly compared to the commonly used PI controller by extensive simulation experiments on a power system with four interconnected CAs. These experiments show that the proposed controller ensures better disturbance rejection, maintains required control quality in the wider operating range, shortens the frequency's transient response avoiding the overshoot and is more robust to uncertainties in the system.

1. Introduction

Power systems are composed of interconnected subsystems or control areas (CAs). Most of European countries are members of "Union for the Co-ordination of Transmission of Electricity" (UCTE) interconnection [1]. It is assumed that each CA consists of a coherent group of generators. CAs are interconnected by the tie-lines. Because of the differences in generation and load in a power system, system's frequency deviates from its nominal value and active power flow interchanges between areas deviate from their contracted values. The purpose of load-frequency control (LFC) in each CA is to compensate for those deviations. That is obtained by changing power outputs of certain generators within the CA. To test LFC algorithms, an example power system is usually modeled as an interconnection of a few CAs. Since all generators in one CA are coherent, all power plants engaged in LFC in a CA can be replaced with one substitute power plant [2]. In some CAs that power plant is of thermal type and in some CAs of hydro type. When modeling a CA, power imbalance and losses can be seen as external disturbances.

Nowadays, in the majority of CAs PI type controllers with constant parameters are used for LFC [3–6]. However, systems with PI control have long settling time and relatively large overshoots in frequency's transient responses [7]. Besides, PI control algorithm provides required behavior of the system only in the vicinity of the nominal operating point, for which it is designed. But, operating point of a power system usually changes a lot, which is primarily caused by the amount and characteristic of power consumption, characteristics of power plants and the number of power plants engaged in LFC in a CA. Future power systems will rely on large amounts of distributed generation with large percentage of renewable energy based sources, what will further increase system uncertainties and thereby induce new requirements to the LFC system [8]. The shortening of time periods in which each level of frequency regulation must finish could be also expected in the future [9].

Therefore, an advanced controller should be developed and used instead of the PI controller in order to: (1) ensure better disturbance rejection, (2) maintain required control quality in the wider operating range, (3) shorten the frequency's transient responses avoiding the overshoots and (4) be robust to uncertainties in the system. Additionally, a new control algorithm for a CA should enable decentralized LFC of interconnected CAs, i.e. its structure and parameters must not depend on applied controllers in neighboring CAs. It should also be a discrete-time control algorithm with sampling time in the range 1–5 s as required in UCTE interconnection [1]. Finally, it should be relatively simple to implement,

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