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Communication time delay estimation for load frequency control in two-area power system

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ABSTRACT

Due to increased size and complexity of power system network, the stability and load frequency control (LFC) is of serious concern in a wide area monitoring system (WAMS) having obtained signals from phasor measurement unit (PMU). The quality of services (QoS) for communication infrastructure in terms of signal delay, packet loss probability, queue length, throughput is very important and must be considered carefully in the WAMS based thermal power system. However, very few studies have been presented that includes QoS for communication infrastructure in load frequency control (LFC) of power system. So this paper presents LFC for two area thermal power system based on estimated time delay and packet loss probability using the Markovian approach. The delay and packet loss probability are modeled by different math functions. Normally, frequency deviation signal is transmitted from remote terminal unit (RTU) to control center and from control center to individual control unit of plants. The delay incurred is located in the forward loop of PSO based PI/PID controller in the form of transport delay. To verify the efficacy of controller performance, the estimated constant delay and time varying delay are applied to the controller in the two area thermal–thermal power system with and without governor dead band (GDB) and generation rate constraints (GRC) for various loads conditions. The study is further demonstrated for time delay, being compensated by 2nd order Padé approximation. The results show that frequency deviation is minimum in terms of stability and transient response.

1. Introduction

LFC is one of the major issues in a power system in terms of stability. It has been extensively investigated in past years [1–2]. The basic objective of LFC in integrated power system area is to require the balancing between total generations against total load demand, including system losses. The power system operating point experiences a change, subsequently causing deviation in nominal system frequency and scheduled tie-line power flow to other areas [3]. The area control error (ACE) is used in LFC schemes to achieve the power balance between interconnected areas and thereby maintain the system frequency very close to its nominal value and tie-line power to its schedule value [4].

1.1. LFC in smart grid application

The basic principle of smart power grid forms the networked control system, which interconnects PMUs, actuators and controllers over a communication network to exchange data for monitoring, and control of generators spread geographically in the power system. Consequently, the stable operation of power system relies heavily on the performance of the communication infrastructure. The diversification in data transmission demands a robust and reliable information and communication technology (ICT) infrastructure.

A typical smart grid (SG) wide area network would mainly have two interconnected networks: the core network using

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fiber optics for connecting head offices and substations, and distribution network handling the broadband connectivity to neighborhood networks, automation and monitoring devices. In the case of unavailability of fiber optics, worldwide interoperability for microwave access (WiMAX) technology has its option. The WiMAX is featured with inherent support to different levels of quality of services (QoS). The traditional communication technologies suffer from issues like latency, bandwidth, security, coverage, etc.

On the other hand, cognitive radio (CR) is a promising technology in providing the more advanced communication infrastructure for SG applications. In an SG application, field sensors send real-time voltage and phase observations to remote power generators which estimate the real voltage and take certain actions in order to stabilize it within some desired range [5]. However, due to operating constraints like, bandwidth, interferences, and channel fading, signal transmission usually undergo packet losses and delay which impose strict requirements on the communication protocols as well as estimation and control policies [6–7].

It is well known that communication infrastructure, especially CR which is wireless network, is unreliable because of time delay, packet loss and the communication failure. The existing communication infrastructure, originally developed to address the needs of a regulated electricity industry, cannot address majority of the new challenges to meet the desired objectives in operation of SG. As a result, adequate implementation of modern control and protection schemes cannot be ascertained [8]. Further a detail survey on the Cognitive Radio Networks (CRN) for communication infrastructure in SG, including the system architecture, communication network compositions, applications, and CR-based communication technologies and its potential application of CR based SG is given in [9]. Authors [10] have discussed the system architecture, algorithms and hardware test bed for the CRN based SG system. The cross-layer framework employs CR communication to avoid the unfriendly propagation conditions in power systems and supports QoS for SG applications [11]. Further the authors [12] have presented fundamental challenges in data communication for SG along with CR based communication architecture having three layers of networks; Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN) respectively. The use of CR technology in machine to machine (M2M) communication for technical application, industry supports and standardization prospective for SG is presented in [13].

1.2. Motivation and approach

Following a load disturbance, the system frequency deviation/control signals are transmitted in the form of time stamped data packets via dedicated communication infrastructure. Efficient models that provide understanding of communication network in SG are important. The analysis of throughput and delays for communication infrastructure is performed based on M/M/1 queuing theory. The system response degrades if communication channels exhibit delays. Heavy congestion (malicious attack) of communication channel results into constant/random packet delays. Due to congestion in network channel, queue lengths become very large, buffer overflows, packets get delayed during transmission, resulting in incomplete information accesses of a communication network. In addition, the communication channel quality of services (QoS) also deteriorates. This issue opens research challenges with the proposal of wide area monitoring based controller implementation. The challenge exists to integrate computing, communication, and control into appropriate levels of power system operation and control functionalities in a new environment.

Modeling the uncertainties, in terms of time delay, packet loss probability, queue length and throughput is greatly highlighted to confirm that communication infrastructure remains robust under malicious attack. So, it is essential to build an appropriate communication infrastructure, otherwise, system may introduce potential degradation of dynamic and static performance of power system and result in system instability [14–15]. In LFC, due to use of open communication infrastructure and phasor measurement units (PMU) in the wide-area monitoring systems (WAMS), communication delays have become assured and raise concerns about the system steady state and dynamic response [16–17].

Basically, in respect of time delays introduced in control action performed, there are two types of delays encountered in power system. The first one is the direct method based on tracing critical eigenvalues. However, the direct method can handle only constant delays in the system. The method is incapable to cope with time varying delays. The second one is the indirect method based on H-infinity robust synthesis, Lyapunov stability theory and linear matrix inequalities (LMIs) techniques to evaluate the delay margin of the controller. Although in spite of some of its limitation, these techniques could deal with both time-varying and constant delays.

Recently, time delay and packet loss estimation in data communication have drawn much attention in network control system [18]. The researchers [19–23] have reported LFC issue with communication delay based on the linear matrix inequality (LMI) technique, the robust decentralized method and PI type controller. A network delay and communication model for third party LFC strategy is discussed in [19]. Furthermore, the study [24] reported time delay in design of LFC in deregulated environment.

Open communication network is preferred over dedicated ones due to its low cost, simple structure and flexibility. However, these have serious concerns in respect of time varying and random delays. Random delays have varying magnitude usually caused by packet drop out in communication channel [19]. Data packet loss takes place in the wide area monitoring system (WAMS) due to adoption of multiple paths for transmission from source to its destination. Different packets may experience different delays depending upon its path length [25–27]. Recently authors [28–29] have designed an optimal output feedback controller for Automatic Generation Control (AGC) integrated with a doubly fed induction generator (DFIG). The performance of LFC with DFIG for frequency link pricing is reported in [30]. Further the performance of LFC in deregulated environment with the superconducting magnetic energy system (SMES) and DFIG is presented in [31].

Most of the LFC studies in the past have been reported considering constant/random delays with known lower and upper bounds and did not estimate the delay and packet