Electrical Power and Energy Systems 100 (2018) 331–349

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Design of sampled data and event-triggered load frequency controller for isolated hybrid power system

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ARTICLE INFO

Keywords:
Load frequency control
Linear matrix inequality
Lyapunov-Krasovskii function
Hybrid wind-diesel system
Battery energy storage

ABSTRACT

Load frequency control is quite important for power system having wind generation, as wind speed is intermittent. Discrete controllers, implemented with high sampling rate, consume more network bandwidth. Hence, this paper presents discrete frequency regulation schemes for isolated hybrid power system containing wind, diesel and battery storage with a focus on minimizing the utilization of network resources. Two methods for utilizing the network resources more efficiently are given and applied on the hybrid wind-diesel-battery power system. In first, the periodic sampling is implemented, sampling time of states measured and sent through network for stabilizing the system is maximized. Secondly, an event based sampling is performed to further reduce the communication burden. Along with the sampling time, time delay introduced by network is also considered and maximum allowable delay bound is obtained in both the methods. The results show that channel bandwidth utilization can be reduced by increasing the sampling time while keeping the system stable. The event-triggered controller implemented can further reduce the required bandwidth. The robustness of the designed controller is verified for the above hybrid power system for different load disturbances, change in wind power, parameter variations and through eigenvalue sensitivity analysis. Finally, the approach is extended to interconnected two-area hybrid power system.

1. Introduction

Traditionally, most of the electrical power sources are based on fossil fuels such as coal, oil and gas which are at the verge of depletion. Burning them, increases the carbon emission and pollution in the atmosphere. Also power demand is increasing day by day, that is why more and more power resources are integrated with the power system. So, the focus is on integration of renewable energy power sources like wind, photovoltaic (PV), geothermal, tidal, etc. Wind and PV power are available in abundance and has a lot of potential for meeting future power demand of electricity market. Out of both, PV has limitation that it is available during the day while wind turbine generator is economical and more efficient than PV energy conversion. Therefore, wind turbine generation has received much attention for isolated areas. Due to intermittent behaviour of wind, wind turbine generator is usually coupled with diesel generator. With the integration of wind power, maintaining frequency to scheduled range is necessary for active power balance in an area. Otherwise, the power system may become unstable leading to system failure.

Various techniques and strategies for frequency regulation of power system having wind turbine generator are proposed by different authors [1–11]. In [1], controllers gains for hybrid wind-diesel power system (HWDPS) are tuned using integral square error technique. To improve the dynamic response of HWDPS variable structure control logic is used in [2]. Doubly fed induction generators (DFIGs) at a wind farm can contribute to active power balance, as proposed in [3]. Dual mode linguistic fuzzy logic controller for HWDPS with superconducting magnetic energy storage is advocated in [4]. Load frequency control (LFC) of isolated area wind hydro power system is presented in [5]. In [6], model predictive control strategy for multi-area LFC considering wind turbines is proposed. In [7], robust LFC of hybrid power systems using particle swarm optimization and linear matrix inequalities (LMIs) is designed. The sliding mode LFC for hybrid power system using disturbance observer is implemented in [8]. Stability of DFIG based wind turbines is analyzed and controller gains are tuned using teaching learning based optimization algorithm in [9]. Controllers gains for HWDPS are tuned using quasi-oppositional harmony search algorithm [10,11].

The controller practically used for frequency regulation is discrete in nature while most of the authors have designed controller based on the assumption that the controller is continuous. Considering the HWDPS model in [1], authors implemented controller for both

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https://doi.org/10.1016/j.ijepes.2018.02.012
Received 11 May 2017; Received in revised form 11 January 2018; Accepted 8 February 2018
0142-0615/

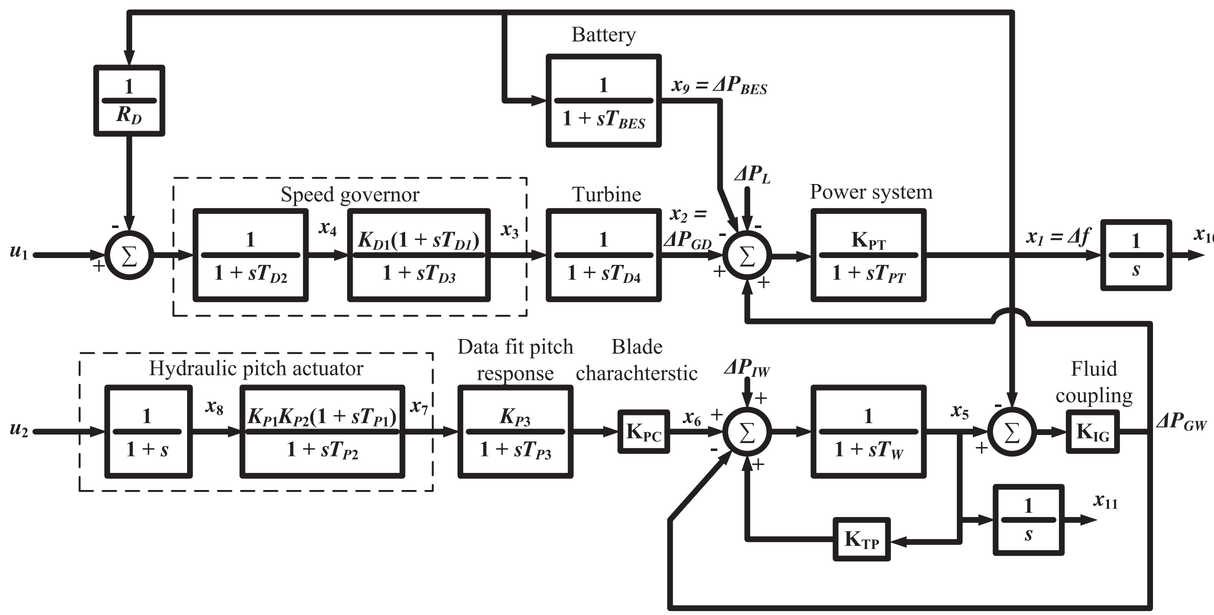

Fig. 1. Block diagram of HWDPS with battery energy storage.

continuous and discrete cases but no analytical work is done to find the appropriate value of sampling interval. Traditional power system uses dedicated channels for communication, so sampling rate can be fast and controller can be assumed as continuous for all practical purpose. But in deregulated and distributed generation environment dedicated communication channel is neither economical nor practically feasible. Instead of dedicated, open communication channel is generally used for controlling wind power for distributed generation as well as for wind farms [12]. These channels have limited bandwidth hence, some analysis is needed to reduce the communication burden while keeping the HWDPS stable. In order to analyse sampled data systems, mainly three methods have been used. In first method, the system is discretized and simple conditions were obtained for stabilizing the system [13]. In second method, a sampled data system can be modelled as continuous system with time delay [14]. In third method, sampled data system is modelled as impulsive system [15]. After their first appearance, several improvements have introduced in the methods to find the maximum sampling time while retaining the stability of the system. The time delay methods are also employed in the literature to find delay dependent stability of thermal LFC scheme as reported in [16–20]. But none has been used to find the maximum sampling time with integrated renewable source till now. This area of research has been tried to analyse here by designing sampled data controller (SDC) for HWDPS model considering time delay and sampling interval.

The SDC has become standard in almost all application because of their simplicity and easy to implement. On the other hand, it has some drawbacks such as if sampling time is small, large bandwidth is occupied whereas if sampling time is large, fault occurs between two sampling instant which can make system unstable. Recently a new sampling technique based on event-triggered controller (ETC) is attracting researchers. In event based sampling, data is sent only if certain condition confirms that event condition is violated. Over periodic sampling, event based sampling can be used to save network resources, power consumption as well as computational burden of the controller in a networked control system [21]. Hence, ETC has been applied to cyber-physical systems in the last few years. After the first appearance in 1962 [22], the event based schemes have been investigated to look for elongated inter event time [23,24]. In [25] system states are continuously observed by event generator in order to detect the event. This event generator is complex and hard to implement [26]. This problem can be overcome by using a software based approach known as self-triggered control as is proposed in the recent past [27,28]. But this scheme has lower average release period as shown in [25,27]. The scheme proposed in [26] resolves the above issues by checking system states at discrete instants only. ETC is also employed in thermal LFC schemes in recent time [29–31]. But, till now none has proposed LFC scheme incorporating ETC for integrated renewable energy sources. A sliding mode controller for multi-area thermal LFC system is designed in [29]. In [31], an ETC considering time delay is designed for multi-area thermal LFC scheme. However, both these approaches do not consider the effects of non-linearities such as generation rate constraint (GRC) and governor dead band (GDB).

In this paper, a method for designing SDC and ETC for frequency regulation of HWDPS is presented, considering effective utilization of network resources. In designing the controllers, effects of time delay and sampling time are also considered. Thereby making the model more close to the actual system. A comparison is also made between both the presented techniques, which show that ETC has the advantage of further reducing the network bandwidth. Dynamic responses of the above said controllers are simulated for step and random load disturbances. Dynamic frequency response for different sampling time is then compared with the hybrid power system model presented in [11]. To show the robustness of the designed controller, the dynamic responses in the presence of physical constraints such as GRC and GDB are also simulated. The effectiveness of the proposed technique is also demonstrated by applying it to a more complex two-area HWDPS. For finding the sensitivity of the designed controllers, eigenvalue sensitivity analysis is performed, which shows the movement of eigenvalues in s-plane due to perturbation in the controller gain. In addition to that, parametric uncertainty is considered to show the robustness of the designed controllers.

Rest of the paper is organized as follows. Section 2 describes the dynamics of HWDPS model with battery energy storage. Section 3 describes methods to find maximum sampling interval, maximum allowable delay bound (MADB) and state feedback controller gain 'K' for the model described in Section 2. In Section 4, simulations are carried out to show effectiveness of the presented methods. Also, both methods are compared by taking common controller. In the last section conclusions are drawn.