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A robust H_∞ controller based frequency control approach using the wind-battery coordination strategy in a small power system

Abdul Motin Howlader [a,*], Yuya Izumi [a], Akie Uehara [a], Naomitsu Urasaki [a], Tomonobu Senjyu [a], Ahmed Yousuf Saber [b,1]

[a] Faculty of Engineering, University of the Ryukyus, 1 Senbaru, Nishihara-cho, Nakagami, Okinawa 903-0213, Japan
[b] Principal Power Engineer, Operation Technology, Inc., ETAP, Irvine, CA, USA

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ABSTRACT

In this paper, a coordinated control method for a wind turbine generator (WTG) and a battery energy storage system (BESS) of a small power system have been presented. The coordinated control approach applies to control the system frequency to reduce the size of BESS and to control the pitch angle system to mitigate the wind turbine blades stress. To achieve these objectives simultaneously, the robust H_∞ control method is applied in this paper. The pitch angle system of the WTG and the output power command system of the BESS are controlled by the H_∞ controllers. The output power command of the WTG is determined from the wind velocities and it is controlled by the pitch angle control system. Concurrently, the output power command of the BESS is calculated according to the state of charge and the frequency deviations in the small power system. The small power system includes a WTG, a BESS and a diesel generator. Numerical simulations are conducted by the MATLAB/SIMULINK® environment to validate the proposed method.

1. Introduction

There are many isolated communities in the world. Diesel generators are the main source of electric power for the isolated communities. In recent years, limited fossil fuels (e.g. coal, oil, gas) and many conflicting objectives such as environmental impact, reliability, imported fuels are serious issues [1]. The diesel-generated electricity is more expensive than large electricity production plants (e.g. gas, hydro, wind), and incurs the transport, fuel and storage costs [2]. Diesel generators are inherently inefficient when operated at a low load factor (below 40–50% of their rated capacity) and diesel engines burn fossil fuels which release harmful emissions into the atmosphere [3,4]. To overcome these problems, renewable energies (e.g. wind, solar, hydro, tide, biomass) have been drawing attention as the clean electricity sources. Wind energy is one of the most rapid growing renewable power sources in the world, and wind power penetration has been increasing to the power grid [5–8]. On the other hand, the wind turbine generator (WTG) can deliver a cheap electricity power as compared with other renewable sources [9]. Therefore, wind–diesel hybrid power systems can install to the isolated communities in order to improve their life standard. This hybrid power system also can be a part of a micro-grid system. With the hybrid power system, the annual diesel fuel can be reduced and, at the same time, the level of emissions can be minimized [10].

However, wind velocity is a highly stochastic element which can deviate quickly. The output power is delivered by the WTG which is proportional to the cube of wind speed. Hence, any deviations in wind speed will cause the wind power fluctuations. The power fluctuations may lead the frequency fluctuation and voltage flicker inside the power system [11]. Therefore, various power smoothing methods are applied to overcome these problems. The pitch angle control is utilized for the output power control of the WTG. There are various pitch angle methods to control the output power of WTGs [11–15]. By using these control methods, the output power fluctuations of WTGs can be reduced at wind speed variations. But these methods increase the wind turbine blade stress extensively due to the rapid pitch actions. To reduce the blade stress, the control regions of the pitch angle and the output power of the WTG should be considered in a frequency domain. The pitch angle control system in a high frequency domain increases the mechanical stress to the wind turbine blades. Moreover, wind energy is an uncertain fluctuating resource and requires tight control management. The conventional proportional–integral (PI) controller is not ideal due to the high turbulence wind velocities and

* Corresponding author. Tel.: +81 98 895 8686; fax: +81 98 895 8708.
E-mail addresses: b985542@tec.u-ryukyu.ac.jp (A.M. Howlader), aysaber@ieee.org (A.Y. Saber).
[1] Tel.: +1 949 716 5839.

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parameter uncertainties. Therefore, the researchers have promoted to interest in the robust control concepts (e.g. H_2 or H_∞ controllers). In [15], the H_∞ control method is applied to generate a smooth output power. However, the control region of the pitch angle in a frequency domain is not clarified. The H_∞ controllers based load mitigation methods for the WTG systems are proposed in [16,17], and there are nothing to mention about the frequency control strategies.

Nowadays, the energy storage system (ESS) is integrated with the renewable sources which are connected into the power grid to maintain the safe operation of the power grid, and balance the supply and demand sides [18–20]. Moreover, the integrated ESS and WTG system can control the frequency in small power systems. There are different types of ESSs in the power systems such as batteries, superconducting magnetic energy storage (SMES), electric double layer capacitor (EDLC), and flywheels [18–25]. Since the SMES has to maintain the conducting state, the operation cost is very high. The installation cost of the EDLC is very high and the flywheel creates a high noise at the large capacity range of operation. The battery energy storage system (BESS) is one of the most rapid growing storage technologies. The BESS installation cost and generating noise are relatively lower than the other storage technologies. However, the installation cost of the large BESS is also very high. If a large battery storage installs in a small power system, the system cost will be increased significantly. Therefore, to reduce the BESS capacity, the power system can provide an enormous economic benefit. A short-term operation can reduce the size of a BESS. For an integrated battery storage and wind turbine systems, the BESS should operate in a short term basis to decrease the size of it.

For that reason, this paper presents a coordinated control method for wind turbine and battery storage in a small power system. The coordinated control method applies to control the system frequency which can reduce the size of a BESS, and the pitch angle control system which can mitigate the wind turbine blade stress. The proposed coordinated control method is implemented through the robust H_∞ controller. The H_∞ controllers are applied to the pitch angle control system of the WTG and the output power command system of the BESS. By using the H_∞ controllers, the desired frequency characteristics of the control systems can be achieved by the proper weighting functions in a frequency domain. The output power command of the WTG is depended on wind velocities and is controlled by the pitch angle control system. In addition, the wind speed variations are assumed as an uncertain parameter to design the H_∞ controller for the pitch angle control system. The H_∞ controller can reduce the low frequency components for the output power errors of the WTG. Therefore, the pitch action decreases which can mitigate the wind turbine blade stress. Concurrently, the output power command of the BESS is determined according to the state of charge and the frequency deviations in the small power system. By using the output power command system, the H_∞ controller can limit the BESS operation within the high frequency domain. Thus, the charge/discharge operations of the BESS are not required to perform at the long term. This phenomenon can reduce the size of a BESS in a small power system. The proposed method is compared with the conventional PI control method which can reduce the frequency deviation, size of BESS and mechanical stress of WTG. Effectiveness of the proposed method is verified by the numerical simulations in MATLAB®/SIMULINK® environment.

2. Small power system model

An integrated power system diagram is shown in Fig. 1. The small power system consists of a wind turbine, a battery storage, a diesel generator and a load. It is assumed that the small power system can operate independently. The detail model of the small power system model is shown in Fig. 2 [26]. In Figs. 1 and 2, the symbols P_d, P_c, P_g, and P_b are the output power of the diesel generator, the combined power of the WTG and the BESS, the output power of the WTG and the output power of the BESS, respectively. The symbols P_L and P_e are the load power and the supply error, respectively. The '$*$' represents the commanded values for different powers. The WTG system is connected to the AC side through a transformer (AC link method). Since the main purpose of this paper is frequency control, the frequency analytical model of the frequency control system is expressed as a simple transfer function for simplified simulations. The power system model does not include the characteristics such as substation facilities, electrical instruments, communication delay.

The flat frequency control (FFC) approach is applied to control the frequency of the diesel generator. The FFC method is commonly used in a stand-alone power system. This method includes an integral control loop which can reduce the frequency deviation, Δf. The system capacity is 687.5 kW.

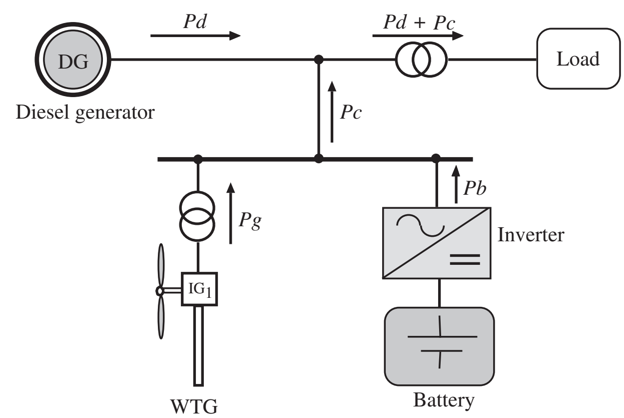

Fig. 1. Proposed small power system model.

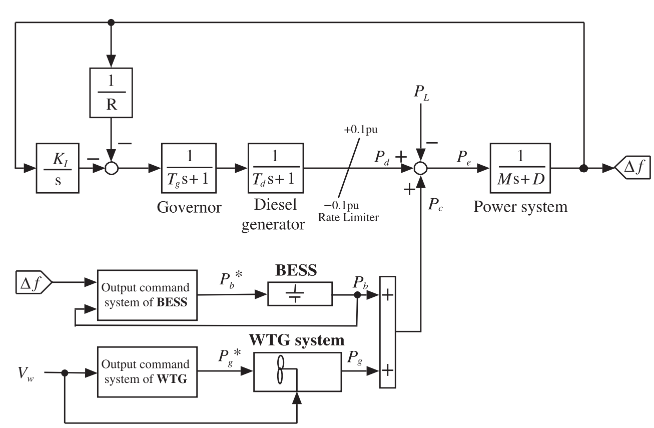

Fig. 2. Small power system model.

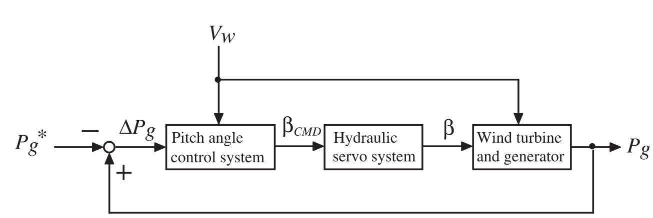

Fig. 3. Wind turbine generator system.