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A minimal order observer based frequency control strategy for an integrated wind-battery-diesel power system

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ABSTRACT

Wind energy is a fluctuating resource which can diverge quickly and causes the frequency deviation. To overcome this problem, the current paper deals with a frequency control scheme for a small power system by a coordinated control strategy of a wind turbine generator (WTG) and a battery energy storage system (BESS). The small power system composes of a wind turbine, a battery storage and a diesel generator. A minimal order observer is utilized as a disturbance observer to estimate the load of the power system. The load deviations are considered in a frequency domain. The low frequency component is reduced by the pitch angle control system of the WTG, while the high frequency component is reduced by the charge/discharge of the BESS, respectively. The output power command of the BESS is determined according to the state of charge, the high frequency component of the frequency deviation and the load variation. The proposed method is compared with the conventional method in different cases. By using the proposed method, the capacity of the battery is decreased by the charge/discharge of the BESS in long term. To enhance the control performance, the generalized predictive control (GPC) method is introduced to the pitch angle control system of the WTG. Effectiveness of the proposed method is verified by the numerical simulations.

1. Introduction

In recent years, the application of renewable energy sources (e.g. wind, solar, hydro, biomass and etc.) has become more extensive due to the needs of higher power quality, better reliability, more flexibility, less cost and smaller environmental footprints [1]. Distributed generations such as wind turbines, photovoltaics, fuel cells and storage devices (e.g. batteries, electric double layer capacitors) are expected to play a vital role to meet the future energy demand [2,3]. There are many isolated islands in the world and the power needs everywhere. Most of the remote and isolated communities or technical installations (e.g. communication relays, meteorological systems, tourist facilities, farms and etc.) which are not interconnected with the national electric distribution grids, and depend on diesel generators to meet the electricity demand [4]. The diesel-generated electricity is more expensive in itself than large electric production plants (e.g. gas, hydro, nuclear, wind) because various costs (such as transport, storage and environmental costs) are associated with this type of power generation [5]. However, among the several renewable energy sources, wind turbine generator (WTG) systems can produce a cost effective output power and it is one of the most rapid growing clean power sources [6–10]. Wind power capacity grew by 20.5% in 2011, with capacity increasing by a record 40.8 GW to reach 239 GW by the end of 2011. In the mean time, total capacity of the solar power grew by 29.3 GW to reach only 63.4 GW. Nowadays, wind power generates 437 TWh of electricity, around 2% of total electricity generation.

Moreover, wind velocity is a highly stochastic component which can diverge quickly. As the generated output power of the wind turbine system is proportional to the cube of wind speed, any deviation in wind velocity will cause a high fluctuation in the generated wind power. The power fluctuation may lead the frequency fluctuation and voltage flicker inside the power system [11]. Therefore, a power smoothing method is needed to overcome these problems. The pitch angle control is utilized to control the output power of the WTG. There are various pitch angle control approaches for WTGs [11–18]. In Refs. [11–15], output power smoothing methods by using the adaptive and robust control

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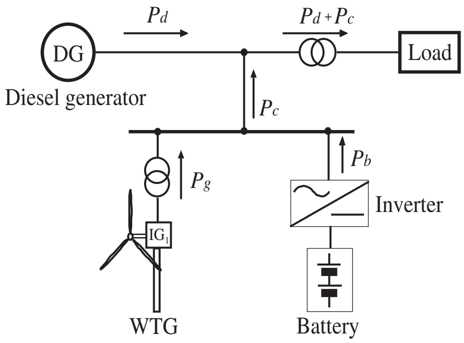

Fig. 1. A single-phase diagram of an integrated small power system.

strategies are proposed, and it is confirmed that the performance of the pitch angle control by the proposed methods can be enhanced. A new strategy of the pitch angle control to ensure the balance between the produced energy and the loads demand in Ref. [16]. In Ref. [17], to consider the effect of the output power fluctuations, variety of control functions that can control the output power of WTGs. In Ref. [18], the output power command of a WTG is determined by solving an optimal problem.

The purpose of output power control of a WTG is the reduction of frequency deviations in a power system. To improve the contribution of wind plants in frequency control of the power system, more efficient and effective utilizations of wind energy has been an important issue [19,20]. The usage of battery energy storage systems (BESS) has created a greater focus on the reduction of adverse effects of the frequency deviations [21–25]. By installing BESSs to a power system with WTGs, the power fluctuations can be reduced and also the power system stabilities can be ensured. Since integrating large batteries with WTGs increase the cost of the power system, it is economically beneficial to utilize small batteries for the output power control of the integrated system.

Therefore, this paper proposes a minimal order observer based frequency control approach for the integrated small power system. A coordination strategy of a WTG and a BESS is applied to the frequency control method. The minimal order observer utilizes for the load estimation of a small power system. The estimated load variations are considered in a frequency domain. The low frequency component is reduced by the WTG using a pitch angle control, while the high frequency component is reduced by the charge/discharge of the BESS, respectively. The generalized predictive control (GPC) [12] is introduced to the pitch angle control system of the WTG which can improve the control performance extensively. The output power command of the BESS is decided by three different components such as the state of charge, the high frequency component of the frequency deviation, and the estimated load of the minimal order observer. The proposed method is compared with the conventional methods in various cases. The proposed method can reduce the frequency deviation and the power fluctuation of the diesel generator. It also ensures that the output of the integrated system can be controlled by the small BESS which is the economically beneficial. Effectiveness of the proposed method is verified by the numerical simulations in MATLAB®/SIMULINK® environment.

2. An integrated small power system

The single-line diagram of an integrated small power system is shown in Fig. 1. The integrated power system includes a WTG, a BESS, a diesel generator, and a load. The system capacity is 687.5 kW. It is assumed that the power system operates separately and it is disconnected from the large power system. The WTG output power, P_g, battery output power, P_b, the combined power, P_c, and the diesel generator power, P_d, flow to the system load. The detail model of a small power system is shown in Fig. 2 [26,27]. In Fig. 2, P_L refers as the system load and P_e is the supply error. The '*' represents the commanded values for the different powers. There is a well known frequency control method for an isolated power system which is the flat frequency control (FFC) method [28,29]. The FFC contains an integral control loop which can lessen the frequency deviation, Δf. This paper gathers some ideas from Ref. [12,13] and it is a continuation of the research on WTG. Hence, the WTG system is based on a fixed speed squirrel-cage induction generator. It is assumed that the WTG system is connected to the AC side through a transformer (AC link method). Since the main

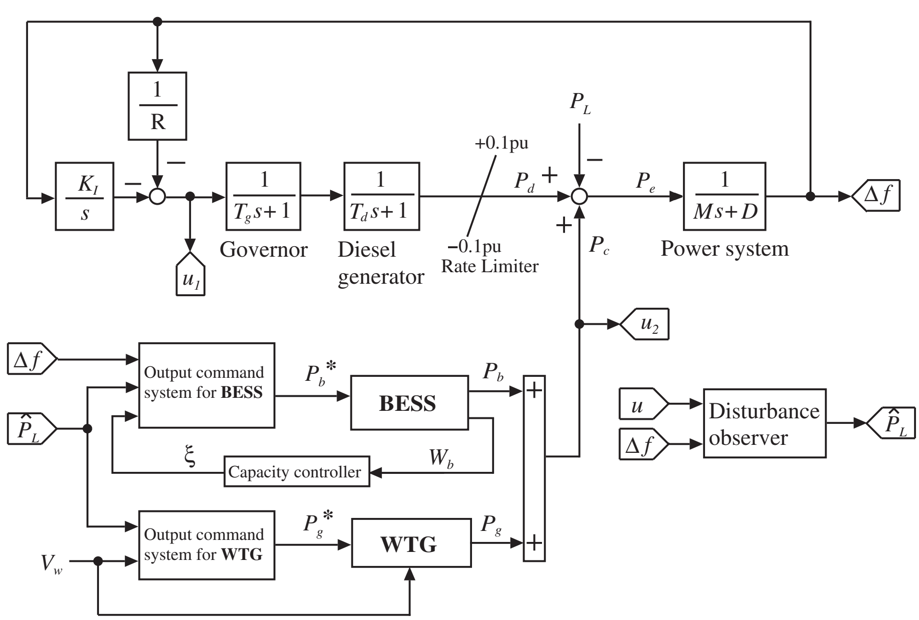

Fig. 2. Small power system model.