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Comparison of Control Characteristic of Energy Storage System According to Controller Input in Wind-Diesel Power System

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Abstract: This paper presents control characteristic according to controller input signals of the energy storage system in a hybrid wind-diesel power system. The wind power system frequency and the diesel power system frequency are used as controller input signals for control characteristic comparison of the energy storage system. Parameters of the controller according to a input signal of each controller are selected by using the genetic algorithm. In order to evaluate each controller's performance, the computer simulations are performed for the wind power system disturbance and the diesel power system disturbance. The frequency characteristics, wind power output characteristics, diesel power output characteristics, and output characteristics of the energy storage system are investigated for each disturbance case. Simulation results show that the controller designed using wind system frequency responds faster to wind system disturbance and the controller designed using diesel system frequency responds faster to power system load changes.

Keywords: Wind Power System, Diesel Power System, Hybrid Power System, Energy Storage System, Genetic Algorithm

I. INTRODUCTION

Recently, the wind power and solar power have been applied to power systems due to lack of fossil fuel and environmental issues. Especially the wind power generation is very economical on islands and remote areas where wind speeds are high. Therefore, the wind diesel hybrid power generation system [1~6] can be considered in an isolated site which is difficult to receive the electric power from the main power system. [7~8].

However, because of the irregular output of wind power sources, the frequency and voltage variations of isolated power systems are very large. To prevent frequency oscillation, it is necessary to control the diesel power system and the wind power generation system. Although the governor control of the diesel system and the pitch control of the wind power generation are mainly used for the frequency control, this control method is limited due to the slow response [7~8].

In order to solve the problem, many researches about frequency control of the wind-diesel hybrid power system have been carried out using various control methods such as pitch control method of the wind system and diesel generation system [1][3]. The PI control [9] & Variable Structure Control (VSC) [5], fuzzy control [10~12], H∞ control [8][13] & control method using the Superconducting Magnetic Energy Storage System (SMES) [1] [3][14] were proposed. [15] Recently, researches on various control methods using flywheel energy storage systems in the wind-diesel power system have been conducted and showed excellent control performance [7][8][15]. Because the active power output of a flywheel energy storage system is very fast, it is possible to control frequency quickly in spite of the sudden load change and the irregular output of the wind power[7][8]. However, these researches have been limited to the study of the controller design to achieve the purpose of excellent control performance.

In this paper, we consider the control characteristics according to the controller input signal of the energy storage system in the wind diesel power system. For this purpose, the genetic algorithm is used to select the optimal parameters of the controller of the energy storage device whose structure is fixed according to the input signal of the controller. As the input signal of the energy storage system controller, the frequency of the diesel system and the frequency of the wind power generation system were used, respectively. By applying the two designed controllers, computer simulations were performed for the case of disturbance in the wind power generation system and the case of disturbance in the diesel power generation system. The frequency characteristics, wind power output characteristics, diesel power output characteristics, and output characteristics of the energy storage system are investigated for each disturbance case.

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II. WIND DIESEL POWER SYSTEM MODEL

Fig. 1 shows the system configuration for the wind diesel hybrid power generation system with the energy storage system [8]. Fig. 2 shows the block diagram for the wind diesel power generation system [1][8][14] with the pitch controller and the flywheel. This block diagram model consists of a wind system model, a diesel system model, a blade pitch control and a generator model.

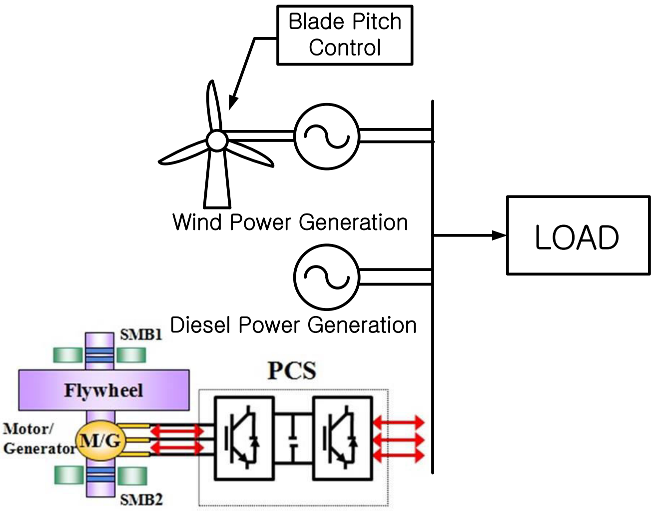


Fig. 1 A wind diesel power generation system with the energy storage system

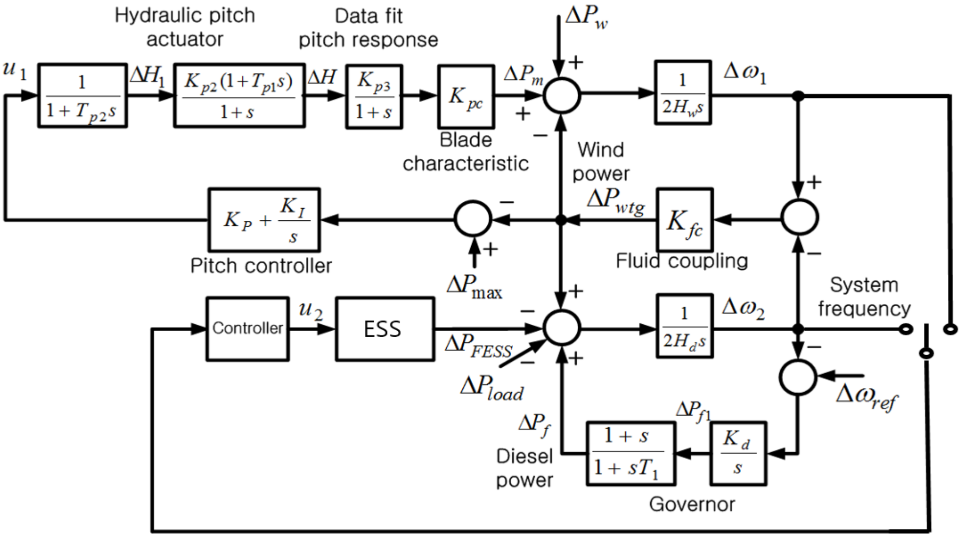


Fig. 2 A block diagram for the wind diesel power generation system with the pitch controller and ESS

2.1 Wind System Model

The wind dynamics model including blade pitch control of the wind turbine [2][7] is as follows,

$$\frac{d}{dt}\Delta H_1 = -\frac{1}{T_{p2}}\Delta H_1 + \frac{1}{T_{p2}}u_1 \quad (1)$$

$$\frac{d}{dt}\Delta H = \left(K_{p2} - \frac{K_{p2}T_{p1}}{T_{p2}}\right)\Delta H_1 - \Delta H + \frac{K_{p2}T_{p1}}{T_{p2}}u_1 \quad (2)$$

$$\frac{d}{dt}\Delta P_m = K_{p3}K_{pc}\Delta H - \Delta P_m \quad (3)$$

$$\frac{d}{dt}\Delta w_1 = -\frac{1}{2H_w}\Delta P_m - \frac{K_{fc}}{2H_w}\Delta w_1 + \frac{K_{fc}}{2H_w}\Delta w_2 + \frac{1}{2H_w}\Delta P_w \quad (4)$$

The transfer function of the hydraulic pitch actuator is split into two blocks. $\Delta H$is the hydraulic pitch actuator variable and ΔH_1 is dummy variable. $\Delta P_m$is the wind power deviation. $\Delta P_w$is change in the wind power input. $\Delta w_1$is wind frequency deviation. T_{p1}, T_{p2} is time constant of the hydraulic pitch actuator, K_{p2} is the hydraulic pitch actuator gain, K_{pc} is the blade characteristic gain, K_{p3} is the data fit pitch response gain, K_{fc} is the fluid coupling gain, H_w is the inertia constant of the wind turbine system.

2.2 Diesel System Model

The diesel dynamics model including the governor system [2][7] is as follows,

$$\frac{d}{dt}\Delta w_2 = -\frac{1}{2H_d}\Delta w_1 - K_{fc}\Delta w_2 + \Delta P_f - \frac{1}{2H_d}\Delta P_{load} \quad (5)$$

$$\frac{d}{dt}\Delta P_{f1} = -K_d\Delta w_2 \quad (6)$$

$$\frac{d}{dt}\Delta P_f = -\frac{K_d}{T_1}\Delta w_2 + \frac{1}{T_1}\Delta P_{f1} - \frac{1}{T_1}\Delta P_f \quad (7)$$

The transfer function of the diesel governor is split into two blocks. ΔP_f is the diesel governor output variable and ΔP_{f1} is dummy variable. ΔP_{load} is change in load. H_d is the inertial constant of the diesel engine, K_d is the gain of diesel governor, T_1 is time constant of the diesel governor.

The linearized equation of the wind diesel hybrid power system in Fig. 2 including the wind dynamics model, blade pitch control of the turbine and the diesel dynamics model including the governor system.

$$\Delta\dot{x} = A\Delta x + B\Delta u + \Gamma\Delta p \quad (8)$$

where, Δx, Δu and Δp are the state, control and disturbance vector respectively. $\Delta x = [\Delta H_1, \Delta H, \Delta P_m, \Delta w_1, \Delta w_2, \Delta P_{f1}, \Delta P_f]$. A, B and Γ are constant matrix which depends on system parameters and the operating point.

$$A = \begin{bmatrix} \frac{-1}{T_{p2}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \left(K_{p2} - \frac{K_{p2}T_{p1}}{T_{p2}}\right) & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & K_{p3} & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{K_{pc}}{2H_w} & \frac{-K_{fc}}{2H_w} & \frac{K_{fc}}{2H_w} & 0 & 0 \\ 0 & 0 & 0 & \frac{K_{fc}}{2H_d} & -K_{fc} & 0 & 1 \\ 0 & 0 & 0 & 0 & -K_d & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-K_d}{T_1} & \frac{1}{T_1} & \frac{-1}{T_1} \end{bmatrix}$$

2.3 Flywheel Energy Storage System (FESS) Model

The FESS can be modeled by the first order transfer function. Therefore, the output power of the FESS can be written as following equation (9).

$$\frac{d}{dt}\Delta P_{FESS} = -\frac{1}{T_{FESS}}\Delta P_{FESS} + \frac{1}{T_{FESS}}u_2 \quad (9)$$

where ΔP_{FESS} is change of the FESS output, T_{FESS} is the time constant of the FESS

III. PARAMETER SELECTION OF ESS CONTROLLER USING GA

Fig. 3 shows the block diagram for selecting parameters of the FESS controller for input signals Δw_1 and Δw_2 using GA.

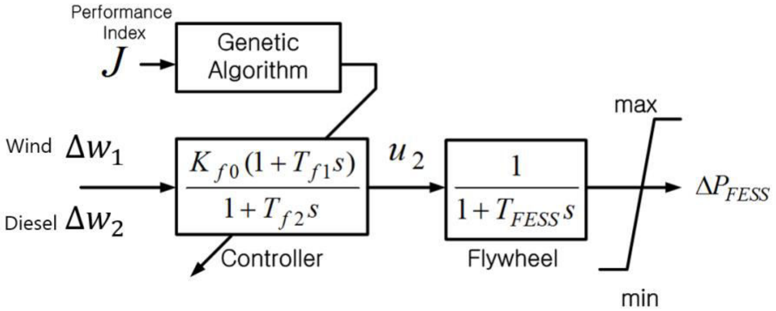


Fig. 3 A block diagram for selecting controller parameter of the FESS using input signal, Δw_1,Δw_2

The inputs of the FESS controller are system frequency $\Delta w_1$and Δw_2 as Fig. 3. The performance index J used to select parameters of the FESS controller using the GA is as follows

$$J = \int_{t=0}^{t=te} t \cdot |\Delta\omega|_1 + t \cdot |\Delta\omega_2| dt \qquad (10)$$

where, t is time, te is simulation time. The FESS output power limit of -0.01 $\leq \Delta P_{FESS} \leq$ 0.01 pu is considered.

To select the parameters of the FESS controller as shown in Fig. 3, the real variable GA using the tournament selection method, the arithmetic crossover and the uniform mutation are used. The population size of the GA is 100 and the generation number is 100. The designed FESS controller parameters K_{f0}, T_{f1} and T_{f2} using input signal Δw_1 are 19.8914, 20.7291 and 20.8080 respectively. The designed FESS controller parameters K_{f0}, T_{f1} and T_{f2} using input signal Δw_2 are 26.9642, 3.0740 and 2.8860 respectively.

IV. SIMULATION RESULTS

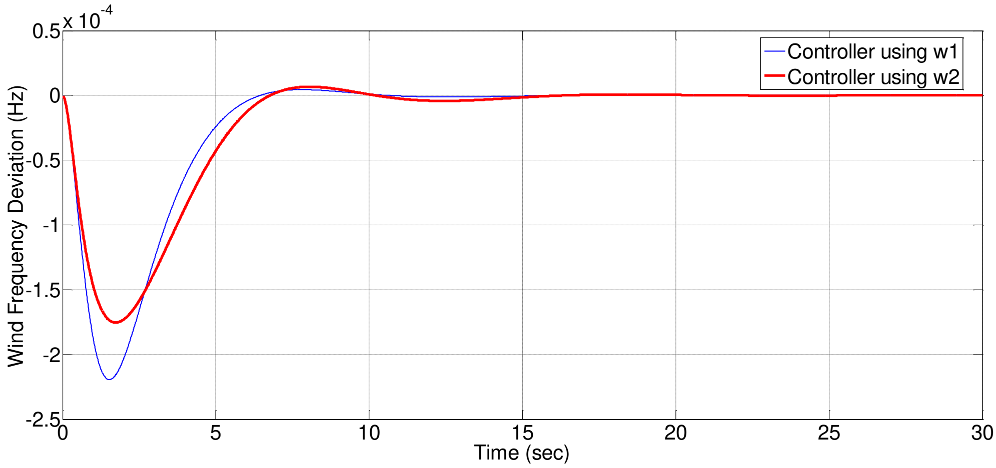
The system parameters for the computer simulation are shown in Table. 1 [7][8][15].

Table 1. System Parameters

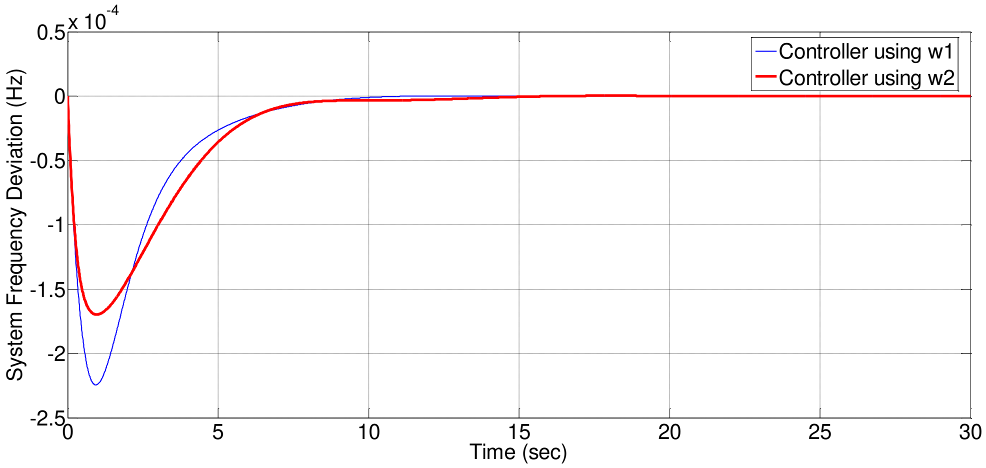
$$H_w = 3.5s \,,\, H_d = 8.5s \,,\, K_{fc} = 16.2Hz/pukW$$

$$K_{p1} = 4.0 \,,\ K_{p2} = 1.25 \,,\, T_{p1} = 0.60s \,,\, T_{p2} = 0.041s$$

$$K_{p3} = 1.4 \,,\, K_{p1} = 0.08 puKw/\deg. \,,\, K_{FESS} = 0.1$$



(a)Wind frequency deviation



(b) System frequency deviation

Fig. 4 Frequency responses for ΔP_{load} 0.01 pu step load variation

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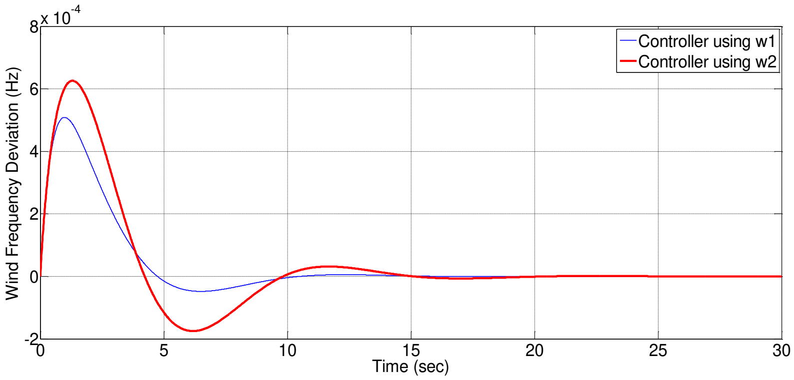
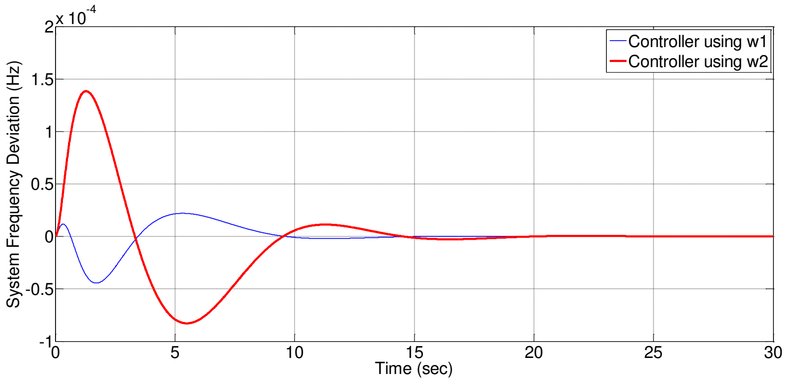
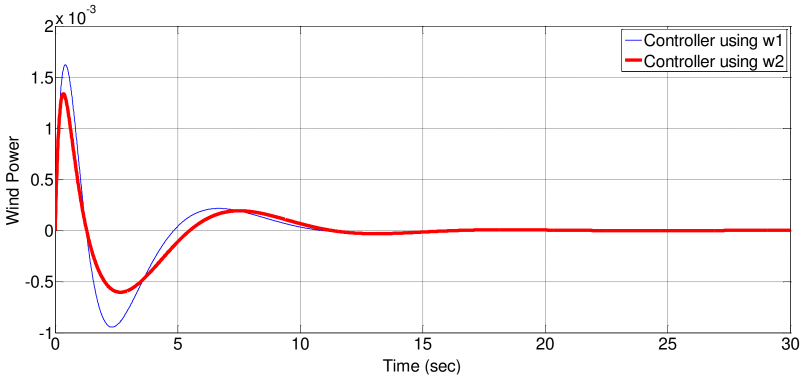


(a)Wind frequency deviation

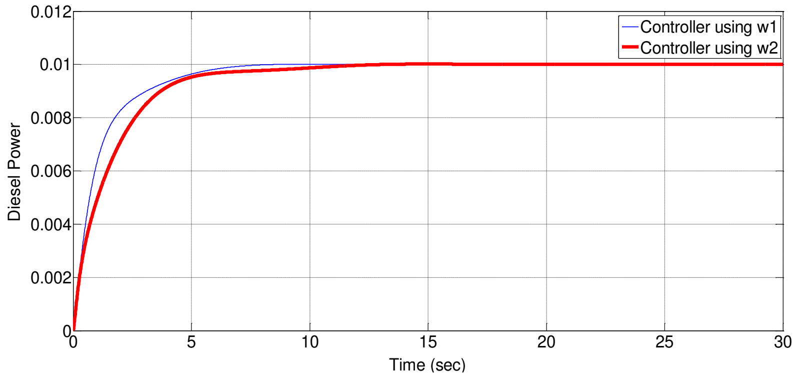


(b) System frequency deviation

Fig. 5 Frequency responses for ΔP_w 0.01 pu step load variation

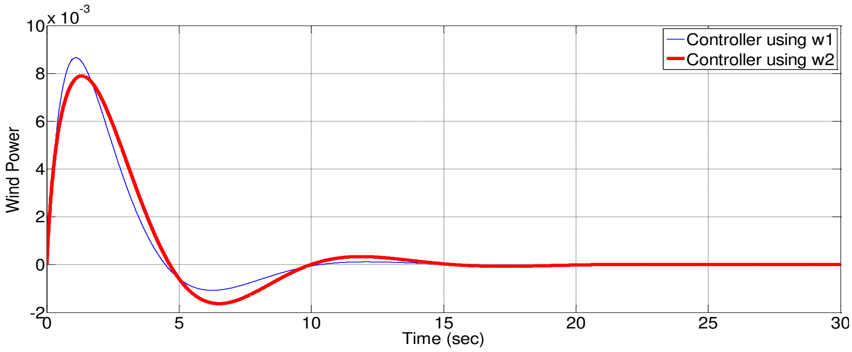


(a) Wind power

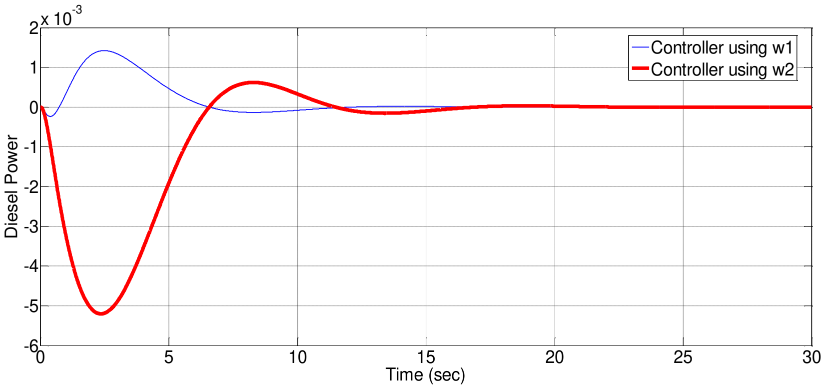


(b) Diesel power

Fig. 6 Frequency responses for ΔP_{load} 0.01 pu step load variation

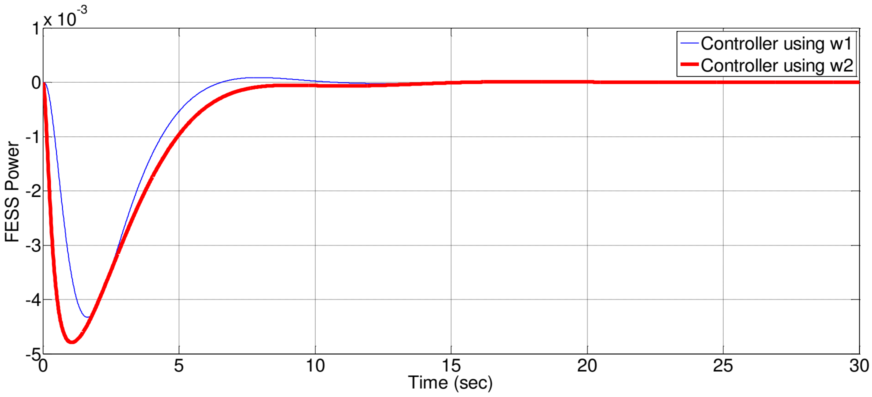


(a) Wind power

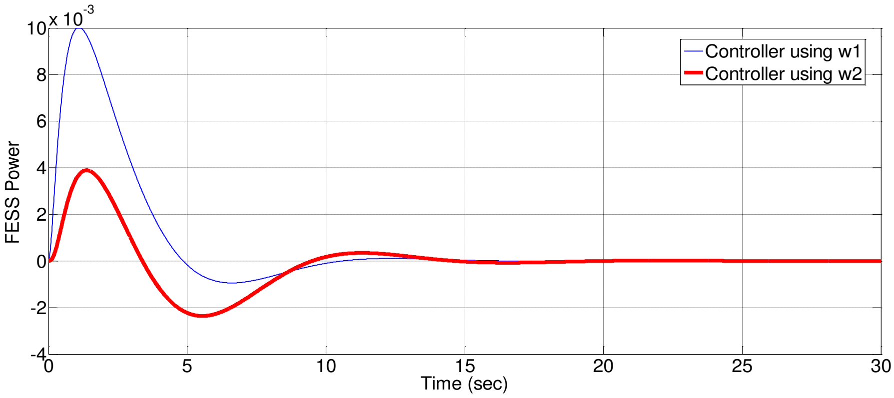


(b) Diesel power

Fig. 7 Frequency responses for ΔP_w 0.01 pu step load variation



(a) 0.01 pu step load variation of ΔP_{load}



(b) 0.01 pu step load variation of ΔP_w

Fig. 8 FESS power according to disturbance

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Fig. 4 shows the simulation results for the frequency deviation of the diesel and wind system with the controller using w_1 and w_2 respectively for a step load change ΔP_{load} of 0.01 pu. Both maximum deviation of wind system frequency and diesel system frequency of the controller using w_2 are smaller than that of the controller using w_1. Fig. 5 shows the simulation results for the frequency deviation of the diesel and wind system with the controller using w_1 and w_2 respectively for a step load change ΔP_w of 0.01 pu. Contrary to Fig. 4, both maximum deviation of wind system frequency and diesel system frequency of the controller using w_1 are smaller than that of the controller using w_2. The results of Fig. 4 and 5 show that the controller designed using the wind system frequency w_1 is more robust to the wind system disturbance, and the controller designed using the diesel system frequency w_2 is more robust to the diesel system disturbance.

Fig. 6 shows the simulation results for the wind power and the diesel power with the controller using w_1 and w_2 respectively for a step load change ΔP_{load} of 0.01 pu. The wind power change with the controller using w_2 are smaller than that of the controller using w_1. For a step load change ΔP_{load} of 0.01 pu, the controller using w_2 can slow down the diesel system output more than the controller using w_1.

Fig. 7 shows the simulation results for the wind power and the diesel power with the controller using w_1 and w_2 respectively for a step load change ΔP_w of 0.01 pu. Both the wind power oscillation and the diesel power oscillation with the controller using w_1 are smaller than that of the controller using w_2.

Fig. 8(a) shows the simulation results for the FESS power with the controller using w_1 and w_2 respectively for a step load change ΔP_{load} of 0.01 pu. The controller using w_2 has a faster FESS output response than the controller using w_1. Fig. 8(b) shows the simulation results for the FESS power with the controller using w_1 and w_2 respectively for a step load change ΔP_w of 0.01 pu. The controller using w_1 has a faster FESS output response than the controller using w_2. Simulation results show that the controller designed using w_1 responds faster to ΔP_w changes and the controller designed using w_2 responds faster to ΔP_{load} changes.

V. CONCLUSION

In this paper, we considered the control characteristics according to the controller input signal of the energy storage system in the wind diesel power system. The genetic algorithm is used to select the optimal parameters of the controller of the energy storage device whose structure is fixed according to the input signal of the controller. As the input signal of the energy storage system controller, the frequency w_1 of the wind power generation system and the frequency w_2 of the diesel system were used, respectively. By applying the two designed controllers, computer simulations were performed for the case of disturbance in the wind power generation system and the case of disturbance in the diesel power generation system. The simulation results such as the frequency characteristics, wind power output characteristics, diesel power output characteristics, and output characteristics of the energy storage system for each disturbance case shows that the controller designed using w_1 responds faster to ΔP_w changes and the controller designed using w_2 responds faster to ΔP_{load} changes.

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BIOGRAPHY

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