http://dx.doi.org/10.11142/jicems.2014.3.2.229

Frequency Control of in Hybrid Wind Power System using Flywheel Energy Storage System

Jeong-Phil Lee * and Han-Guen Kim **

Abstract – In this paper, a design problem of the flywheel energy storage system controller using genetic algorithm (GA) is investigated for a frequency control of the wind diesel hybrid power generation system in an isolated power system. In order to select parameters of the FESS controller, two performance indexes are used. We evaluated a frequency control effect for the wind diesel hybrid power system according to change of the weighted values of a performance index.

To verify performance of the FESS controller according to the weighted value of the performance index, the frequency domain analysis using a singular value bode diagram and the dynamic simulations for various weighted values of performance index were performed.

To verify control performance of the designed FESS controller, the eigenvalue analysis and the dynamic simulations were performed. The control characteristics with the two designed FESS controller were compared with that of the conventional pitch controller.

The simulation results showed that the FESS controller provided better dynamic responses in comparison with the conventional controller.

Keywords: Flywheel energy storage system, Wind power, Frequency control, Genetic algorithm

1. Introduction

A new and renewable energy source such as wind power, solar power, fuel cell etc., are considered as electrical energy source due to lack of fossil fuels and environmental issues. Especially, the wind power is very economical on island or in remote location where wind speed is fast. 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.

However, the irregular output of the wind power source cause a fluctuation of frequency and voltage in the isolated power system. The sudden load change in the isolated power system may cause large oscillation of frequency in the power system. The frequency control by the governor control of diesel and the pitch control of the wind power are limited due to their slow response.

In this paper, a design problem of the flywheel energy storage system controller according to the weighted values of performance index using genetic algorithm (GA) is investigated for a frequency control of the wind diesel hybrid power generation system in an isolated power system.

In order to select parameters of FESS controller, two performance indexes are used. One is to have the weighted value, the other is not to have the weighted value. In case of having the weighted value, the dynamic characteristics and the frequency domain analysis using singular value bode diagram were performed according to magnitude change of the weighted value.

To verify robust performance of the FESS controller in the isolated wind diesel hybrid power generation system, the eigenvalue analysis and the dynamic simulation under various disturbances were performed.

The control characteristics of the FESS with controllers designed by two performance indexes were compared with that of the conventional controller. The simulation results showed that the FESS controller provided better dynamic responses in comparison with the conventional controller. 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

* Dept. of New & Renewable Electric Energy, Kyungnam College of Information & Technology, Korea. (jeong-pil@eagle.kit.ac.kr)

** Dept. of New & Renewable Electric Energy, Kyungnam College of Information & Technology, Korea. (khang@kit.ac.kr)

Received 10 August 2014 ; Accepted

the irregular output of the wind power.

2. Wind Diesel Hybrid Power System Model

Fig. 1 shows the system configuration for the wind diesel hybrid power generation system. Fig. 2 shows the block diagram for the wind diesel power generation system [1~6] 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.

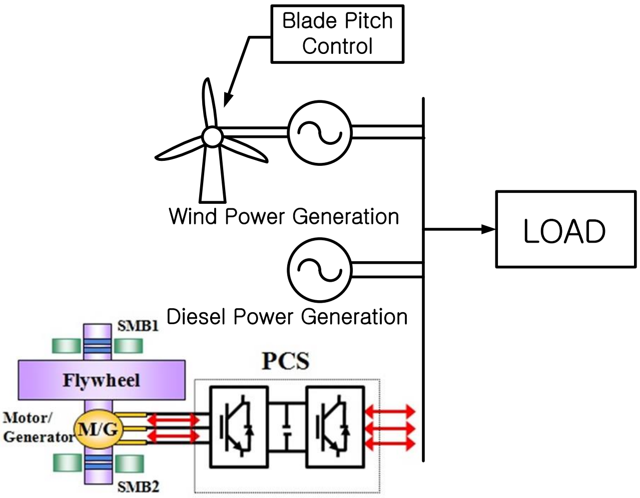


Fig. 1. A wind diesel hybrid power generation system with FESS

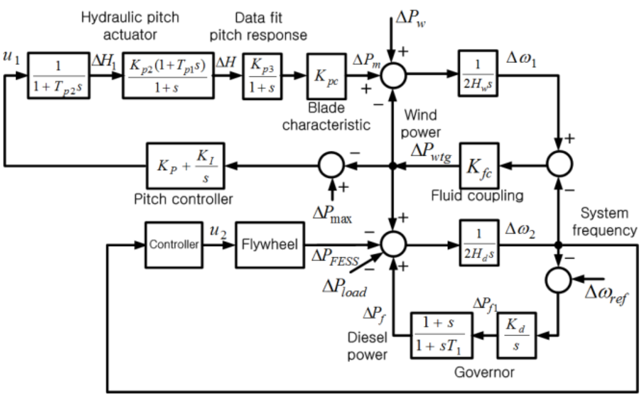


Fig. 2. A Block diagram for wind diesel power generation system with pitch controller and flywheel

2.1 Wind Diesel Hybrid System Model

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[2][5].

$$\Delta\dot{x} = A\Delta x + B\Delta u + \Gamma\Delta p \quad (1)$$

where, Δx, Δu and Δp are the state, control and disturbance vector respectively. A, B and Γ are constant matrices which depend on system parameters and the operating point.

The state, control and disturbance variables without controller are as following,

$$\Delta x = [\Delta H_1, \Delta H, \Delta P_m, \Delta w_1, \Delta w_2, \Delta P_{f1}, \Delta P_f]$$

$$\Delta u = [u_1], \quad \Delta p = [\Delta P_w, \Delta P_{Load}]$$

where,

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

$$B = \begin{bmatrix} \frac{1}{T_{p2}} \\ \frac{K_{p2}T_{p1}}{T_{p2}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \qquad \Gamma = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{1}{2H_w} & 0 \\ 0 & \frac{-1}{2H_w} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

The transfer function of the hydraulic pitch actuator is split into two blocks. ΔH is the hydraulic pitch actuator variable and ΔH_1 is dummy variable. ΔP_m is the wind power deviation. ΔP_w is change in the wind power input. Δw_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.

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.

2.2 Flywheel System model

The FESS can handle high power level and charge/discharge speed of the FESS is very fast. The FESS can be modeled by the first order transfer function. Therefore the output power of the FESS can be written as following equation.

$$\frac{d}{dt}\Delta P_{FESS} = -\frac{1}{T_{FESS}}\Delta P_{FESS} + \frac{1}{T_{FESS}}u_2 \qquad (2)$$

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

3. Design of FESS controller using GA

Fig.3 shows the block diagram for selecting parameters for the FESS controller using GA.

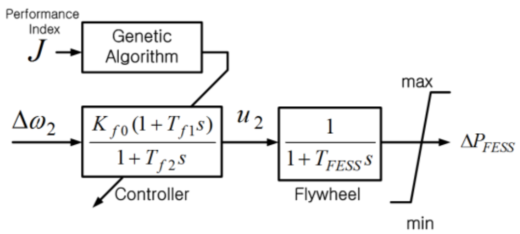


Fig. 3. A Block diagram for selecting controller parameters of the flywheel

The input of the FESS controller is a system frequency $\Delta\omega_2$ as Fig. 3. The two performance indexes J_1 and J_2 used to select parameters of the FESS controller using the GA is as follows

$$J_1 = \int_{t=0}^{t=te} t\cdot|\Delta\omega|_1 + t\cdot|\Delta\omega_2|dt \qquad (3)$$

$$J_2 = \int_{t=0}^{t=te} t\cdot|\Delta\omega|_1 + t\cdot|\Delta\omega_2| + \alpha\cdot\max(|\Delta\omega_1|) + \beta\cdot\max(|\Delta\omega_2|)dt \qquad (4)$$

where, t is time, te is simulation time, α and β are weighted values. The FESS output power limit of -0.01 $\leq$ $\Delta P_{FESS} \leq$ 0.01 (pukW) is considered.

4. Simulation Results

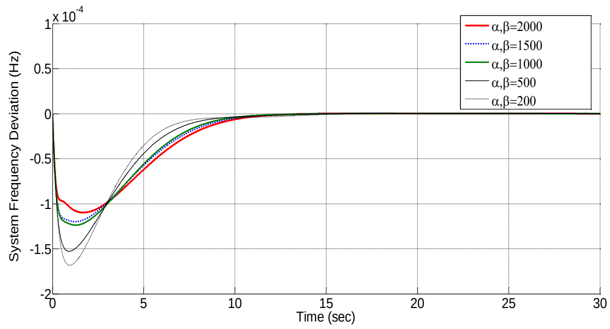
The system parameters for the computer simulation are shown in Table. 1 [2][3][5].

Fig. 4 shows the simulation results for the frequency deviation of the diesel and wind system with the FESS controller using J_2 according to weighted value α,β change for a step load change of 0.01 (p.u.kW). The larger weighted value, undershoot become smaller and settling time become longer. The integral square error (ISE) for each weighted values are 6.78e-6, 6.28e-6, 5.543e-6, 5.23e-6, and 4.95e-6. The weighted value of 2,000 has the smallest ISE value.

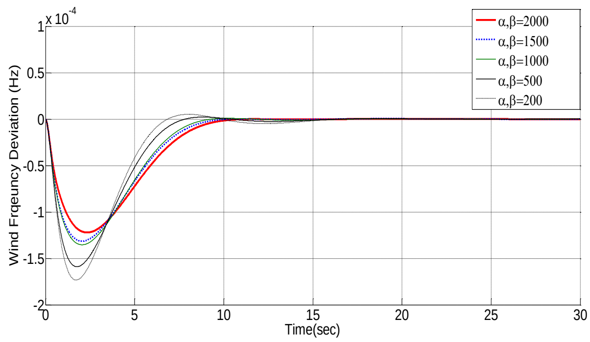
Table 1. System Parameters

$H_w = 3.5s$, $H_d = 8.5s$, $K_{fc} = 16.2Hz/pukW$
$K_{p1} = 4.0$, $K_{p2} = 1.25$, $T_{p1} = 0.60s$, $T_{p2} = 0.041s$
$K_{p3} = 1.4$, $K_{p1} = 0.08 pukW/deg.$, $K_{FESS} = 0.1$

Fig. 5 shows the singular value bode plot of closed loop with the FESS controller using J_2 according to weighted value α,β change.



(a) Diesel system frequency deviation



(b) Wind system frequency deviation

Fig. 4. Frequency responses for 0.01 p.u. step load variation according to weighted value α,β change

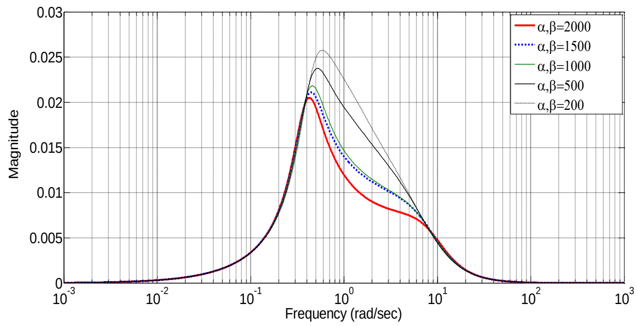


Fig. 5. Singular value bode plot of $G(s)/(1+K(s)G(s))$ according to weighted value α, β change

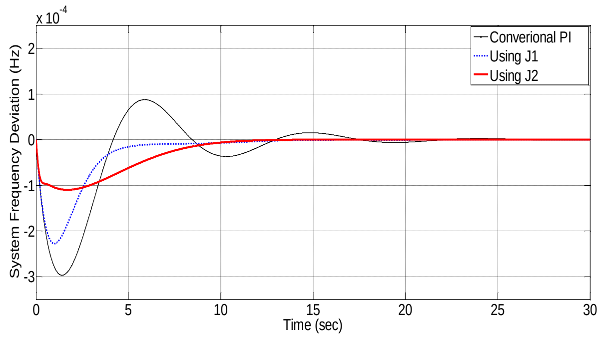
Table 1. Eigenvalues and damping ratio

	Eigenvalues	Damping ratio
Conventional PI[3]	-39.0, -24.4, -34.8 -0.197±j0.688 -0.574±j0.511 -1.23, -10.0	1 0.276 0.747 1
Using J_1	-0.278±j0.413 -0.974±j0.0686 -0.844±j1.08 -3.24, -9.92, -24.4, -39.0	0.559 0.998 0.615 1
Using J_2	-0.159±j0.363 -0.665±j0.313 -6.30±j6.36 -1.05, -2.04, -24.4, -39.1	0.401 0.905 0.703 1

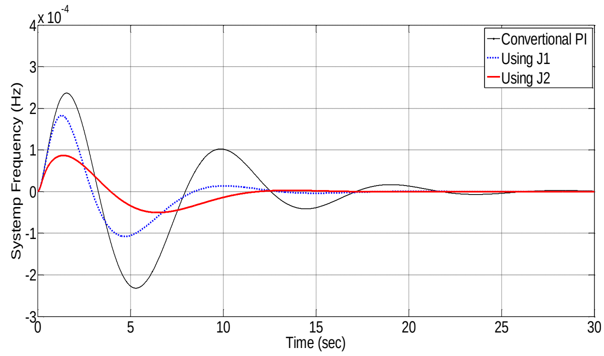
Table 2 shows the eigenvalues and damping ratio for the conventional PI controller and the FESS controllers using J_1 and J_2. The damping ratio for the FESS controller using J_2 is improved in comparison with the conventional controller and the FESS controller using J_1.

Fig. 6 shows the simulation results for the frequency deviation of the diesel and wind system with the conventional PI pitch control[3], the FESS controller using J_1 and J_2 respectively for a step load change of 0.01 (p.u.kW). The frequency oscillations with the FESS controller using J_1 and J_2 in Fig. 4(a), (b) are significantly suppressed and settling time of the frequency response is very fast. The settling time for FESS controller using performance index J_1 is faster than that for FESS controller using performance index J_2. On the other hand, maximum deviation of frequency using the FESS controller using J_1 is smaller than that using the FESS controller using J_2.

Fig. 7 shows random load changes. Fig. 8 shows a comparison of the dynamic simulation results for frequency variation when a random load changes like Fig. 7 are applied. The frequency oscillations with the FESS controller using J_1 and J_2 in Fig. 8 are significantly suppressed and settling time of the frequency response is very fast. The results showed that the FESS controller using J_2 was more robust than that using the conventional and the FESS using J_1.



(a) Diesel system frequency deviation



(b) Wind system frequency deviation

Fig. 6. Frequency responses for 0.01 p.u. step load variation

Fig. 9 shows random wind power input changes. Fig. 10 shows a comparison of the dynamic simulation results for frequency variation when a random wind power changes like Fig. 9 are applied.

The frequency oscillations with the FESS using J_1 and J_2 in Fig. 10 are significantly suppressed and settling time of the frequency response is very fast. The results showed that the FESS using J_2 was more robust than that using the conventional and FESS controller using J_1.

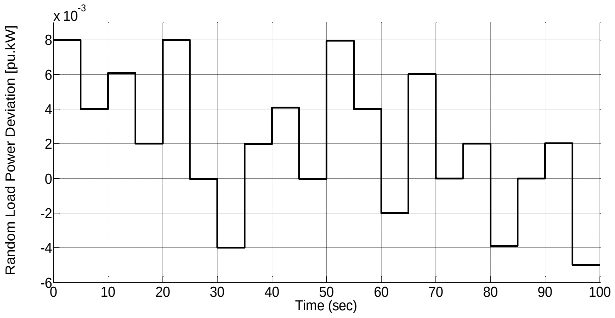
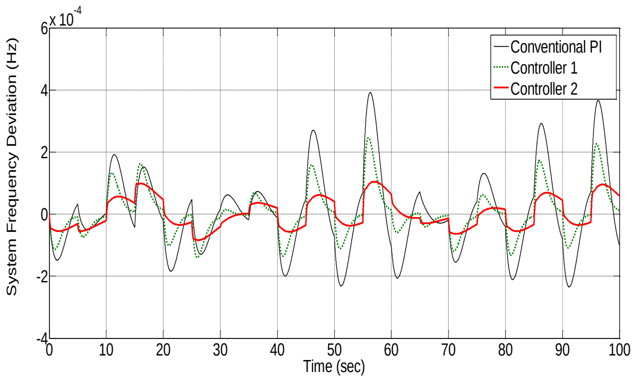
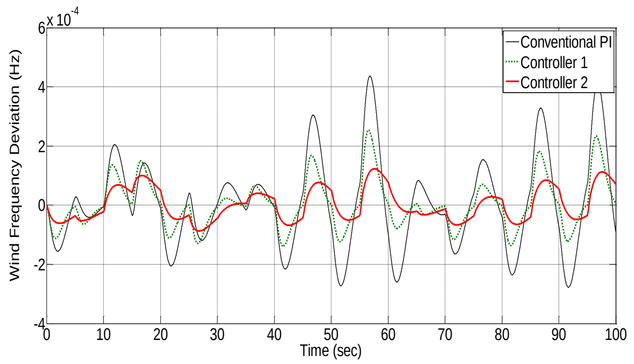


Fig. 7. Random load variation



(a) Diesel system frequency deviation



(b) Wind system frequency deviation

Fig. 8. Frequency responses for random load variation

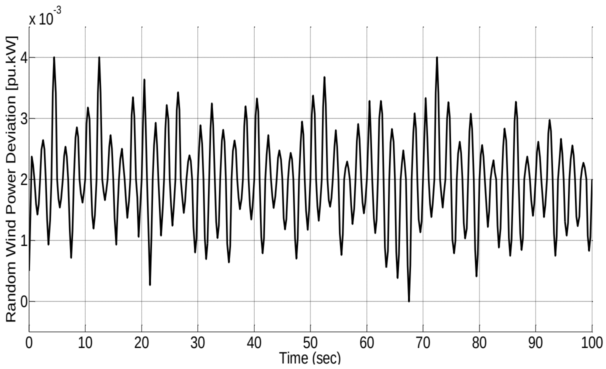
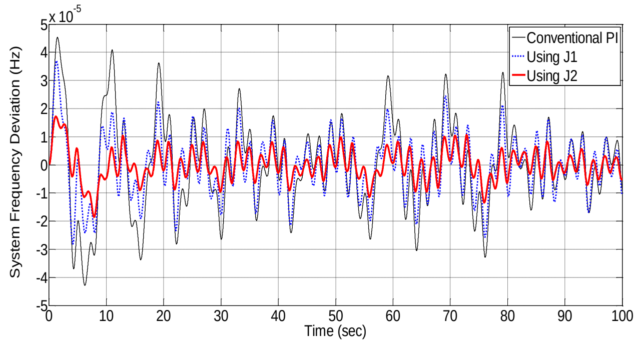
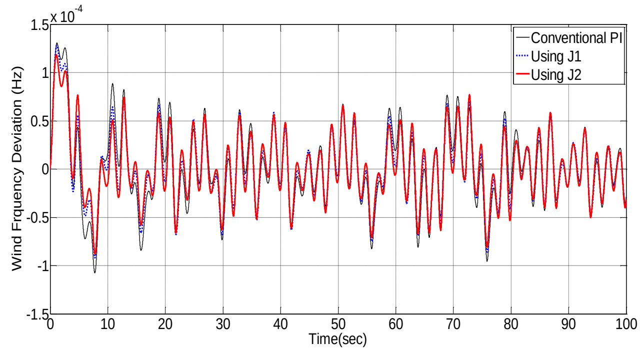


Fig. 9. Random wind power input change



(a) Diesel system frequency deviation



(b) Wind system frequency deviation

Fig. 10. Frequency responses for random wind power input change

5. Conclusion

In this paper, a frequency control effect of FESS controller in the wind diesel hybrid power system according to change of the weighted values of performance index was assessed.

The controller performance according to the weighted value change of the performance index was very different. We could adjust the magnitude of maximum frequency deviation and the magnitude of settling time by means of the weighted values change.

The simulation results showed that the FESS controller provided better dynamic responses in comparison with the conventional pitch controller. Because the active power output of the 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.

Acknowledgements

This work was supported by the Human Resources Development of the Korea Insitute of Energy Technology Evaluation and Planning(KETEP) grant funded by Ministry of Trade, Industry and Energy (No.20124010100020).

References

[1] S. C. Tripathy, M. Kalantar, and R. Balasubramanian, "Dynamics and stability of wind and diesel turbine generators with superconducting magnetic energy storage unit on an isolated power system," *IEEE Trans. On Energy Conversion*, vol. 6, no. 4, pp. 579-585, Dec., 1991

[2] S. C. Tripathy and I. P. Mishra, "Dynamic performance of wind-diesel power system with capacitiver energy storage," *Energy Convers. Mgmt*, vol. 37, no. 12, pp. 1787-1798l, 1996

[3] S. C. Tripathy, "Dynamic simulation of hybrid wind-diesel power generation system with superconductor magnetic energy storage," Energy Convers. Mgmt, vol. 38, no. 9, pp. 919-930, 1997

[4] T. S. Bhatti, A. A. AL-Ademi and N. K. Bansal, "Load frequency control of isolated wind diesel hybrid power system," Energy convers. Mgmt, vol. 38, no. 9, pp. 829-837, 1997

[5] D. Das, S. K. Aditya, and D. P. Kothari, "Dynamics of diesel and wind turbine generator on an isolated power system," Electrical power and energy system, 21, pp. 193-189, 1999

[6] V. P. Singh, S. R. Mohanty, N. Kishor, and P. K. Ray, "Robust H-infinity load frequency control in hybrid distributed generation system," Electrical power and energy systems, 46, pp. 294,305, 2013

Jeong-Phil Lee received M.S and Ph. D. degree in electrical engineering from Dong-A University. He has experience for flywheel energy storage system in Korea Electric Power Research Institute(KEPRI). He is presently a professor of department of new and renewable electric energy at the Kyungnam College of Information & Technology. His research interests are power system, energy storage system and robust control.

Han-Guen Kim received Ph. D. degree in electrical engineering from Dong-A University. He is presently a professor of department of new and renewable electric energy at the Kyungnam College of Information & Technology. His research interests are sensor and measurement control.