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PSO based Robust Frequency Control of Wind-Diesel Power Plant using BES

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Abstract

This paper presents a suitable mathematical model of Wind-Diesel hybrid power system is developed to study its response following a frequency disturbance on an island electric system. A robust controller is designed for the governor wind-diesel system to improve the system dynamic performance. Further to reduce system oscillations, a BES which will supply and absorb active power quickly. In addition, variation of system parameters, unpredictable power demand causes various uncertainties in the system. This paper focuses on a new robust controller design of BES for frequency control in a hybrid system. The co-prime factorization method is used to represent the unstructured uncertainties in the system modeling. The structure of BES controller is a first order lead lag compensator. To tune the controller parameters, the optimization problem is formulated based on PSO based H_∞ loop shaping control is used for designing a robust controller.

Index Terms: Battery energy storage, frequency controller, H_∞ loop shaping, particle swarm optimization, robust control, system uncertainties.

Introduction

A lot of work reported in the literatures to improve the performance of LFC. Fosa and

Elgerd, 1970 [1],[2].Chan and Hsu, 1981, Das et al., 1991[3], [4]. One alternative to improve the performance of LFC is the introduction of storage facilities during peak load period and specially BES facility. BES also improves the reliability of supply during peak load periods. Storage facilities possess additional dynamic benefits such as load leveling, spinning reserve, area regulation, long line stabilization, power factor correction and black start capability. Some of these applications have been successfully demonstrated at a 17MW BES facility in Berlin [5], (Kunish et al., 1986). Recently effect of BES system on LFC is also reported in [6] Kottick et al. (1993) and Chun-Feng Lu et al [7]. (1995).

Load perturbations in completely isolated power systems have a considerable effect on the network's frequency. This is due to the fact that the kinetic energy stored in the rotating machines is usually the main source of immediate reserve available in the power system. Furthermore, the rapid output power variations required from thermal units result in cyclic fluctuations in steam pressure and temperature. Such fluctuations may adversely affect heat resisting alloy of super heaters thus shortening their life time. To overcome such problems, it may be necessary to reduce both the frequency fluctuations and the response required of the generating units. This may be achieved by means of BES facilities which would regulate the generating units response caused by load disturbances. This regulation is accomplished by discharging the energy stored in the batteries into the power network whenever there is a sudden frequency drop and charging them when the frequency increases sharply. Battery facilities are well suited for this task because it can provide fast active power compensation.

Wind power systems are considered economically for supply of electrical energy to remote and isolated areas where utility lines are uneconomical to install due to high costs, right of way difficulties or environmental impacts [8],[9]. Since wind power sources are naturally fluctuating or intermittent, they are generally integrated with the diesel generation [10], [11]. The hybrid wind-diesel power generation provides high reliability of the system to supply power to the isolated load. Different technologies such as flywheel [12], battery energy storage [13], superconducting Magnetic Energy Storage (SMES), etc., can be adopted to alleviate system frequency fluctuation in isolated systems [14],[15] and a grid connected systems [16],[17]. Among of them, a BES unit which is able to supply and absorb active power rapidly, has been highly expected as one of the most effective controller of system frequency [14],[15]. Especially, the application of BES to control frequency in a hybrid wind-diesel power system due to load changes has been presented in [5]-[7]. Even the BES shows satisfactorily frequency control effect, it may not be able to tolerate system uncertainties such as variation of system parameters, random load changes, fluctuating wind power input etc. As a result, the BES may lose control effect and fail to reduce frequency fluctuation. To enhance the robustness of the BES controller against system uncertainties, a robust frequency controller of BES is highly expected.

This paper proposes a new robust frequency controller of BES in a hybrid wind-diesel power system. To take system uncertainties mentioned above into account in the control design, the normalized co prime factorization [18], [19] is applied to represent all unstructured uncertainties in the system modeling. In this study, the configuration of the frequency controller of BES is the first-order lead/lag compensator. The performance and stability conditions in the H_∞ loop shaping method [18], [19] are applied to formulate the optimization problem. To achieve the controller parameters, the Particle Swarm Optimization (PSO) [20], [21] is used to solve the optimization problem. Simulation studies are carried out to confirm the superior robustness of the proposed BES against system uncertainties.

This paper is organized as follows. Section III describes the frequency control problem in the study system and the mathematical modeling of the study system. Subsequently, Section IV presents the proposed control design. In Section V, simulation studies are shown. Finally, Section VI the conclusion is given.

Problem Formulation

Fig. 1 shows the basic configuration of the hybrid wind-diesel power system which includes a BES unit [17]. In addition to the random wind energy supply, it is assumed that loads with sudden change have been placed in this isolated system. Variation of wind power and load change results in a serious problem of large frequency fluctuation in the system. Such frequency fluctuation severely affects the system stability. Furthermore, the life time of machine apparatuses on the load side is reduced. To tackle this problem, the BES is installed in the system to compensate for power variations and minimize frequency fluctuation.

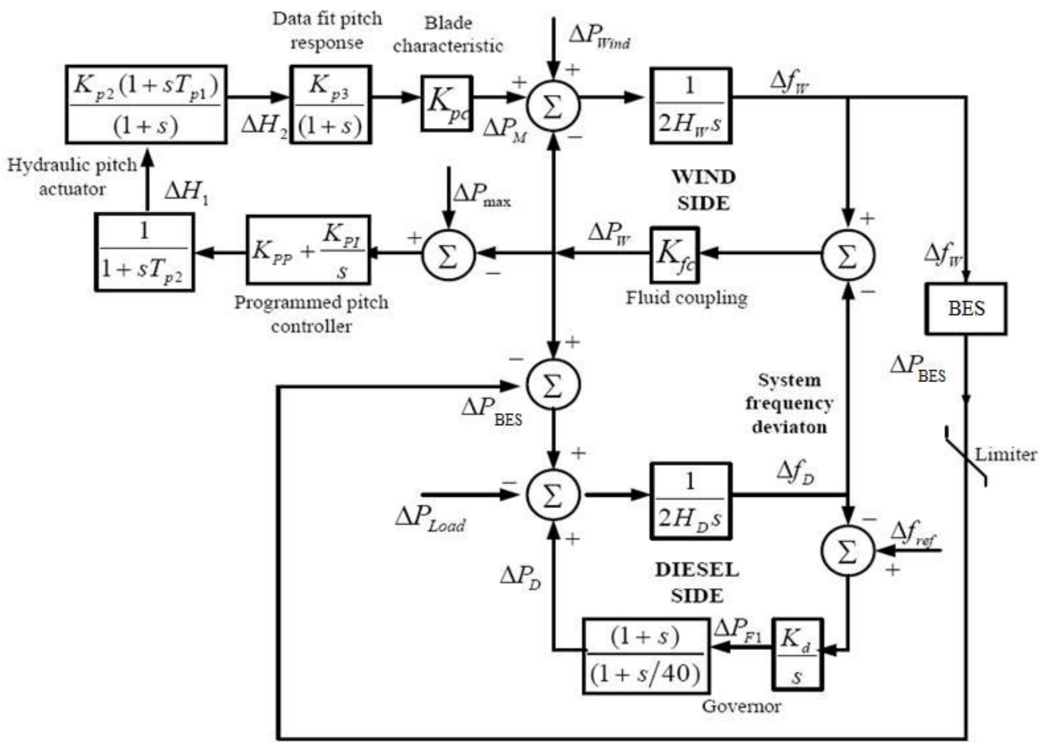

Figure 1: Block Diagram of Wind-Diesel System with BES.

State Equation of Wind-diesel System

$$\Delta f_w = \frac{1}{2H_w}\left[\Delta P_{wind}\right] + \frac{\Delta P_M}{2H_W} - \frac{K_{fc}(\Delta f_D)}{2H_W} \tag{1}$$

$$\Delta f_D = \frac{1}{2H_D}(K_{fc}\Delta f_W - K_{fc}\Delta f_D - \Delta P_{load} + \Delta P_d) \tag{2}$$

$$\Delta P_M = (K_{PC} * K_{P3})\Delta H_2 - \Delta P_M \tag{3}$$

$$\Delta P_{f1} = K_D(\Delta f_{ref} - \Delta f_o) \tag{4}$$

$$\Delta P_D = 40\Delta P_D - 40\Delta P_{D1} + 40\Delta P_{F1} \tag{5}$$

$$\Delta H_1 = \frac{1}{T_{P2}}\Delta x_1 - \frac{1}{T_{P2}}\Delta H_2 \tag{6}$$

$$\Delta H_2 = (K_{P2} - K_{P2}\frac{K_{P2}T_{P1}}{T_{P2}})\Delta H_1 - \Delta H_2 +_{P2}\frac{T_{P1}}{T_{P2}}\Delta x_1 \tag{7}$$

$$\Delta K_c = (-\frac{K_{PP}K_{fc}}{2H_W}\Delta P_{wind} - \frac{K_{PP}K_{fc}}{2H_W}\Delta P_M + \frac{K_{PP}K_{fc}}{2H_W}\Delta P_W + \frac{K_{PP}K_{fc}}{2H_D}\Delta P_W - \frac{K_{PP}K_{fc}}{2H_D}\Delta P_{LOAD} + \frac{K_{PP}K_{fc}}{2H_D}\Delta P_D - K_{PI}\Delta P_W \tag{8}$$

The state equation of the system can be represented by

$$\dot{\Delta \mathrm{X}} = A\Delta X + B\Delta P_{BES} \tag{9}$$

As shown in fig. 2, the block diagram of BES [16] consists of two transfer function connected in series, i.e. the BES model and the frequency controller. The BES can be modeled by the first order transfer function with time constants T_{BES} = 0.03sec. For the frequency controller, it is practically represented by a lead lag compensator with first order. In the controller there are three parameters i.e., K_{BES}, TS_{BES1} and TS_{BES2}. the input signal of the controller is only the frequency deviation.

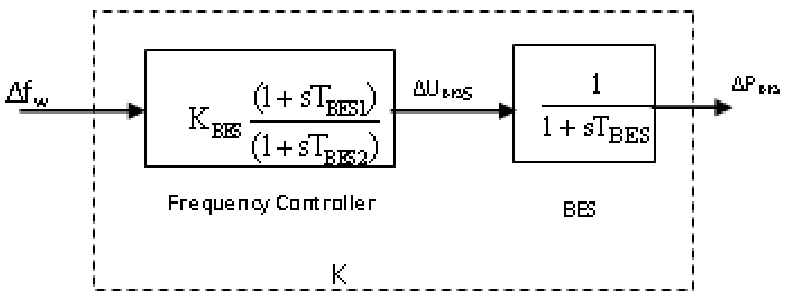

Figure 2: Block diagram of BES with frequency controller.

Proposed Method

The objective of the control design is to optimize three control parameters, so that the resulted controller is robust to system uncertainties. Based on the H_∞ loop shaping control the optimization problem can be formulated a subsequently, the PSO is applied to solve the problem.

i. Selection of the Weighing Functions

Loop shaping weights W_1, W_2 are usually designed in to two stages. In the first stage, the desired loop-shape is determined. This usually involves translating time-response requirement and closed loop performance specification in to the frequency domain. In the second stage, the designer selects loop shaping weights W_1, W_2 so that G_s has desired loop shape. All of these can be fairly time consuming; trial and error can never be guaranteed. But in this [20] paper it is done by a systematic procedure by first designing a lead compensator and then using its loop shaping weight which has given excellent result.

$$W_1 = K_w \frac{S+a}{S+b} \text{ and } W_2 = 1 \tag{10}$$

Where K_w, a and b are positive values. Because, the frequency control problem is in a vicinity of low frequency (< 1Hz), W_1 is set as a high pass filter (a<b).

ii. Formulate the Shaped Plant G_S

In fig. 3 shows pre compensator W_1 and post compensator W_2 are employed to form the shaped plant $G_s = W_2*G*W_1$ is enclosed by the solid line. The proposed robust controller $K=W_1 K_\infty W_2$ is enclosed by the dotted line. K_∞ is the H_∞ controller.

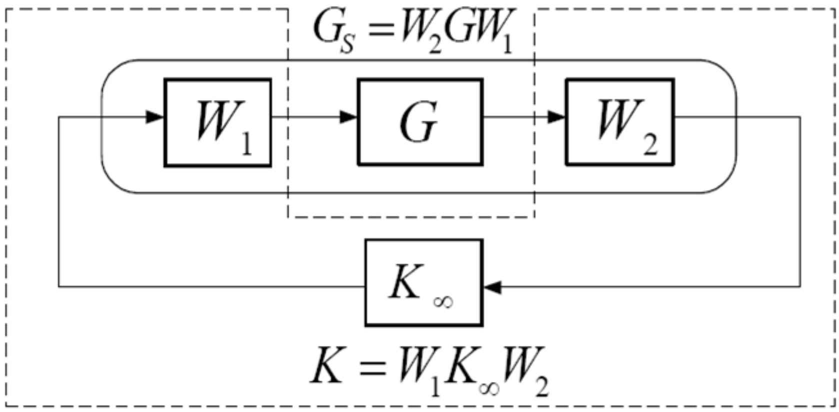

Figure 3: Shaped Plant G_s & Robust Controller K.

iii. Evaluate the Robust Stability Margin of the System

In this work, variation of system parameters, generating and loading conditions Etc., are defined as unstructured system uncertainties. Because these uncertainties cannot be clearly represented by mathematic equations, co-prime factorization is utilized to represent these unstructured uncertainties. Shaped plant G_s is expressed in form of normalized left co-prime factor $G_s = M_s^{-1} * N_s$, when the perturbated plant G_Δ is determined as follows:

$$G_\Delta=(M_S+\Delta M_S)^{-1}(N_S+\Delta N_S):\|\Delta N_S \Delta M_S\|\leq 1/\gamma \quad (11)$$

Where ΔM_s and ΔN_s are stable unknown transfer functions which represent unstructured uncertainties in the nominal plant model G. Based on this definition, the robust control problem can be established by G_Δ and K as depicted in figure 3. The objective of robust control design is to stabilize not only the nominal plant G but also the family of perturbed plant G_Δ. In (11), $1/\gamma$ is defined as the robust stability margin. The maximum stability margin in the face of system uncertainties is given by the lowest achievable value of γ, i.e.γ_{min}. Hence, min γ implies the largest size of system uncertainties that can exist without destabilizing the closed-loop system in fig. 3. The value of γ_{min} can be easily calculated from.

$$\gamma_{min}=(1+\lambda_{max}(XZ))^{1/2} \quad (12)$$

Where $\lambda_{max}(XZ)$ denotes the maximum eigen value of XZ. For minimal state space realization *(A, B,C, D)* of G_s, the values of X and Z are unique positive solutions to the generalized control algebraic Riccatti equation

$$(A-BS^{-1}D^TC)^TX+X\,(A-BS^{-1}D^TC)-XBS^{-1}B^TX+C^TR^{-1}C=0 \quad (13)$$

and the generalized filtering algebraic Riccati equation:

$$(A-BS^{-1}D^TC)Z+Z\,(A-BS^{-1}D^TC)^T-ZC^TR^{-1}CZ+BS^{-1}B^T=0 \quad (14)$$

Where $R = I + DD^T$ and $S = I + D^TD$. Note that no iteration on γ is needed to solve for γ_{min}. To ensure the robust stability of the nominal plant, the weighting function is selected so that $\gamma_{min} \leq 4$.if γ_{min} is not satisfied then go to step 1 and adjusts the weighting functions.

iv. Formulate the objective function for PSO optimization

From the figure K can be defined as

$$K_\infty=W_1^{-1}*K(s)*W_2 \quad (15)$$

W_2=1, the necessary and sufficient condition of the robust controller K(s). In this part, the performance and robust stability conditions in H_∞ loop shaping design approach are adopted to design a robust frequency controller K for SMES. The frequency controller is represented by

$$K=K_{BES}\left(\frac{1+ST_{BES1}}{1+ST_{BES2}}\right) \quad (16)$$

The control parameters K_{BES}, T_{BES1} and T_{BES2} are optimized by PSO. The objective function is derived based on the following concept. As shown in figure 3, the designed controller *K* is to be represented as

$$K=W_1K_\infty W_2 \tag{17}$$

$$K_\infty W_2=W_1^{-1}K \tag{18}$$

Selecting W_2=1 yields

$$K_\infty=W_1^{-1}K \tag{19}$$

The necessary and sufficient condition of the designed robust controller k is

$$\left\| \begin{bmatrix} \mathrm{I} \\ K_\infty \end{bmatrix} \left(I-G_sK_\infty\right)^{-1}\begin{bmatrix} I & G_s \end{bmatrix} \right\|_\infty \le \gamma \tag{20}$$

Substituting (19) in to (20) yields

$$\left\| \begin{bmatrix} \mathrm{I} \\ W_1^{-1}K \end{bmatrix} \left(I-G_sW_1^{-1}K_\infty\right)^{-1}\begin{bmatrix} I & G_s \end{bmatrix} \right\|_\infty \le \gamma \tag{21}$$

$K_{BES,min}<K_{BES}< K_{BES,max}$

$T_{BES1,min}<T_{BES1}<T_{BES1,max}$

$T_{BES2,min}<T_{sBES2}<T_{BES2,max}$

Where K_{BES} Gain of BES, T_{BES1},T_{BES2} time constant of BES.The control parameters K_{BES}, T_{BES1}, T_{BES2} are optimised by PSO.Equation (21) implies that if the ∞-norm of transfer function matrix in the left side is lower than γ, the robust controller *K* can be obtained. As a result, the ∞-norm of the left side term in (21) can be used to formulate the optimization problem as

$$Min \left\| \begin{bmatrix} \mathrm{I} \\ W_1^{-1}K \end{bmatrix} \left(I-G_sW_1^{-1}K_\infty\right)^{-1}\begin{bmatrix} I & G_s \end{bmatrix} \right\|_\infty \le \gamma \tag{22}$$

Subject to

$\le K_{BES} \le 50.0$,

$0.001 \le T_{BES1} \le 1.0$,

$0.001 \le T_{BES2} \le 1.0$,

This optimization problem is solved by PSO algorithm [20].

v. PSO Algorithm

The PSO algorithm [20], [21], Specify the parameters of PSO. Initialize a population of the particles with random position and velocity.

vi. Evaluate the objective function in (22) for each particle

vii. Compare the fitness value of each particle with it's the best position for each particle (Pbest). The best fitness value among all the pbest is the best position of all particles in the group (gbest).

viii. Update the velocity V_i and position of particle x_i by

$$V_{i+1}= w*v_i+c_1*rand_1*(pbest-x_i)+ c_2*rand_2*(pbest-x_i)$$

$$X_{i+1}=x_i+v_{i+1}$$

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} iter$$

Where c_1 and c_2 are the cognitive and social acceleration factors, respectively. rand1 and rand2 are the random numbers of range 0 to 1 respectively. W is the inertia weight factor. W_{min} and w_{max} are the minimum and maximum of inertia weight factors, respectively. Iter and iter max are the iteration count and maximum iteration, respectively.

ix. When the maximum number of iteration is arrived, stop the process. Otherwise go to process (vi)

Simulation Results

Step 1: Selection of weighting functions. The linearized wind-diesel model is used in this simulation studies. System parameters are given in appendix. Here the designed results of the robust frequency controller of BES based on the proposed are explained as follows as given in equation (10). The shaped plant Gs is established by weighting functions W_1 and W_2.the weighting functions are chosen as

$$W_2=1,\ K_w=658,\ a = 100,\ b= 447$$

Where K_w, a and b are positive values. Because, the frequency control problem is in a vicinity of low frequency (<1 Hz), W_1 is set as a high-pass filter (a<b).

Step 2: Formulate the shaped plant G_s as shown in the fig. 3, a pre-compensator W_1 and a post-compensator W_2 are employed to form the shaped plant $G_s=W_2GW_1$, which is enclosed by a solid line.

Step 3: Evaluate the robust stability margin of the system note that no iteration on γ is needed to solve for γ_{min}. To ensure the robust stability of the nominal plant, the weighting function is selected so that $\gamma_{min} \leq 4$. If γ_{min} is not satisfied, then go to step 1 process and adjust the weighting functions. From the program: Gain margin = 1.31 (for system without BES) Gain margin = 1.424 (for system with BES)

Step4: Formulate the objective function for PSO optimization

Minimize

$$\left\| \begin{bmatrix} I \\ W_1^{-1}K \end{bmatrix} \left(I - G_s W_1^{-1} K_\infty\right)^{-1} [I \quad G_s] \right\|_\infty \le \gamma$$

Subject to

$$1.0 \le K_{BES} \le 50.0,\ 0.001 \le T_{BES1} \le 1.0,\ 0.001 \le T_{BES2} \le 1.0$$

Step5: Initialize the search parameters for PSO. Define PSO parameters such as population Size = 100, Maximum Generation = 100, C_1=2, C_2=2, W_{min}=0.4 and W_{max}=0.9.

Step6: Randomly generate the initial solution. Set the first generation, Gen=1

Step7: Evaluate the objective function of each individual population.

Step8: Select the best individual in the current generation. Check the maximum generation. If the current generation is the maximum generation, then stop. If the current generation is less than the maximum generation then go to step 9.

Step9: Update the velocity factor.

Step10: When the maximum number of iterations is reached stop the process. Otherwise go to step number 6.

The optimization is performed and the variables are obtained through Particle Swarm technique. The results obtained are given as K_{BES} = 49.8, T_{BES1} = 0.9547, T_{BES2} = 0.5680.The controller obtained is given by the following expression:

$$K = 49.8\left(\frac{1+S\ (0.9547)}{1+S\ (0.5680)}\right)$$

Case 1: First, 0.01 pu kW step increase in the wind-diesel power input is applied to the system at t = 0.0 s figure 6 shows the frequency deviation of the wind-diesel side which represents the system frequency deviation without, with and proposed BES frequency controller, the system without BES controller frequency highly oscillates and the peak frequency deviation is very large. The frequency oscillation takes about 42 seconds to reach zero. This indicates that the frequency controller in the governor side control loop in the wind-diesel side is not able to work well. On the other hand, the peak frequency deviation is reduced significantly and returns to zero within shorter period in case of BES and the proposed BES. Similarly second, a 0.02 pu KW step increase in the wind-disel power input is applied to the system at t=0.0 s. Fig. 7

shows the frequency deviation of the wind-diesel side which represents the system frequency deviation without, with and proposed BES frequency controller, the system without BES controller frequency highly oscillates and the peak frequency deviation is very large. The frequency oscillation takes about 50 seconds to reach zero. From this study, reveals that the proposed BES controllers are quite robust and the optimum BES gain once set for nominal condition need not be changed for +25% variations in system operating load condition from their nominal values.

Case 2: The power output deviations of both BESs are shown in fig. 8. The peak power output of the proposed BES is lower than that of the conventional BES. Next, a 0.01 pu kW step increase in the load power is applied to the system at $t = 0.0$ s. From the result the proposed BES are able to damp the power deviations quickly in comparison to without BES case.

Case 3: Random load change, the random load change as shown in fig. 9 is applied to the system. Fig. 10 depicts the system frequency deviation under normal system parameters. Clearly, the control effect of the proposed BES is better than that of the conventional BES. The values of IAE of system frequency deviation under the variation of K_{fc} from-30 % to +30 % of the normal values are shown in fig. 10. As K_{fc} decreases, the values of IAE in case of BES become larger. On the other hand, the values of IAE in case of the proposed BES are lower and rarely change. The proposed BES is more robust than the BES [15] against the variation of system parameters under this random load change.

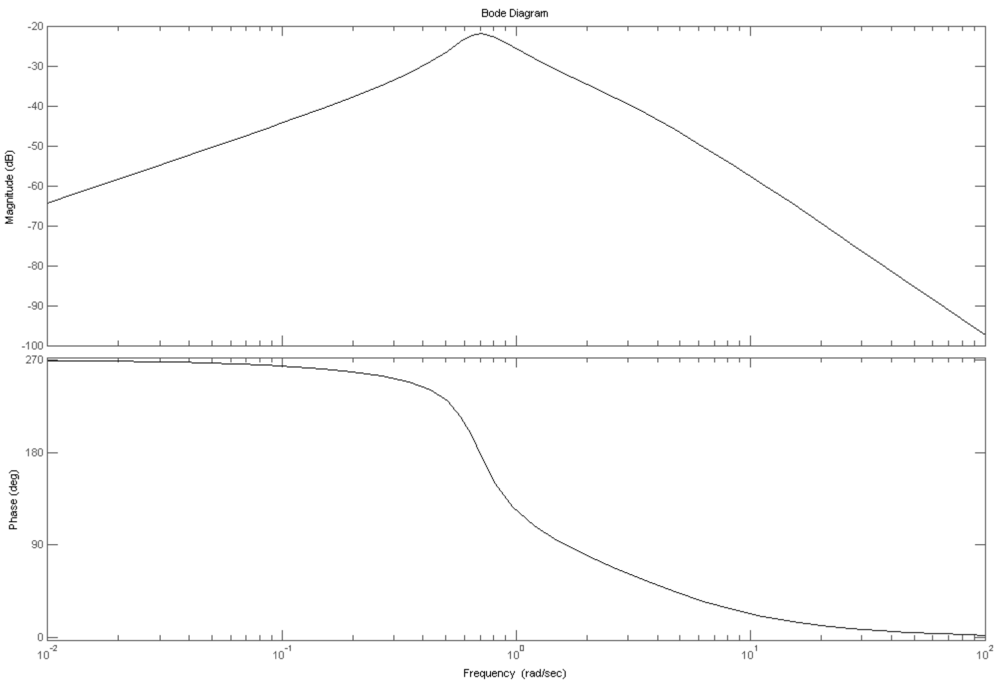

Figure 4: BODE Plot for System without BES.

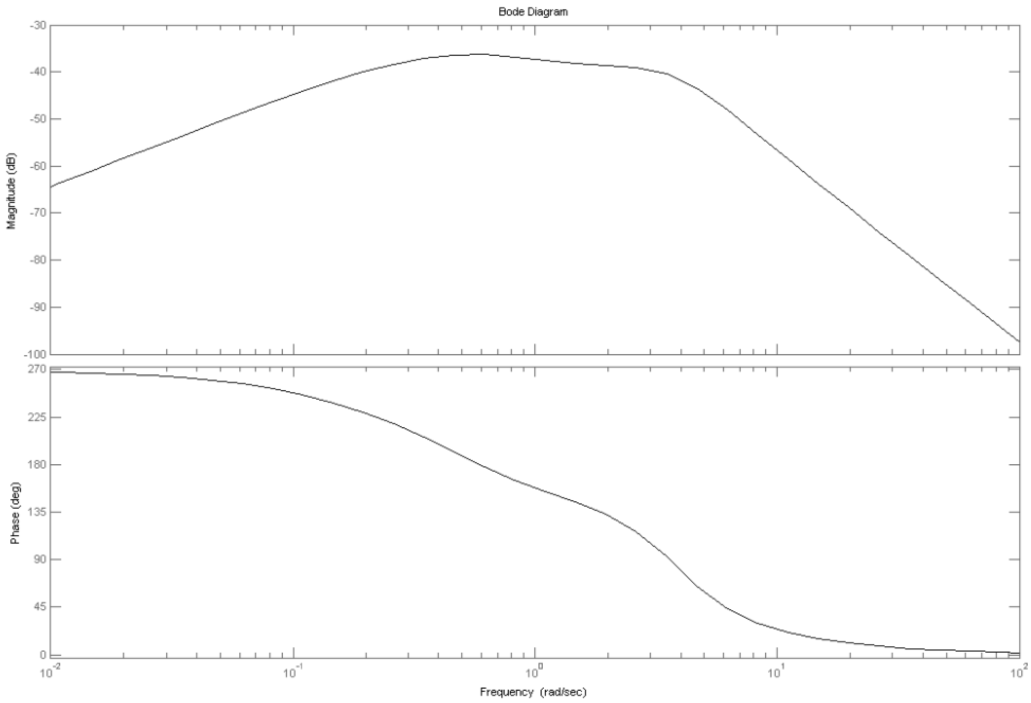

Figure 5: BODE Plot for system with BES.

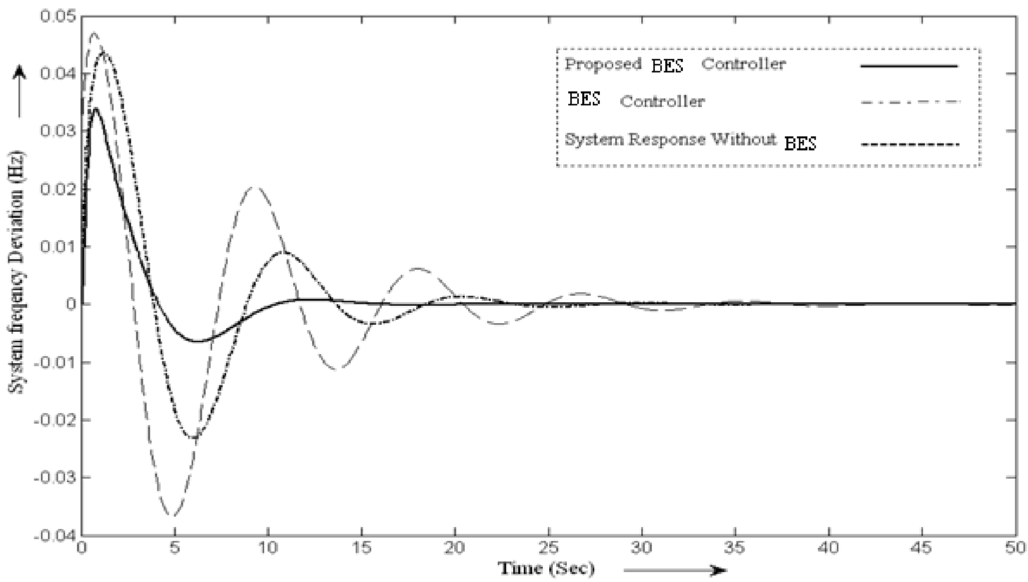

Figure 6: System Frequency Deviation against a 10% Load.

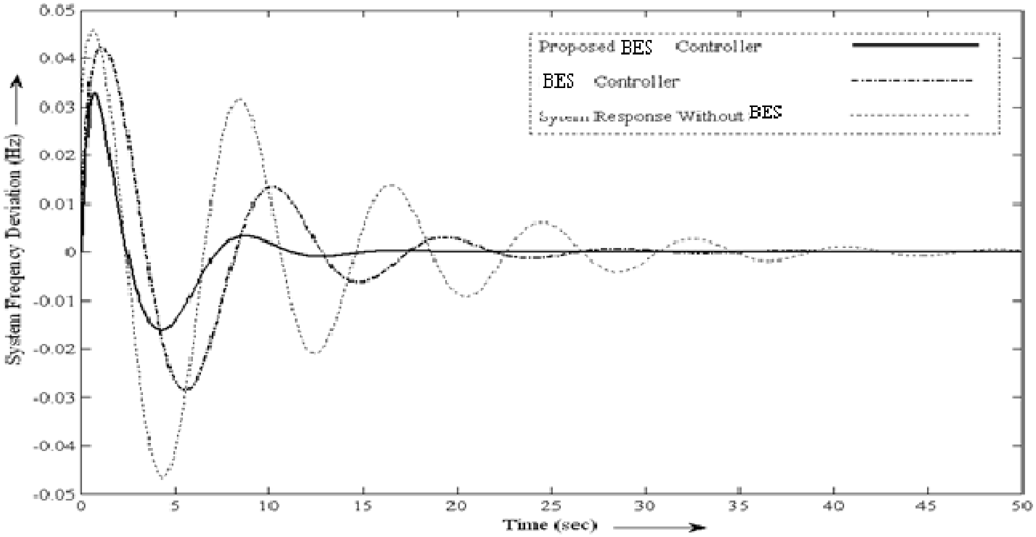

Figure 7: System Frequency Deviation against a 20% Load.

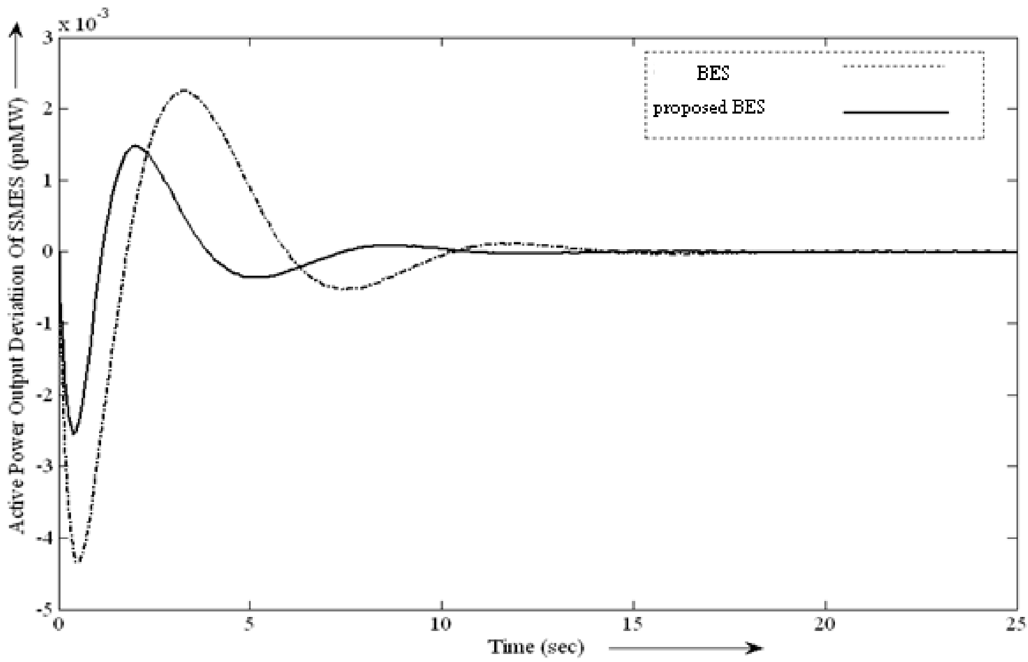

Figure 8: Power Output Deviation of BES against a Step Load.

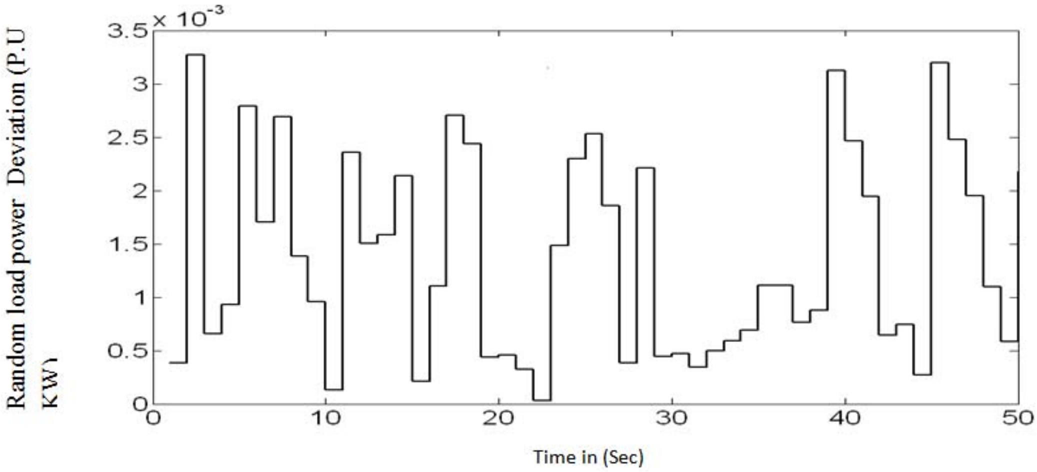

Figure 9: Random Load Change for Wind-Diesel System.

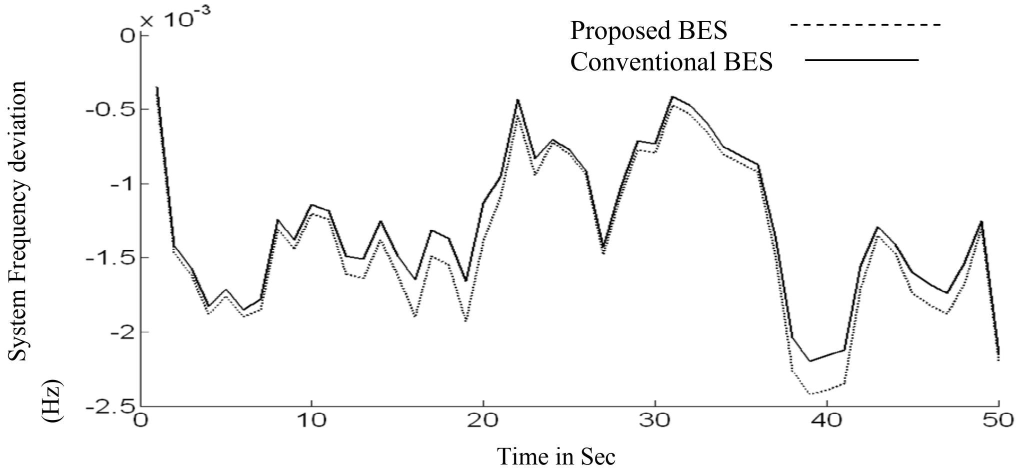

Fig 10 System frequency deviation under normal system Parameters

Figure 10: System frequency deviation under normal system Parameters.

Conclusion

The robust controller of BES for frequency control in the wind-diesel turbine has been presented. In the proposed controller design, unstructured uncertainties in the system such as variation of the system parameters, power variations due to load changes and power etc., are modeled by co-prime factorization. The structure of frequency controller is practically based on the first order lead lag compensator with a single input signal. Consequently, it is easy to implement in practical systems. To obtain the controller parameters, the optimization problem based on H_∞ loop shaping technique can be automatically solved by PSO. A simulation result clearly confirms that the proposed robust BES controller is much superior to the BES in [15] in terms of the robustness against uncertainties, random load change. Besides, the small power capacity of BES is required for robust frequency control.

Appendix

P_R = 350 KW, H_W = 3.5 s, H_D=8.5 s, K_{fc} = 16.2 Hz/puKW, K_D = 16.5 Hz/pu KW, K_{P2} = 1.25, K_{P3} = 1.4, T_{P1} = 0.6 s, T_{P2} = 0.041 s, K_{PC} = 0.08, K_{PI} = 4.0, K_{PP} = 1.5, K_p=120, T_p=20, K_r=0.5, T_r=10, T_g=0.08, T_t=0.3, R=2.4, B=0.425,c_{bp}=52497, r_{bp}=10, c_{b1}=1, r_{b1}=0.001, r_{bt}=0.0167, r_{bs}=0.013, X_{co}=0.0274, I_{bes}=4.426, K_{bp}=20, T_{bp}=0.026

Symbols

P_r	area capacity
H_w	inertia constant for wind system
H_d	inertia constant for diesel system
K_{fc}	fluid coupling between wind and diesel system
K_d	governor gain
K_{pi}	integral controller gain of pitch controller
K_{pp}	proportional controller gain of pitch controller
K_{p2}	gain of hydraulic pitch actuator
K_{p3}	gain of data fit pitch response
T_{p1}	time constant of hydraulic pitch actuator
T_{p2}	time constant of hydraulic pitch actuator
K_{pc}	blade characteristic
ΔP_d	power output deviation of diesel side
ΔP	wind change in wind power
ΔP_w	power output deviation of wind side
Δf_w	frequency deviation of wind generation side
Δf_d	frequency deviation of diesel generation side
ΔP_{BES}	power output deviation of BES
ΔX	state vector
ΔU_{BES}	control signal deviation of SMES controller
K_{BES}	gain of frequency controller
T_{BES1}	time constant of frequency controller
T_{BES2}	time constant of frequency controller
E_{b1}	battery over voltage
ΔE_{co}	BES of constant power mode
K_{pb}	Control loop gain
T_{bp}	Measurement time device constant
E_t	Line to neutral r.m.s voltage
E_p	Compensating power deviation
E_{do}	ideal no load maximum d.c. voltage
E_{co}	d.c. voltage without overlap

X_{co}	Commutating reactance converter firing angle
E_{boc}	battery open circuit voltage
E_{b1}	battery overvoltage
r_{b1}	connecting resistance
r_{bs}	internal resistance
I_{BES}	d.c. current flowing into battery
C_{b1}	overvoltage capacitance
r_{bp}	self-discharge resistance
c_{bp}	battery capacitance
PSO	Particle swarm optimization
BES	Battery energy storage
LFC	Load frequency control

References

[1] Elgerd, O. I. (1982). "Electric Energy Systems Theory-An introduction (a book)". McGraw-Hill Publishing Co. Ltd. New York, 2nd edition.

[2] Fosha, C. E. and Elgerd, O. I. (1970). "The megawatt-frequency control problem: a new approach via optimal control theory", IEEE Trans. Power Apparatus. Systems, 89, 563-577.

[3] Chan, W. C. and Hsu Y. Y. (1981)."Automatic generation control of interconnected power systems using variable structure controllers", Proc. IEE. Vol. 128. Pt. C., No. 5. pp. 269-279.

[4] Das, D., Kothari, M. L., Kothari, D. P. and Nanda, J. (1991)."Variable structure control strategy to automatic generation control of an Interconnected reheat thermal system", Proc. IEE, Part-D. Vol. 138, pp 579-585.

[5] Kunisch, H. J., Kramer, K. G. and Dominik, H. (1986). "Battery energy storage, another option for load frequency control and Instantaneous reserve", IEEE Trans. Energy Conversions, 1 (3), pp 41-46.

[6] Kottick, D., Balu, M. and Edelstein, D. (1993). "Battery energy storage for frequency regulation in an island power system", IEEE Trans. Energy Conversion, 8 (3), pp 455-459.

[7] Lu Chun-Feng, Liu Chun-Chang and Wu Chi-Jui (1995). "Effect of battery energy storage system on load frequency control considering governor dead band and generation rate constraint", IEEE Trans. Energy Conversion, 10 (3), pp 555-561.

[8] Ackermann, T., "Wind power in power systems", John Wiley & Sons Ltd, 2005.

[9] Patel,M.R.,Wind and solar power systems, design, analysis and operation,2nd Edition, CRC Press, 2006.

[10] Hunter, R., and Elliot, G., "Wind-diesel systems,guide to technology and its Implementation", Cambridge University Press, 1994.

[11] Lipman, N.H., "Wind-diesel and autonomous energy systems", Elservier Science Publishers Ltd, 1989.

[12] Davies, T.S., Jefferson, C.M., and Mayer, R.M., "Use of flywheel storage for wind-diesel system," Journal of Wind Engineering and Industrial Aerodynamics, vol.27, pp. 157-165, 1988.
[13] Kunisch, H.J., Kramer, K.G., and Demonik, H., "Battery energy storage: another option for load-frequency control and instantaneous reserve," IEEE Transactions on Energy Conversions, vol. 1, no. 3, pp. 41-46, 1986.
[14] Takahashi, R, and Tamura, J., "Frequency stabilization of small power system with wind farm by using flywheel energy storage system," Proc. Of IEEE International Symposium of Diagnostics for Electric Machines, Power electronics and Drives 2007, pp.393-398.
[15] Aditya, S.K., and Das, D., "Application of battery energy storage system to load frequency control of an isolated power system," International Journal of Energy Research, vol. 23, no. 3, pp. 247-258, 1999.
[16] Lazarewicz, M.L., and Rojas, A., "Grid frequency regulation by recycling electrical energy in flywheels," Proc. IEEE Power Engineering Society General Meeting 2004, vol.2, pp. 2038-2042.
[17] Aditya, S. K., and Das, D., "Battery energy storage for load frequency control of an interconnected power system." Electric Power Systems Research,vol. 58, no. 3, pp. 133-213, 2001.
[18] Macfarlane, D.C., and Glover, K., "Robust controller design using normalized coprime factor plant descriptions," Lecture notes in control andinformation sciences, vol. 138, Springer, 1990.
[19] Skogestad,S, and Postlethwaite, Multivariable feedback control: analysisand design". 2nd edition, John Wiely, 2005.
[20] James Kennedy and Russell Eberhart, "Particle Swarm Optimisation",Proc IEEE 1994, pp1942-1948.
[21] James Kennedy and Russell Eberhart,"A new Optimizer Using Particle Swarm Theory", 6th international symposium on micro machine and human science. Proc IEEE, 1995, pp 39-43.

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