Optimal PID Controller Design Using Krill Herd Algorithm for Frequency Stabilizing in an Isolated Wind-Diesel System

H. A. Shayanfar*[1], H. Shayeghi[2], A. Younesi[2]
[1] Center of Excellence for Power System Automation and Operation, Electrical Engineering Department, Iran University of Science & Technology, Tehran, Iran
[2]Electrical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran

Abstract – *The main purpose of this paper is to design an optimal PID controller for frequency stabilization in an isolated wind-diesel power system. Optimal tuning of PID controller, formulated as an optimization problem and solved using Krill Herd (KH) algorithm. In order to prove the performance of proposed method, simulation carried out in four cases, step change in load of diesel side, step change in wind speed, random changing of the diesel side load, and random changing of the wind speed. Also, performance indices like overshoot, undershoot, settling time, ITAE and ISTSE are calculated and compared with Bee Colony (BC) algorithm. Results show that the proposed method is very robust and effective.*

Keywords: Wind-Diesel System, Krill Herd Algorithm, PID Controller

1 Introduction

In the entire world, electricity is one of the most demanding forms of energy in every one's daily life. There are groups of people that do not have access to the grid electricity, they are located in either remote or isolated communities, where grid connectivity is not at all neither economical nor viable. For this group of people, electricity is mainly supplied by small diesel-based power generation that it is very harmful for the environment [1]. Therefore renewable energy sources are used for reduce the dependency of this power generation systems to the fuel and as a result reduce the harmful effect of this systems to the environment. However, renewable energy sources are mostly intermittent, so they can't supply quality power constantly. This problem solved by combining more renewable energy sources together with non-renewable or storage devices [2-5]. The oscillations of wind speed and load demand lead to mismatch between the power generation and load demand resulting in mismatch in system frequency (f) and power (P) from their nominal values.

In the past, many researches have been proposed for controlling the oscillations of the frequency in hybrid power system generations.

*Corresponding Author, H. A. Shayanfar, hashayanfar@yahoo.com

This controllers are include control of pitch in wind side and governor in diesel side.

Many control strategies have been proposed in the literature. In [6-7], optimization of controller parameters proposed. Also, in [8-9] PI controller, in [10-12] variable structure control and in [13-14] energy storage controller have been reported.

The proportional-integral-derivative (PID) controller has its widespread acceptance in the industrial processes due to its simplicity in understanding and its applicability to a large class of process having different dynamics [15]. Thus, in this paper two PID controllers designed simultaneously, one for diesel side and another for pitch control of wind side.

It is shown that the appropriate selection of PID controller parameters results in satisfactory performance during system upsets. Thus, the optimal tuning of a PID gains is required to get the desired level of robust performance. Since optimal setting of PID controller gains is a multimodal optimization problem (i.e., there exists more than one local optimum) and more complex due to nonlinearity, complexity and time-variability of the real world power systems operation. Hence, local optimization techniques, which are well elaborated upon, are not suitable for such a problem. For this reason, a new bio-based swarm intelligence algorithm, called Krill Herd (KH) is proposed for optimal tuning of the PID controller gains to stabilize a synchronous machine connected to an infinite bus in this paper. The KH algorithm is based on the description of the herding of the krill agents in response to specific biological and environmental processes. The objective function of each krill individual is defined as its distances from food and highest density of the agent [16].

In this paper, optimal PID controller design for the frequency oscillation damping of a wind-diesel hybrid system, is formulated as an optimization problem and solved using Krill Herd (KH) algorithm. The results of the proposed method is compared with the Bee Colony (BC) algorithm. Simulation results show that the KH-based PID controller (KH-PID) has better performance in compared with BC-based PID controller (BC-PID) from the perspective of the response to step change in load demand of diesel side, step change in wind speed. Also, two performance indices according to the system defined and with overshoot, undershoot, and settling time calculated for both KH-PID and BC-PID controllers, which proves that the proposed KH-PID controller is very effective and robust compare to BC-PID controller.

2 System Modeling

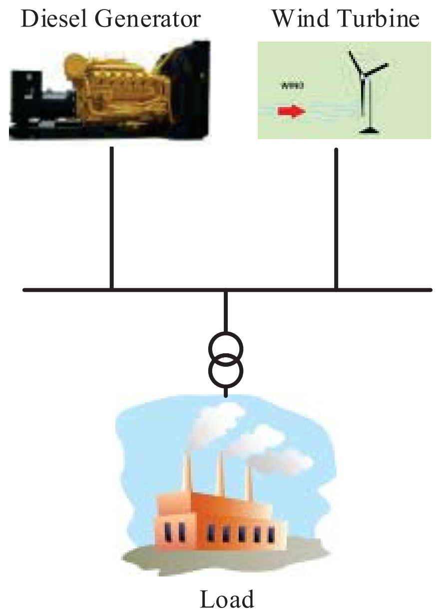

Fig. 1. Configuration of a hybrid wind-diesel isolated power system

Fig.1 shows the configuration of the hybrid wind-diesel isolated power system. Also, transfer function model of this system is shown in Fig. 2 [17]. Parameters of this system are given in [9].

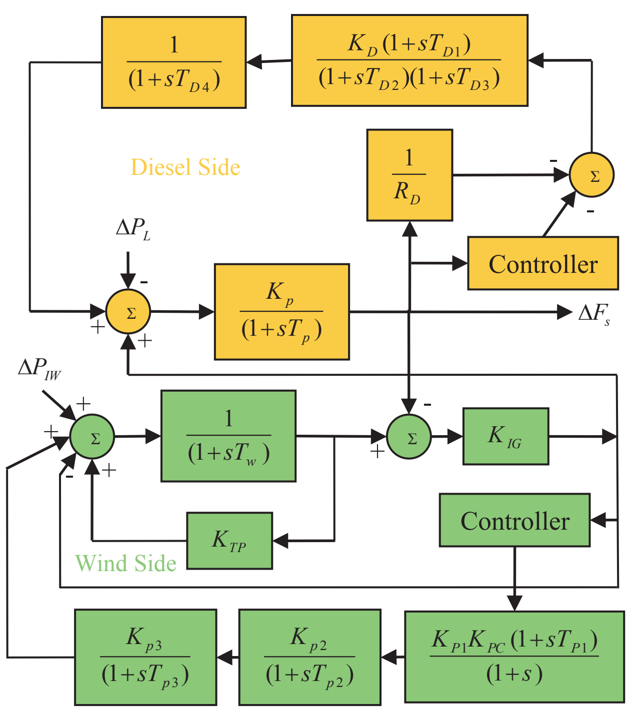

Fig. 2. Transfer function model of hybrid wind-diesel system

3 Krill Herd (KH) Optimization Algorithm

Krill Herd algorithm is one of the bio-inspired optimization algorithms that is being used for solving optimization problems. KH algorithm inspired from the krill herding motions. The time-dependent position on an individual krill in 2D surface is governed by the three main actions: movement induced by other krill individuals, foraging activity, and random diffusion. Eq. (1) shows the lagrangian model of this three actions.

$$\frac{dX_i}{dt} = N_i + F_i + D_i \tag{1}$$

Where N_i is the motion induced by other krill individuals, F_i is the foraging motion, and D_i is the physical diffusion of the ith krill individuals. N_i for a krill individual is defined in Eqs. (2) and (3).

$$N_i^{new} = N^{\max}\alpha_i + \omega_n N_i^{old} \tag{2}$$

Where,

$$\alpha_i = \alpha_i^{local} + \alpha_i^{t\,\mathrm{arget}} \tag{3}$$

And N^{max} is the maximum induced speed, ω_n is the inertia weight of the motion induced in the range [0,1], N_i^{old} is the last motion induced, α_i^{local} is the local effect provided by the neighbors, and α_i^{target} is the target direction effect provided by the best krill individuals. The foraging motion is formulated in term of two main effective parameters. The first one is the food location and the second one is the previus experience about food location. Eqs. (4) and (5) describe this motion.

$$F_i = V_f \beta_i + \omega_f F_i^{old} \tag{4}$$

Where,

$$\beta_i = \beta_i^{food} + \beta_i^{best} \tag{5}$$

And V_f is the foraging speed, ω_f is the inertia weight of the foraging motion in the range [0,1], F_i^{old} is the last foraging motion, β_i^{food} is the food attractive and β_i^{best} is the effect of the best fitness of the ith krill so far. The physical diffusion of the krill individuals is considered to be a random process, and described in Eq. (6).

$$D_i = D^{\max}\left(1 - \frac{iter}{iter_{\max}}\right)\delta \tag{6}$$

Where D^{max} is the maximum diffusion speed, and δ is a random directional vector and its arrays are random values between -1 and 1.

Finally, the position vector of a krill individual during the interval t to $t + \Delta t$ is given by Eq. (7).

$$X_i(t + \Delta t) = X_i(t) + \Delta t \frac{dX_i}{dt} \tag{7}$$

Δt is a very important constant and should be carefully set according to the optimization problem. Δt completely depends on the search space and can be simply obtained using Eq. (8).

$$\Delta t = C_t \sum_{j=1}^{NV} (UB_j - LB_j) \tag{8}$$

Where NV is the total number of variables, LB_j and UB_j are lower and upper bounds of the jth variables, respectively. C_t is a constant number between [0,2]. Simplified flowchart of the Krill Heard algorithm shown in Fig. 3 [16].

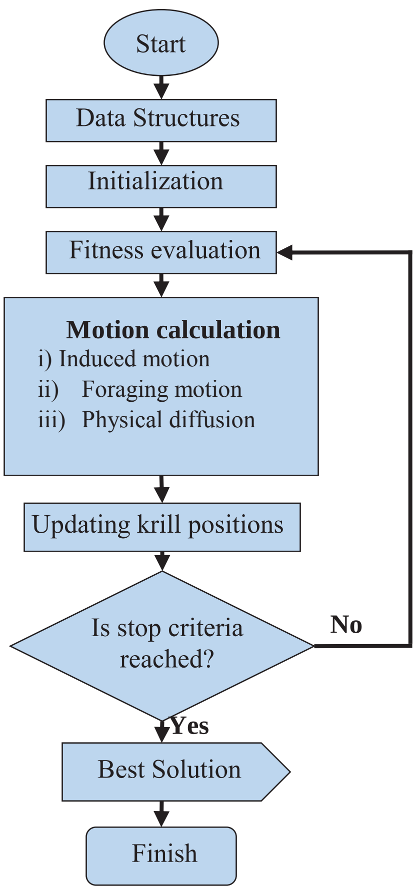

Fig. 3. Flowchart of the KH algorithm

4 Problem Formulation

PID controllers are being extensively used by industries today due to their simplicity. Its main duty in this paper is to eliminate the steady state error and improvement of dynamic response. The structure of PID controller that is used in this paper shown in Fig. 4. It has three parameters, K_{PN}, K_{IN}, and K_{DN}. Where N can be D or W, for diesel side and wind sides, respectively.

In the proposed system, there are two PID controllers, one for diesel side that its parameters denoted by K_{PD}, K_{ID}, and K_{DD}, and another for wind side that its parameters denoted by K_{PW}, K_{IW}, and K_{DW}. Therefore, there are six parameters that have to be well tuned. To increase frequency stabilization, a time based objective function is considered as follows:

$$J = \int_0^5 t \, |\Delta F_s| dt \tag{9}$$

Where, ΔF_s is the frequency deviation, and t is the simulation time. In the optimization process, it is aimed to minimize J in order to damp frequency oscillations.

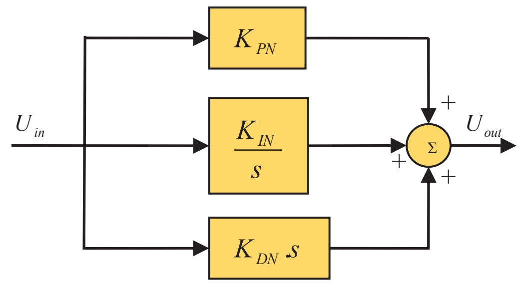

Fig. 4. PID controller structure

The design problem can be formulated as the following constrained optimization problem, where the constraints are the PID gains.

Minimize J Subject to:

$$\begin{aligned} & 0 \le K_{PD} \le 350 \\ & 0 \le K_{ID} \le 150 \\ & 0 \le K_{DD} \le 50 \\ & 0 \le K_{PW} \le 350 \\ & 0 \le K_{IW} \le 150 \\ & 0 \le K_{DW} \le 50 \end{aligned} \tag{10}$$

Results of the PID parameters based on the objective function J, solved using the proposed KH and BC algorithms (see Ref. [17] for more details) are given in Table 1. Fig. 5 shows the minimum fitness functions evaluating process.

Table 1. Optimal PID gains

Algorithm	K_{PD}	K_{ID}	K_{DD}	K_{PW}	K_{IW}	K_{DW}
KH	299.9	65.98	25.49	214.9	125.5	4.9
BC	240.36	55.67	0.326	38.69	0.779	9.08

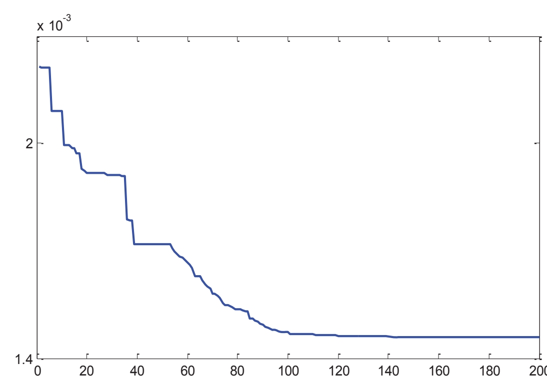

Fig. 5. Fitness convergence of the proposed KH algorithm

5 Simulation Results

In order to show the effectiveness of the proposed algorithm four case of simulations are considered.

Case 1. Step change in load demand of the diesel side

In this case of the simulations it's assumed that in t = 1 sec, a step change (ΔP_L=0.01 pu) occurred in diesel side load. Fig. 6 shows the frequency response of the system with KH-PID and BC-PID controllers.

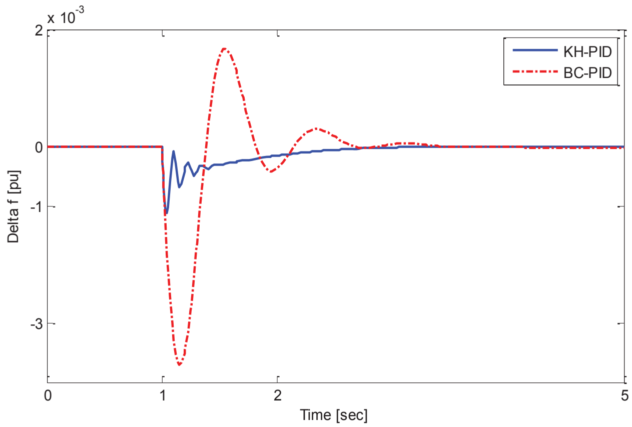

Fig. 6. Frequency response under load increase in diesel side

Also, performance indices like overshoot, undershoot, settling time, ITAE, and ISASE are calculated and shown in Table 2.

Table 2. Comparison of performance indices of two controllers for case 1

Algorithm	OS[%]	US[%]	Ts[sec]	ITAE	ISTSE
KH	0	0.1	1.25	0.6	2.59
BC	0.16	0.36	1.57	2.22	50.77

ITAE and ISTSE based on the system performance characteristics are defined as:

$$ITAE = 1000 \times \int_{0}^{\text{Upper limit}} t\,|\Delta f_s|\,dt \qquad (11)$$

$$ISTSE = 10^6 \times \int_{0}^{\text{Upper limit}} t^2 \Delta f_s^{\,2}\,dt \qquad (12)$$

As Fig. 6 and data of Table 2 show, the proposed KH-PID controller is very effective in compared with BC-PID controller.

Case 2. Step change in wind speed

In this case of the simulations it's assumed that in t = 1 sec, a step change (ΔP_{IW}=0.01 pu) occurred in wind speed. Fig. 7 shows the frequency response of the system with KH-PID and BC-PID controllers.

Also, performance indices like overshoot, undershoot, settling time, ITAE, and ISASE are calculated and shown in Table 3.

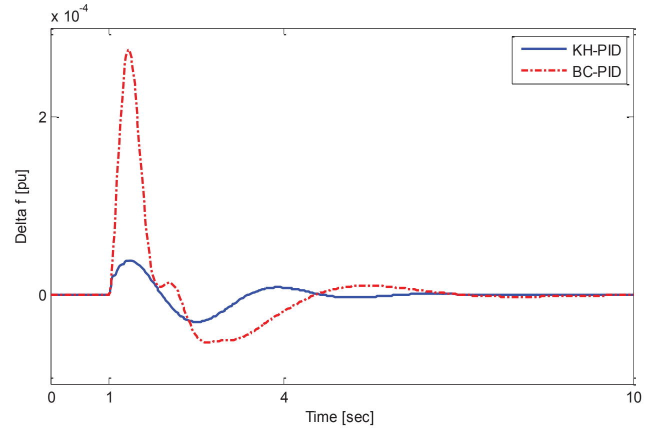

Fig. 7. Frequency response under wind speed increase

Table 3. Comparison of performance indices of two controllers for case 2

Algorithm	OS[%]	US[%]	Ts[sec]	ITAE	ISTSE
KH	0.0038	0.003	5.2	0.1523	0.0653
BC	0.0275	0.005	5.3	0.5247	0.7843

Data of Table 3, and Fig. 7 proves the results of case 1 of simulations.

Case 3. Random change in load of diesel side

In this case of simulations, assume that random load change shown in Fig. 8 applied to the system. Fig. 9 shows that the control effect on the system frequency deviation of the KH-PID controller is superior to that of the BC-PID controller.

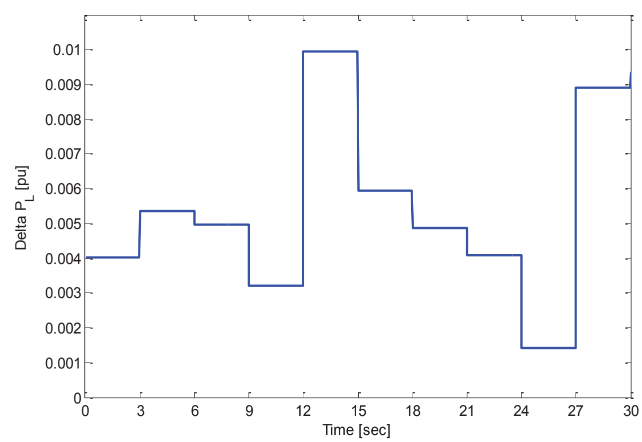

Fig. 8. Random load change

Case 4. Random change in wind speed

Same as case 3, in this case of simulations, assume that random wind speed shown in Fig. 10 applied to the system. Fig. 11 shows that the control effect on system frequency deviation of the KH-PID controller is superior to that of the BC-PID controller.

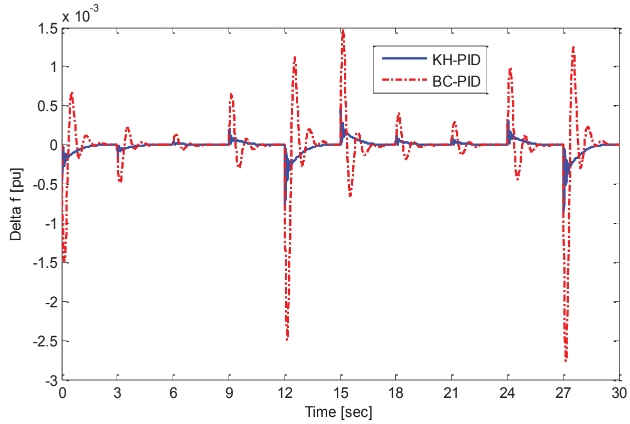

Fig. 9. System frequency response under random change in load of diesel side

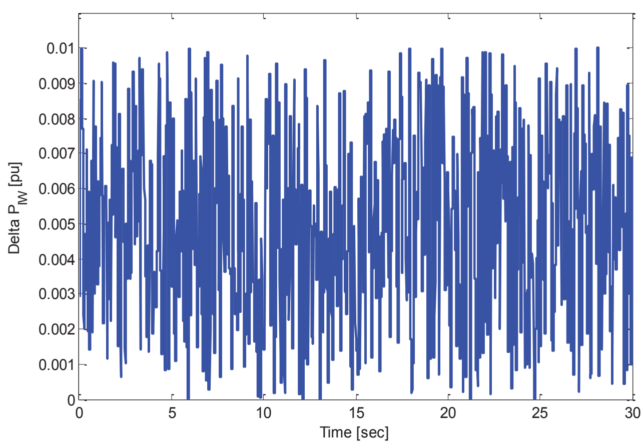

Fig. 10. Random change of wind speed

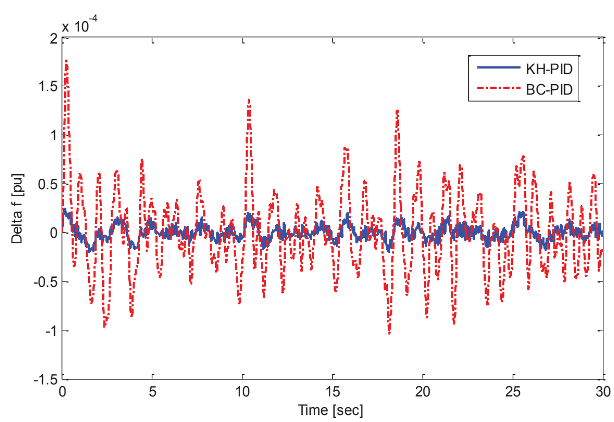

Fig. 11. System frequency response under random change in wind speed

6 Conclusions

In this paper, optimal PID controller design for the frequency control of a wind-diesel hybrid system, is formulated as an optimization problem and solved using Krill Herd algorithm. The results of the proposed method compared with Bee Colony algorithm. In order to prove the performance of proposed method, simulation carried out in four cases, step change in load of diesel side, step change in wind speed, random changing of the diesel side load, and random changing of the wind speed. Simulation results show that the KH-based PID controller (KH-PID) has better performance in compared with BC-based PID controller (BC-PID) from the perspective of the response to step change in load demand of diesel side, step change in wind speed. Also, two performance indices according to system defined and with overshoot, undershoot, and settling time calculated for both KH-PID and BC-PID controllers, which proves that the proposed KH-PID controller is very effective and robust compare to BC-PID controller.

7 References

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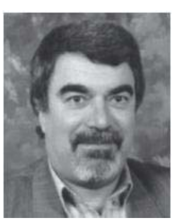
8 Biography



Heidar Ali Shayanfar received the B.S. and M.S.E. degrees in electrical engineering in 1973 and 1979, respectively. He received the Ph.D. degree in electrical engineering from Michigan State University, East Lansing, MI, USA, in 1981. Currently, he is a Full Professor with the Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran. His research interests are in the application of artificial intelligence to power system control design, dynamic load modeling, power system observability studies, voltage collapse, congestion management in a restructured power system, reliability improvement in distribution systems, smart grids and reactive pricing in deregulated power systems. He has published more than 497 technical papers in the international journals and conferences proceedings. Dr. Shayanfar is a member of the Iranian Association of Electrical and Electronic Engineers.

Abdollah Younesi received B.S degree in Electrical Engineering from Faculty of Technical Eng. Department of the Mohaghegh Ardabili University, Ardabil, Iran in 2012. Currently He is a M.S.E. student in Technical Eng. Department of the University of Mohaghegh Ardabili, Ardabil, Iran. His area of interest are application of artificial intelligence in power system automation and control, application of Reinforcement Learning to power system control, Fuzzy Systems, Heuristic optimization in power system control. He is a student member of Iranian Association of Electrical and Electronic Engineers (IAEEE) and IEEE.

Hossein Shayeghi received the B.S. and M.S.E. degrees in Electrical and Control Engineering in 1996 and 1998, respectively. He received his Ph. D. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran in 2006. Currently, he is a Full Professor in Technical Engineering Department of University of Mohaghegh Ardabili, Ardabil, Iran. His research interests are in the Application of Robust Control, Artificial Intelligence and Heuristic Optimization Methods to Power System Control Design, Operation and Planning and Power System Restructuring. He has authored of 6 books in Electrical Engineering area. He has published more than 280 papers in International Journals and Conference proceedings. He is a member of Iranian Association of Electrical and Electronic Engineers (IAEEE) and IEEE