Frequency Control of Isolated Power System Integrated with Renewables using Biogeography Based Krill Herd Migration Optimized Controllers

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Abstract- Biogeography based krill herd migration (BBKH) optimizer is used in this paper to find the optimal gains of the conventional controllers to enhance the frequency profile of the isolated power system. This model is integrated with solar, wind along with conventional thermal and hydro units. The integral (I) and proportional-integral-derivative (PID) classical controllers are selected to study the frequency control of test system under various loading conditions. Further, the primary regulation gains of the conventional plants are also considered as decision variables along with the controller gains to study the impact of their variations on the system frequency. At regular and random load disturbances, these controllers improve the system frequency profile even the volatile nature of the renewables exist. Comparative assessment of BBKH over other heuristic algorithms shows the improvements in the frequency control of the isolated power system.

Keywords Frequency control; PID controller; wind; BBKH algorithm.

1. Introduction

Penetration of the large number of renewables into conventional power system increase the power imbalance between the generation and demand since the inputs of renewables like irradiance and wind speed are volatile in nature [1]. The changes in generation side power along with the regular load perturbations affect the system frequency. The automatic generation control (AGC) mechanism provided in an isolated power system, a distribution generating microgrid system and an interconnected system with diverse resources [2] minimize the deviations of the frequency by making the active power difference between sources and loads as zero. A detailed literature review is presented in [2] based on categorizing the systems, controllers, and the conditions of the AGC. Further, the impacts of the integration of wind and solar power generating sources on the load frequency control studies of the various systems were discussed in [3]. Especially, the controller gain parameters are tuned with the help of optimization techniques and this task is common in each individual study [4] irrespective of configuration and structure of the systems.

Among different types of power system models, the frequency control of an isolated system is a focusing area when it is integrated with solar and wind. The AGC studies are carried out for a single area power system without renewables in [5], [6] with classical controllers. The tuned gain values are obtained with particle swarm optimization (PSO) algorithm. When an isolated power system is integrated with wind, frequency control during the load perturbations is presented in [7]. In [7], bio geography-based optimization (BBO) algorithm is applied for finding PID controller parameters. In [8], a diesel system is attached for an isolated power system and the fractional order controller (FOC) is implemented as supplementary controller to reduce frequency disturbances. The frequency profile of the isolated power system is enhanced with energy storage units and the related study is carried out in [9]. In both [8] and [9], PSO is used for tuning of controller parameters. In [10], the sliding mode controller is designed for a hybrid power system including renewables based on disturbance observer to improve the response during load perturbations compared to conventional controllers. All these controllers are falls under secondary controllers. In [11], a comparison is made in between the primary and the secondary controllers for an isolated microgrid system with classical controllers and the optimal parameter gains of the controllers are achieved with the crow search algorithm (CSO). A new optimal control strategy is proposed in [12] for a hybrid wind-diesel power system in presence of storage units. During uncertainties, the classical controllers may not provide required improvements therefore new strategies are adopted in recent works [13]-[28]. In detail, multi objective PID controller and fuzzy logic controllers were implemented in [13] to reduce the isolated microgrid frequency deviations. Further, artificial neuro-fuzzy inference systems (ANFIS) are developed to enhance the system stability during load perturbations. In [14], fuzzy PID controller is applied for isolated power system with improved sine cosine algorithm (ISCA) assistance. The optimization algorithm helps to find the gains of the controller. In presence of wind, the frequency control is challenging, and issues are addressed in [15]-[18] with classical controllers. In [19], fuzzy tilt integral-derivative with filter controller is investigated for the system with PV. The power transfer capacity of these renewables increases with high voltage direct transmission (HVDC) systems discussed in [20] is another choice to improve the frequency profile of the power system. The response further increases with advanced controller [21]-[28].

In this paper, BBKH optimizer is applied for tuning the classical controllers for a system with thermal, hydro, solar and wind units. Unlike existing systems, the test system integrated with both wind and solar of higher capacities suit for present trend. For wind, both droop and inertia control mechanisms are considered whereas I and PID controller is used for rest of the units of the test system. To improve the power transfer capability of wind, HVDC tied wind farm is used in the model. Studies are carried out for both secondary controllers tuning, primary regulation coefficients tuning. Comparisons are made at different loadings when the system controller by both integral and PID supplementary controllers. To show the merits of BBKH optimization algorithm, other heuristic algorithms are taken for comparison. Results are carried out MATLAB/SIMULINK environment with a test system whose model is provided in section 2. BBKH optimizer overview is presented in section 3 followed by results in section 4. Finally, conclusions are included in section 5.

2. System Modelling with Controllers

To examine the frequency variation during load disturbances, an isolated power system model is selected in this paper consist of both conventional and renewable power generating units. Thermal and hydro power plants fall under the category of conventional units, solar and wind power plants fall under the category of renewable units. Each plant transfer functions are separately represented, and the overall block diagram of the isolated power system is shown in Fig 1. In case of thermal power plant, both dead-band and reheat turbine mechanisms are considered in the mathematical model [7]. The overall transfer functions of the thermal and hydro units are given by

$$G_{TH}(S) = \frac{(0.8-\frac{0.2S}{\pi})(1+SK_rT_r)}{(1+ST_{sg})(1+ST_r)(1+ST_t)} \tag{1}$$

$$G_{HY}(S) = \frac{(1-ST_{rs})(1-ST_w)}{(1+ST_{gh})(1+ST_{rh})(1+0.5ST_w)} \tag{2}$$

These conventional units are regulated by primary control loops with regulation gains of R_{TH} and R_{HY}. Controller-I is placed in the secondary frequency control loop to improve the frequency profile of the isolated power system during load disturbances. For solar and wind generating units, a linearized models are considered with transfer functions shown in Equations (3) and (4).

$$G_{PV}(S) = \frac{a+Sb}{S^2+cS+d} \tag{3}$$

$$G_W(S) = \frac{1}{1+ST_{wt}} \tag{4}$$

In this test system, solar power is regulated by controller-II [19] and the wind generation (WG) is controlled by both droop and inertia control strategies [20]. The frequency response in determined by droop gain of the frequency control loop during stable operation when the WG is controlled by droop control mechanism. This approach helps to WG to participate directly in primary frequency response of the isolated power system during load perturbations. This mechanism injects the active power is equal to

$$p_{w(in)} = \frac{-\Delta f}{R_{wt}} \tag{5}$$

In Equation (5), R_{wt} is the speed regulation constant of wind plant. Another control strategy used in grid integrated wind farm is inertia control to reduce the maximum rate of frequency. Using this mechanism, the amount of active power injected in system is given by

$$p_{w(in)} = -k\frac{df}{dt} \tag{6}$$

In Equation (6), k is the inertia constant like H in regular power system. Instead of using the individual control mechanisms, combination of both strategies provides necessary frequency control irrespective of system load power and wind speed disturbances. Further, integral (I) and proportional-integral-derivative (PID) controllers are used for thermal, hydro, and solar systems to regulate their power generations. The optimal parameter gains of these controllers influence the system behavior and therefore, biogeography-based krill herd migration (BBKH) algorithm is used in this paper to find those parameters.

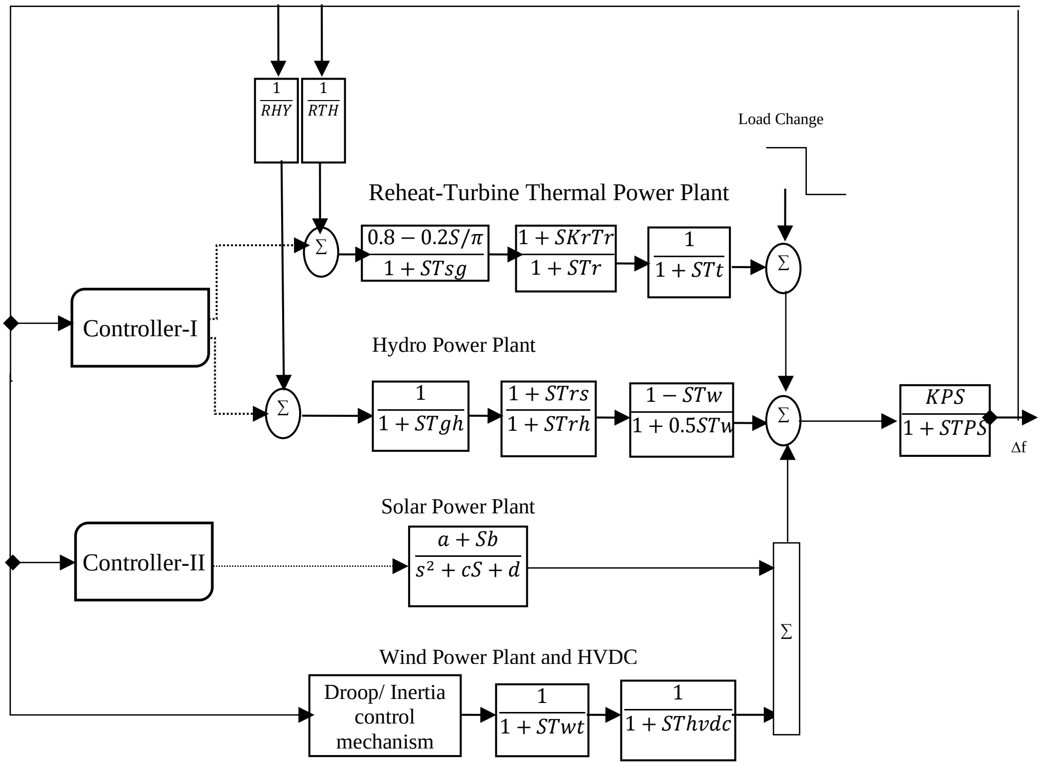

Fig. 1. Block diagram of isolated power system integrated with solar and wind units

3. Biogeography Based Krill Herd Migration (BBKH) Optimizer

BBKH is a hybrid optimizer implemented from the concepts of biogeography-based optimization (BBO) and krill herd (KH) optimizer. The habitat migration operator used in BBO incorporated in KH optimizer to improve the exploitation ability of KH, since it has poor exploitation ability. This change enhances the local search performance, and the operator is termed as krill migration (KM) operator. By combining KM and KH, better convergence results are guaranteed [21]. The step wise procedure of BBKH as follows:

Step-1: **Initialization-**a randomly generate ‘P’ population (each represents a feasible solution) of krill.

Step-2: **Set all initial parameters**- Foraging speed (V_f), maximum speed (N_{max}), maximum diffusion speed etc.

Step-3: **Fitness value calculation**- Substitute each solution in the objective function and evaluate fitness

Step-4: **Updating krill position**-For iteration i, sort the krill from best to worst (solution corresponding fitness values based on objective function) and store the best solution.

Step-4: **New krill generation**- For all populations, perform motion calculation and update the position of each krill using the position updating equation.

Step-5: **Tuning of krill**-By applying KM operator, tune krill position and replace worst with best.

Step-6: **Best solution**-At the end of final iteration, report best solution.

The motion calculation and position update equations within details are available in [21]. For identification of optimal parameter gains of the controller I and II of the test system, BBKH is used in this work. The objective of the work is to minimize the frequency disturbances and hence the fitness function of the BBKH optimizer is given by

$$Fitness\ Function\ (J) = \sum_{i=1}^{N} \Delta f(i)^2 \qquad (7)$$

This solution corresponding to minimum value of fitness function is used for simulation results. The number of decision variables of the solution depend on the controller type and count. In case of I controller, the dimension of the optimization problem is 2 and in case of PID controller, it is 6.

4. Simulation Results

The system shown in Figure 1 is simulated in MATLAB/SIMULINK to investigate the frequency control studies at various loadings and system uncertainties. The comparisons are made in between I and PID supplementary controllers to show the merits of PID over I controller. In fact, PID controller yield superior results irrespective of nature of loading. The case studies are presented from case-1 to case-6.

Case 1- In this case, a simple load change of 0.01 pu is simulated and frequency deviations of the PV-wind-integrated isolated power system with I and PID supplementary controllers are presented in Figure 2.a. The PV and wind power changes of this case are provided in Figure 2.b and 2.c. The tuning parameters of both I and PID controllers are achieved with BBKH and presented in Table 1.

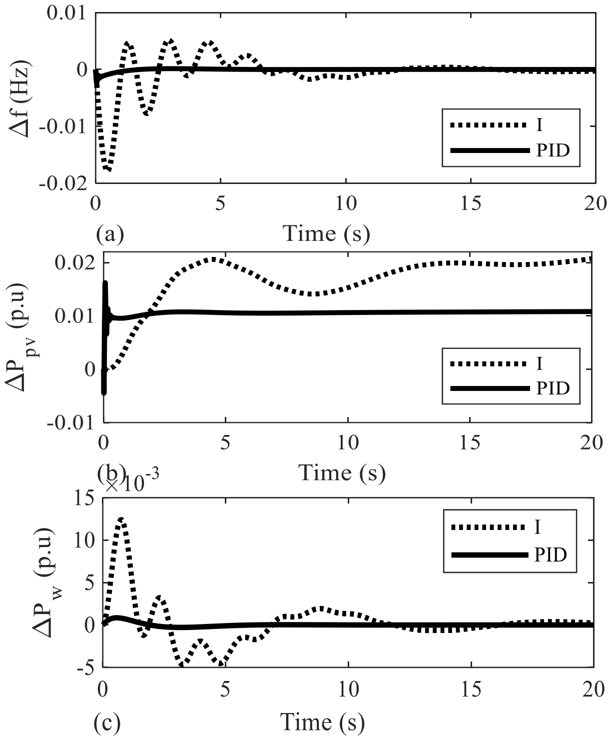

Fig. 2. Test system responses a. Δf, b. ΔP_{pv}, c. ΔP_w during load change of -0.01 p.u.

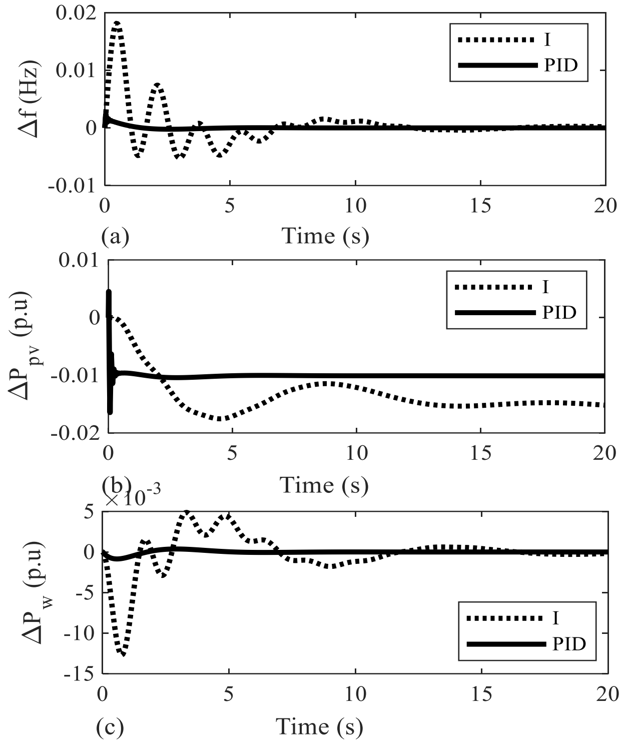

Fig. 3. Test system responses a. Δf, b. ΔP_{pv}, c. ΔP_w during load change of 0.01 p.u.

With PID controller, the frequency deviations are controlled better to I controller and the performance specifications are reported in Table 2.

Case 2- When a load increase of 0.01 pu is initiated in the system, the frequency deviations, PV, and wind power variations are presented in Figure 3.a, 3.b and 3.c respectively. Similar observations are made as discussed in case 1 since both loadings are falls under simple load perturbations. However, the optimal tuned values of the secondary controllers are provided in Table 1 and the response specifications are presented in Table 2.

Case 3- A random load disturbance is created with loading of -0.01, 0.05, -0.03 at times 0, 20, 50 and the corresponding system frequency deviations are presented in Figure 4.a. For each loading, the changes in PV and wind power outputs are plotted in Figure 4.b and Figure 4.c. PID assisted results provide better frequency profile in all disturbances and the optimal gains of this PID controllers are provided in Table 1. In all these cases, only secondary controller parameters are selected as decision variables and their optimal values corresponding to minimum fitness values are extracted as best solution. Table 2 provides 0.05 loading case results.

Case 4- In limited works, primary regulation coefficients are also treated as decision variables along with secondary/supplementary controller gains. In this case, the primary regulation coefficients of thermal and hydro power plants are considered as variables along with integral gain parameters and the comparative responses are presented in Figure 5. The optimal values of the coefficients are 3.6446 and 4.2068. This investigation further extended to random load disturbances case and responses are presented in Figure 6.

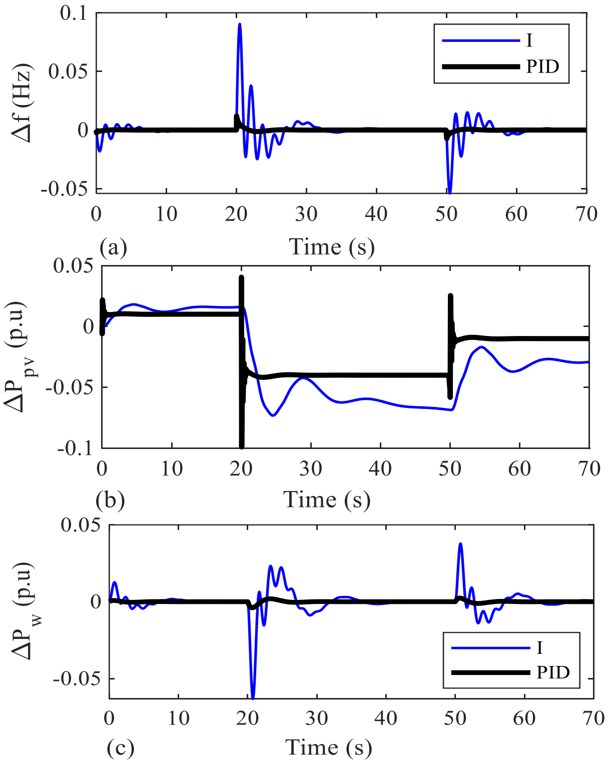

Fig. 4. Test system responses a. Δf, b. ΔP_{pv}, c. ΔP_w during random load perturbations along with I controller-based results comparisons.

Table 1. Controllers tuned values with regular cases.

Case	controller	Conventional			PV		
		K_p	K_i	K_d	K_p	K_i	K_d
1	I	--	-0.9031	--	--	-0.1145	--
	PID	-0.6627	-0.8390	-0.2522	-0.9723	-0.8073	-0.6814
2	I	--	-0.5007	--	--	-0.0975	--
	PID	-0.9508	-0.1258	-0.2164	-0.8988	-0.9782	-0.6840
3	I	--	-0.5512	--	--	-0.0969	--
	PID	-0.7207	-0.0238	-0.2224	-0.8028	-0.9257	-0.8421

Table 2. Performance specifications at different cases

Case	I			PID		
	Peak change	Settling time	Fitness value	Peak change	Settling time	Fitness value
1	-0.0177	16	0.0138	-0.0021	4	3.4359e-05
2	0.0179	16	0.0141	-0.0022	4	3.5933e-05
3	0.09	20	0.5977	0.012	6	0.0016

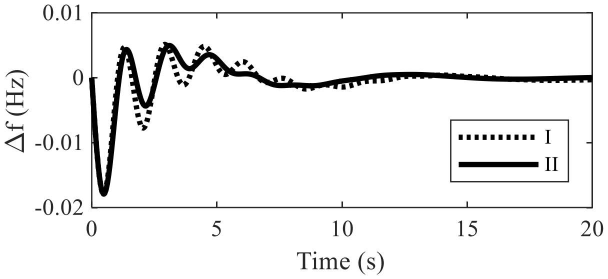

Fig. 5. Optimal R Vs nominal value results comparison in case of I controller

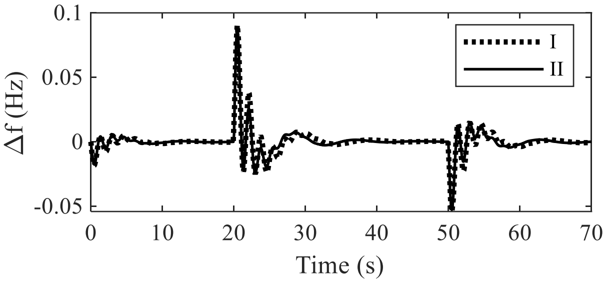

Fig. 6. Optimal R Vs nominal value results comparison in case of I controller at random load

Case 5- Figure 7 shows the frequency deviations of the test system at optimal and nominal primary regulation coefficients along with secondary PID controller. The enhancement of the response specifications with optimal regulation coefficients is observed in Figure 7 in terms of overall changes, peak overshoot and settling time. These simulations are carried out at random load disturbances. The optimal regulation coefficients of this case are 2.2904 and 2.5190 for thermal and hydro plants respectively. The additional benefits are obtained with increasing the decision variables of the control problem.

Case 6- The proposed tuning mechanism is tested during noise condition for both I and PID secondary controllers and the changes in system frequency are plotted in Figure 8. The BBKH tuned gain parameters of the supplementary controllers handle the noise situations in better way compared to system with only primary regulation.

Case 7- The merits of the BBKH tuning are identified when the results are compared with other approaches available in literature. In this paper, PSO [4], DE [24] and BBO [7] algorithms are used for the comparison. The proportional, integral, and derivative gains of the PID controller are identified with these heuristic algorithms and corresponding results are plotted in Figure 9. BBKH results provide better results compared to other algorithms.

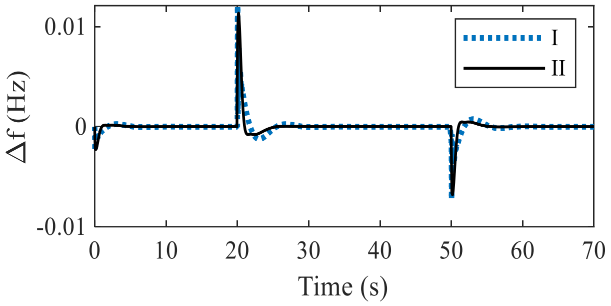

Fig. 7. Optimal R Vs nominal value results comparison in case of PID controller at random load

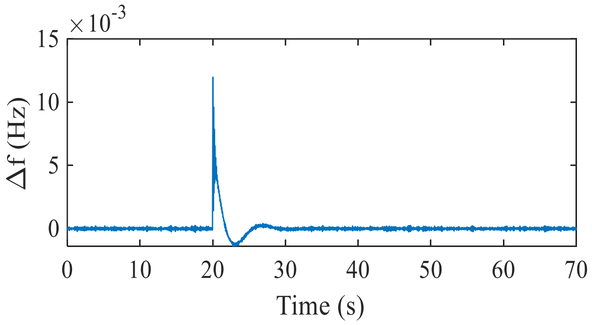

Fig. 8. Response in presence of noise

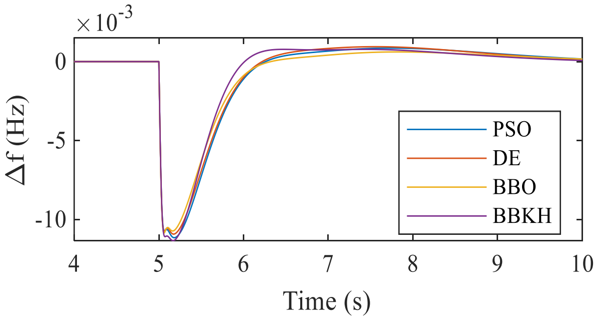

Fig. 9. Comparison results with other optimization algorithms

5. Conclusion

This paper deals the frequency control studies of an isolated power system integrated with both wind and solar power. Separate classical controllers are designed for conventional and PV systems whereas droop and inertia control strategies are adopted for wind. The controller parameters are tuned with BBKH algorithm. The results investigated at different loadings, random disturbances, and noise conditions. Further, individual, and simultaneous primary and secondary control tuning approaches are used for the study. Finally, comparisons with other optimization algorithms reveal the merits of BBKH in terms of response improvements.

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