LOAD FREQUENCY CONTROL SCHEME OF HYBRID WIND DIESEL SYSTEM BASED ON MINE BLAST ALGORITHM

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Abstract: *The frequency control of micro smart grid is a very important issue to satisfy the power quality conditions. For this objective, this paper proposes a new optimization technique based on mine blast algorithm (MBA) for optimizing the gains of the blade pitch PID controller of the wind turbine generator for enhancing the performance of the hybrid wind-diesel system. Simulation has been carried out with a step disturbance in wind input and load power. Furthermore, system performance is studied for harsh step load and wind disturbance with changing the fluid coupling between wind and diesel systems. The wind and diesel frequency and power deviations are obtained and discussed. The results of the proposed system are compared with classical PI and GA PID controllers. Results prove that the MBA-based scheme is able to damp the oscillations in the system frequency responses by reducing the overshoot, settling time and steady-state error compared to other systems.*

Key words*: Hybrid system, Diesel generator, Pitch control, and mine blast algorithm.*

1. Introduction

Generation of electric power based on renewable sources in remote areas have considerable attention in the search field due to fossil fuels problems. Fossil fuel problems are the cost of fuel and its transportation to the isolated generation areas. Moreover, it emits gases that are harmful to the environment [1-2]. Renewable energy plants are the solutions for these matters; they are clean and available as natural infinite resources. Wind and solar systems are the most used sources for renewable power generation.

Nowadays wind powers generators have attracted a lot of attention, they are suitable for regions to exist in the isolated islands, and have the higher efficiency for energy conversion with low generating cost compared to photovoltaic systems [3]. Most of the isolated and remote communities are not interconnected to their national grid and the diesel generators are the main source for supplying their load [4].Besides the mentioned drawbacks of the fuel based generation systems, diesel generators are not efficient when operating at a low load factor below 40-50% of their rated capacity [5-6]. The wind energy highly has a direct cubic relation with wind speed. This relation leads to fluctuation of wind power with time, together with the household demand, are the only external variables influencing the system. Therefore the diesel unit can be installed with wind system as the hybrid system in the isolated communities. Hybrid wind-diesel systems lessen the fuel usage and reduce the generation costs in the small power system. In addition, the level of emissions can be minimized [7- 8]. And the required cost to extend the connection between the national grids and the remote areas is omitted [9-12].

For stable operation, the generation system must supply power equal to the load demand. The load variation and intermittence behavior of wind supply cause fluctuation in the system frequency and voltage flicker inside the power system [13]. Therefore; to control the angle of the wind turbine blade, a pitch controller is implemented and tuned for the hybrid system. Recently some researchers have proposed controller design methods to optimize the gains of the PI pitch controller in the wind turbine based on Lyapunov theorem [14-15] to damp fluctuation of the output frequency. Gains of the turbine blades and diesel governor side are tuned by PID controller [16-17]. These gains are optimized based on minimizing the IAE performance index. In [18] a variable structure controller scheme is proposed to improve the performance of the system. In [19-22], genetic algorithm (GA) has been used to tune the control parameters of the pitch controller for frequency control. Other techniques based on the artificial intelligence (AI) are proposed, an FLC is designed for control of hybrid wind-diesel system [23-26] and the second type is based on neural network (ANN) as in [27]. Practical swarm algorithm (PSO) is designed also to optimize the PID gains of the blade pitch controller as in [28-29]. Two control schemes GA and PSO are used in [30]. Pattern search (PS) and PSO are designed in [31]. BCO is used in ref. [32]. BFO is designed in ref. [33]. H_∞ control method is applied to the pitch system as in [34-35]. DE algorithm is developed and used for tuning the PID controller parameter in [36].

MBA is a population-based algorithm recently introduced [37-39]. It is simple, real coding, and easy to use and converge fast. It is robust and requires few control parameters. This paper is divided as follows; dynamic modeling for the system is discussed in section 2. In section 3 controller design and the objective function is presented. MBA algorithm is discussed in section 4. Simulation and results are discussed in section 5, and the conclusion is given in section 6.

2. System modeling

The wind-diesel system [20] is illustrated in Fig. 1.

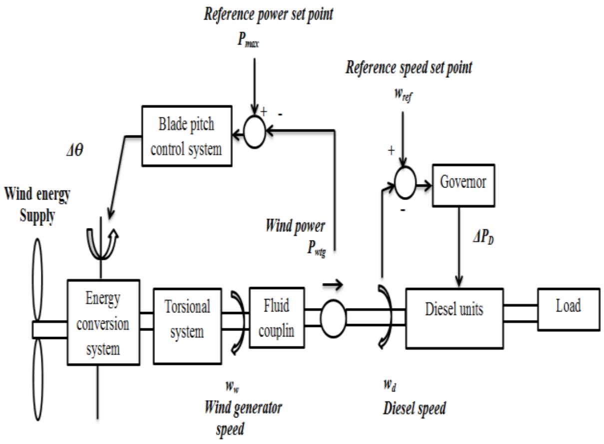

Fig. 1. Basic configuration of a hybrid system.

The hybrid model consists of wind and diesel generators to supply load. The wind system is modeled to simulate wind behavior effect including disturbance. It is synchronized with the diesel system by satisfying the conditions of synchronization which are, the wind speed is to be within an acceptable range and there must be a match in phase between wind and diesel output voltages. The speed governor control system is used for controlling the diesel behavior in this model. The power set point is adjusted from zero to the maximum value. The adjustable reference set point to prevent diesel from dropping to a value less than 50 % of the nominal power, it could result in engine damage.

The inertia of the diesel generators and load has been lumped together. The diesel governor compares the system speed to a reference speed and compensates for speed error by changing the fuel rate. When pitch angle control is active, it compares the generated power to P_{max} (power reference) and compensates for power error by changing the blade angle and thus controls the input power. The block diagram is formulated in Fig. 2.

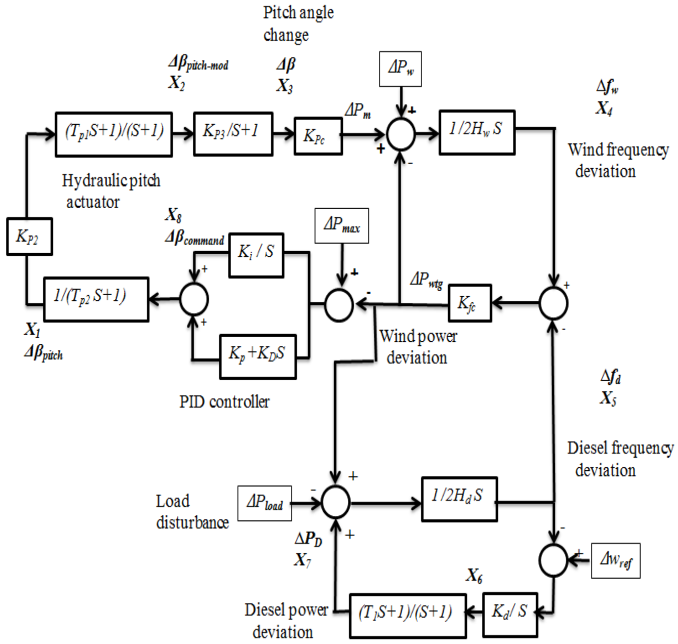

Fig. 2. Block diagram of wind-diesel power system.

And the state space equations are:

$$\overset{\bullet}{X} = AX + BU \quad (1)$$

$$Y = CX + DU \quad (2)$$

Where X is the system state variables, it is a vector of order 8[th] whose elements are illustrated as shown in fig. (2). U is the control input. Y is output vectors and A, B, C & D is constant matrices associated with wind-diesel system respectively.

$$U = [\Delta P_w \;\; \Delta P_{load}] \quad (3)$$

$$Y = [\Delta f_w \;\; \Delta f_d \;\; \Delta P_d \;\; \Delta P_{wtg}] \quad (4)$$

Where ΔP_w and ΔP_{load} are the changes in wind and load power.
Δf_w and Δf_d are the frequency deviations of the wind and diesel generators.
ΔP_d is the diesel power deviation.
ΔP_{wtg} is the wind output power deviation.
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ΔP_{wtg} is the wind output power deviation.

3. Control system and objective function

Most of the industrial controllers today are PID controllers, due to their robustness, and simplicity. These systems can be designed in a different structure such as PI and PID to select and control wind turbine blade's angle for achieving a better dynamic performance of the wind-diesel system. The control input to the pitch actuator is the PID controller's output.

$$U_1 = K_p.ACE + K_I \int_0^t ACE\ dt + K_D \frac{dACE}{dt} \quad (5)$$

The area control error $ACE = (\Delta P_{max} - \Delta P_{wtg})$.

K_p, K_I and K_D are PID gains respectively. For the study system, P_{max} is constant, therefore ΔP_{max} =0. The system parameters are given in the appendix. The performance index is considered as the absolute error integral (IAE) of the wind and diesel frequencies, thus the fitness function is written as:

$$J = \int_0^t (\Delta fw^2 + \Delta fd^2)\, dt \quad (6)$$

The optimization problem is written as follows:
Minimize the fitness function J, Subject to the following constraints,

$$K_p^{min} \le K_p \le K_p^{max}$$
$$K_I^{min} \le K_I \le K_I^{max} \quad (7)$$
$$K_D^{min} \le K_D \le K_D^{max}$$

The gains range for each of K_p, K_I and K_D [0 to 100].

4. Mine blast algorithm

The MBA algorithm is first proposed in [37], it is based on the mine explosion observation, the shrapnel pieces collide with other bombs resulting in their explosion. The shrapnel pieces collision with mines leads to discovering the optimal solution that has the most explosive effect. The algorithm randomly selects the first shot points x_0^f

$$X_o = LB + rand \times (UB - LB) \quad (8)$$

Where UB and LB are the upper and lower limits, respectively, and $rand$ is a random number. The mine bomb explosion produces shrapnel pieces N_s causing another mine to explode at X_{n+1} location:

$$X_{n+1}^f = X_{e(n+1)}^f + \exp\left(-\sqrt{\frac{m_{n+1}^f}{d_{n+1}^f}}\right) X_n^f, \quad (9)$$

$n = 1, 2, 3, \ ...$

Where, d_{n+1}^f and m_{n+1}^f are the distance and the direction of the shrapnel piece in each iteration. The new location of mine bomb $X_{e(n+1)}^f$ can be obtained as:

$$X_{e(n+1)}^f = d_e^f \times rand \times \cos(\theta), \quad (10)$$

$n = 1, 2, 3, \ ...$

The shrapnel pieces angle θ is equal to 360/N_s. MBA has two processes to search the optimal point; the exploration process begins if the exploration factor (μ) is higher than iteration number (K). The exploration equations of the solution space are:

$$X_{e(n+1)}^f = d_{n+1}^f \times \cos(\theta), \qquad n = 1, 2, 3, \ ... \quad (11)$$

$$d_{(n+1)}^f = d_e^f \times (|randn|)^2 \qquad n = 1, 2, 3, \ ... \quad (12)$$

And the exploitation process is active when the value of μ is lower than K. The algorithm reduces the initial distances of shrapnel pieces. The reduction in d_0^f can be calculated as

$$d_n^f = \frac{d_{n-1}^f}{\exp(K/\alpha)}, \qquad n = 1, 2, 3, \ ... \quad (13)$$

Where α and K are reduction constants and iteration number index, respectively. Shrapnel pieces' distance d_{n+1}^f and direction m_{n+1}^f are defined as:

$$d_{n+1}^f = \sqrt{(X_{n+1}^f - X_n^f)^2 + (F_{n+1}^f - F_n^f)^2} \qquad (14)$$

$$m_{n+1}^f = \frac{(F_{n+1}^f - F_n^f)}{(X_{n+1}^f - X_n^f)} \quad n = 0,1,2,3....... \qquad (15)$$

F is the fitness value for *X*. The main processes of MBA algorithm including exploration in color lines and exploitation in black lines are illustrated in Fig. 3. The steps of MBA optimization algorithm are summarized in ref. [37] and its flowchart is illustrated in Fig. 4.

5. Simulation results

MBA is used to tune the PID gains of the blade pitch controller for the wind turbine according to the integral of absolute error (ISE) criteria based on minimization of the errors of wind and diesel frequencies deviations. MBA algorithm code is written in Matlab 2010R m.files. Four case studies are discussed to test the proposed scheme under wind and load disturbances. MBA control scheme is compared with the classical PI and GA based systems.

5.1 Case 1

The system is tested under 25% increase in the input wind power. Results of the wind-diesel system are illustrated in Fig. 5. The transient response of the wind frequency deviation, diesel frequency deviation, diesel power deviation and the output wind power deviation shows that the MBA proposed system rejects the load disturbance by damping the frequency deviations of the wind and diesel generators by reducing the peak overshoot and settling time.

System performance parameters are listed in Table. 1, the MBA maximum overshoot is about 0.00872 Hz it is about 0.4 of classical and GA systems, it reaches to its peak value in 2.1043 seconds (0.42 times of other systems) and the rise time is about 0.0002 seconds. As shown in Fig. 5-a, MBA system steady-state error reaches to zero (0.0087 Hz) compared to other systems which fail to reach zero steady-state error.

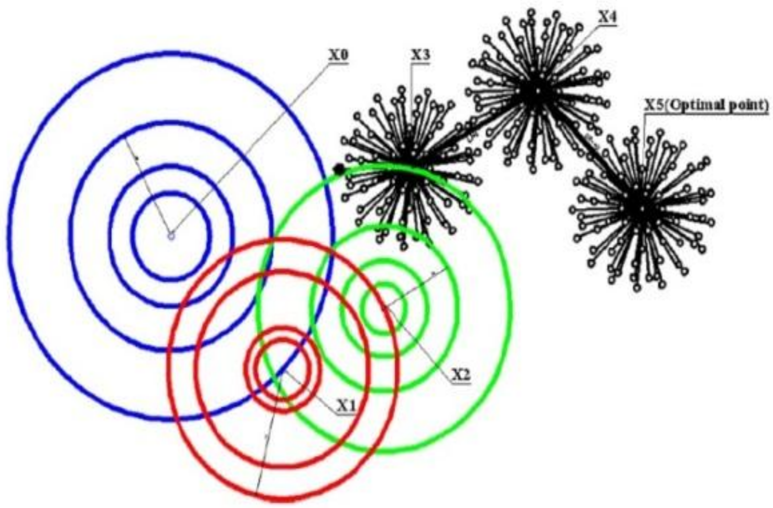


Fig. 3. Schematic view of the mine blast algorithm processes.

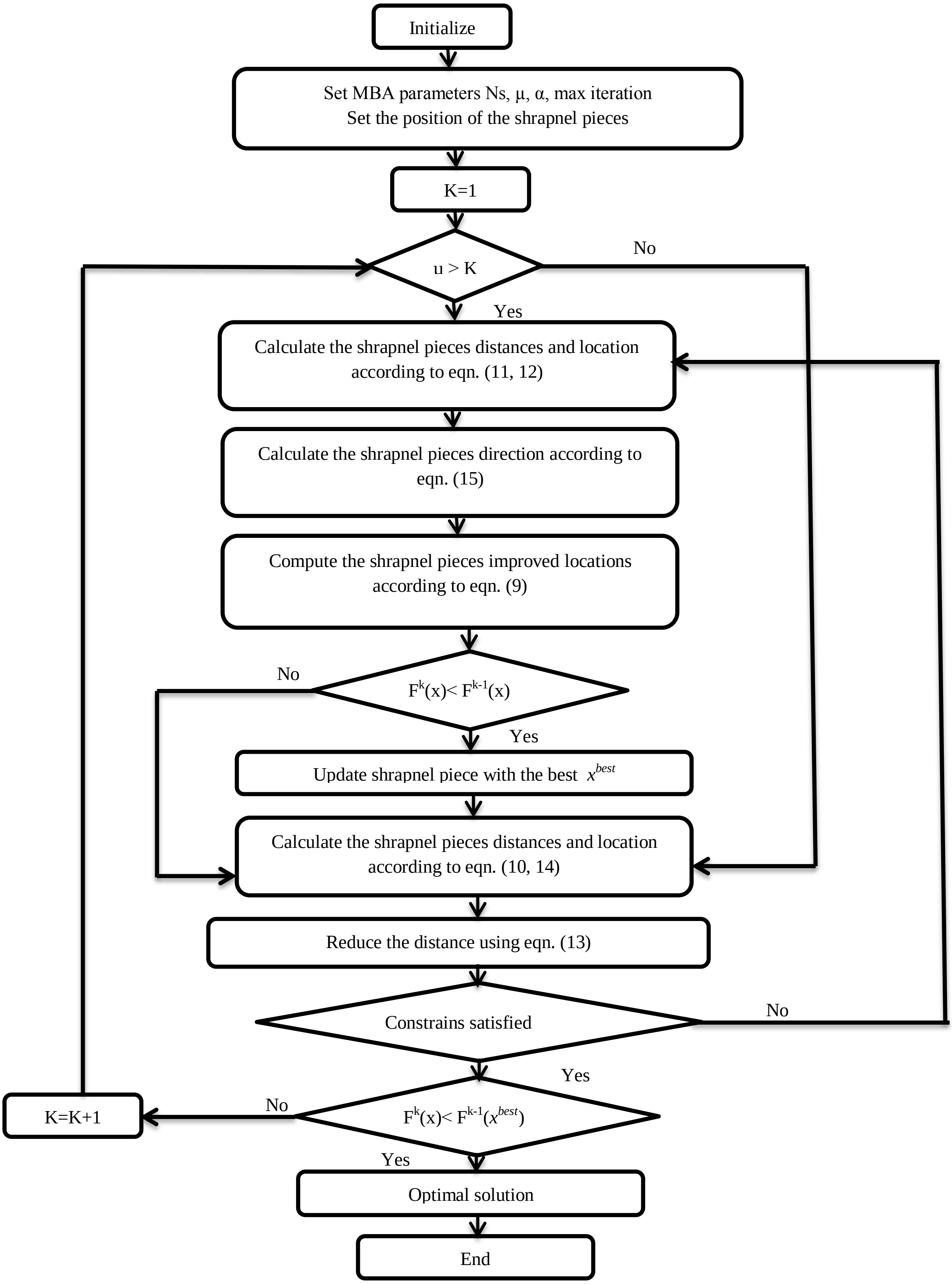
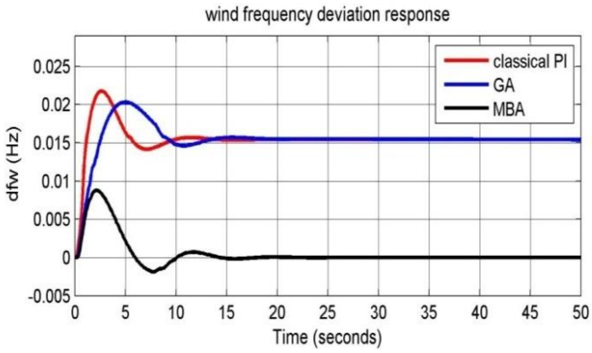


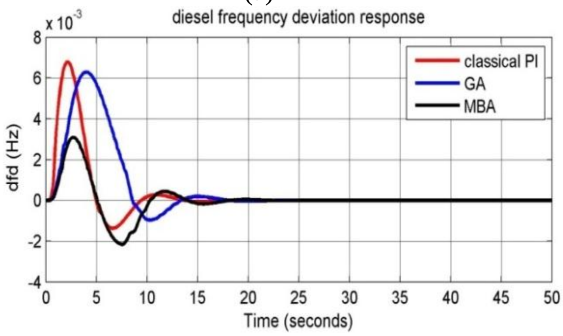
Fig. 4. Flowchart of the MBA algorithm.

Table 1. System (diesel) performance parameters.

Δf_d response under ΔP_w=0.25 pu kw			
	Classical system	GA system	MBA system
O.S (Hz)	0.02174	0.0203	0.0087 2
TOS (s)	2.60942	4.96632	2.1043
U.S (Hz)	0.01415	0.01405	- 0.0018
R.T (s)	0.69267	1.76196	0.0002
e_{ss} (Hz)	0.02174	0.02031	0.0087



(a)



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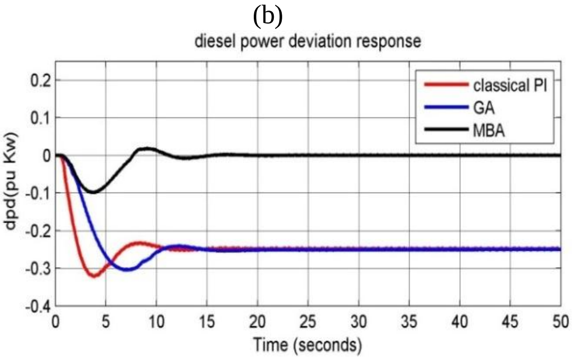

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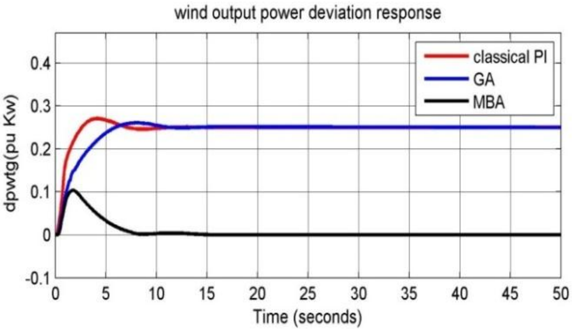


(d)

Fig. 5. System transient response curves for deviation in (a) wind frequency (b) diesel frequency (c) diesel output power and (d) wind power for 25% change in wind input power.

5.2 Case 2

In this case, the proposed system is tested to confirm its robustness. The operating conditions are represented as 10 % in load power change with 25 % in wind input power. Results are presented in Fig. 6 prove that the system dynamic response of the proposed MBA-based control scheme damp all fluctuations of the wind frequency, diesel frequency, diesel output power and wind output power, decrease maximum overshoot to 0.006912 Hz (0.38 times of GA system)and rise time to 0.000639 seconds (0.274 times other systems). In addition the steady state error reaches to 5.1798e-08 Hz (zero steady error). All parameters are listed in Table 2.

Table 2. System (diesel) performance parameters.

Δf_d response under ΔP_w=0.25 pu kw , ΔP_{load} =0.1pu			
	Classical system	GA system	MBA system
O.S (Hz)	0.019311	0.01808	0.006912
TOS (s)	2.941176	4.78991	1.764705
U.S (Hz)	0.014256	0.01401	-0.00168
R.T (s)	0.880394	2.17400	0.000639
e_{ss} (Hz)	0.015432	0.01541	5.1798e-08

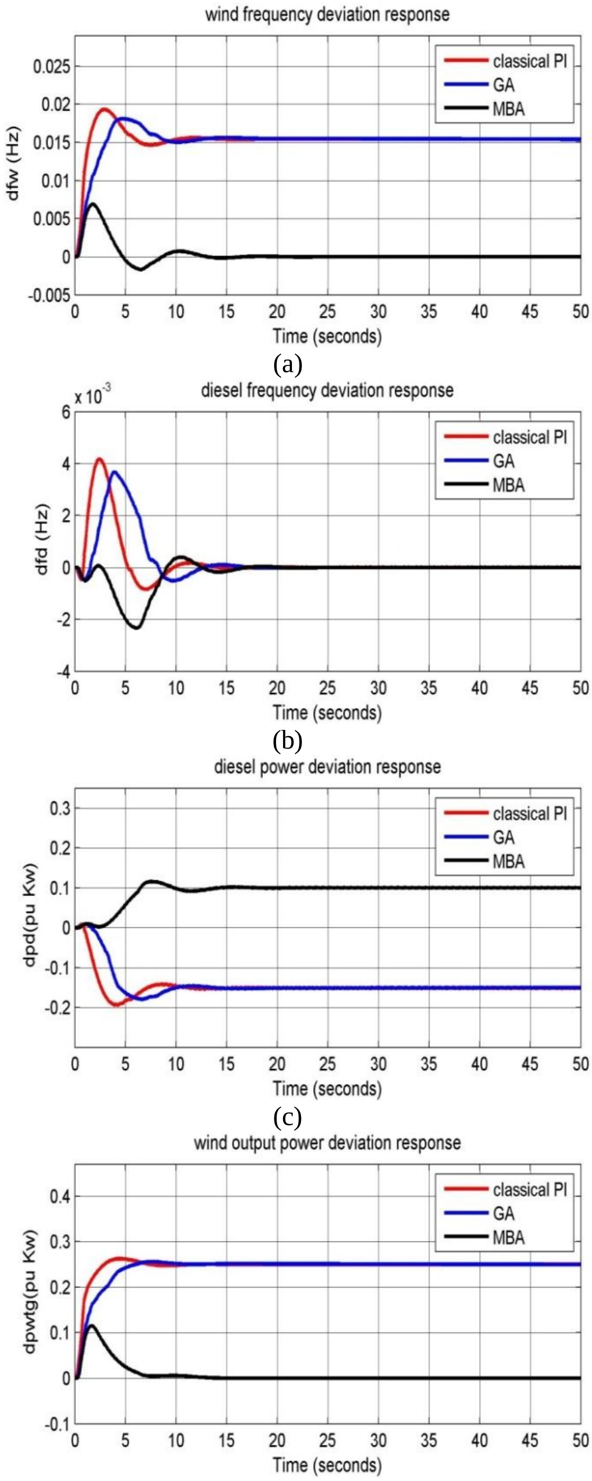


Fig. 6. Illustrates the system transient response curves for deviation in (a) wind frequency (b) diesel frequency (c) diesel output power and (d) wind power for 10 % step load change and 25% change in input wind power.

5.3 Case 3

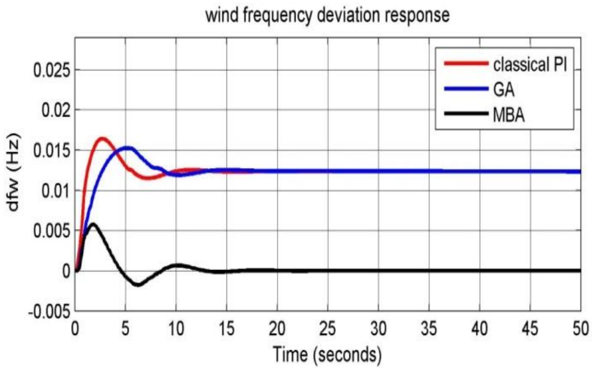
In this case, systems are tested under harsh conditions to confirm its effectiveness. The operating conditions are represented as 10 % in load power change with 25 % in wind input power and 25 % increase in K_{fc}. K_{fc} is chosen because it is the dominant parameter in the system [20].

Results are presented in Fig. 7 show that the system dynamic response of the proposed MBA-based control scheme can withstand these severe operating conditions. It can be verified from Table 3 that the MBA system decreases maximum overshoot to 0.0057 Hz (0.37 times of other systems). Rise time and steady error are also very low compared to other systems. Then the MBA-based system can withstand these severe conditions.

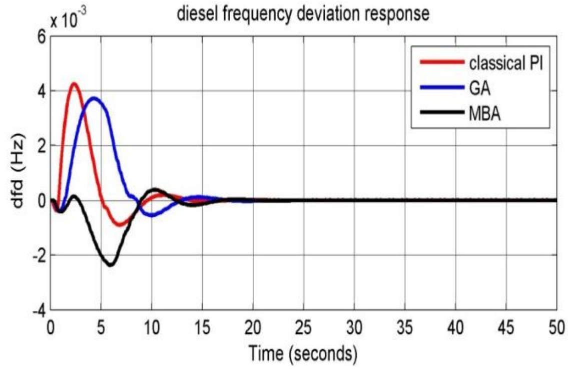
The simulation results prove the robustness and effectiveness of the proposed system over PI classical and GA-PID optimized control systems.

Table 3. System (diesel) performance parameters.

Δf_d response under ΔP_w=0.25 pu kw , ΔP_{load} =0.1pu, K_{fc} = 1.25 K_{fc}			
	Classical system	GA system	MBA system
O.S (Hz)	0.0164	0.01525	0.005753
TOS (s)	2.68907	5.21008	1.84873
U.S (Hz)	0.01120	0.01116	-0.001776
R.T (s)	0.76755	1.75016	8.940e-05
e_{ss} (Hz)	0.01234	0.01232	3.6188e-09



(a)



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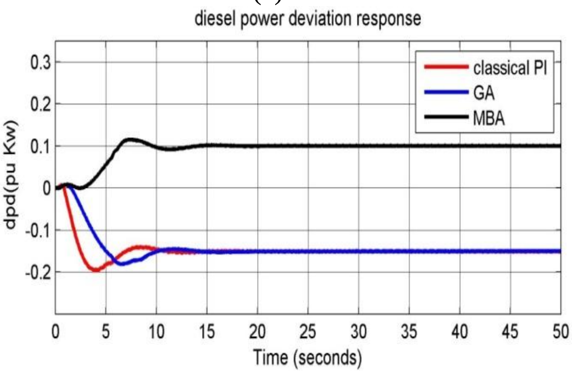

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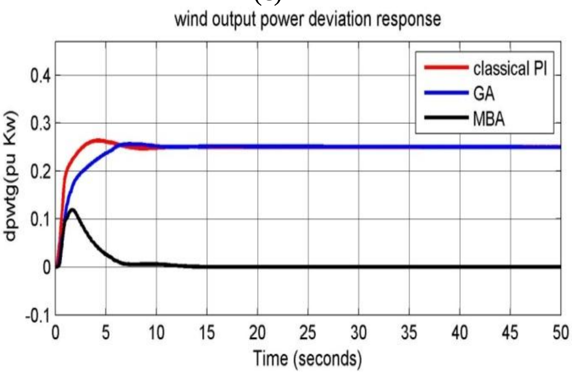

(d)

Fig. 7. Illustrates the system transient response curves for (a) wind frequency deviation (b) diesel frequency deviation (c) diesel output power deviation and (d) wind power deviation for 10 % step load change with 25 % change in input wind power and 25% K_{fc}.

5.4 Case 4

In this case, systems are tested under parameter variation conditions to confirm its effectiveness. The fluid coupling coefficient is chosen because it is the dominant parameter in the system as mentioned above. It means that the control system response is sensitive to this parameter. The operating conditions are represented as 30 % in wind input power and a variation in K_{fc} from -30% to 30%.

Results are presented in Fig. 8 show that the system dynamic response of the systems. As K_{fc} decreases, the values of IAE of the classical PI and GA systems highly increase. But the values of the MBA controller are much lower and almost constant than other two controllers. Table 4 shows the MBA based system response under fluid coupling variation. At change in K_{fc} equal to -30 % and -15 %, the steady state error change is 1.25 %. Also for rise time the change from base case (no fluid coupling change) doesn't exceed 1 %. And the change in maximum overshoot and settling time doesn't exceed 5 %. Then it is observed from the discussion that all performance parameters values vary within acceptable ranges and are nearly equal to the respective values obtained with nominal system parameter. So MBA based system is robust for fluid coupling variation and effective compared to other systems.

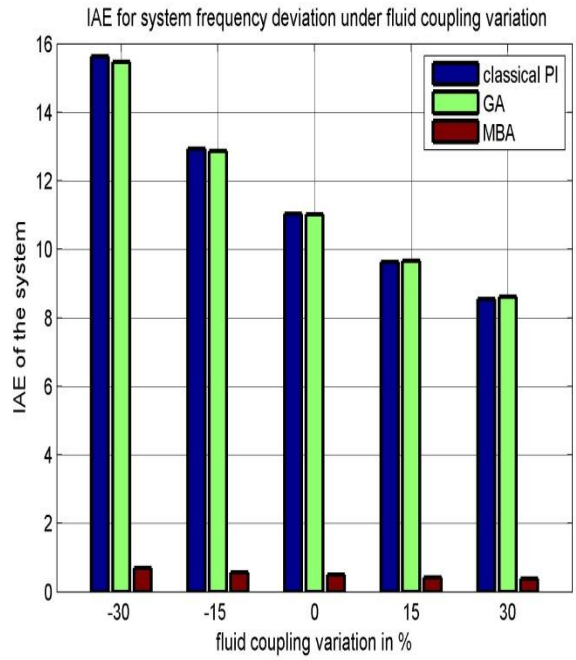

Fig. 8. IAE for wind frequency deviation under change in K_{fc}.

Table 4. Wind frequency performance parameters under fluid coupling variation.

% change in K_{fc}	Performance parameters of diesel frequency Δf_w under K_{fc} variation			
	O.S (Hz)	R.T (s)	S.T (s)	$e_{s.s}$ (Hz)
-30	0.0006	8.81e-04	18.25	7.116 e-08
-15	0.0006	1.847e-05	17.64	-4.33e-08
0	0.0005	1.88e-04	17.281	-4.33e-08
15	0.0005	5.45e-05	16.09	-2.56e-07
30	0.0005	0.00014	16.138	-6.8e-07

Table 5. Diesel frequency performance parameters under fluid coupling variation.

% change in K_{fc}	Performance parameters of diesel frequency Δf_d under K_{fc} variation			
	O.S (Hz)	R.T (s)	S.T (s)	$e_{s.s}$ (Hz)
-30	0.0135	0.0009	14.4727	7.11e-08
-15	0.0118	0.0009	13.8786	7.116e-08
0	0.0105	0.0004	13.5690	7.116e-08
15	0.0096	0.0007	12.3519	7.116e-08
30	0.0088	0.0001	14.7959	7.116e-08

6. Conclusion

The MBA based control scheme is presented to optimize the isolated hybrid system. This hybrid system consists of wind and diesel generators. MBA is designed in this paper to tune the PID gains of the blade pitch controller of the wind turbine. This system is compared with the classical PI and GA optimized controllers. Four case studies are studied in the simulation under load and input wind power disturbances and harsh conditions with increasing the fluid coupling between wind and diesel generators which is the dominant parameter. The results obtained from simulation confirm the robustness and effectiveness of the MBA-based scheme compared with other systems as it is able to damp the output deviation in frequencies and power of the system, reduces the overshot, reduces the settling time, and the dominant advantage of the system is that it is simple and converges quickly during optimization process.

Appendix

Appendix 1. Wind and diesel generators data

Inertia constant for wind system, H_w	3.5 s.
Inertia constant for diesel system, H_d	8.5 s.
Fluid coupling between wind and diesel systems, K_{fc}	16.2 pu kw/Hz
Governor gain, K_d	16.5 pu kw/Hz
Governor time constant, T_1	0.025 s.
Gain of hydraulic pitch actuator K_{p2}	1.25
Time constant of hydraulic pitch actuator T_{p1}	0.6 s.
Time constant of hydraulic pitch actuator T_{p2}	0.041 s.
Gain of data fit pitch response, K_{p3}	1.4
Blade pitch characteristic gain, K_{pc}	0.08 pu Kw/deg

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