DESIGN OF PID CONTROLLER OF HYBRID RENEWABLE WIND-DIESEL SYSTEM BASED ON MULTIOBJECTIVE OPTIMIZATION TECHNIQUES IN REMOTE AREAS

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Abstract: *As a main electric power source for remote area, standalone diesel generators have many problems such as operation at a load factor below 50%, cost of fuel including transportation and Co2 emissions. So the hybrid renewable wind-diesel system is a must for solving that problem. The output power of wind turbine is proportional to the cube of wind speed, which causes the fluctuations of the generated output power that may lead to frequency deviation for the hybrid micro grid system. Consequently, frequency is one of the conditions of quality conditions of any micro grid. So keeping frequency within the allowable standard limits is main objective. The micro grid system is consists of 150 KW wind turbine generator, 200 KW diesel generator to feed a load. MOPSO algorithm optimizes the gains of the blade pitch PID controller of the wind turbine generator. The proposed system is compared with GA-PID optimized and classical PI controllers. Simulation has been carried out with a step disturbance in wind input and load power with sensitivity analysis based on parameter variation. Results prove the robustness of MOPSO based scheme that damps the oscillations in the system frequency deviation response.*

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

1. Introduction

Renewable energy is the solution for solving the Fossil fuel problems [1]; they are available as natural sources of energy. Two of the most famous renewable energy is the wind and photovoltaic solar systems. They are suitable for remote and isolated islands [2]. Diesel generators are the main power source for supplying remotely region load. They are not efficient when operating at a low load factor below 50% of their rated capacity [3]. Diesel system can be installed with wind system. Hybrid wind-diesel systems reduce the fuel and reduce the generation costs in the small power system. In addition, the level of emissions can be minimized [4]. The load disturbances and intermittence behavior of wind supply cause fluctuation in the system frequency and power response [5]. Therefore; a PID pitch controller is designed and tuned for the hybrid system. Gains of the wind blades and diesel governor side are tuned by PID controller [6]. In [7], a variable structure controller scheme is proposed. In [8], genetic algorithm (GA) has been used. Particle swarm algorithm (PSO) is designed also to optimize the PID gains as in [9]. BFO is designed in [10]. PSO is a population-based approach which arose from swarming behaviors that observed in flocks of birds and swarm of bees [11]. MOPSO is a multiobjective algorithm that used to solve the problems with multiobjective functions.

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. MOPSO algorithm is discussed in section 4. Simulation results are discussed in section 5, and the conclusion is given in section 6.

2. System modeling

The wind-diesel system [7, 12] is illustrated in Fig. 1

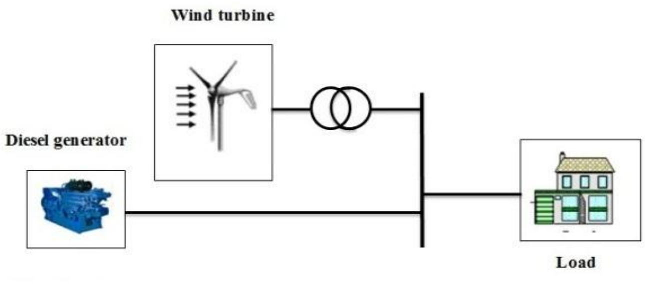


Fig. 1. Basic configuration of a hybrid system.

The hybrid model consists of wind and diesel generators to supply load. The pitch control system is used to control the wind turbine output power by controlling the angle of the blades. When pitch angle control is active, the controller compares the generated actual power to P_{max} (power reference) and compensates for power error by changing the blade angle and thus controls the output power.

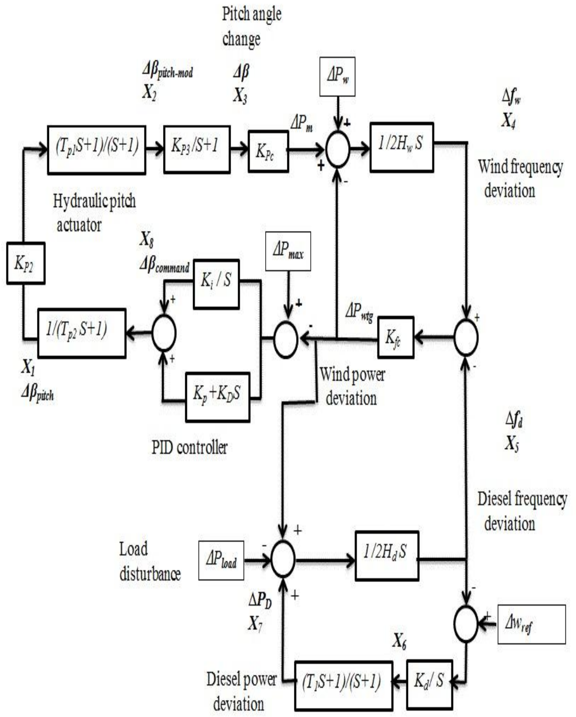


Fig. 2. Block diagram of wind-diesel power system.

And the state space equations are:

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

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

Where X is the system state variables, it is a vector of order 8th 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.

3. Control system and objective function

PID controllers are designed to select and control wind turbine blade's angle for achieving a better dynamic performance of the wind-diesel system. The input to the pitch system is formulated as:

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

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

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

$$J_1 = \int_0^t \left|\Delta P_{wtg}\right|.dt \quad (6)$$

$$J_2 = \int_0^t \left|\Delta f_w\right|.dt \quad (7)$$

$$J_3 = \int_0^t \left|\Delta P_D\right|.dt \quad (8)$$

$$J_4 = \int_0^t \left|\Delta f_d\right|.dt \quad (9)$$

The optimization problem is written as follows:

Minimize the fitness function J , Subject to the following constraints,

$$K_p^{min} \le K_p \le K_p^{max}$$
$$K_I^{min} \le K_I \le K_I^{max} \quad (10)$$
$$K_D^{min} \le K_D \le K_D^{max}$$

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

4. MOPSO algorithm

Real problems may have more than one objective aim to be optimized. In these problems, required objectives may be in conflict, and the optimal solution is the tradeoff between the possible solutions [13]. Multi-objective algorithm is developed to make PSO algorithm able to deal with MOO problems with some modifications. The best solution of every individual particle is updated with the new updated solution. Also, two major issues should be considered. Firstly, the fitness function assignment and selection should be addressed. Fitness has a proportional relation to the dominance rank of available solutions. And the swarm diversity blocks premature convergence then get a distributed Pareto front. The steps of MOPSO optimization algorithm are listed in [14].

As shown in Fig. (3), the way in which a general MOPSO algorithm works. First, the swarm is initialized. Then, a set of leaders is also initialized with the non-dominated particles from the swarm. The set of leaders is usually stored in an external archive. Later on, some sort of quality measure is calculated for all the leaders in order to select (usually) one leader for each particle of the swarm. At each generation, for each particle, a leader is selected and the flight is performed. Most of the existing MOPSOs apply some sort of mutation operator5 after performing the flight. Then, the particle is evaluated and its corresponding p_{best} is updated.

A new particle replaces its p_{best} particle usually when this particle is dominated or if both are incomparable (i.e., they are both non-dominated with respect to each other). After all the particles have been updated, the set of leaders is updated, too. Finally, the quality measure of the set of leaders is recalculated. This process is repeated for certain (usually fixed) number of iterations.

5. Simulation results

MOPSO is used to tune the PID gains of the blade pitch controller for the wind turbine according to the integral of absolute error (IAE) criteria based on minimization of the errors of wind and diesel frequencies deviations. Three case studies are discussed to test the proposed scheme under wind and load disturbances. MOPSO control scheme is compared with the classical PI and GA based systems.

```
Begin
    Initialize swarm
    Initialize leaders in an external archive
    Quality(leaders)
    g = 0
    While g < gmax
            For each particle
                    Select leader
                    Update Position (Flight)
                    Mutation
                    Evaluation
                    Update pbest
            EndFor
            Update leaders in the external archive
            Quality(leaders)
            g++
    EndWhile
    Report results in the external archive
End
```

Fig. (3) Pseudocode of a general MOPSO algorithm.

5.1 Case 1

A 30 % increase in the input wind power is applied to the system. Results of the wind-diesel system are illustrated in Fig. 4. The transient response of the deviation in frequency and power of wind and diesel shows that the MOPSO proposed system rejects the wind input disturbance by damping the oscillation in the output response, the peak overshoot is about 0.0068 Hz it is about 0.27 of classical and GA systems, it reaches to its peak value in 1.346 seconds (0.26 times of other systems) and the rise time is about 0.001 seconds. As shown in Fig. 4-a, classical and GA systems fail to reach zero steady-state error.

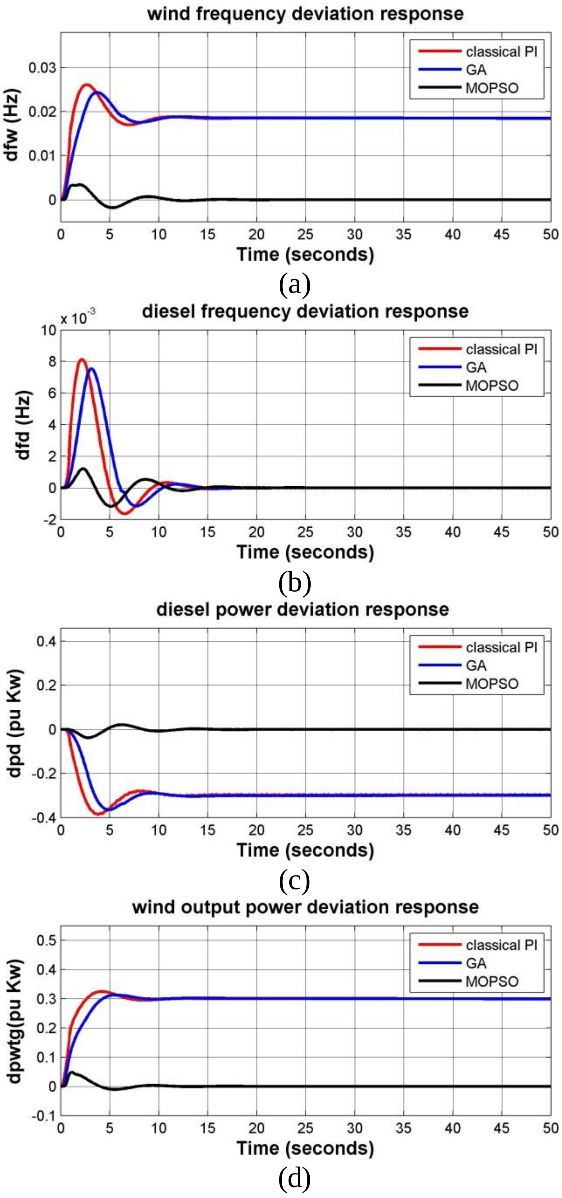


Fig. 4. System transient response curves for deviation in (a) wind frequency (b) diesel frequency (c) diesel output power and (d) wind power for 30% change in wind input power.

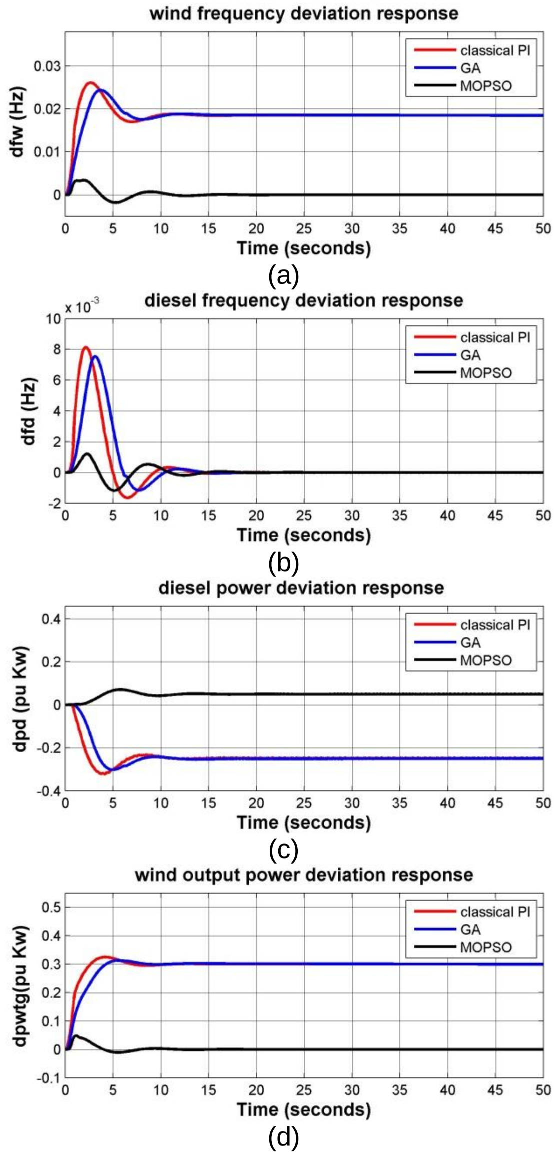


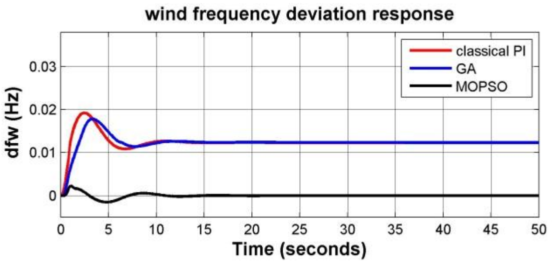
Fig. 5. Illustrates the system transient response curves for deviation in (a) wind frequency (b) diesel frequency (c) diesel output power and (d) wind power for 5 % step load change and 30 % change in input wind power.

5.2 Case 2

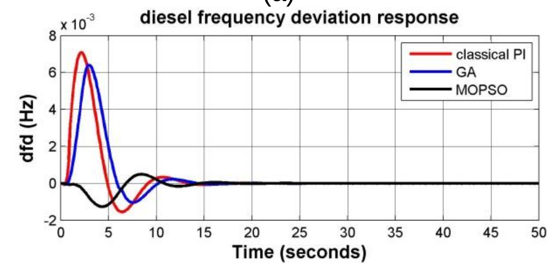
In this case, the operating conditions are represented as 5 % in load power change with 30 % in wind input power. Results illustrated in Fig. 5 prove that the response of the proposed MOPSO-based scheme damp all fluctuations of the deviation in frequency and power of wind and diesel generator.

5.3 Case 3

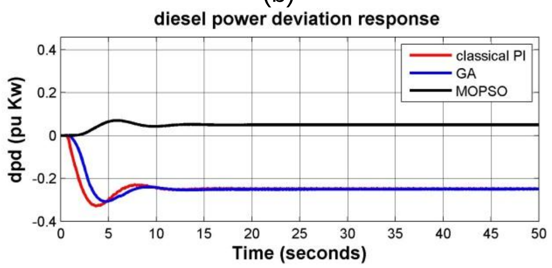
The operating conditions are represented as 5 % in load power change with 30 % in wind input power and 50 % increase in K_{fc}. K_{fc} is chosen because it is the dominant parameter in the system [7-8].Fig. 6 shows that the dynamic response of the proposed MOPSO-based scheme withstands these harsh operating conditions. The MOPSO system decreases peak overshoot to 0.005 Hz (0.32 times of other systems). Rise time and steady error are also very low compared to other systems. The fluid coupling parameter is also vary from -30% to 30%. Results are presented in Fig. 7. As K_{fc} decreases, the values of IAE of the classical PI and GA systems highly increase. But the values of the MOPSO controller are much lower and almost constant than other two controllers. The change in steady state error, rise time, maximum overshoot and settling time from base case doesn't exceed 3 %. Then performance parameters values vary within acceptable limits and are nearly equal to the values obtained with nominal system parameter. The simulation results prove the robustness and effectiveness of the proposed system over PI classical and GA-PID optimized control systems.



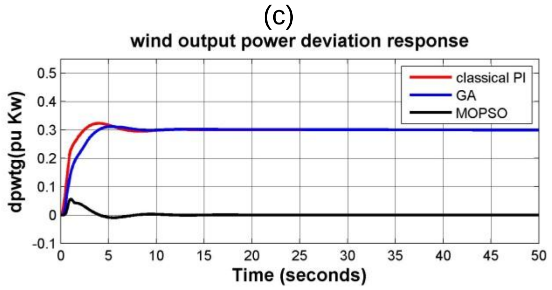
(a)



(b)



(c)



(d)

Fig. 6. 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 5 % step load change with 30 % change in input wind power and 50% K_{fc}.

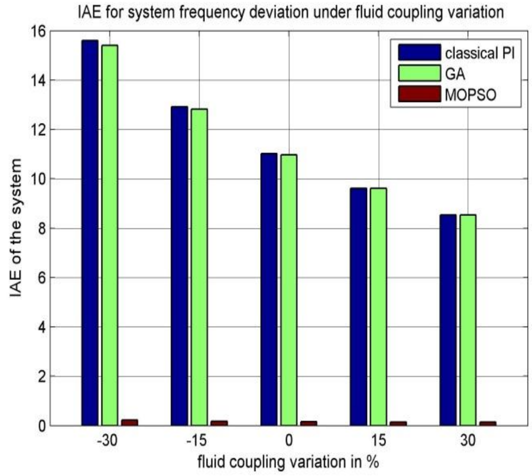


Fig. 7. IAE for wind frequency deviation under change in K_{fc}.

6. Conclusion

The MOPSO based control scheme is presented to optimize the isolated hybrid wind-diesel system. MOPSO is designed in this paper to tune the PID gains of the blade pitch controller of the wind turbine based on optimizing four objective functions .This system is compared with the classical PI and GA optimized controllers. Three case studies are studied in the simulation under load and input wind power disturbances and harsh conditions with increasing the fluid coupling coefficient.

The results obtained from simulation confirm the robustness and effectiveness of the MOPSO-based scheme compared with other systems in the following points.

- The proposed system is able to damp the output deviation in frequencies and power of the system, reduces the overshoot, and reduces the settling time.
- The Dominant advantage of the system is that it is simple and optimizes four objective functions at one time 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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