Optimal Controller Design for Automatic Generation Control Under Renewable Energy Disturbance

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Abstract This paper presents a comparison between four types of optimization algorithms to design a suitable controller optimally for automatic generation control (AGC) under disturbance due to wind generator variation. To select the proper optimization technique, two case studies are considered. The first one is a single-area AGC without disruption due to wind generators, and the other research is carried out with the wind generator disturbance. In both cases, the system had a time delay and a small disruption at a specific time. In each case, four optimization techniques are carried out, gravitational search algorithm, genetic algorithm, the crow search algorithm, and the harmony search algorithm. The simulation results are performed using the MATLAB program. Also, a comparison between the techniques is carried out. Finally, the paper suggested a suitable method to design the controller of AGC according to the cases studied.

Keywords Automatic generation control (AGC) · Crow search algorithm (CSA) · Genetic algorithm (GA) · Gravitational search algorithm (GSA) · Harmony search algorithm (HSA)

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1 Introduction

Power system utilities are connected through tie-lines in order to exchange power. AGC provides a means to achieve accepted operating conditions by regulating the tie-line flow and system frequency; multiple parameters can be used to control the frequency. The governor droop (R) is one of the parameters which can reduce the steady-state error in frequency [1–4] defined limits for selection of R. Another parameter, according to [5, 6], is the governor frequency bias setting (B), which should be not less than the area frequency response. According to Sahu et al. [7], numerous researches have presented different optimization techniques to design a controller for AGC, as in [8–10] with proper selection of the droop and governor frequency bias setting, the problem now is to design of a suitable controller [11, 12]. The most frequently used in industries is the Proportional–Integral (PI) controller. The challenge is to optimize the gains of the PI controller. Authors of [7] found that a controller for AGC can be designed by tuning the controller gains through suitable optimization algorithms. According to Gozde and Taplamacioglu [13], craziness-based PSO is used to obtain the gain values of the PI controllers. Ali and Abd-Elazim [14] obtained the PI controller gain values by bacteria foraging technique. Differential evolution (DE) algorithm is used in [15] to select the PI gain values. Sahu et al. [7] explained another method to design controller gain using neural network and fuzzy logic to adopt self-tuning as in [16–18]. Although, the importance of renewable energy studies, which were carried out worldwide [19–22], a lot of previous studies have not considered wind generators in AGC controller design. In this paper, a comparison between several optimization techniques is carried out in order to optimize the parameter of a PI controller for AGC. In this paper, a comparison is carried out for AGC without wind generator participation followed by comparison for complicated cases considering disturbance due to wind generators. Finally, the paper proposed a suitable method to optimize the controller gain values.

2 System Understudy

A single-area AGC system dynamic model with wind generator disturbances is shown in Fig. 1. The transfer function of the generator, turbine, and governor is modeled as the linear first order. The PI controller transfer function (TF) is:

$$\mathrm{TF} = K_p + K_i * \left(\frac{1}{S}\right) \quad (1)$$

The time delay is modeled as an exponential function with time constant (2 s) as explained in [23] and the gain values represent the droop and governor frequency bias.

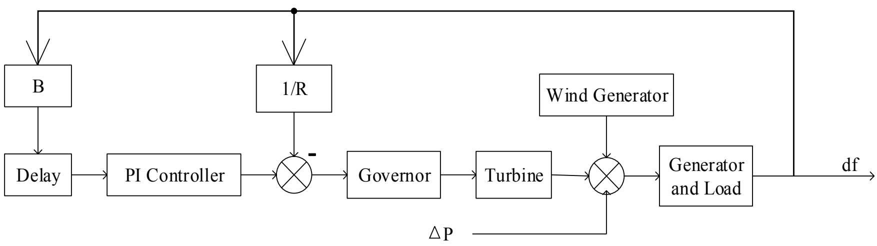


Fig. 1 Single-area dynamic model of AGC with wind generator disturbance, including a time delay

Governor model = $1/(1 + sT_g)$, turbine model = $1/(1 + sT_{ch})$, generator and load model = $1/(Ms + D)$, droop = $1/R$, governor frequency bias = B. The data of the system are presented as follows [23]. $T_{ch} = 0.3$ s, $T_g = 0.1$ s, $R = 0.05$, $D = 1$, $B = 21$, $M = 10$ s. Wind generator data with swept area 5538.96 m^2 and assume $C_p = 0.5$ is shown in Fig. 2.

From the data in Table 1, power can be calculated as follows:

$$\text{Power} = \frac{1}{2} * \rho * C_p * A * V^3 \quad (2)$$

where, ρ = density of air 1.225 (kg/m^3), C_p = power coefficient, A = swept area (m^2), V = wind speed (m/s).

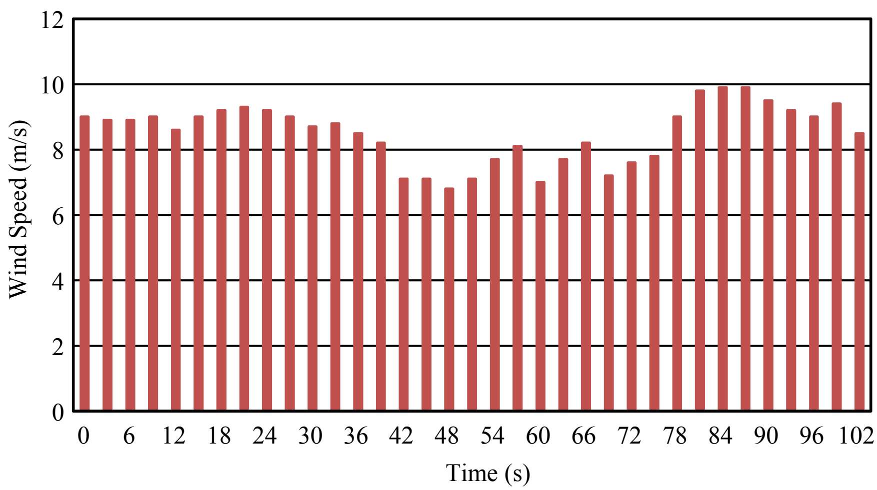


Fig. 2 Variation of wind speed data with time

Table 1 PI controller parameters and ISE using GA, GSA, crow, and harmony search methods without wind generator

Parameter	GA	GSA	Crow	Crow with GA and GSA results as the initial point	Harmony
K_p	0.4218	0.432	0.33544	0.4275	0.4430
K_i	0.2928	0.299	0.34935	0.2982	0.3043
ISE	6.81×10^{-5}	6.80×10^{-5}	7.02×10^{-5}	6.81×10^{-5}	6.81×10^{-5}
Maximum overshoot	0.0004874	0.0005723	0.001067	0.0005612	0.0006705

3 Problem Formulation and Results with Discussion

3.1 Problem Formulation

In this paper, the objective function is to minimize the integral of squared error (ISE), which can be calculated as follows:

$$\text{ISE} = \int_0^t \mathrm{d}f^2.\mathrm{d}t \tag{3}$$

where ‘d*f*’ is the deviation in system frequency from the desired value of frequency. The techniques such as GA, GSA, and crow search algorithms are presented in this paper. These techniques will aid in the selection of optimized parameters for a PI controller in order to minimize the ISE and reduce the integration of frequency error. There are two parts to this study, the first considers an AGC without any wind disturbance or its effects, and the second part will consider the effects of wind disturbance on the system.

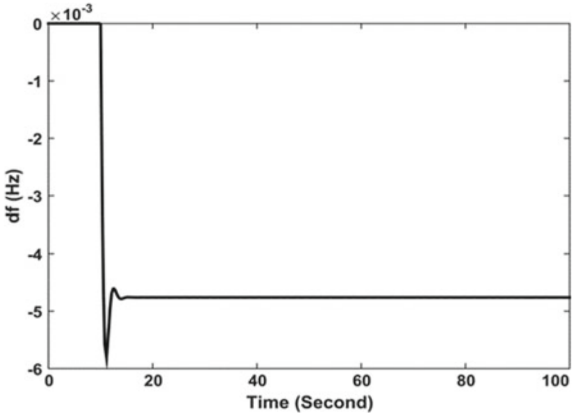
3.2 Results and Discussion

The single-area AGC model shown in Fig. 1 is used to optimize the gain of the PI controller using MATLAB with and without wind generator disturbances. The variation in both cases has been plotted with step size of 10 s.

3.2.1 Case Study 1

An AGC without wind generator disturbance and any type of control system has been considered. The error in frequency can be observed in Fig. 3. The steady-state error is high, around 5×10^{-3}.

Fig. 3 Frequency deviation with time without wind generator



After applying GA, GSA, crow with random initial point, crow with GA and GSA results as the initial value in order to improve the crow output and finally the harmony optimization technique. All methods have succeeded in minimizing the steady-state error, as shown in Figs. 4, 5, 6, 7 and 8. A comparison between gain values of all the mentioned methods is shown in Table 1. It is to be noted that the excellent initial point for CSA can improve its results.

Figure 9 illustrates df after the application of each technique to optimize the PI controller gain. Finally, it can be concluded that all optimization algorithms succeeded in improving system performance. Optimization with wind generator disturbances is considered henceforth.

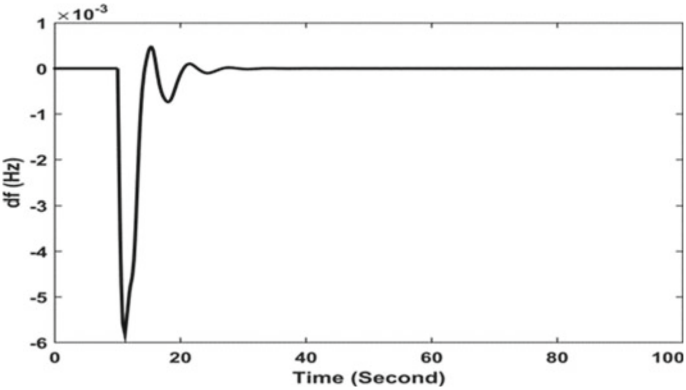


Fig. 4 ‘d*f*’ after using GA to optimize the PI controller gain

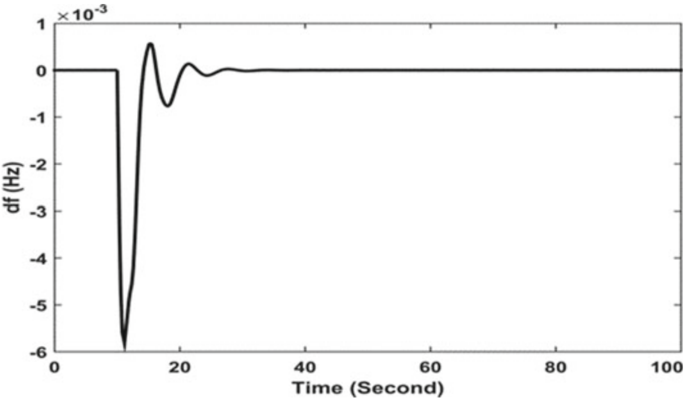


Fig. 5 'd*f*' after using GSA to optimize the PI controller gain

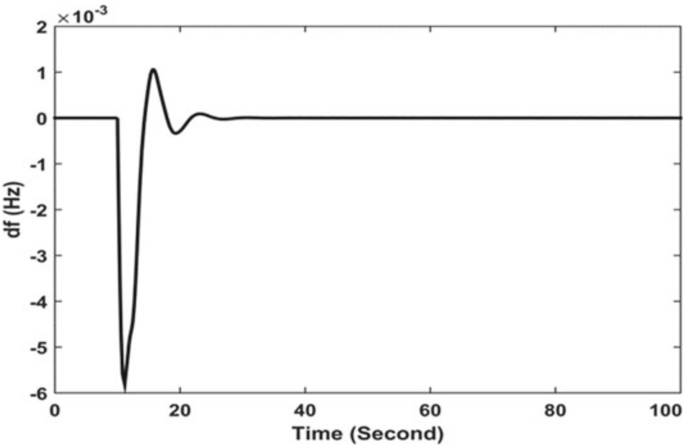


Fig. 6 'd*f*' after using CSA to optimize the PI controller gain

3.2.2 Case Study 2

AGC with disturbance due to wind generator variation is considered. The error in frequency with disturbance due to wind generator variation is shown in Fig. 10 in the absence of any controllers. It is clear that the steady-state error is high around 0.03.

After applying GA, GSA, c with random initial point, crow with GA and GSA results as the initial value in order to improve the crow output and finally the harmony optimization technique. The steady-state error and the maximum overshoot are improved, as shown in Figs. 11, 12, 13, 14 and 15. The values of PI controller gains and comparison between the techniques are shown in Table 2. Also, the proper selection of the initial CSA changes its output from unstable to a stable condition. Figure 16 shows the response of df due to each technique.

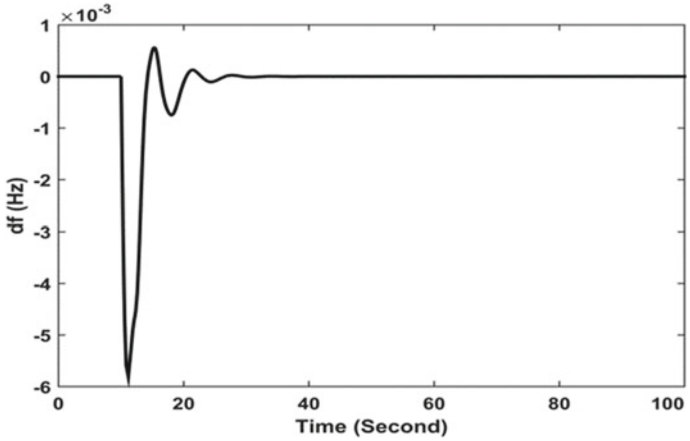


Fig. 7 'd*f*' after using crow with initials are considered as GA and GSA results to optimize the PI controller gain

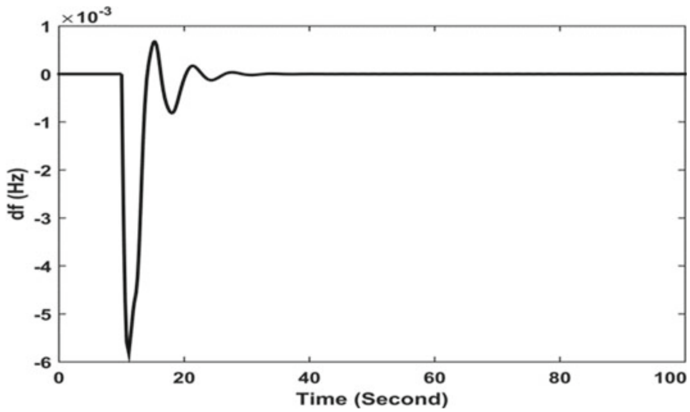


Fig. 8 'd*f*' after using harmony to optimize the PI controller gain

4 Conclusion

It is evident that the best method to optimize the PI controller in the cases presented is the GSA, which gave the best value of error and maximum overshoot. The result obtained by harmony was better than that of GA; it was observed that the crow method is highly reliant on the starting point as it gave excellent results when the initial point was assumed from the outcomes of GA and GSA methods. This paper has applied optimization techniques to evaluate the AGC performance. The paper has considered the application of wind energy as a disturbance to the system, which is considered being an essential issue with the ever-rising penetration of renewable

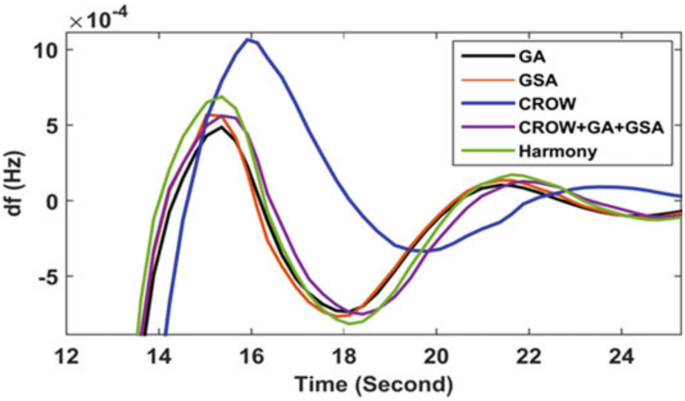


Fig. 9 ‘d*f*’ after using each technique to optimize the PI controller gain

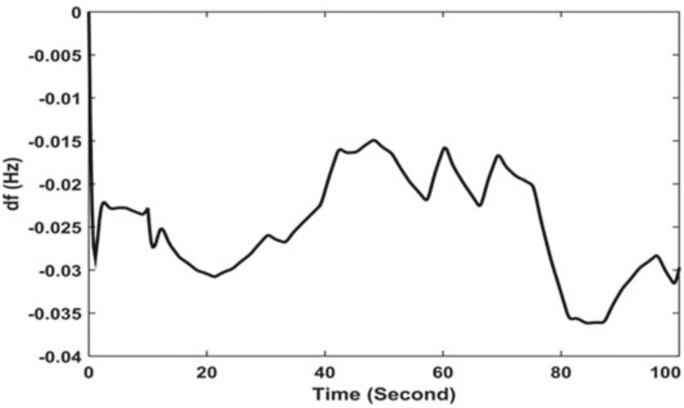


Fig. 10 ‘d*f*’ without control under disturbance due to wind generator variation

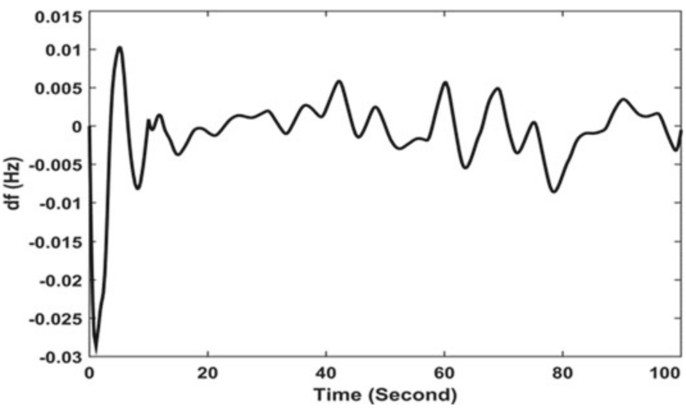


Fig. 11 ‘d*f*’ after using GA to optimize the PI controller gain

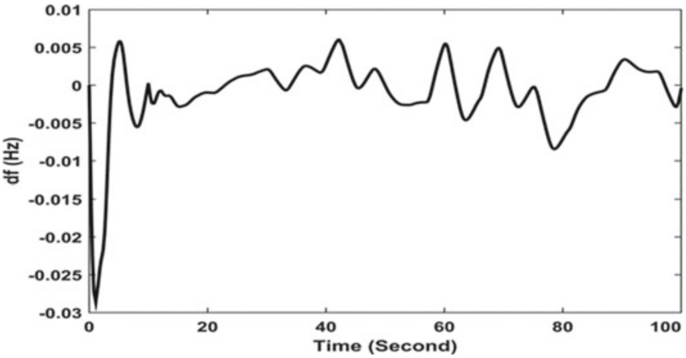


Fig. 12 ‘d*f*’ after using GSA to optimize the PI controller gain

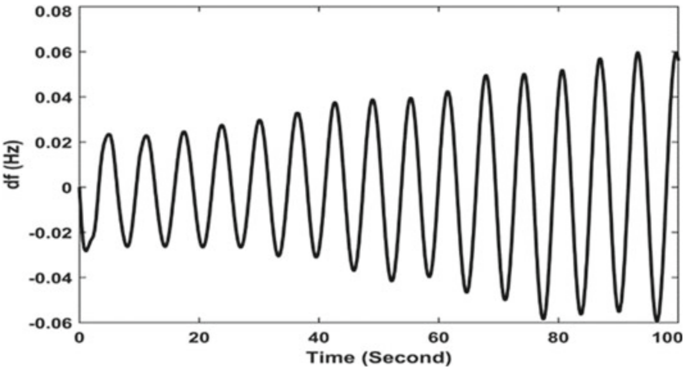


Fig. 13 ‘d*f*’ after using CSA to optimize the PI controller gain

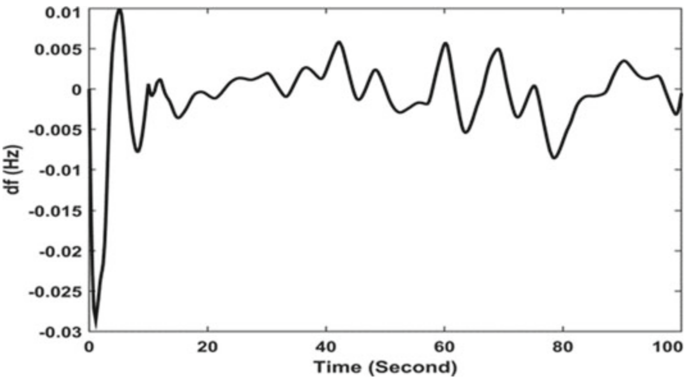


Fig. 14 ‘d*f*’ after using crow with initials are considered as GA and GSA results to optimize the PI controller gain

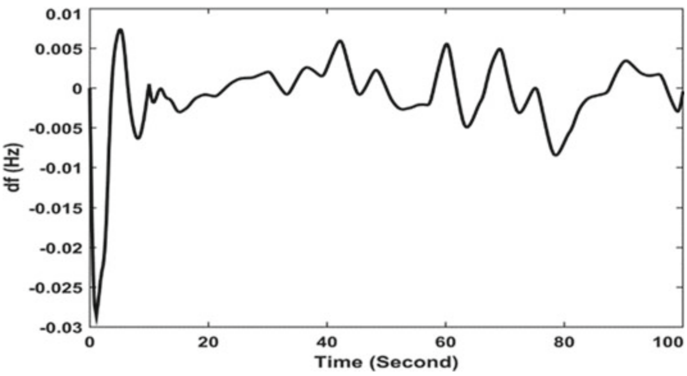


Fig. 15 ‘d*f*’ after using harmony to optimize the PI controller gain

Table 2 PI controller parameters and ISE using GA, GSA, crow, and harmony search methods with the wind generator

Parameter	GA	GSA	Crow	Crow with GA and GSA results as the initial point	Harmony
K_p	0.5469	0.4846	Unstable	0.5364	0.5085
K_i	0.3922	0.3321		0.3886	0.3532
ISE	0.0025	0.0023		0.00257	0.0024
Maximum overshoot	0.01024	0.005751		0.009823	0.0075

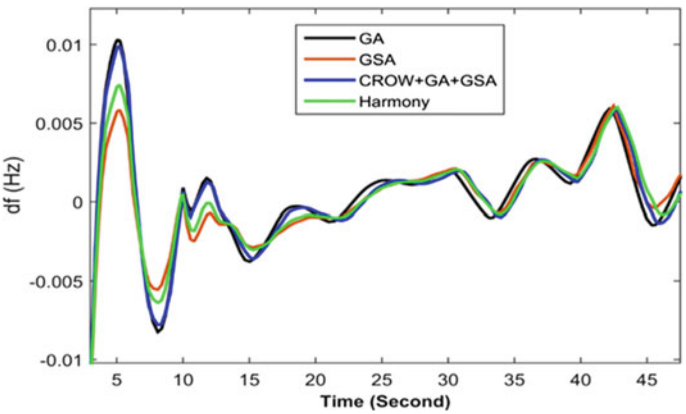


Fig. 16 ‘d*f*’ after using each technique to optimize the PI controller gain

energy. Finally, the paper presents the dependence of the crow search optimization method on the initialization parameters.

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