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Adaptive Frequency Control of an Isolated Microgrids Implementing Different Recent Optimization Techniques

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ABSTRACT

In recent years, significant improvements have been made in the load frequency control (LFC) of interconnected microgrid (MG) systems, driven by the growing demand for enhanced power supply quality. However, challenges such as low inertia, parameter uncertainties, and dynamic complexity persist, posing significant hurdles for controller design in MGs. Addressing these challenges is crucial as any mismatch between demand load and power generation inevitably leads to frequency deviation and tie-line power interchange within the MG. This work introduces sophisticated optimization techniques (grey wolf optimization (GWO), whale optimization algorithm (WOA), and balloon effect (BE)) for LFC, focusing on the optimal online tuning of integral controller gain (Ki) for controlled loads. The WOA regulates the frequency of the system so variable loads can be accommodated and 6 MW of PV is added to the MG. A PV and a diesel generator-powered isolated single area MGs with electrical random loads are managed by the adaptive controller by regulating the frequency and power of the PV. Online tuning of integral controllers is possible using the WOA. A comparison is carried out between the WOA+BE and three other optimizers, namely the GWO, GWO+BE method, and the WOA. This paper shows the effect of add BE identifier to standard WOA and GWO. MATLAB simulation results prove that the BE identifier offers a significant advantage to the investigated optimizers in the issue of adaptive frequency stability even when disturbances and uncertainties are concurrent.

1. Introduction

Globally, we strive to transition to a low-carbon life through the use of renewable energy sources (RESs), which provide electricity at reasonable prices. The goal of becoming emissions-free by the

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mid-century or shortly thereafter is being pursued by an increasing number of countries [1], [2]. Currently, conventional power generation methods, particularly fossil fuels, are causing major climatic problems [3]. Among scientists and researchers, solar, hydrogen and wind are considered to be sustainable and attractive renewable resources (RE) [4]-[6]. Many agricultural and industrial activities require reliable and clean energy sources, which can be obtained from renewable sources. Additional benefits include their free and economical nature and their role in promoting environmental sustainability [7].

Providing consumers with reliable, efficient and secure electricity is the primary purpose of a power system. Consumers have power requirements ranging from a few tens of kilowatts for domestic use to hundreds of megawatts for industrial use. Although the power system is vast and intricate, it comprises an electrical network encompassing generation station, transmission lines, distribution networks, and loads spread across a considerable area [8]-[10]. Depending on the needs of consumers, the load on the power system changes from time to time. For the power system to remain stable and operate reliably, well-designed controllers are required to regulate the system variations. As known, active power greatly influences frequency and reactive power greatly influences voltage. Thus, microgrid control issues can be separated into two independent problems. In one case, active power is regulated along with frequency, and in another case, reactive power is regulated along with voltage. Load frequency control (LFC) integrates both active power control and frequency regulation [11], [12].

The subject of LFC has been extensively researched and studied over a considerable period within power systems. The LFC plays a crucial role in ensuring the reliability of a power system as an ancillary service with changes in structure of the system and the escalating size and intricacy of interconnected systems, its significance has escalated [13], [14]. The total production of power must match the total load demand and associated system losses for interconnected power systems to operate efficiently [13]. Therefore, when the demand deviates by a small amount from its nominal value, the operating point of the power system changes, which may result in deviations in the nominal frequency of the system and scheduled tie-line power exchanges, which may result in undesirable effects [15]. Optimal control theory was used to consider a dynamic aspect of LFC and ref., [16] formulates the problem as a parameter optimization problem. A system transient is minimized and the control action minimized in accordance with the steady state, dynamic limit, and area decentralization by finding the proportional and integral gain of a PI controller. A frequency control method for the MG is of great importance due to its high absorption capacity as well as its potential impact on the MG [17]. Therefore, in an isolated MG, a robust controller that performs well under a variety of conditions is essential [18]. As far as practicable, LFC maintains a balanced power output within parameters that deviate from the nominal value and within parameters that allow it to function dynamically in a fashion that is practical [19].

In LFC applications, integral controller (I) is commonly used to adjust gain offline. However, this controller yields poor dynamic performance with changing the load and system parameters. This problem has been solved by proportional integral (PI) controllers with fixed parameters [20]. Several types of controllers have been used to formulate a better LFC response, including model predictive control [21], adaptive control [18], and conventional PID control [19]. Further, there have been a number of robust, optimal, and intelligent control methods discussed for LFC [22]-[24]. An observer-based optimizer with unknown inputs has also been presented in [25]. There have been several industrial applications of WOA for optimizing gains of conventional controllers [26]. PI-FOPID controllers with WOA can improve the frequency response of hybrid MGs. Also comparing the results of WOA with GWO based on multi-layer perceptron’s (MLPs) was done in [27], [28]. As a solution to this issue, this study recommended adjusting the balloon effect (BE) for greater sensitivity to disturbances and parameter variations [29].

In this study, an algorithm combining WOA and BE is proposed for determining adaptive frequency regulation in smart MG. Models include a combination of diesel generators, electrical loads, and PV systems. In this study we examine the ability of the (WOA+BE) technique to deal with fluctuations in frequency by incorporating both random demand loads and PV system. Furthermore, it is compared with, GWO, fixed integral controller, standard WOA and GWO+BE optimizer to show its robustness and accuracy. In this work, there are a number of outstanding features, including:

- An online adaptive LFC is generated using the WOA+BE optimizer and the output of a simplified MG transfer function.
- We discuss the effectiveness of the WOA + BE identifier in optimizers that are used to regulate the integral controller's frequency and the effectiveness of a GWO + BE optimizer for MG.

2. Investigated Dynamics Model and Applied Optimizers

2.1. Power System Dynamics Model

In the proposed MG power system as in (Fig. 1), the dynamic model is represented by the next equations [30]. A Load-generator dynamic relationship between supply error ΔPd -ΔPL and frequency deviation (Δf) can be expressed as:

$$\Delta f = \left(\frac{1}{M}\right).\Delta Pd - \left(\frac{1}{M}\right).-\Delta PL - \left(\frac{D}{M}\right).\Delta f \tag{1}$$

The diesel generator’ dynamic can be expressed as:

$$\Delta Pd = \left(\frac{1}{Td}\right).\Delta Pg - \left(\frac{1}{Td}\right).\Delta Pd \tag{2}$$

Governors' dynamics can be described as follows:

$$\Delta Pg = \left(\frac{1}{Tg}\right).\Delta Pc - \left(\frac{1}{R.Td}\right).\Delta f - \left(\frac{1}{Tg}\right).\Delta Pg \tag{3}$$

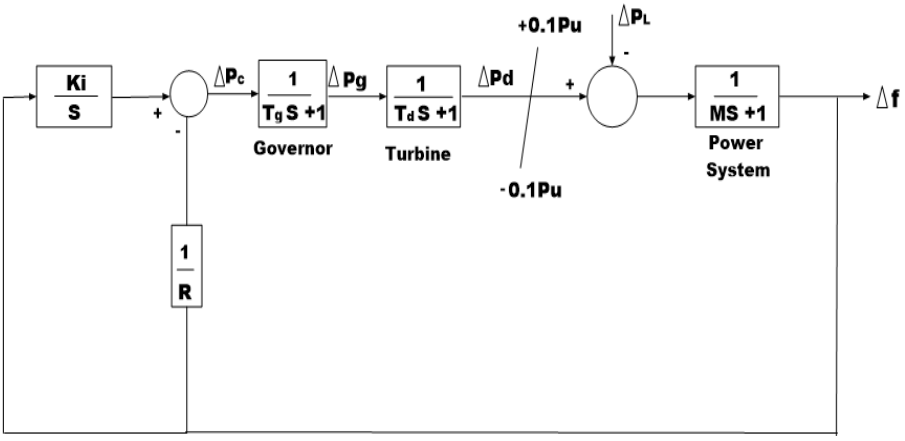


Fig. 1. Block diagram of the model of microgrid power system

where Δ*Pg*: The governor output change; Δ*Pd*: Changing the diesel power; Δ*f*: changing the frequency; Δ*PL* changing the load; Δ*Pc*: modifying the supplementary control; *M*: Represents the equivalent inertia constant; *D*: Denotes the equivalent damping coefficient; *R*: Stands for the speed drop characteristic*;* *Tg*: Represents the governor time constant; *Td*: Signifies the turbine time constant t and (Δ*f,* Δ*Pd,* Δ*Pg*) equal to ($\frac{\mathrm{df}}{\mathrm{dt}}$, $\frac{\mathrm{dPd}}{\mathrm{dt}}$, $\frac{\mathrm{dPg}}{\mathrm{dt}}$), respectively.

2.2. WOA Method

Humpback whales emulate the social behavior of whales using the WOA. Using bubble-net hunting as an inspiration, the algorithm was developed. There are spindle cells in whales' brains that are similar to those in human brains, say Hof and Van Der Gucht [27]. As a result of these cells, humans are able to judge, feel emotion, and have social behavior. It is believed that whales are highly intelligent animals that move. Taking its inspiration from humpback whale hunting behavior, the WOA algorithm has been developed. A humpback whale usually hunts krill's or small fish near the surface of the sea. The bubbles are created along a circle or 9-shaped path as they swim around the prey. Following is a description of the mathematical model for WOA:

- Encircling the prey.
- Bubble net attack.
- Search for prey.

In order to catch prey, humpback whales will circle them as soon as they identify their location. In the WOA algorithm, the assumption is that the current best candidate solution is close to the optimal design since the exact optimal position in the search space is unknown. Fig. 2 illustrates a flowchart of the proposed whale optimization algorithm [31].

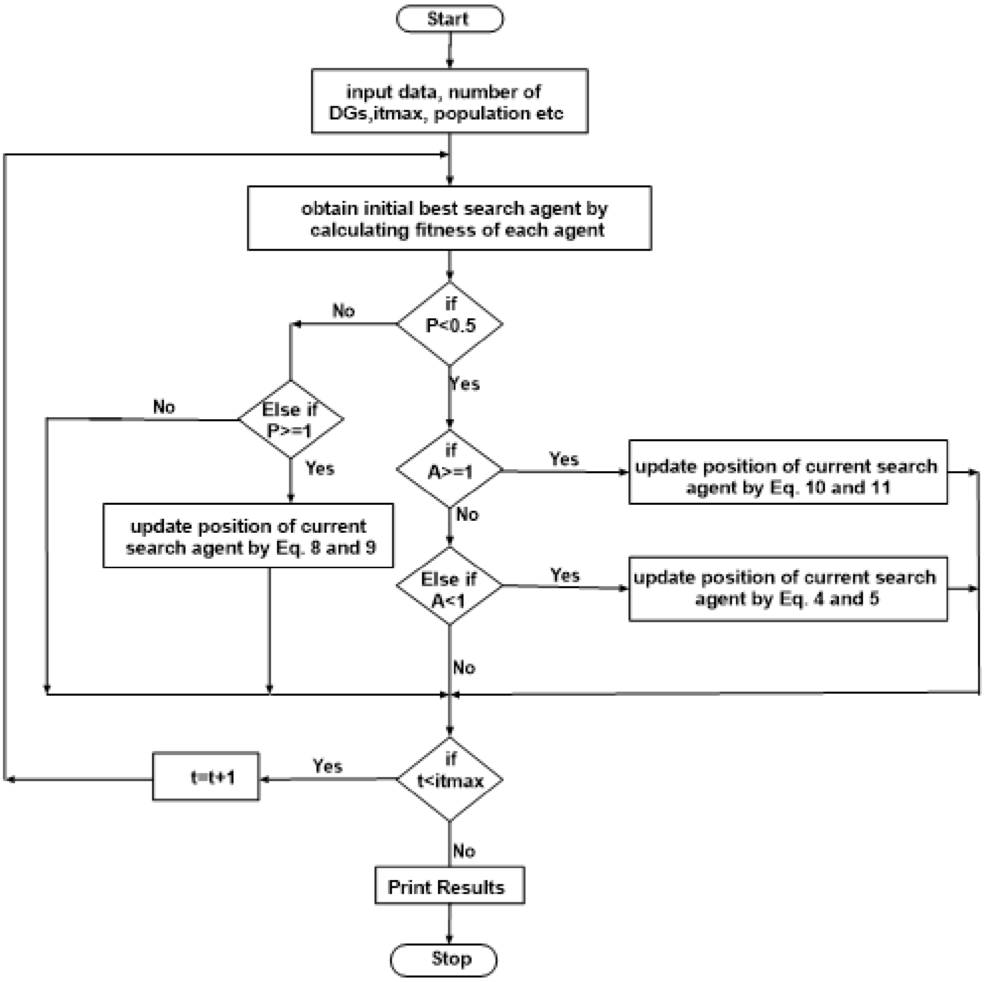


Fig. 2. Flowchart of the WOA

2.3. GWO Method

Grey wolves (GWs), belonging to the canidae family, are apex predators and exhibit social hierarchy, tracking, encircling, and attacking prey, which are mimicked in the GWO. GWs packs are the most common form of life for GWs. The group size is 5-12 on average. It is particularly interesting to note how rigid their social hierarchy as in [32]. Alpha (α) is male or female who leads the group. It is primarily the α who decides where and when to hunt, sleep, and wake up. There is a consensus between the α and the pack regarding all decisions. Betas (β) is the second level of the GW hierarchy.

Beta wolves assist the α wolf with decisions and other activities in the pack. It is probable that one of the α will pass away or become very old, so the β wolf can be the best candidate to be the α wolves should be respected, but β wolves should also command lower-level wolves [33]. The third level of the GW hierarchy is delta wolves (δ). They have to subjected to the first and second levels of the GW hierarchy (α and β), but they predominate the fourth level of the GW hierarchy (ω). They are hunters who help the α and β when hunting prey and they provide the food for the herd [33]. The lowest ranking GW is ω. In this case, the ω acts as a scapegoat. A dominant GW must always submit to an ω wolf. It is the last group of GW that is allowed to eat. Despite the fact that it may appear that the ω does not have a significant role in the pack, there have been reports that when the ω is lost, the entire pack suffers internal problems and fighting [33]. GWs also exhibit a group hunting behavior in addition to their social hierarchy. The computational flowchart of adaptive GWO in shown in Fig. 3. The following are the main phases of GW hunting according to [33]:

- In the first step, the prey is tracked, chased, and approached.
- Encircling the prey and harassing it until it remains motionless.
- Approach the prey and attack it.

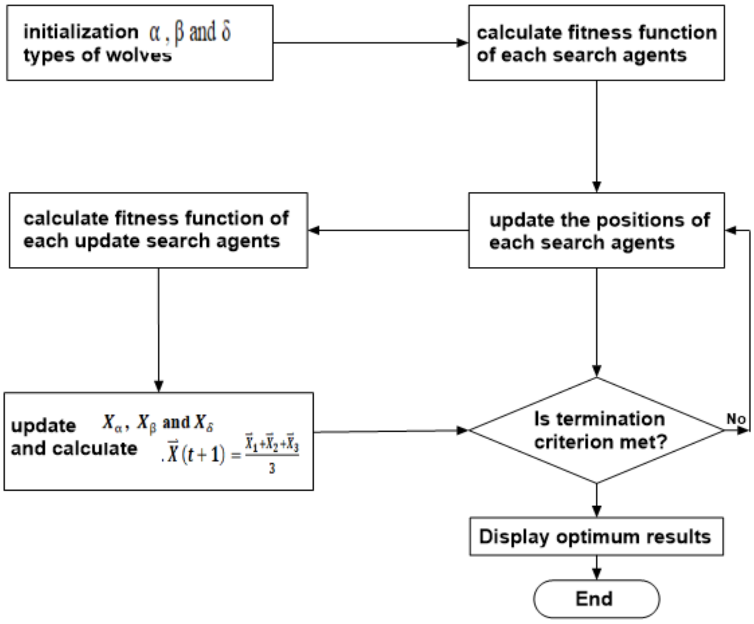


Fig. 3. Flowchart of adaptive GWO

2.4. BE Identifier (BEI) Method

The BE is the result of air expanding the balloon. A system challenge like disturbances and parameter uncertainty can greatly affect $G_i(s)$ through the BE. The BEI affects the objective function of a strategy at any iteration, as illustrated in Fig. 4-a. As a result, this method enhances the algorithm process [29]. Any iteration (*i*) of MG will have the following online transfer function:

$$G_i(s) = \frac{Y_i(s)}{U_i(s)} \tag{4}$$

Additionally, $G_i(s)$ depends on its previous value$G_{i-1}(s)$. AL_i Is the gain, while $G_0(s)$ is the nominal process transfer function.

$$G_i(s) = AL_i G_{i-1}(s) \tag{5}$$

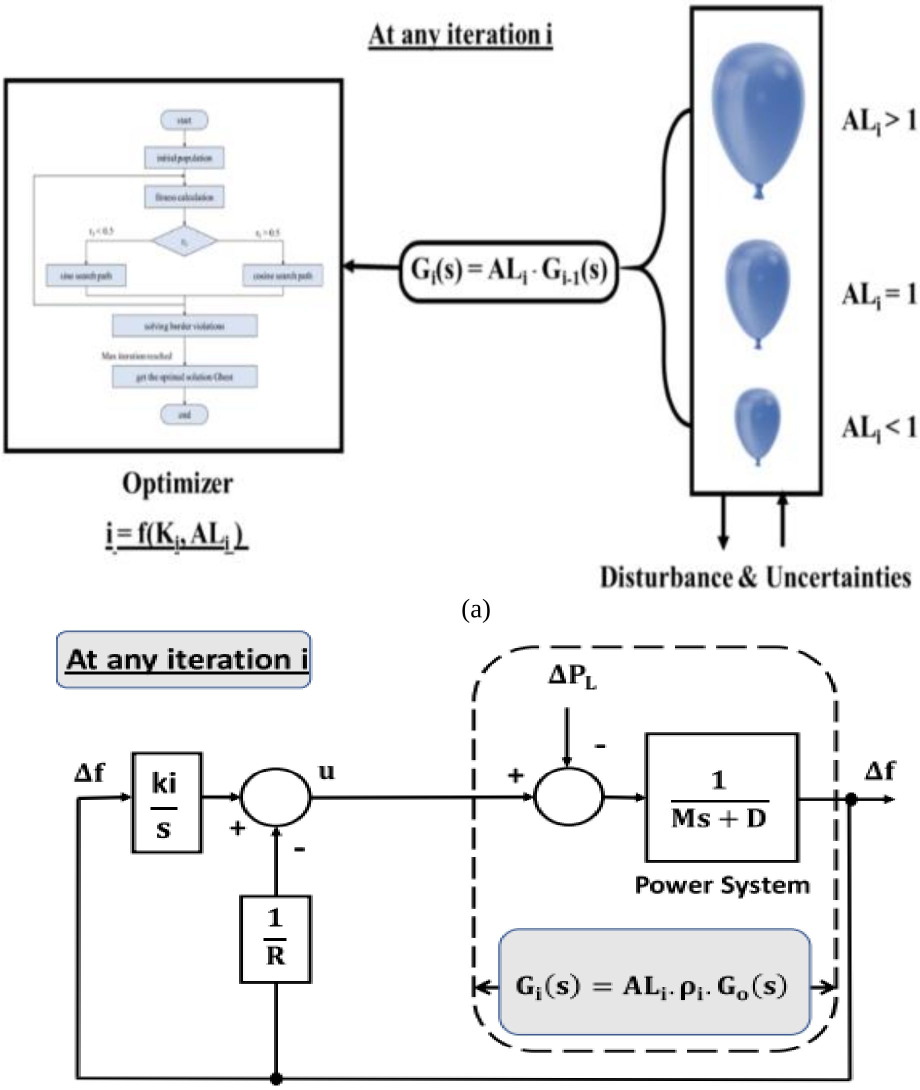
$$G_{i-1}(s) = \rho_i G_0(s) \tag{6}$$

Where

$$\rho_i = \prod_{n=1}^{i-1} AL_n \tag{7}$$

$$G_i(s) = AL_i \rho_i G_0(s) \tag{8}$$

The coupled optimization technique is positively affected by BE as a system identifier that detects system difficulties, such as load disturbances and system parameter changes.



(a)

(b)

Fig. 4. a) BEI method, b) model of MG for any optimization+BE

2.5. Optimizer Based BEI

The simplified MG model shown in an optimization strategy-based BEI is discussed, with Fig. 4-b aiding in calculating parameters for a second-order closed-loop system [29];

$$\mathrm{T.F} = \frac{wn^2}{S^2+2\eta Wn+Wn^2} = \frac{\frac{Ki}{Mo}}{S^2+\left(\frac{\left(Do+\frac{1}{Ro}\right)}{Mo}\right)S+\frac{Ki}{Mo}} \tag{9}$$

where D_o, R_o and M_o are the nominal values of D, R and M, respectively.

$$\omega_n = \sqrt{\text{Ki/Mo}}, \eta = \frac{\frac{(Do+\frac{1}{Ro})}{Mo}}{2\omega_n} \tag{10}$$

$$T_r = \frac{\pi-\sqrt{(1-\eta^2)}}{\omega_n\sqrt{(1-\eta^2)}}, T_s = \frac{4}{\eta\omega_n}, M_P = e^{\frac{-\pi\,\eta}{\sqrt{(1-\eta^2)}}} \tag{11}$$

This represents the objective function of the optimizer-based BEI.

$$J = min \sum(T_r + T_s + M_P) \tag{12}$$

The J of the optimizer-based BE depends on AL_i and k_i to tackle system challenges.

3. Results and Discussion

For tuning LFC controllers of small isolated power systems, a modified technique optimizer +BE is proposed. The simulation tests are performed using MATLAB/Simulink. Fig. 5 show a proposed 20MW diesel generator for the MG. Table 1 and Table 2 present the nominal parameters of the system and the parameters used in the WOA, respectively. In addition, Table 3 lists the parameters of the applied GWO.

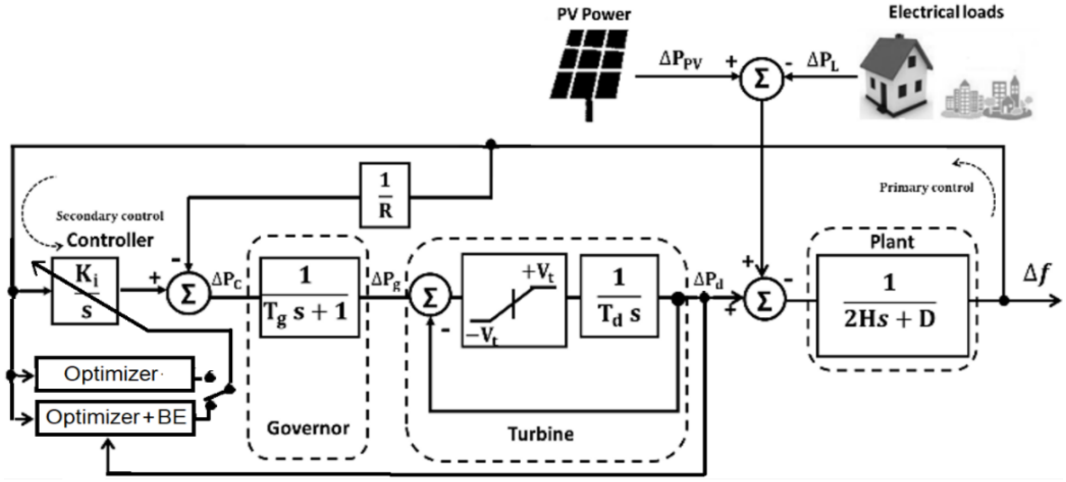


Fig. 5. The investigated MG system

Table 1. Parameters of the MG under study

Symbols	Unit	Value
D	Pu/Hz	0.015
H=(M/2)	Pu.sec	0.08335
R	Hz/Pu	3
Tg	Sec	0.08
Td	sec	0.4

Table 2. Parameters of the WOA

Symbols	Value
Population Size (K)	5
Maximum Iteration (IT max)	100
A	2
Initial Values for Design Variables (Ki)	[0.040,0.025,0.017,0.08,0.030]

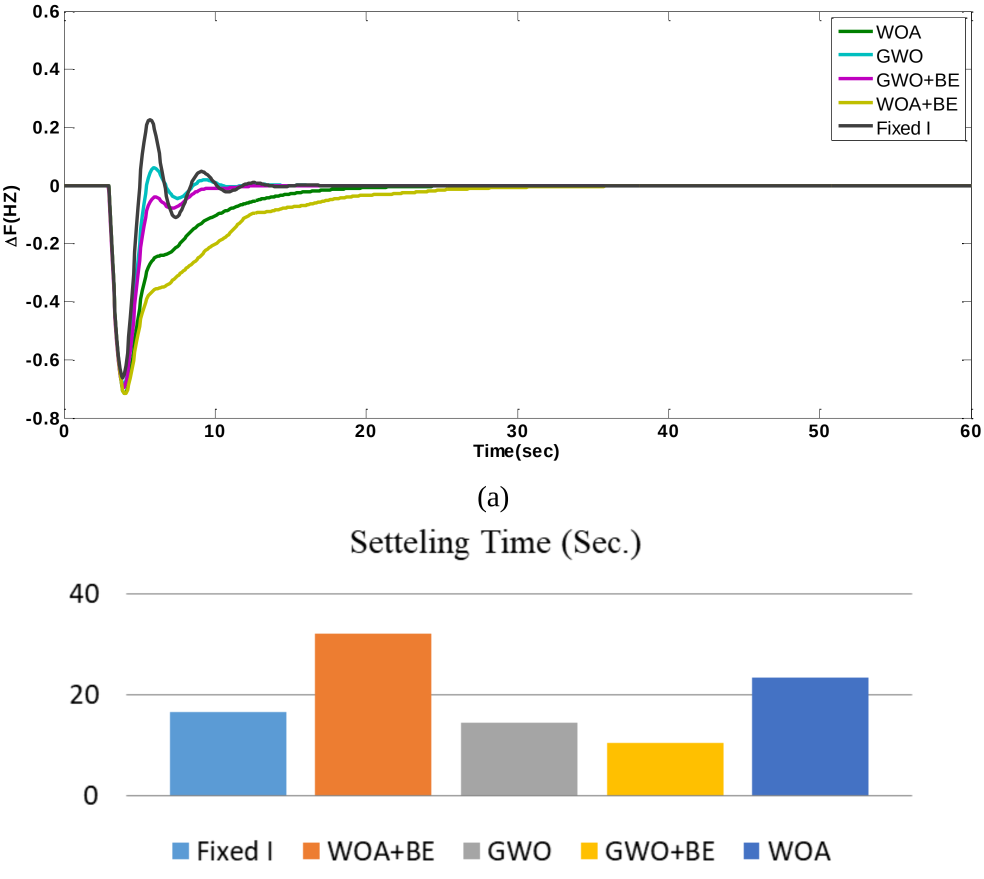
3.1. First Case: Load Change

Testing is carried out using nominal parameters and step-by-step load changes in this case. This case involves changing the load from 0 *pu* to 0.02 *pu* at 3 seconds. Also considered are the WOA +

BE and GWO + BE dead-bands of the governor, in addition to the turbine GRC. It is 10% per minute for the turbine generation rate constraints (GRC) while 0.05 *pu* for the governor dead-band [30]. As shown in Fig. 6, system frequency deviation changes when integrated controllers with fixed parameters, adaptive integral controllers using WOA, GWO, GWO+BE and WOA+BE are applied. As compared to using an integral controller with fixed parameters, GWO or WOA, the results indicate that M_p can be minimized to approximately 10% when using normal (WOA or GWO) +BE.

Table 3. GWO parameters

Symbols	Value
Population Size (K)	5
Maximum Iteration (IT max)	50
Convergence constant (a)	(2)



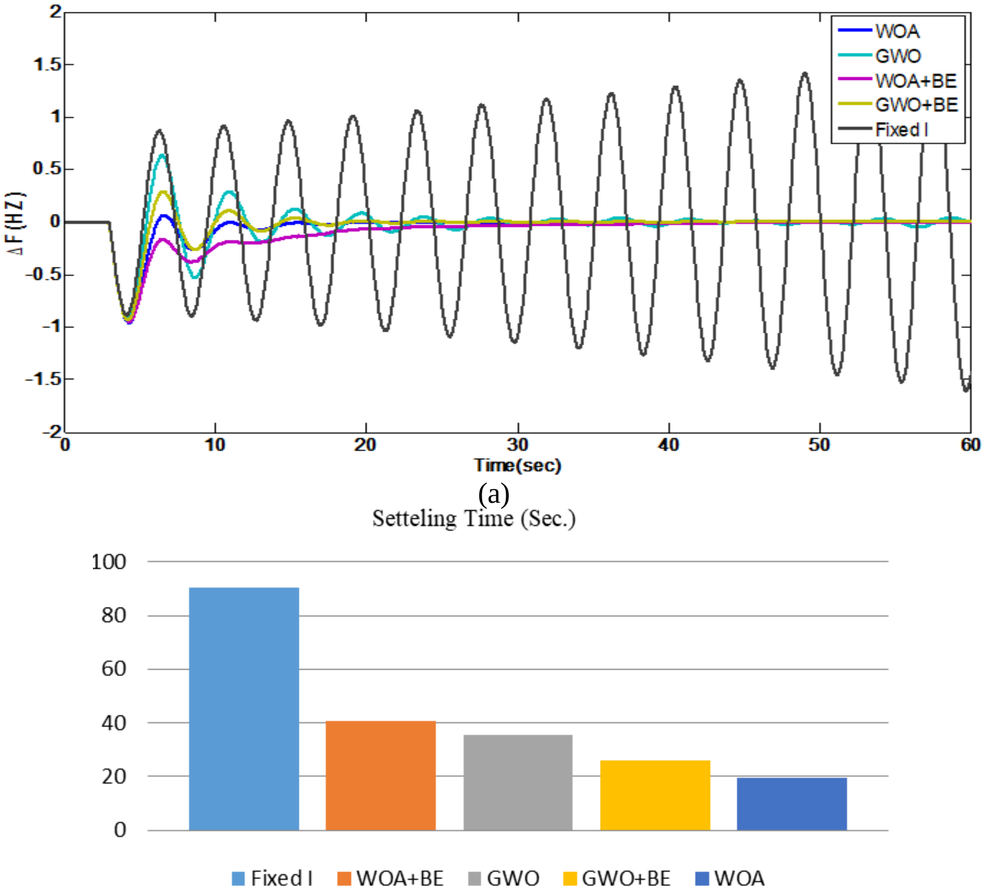
(a)

(b)

Fig. 6. The system response for case 1 includes: (a) frequency deviation, and (b) column charts depicting settling times

3.2. Second Case: Change in System Parameters

Evaluate a proposed control scheme considering variations in parameters. The demand load remains constant, while the time constant of the power system is increased by 200%. Additionally, D is reduced to 0.08 pu MW/Hz, and the time constant is further increased by 200%. In Fig. 7, five different controllers are compared (fixed I, tuned by WOA, tuned by GWO, GWO+BE and WOA+BE). Based on Fig. 7, the frequency response of the fixed-parameter I controller and GWO are deemed unacceptable. WOA demonstrates effectiveness in addressing these issues. Moreover, systems employ the proposed WOA+BE exhibit superior performance compared to those using the standard WOA. Similarly, the performance of the proposed GWO+BE system surpasses that of the standard GWO. Additionally, system with proposed WOA+BE demonstrates best performance and it is recommended to be applied to such case of study.



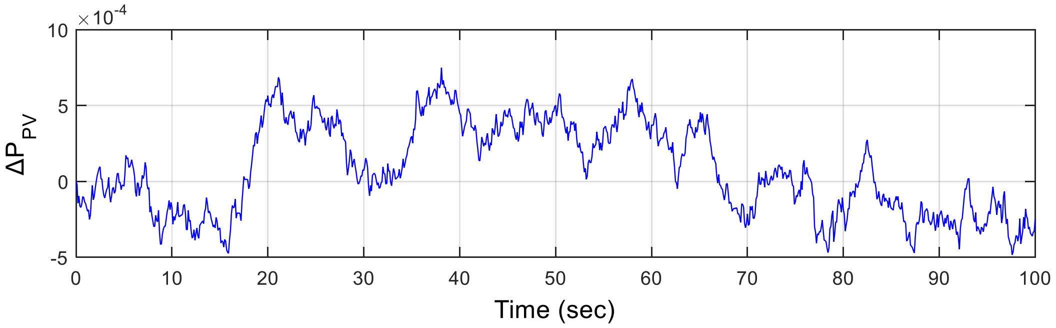
(a)

(b)

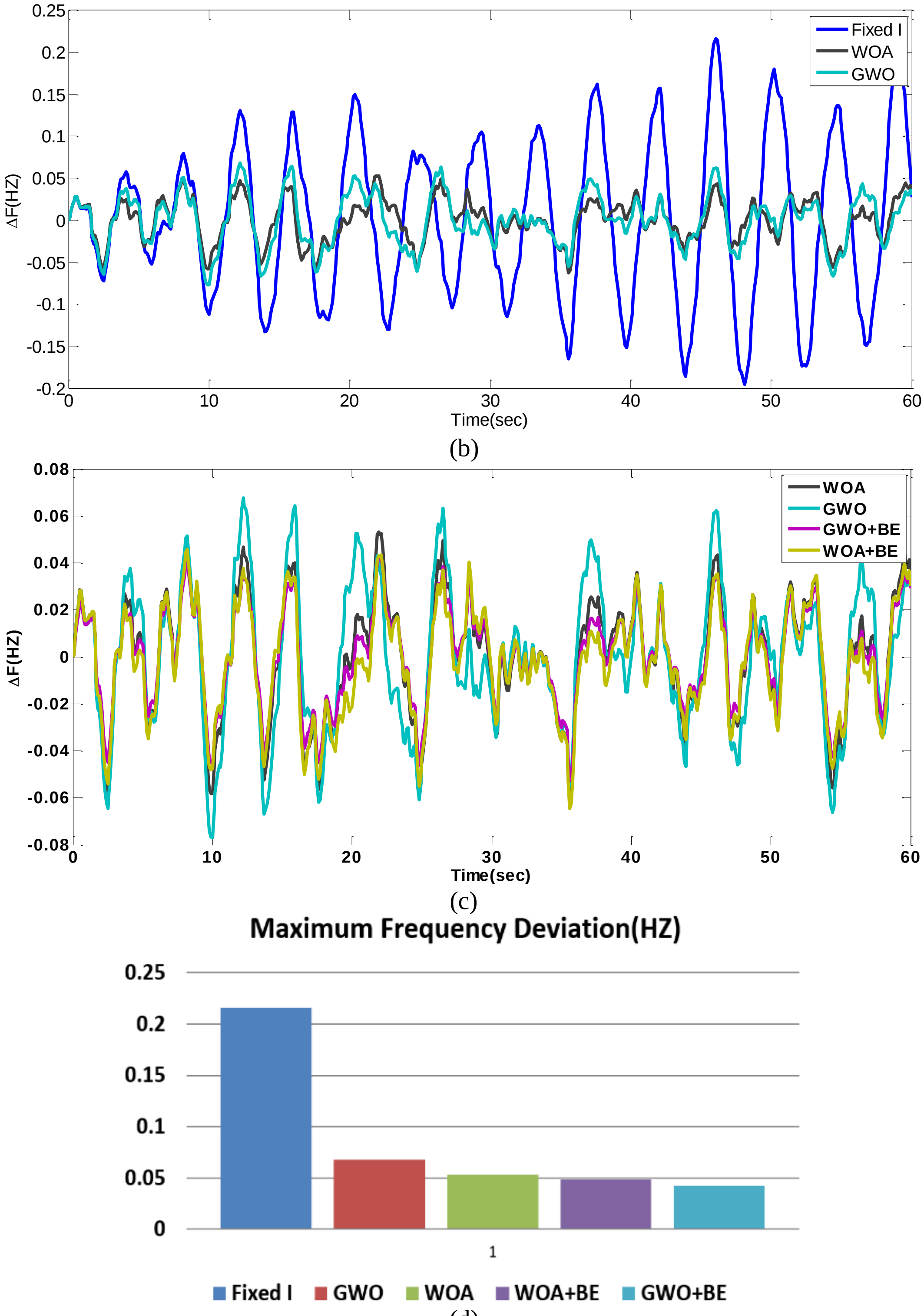
Fig. 7. System response for case 2: (a) frequency deviation, (b) column charts of settling times

3.3. Third Case: Impact of Integrating PV System

The system has been tested under multiple operating conditions. An additional 6 MW PV generator is added to the MG as an additional generation source while testing with variable load and nominal parameters. PV power is illustrated in Fig. 8-a. Represented in Fig. 8-b are the comparisons between five different controllers (fixed I, tuned by WOA, tuned by GWO, GWO+BE and WOA+BE) Fig. 8-c illustrates the change in system frequency deviation when applying GWO, using proposed GWO+BE, applying WOA and using proposed WOA+BE. According to the Fig. 8-d, the GWO exhibit the most favorable frequency response for the system when paired with the conventional controller.



(a)



(b)

(c)

(d)

Fig. 8. The system response for case 3 includes: (a) PV power, (b) frequency deviation using fixed I, WOA, and GWO, (c) frequency deviation by using WOA, WOA+BE, GWO and GWO+BE and (d) maximum frequency deviations

Additionally, integrating WOA with BE yields better performance than the standard WOA approach. Also, the proposed GWO+BE system performs better than standard GWO. Additionally, the proposed WOA or GWO+BE system gives good performance and fastest response times. From the results, in such case of penetrations, GWO+BE is recommended to be applied.

4. Conclusion

The system performance has been impacted by a number of sporadic disruptions, such as diesel generators, loads, and PV, as well as modifications to the system constant parameters. An MG with 30% PV was looked upon. An adaptable LFC mechanism was proposed in this work using WOA+BE and GWO + BE. Unlike the normal controller, the WOA + BE control method allows frequency regulation even in the presence of load disturbances and parameter uncertainty. The results attained with the suggested controller were compared to those attained with alternative controllers (adaptive controller with WOA, GWO, and GWO+BE, and traditional I controller). WOA+BE and GWO+BE exhibiting enhanced efficacy in frequency regulation in the face of perturbations and uncertainty in parameters. given that the majority of intelligent and classical controllers do not ensure sufficient performance throughout a broad variety of operating situations. Through the use of the WOA+BE, many uncertainty circumstances are avoided. The frequency deviation responses are used to assess the performance of a controller. The fixed-parameter I controller's and GWO's frequency response is considered unsatisfactory. WOA, however, appears capable of handling these problems well. In addition, systems that use the suggested WOA + BE perform better than those that use the standard WOA alone. In a similar vein, the suggested GWO + BE system performs better than the GWO standard. BE increases WOA, and GWO improves LFC and responds better. To improve LFC and lessen oscillations, a controller with gains adjusted by WOA+BE is advised.

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Data Availability: The data used to support the findings of this study are available at reasonable request from the corresponding author.

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