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Development of Load Frequency Control of Two Area Interconnected Network Incorporated with Distributed Energy Sources

Adamu, Ahmed Kana[1*] , A. B. Kunya, A. S. Abubakar
Ahmadu Bello University, Zaria
Ahmedkanadamu001@gmail.com*

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ABSTRACT

The frequency of power systems is highly sensitive to load changes, and the increasing integration of distributed energy sources (DESs) further complicates frequency stabilization. To address these challenges, Load Frequency Control (LFC) is implemented to maintain frequency within acceptable limits. This work proposes a grasshopper optimization algorithm based on proportional integral derivative (GOA-PID) controller designed to improve system performance amid load variations and mitigate disturbances from DESs, specifically Wave Energy Conversion Systems (WECS) and Photovoltaic (PV) systems. Three different scenarios were considered in order to test the robustness of the proposed technique. The first scenario considered different load variation, the load in Area 2 is increased by 1% at t=0 seconds, then by 6% at t=30 seconds, and finally, a 6% load increase is applied in Area 1 at t=60 seconds. The simulation result show that in area 1, and area 2 the GOA-PID performed best in terms of undershoot, overshoot and settling time with a percentage improvement of 48.52%, 4.5% and 16.95% respectively when compared with ADAPTIVE-PI. The second analysis considered the impact of wave-induced disturbances on system stability and frequency regulation, offering insights into the LFC system's robustness and responsiveness in scenarios involving renewable energy sources with variable outputs. The results obtained in area 1 shows that proposed technique outperform adaptive-PI with a percentage improvement of 16.16% and 46.73% considering the undershoot and overshoot. Finally, a disturbance was introduced to the network by incorporating PV system, the obtained results show a percentage improvement of 42.66%, 32.85% and 40.89% in terms of undershoot, overshoot and settling time when compare with other technique.

1. INTRODUCTION

The main aim of LFC is to return the frequency and interchanging power to their scheduled amounts. LFC is considered as a part of Automatic Generation Control (AGC) that has a main role in control and performance of power system and increasing the size and complexity of power system along with power demand growth necessitates new intelligent systems with different energy sources including renewable energy sources. In order to meet this projected demand, there is need to deploy cost-effective and environmentally-friendly renewable energy sources. An interconnected power network regulates the frequency to lie within the nominal range and it also controls the exchange of power. Both the active and the reactive demands are changing continuously with the dynamic change in the load, thereby, producing oscillations. The oscillations of the system can be quickly adjusted to the normal range using the Automatic Generation Control (AGC). The frequency of the power system fluctuates due to the losses in the system and the generation-load mismatch. This can also cause fluctuations in the tie-line power between the areas of the test system. The system dynamics must be stable which, can be achieved by controlling the generators and the tie-line power. This control is commonly known as the area control error (ACE).

A Microgrid (MG) is basically a cluster of load supplied by such micro-sources as wind, turbines, micro-turbines, solar photovoltaic (PV) and fuel cells operating as a sole controllable system which is capable of delivering both heat and power to a specific area (Ghanbari et al., 2013).

The interconnection of MGs can be controlled and adjusted to work in both grid-connected and islanded modes of operation respectively (Al-Saedi et al., 2013). In the grid-connected mode, the MG deliver power to the Utility grid during peak load hours of the day, or alternatively, it may import the power from the grid to meet the specified load connected to the MG. During this mode of operation, the

major control concern is to regulate the active and reactive power flow among Distributed Generators (DGs) connected within the MG and between MG and the main grid. Furthermore, for the grid-connected mode of MG operation with the main grid, the system's voltage and frequency are controlled by giant power system and hence it is not a 'Control objective' for MG controls (Olivare et al.,2014). This is so because MG systems with high penetration of DGs may experience severe voltage and frequency oscillations during DG insertion or load change. For large scale power systems which consist of interconnected control areas, load frequency is critical in view to keep the frequency and inter area tie power near to the scheduled values (Saxena, 2019). In an interconnected power system, load frequency control (LFC) is necessary to keep the frequency of each area and the tie-line power exchange within the specified limit. The main objective of LFC is to regulate the frequency and tie-line power flow within the control area. The main control challenges in LFC are system model parametric uncertainty, non-linearity present in a realistic power system, and load-disturbances (Kumar et al., 2021) Power system frequency regulation or load frequency control (LFC) has been one of the major challenges in interconnected electrical networks. Therefore, the interest in LFC is growing up rapidly due to the interest in large, interconnected power systems (Nour et al., 2016). Operation of power system control is an important task for reliable and secure operation because of increasing system size and varying loads (Sivachandran et al., 2016). Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude, so the control of the real and reactive power in the power system is dealt separately as a result in dependence in frequency and voltage respectively (Sivachandran et al., 2016). LFC has been one of the core issues in interconnected power systems. As a result of this challenge, many researchers have come up different techniques for solving LFC problem by using classical PID controller (Konar et al., 2014), (Regar et al., 2017), and (Sarath & Monica, 2018). The tuning of the control parameters was achieved by using a swarm artificial intelligent technique, such as Genetic Algorithm (GA) (Konar et al., 2014), (Regar et al., 2017), and Bacteria Forging Optimization Algorithm (Sarath & Monica, 2018) and hybrid approach combining Genetic Algorithm (GA).
Section 1 introduces the importances of load frequency control (LFC), section 2 provides literature review of LFC, Section 3 provides the methodology, section 4 discusses the result and finally section 5 present the conclusion.

2.0 Literature Review

Mehdi et al., (2016) Proposed Load frequency Control (LFC) through contribution in a Hybrid generation Grid via Particle swarm Optimization (POS) algorithm. LFC is considered as part of automatic generation Control (AGC) which has the main role in control and performance of the power system is discussed in the study. Simulation result shows that both frequencies overshoot and undershoot as well as setting time decreases significantly and increase in the system stability and eliminate the requirement for energy storage devices to a certain extent. Abd-elazim et al., (2016) developed a LFC of a two-area system composing of Photovoltaic, PV grid and a thermal generator via Firefly Algorithm (FA) for optimal tuning of PI Controllers and also a maximum power point tracking of PV was considered in this work. However, the PI Controller has a long computational time. Tan and Rong, (2017) Proposed Load Frequency Control (LFC) with power systems with Governor Deadband (GDB) and Generation Rate Constraint (GRC) non-linearities is discussed in the study, with the objective to add anti-windup schemes for any designed LFC Controller, so that the stability and performance of the existing LFC controller can be retained when there are non-linearities. Effects of GDB and GRC on the performance of LFC controllers are first analyzed via describing function method. Anti-windup schemes are the proposed to compensate the GDB and GRC non-linearities. For GDB, the error between the realistic and the ideal output of the generator is added to the output of LFC controller for rejection, and for GRC, the error between the realistic and the ideal outputs of the turbine is fed back to the observer of the LFC controller for estimation and elimination. Simulation shows that the compensation schemes are effective in overcoming the adverse effects of GDB and GRC. Dalhabet et al. (2020) LFC of Powers system using ESO, developed a LFC of a two area system using Electro Search Optimization and Balloon Effect. In this work (ESO+ BE) algorithm is applied to tune the load frequency controller of a small single area power system. The system made more efforts in enhancing the system compare to the system with other Controllers like Jaya, Classic ESO algorithms. Nonlinearities such as turbine GRCs and governor dead bands is study in this work. Dahiya et al., (2022) Proposed frequency Regulation of Interconnected system using Black Widow Optimization. In this work PID Controllers tuned with Black Widow Optimization Algorithm in the Power system realm to minimize the fitness function which is Integral Time Absolute Error composing frequency and Tie-line power variation. The Proposed BWOA tuned PID improves Setting time of dynamic response of frequency in Area 1, frequency Area 2 and Tie-line power. Dillip et al., (2019) This Paper proposes a new Search Group Algorithm based on PID Controller to deal with the Automatic Generation control of two-area with six unit power system. The Proposed controller SGA tuned PID controller improves the performance in a large compared with FA tuned PID Controller. Sensitivity analysis is study in this wok. However, the simulation result shows the Proposed SGA optimized PID Controller is much more effective, robust and furnish best system performance as comparison to FA tuned PID Controller.

Gupta et al., 2020 Load Frequency Control using Hybrid Intelligent Optimization for Multiple-source power system used to tune the parameters of Proportional Integral Derivative (PID) controller to achieve the automatic load frequency of multi-source power system. A two-area power system was designed using MATLAB-Simulink tool, consisting of three types of power sources, thermal power plant, hydro power plant and gas-turbine power plant. The result shows that the proposed algorithm performed better than the other techniques. It present a heuristic-based hybrid optimization technique to achieve the objective of automatic load frequency which regulates the frequency deviation and the tie-line power in multiple-source power source. More also, the setting time and peak overshoot were considered to measure the effect on the frequency deviation in Area 1, Area 2 and tie-line power flow were 8.5sd, 7.2s and 3.0s respectively. Hassan and Aysha, (2022): Developed LFC of Microgrid system by Battery and Pumped-Hydro Energy storage using Quasi-Newton method. The approach used is to optimize the controller of the microgrid system. The proposed microgrid system's performance was examined for a 24hour period under several most likely operational scenarios. The frequency fluctuation function was reduced using Broyden-fetcher-Goldford-shano methodology, which is descend-direction Quasi-method-based optimization method, its produces an ideal with a decentralized PI structure that was resistant to disturbance. The simulation result shows that the performance of the MG system, by including the hydroelectric power plant system with pump storage for 24hour, under various operating conditions. It reveals that by including the storage unit in system, its exhibits a more consistent and smooth dynamic performance, using renewable energy effectively. Mehdi et al., (2016) This paper proposes a new Particle Swarm Optimization algorithm based on PID controller to improve load frequency control through PV contribution in a hybrid generation grid. In this study, controller parameters are obtained by PSO algorithm under modified objective function. The system response is improved noticeably with PV system contribution in frequency control. Both frequency overshoot and under shoot as well as settling time has increases significantly in this study. With this approach the system reaches to its steady state faster in terms of system frequency and unit power variation and in a smoother way with lower fluctuation rather than before. Tarek et al., (2020) Developed Adaptive Load Frequency Control in power systems using optimization techniques based on new optimization methods such as Jaya, Practical Swarm Optimization algorithm etc. The Proposed Adaptive are on-line tuned PID controller to improves the dynamic performance over a wide range of operating condition and various load scenarios. The simulation result indicates that Adaptive controller tuned by the Jaya Optimization method gives good response compared with the system with the adaptive controller tuned by PSO. The system with Jaya algorithm has been compared to system with a convectional controller in case of frequency fluctuations resulting from a wind energy source. Ahmed et al., (2023) PSO tuned interval type-2 Fizzy logic for load frequency control of two-area multi-source interconnected power system. The approach has been proposed for two-area multi-source intelligence power system with central park power plants in each area while considering non-humanities in the power system. In order to enhance the performance of the proposed LFC, particle swarm optimization PSO technique have been utilized to optimize the proposed LFC gains to minimize the steady state error over/under shooting value, setting time and system oscillation for the investigated power system frequency. The performance and the superiority of the proposed PSO turned IT2LFC was evaluated and compare with another LFC based on PSO turned cascaded PID controller while applying severe demand load and solar irradiance. Changes the result shows that the fingerprint of uncertainty in the proposed controller has significantly reduced undesired system oscillation during transient and steady state. Integration of RFB has enhanced the performance of the proposed controller since it has reduced the power system setting tune oscillation and over/under shorting values. Mohammed et al., (2023) this paper introduced a new genetic algorithm based method is presented to obtained optimal gains of controller included in two-area interconnected power system which solve this non-linear problem. The suggested method was implemented on a single two-area interconnected system and the result showed reasonable fast response with the steady-state error to step load disturbance. This is while, the efficient and improvement of suggested method examined with comparing its result with corresponding method of LFC. Practical cases show that "IAE" and "ISE" function will cause more minimization in overshoot than "ITSE" and due to the fact, that "ISE" will cause fast response with shorter setting time to this function was considered as the objective function in this study.

3.0 Methodology

The following sequential steps are used in achieving the stated objective:

3.1 Modelling of multi-area network with integration of RESs

The formation of multi-area power system model is initiated by modelling a single area and extending the model to multiple areas. Figure 3.1 shows the Matlab/Simulink model of multi-area network integrated with renewable energy sources. The multi-area network integrated with RESs was model on Matlab/Simulink environment, with each area comprising of multi-stage controller, GDB, governor, turbine, reheater, GRC and power system. A wind energy is incorporated in area 1 and a PV power is integrated in area 2 as depicted in Figure 1. Figure 1 demonstrates the complete model of the system, where, *R* represents speed regulation or droop due to governor action and it contributes to feedback of the primary LFC loop. Moreover, *B* is area frequency bias parameter, which helps in completing feedback of the secondary LFC loop to generate the error signal that feeds the

Multistage Derivative Proportional Filter with One Plus Proportional Integral controller.

$$\frac{1}{T_g s + 1} \quad (1)$$

$$\frac{1}{T_t s + 1} \quad (2)$$

$$\frac{K_R T_R s + 1}{T_R s + 1} \quad (3)$$

$$\frac{K_P + 1}{T_P s + 1} \quad (4)$$

Equation (1) to (4) show the mathematical model of the system component which comprises of speed governor, turbine, reheat and power system.

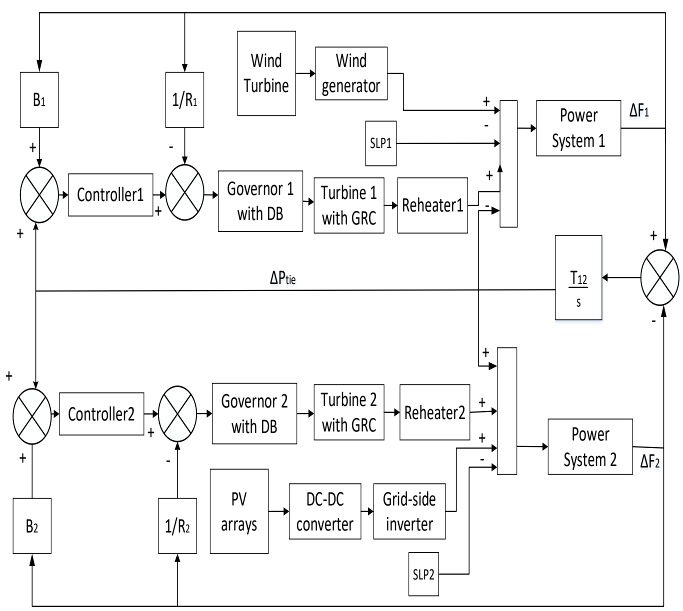

Figure 1: Two-area network integrated with renewable energy sources model

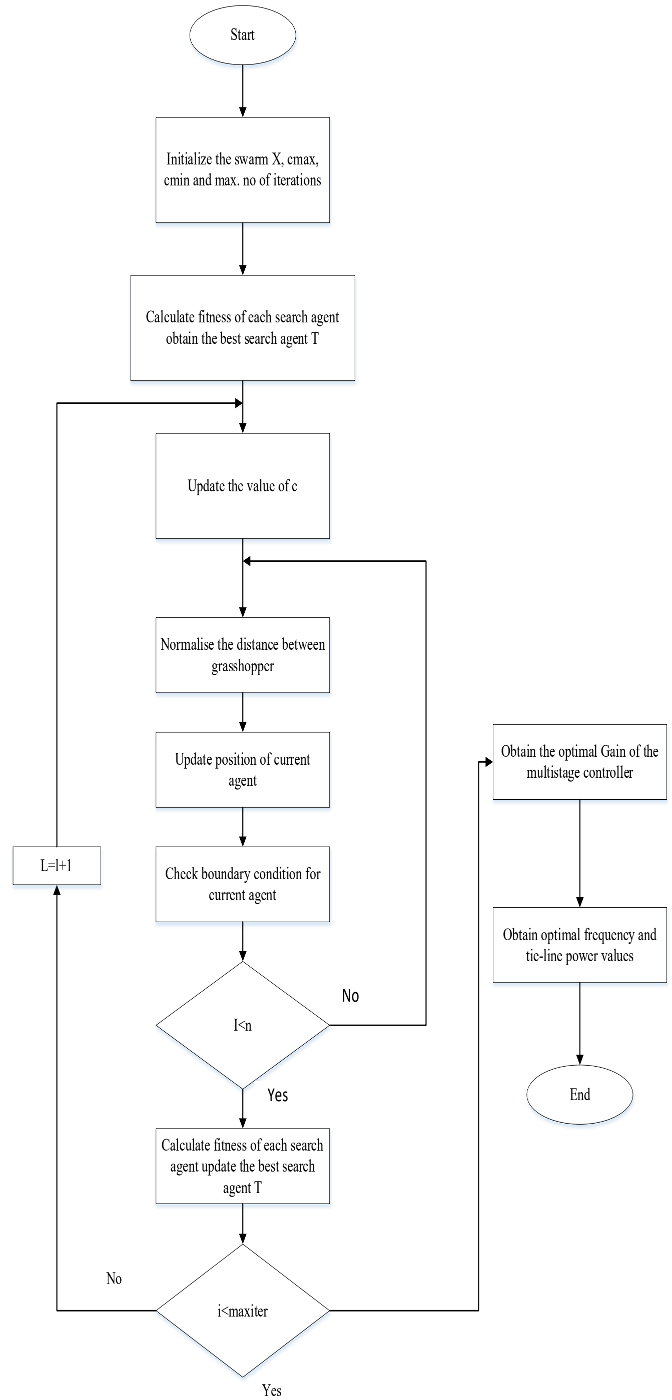

Figure 2: Flow chart of developed worked

4.0 Results and Discussion

In this chapter, results and discussion of the analysis carried out based on the theoretical concepts in the preceding chapters are presented.

4.1 Simulation results and discussion

Matlab/Simulink program was used to model adaptive load frequency control of two area interconnected systems using grasshopper optimization algorithm. The GOA code is interfaced with the such detailed model to carry out the optimization process. The system performance is assessed under different operating conditions.

4.1.1 Comparative analysis under different load variation

In this study, load variations are introduced in two areas at different time intervals to assess the performance of the proposed technique in comparison to an adaptive PI controller. Initially, the load in Area 2 is increased by 1% at t=0 seconds, then by 6% at t=30 seconds, and finally, a 6% load increase is applied in Area 1 at t=60 seconds, as shown in Figure 3 and Figure 4.

Both control techniques—adaptive PI and the proposed method—are tested under identical system parameters and load change conditions. Figures 5 and 6 present the resulting frequency deviations in Areas 1 and 2, respectively, following these load variations. The comparison highlights how each technique responds to the shifts in load and demonstrates the effectiveness of the proposed technique in mitigating frequency deviation across both areas. Table 1 shows the optimized controller parameters. Table 2 shows the transient response of the proposed technique as compared with that of the adaptive PI controller. It can be seen that GOA-PID out performed adaptive PI controller in terms of maximum under shoot, overshoot and settling time in both areas respectively.

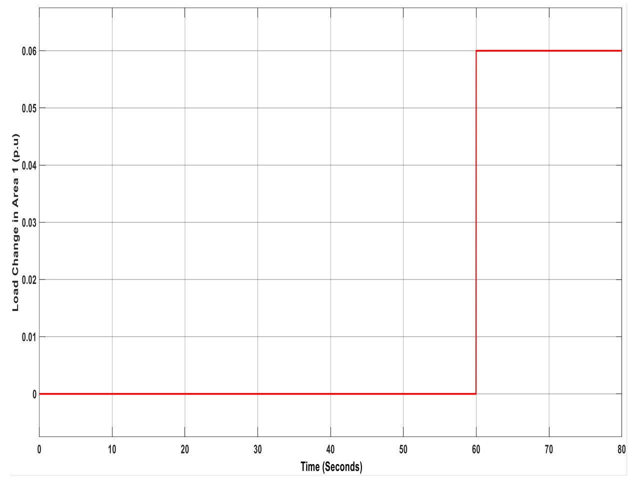

Figure 3: Load Change in Area 1

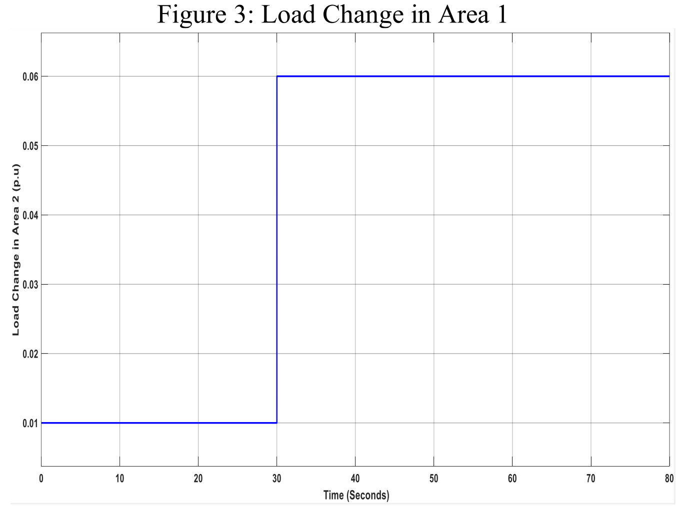

Figure 4: Load Change in Area 2

Table 1: Optimal values of proposed controller gain

Controller Parameters	GOA-PID Controller Gains	Controller Parameters Area 1	ADAPTIVE-PI Controller Gains	Controller Parameters Area 2	ADAPTIVE-PI Controller Gains
Kp1	1.0614	K_{a1}	138.9	K_{a2}	71.8
Ki1	2	K_{d1}	979.6	K_{d2}	773
Kd1	0.38005	K_{p1}	1000	K_{p2}	6487
N	100	K_{i1}	200	K_{i2}	500
Kp2	2	a_1	399	a_2	300
Ki2	0.7654	b_1	1009.4	b_2	1239.1
Kd2	0.55479				
N	100				

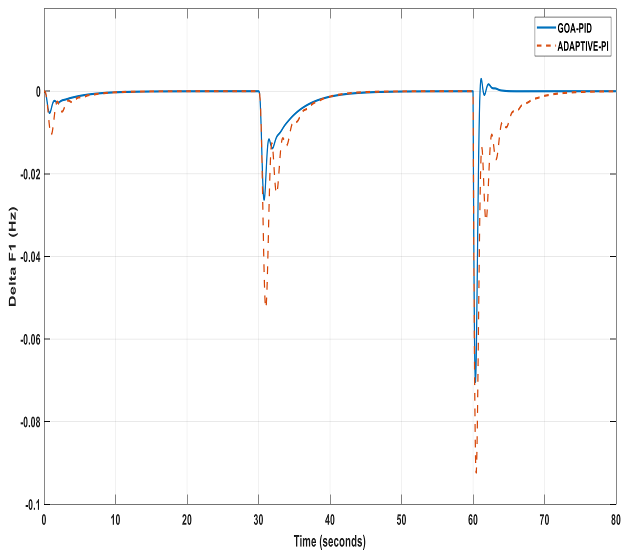

Figure 5: Change in Frequency deviation in Area 1

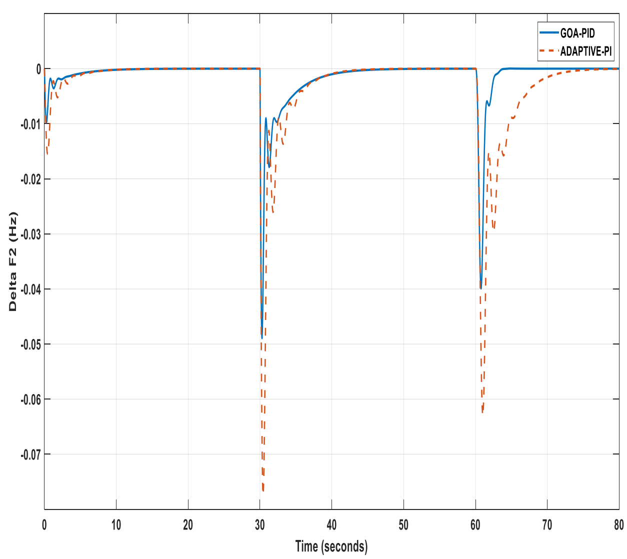

Figure 6: Change in Frequency deviation in Area 2

Table 2: Transient response

Technique	**Response**	**MUS**	**MOS**	**T$_s$(s)**
GOA-PID	$\Delta F_1(s)$	5.4e-3	11.99 e-3	65.053
ADAPTIVE-PI		10.49 e-3	12.56 e-3	78.334
GOA-PID	$\Delta F_2(s)$	8.57e-3	8.89e-3	66.25
ADAPTIVE-PI		15.39 e-3	11.41 e-3	76.85

Table 3 shows the percentage improvement of the two-area network incorporated with PV considering a SLP of 6%. It is observed that in area 1, and area 2 the GOA-PID performed best in terms of undershoot and overshoot when compared with ADAPTIVE-PI.

Table 2: Percentage Improvement

Response	Control Scheme	Transient	Improvement (%)
$\Delta F_1(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS $T_s(s)$	48.52 4.50 16.95
$\Delta F_2(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS $T_s(s)$	44.3 22.08 13.44

4.1.2 Comparative analysis incorporated with wind Energy

This section evaluates the dynamic performance of the proposed Load Frequency Control (LFC) system when a Wave Energy Conversion System (WECS) is incorporated. In the studied system, WECS units are deployed in both areas, with their associated disturbances modeled based on irregular wave patterns, as depicted in Figure 7.

The analysis considers the impact of these wave-induced disturbances on system stability and frequency regulation, offering insights into the LFC system's robustness and responsiveness in scenarios involving renewable energy sources with variable outputs. Frequency deviation in Area 1 and Area 2 is displayed in Figure 8 and Figure 9. Table 4 shows the transient response of the proposed technique as compared with that of the adaptive PI controller. It can be seen that GOA-PID out performed adaptive PI controller in terms of maximum under shoot and overshoot.

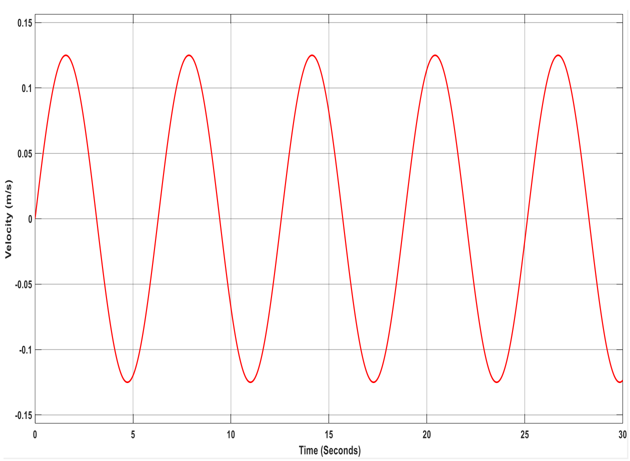

Figure 7: Irregular wave Energy

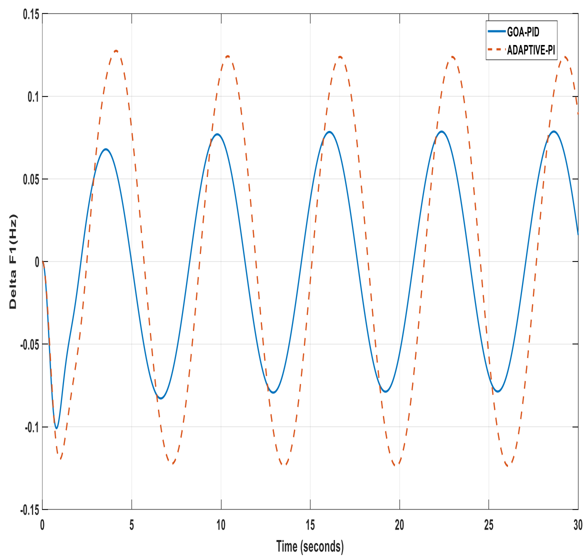

Figure 8: Change in Frequency deviation in Area 1

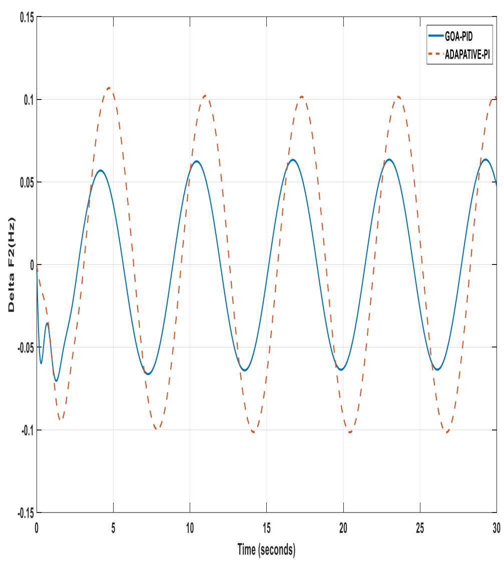

Figure 9: Change in Frequency deviation in Area 2

Table 4: Transient response

Technique	**Response**	**MUS**	**MOS**
GOA-PID	$\Delta F_1(s)$	0.10	67.90e-3
ADAPTIVE-PI		0.12	127.48e-3
GOA-PID	$\Delta F_2(s)$	70.32e-3	56.67e-3
ADAPTIVE-PI		94.53e-3	106.69e-3

Table 5 shows the percentage improvement of the two-area network incorporated with PV considering a SLP of 6%. It is observed that in area 1, and area 2 the GOA-PID performed best in terms of undershoot and overshoot when compared with ADAPTIVE-PI.

Table 5: Percentage Improvement

Response	Control Scheme	Transient	Improvement (%)
$\Delta F_1(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS	16.66 46.73
$\Delta F_2(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS	25.61 46.88

4.1.3 Comparative analysis incorporated with PV

In this case study, a disturbance is introduced in the thermal sub-system, and the resulting frequency deviations in the two areas, along with the tie-line power deviation, are shown in Figures 10–12, respectively. The results demonstrate that the proposed technique outperforms the adaptive controller by achieving reduced undershoot, overshoot, and settling time as shown in Table 6. This improvement highlights the proposed technique's enhanced stability and responsiveness in mitigating frequency and power fluctuations under thermal disturbances.

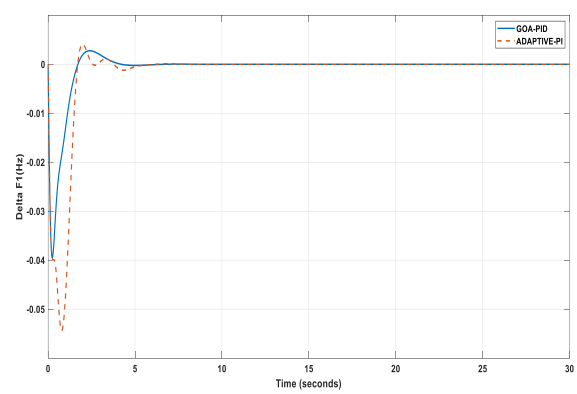

Figure 10: Change in Frequency deviation in Area 1

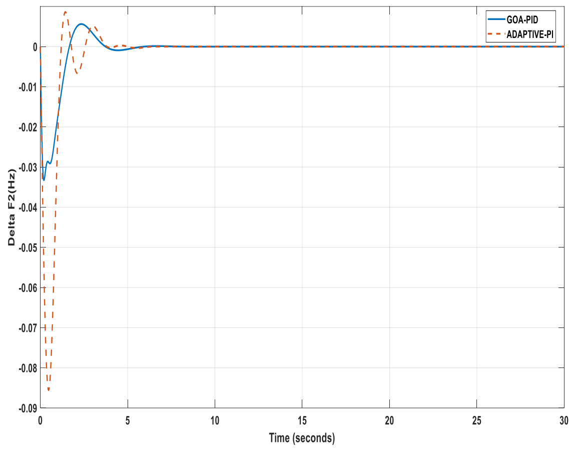

Figure 11: Change in Frequency deviation in Area 2

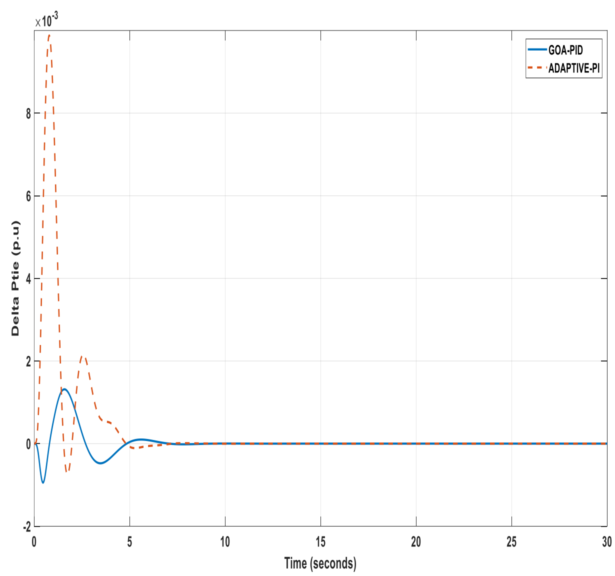

Figure 12: Change in Frequency deviation in Power tie-line

6: Transient response

Technique	**Response**	**MUS**	**MOS**	**T_s(s)**
GOA-PID	$\Delta F_1(s)$	31.18e-3	2.76e-3	6.36
ADAPTIVE-PI		54.38e-3	4.05e-3	10.76
GOA-PID	$\Delta F_2(s)$	32.94e-3	5.58e-3	7.31
ADAPTIVE-PI		85.52e-3	8.5e-3	12.35
GOA-PID	Ptie (pu)	9.4e-4	1.31e-3	8.17
ADAPTIVE-PI		7.4e-4	9.88e-3	10.31

Table 7 shows the percentage improvement of the two-area network incorporated with PV considering a SLP of 6%. It is observed that in area 1, and area 2 the GOA-PID performed best in terms of overshoot and settling when compared with ADAPTIVE-PI.

Table 7: Percentage Improvement

Response	Control Scheme	Transient	Improvement (%)
$\Delta F_1(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS $T_s(s)$	42.66 32.85 40.89
$\Delta F_2(Hz)$	GOA-PID - ADAPATIVE-PI	MUS MOS $T_s(s)$	61.48 34.35 40.81
$\Delta P_{tie}(p.u)$	GOA-PID - ADAPATIVE-PI	MUS MOS $T_s(s)$	-27.02 86.74 20.75

5.0 Conclusion

This research presents development of load frequency control of two area interconnected network incorporated with distributed energy sources. The control system employs a Grasshopper Optimization Algorithm (GOA)-based Proportional Integral Derivative controller, referred to as GOA-PID. The controller parameters were optimized using the GOA by minimizing Integral Time Absolute Error (ITAE). Three different scenarios were considered in order to test the robustness of the proposed technique. The first scenario considered different load variation, the load in Area 2 is increased by 1% at t=0 seconds, then by 6% at t=30 seconds, and finally, a 6% load increase is applied in Area 1 at t=60 seconds. The simulation result show that in area 1, and area 2 the GOA-PID performed best in terms of undershoot, overshoot and settling time with a percentage improvement of 48.52%, 4.5% and 16.95% respectively when compared with ADAPTIVE-PI. The second analysis considered the impact of wave-induced disturbances on system stability and frequency regulation, offering insights into the LFC system's robustness and responsiveness in scenarios involving renewable energy sources with variable outputs. The results obtained in area 1 shows that proposed technique outperform adaptive-PI with a percentage improvement of 16.16% and 46.73% considering the undershoot and overshoot. Finally, a disturbance was introduced to the network by incorporating PV system, the obtained results show a percentage improvement of 42.66%, 32.85% and 40.89% in terms of undershoot, overshoot and settling time when compare with other technique.

The study's results indicate that the GOA-PID controller achieves superior control performance, providing enhanced frequency stability and minimized tie-line power deviations under various operating scenarios.

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