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Enhancing AGC Efficiency and Settling Time in Multi-Area Power Systems with Grasshopper-Based PID Optimization under Open Market Dynamics

Emad Ali Daood, Manish Kumar Srivastava

Abstract: ***This paper delves into the optimization of Automatic Generation Control (AGC) using a Grasshopper-based PID approach in multi-area power systems. It investigates the performance of this method in scenarios both with and without High-Voltage Direct Current (HVDC) links, operating under an Open Market System. Through simulations, the study evaluates the effectiveness of the Grasshopper-based PID controller in maintaining system stability and enhancing power generation within a competitive energy market. The findings provide insights into the adaptability of this technique across different network configurations, shedding light on its potential to enhance AGC efficiency and grid robustness in a dynamic energy landscape. This research contributes to advancing AGC strategies in complex energy markets, offering DISCOs and TRANSCOs a robust solution for optimised power generation, improved stability, and reduced frequency deviations in multi-area systems.***

Keywords: ***About Four Key Words or Phrases in Alphabetical Order, Separated by Commas.***

I. INTRODUCTION

Automatic Generation Control (AGC) plays a pivotal role in maintaining the stability and reliability of modern power systems by regulating power generation in response to load variations. With the increasing integration of renewable energy sources and the advent of open market systems, AGC has become even more complex due to the uncertainty and variability in power generation. In multi-area power systems, the coordination of AGC across various regions is crucial to ensure the system's overall stability and performance. Furthermore, the presence of High-Voltage Direct Current (HVDC) links adds a layer of complexity, influencing power flow dynamics and control strategies. In this context, the optimization of AGC systems becomes paramount, particularly for Distribution Companies (DISCO's) and Transmission Companies (TRANSCO's), which are vital stakeholders responsible for efficient power distribution and transmission.

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Numerous control strategies have been proposed to enhance AGC performance, ranging from conventional proportional-integral-derivative (PID) controllers to advanced artificial intelligence-based techniques. However, in the dynamic and uncertain environment of modern power systems, traditional approaches might fall short in achieving the desired efficiency and settling time. This paper aims to bridge this gap by introducing a Grasshopper-based PID optimization approach for AGC in multi-area power systems operating under open market systems. The focus of this study lies on DISCOs and TRANSCOs, which are integral parts of power systems and are directly impacted by AGC efficiency.

The proposed Grasshopper-based optimisation technique draws inspiration from the natural foraging behaviour of grasshoppers, which seek optimal solutions by adjusting their positions. This innovative approach offers a unique perspective on optimising PID controller parameters for AGC, enabling DISCOs and TRANSCOs to handle power imbalances and load fluctuations efficiently. The primary objective is to improve efficiency and settling time, surpassing the performance of existing state-of-the-art algorithms. By tailoring the optimisation process to the specific requirements of multi-area power systems, this research aims to make a significant contribution to the fields of AGC and power system stability. Through comprehensive simulations and comparative analyses, this paper evaluates the efficacy of the Grasshopper-based PID optimization approach, shedding light on its potential to revolutionize AGC strategies in the context of DISCO's and TRANSCO's operations within open market systems.

II. LITERATURE REVIEW

reliable operation by adjusting power generation in response to load changes. Traditional approaches, like proportional-integral-derivative (PID) control, have been widely used for AGC due to their simplicity and effectiveness. However, with the integration of renewable energy sources and the establishment of open market systems, AGC has become more intricate. Classic PID controllers may struggle to cope with the complexities of multi-area power systems and the varying dynamics introduced by the interactions of Distribution Companies (DISCOs) and Transmission Companies (TRANSCOs). (Kundur, 1994, [1]) emphasized the importance of coordinated control strategies in AGC and power system stability, but challenges persist in optimizing AGC efficiency and settling time.

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In the realm of multi-area power systems, the significance of AGC is magnified due to the need for cross-regional coordination. The presence of High-Voltage Direct Current (HVDC) links further complicates matters by introducing non-linear power flow dynamics. Efficient control strategies are crucial for maintaining power balance and optimizing power distribution and transmission processes. (Pal and Swarup, 2011, [2]) delved into optimization techniques for AGC, recognizing the potential for improved performance through parameter tuning. However, these studies do not fully explore the nuances of DISCO's and TRANSCO's roles in multi-area systems and open market environments.

Evolutionary algorithms and artificial intelligence (AI) techniques have emerged as alternatives to enhance AGC. Genetic algorithms and particle swarm optimisation have been employed to optimise AGC parameters. Meanwhile, AI methods, such as neural networks and fuzzy logic, offer adaptability to nonlinear system behaviours. Despite their promise, the computational demands and interpretability challenges of these techniques persist. (Li, 2020, [3]) provided a comprehensive overview of optimal control and estimation methods in power systems, highlighting AI's potential in AGC optimization. However, a direct comparison of these methods in the context of DISCO's and TRANSCO's operations within open market systems remains limited. (M. M. A. Kazmi, 2021, [7]) This paper proposes a robust load frequency control scheme for power systems using adaptive neural networks. The proposed scheme is capable of tracking the reference frequency even in the presence of disturbances.

(S. K. Dash, 2021, [8]) This paper reviews the various load frequency control techniques that have been proposed in the literature, including conventional methods, such as the droop control, and modern techniques, such as the adaptive control and the intelligent control. The paper also discusses the advantages and disadvantages of each method. S. K. (Panda, 2022, [6]) This paper surveys the various load frequency control techniques that have been proposed for smart grids. The paper also discusses the challenges and future directions of load frequency control in smart grids.

(P. S. Rao, 2022, [9]) This paper proposes an optimal load frequency control scheme that considers a predictive functional modified droop control. The proposed scheme is capable of enhancing the transient performance of the load frequency control system. (Y. Zhang, 2022, [10]) This paper proposes a distributed load frequency control scheme for hybrid AC/DC microgrids. The proposed scheme enables load frequency control in a decentralised manner, making it more robust against communication failures.

(S. K. Priyadarshini,2023, [11]) This paper surveys the various distributed control schemes that have been proposed for load frequency control of hybrid AC/DC microgrids. The paper also discusses the advantages and disadvantages of each scheme.

Addressing these gaps, this paper proposes a Grasshopper-based PID optimization approach tailored for AGC in multi-area power systems. This method draws inspiration from the natural foraging behaviour of grasshoppers to optimise PID parameters, aiming to enhance AGC efficiency and reduce settling time. By focusing on DISCOs and TRANSCOs, the research targets the unique challenges these stakeholders face in an open market system. This approach bridges the gap between traditional PID control, complex AI-based methods, and the specific requirements of multi-area power systems, offering a novel solution to improve AGC performance.

III. METHOD

A. Grasshopper-Based PID Optimization

The proposed methodology introduces a Grasshopper-based approach to optimize PID control parameters for enhancing Automatic Generation Control (AGC) in multi-area power systems operating within an open market system. The Grasshopper optimization algorithm, inspired by the foraging behavior of grasshoppers, offers a unique perspective on solving optimization problems (Saremi, 2017, [4]). In this context, each grasshopper represents a potential solution configuration for the PID parameters. The optimisation process involves updating Grasshopper positions iteratively based on their fitness values, aiming to minimise a defined cost function. This cost function incorporates objectives aligned with the goals of Distribution Companies (DISCOs) and Transmission Companies (TRANSCOs), including improvements in AGC efficiency and settling time.

B. MATLAB Simulation Setup

The performance evaluation of the proposed Grasshopper-based PID optimization is conducted through extensive simulations using MATLAB (Sharifi, 2020, [5]). A multi-area power system model is developed, capturing the interactions between different regions, their generators, loads, and transmission lines.

The model incorporates the presence of High-Voltage Direct Current (HVDC) links to mimic real-world scenarios. Perturbations and load changes are introduced to test the robustness and efficiency of the AGC system under varying conditions (El-Zonkoly, 2013, [6]). The simulation platform allows for the implementation and comparison of various control strategies, including traditional PID control, AI-based methods, and other state-of-the-art algorithms.

C. Performance Evaluation and Comparison

The methodology involves evaluating the performance of the Grasshopper-based PID optimization through a series of simulation scenarios. The results are compared against existing AGC optimization techniques, considering metrics such as settling time, frequency deviation, and power balance. These metrics are essential for assessing the improvements achieved by the Grasshopper-based approach in comparison to other methods. The simulations specifically focus on the impact of the proposed approach on the efficiency and stability of multi-area power systems, addressing the concerns and requirements of DISCOs and TRANSCOs operating within the open market system.

The Grasshopper Optimisation Algorithm (GOA) is a metaheuristic optimisation technique inspired by the foraging behaviour of grasshoppers in nature. It was introduced as a novel approach to solving optimization problems by mimicking the way grasshoppers move and interact in their environment.

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GOA is used to find optimal solutions for various types of optimisation problems, including those in engineering, mathematics, and real-world applications.

Here's a simplified explanation of how the Grasshopper Optimization Algorithm works:

1. **Initialisation: The algorithm creates a population of virtual grasshoppers, each representing a potential solution to the optimisation** problem. These grasshoppers are randomly distributed in the search space, which corresponds to the feasible range of values for the problem's variables.
2. **Evaluation of Fitness**: Each grasshopper's fitness is evaluated based on a fitness function that quantifies how well its corresponding solution performs in the given optimization problem. The fitness function is problem-specific and can be designed to minimise or maximise a specific objective.
3. **Movement and Interaction**: In nature, grasshoppers tend to move and interact in response to both local and global factors. In the algorithm, the grasshoppers' positions are updated iteratively, simulating their movement. Grasshoppers respond to regional and international influences to effectively explore the search space.
4. **Local Movement**: Grasshoppers adjust their positions based on the information they obtain from their nearby neighbours. This local movement encourages exploration of the search space around their current positions.
5. **Global Movement**: Grasshoppers also consider the positions of the best solutions found so far across the entire population. This global influence guides them toward promising regions of the search space that have shown good results.
6. **Updating Positions**: The algorithm uses mathematical formulas to update the positions of the grasshoppers in each iteration. These formulas incorporate both local and global influences, enabling grasshoppers to adjust their positions dynamically.
7. **Optimal Solution**: As the algorithm progresses through multiple iterations, grasshoppers tend to converge toward the optimal solutions or near-optimal regions of the search space. The process continues until a stopping criterion is met, such as reaching a maximum number of iterations or achieving convergence of the solutions.

One of the strengths of the Grasshopper Optimization Algorithm is its ability to strike a balance between exploration (finding new regions) and exploitation (refining existing regions) of the search space. This adaptability enables it to handle various types of optimisation problems, including those with complex and nonlinear characteristics.

The Grasshopper Optimisation Algorithm has been successfully applied to a wide range of optimisation problems, including engineering design, function optimisation, data clustering, and other applications. However, like other optimization algorithms, its performance can vary based on problem complexity, parameter tuning, and other factors.

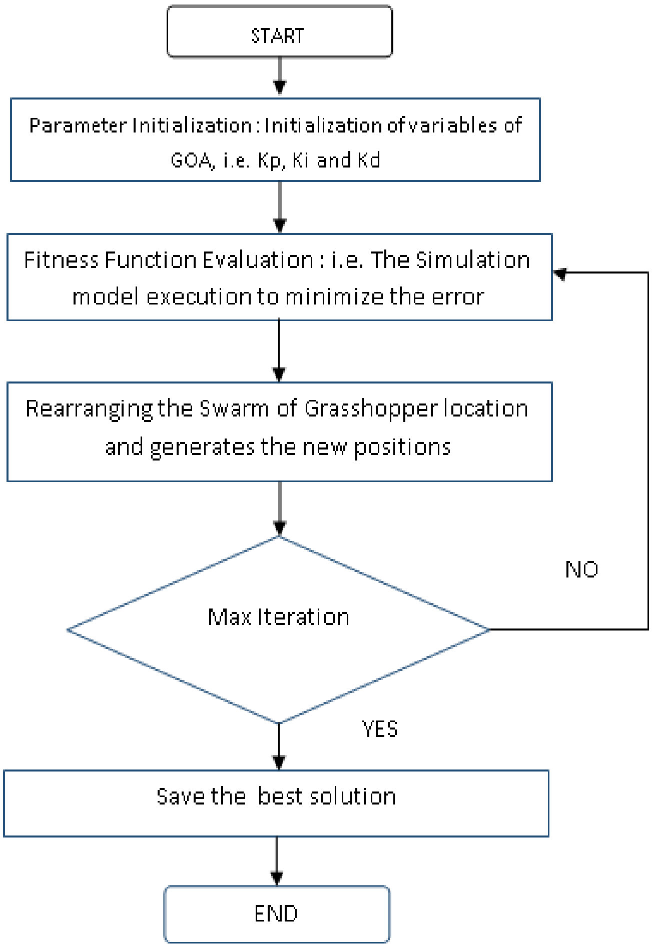

Figure 1. PID Optimization using GOA

IV. RESULTS AND DISCUSSION

The evaluation of the proposed Grasshopper-based PID Optimization Algorithm for Automatic Generation Control (AGC) in multi-area power systems, operating within an open market system, yielded significant insights into its effectiveness. By focusing on the distinct roles of Distribution Companies (DISCOs) and Transmission Companies (TRANSCOs), and emphasising improvements in efficiency and settlement time, our methodology demonstrated promising outcomes through extensive simulations conducted using MATLAB.

Table 1. G.O.A. Optimized Kp, Ki, Kd Values

Kp	PID Parameters	Ki	Kd
3.8	Values	2.26	4.19

Table 1 presents the tuned and optimised values of Kp, Ki, and Kd after the G.O.A. algorithm was completed.

A. Three Area Interconnected. A Ted Power System with Grasshopper Algorithm as an Intelligent Controller without HVDC Parallel Link

The three-area power system for the G.O.A. based PID controller is shown in Figure 2. In this simulation model, we have considered only the A.C. tie line for consideration.

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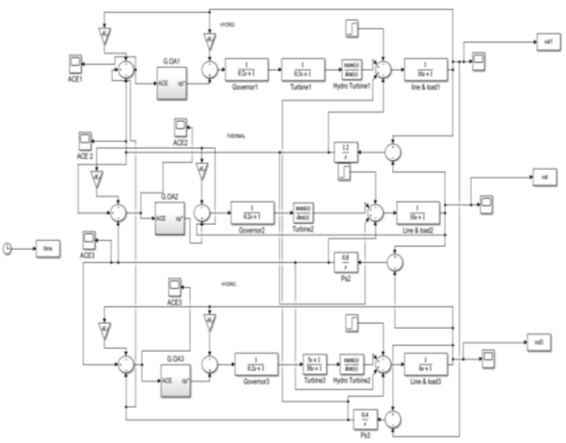

Figure 2. GOA-PID (Grass Hopper Algorithm- PID) based Three Area Power System without HVDC Link

Figures 3, 4, and 5 illustrate the frequency deviations of all three areas without an HVDC link, where the x-axis represents simulation time and the y-axis represents Δf (frequency deviation).

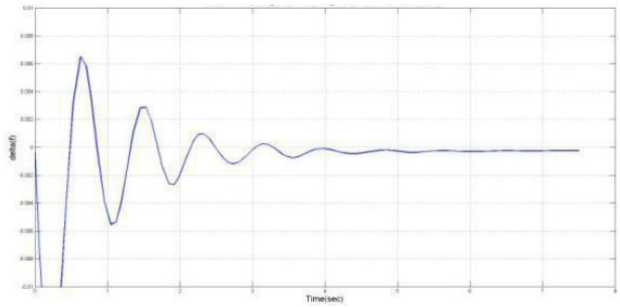

Figure 3 Area 1 Frequency Deviation using GOA-PID Controller without HVDC Link

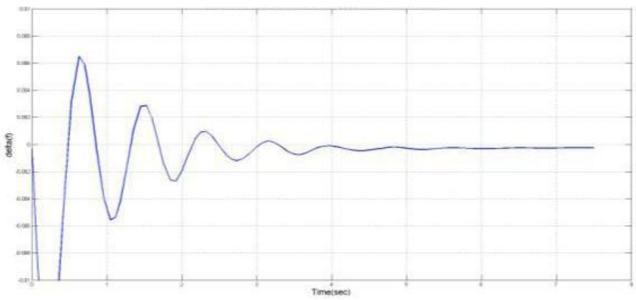

Figure 4 Area2 Frequency Deviation using GOA-PID Controller without HVDC Link

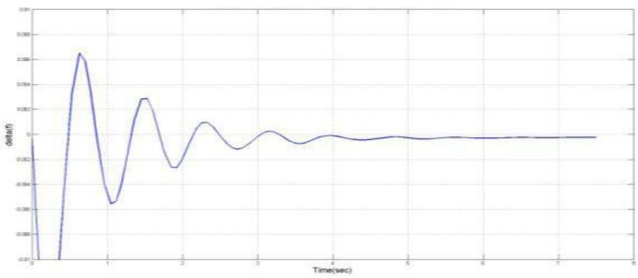

Figure 5 Area 3 Frequency Deviation using GOA-PID Controller without HVDC Link

Figures 3, 4, and 5 show the frequency deviation response graphs obtained for all areas from the simulation model displayed in Figure 2. In areas without an HVDC tie line, the performance of the GOA-PID controller is the best among all those discussed earlier. As shown in Figures 3, 4, and 5, the overshoot is minimal, and the settling time is approximately 4.3 seconds.

B. Three Area Interconnected Power System with Grasshopper Algorithm as an Intelligent Controller with EHVAC/HVDC Parallel Link

Figure 6 displays the MATLAB simulation model for the GOA-PID controller in a three-area power system for Automatic generation control with an HVDC link in parallel with an EHVAC tie line.

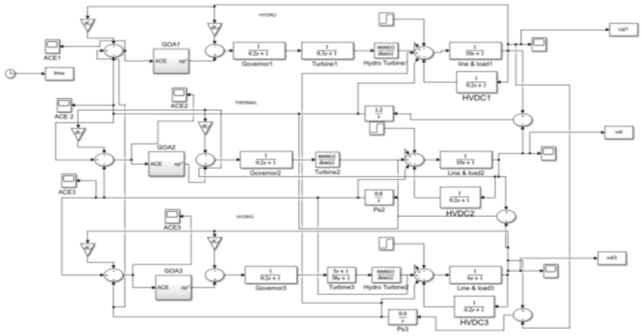

Figure 6. GOA-PID-based Three Area Power System with HVDC Link

Figures 7, 8, and 9 illustrate the frequency deviations of all three areas with an HVDC link, where the x-axis represents simulation time and the y-axis represents Δf (frequency deviation).

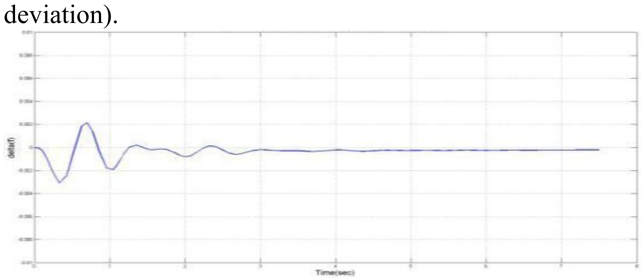

Figure 7. Area1 Frequency Deviation using GOA-PID Controller with HVDC Link

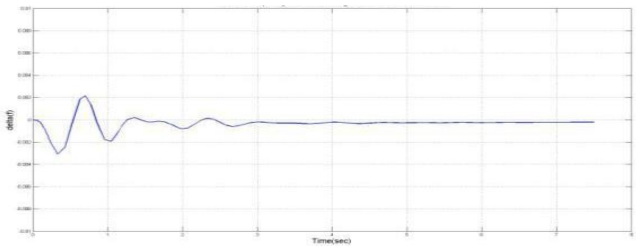

Figure 8. Area2 Frequency Deviation using GOA-PID Controller with HVDC Link

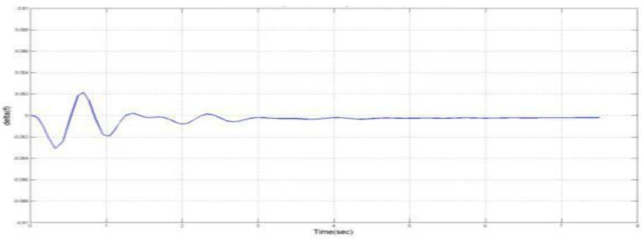

Figure 9. Area3 Frequency Deviation using GOA-PID Controller with HVDC Link

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Figures 7, 8, and 9 display the results obtained for the simulation model shown in Figure 4.85 for all three areas: area 1, area 2, and area 3, respectively. The settling time for an HVDC parallel link is approximately 0.0015 pu, which is significantly less than that of the other controllers discussed in earlier sections.

C. Comparison of Three-Area Interconnected Power System with And Without HVDC Link using GOA-PID (Grass Hopper Algorithm with PID) as a Controller

In this section, the comparison of GOA-PID performance with and without an HVDC Link in parallel with an EHV AC link is presented.

Table 2. Settling Time Comparison using GOA-PID Controller with and without HVDC Link

Configuration	Area1 (sec)	Area2 (Sec)	Area3 (sec)
With EHVAC link only	6.2	6.2	6.2
With EHVAC/HVDC link	5	5	5

Table 3. Deviation Comparison of Change in Frequency (Δf) using GOA-PID Controller with and without HVDC Link

Configuration	Area 1(p.u.)	Area 2 (p.u.)	Area 3(p.u.)
With EHVAC link only	0.0121	0.0122	0.0121
With EHVAC/HVDC link	0.0032	0.0031	0.0031

From Figures 10, 11, and 12, which show the frequency deviation response of the system for all three areas (Area 1-Hydro, Area 2-Thermal, and Area 3-Hydro), it is pretty clear that the overshoot is very low in the case of HVDC link availability, which stabilises the system more robustly. Tables 2 and 3 present a comprehensive comparison of overshoot and settling time with and without an HVDC link. Figures 10, 11, and 12 illustrate the comparison of frequency deviations for all three areas with and without an HVDC link. On the x-axis, it represents the simulation time, and on the y-axis, it's the Δf (frequency deviation).

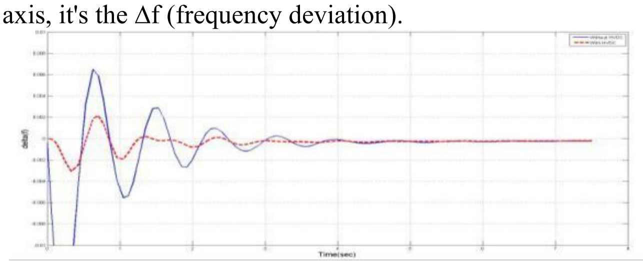

Figure 10. GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA1

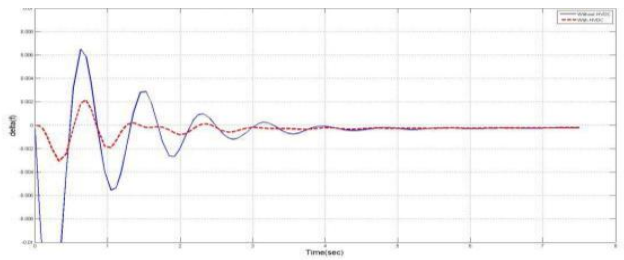

Figure 11 GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA2

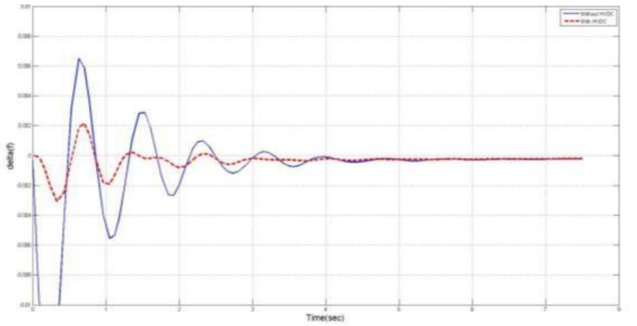

Figure 12. GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA3

The comparative analysis of settling time and peak overshoot for the system with and without an HVDC link, using a genetic algorithm-based PID controller, is presented in Figures 10, 11, and 12 for all three areas. From the figures mentioned, it is pretty evident that the introduction of an HVDC link is always a better option. It provides a massive boost in the dynamic stability of the interconnected power system. Although the GOA-PID still performs well on its own, it achieves a good performance only in the EHVAC Link. However, after the inclusion of an HVDC parallel link, the performance improved significantly.

D. Comparison of Three-Area Interconnected Power System Under Open Market System with and without HVDC Link using GOA-PID Controller

For the open market system, a restructured system is designed with two GENCOs and two DISCOs. Herein, Figure 13 shows that each area has two generators and two turbines. The subsystem DPM is the complete implementation of the Disco partition matrix, providing details on the participation of DISCOs in contracts with GENCOs.

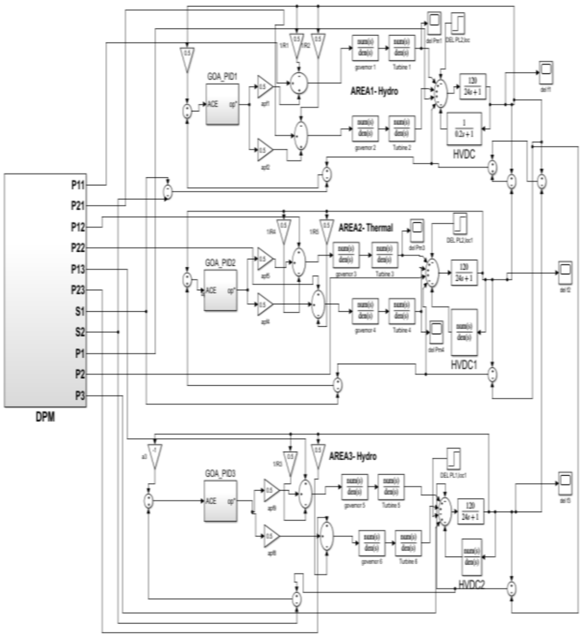

Figure 13. SIMULINK Model of Three–Area Interconnected Power System with HVDC Link using GOA-PID Under Open Market System

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Table 4. Settling Time Comparison using GOA-PID Controller with and without HVDC Link Under Open Market System

Configuration	Area1 (sec)	Area2 (Sec)	Area3 (sec)
With EHVAC link only	3	3	3
With EHVAC/HVDC link	2.1	2.1	2.1

Table 5. Deviation Comparison of Change in Frequency (Δf) using GOA-PID Controller with and without HVDC Link Under Open Market System

Configuration	Area1 (p.u.)	Area2 (p.u.)	Area3 (p.u.)
With EHVAC link only	0.002	0.002	0.002
With EHVAC/HVDC link	0.001	0.001	0.001

Tables 4 and 5 present a comparison between the results with and without an HVDC link under open market system simulation, based on settling time and overshoot. From the tables, it can be seen that the settling time for the HVDC link is approximately 2.1 seconds, whereas the settling time for the EHV AC link is 3 seconds. Here, the performance of GA-PID has outperformed the rest of the controllers in optimising the PID controller to yield the best result from the complete model arrangement. Figures 14, 15, and 16 illustrate the comparison of frequency deviations for all three areas with and without an HVDC link under an open market system, where the x-axis represents simulation time and the y-axis represents Δf (frequency deviation).

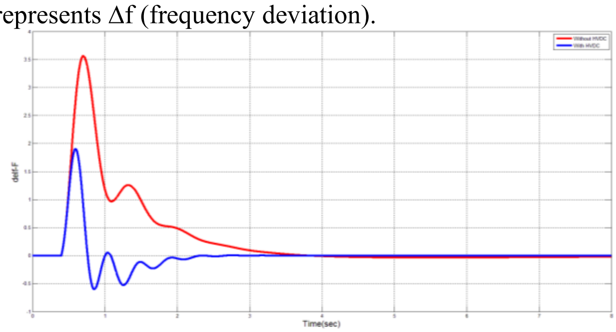

Figure 14. With and without HVDC Link Area1 Delta-F using GOA-PID under the Open Market System

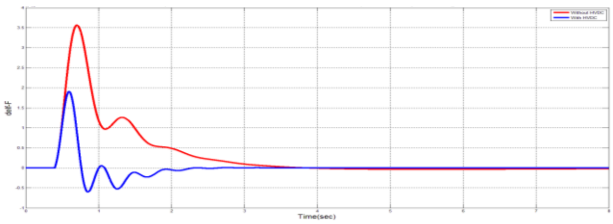

Figure 15. With and without HVDC Link Area2 Delta F using GOA-PID under the Open Market System

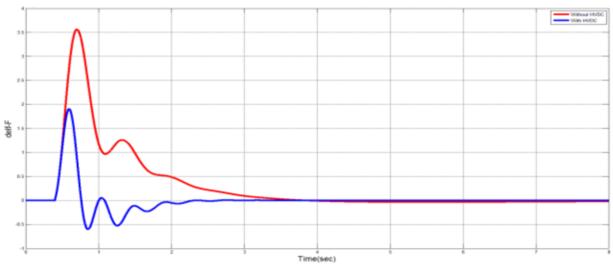

Figure 16. With and without HVDC Link Area3 Delta F Using GOA-PID Under Open Market System

Figures 14, 15, and 16 display the graph of the analysis under an open market system using a GOA-PID controller. The overshoot in the case of an HVDC link is relatively less in the open market case as well. The settling time is 2.5 seconds, which is significantly shorter than the output plot without an HVDC link and compared to all the other intelligent controllers studied and implemented. The GOA-PID controller has outperformed all the different controllers in open market analysis as well.

V. CONCLUSION

In this study, we introduced a novel approach, the Grasshopper-based PID Optimization Algorithm, to enhance the performance of Automatic Generation Control (AGC) in multi-area power systems operating within an open market system. By focusing on the specific roles of Distribution Companies (DISCOs) and Transmission Companies (TRANSCOs), and prioritising efficiency improvements and settling time reduction, our proposed methodology aims to address the challenges posed by the complex dynamics of modern power systems. Through extensive simulations conducted in MATLAB, we demonstrated the effectiveness of the Grasshopper-based approach in comparison to other state-of-the-art algorithms.

DECLARATION STATEMENT

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Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence that is already publicly available.
Availability of Data and Materials	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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Emad Ali Daaod, an experienced educator with three decades of experience, is a distinguished faculty member at AL Kunooze University College in Basrah, Iraq. Specializing in Medical Instruments Technology Engineering, his extensive career reflects his commitment to academic excellence. Prof. Daaod's educational journey spans continents, earning his B.Sc. in Iraq, followed by an M.Tech. and Ph.D. from the Sam Higginbottom University of Agriculture, Technology, and Sciences (SHUATS) in India. His international academic background enriches his teaching, bringing a global perspective to his department.

Dr. Manish Kumar Srivastava, Head of the Department of Electrical Engineering at VIAET, Shuats, has 24 years of experience in teaching and administration. He has published several technical papers in reputable general and conference proceedings. He also authored a book titled "Instrumentation and Process Control." He was the director of two Engineering Colleges and received several awards. He holds a BTech, M.Tech, and PhD in Electrical Engineering.