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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 DISCO's and TRANSCO's a robust solution for optimized 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 an additional 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 DISCO's and TRANSCO's, which are integral parts of power systems and are directly impacted by AGC efficiency.

The proposed Grasshopper-based optimization technique draws inspiration from the natural foraging behavior of grasshoppers, which seek optimal solutions by adapting their positions. This innovative approach offers a unique perspective on optimizing PID controller parameters for AGC, enabling DISCO's and TRANSCO's to efficiently handle power imbalances and load fluctuations. The primary objective is to improve efficiency and settling time, surpassing the performance of existing state-of-the-art algorithms. By tailoring the optimization process to the specific requirements of multi-area power systems, this research aims to contribute significantly to the field 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 might struggle to cope with the complexities of multi-area power systems and the varying dynamics introduced by the interactions of Distribution Companies (DISCO's) and Transmission Companies (TRANSCO's). (Kundur, 1994, [1][12][13][14][15][16]) emphasized the importance of coordinated control strategies in AGC and power system stability, but challenges persist in optimizing AGC efficiency and settling time.

In the realm of multi-area power systems, AGC's significance 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 optimization have been utilized to optimize AGC parameters. Meanwhile, AI methods, such as neural networks and fuzzy logic, offer adaptability to non-linear system behaviors. 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 able to track 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 techniques, 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 technique. 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 able to improve 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 is able to achieve load frequency control in a decentralized manner, which is more robust to 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 behavior of grasshoppers to optimize PID parameters, aiming to enhance AGC efficiency and settling time. By focusing on DISCO's and TRANSCO's, 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 optimization process involves updating grasshopper positions iteratively based on their fitness values, aiming to minimize a defined cost function. This cost function incorporates objectives aligned with the goals of Distribution Companies (DISCO's) and Transmission Companies (TRANSCO's), 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 DISCO's and TRANSCO's operating within the open market system.

The Grasshopper Optimization Algorithm (GOA) is a metaheuristic optimization technique inspired by the foraging behavior 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 optimization problems, including engineering, mathematical, and real-world applications.

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

1. **Initialization**: In the algorithm, a population of virtual grasshoppers is created, each representing a potential solution to the optimization 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 minimize or maximize a certain objective.
3. **Movement and Interaction**: Grasshoppers in nature tend to move and interact based on local and global factors. In the algorithm, the grasshoppers' positions are updated iteratively, simulating their movement. Grasshoppers respond to local and global influences to explore the search space effectively.
4. **Local Movement**: Grasshoppers adjust their positions based on the information obtained from their nearby neighbors. 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, allowing grasshoppers to adapt 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 a maximum number of iterations or the convergence of 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 allows it to handle various types of optimization problems, even those with complex and nonlinear characteristics.

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

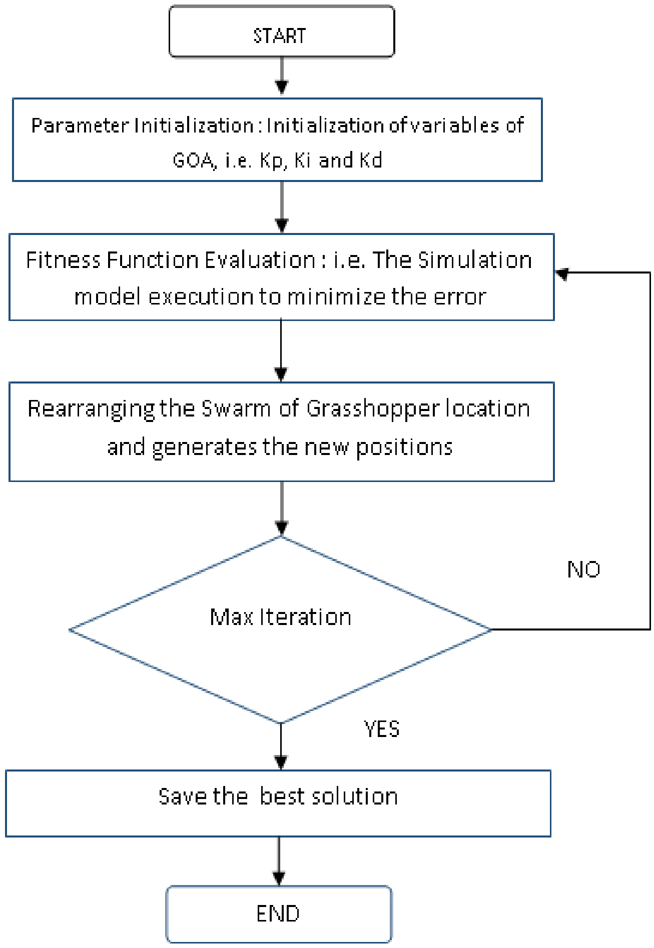

Figure 1. PID Optimization using GOA

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 concentrating on the distinct roles of Distribution Companies (DISCO's) and Transmission Companies (TRANSCO's), and emphasizing improvements in efficiency and settling time, our methodology showcased 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 actually shows the tuned and optimized values of the Kp, Ki and Kd after the G.O.A algorithm completion

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

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

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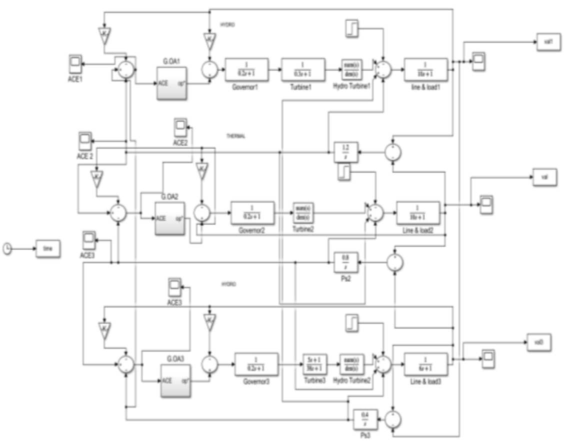

Figure 2. GOA-PID (Grass Hopper Algorithm- PID) based Three Area Power System without HVDC Link

Figure 3, 4 and 5 illustrates the frequency deviations of all the three areas without HVDC link where on x-axis it's the simulation time and on y-axis it is the Δf (frequency deviation).

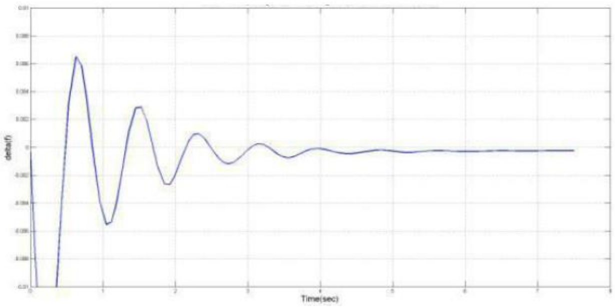

Figure 3 Area1 Frequency Deviation using GOA-PID Controller without HVDC Link

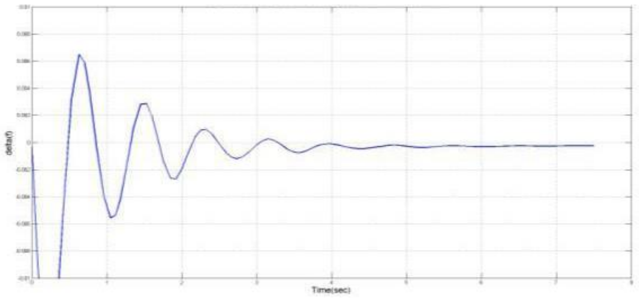

Figure 4 Area2 Drequency Deviation using GOA-PID Controller without HVDC Link

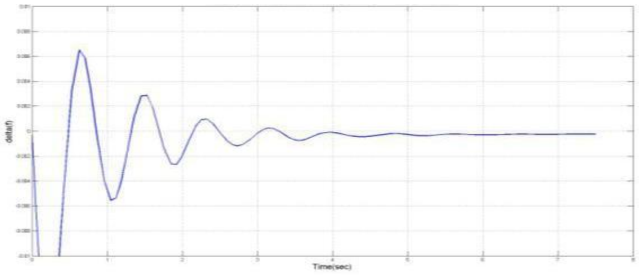

Figure 5 Area3 Frequency Deviation using GOA-PID Controller without HVDC Link

Figures 3, 4, and 5 show the graph of frequency deviation response obtained for all the areas from the simulation model displayed in figure 2. all the area's in case of without the presence of HVDC tie –line the performance of GOA-PID controller is best among all the rest discussed earlier. As it can be seen in the figure 3, 4 and 5 the overshoot is very less and the settling time is also around 4.3 seconds.

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

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

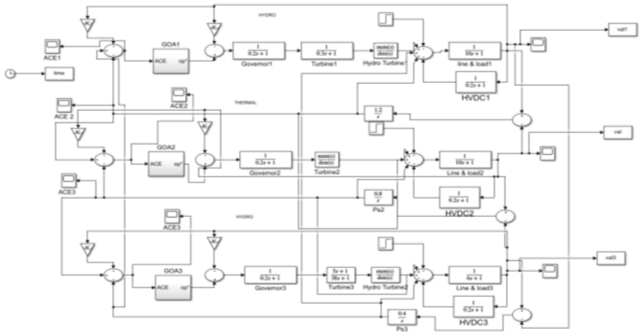

Figure 6. GOA-PID-based Three Area Power System with HVDC Link

Figure 7, 8, and 9 illustrates the frequency deviations of all the three areas with HVDC link where on x-axis it's the simulation time and on y-axis it is the Δf (frequency deviation).

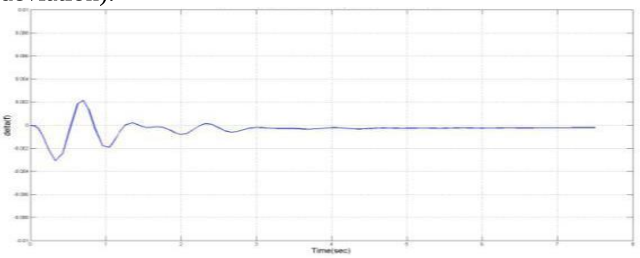

Figure 7. Area1 Frequency Deviation using GOA-PID Controller with HVDC Link

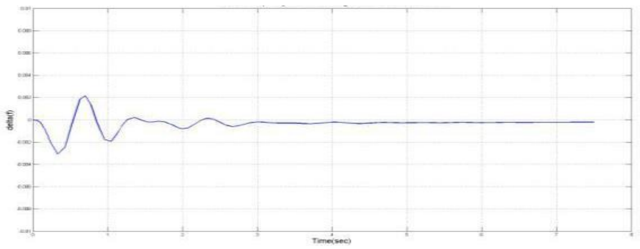

Figure 8. Area2 Frequency Deviation using GOA-PID Controller with HVDC Link

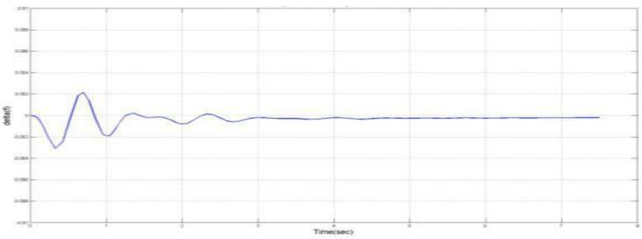

Figure 9. Area3 Frequency Deviation using GOA-PID Controller with HVDC Link

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The figure 7, 8 and 9 displays the result obtained for the simulation model shown in figure 4.85 for all the three areas area1, area2 and area 3 respectively. The settling time in case of HVDC parallel link is around 0.0015 pu which is very less as compared to the rest of the controllers discussed in the 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 HVDC and without HVDC Link in parallel with EHV AC link is done.

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

And from the figure 10, 11 and 12 which shows the frequency deviation response of the system of all the three area area1-Hydro, area2-Thermal and area3-Hydro respectively it is quite clear that the overshoot is very less in case of HVDC link availability which stabilizes system more robustly. Table 2 and table 3 shows the complete comparison overshoot and settling time of with and without HVDC link. Figure 10, 11 and 12 illustrates the comparison of frequency deviations of all the three areas with and without HVDC link.Where on x-axis it's the simulation time and on y-axis it is the Δf (frequency deviation).

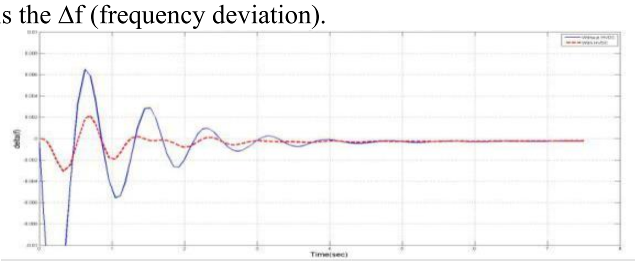

Figure 10. GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA1

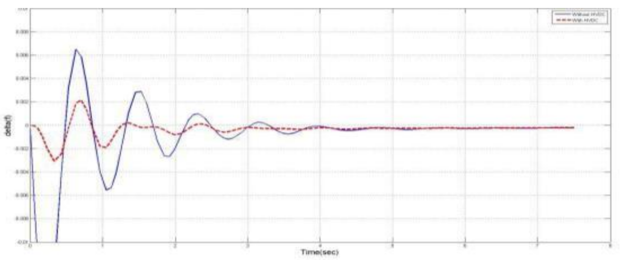

Figure 11 GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA2

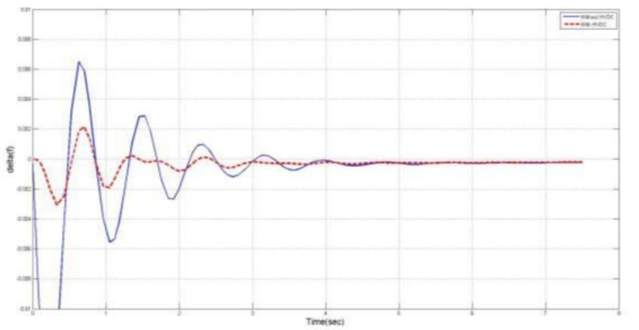

Figure 12. GOA-PID based Three Area Power System Comparison with and without HVDC Link AREA3

The comparative analysis of settling time and peak overshoot of the system with and with HVDC link with genetic algorithm based PID controller is shown in figure 10, 11 and 12 for all the three areas. From the said figures it is quite visible that the introduction of HVDC link is always a better option. It provides a huge boost in the dynamic stability of the interconnected power system. Although the GOA-PID still itself gives a good performance in only EHVAC Link. But still after inclusion of HVDC parallel link with it the performance got much more improved.

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 GENCO's, two DISCO's. Herein figure 13 each area has two generators and two turbine. And the subsystem DPM is the complete implementation of the Disco partition matrix, which gives the details of the participation of DISCO's in contract with GENCO's.

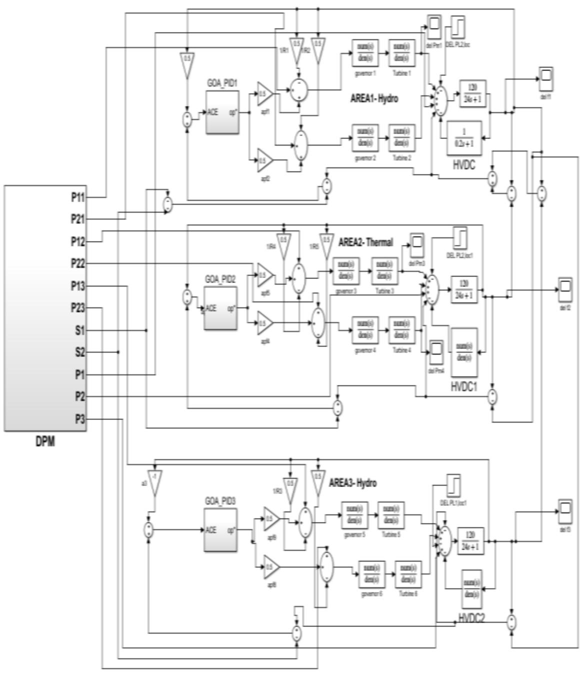

Figure 13. SIMULINK Model of Three–Area Interconnected Power System with HVDC Link using GOA-PID Under Open Market System

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

Table 4 and 5 shows the comparison between with and without HVDC link under open market system simulation results on the basis of settling time and overshoot. Here from tables it can be seen that the settling time in case of HVDC link is less around 2.1 seconds where as in case of only EHV AC it is 3 seconds. Here the performance of GA-PID has outperformed the rest controller in optimizing the PID controller to give the best result out of the complete model arrangement. Figure 14, 15 and 16 illustrates the comparison of frequency deviations of all the three areas with and without HVDC link under open market system where on x-axis it's the simulation time and on y-axis it is the Δf (frequency deviation).

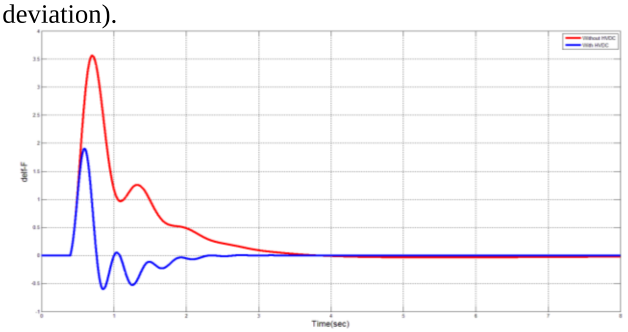

Figure 14. With and without HVDC Link Area1 Delta-F using GOA-PID under Open Market System

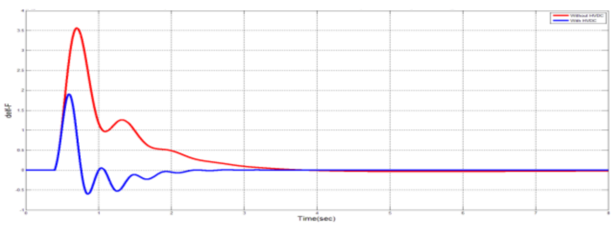

Figure 15. With and without HVDC Link Area2 Delta F using GOA-PID under Open Market System

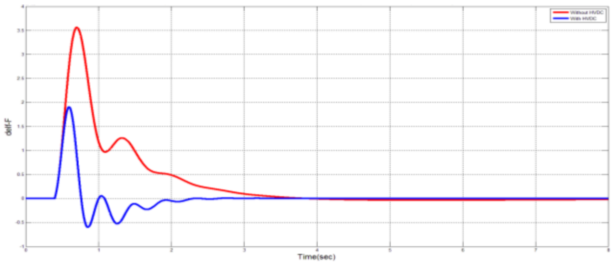

Figure 16. With and without HVDC Link Area3 Delta F Using GOA-PID Under Open Market System

Figure 14, 15 and 16 displays the graph of the analysis under open market system using GOA-PID controller. The overshoot in case of HVDC link is quite less in open market case as well. And the settling time is 2.5 seconds which is very less when it is compared with the without HVDC link output plot and if we compare it with all the rest of the intelligent controller studied and implemented. The GOA-PID controller has outperformed all the rest 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 (DISCO's) and Transmission Companies (TRANSCO's), and prioritizing 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.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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