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Optimized Multi Agent System for Stability Enhancement of Inter Connected Power System

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ABSTRACT- Due to the rising use of renewable energy sources and the use of contemporary power electronic equipment, power system stability has become a major challenge in current power systems. Controlling the power system characteristics can increase the stability of the power system. The traditional techniques for improving power system stability, such as the use of FACTS devices, are costly and may not be effective in handling the dynamic changes of the power system. As a result, by optimizing the power system parameters, an optimization-based multi-agent system can improve the stability of the power system. The Grey Wolf Optimizer based Multi Agent System (GWO-MAS) is proposed in this paper to improve power system stability. The control agents of Distributed Generations (DGs) are optimized using GWO algorithm based on the deviations in frequencies of DGs. Particle Swarm Optimization based Multi Agent System (PSO-MAS) and Conventional Multi Agent System performance are compared with the suggested technique's implementation on IEEE 30 bus system and testing in MATLAB/Simulink environment. The outcomes showed that the suggested approach is successfully improving the stability of an interconnected power system.

Keywords: Particle Swarm Optimization based Multi Agent System (PSO-MAS), Conventional Multi Agent System (C-MAS), MATLAB, Distributed Generations (DGs).

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1. INTRODUCTION

Multi-agent systems (MAS) are widely used in many domains, including control, robotics, optimization, and power systems. Stability enhancement is one of the most important uses of MAS in power systems. The goal of this literature review is to provide an overview of recent studies on employing MAS to improve power system stability.

The basic concept behind today's electrical power infrastructure has remained the same for decades. The structure of the centrally regulated power system may be ineffective from various angles. A centrally regulated power system structure lacks real-time information regarding demand or customer termination points, and the entire structure is built to resist peak demand. These traditional power networks require improvements in a variety of areas, including grid losses, DSM (Demand-side management), power monitoring, shorter and fewer outages etc., [1].

The issue is that electricity requirements are becoming increasingly complex, and the current centrally managed structure needs to be more capable of meeting them [2]. As demand grows, the structure of the centralized power system becomes more intricate and inefficient. When global energy demand is taken into account, the global share of electrical energy in total energy consumption is estimated to rise from 20% to 23% and 27% by 2040 [3]. As a result of these considerations, it is clear that the current centralized power system structure will be incapable of meeting future electricity demand. To address this issue, new concepts such as intelligent microgrids, multi-energy systems, and cutting-edge communication technologies are emerging. One of the key drivers of this trend is an increase in renewable energy generation in the global power sector. To create power, a variety of environmentally friendly energy sources (solar, wind, biomass, hydro, and ocean) can be used. Yet, managing these DESs is difficult. Flexible regulation of many scattered energy sources is difficult for a centralized power system organization. As a result, to handle these DER efficiently, the energy system is changing away from its centralized structure and towards a more decentralized one [4]. The most recent IoT and MAS-based communication concepts are being integrated with the micro grid concept. These concepts are being used by smart microgrids to build effective energy management approaches and algorithms. Furthermore, it promotes the use of green energy while promoting the flexible and secure operation of distributed energy sources [5].

In the power industry, the concept of a microgrid has a bright future. Decentralize, democratize, and decarbonize are the "three D's" of modern power system planning, which refer to three critical tendencies in modern power systems. These changes are being made for various reasons, including the need to improve the dependability and resilience of the power system, reduced CO_2 emissions, and lower electricity prices. Microgrids immediately became the most adaptable system design for the dependable control of distributed energy resources [6]. Microgrids, however, confront a variety of problems and challenges. The APAC microgrid market is anticipated to grow at a 31.31% annual rate between 2013 and 2023 [7]. Introducing IoT for microgrids represents a significant turning point in analyzing the future electrical network. IoT is quickly becoming one of the most critical components of current smart microgrids [8]. IoT-based concepts have been thoroughly researched for a range of microgrid applications. Advanced sensor and wireless communication technology improve the performance and reliability of these principles in intelligent grid applications [9]. Managing DERs on a microgrid is a complicated procedure that involves communication.

The authors of this review contend that the best strategy for microgrids to optimize DER control is MAS system-based energy management systems. This review discusses the most recent MAS-based energy management models that have been put out for use in micro grids.

Real et al. [10] introduced a novel DMPC paradigm to the combined environmental and financial dispatch concerns associated with a smart grid in case studies. In light of innovative grid communication technology, In order to maximize societal welfare, Chandra et al. [11] suggested an optimization model that standardizes operational conditions and enhances the dynamic stability of electricity markets as a whole. In the following paragraphs, we will discuss an intelligent home test bed that can aid in the transition from an archaic power system to a new smart grid.

The most effective approach to accomplish this would be to maximize social well-being. [12] covers smart grid demand management as well as the role of end users in the implementation of an intelligent design. In smart grids, a technique known as multi-objective particle swarm optimization is employed to provide direct load control (DLC). The research of Karimi and colleagues [13] concentrated on concatenating several micro smart metering messages to data concentrator devices. This research aimed to consider the concatenation of several micro smart metering signals to reduce protocol overhead and increase network utilization. To increase the penetration of intermittent renewable energy into smart grids, the authors of [14] proposed creating an algorithm based on dynamic stochastic adaptive critical design that optimises power flow. In order to find high-impedance faults in smart grids, Malihoudis et al. created a technique. This techniqueology was proved in their study. [15]. A comparison of adaptive street-based tertiary control approaches for smart grids is provided in [16]. One of the potential applications for MASs, which have received a lot of interest for various reasons, is the creation of unscrewed aerial vehicles. In recent years, scholars from multiple disciplines have become increasingly interested in the MAS's possible applications [17]. Biophysics, system engineering, control sciences, and smart grids are among these disciplines. Various fields of study have performed extensive research into the MASs notion. [18]. Jing and his colleagues presented two non-smooth leader-following formation strategies for MASs with directed communication typologies. The purpose of these protocols is to be used in massive autonomous systems [19]. [20, 21] look into the difficulty of achieving collision-free consensus in an agent network with a single integrator. In a stochastic delayed MAS with nonlinear dynamics where the system switched asynchronously, Wu et al. investigated the distributed exponential consensus. [22]. This part [23] will discuss using MASs to create workflows aware of their context. Furthermore, MASs has been employed in smart grids, and scholars are investigating the possibility of applying them in other contexts. The above literature review highlights the recent researches on the application of MAS for stability enhancement in power systems. The reviewed studies show that MAS can effectively coordinate the actions of multiple devices or agents to increase the resilience of power systems. Future research can focus on the integration of MAS with other advanced technologies such as artificial intelligence, machine learning, and blockchain to further enhance the performance and reliability of power systems.

In order to improve the stability of interconnected power systems, this research developed a multi-agent system based on the Grey Wolf Optimizer (GWO) algorithm, and the effectiveness of the system was evaluated in comparison to conventional MAS and PSO-MAS techniques. There are six sections in this essay: *Section 1* discusses literature and problem identification. *Section 2* introduces the multi-agent strategy to controlling distributed generators. *Section 3* introduces the PSO implementation to MAS. After providing the GWO implementation to MAS in the *section 4, section 5* presents the simulation model and results, and *section 6* concludes.

2. MULTI-AGENT APPROACH IN CONTROL OF DISTRIBUTION GENERATORS

As the number of DGs in electric power distribution networks increases, DG operation and management become a major concern. By providing the load with on-site power during SS operation, DG deployment in distribution systems aims to reduce reliance on the main substation. However, when there are severe disturbances, These DGs might be detrimental to the system. It becomes challenging to locate synchronized controllers for every DG in every operational circumstance. A distribution gateway (DG) is a point of control or a path that can be used to regulate and enhance the stability and reliability of electrical power distribution networks.

The multi-agent framework's application to the management and operation of DGs is covered in this section. The agents are taught to behave in a manner consistent with the main objective of the procedure. While each agent acts locally and relies as much as is practical on local inputs to achieve its local aim, the global goal is nevertheless achieved in the sense of perfect local performance. Communicating with the agents will help you

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avoid conflicting activities. The control process is set up in the world of distributed generators in a variety of parallel but also hierarchical ways. Each DG has a separate intelligent controller. All agents are linked to a single global agent through the information base. The complete system depicted in *figure 1*, as seen in *figure 2*, can be separated into three distinct layers. In the lowest layer, there are distributed generators that reflect the physical distribution network. The control system layer, or more specifically one or more controllers attached to each DG, is contained in the middle layer. Multi-agent system layer is on top. Each DG in this layer has a local control agent assigned to them, and the overall process is monitored and optimized by a global control agent.

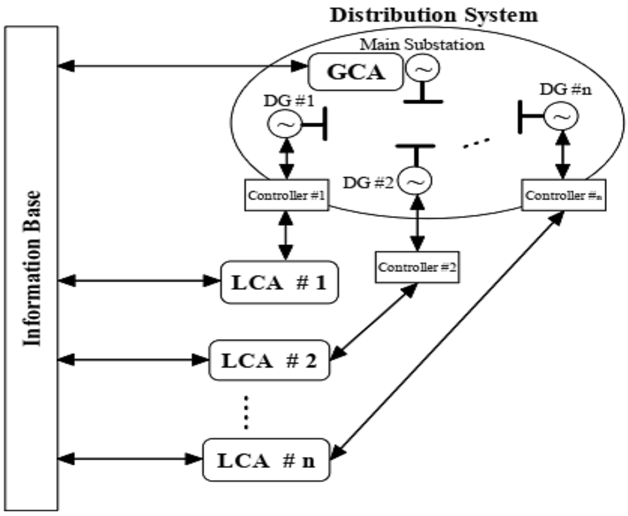

Figure 1: The Multi-Agents Structure in Control of Distributed Generator

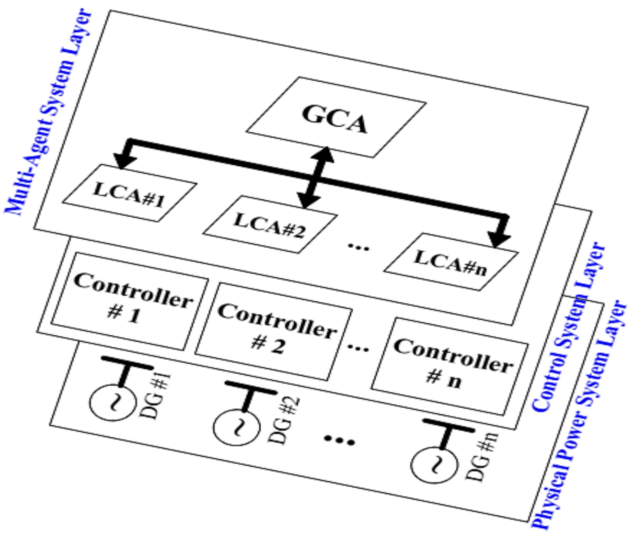

Figure 2: The Control of a Distributed Generator via the Multi-Agents Layer

2.1 Local Control Agents (LCA)

A controller located on DG is directly linked to a local control agent (LCA). It has instant access to local metrics, such as knowledge of DG bus or operational status. This agent's operation is depicted in *figure 3*.

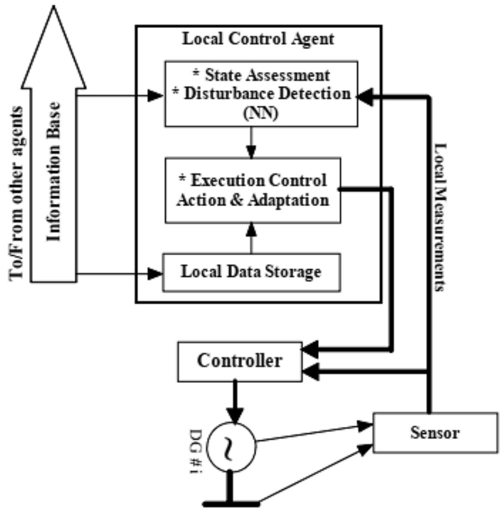

Figure 3: The Local Control Agent

3. PSO ALGORITHM FOR MAS

In order to identify the best answer to a given problem, the Particle Swarm Optimization (PSO) metaheuristic optimisation technique imitates the behaviour of a swarm of particles moving in a search area. Multi-agent systems (MAS) are computational systems made up of numerous agents that collaborate with one another and their surroundings to accomplish a shared objective [24].

Combining PSO with MAS can lead to an efficient and effective optimization technique that can be used for stability enhancement in power systems. The implementation of the PSO algorithm based on MAS for stability enhancement involves the following steps:

- *Define the problem*: The first step is to define the stability enhancement problem to be solved. This can be done by identifying the necessary optimization of the objective function, the constraints that need to be satisfied, and the variables that can be adjusted to improve stability.
- *Develop the PSO algorithm*: Develop the PSO algorithm by defining the fitness function, the velocity update equation, the particle update equation, and the termination criteria. The fitness function evaluates the quality of a solution, the velocity update equation determines how the particles move in the search space, and the particle update equation updates the position of each particle based on its velocity. The termination criteria determine when the optimization process should stop.
- *Develop the MAS*: Develop the MAS by defining the agents, their behaviors, and the communication protocols. In this case, the agents could be the generators, and their behavior could be adjusting their output power to improve stability. The communication protocols could be based on local or global information exchange.
- *Integrate the PSO algorithm with MAS*: Integrate the PSO algorithm with MAS by assigning each particle to an agent and letting the agents use the PSO algorithm to optimize their output power. The agents can communicate with each other to exchange information and coordinate their actions.

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Evaluate the results: Analyze the outcomes by contrasting the PSO algorithm's efficiency with that of other optimization techniques and by analyzing the impact of the optimized output power on system stability.

4. GREY WOLF OPTIMIZATION ALGORITHM FOR A MULTI-AGENT SYSTEM

A well-known optimization algorithm called the Grey Wolf Optimizer (GWO) draws its inspiration from the natural hunting techniques of grey wolves. It is a meta-heuristic algorithm for resolving challenging optimization issues. A multi-agent system, on the other hand, is a system made up of numerous autonomous agents that collaborate with one another to accomplish a particular objective [25].

In recent years, researchers have proposed using the GWO algorithm as a basis for developing multi-agent systems to solve complex optimization problems. These multi-agent systems are known as Grey Wolf Optimizer-based Multi-Agent Systems (GWOMAS). In a GWOMAS, the agents collaborate in order to optimist a specific objective function. Each agent in a GWOMAS represents a single grey wolf, and they work together to form a pack. The agents communicate with each other and share information about their current position and the quality of their solution. This communication helps the agents to explore the search space more efficiently and converge towards the optimal solution. Numerous optimization issues, such as engineering design, scheduling, and data mining, have been tackled using the GWOMAS. These research' findings demonstrate that the GWOMAS algorithm performs better in terms of convergence time and solution quality than other cutting-edge optimization techniques.

To further illustrate the implementation of GWO-based MAS, let's take an example of optimizing the weights of a neural network using GWO-based MAS. The implementation can be done using Python language as follows:

- *Define the problem*: The problem is to find the optimal weights of a neural network that minimizes the error between the predicted and actual outputs.
- *Initialize the agents*: The agents can be represented as a set of weight vectors. The agents are initialized randomly in the search space.
- *Define the search space*: The search space is the range of values for each weight in the neural network.
- *Define the fitness function*: The mean squared error (MSE) between the expected and actual neural network outputs is referred to as the fitness function. Each agent's fitness value is determined using this technique.
- *Determine the social hierarchy*: The social hierarchy can be determined based on the agents' fitness values. The agents with lower MSE are considered better performers and can be selected as leaders.
- *Update the positions of the agents*: The GWO algorithm is used to update the positions of the agents. The positions of the alpha, beta, and delta agents are used to update the positions of the other agents.
- *Evaluate the fitness of the new solutions*: After updating the positions of the agents, Utilizing the fitness function, the fitness of the new solutions is assessed.
- *Steps 5–7 should be repeated until the termination requirement is met*: The procedure of updating the positions of the agents and assessing the suitability of the new solutions is repeated until the termination criterion is reached. The termination criterion might be either a maximum number of iterations or a fitness function cutoff value.
- *Output the best solution*: The best solution found by the GWO-based MAS is the set of weights that minimizes the MSE between the predicted and actual outputs.

Here is a simple pseudo-code implementation of the GWOMAS algorithm:

```
Initialize a population of grey wolves (agents) with random
positions and velocities.
Define the objective function to be optimized.
Set the maximum number of iterations (max_iterations).
Set the number of grey wolves (num_agents).
For each agent:
   Initialize the agent's position and velocity.
   Evaluate the agent's fitness based on the objective
function.
   Update the agent's best position and best fitness.
   Set the leader agent as the one with the best fitness.
While the number of iterations is less than max_iterations:
   For each agent:
      Calculate the exploration and exploitation probabilities
(ExpProb and ExpA).
      Update the agent's velocity using the formula:
         velocity = velocity * ExpProb + ExpA * (leader's
position - agent's position)
      Update the agent's position:
         position = position + velocity
      Ensure the agent's position is within the search space
boundaries.
      Evaluate the agent's fitness based on the objective
function.
      If the new fitness is better than the previous best fitness,
update the best position and best fitness.
      Update the leader agent by selecting the one with the
best fitness among all agents.
   Increment the current iteration counter.
End While
Return the best solution found by the leader agent.
Function to Ensure Boundaries:
   If a position component is outside the search space
boundaries, adjust it to stay within the boundaries.
Main:
   Initialize a population of grey wolves.
   Run the GWO-based Multi-Agent System algorithm.
   Print the best solution found by the leader agent.
```

5. SIMULATION MODEL OF GREY WOLF OPTIMIZER ALGORITHM BASED MULTI AGENT SYSTEM

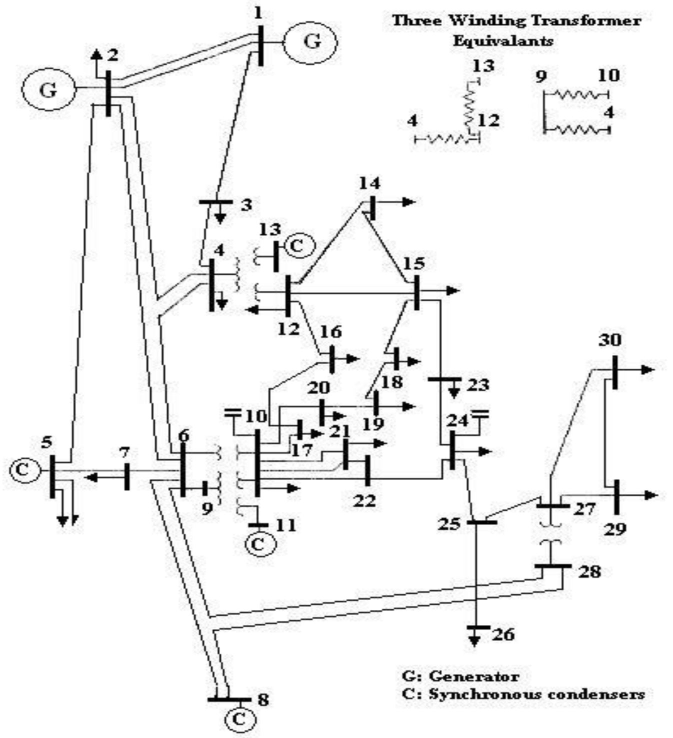

Figure 4(a): IEEE 30 bus system single line diagram

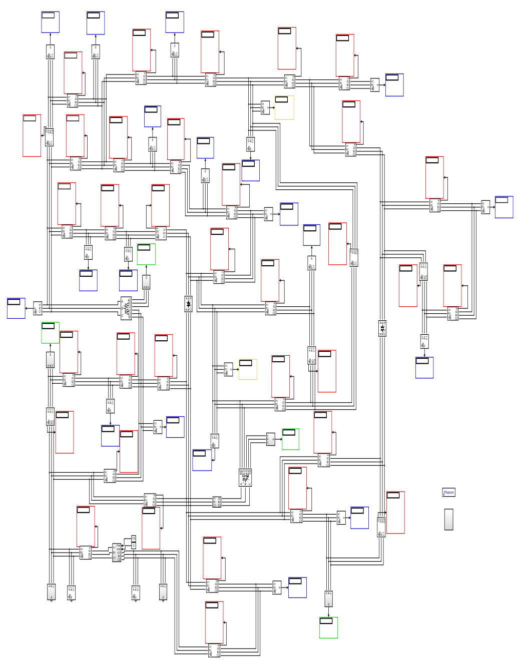

Figure 4(b): Simulation diagram of IEEE 30 bus system

In *figure 4*, the test system's single line diagram and simulation diagram are displayed. The proposed solution is applied to the test system and implemented in a MATLAB/SIMULINK environment with a 0.2 p.u load disturbance that starts at 6 seconds to show how effective it is.

Rotor speed deviations of generator 2 concerning generator 1 are shown in *figure 5*. *Figure 5* depicts the efficiency of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the oscillations effectively in comparison to the usual MAS technique; the GWOMAS technique is predominantly damping the oscillations compared with the PSOMAS technique and conventional MAS technique.

The differences in rotor speed between generators 3 and 1 are seen in *figure 6*. *Figure 6* shows how the traditional MAS, PSOMAS, and GWOMAS techniques performed. This graph demonstrates how successfully the PSOMAS techniqueology dampens oscillations when compared to the traditional MAS technique, and how significantly the GWOMAS approach dampens oscillations when compared to both the PSOMAS technique and the traditional MAS technique.

Figure 7 depicts the rotor speed deviations of generator 4 with generator 1. *Figure 7* illustrates the performance of the conventional MAS, PSOMAS, and GWOMAS approaches. This figure shows that the PSOMAS technique decreases the maximum overshoot and settling time of oscillations compared to the conventional MAS technique; the GWOMAS approach decreases the maximum overshoot and settling time of oscillations compared to the PSOMAS technique and the conventional MAS technique.

Rotor speed deviations of generator 5 concerning generator 1 are displayed in *figure 8*. In *figure 8*, the presentation of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the oscillations effectively in comparison with CMAS technique; the GWOMAS technique is predominantly damping the oscillations compared with the PSOMAS technique and conventional MAS technique.

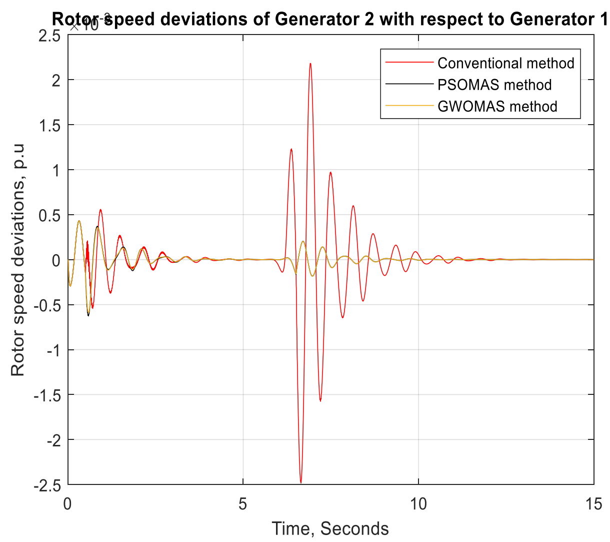

Figure 5: Rotor Speed variations of Generator 2's Rotor with relation to time

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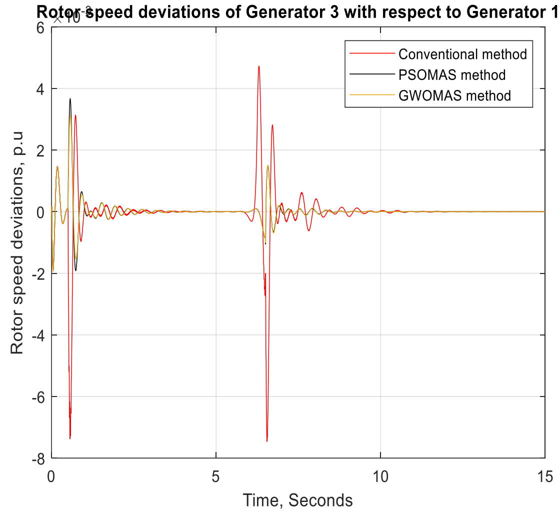

Figure 6: Rotor Speed variations of Generator 3's Rotor with relation to time

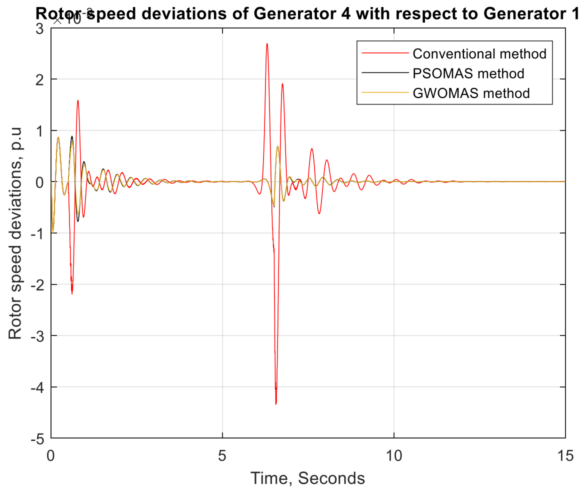

Figure 7: Rotor Speed variations of Generator 4's Rotor with relation to time

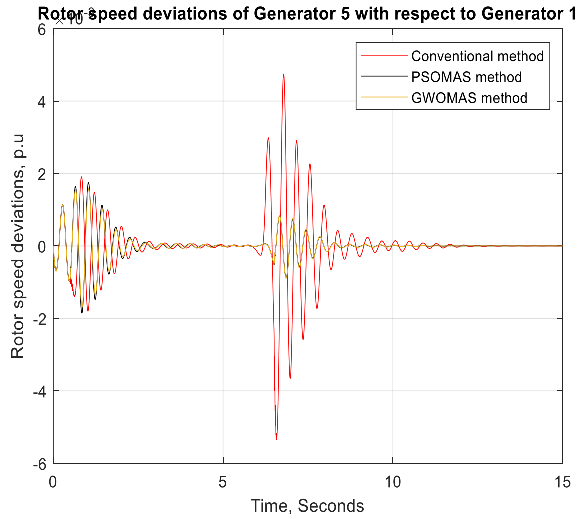

Figure 8: Rotor Speed variations of Generator 5's Rotor with relation to time

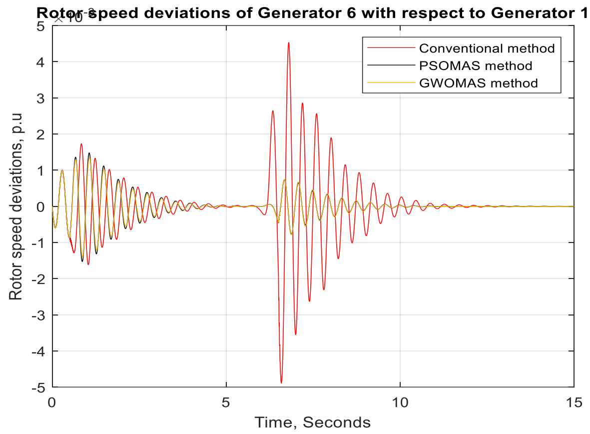

Figure 9: Rotor Speed variations of Generator 6's Rotor with relation to time

Figure 9 depicts the rotor speed deviations of generator 6 with generator 1. *Figure 9* illustrates the performance of the conventional MAS, PSOMAS, and GWOMAS approaches. This figure shows that the PSOMAS technique effectively dampens the oscillations in comparison with CMAS technique; the GWOMAS approach substantially dampens the oscillations in comparison with PSOMAS technique and the conventional MAS technique.

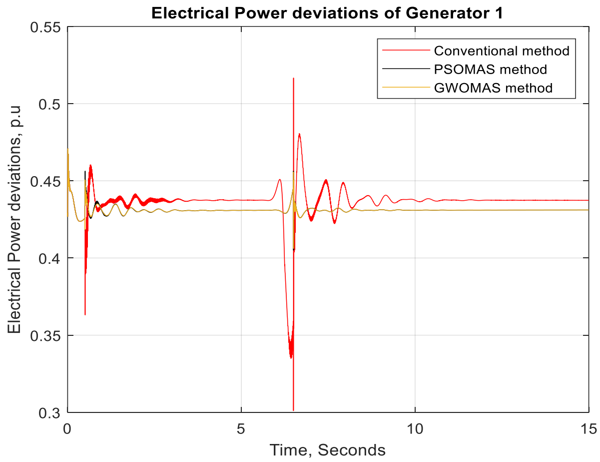

Figure 10: Generator 1 electrical power

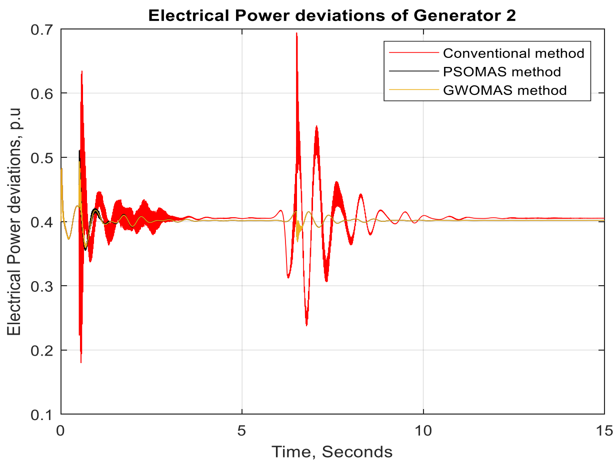

Figure 11: Generator 2 electrical power

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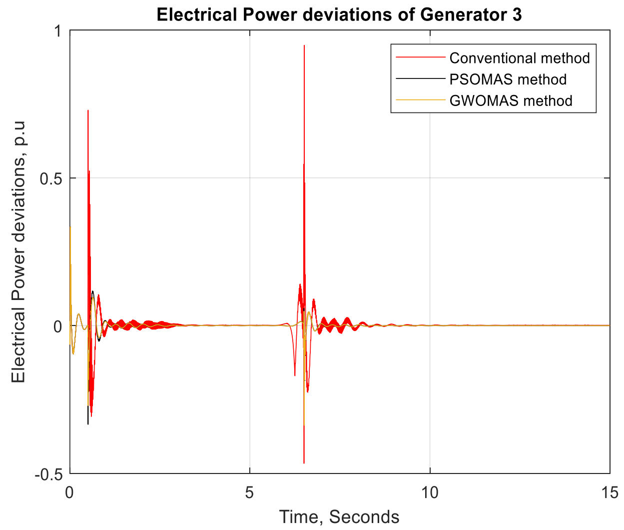

Figure 12: Generator 3 electrical power

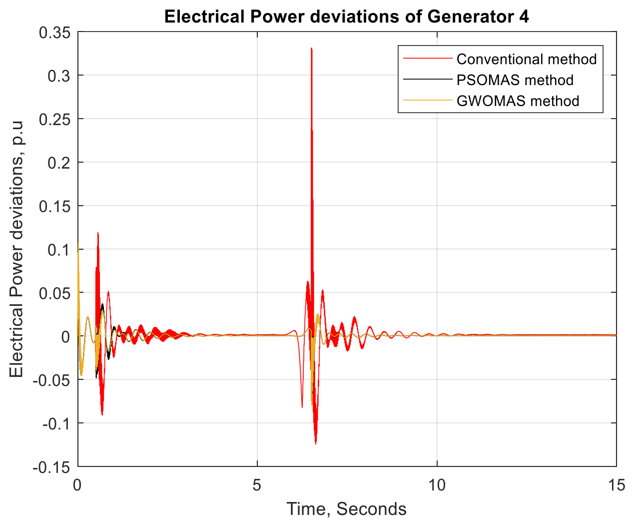

Figure 13: Generator 4 electrical power

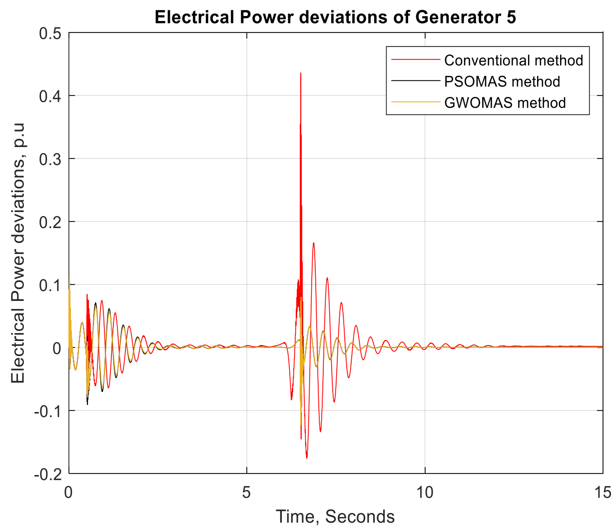

Figure 14: Generator 5 electrical power

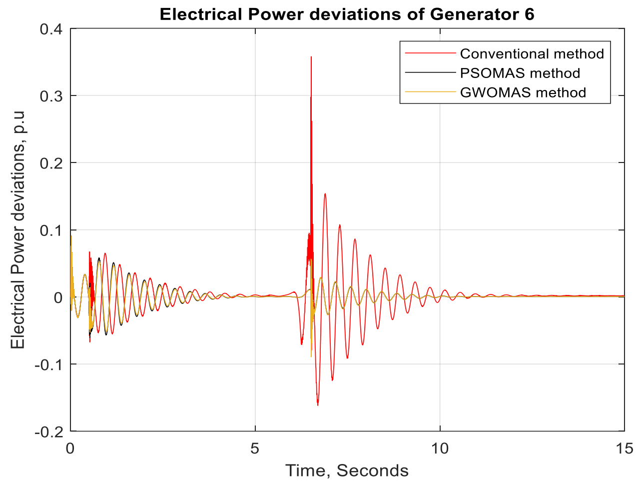

Figure 15: Generator 6 electrical power

Electrical power deviations of generator 1 are shown in *figure 10*. In *figure 10*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the power oscillations effectively in comparison with CMAS; the GWOMAS approach is predominantly damping the power oscillations compared with the PSOMAS technique and conventional MAS technique.

Electrical power deviations of generator 2 are shown in *figure 11*. In *figure 11*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques. It is evident from this figure that the PSOMAS approach, as opposed to the traditional MAS technique, effectively minimizes peak overshoot, settling time, and SS inaccuracy of the power oscillations; the GWOMAS technique predominantly overshoots, settling time & power oscillations compared with the PSOMAS technique and conventional MAS technique.

Figure 12 displays the electrical power deviations of Generator 3. The effectiveness of the traditional MAS, PSOMAS, and GWOMAS approaches are shown in *figure 12*. In contrast to the conventional MAS technique, the PSOMAS technique effectively reduces peak overshoot, settling time, and SS inaccuracy of power oscillations while the GWOMAS technique primarily overshoots, settles slowly, and exhibits power oscillations when compared to the PSOMAS technique and conventional MAS technique.

Figure 13 depicts the electrical power variations of Generator 4. *Figure 13* shows how well the traditional MAS, PSOMAS, and GWOMAS approaches perform. Compared to the standard MAS technique, PSOMAS effectively minimizes peak overshoot, settling time, and power oscillation SS inaccuracy. Compared to the PSOMAS and traditional MAS techniques, the GWOMAS technique primarily overshoots, settles slowly, and exhibits SS inaccuracy of the power oscillations.

Electrical power deviations of generator 5 are shown in *figure 14*. In *figure 14*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the power oscillations effectively in comparison of CMAS; the GWOMAS technique is predominantly damping the power oscillations compared with the PSOMAS technique and conventional MAS technique.

Electrical power deviations of generator 6 are shown in *figure 15*. In *figure 15*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques. From this figure, it is clear that the PSOMAS technique reduces peak overshoot, settling time & SSE of the power oscillations effectively in comparison of CMAS; the GWOMAS technique predominantly overshoots, settling time & SSE of the power oscillations compared with the PSOMAS technique and conventional MAS technique.

Rotor angle deviations of generator 2 concerning generator 1 are shown in *figure 16*. In *figure 16*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the oscillations effectively in comparison of CMAS; the GWOMAS technique is predominantly damping the oscillations compared with the PSOMAS technique and conventional MAS technique.

Figure 17 depicts the rotor angle deviations of generator 3 with generator 1. *Figure 17* illustrates the performance of the conventional MAS, PSOMAS, and GWOMAS approaches. This figure shows that the PSOMAS technique effectively dampens the oscillations compared to the conventional MAS technique; the GWOMAS approach substantially dampens the oscillations compared to the PSOMAS technique and the conventional MAS technique.

Figure 18 depicts the rotor angle deviations of generator 4 with generator 1. *Figure 18* illustrates the performance of the conventional MAS, PSOMAS, and GWOMAS approaches. This figure shows that the PSOMAS technique reduces the peak overshoot & settling time of oscillations compared to the conventional MAS technique; the GWOMAS approach reduces the peak overshoot & settling time of oscillations compared to the PSOMAS technique and the conventional MAS technique.

Rotor angle deviations of generator 5 concerning generator 1 are shown in *figure 19*. In *figure 19*, the performance of the conventional MAS, PSOMAS, and GWOMAS techniques are shown. From this figure, it is clear that the PSOMAS technique damps the oscillations effectively in comparison of CMAS; the GWOMAS technique is predominantly damping the oscillations compared with the PSOMAS technique and conventional MAS technique.

Figure 20 depicts the rotor angle deviations of generator 6 with generator 1. *Figure 20* illustrates the performance of the conventional MAS, PSOMAS, and GWOMAS approaches. This figure shows that the PSOMAS technique effectively dampens the oscillations compared to the conventional MAS technique; the GWOMAS approach substantially dampens the oscillations compared to the PSOMAS technique and the conventional MAS technique.

Figure 16: Variations in rotor angle of Generator 2 with regard to time

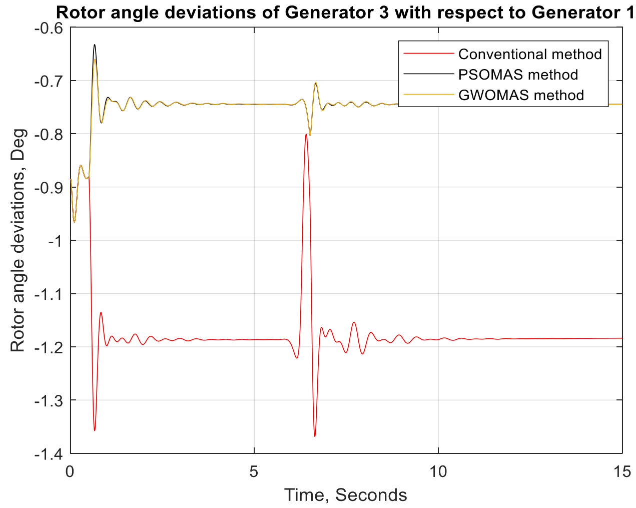

Figure 17: Variations in rotor angle of Generator 3 with regard to time

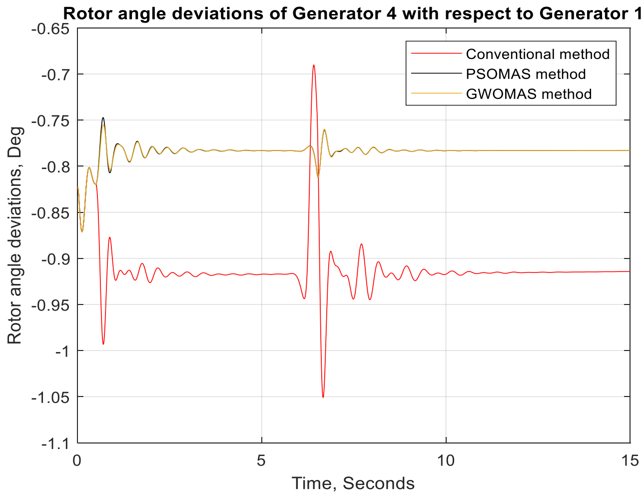

Figure 18: Variations in rotor angle of Generator 4 with regard to time

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Figure 20: Variations in rotor angle of Generator 6 with regard to time

6. CONCLUSION

This paper proposed Grey Wolf Optimizer Algorithm based Multi Agent System (GWOMAS) for stability enhancement of interconnected power systems. The suggested method is put to the test using an IEEE 30 bus system and put into practise in a MATLAB/SIMULINK environment. Reduction of peak overshoot and settling time is regarded as one of the performance indicators for the suggested controller's efficacy. The results obtained from simulation studies demonstrated that the GWOMAS technique effectively decreases the peak overshoot & settling time as compared with PSOMAS & conventional MAS techniques.

7. LIMITATIONS OF GWO & DIRECTIONS FOR FUTURE WORK

GWO can refer to different things, but in the context of optimization algorithms, it most likely stands for Grey Wolf Optimization, which is a nature-inspired optimization algorithm. Like any optimization method, Grey Wolf Optimization (GWO) has its limitations:

1. Convergence Speed: GWO might not converge as quickly as some other optimization algorithms, such as Particle Swarm Optimization (PSO) or Genetic Algorithms (GA). It might require a large number of iterations to find an optimal solution.
2. Premature Convergence: GWO is susceptible to premature convergence, where it gets stuck in a local optimum instead of finding the global optimum. This issue can limit the algorithm's ability to explore the entire search space effectively.

7.1 Directions for future work

In this work we focused on MAS & GWO combination for Fractional Order Controller, in future this work can extend with advanced controllers and updated optimization algorithms.

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