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Application of Grey Wolf Optimization based Multi Agent System for All Electric Naval Ship

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Abstract

The concept of an all-electric naval ship, while delivering unequalled advantages in terms of efficiency and operational flexibility, has raised new concerns about stability and power flow regulation. The introduction of a full power electronics power system has resulted in additional system dynamics challenges, especially when dealing with the new medium-voltage direct current distribution. Researchers have considered two main approaches to ensuring the power system's secure operation: reducing the dynamics of the large load to operate in a range of dynamics compatible with traditional generation systems, or making the generator set smarter via its power electronics interface. Power availability is crucial in the shipping industry, which depends on regular power output and the reliability of power and propulsion systems. This study proposes a multi-level technique for hybrid power generation control. To do this, a mathematical model for each power system component is provided first, followed by a model of the entire on-board power system. The results demonstrated that the proposed approach successfully improves the stability of an interconnected power system when compared to GA-based MAS.

Keywords: Grey Wolf Optimization based Multi Agent System (GWO-MAS), Conventional Multi Agent System (C-MAS), MATLAB, Distributed Generations (DGs).

I. INTRODUCTION

Historically, the electrical power system was not given much care in ship design. The introduction of ships with electrical propulsion signaled the start of the transition. The development of the all-electric ship (AES) concept by the United States Navy offered an additional substantial incentive. Power electronics, specifically the concept of a power electronic building block, is the primary technology that has drastically transformed design possibilities [1], [2]. The AES was one of the first genuine power systems based on power electronics to be examined, at least as a design idea. A similar progression occurred in the avionics business with the idea of more electric planes [3]. Power electronics enabled previously unheard-of capabilities for actively managing the power flow of the system. Standardization efforts have resulted in automated design principles that are completely independent of hardware and efficient at the system level [4]. Avionic and ship power systems suggested architectures based on total control of the power flow in this regard, predicting terrestrial power systems [6]. The interest in direct current (dc) technology, which is currently making its way into terrestrial systems, is a good example of this trend [5].

The AES is a full-fledged electric system that distributes electricity to propulsion motors and other major and minor, critical and noncritical loads onboard. Other industries, particularly the aircraft industry, have researched and applied power-electronics-based electrical power distribution. This is why the study on the AES that led to the current design is cantered on the system, which is the primary focus here. Because of this equivalence, the concept of total automation can be divided into two major problems: the first one is power balance between generation and load, with associated power distribution and load-shortening measures and second one is voltage stability and the related short-term real-time corrections. A medium voltage DC system is also more energy efficient since it has a better power density, reduced losses, and more space flexibility while still supplying a large share of DC loads. Furthermore, when compared to AC power systems, DC power systems facilitate the integration of energy storage devices [7,8].

Despite the advantages of the AES, the electric ship network differs from a land-based electric system in that it is infinite. Because the AES runs under various conditions, the electric load and volatility of power consumption change greatly. As a result, it is difficult to grasp how the AES's many electrical and mechanical components interact with one another.

Furthermore, experimental verification is challenging due to the size and complexity of the ship's components. Numerous simulation studies on the electrical assessment of the AES in various situations have been undertaken [8-14].Transient reactions in relation to generator output and AES load management have been studied in studies [8-11]. The study in [12] looks at the impact of changing AES parameters. The general AES design technique is proposed in the publication [13]. The research in [14] increases the stability of AES when paired with SMES and a battery. The best operation approach under fault conditions is provided in the work [15].

This study created a multi-agent system based on the Grey Wolf Optimization (GWO) algorithm to increase the stability of interconnected power networks, and the system's effectiveness was evaluated in comparison to systems that did not use MAS approaches. This paper is divided into six sections: The first section examines literature and problem identification. The second portion introduces the mathematical modeling of distributed generators. The third and fourth sections introduce the GA and GWO implementations to MAS. After presenting the GWO implementation to MAS in the fourth section, section 5 gives the simulation model and results, and section 6 concludes.

II. Mathematical Modeling

Diesel Engine

A first-order model is applied to the diesel engine, which serves as the generator's prime mover. Consequently, the engine model can be illustrated as follows:

$$\dot{T}_{m,i} = \frac{1}{T_{de,i}}(-T_{m,i} + z_i) \quad (1)$$

$$\dot{X}_{gov,i} = w_i^* - w_i \quad (2)$$

$$z_i = k_{p,gov_i}(w_i^* - w_i) + k_{i,gov_i} X_{gov,i} \quad (3)$$

Where

$T_{m,i}$ is per unit mechanical torque

z is per unit fuel index

$T_{de,i}$ is diesel engine time constant

The fuel index is determined by PI controller that includes GOV dynamics and fuel supply system.

For the generator in direct and quadrature (dq) axis, the 3rd order (The One-Axis or Flux-Decay) model is utilized. This simplified model ignores d-axis transient emf, damper winding effects, and rotor body eddy currents that are not essential to the system-level study. To incorporate the dynamics of the AVR controller into the system, the model can still depict the impact of the excitation voltage from the AVR. The model is therefore stated as follows:

$$\dot{\delta} = w_i - w_i^* \quad (4)$$

$$\dot{w}_i = \frac{1}{2H_i}(T_{m,i} - T_{e,i} - D_i w_i) \quad (5)$$

$$\dot{e}' = \frac{1}{T'_{do,i}}\left(E_{f,i} - e'_{q,i} - \frac{(x_{gd,i} - x'_{gd,i})}{I_{nom,i}} i_{sd,i}\right) \quad (6)$$

$$\dot{X}_{avr,i} = v_{s,i}^* - \sqrt{v_{sd,i}^2 + v_{sq,i}^2} \quad (7)$$

$$E_{f,i} = k_{p,avr_i}\left(v_{s,i}^* - \sqrt{v_{sd,i}^2 + v_{sq,i}^2}\right) + k_{i,avr_i} X_{avr,I} \quad (8)$$

$$T_{e,i} = \frac{e'_{q,i} i_{sq,i}}{w_i I_{nom,i}} + \frac{(x_{gd,i} - x'_{gd,i}) i_{sd,i} i_{sq,i}}{w_i I_{nom,i}^2} \quad (9)$$

$$v_{sd,i} = \frac{x_{gq,i}}{I_{nom,i}} i_{sq,i} \quad (10)$$

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$$v_{sq,i} = e'_{q,i} - \frac{x'_{gd,i}}{I_{nom,i}} i_{sd,i} \quad (11)$$

Where

δ_i is relative load angle in per unit

H_i is the inertia constant in $kg - m^2$

Ω is the base angular velocity (rad/sec)

S is the three phase rating of the alternator (VA)

$T_{e,i}$ is the electrical torque (per unit)

D_i is the damping coefficient (per unit)

$e'_{q,i}$ is the q-axis transient emf (per unit)

$T'_{do,i}$ is the direct axis transient time constant (per unit)

$E_{f,i}$ is the field voltage (per unit)

$x_{dg,i}$ is the d-axis reactance of the generator (per unit)

$x_{qg,i}$ is the q-axis reactance of the generator (per unit)

$I_{nom,i}$ is the nominal current (Amps)

III. GENETIC ALGORITHM FOR FRACTIONAL ORDER MULTIAGENT SYSTEM

Implementing a Genetic Algorithm (GA) for optimizing a fractional order controller in a multi-agent system is a complex task. Here, I'll provide you with a high-level overview of the steps involved in such an implementation. Please note that the actual implementation details can be quite involved, and you may need to adapt this outline to your specific problem.

1. Define the Problem: Start by clearly defining the problem you want to solve. Determine the objectives, constraints, and the fractional order controller's structure.

2. Encoding: Design a suitable encoding scheme for the fractional order controller. You may use real-valued encoding for the controller's parameters, and possibly binary encoding for other aspects of the system.

3. Initialization: Initialize a population of potential solutions. Each solution represents a set of controller parameters.

4. Fitness Function: Define a fitness function that evaluates the performance of the controller. This function should consider the system's dynamics, objectives, and constraints. It might require running simulations of the multi-agent system.

5. Selection: Use a selection mechanism (e.g., roulette wheel or tournament selection) to choose solutions from the current population to create a mating pool. Solutions with higher fitness values should have a higher probability of being selected.

6. Crossover (Recombination): Apply crossover operators to the solutions in the mating pool to create new offspring. Fractional order controllers may require specialized crossover methods based on their structure.

7. Mutation: Apply mutation operators to the offspring to introduce small random changes in the controller parameters. Again, mutation operators will be specific to your problem.

8. Replacement: Create a new population by combining the current population, offspring, and potentially introducing elitism (keeping the best solutions from the previous generation).

9. Termination Criteria: Determine the stopping conditions for the algorithm. This can be a fixed number of generations or convergence criteria based on the fitness values.

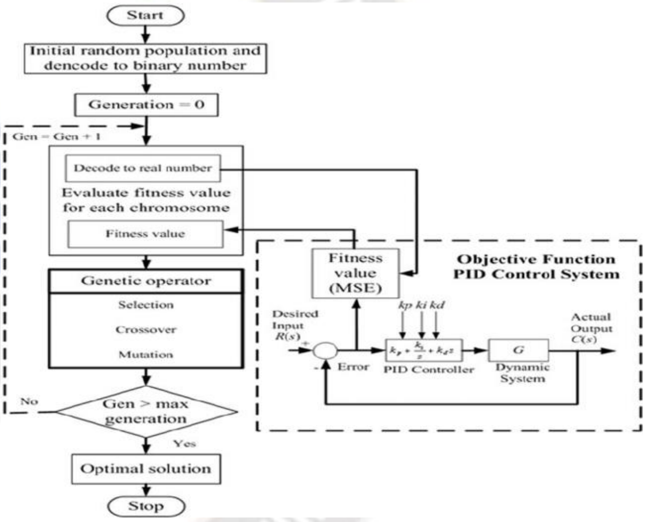

Fig.1. GA flowchart for Fractional Order Controller Multi-agent System

10. Genetic Algorithm Loop: Iterate through steps 5 to 8 for a fixed number of generations or until a termination condition is met.

11. Post-processing: Once the GA terminates, select the best solution found, which represents the optimized fractional order controller parameters.

12. Implement the Controller: Implement the fractional order controller using the optimized parameters in your multi-agent system simulation or control system.

13. Testing and Evaluation: Test the system with the optimized controller and evaluate its performance based on various metrics and objectives defined earlier.

14. Fine-tuning: Depending on the performance results, you may need to fine-tune the fractional order controller and repeat the optimization process.

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15. Documentation and Reporting: Document the results, including the final controller parameters and the performance of the multi-agent system. This information can be used for further analysis or as a reference for future work.

The key challenge in this process is defining a suitable encoding, genetic operators, and a fitness function that capture the essence of the problem and the characteristics of fractional order controllers. This often requires domain-specific knowledge and expertise.

IV. GREY WOLF OPTIMIZER ALGORITHM FOR FRACTIONAL ORDER MULTIAGENT SYSTEM

Implementing the Grey Wolf Optimizer (GWO) algorithm for a fractional-order controller in a multi-agent system involves several steps. The GWO algorithm is a nature-inspired optimization algorithm that simulates the hunting behavior of Grey wolves to find optimal solutions. Here's a step-by-step guide on how to implement the GWO algorithm for a fractional-order controller in a multi-agent system:

1. Problem Definition: Define the problem you want to solve using the fractional-order controller in your multi-agent system. This could be an optimization problem or a control problem.

2. Fractional Order Controller Model: Design the fractional-order controller model that you want to optimize. This might involve creating a transfer function or a differential equation that represents the controller.

3. Objective Function: Create an objective function that represents the performance or cost of the controller for your multi-agent system. This function should be based on the problem definition and the performance criteria.

4. Initialization: Initialize a population of grey wolves. Each wolf in the population represents a potential solution (controller parameters) for the optimization problem.

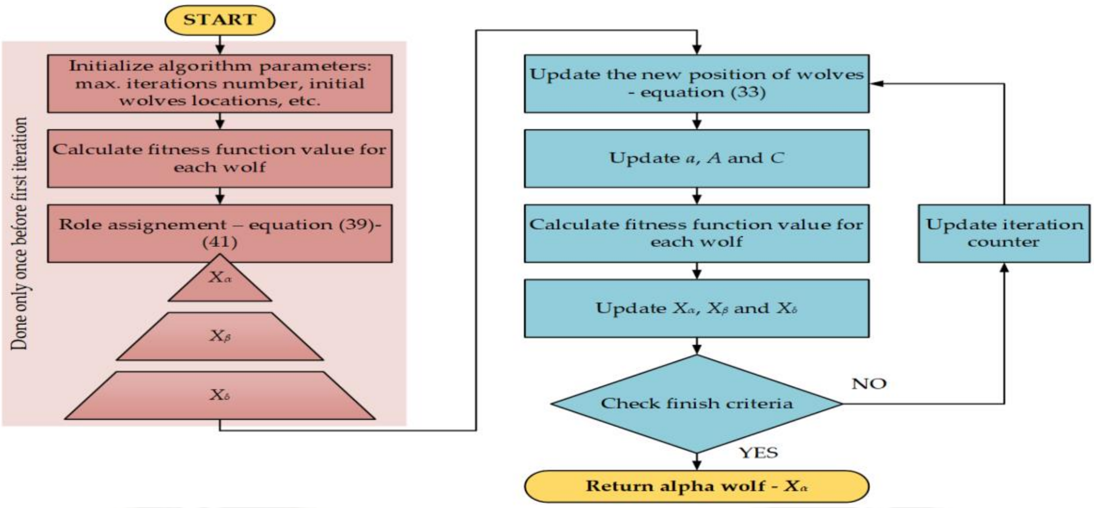

Fig.2. GWO flowchart for Fractional Order Controller Multi-agent System

5. Iteration: Implement the main loop of the GWO algorithm, which consists of several iterations. In each iteration, the algorithm performs the following steps:

a. Update Wolf Positions: Update the positions of the grey wolves based on their current positions and the positions of the alpha, beta, and delta wolves, which represent the best solutions found so far.

b. Evaluate Objective Function: Evaluate the objective function for each wolf based on its current position.

c. Update Alpha, Beta, and Delta Wolves: Update the alpha, beta, and delta wolves based on the objective function values. These wolves represent the best solutions found so far.

d. Search for Prey: Update the positions of the wolves based on the hunting behavior. This step mimics how wolves hunt in nature.

e. Convergence Check: Check for convergence conditions to determine if the algorithm should stop. Convergence could be based on the number of iterations, a threshold value, or other criteria.

6. Solution Extraction: Once the algorithm converges or reaches a stopping condition, extract the solution represented by the alpha, beta, or delta wolf.

7. Fractional Order Controller Implementation: Implement the fractional-order controller using the parameters obtained from the GWO algorithm.

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8. Multi-Agent System Integration: Integrate the fractional-order controller into your multi-agent system. Ensure that the controller interacts with the agents appropriately, and its performance is monitored.

9. Testing and Evaluation: Test the multi-agent system with the fractional-order controller in a simulated or real-world environment. Evaluate the system's performance and make any necessary adjustments.

10. Fine-Tuning and Optimization: If the performance is not satisfactory, you can consider fine-tuning the GWO algorithm parameters or the fractional-order controller parameters to achieve better results.

V. SIMULINK MODEL & RESULTS

The principal components of the system are:

- 30 MVA Gas Turbine, Round Rotor Alternator, 5 MVA Diesel Generator, Salient Pole Alternator,

.

- 11.5 MVA Base Load, 6 MVA Switched Hotel Load
- 20 MVA Average-Value Propulsion Rectifier, 1 MVA Direct Online Start, Squirrel Cage Bow Thruster

The sequence of events during the simulation is:

- 10 seconds - Hotel Load disconnected, 20 seconds - Propulsion begins ramping up, 30 seconds - Full power ahead
- 40 seconds - Propulsion begins ramping down, 60 seconds - Bow Thruster start up, 60 seconds - Hotel Load connected

The simulation diagram is shown in fig.3 is simulated in MATLAB/Simulink environment and the results without MAS, GAMAS & GWO based MAS is shown in Fig.4 to Fig.16

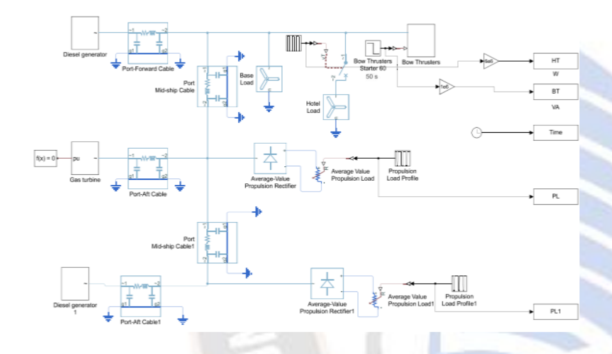

Fig.3. Simulation diagram of AENS

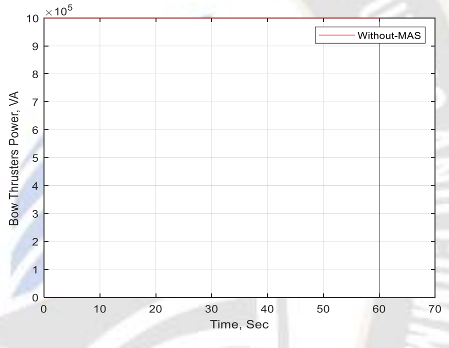

Fig.4. Bow Thruster power variation with respect to time

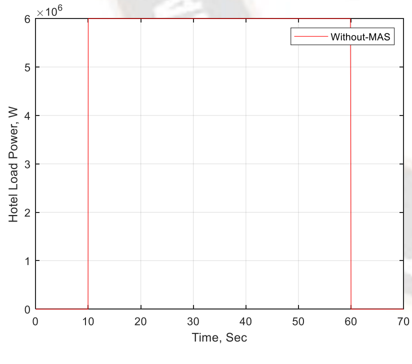

Fig.5. Hotel Load power variation with respect to time

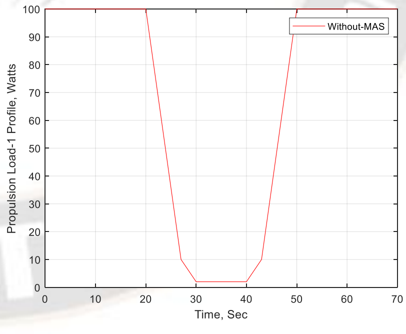

Fig.6. Propulsion Load-1 variation with respect to time

Figure 4 depicts the power drawn by Bow Thrusters. In this picture, from 0 to 60 seconds, bow thrusters are activated; after 60 seconds, the power consumed by them is zero. As a result, this variation in bow thruster strength is interpreted as a step signal. Figure 5 depicts a hotel load of 6MW connected in AENS over a period of 10 to 60 seconds. Figures 6 and 7 depict AENS propulsion loads, with the propulsion loads ranging from 20 to 50 seconds. Throughout the experiment, an 11.5 MVA base load is connected. Figures 8–16 demonstrate the power supplied by DGs, load angles of DGs, and terminal voltages of DGs with these load fluctuations. Figure 8 depicts diesel plant-1 power changes with two control approaches. It is obvious from this that the power variations are dampening very quickly and attaining the steady state power when compared to when no MAS is present. As a result, the proposed technique effectively minimizes the power fluctuations of diesel plant-1 when compared to no MAS. Figure 9 depicts diesel plant-2 power variations with three control approaches. It is obvious from this that the power variations are dampening very quickly and attaining the steady state power when compared to when no MAS & GAMAS is present. As a result, the proposed technique effectively minimizes the power fluctuations of diesel plant-2 when compared to no MAS.

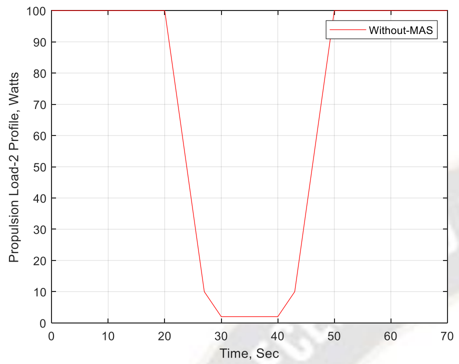

Fig.7. Propulsion Load-2 variation with respect to time

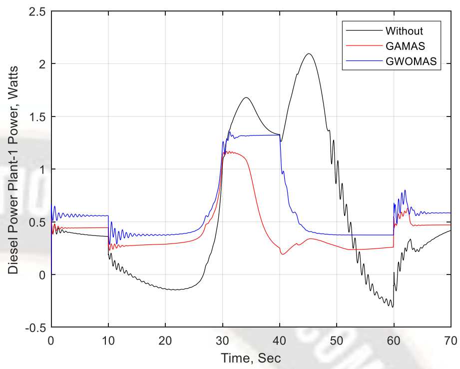

Fig.8. Diesel Power Plant-1 power variation with respect to time

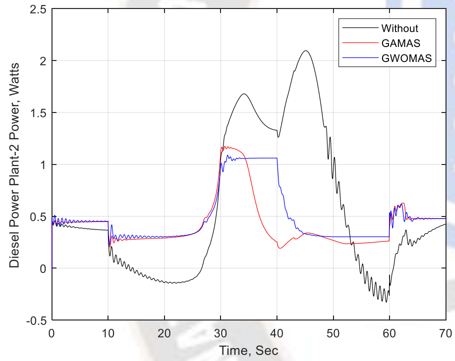

Fig.9. Diesel Power Plant-2 power variation with respect to time

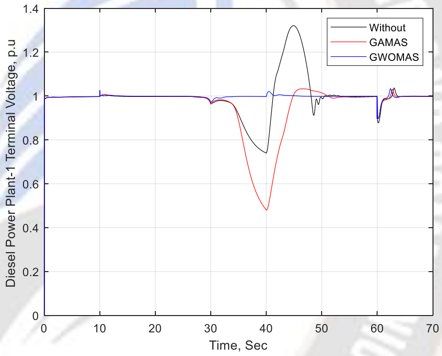

Fig.10. Diesel Power Plant-1 Terminal Voltage variation with respect to time

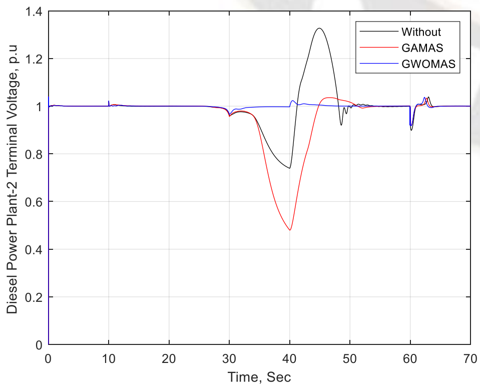

Fig.11. Diesel Power Plant-2 Terminal Voltage variation with respect to time

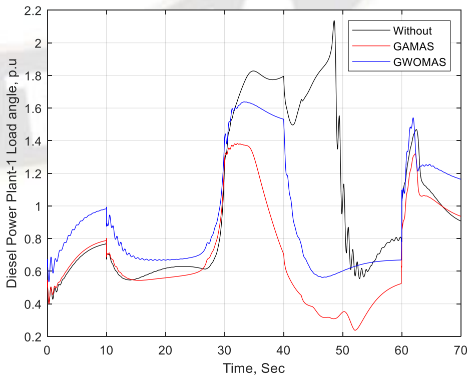

Fig.12. Diesel Power Plant-1 Load Angle variation with respect to time

Figure 10 depicts diesel plant-1 terminal voltage changes with three control approaches. As a result, the terminal voltage changes dampen relatively quickly and attain steady state power when compared to when no MAS & GAMAS is

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present. As a result, the suggested technique effectively minimizes the terminal voltage variations of diesel plant-1 when compared to no MAS.

Figure 11 depicts diesel plant-2 terminal voltage changes with three control approaches. It is obvious from this that the terminal voltage variations are dampening very quickly and approaching steady state power when compared to without MAS & GAMAS. As a result, the suggested method effectively minimizes the terminal voltage variations of diesel plant-2 when compared to the absence of MAS and GAMAS.

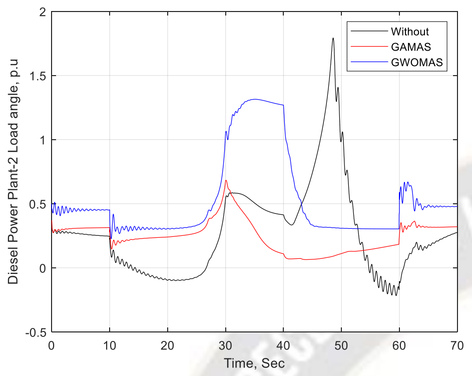

Fig.13. Diesel Power Plant-2 Load Angle variation with respect to time

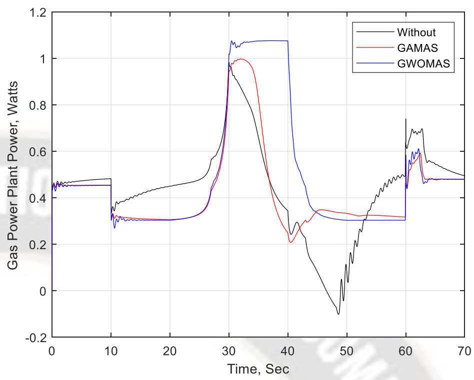

Fig.14. Gas Power Plant Power variation with respect to time

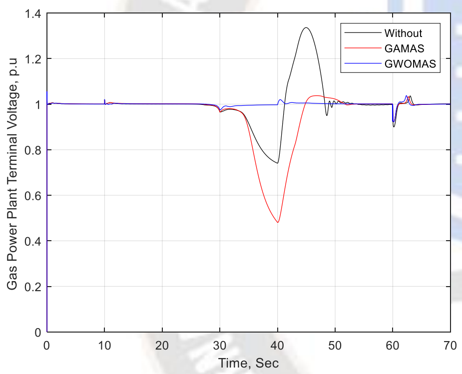

Fig.15. Gas Power Plant Terminal Voltage variation with respect to time

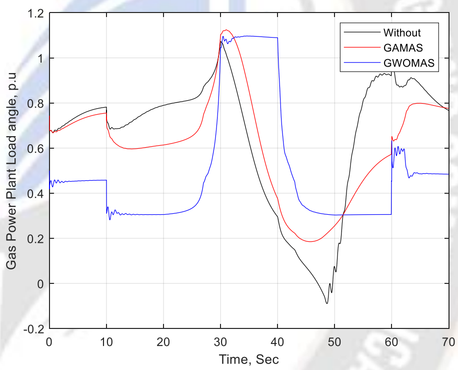

Fig.16. Gas Power Plant Load Angle variation with respect to time

Figures 12 and 13 depict the load angle fluctuations of diesel plants 1 and 2. The oscillations in load angle across the simulation period are not successfully dampening without the MAS approach & GAMAS, but the proposed method efficiently damps load angle changes when compared to the non-MAS method.

Figure 14 depicts fluctuations in gas plant power with three control approaches. It is obvious from this that the power variations are dampening very quickly and attaining the steady state power when compared to when no MAS & GAMAS is present. As a result, the proposed technique effectively minimizes the power fluctuations of diesel plant-2 when compared to no MAS & GAMAS.

Figure 15 depicts fluctuations in gas plant terminal voltage caused by three different control approaches. As a result, the terminal voltage changes dampen relatively quickly and attain steady state power when compared to when no MAS & GAMAS is present. As a result, the suggested technique effectively minimizes the terminal voltage variations of diesel plant-2 when compared to no MAS & GAMAS.

Figure 16 depicts the load angle variations of a gas plant. The oscillations in load angle across the simulation period are not successfully dampening without the MAS & GAMAS approaches, but the proposed method efficiently damps load angle changes when compared to the non-MAS & GAMAS methods. The simulation results show that the suggested method efficiently reduces terminal voltages, load angle variations, and power deviations of diesel and gas plants as compared to the non-MAS & GAMAS methods.

VI. Conclusion

This work presented a Fractional Order Multi Agent System based on Grey Wolf Optimization for reducing power quality issues in All Electric Naval Ships (AENS). The proposed approach is implemented in the MATLAB/Simulink environment, and its performance is compared to that of the absence of MAS & GAMAS. The simulation results showed that the suggested technique efficiently reduces oscillations of power fluctuations, load angle variations, and terminal voltage changes in AENS diesel and gas plants. As a result, the proposed solution effectively reduces power quality difficulties.

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