An Optimization based PID controller for Load Frequency Control of Power System

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Abstract: *This paper presents an Optimization Algorithm applied to a power system model to mitigate frequency deviations and maintain stable frequency levels amidst load variations. The study leverages Load Frequency Control (LFC) to address network imbalances caused by fluctuating loads. The LFC loop automatically regulates and stabilizes the system's frequency, keeping it within acceptable limits. In this context, the Whale Optimization Algorithm (WOA) is utilized to optimize the gain parameters of the PID controller in the feedback loop. By fine-tuning these gains, the WOA enhances the system's stability and improves its performance, ensuring consistent frequency regulation despite load changes.*

Keywords: **Microgrid, Load Frequency Control, Optimization Algorithm, Whale Optimization Algorithm**

1. INTRODUCTION

The increasing demand for electricity in today's world poses significant challenges in maintaining a balance between power generation and consumption. As the load on power generation systems rises, ensuring system stability becomes more complex, often leading to potential issues with power quality. Power systems are designed to operate within defined standards to maintain quality, but sudden load variations can cause deviations from these standards. Load Frequency Control (LFC) systems are employed to manage the frequency oscillations that arise from such deviations [1].

In any power system, it is essential for all electrical loads whether in commercial or industrial sectors to operate at their specified frequency and voltage levels for optimal performance. However, the dynamic nature of modern power systems leads to frequent changes in load patterns, which often result in frequency deviations. These deviations can significantly impact the efficiency and overall operation of the power grid, thereby compromising power quality. To mitigate this, Load Frequency Control (LFC) loops are employed. These control mechanisms automatically regulate the network’s frequency, ensuring it stays within predefined limits. By continuously adjusting the generation output in response to load changes, LFC systems play a critical role in maintaining power system stability and reliability [2].

Frequent fluctuations occur when there is an imbalance between electricity demand and generation [3]. Power-generating units work to restore the frequency to its scheduled level after disturbances by adjusting real power output. Load Frequency Control (LFC) systems are responsible for regulating frequency within specific areas, a task that has become increasingly critical with the growing interconnectedness of power networks and evolving system architectures. Researchers continue developing various LFC techniques to maintain system frequency at desired levels under normal operating conditions and during load disturbances. Power networks consist of diverse loads, and fluctuations in these loads can impact turbine speed, which in turn affects the network’s frequency. Therefore, maintaining a consistent frequency is essential to ensure the stable operation of the power system [4].

2. System Modelling

In a single-area power network, key components consist of a turbine, a governor, and the load, all regulated by a feedback speed regulator [12].

In a power system model, the generator model uses the swing equation of a synchronous generator to account for small disturbances, or perturbations, caused by load changes. When electrical load varies, the mechanical load adjusts accordingly, shifting the load angle. The load model includes both frequency-independent loads, representing baseline consumer demand, and frequency-dependent loads, which adjust with system frequency changes. To maintain stability and control generator output, control systems use algorithms like PID controllers and advanced strategies to regulate system frequency within limits by responding to load shifts and disturbances. These controls are crucial for coordinating generators and sustaining grid stability.

Figure 1 illustrates a block diagram depicting this configuration, incorporating a PID controller. The transfer function descriptions of the blocks within a single-area power network are provided by equations (1) to (4):

- Governor dynamics: $G_G(s) = \frac{1}{1+sT_G}$ (1)
- Turbine dynamics: $G_T(s) = \frac{1}{1+sT_T}$ (2)
- Load and machine dynamics: $G_L(s) = \frac{1}{1+sT_P}$ (3)

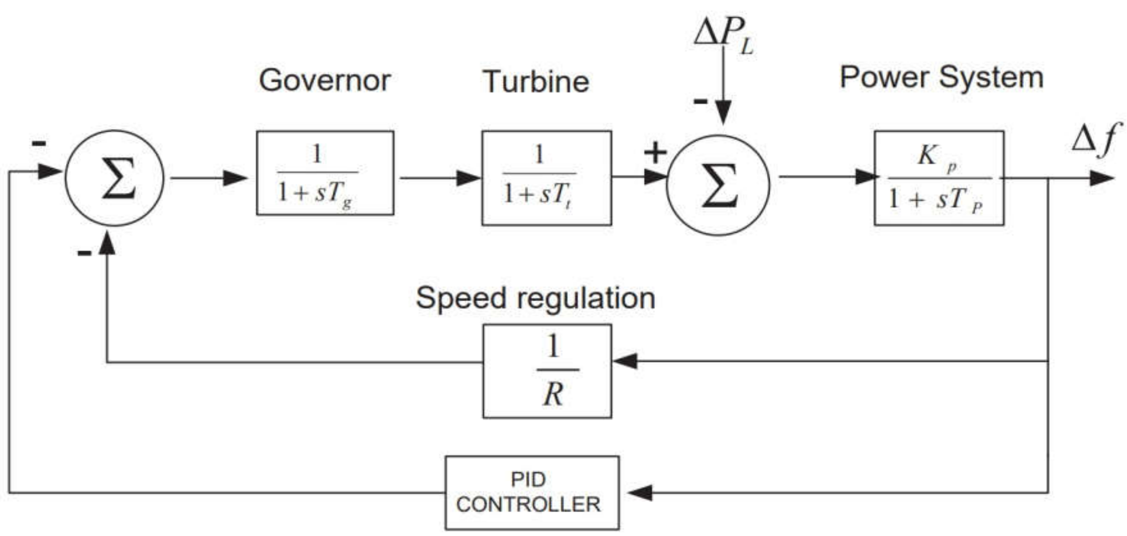

Figure 1. Single area power network using a PID controller

The transfer function for the PID feedback control loop mechanism is expressed as:

$$G_c(s) = K_p + \frac{K_i}{s} + K_D s \tag{4}$$

In the PID feedback control loop mechanism, K_P, K_i and K_D is the coefficients for the proportional, integral, and derivative terms.

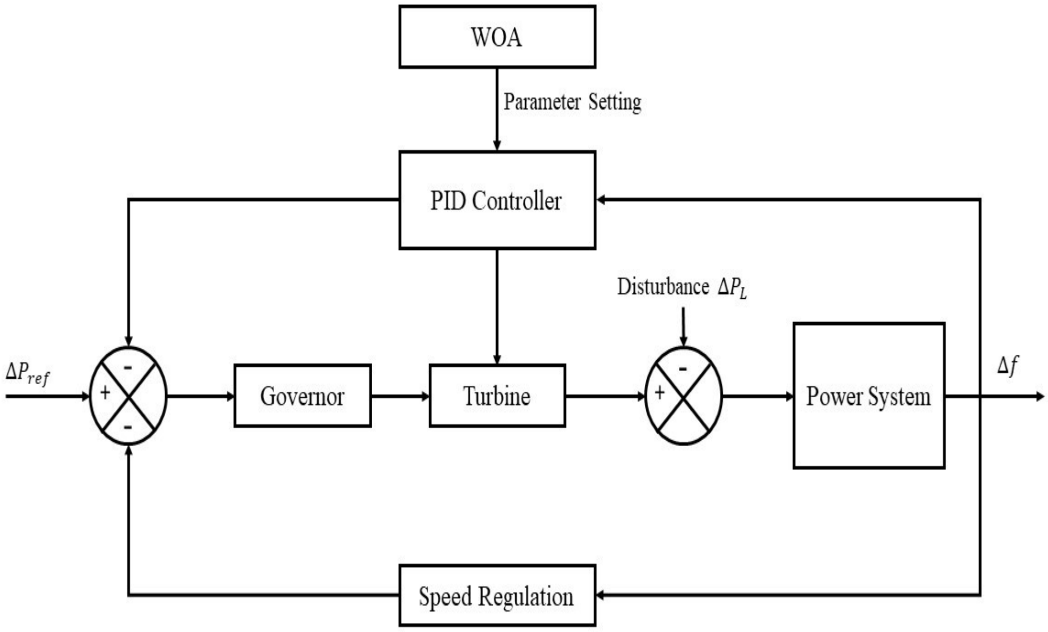

Figure 2. Block Diagram of an Optimization based PID controller for single area network.

The figure 2 is a block diagram representation of a single area network using a PID controller, which parameters are set using the Whale Optimization Algorithm (WOA).

3. Optimization Tool- Whale Optimization Algorithm (WOA)

Seyedali Mirjalili introduced the Whale Optimization Algorithm in 2016, inspired by the sophisticated hunting strategies of humpback whales, notably their innovative bubble net feeding technique. This algorithm mimics the social behavior and intelligence observed in these whales, particularly their circular bubble net attacking strategy when hunting schools of small fish near the water's surface. The optimization process involves three key stages: Encircling Prey, Bubble-net Attacking, and search for Prey. These stages enable the WOA to systematically search for the optimal set of control parameters that minimize the objective function, representing the frequency change resulting from load variations in the power system.

The WOA is mathematically structured as the following:

3.1. Encircling Prey:

Initially, a humpback whale locates its prey and surrounds it. In the context of optimization, prey represents the global best solution. Each whale adjusts its position towards the global best, mimicking the encircling behavior of the whales. Mathematically, this behavior is represented by equations (5) and (6), where vectors $\vec{A}$ and $\vec{C}$ are used to narrow the search area in eq (7) and (8).

$$\vec{P} = |\vec{A}.\ \vec{R}^*(t) - \vec{R}\ (t)|, \quad (5)$$

$$\vec{R}\ (t+1) = \vec{R}^*\ (t) - \vec{C} * \vec{P}, \quad (6)$$

$$\vec{C} = 2\vec{a} * \vec{r} - \vec{a}, \quad (7)$$

$$\vec{A} = 2 * \vec{r}, \quad (8)$$

Here $\vec{r}$ represents random number [0,1], while the vector $\vec{a}$ linearly decreases from 2 to 0.

3.2. Bubble-net Attacking:

Following the initial phase, the whale adjusts the radius of the bubble net circle and closes in on the prey through a spiral trajectory defined by equation (9). This spiral path dynamically contracts, mirroring the whale's gradual approach to its target. Employing a combination of a shrinking cycle and a spirally reducing mode, each with an equal 50% likelihood, the whale effectively homes in on its prey. Mathematically, this is represented by equation (10).

$$\vec{R}(t+1) = \vec{P}'.e^{hl}.\cos(2\pi l) + \vec{R}^*(t), \quad (9)$$

$$\vec{R}\ (t+1) = \begin{cases} \vec{R}^*(t) - \vec{C}.\vec{P}, & if\ p < 0.5, \\ \vec{P'}.e^{hl}.\cos(2\pi l) + \vec{R}^*(t), & otherwise \end{cases} \quad (10)$$

3.3. Search for Prey:

During this phase, whales initiate a random exploration of their prey. This quest involves decrementing vector A, symbolizing the disparity between their present location and the randomly selected position vector within the population. Mathematically, this process is represented by equations (11) and (12).

$$\vec{P} = |\vec{A}.\vec{R}_{rand} - \vec{R}|, \quad (11)$$

$$\vec{R}(t+1) = \vec{R}_{rand} - \vec{C}.\vec{P}, \quad (12)$$

Overall, the Whale Optimization Algorithm effectively emulates the hunting behavior of humpback whales. The flowchart of WOA is presented in figure 3. The proposed approach demonstrates promising results in addressing optimization problems across diverse domains.

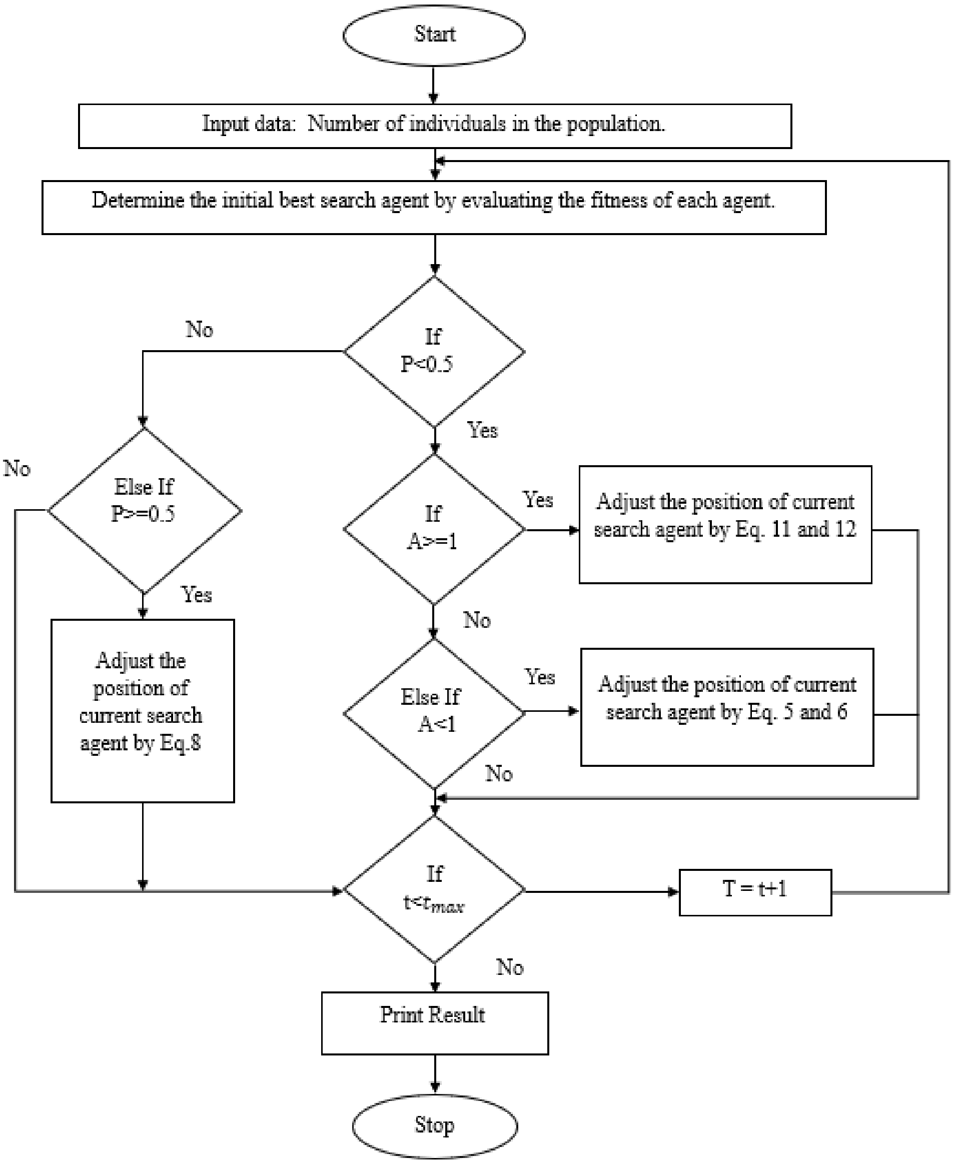

Figure 3. Flowchart of the Whale Optimization Algorithm

4. Simulation and Results

The simulation is done in LabView software. The system consists of governor, turbine, power system model, and a feedback speed regulator. The controller used is a PID control loop mechanism which provides damping torque. The power system model considered here is a single-area power system. The current system which is mathematically structured is implemented in LabVIEW. Initially, classical PID controller was used. Further, the Whale Optimization Algorithm (WOA) is used to tune the gain values (K_P, K_i, K_d) of the PID controller on run time. The WOA algorithm is also implemented in the LabVIEW platform. The simulated result are described in three cases, which are described as the following.

4.1 Case I- Frequency variation without using controller:

The load variation is introduced at t=0 sec. Figure 4 shows the frequency variation without a controller.

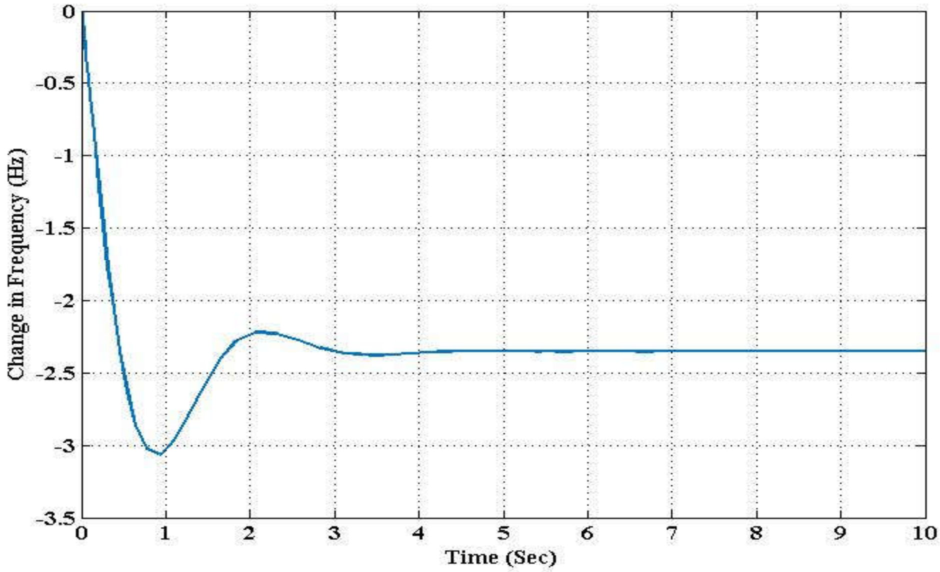

Figure 4: Frequency variation without using controller.

It is observed that without any controller the frequency deviation is very high, and it is also not stable.

4.2 Case II- Frequency variation of the system with the PID controller

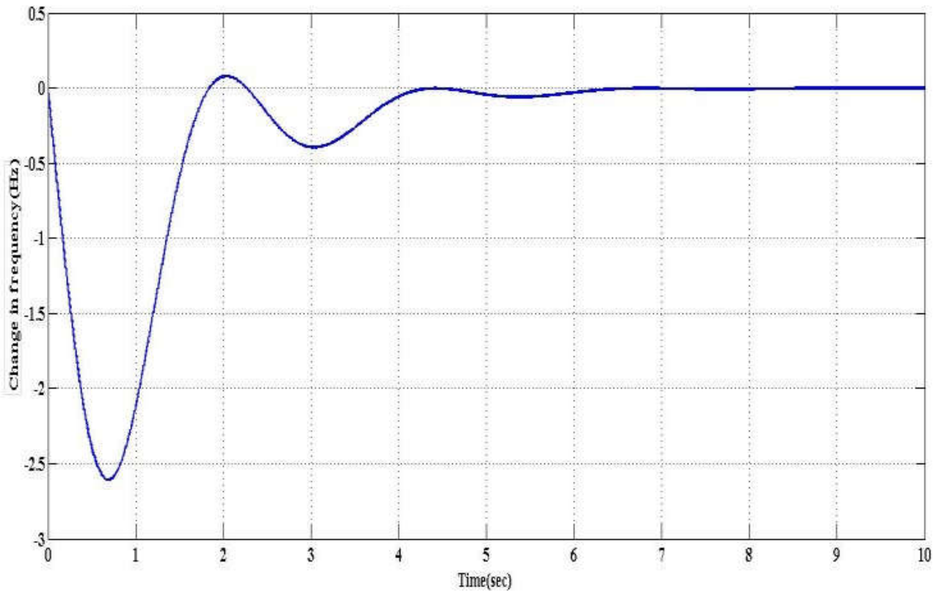

Figure 5: Frequency variation in the presence of PID controller.

Figure 5 shows the frequency variation of the system with the PID controller. It can be observed that frequency variation has significantly reduced and better waveform is obtained with the PID controller. Though the peak overshoot is high. The settling time is observed as approximately 6 seconds. The gain values used to tune the PID controller are

K_p= -0.09, K_i=0.27, K_d= -0.03 which are set randomly.

4.3 Case II- Frequency variation with the WOA-based PID controller

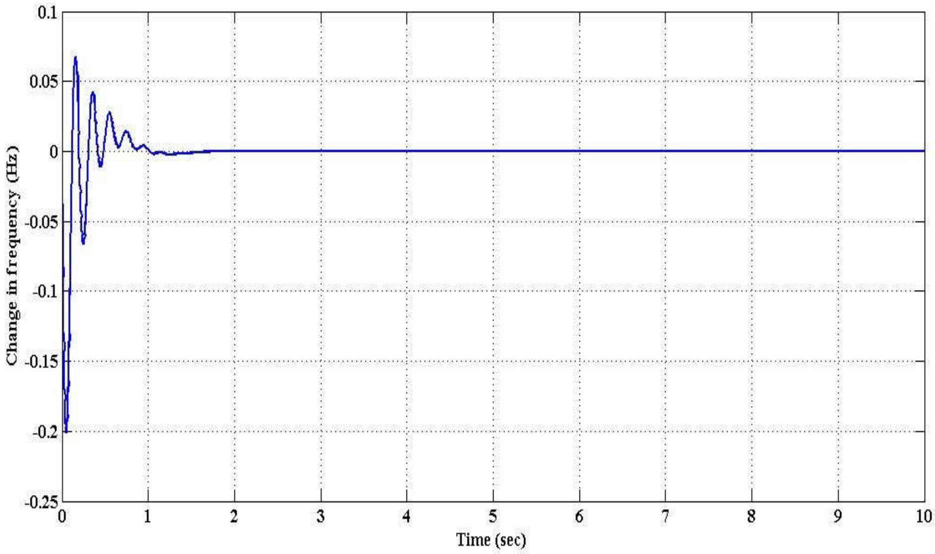

Figure 6: Frequency variation using WOA-based PID controller.

The load variation is introduced at t = 0sec. It can be observed in Figure 6 that frequency variation is significantly reduced unlike the case where frequency variation is observed with a PID controller without any optimization algorithm (Figure 5). Here it is observed that peak overshoot is drastically reduced, and the settling time is also reduced from 6 seconds (in classical PID controller) to 1 second (WOA-based PID controller). The gain values that were obtained by using WOA to tune the PID controller are K_p: -22.3, K_i:0.21, K_d:0.19.

5. Conclusion

In summary, incorporating the Whale Optimization Algorithm (WOA) into LFC systems within a Single Area Power System offers a significant opportunity to improve system performance and stability. Utilizing WOA to optimize critical control parameters like PID controller gains and time constants can effectively minimize frequency deviations and ensure stable operation. The core aim of designing an efficient LFC system for a single-area power configuration, where generation and load are managed within the same control area, is to regulate system frequency amidst varying load conditions and disturbances. WOA's capacity to explore intricate search spaces efficiently renders it suitable for optimizing the complex parameters of the LFC controller, leading to enhanced dynamic response and reduced frequency deviations. Furthermore, metaheuristic optimization techniques like WOA offer distinct advantages over conventional methods, particularly in tackling nonlinear and highly complex optimization problems. Through the application of WOA, the LFC system stands to attain superior solutions and overcome the constraints associated with traditional optimization approaches. In essence, the incorporation of WOA into LFC systems represents a promising avenue for advancing power system control strategies, ultimately fostering stability and efficiency in single-area power systems.

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