Research Article

PID Tuning Of Automatic Voltage Regulator Using MFO And WOA Techniques

Shiva Bhatnagar[1*], Sachin Puntambekar[2]

[1*]Medi-Caps University , Indore,Madhya Pradesh, India.

[2]Medi-Caps University ,Indore,Madhya Pradesh, India. Sachin.Puntambekar@Medicaps.Ac.In;

*Corresponding Author: Shiva Bhatnagar
*E-Mail:Shrivastava.Shiva09@Gmail.Com;

ARTICLE INFO	ABSTRACT
	In this paper, two novel artificial intelligence based optimization methods Moth Flame Optimization (MFO) and Whale Optimization Algorithm (WOA) are applied and compared in terms of proportional, integral and derivative controller parameters for the improvement of dynamic performance of power utility of an Automatic Voltage Regulator(AVR).For multi-variable and multi-objective problems as in the case of AVR, the evolutionary algorithm of optimization becomes a solution. But in many cases, the use of conventional optimization methods is difficult for system optimization due to various parameter dependencies which makes MFO and WOA both very feasible and reliable as these belong to the most promising Swarm Intelligence Optimization family whose variants are easy to understand and simple to operate. Navigation methodology followed by the moths is the main inspiration for MFO technique to be used. Moths fly at night with the maintenance of a fixed angle with respect to the moon which makes it an effective method to move in a straight line for long distances. On the other handywoman is inspired by the hunting behavior of humpback whales. It includes three operators for simulation-The search for prey, encircling prey, and bubble net foraging behavior of humpback whales. Here, we are comparing our results with very common algorithm which is Genetic algorithm. **Keywords:** Moth Flame Optimization (MFO), Whale Optimization Algorithm (WOA), Automatic Voltage, Regulator (AVR), Proportional-Integral-Derivative (PID) controller parameters, Dynamic performance, improvement, Power utility, Evolutionary algorithm

1 Introduction

A PID Controller is basically a generic control loop feedback mechanism (controller) widely used in industrial control systems. The PID Controller algorithm consists of three distinct stable parameters, which are Proportional, Integral and Derivative and is consequently termed as three-term controller whose values can be denoted as P, I, and D. The optimization algorithms search is to find the set of inputs to an objective function those results in optimum outputs. In order to achieve better performance parameters there is need for implementation of optimization techniques to obtain some satisfactory results.

According to increasing system complexity and work expansion, the optimization of motor control and hence the rotor velocity control is required to be more optimized. Many optimization technologies like conventional optimization, Genetic Algorithm etc. Have been used but the search for better results is still going on.

Various optimization techniques are used to optimize any electrical system prior to installation in the field. There are different types of evolution algorithms which are used by researchers for adaptation of the PID controller to the automatic voltage regulator (AVR) but still there are some parameters in AVR for which the optimum results are yet to be found. Here we are using MFO and WOA Optimization Techniques because the voltage regulators are used to control the terminal voltage by adjusting the generator's exciter voltage.AVR system needs to keep a track on the generator's terminal voltage constantly and under any load conditions in

order to keep the voltage in pre-established limits.The performance of AVR is very important as it influences the voltage level during steady state operation and reduce the voltage oscillations during transient periods and thus effecting the overall system's performances. AVR is installed near the generator and connected to sensor for adjustment of the generator input. In figure: 1 Automatic voltage regulator block diagram is shown. In this, Amplifier, exciter, generator is connected in series and a sensor is connected in feedback of above blocks[2]
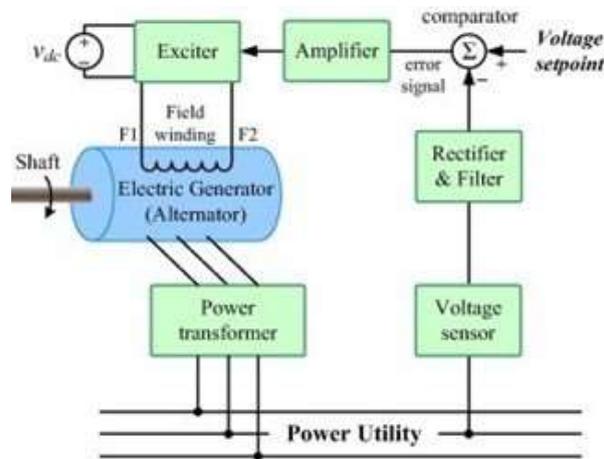

Fig. 1 AVR scheme [1]

In an electric power grid, number of generators connected to similar bus bar with its own automatic voltage regulator. As previously mentioned, AVR is used to sustain the output voltage of a SG at a reference level. As pictured in Figure. 1, amplifier, exciter, generator and sensor are mainly four essential components of an AVR. In this system, the mechanism to control the voltage of power utility is to control the input of the generator which is connected to via power transformer. The voltage level of power utility is on line measured using a voltage sensor and used as feedback signal. After this, feedback signal is compared to the reference voltage through comparator for obtaining voltage error signal. This error signal is then amplified by amplifier, and fed to exciter which adjusts the voltage or current of the field winding of generator.

To investigate the dynamic performance of the AVR mathematically, transfer function modeling is needed
For an AVR system with amplifier, exciter, generator, and sensor time constants, respectively, the mathematical modeling equation in the Laplace domain for the overall system, without considering any controller, can be given by [3]:

$$k_1(\tau_4 s +1)\Delta V (s) = \Delta V (s) (1)^t k_1 + (\tau_1 s + 1)(\tau_2 s + 1)(\tau_3 s + 1)(\tau_4 s + 1)ref$$

where k_1 is the amplifier gain and τ_1, τ_2, τ_3, and τ_4 are the time constants of the amplifier, exciter, generator, and sensor, respectively. Using the inverse Laplace trans- form, the system-governing differential equation in the time domain can be obtained as follows:

From the previous equation, the AVR dynamic system, without a controller, can be fully described by a fourth-order linear ordinary differential equation, and the dynamic system stability can be studied using the following characteristic equation:

In figure-2, a system model of AVR is shown where time constants are used and saturation or other nonlinearities are avoided, similar to literature studies [2-8].
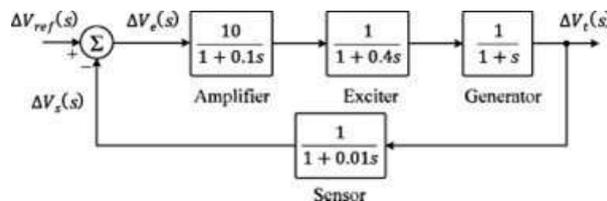

Fig. 2 AVR system model

In order to improve the transient response of the AVR system, a PID controller needs to be used in the feedback system. The proportional-integral-derivative (PID) controller mainly consists of three main components: constant gain (**kp**), constant integrator gain (ki), and constant differentiator gain (**kd**)U
Using the PID controller, as connected in Figure 3, results in extracting the AVR system model in Equation (1) to consider the controller effect, which is fully described by:
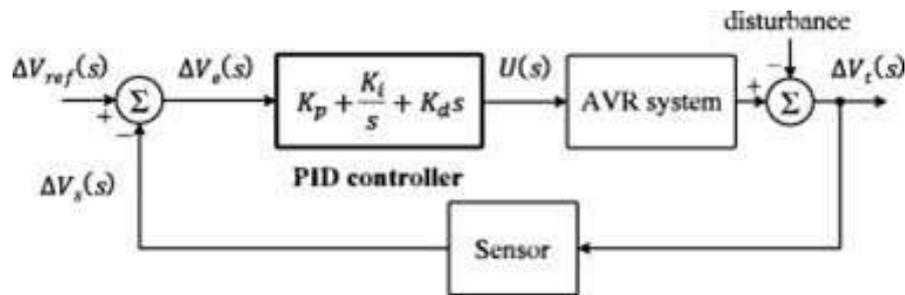
$$H\Delta V_t(s) = \frac{k_1(k_p s^2 + k_d s + k_i)(\tau_4 s + 1)}{s(\tau_1 s + 1)(\tau_2 s + 1)(\tau_3 s + 1)(\tau_4 s + 1) + k_1(k_d s^2 + k_p s + k_i)}\Delta V_{ref}(s) \quad (6)$$

The AVR dynamic system-governing differential equation in the time domain takes the form:

$$H\left[\prod_{i=1}^{4}\tau_i D^5 + \sum_{\substack{t i=1 \\ j>i}}^{4}\tau_i\tau_j\tau_k D^4 + \sum_{\substack{i=1 \\ j>i}}\tau_i\tau_j D^3 + (k_1 k_d + \sum_{i=1}\tau_i)D^2\right.$$
$$+ (k_1 k_p + 1)D_t + k_1 k_i \Delta V(t)$$
$$= k_1[\tau_4 k_d D^3 + (\tau_4 k_p + k_p)D_t + k_i]\Delta V_{ref}(t) \quad (7)$$

During the system design process, the PID-AVR system stability can be studied using the following system characteristic equation:

$$H\left[\prod\tau_i s^5 + \sum_{\substack{i=1 \\ j>i}}^{44}\tau_i\tau_j\ \tau_k s^4 + \sum_{\substack{i=1 \\ k>j}}^{4}\tau_i\tau_j\ s^3 + (k_1 k_d + \sum_{i=1}^{4}\tau_i)s^2 + (k_1 k_p + 1)s + k_1 k_i = 0 \quad (8)\right.$$

The objective is to reach to the desired performance. Mathematically, it is defined as Where, $\Delta V_e(n)$ is the error between the reference voltage and measured voltage for the nth sample, and N is the total number of samples collected. As shown in Figure 2 and Figure 3, $\Delta V_e(n)$ highly depends on K_p, K_i, and K_d. Hence, optimization has been performed to reduce the total error.

2 Genetic Algorithm
Genetic Algorithm is a stochastic global adaptive search optimization technique based on the mechanism of natural selection. It is a heuristic mimicking the natural evolution process and is routinely used to generate useful solutions of an optimization problem. In GA, a population of strings called chromosomes encode the possible solutions of an optimization problem and evolve for a better solution by process of reproduction.
The process of evolution starts from a population of randomly generated individu- als. Optimization is achieved in generations where in each generation, fitness function evaluates each individual in the population and multiple individuals are selected stochastically based on their fitness. These selected individuals are modified to form a new population. The algorithm terminates when either produces a maximum number of generations, or a satisfactory fitness level has been reached for the chosen popula- tion.GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem, the performance of which is evaluated by a fit ness function. Basically, GA consists of three main stages; they are Selec- tion, Crossover and Mutation. The application of these three basic operations allows the creation of new individuals, which may be better hand, their parents. This algo- rithm is repeated for many generations and finally stops when reaching individuals that represents the optimum solution of a problem [4-5].

3 Moth Flame Optimization
MFO algorithm inspired by nature is made based on the moth's transverse orientation into space. For navigating, transverse orientation utilizes a fixed angle through moth about the moon for flying in straight directions at night.
With the local search strategies, the algorithms based upon the populations are combined by the MFO to yield an algorithm that can explore globally and exploit locally. MFO can be easily integrated and is flexible and straightforward, and in addi- tion, it has high similarity with the Metaheuristics. MFO can also be brought

into use for solving an extended range of issues. Considering these advantages, the successful implementation of MFO was made for optimizing numerous problems. A few of the examples which can be illustrated for its applications are image processing, energy, power, economic, classification, estimating parameters, etc. [8].Figure 4 exhibits the flow chart of the MFO. It has been acknowledged that both flames, as well as the moths, are the solution. How they are updated and treated within the each iteration defines the differences among them. Since the moths move around the spaces, they are considered as the searching agent. Presently, the best solutions which are attained through the moths till now are the flames. Flames can be regarded as pins or flags that fell from the moths when exploring searching spaces. This is the reason because of which moths never miss their target of attaining the optimum solutions.[1,2,9].
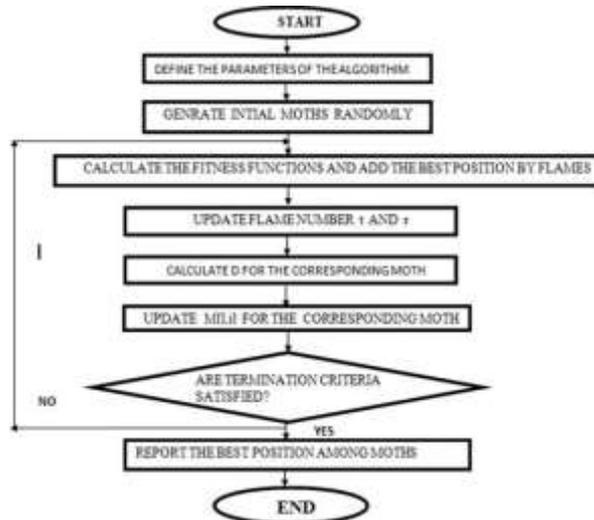

Fig. 4 The MFO flow chart.[9]

Whale Optimization Algorithm (WOA)

Whale Optimization Algorithm (WOA) is a new meta heuristic optimization algorithm for solving optimization problems. Like other evolutionary optimization algorithm this algorithm is also evolve the solution with different operator prey, encir- cling prey, and bubble-net for aging [11].The flow chart of the WOA is shown in figure 5.
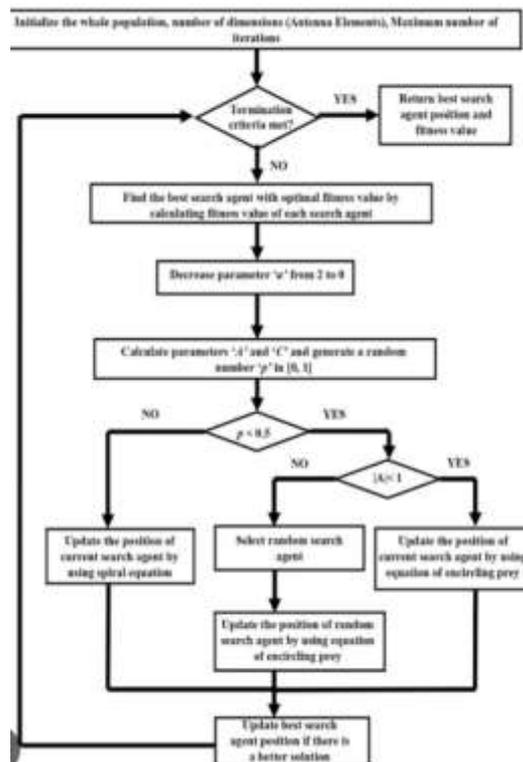

Fig. 5 WOA algorithm

This algorithm simulates the social behavior of humpback whales. Like MFO,WOA also use a set of random candidates solution and it specially uses three rules to update and improve the position of candidate solutions in each group in each step which are Encircling Prey, Spiral Updating Position and Search for Prey.
The MFO and WOA algorithm are applied for optimization of transient response of AVR. The next section presents the simulation study for this and demonstrates the comparative study based on the results.

4 Simulation and Results

The simulation model of the AVR is shown in figure 2 and the PID based control scheme is shown in the figure 3. The following parameters are used for optimization. The output of system model is given here without optimization in figure6and
7.Thevalue of constants of PID is as follows Kp=5, Ki=1.9 , Kd=2

Table 1 Simulation Parameters

S. no	Parameter	Value
1	No of parameters	3(**Kp**, **Ki**, **Kd**)
2	Solution size	20
3	No. of iteration	60
4	Lower bound of the variable	[0.1 0 -2]
5	Upper bound of the variable	[10 5 2]
6	Initial solution	Random selection

Fig. 6 Output signal wave for mof the AVR w.r.t. reference signal without optimization of PID controller
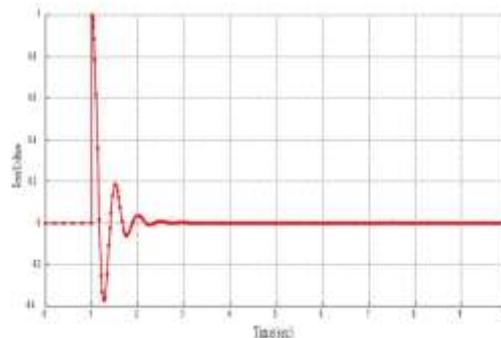

Fig. 7 The error voltage signal used for controlling the voltage of power utility Simulation results with MFO:

The optimization curve is shown in the figure 6. It can be observe that 50 iterations have been run to achieve the convergence of optimization.
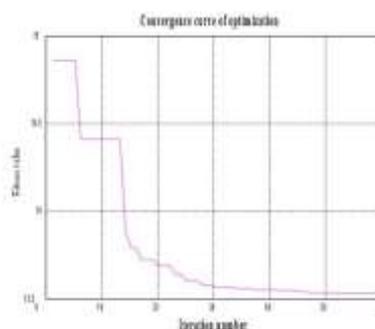

Fig. 8 Optimization Curve

The optimized coefficient of the PID controller is as follows,
KP =3.01, Ki=1.21, Kd=1.24
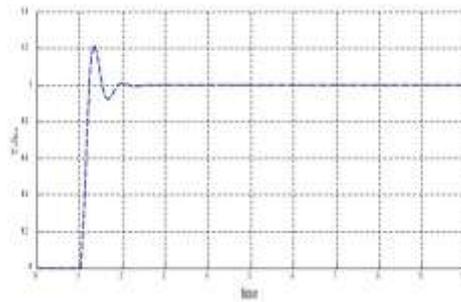The output and error signal can be seen in figure 9 andfigure10.

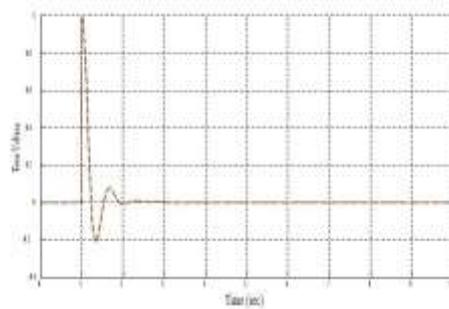**Fig. 9** Optimized out voltage of AVR after optimization using MFO

Fig. 10 Error signal with optimized PID coefficient using MFO

The optimized performance is shown in table 2:

Table 2 Comparison of the AVR performance with and without optimization

Parameters	Without Optimization	With MFO Optimization
Overshoot level	39%	20%
Study state error	5.05%	4.6 %
Study state time	1.4 sec	1.25 sec

It is clear improvement in the performance of AVR after optimization of PID controller with MFO algorithm.
Now simulation is further proceed to evaluate the performance of one more algorithm WOA.

Simulation results with WOA: The optimization curve is shown in the figure11.
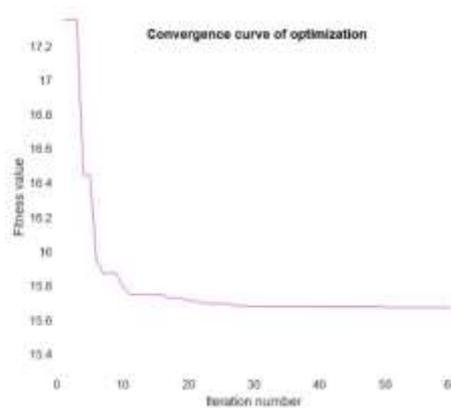It can be observe that   35 iteration has been taken for the optimization.

Fig. 11 Convergence Curve of WOA

The optimized coefficient of the PID controller is as follows,
KP =2.85, Ki=1.4, Kd=1.6

The table 3 gives a comparative analysis of the performance of AVR with and without optimization.

Parameters	Without	With	MFO With	WOA
Overshoot level	39%	20%	26%	
Study state	5.05%	4.6 %	4.8 %	
Study state	1.4 sec	1.25 sec	1.3 sec	

5 Conclusion

The simulation of AVR system optimization has been done with MFO and WOA method. With this algorithm, error has been significantly reduced by the optimization in limited iteration which indicated the significant reduction in the complexity of algorithm. From the table 3 of result section, MFO based optimization improves the results significantly. However the WOA algorithm shown in improved convergence and required less than 40 iterations for convergence. However optimization performance of MFO is better.

References

1. Sahoo2023Saroj Kumar Sahoo and Apu Kumar Saha, "Moth Flame Optimization: Theory, Modifications, Hybridizations, and Application", Achieves of Computa- tional methods in Engineering, 0, 91-426 (2023), August 2022.
2. Shehab2019 Mohammad Shehab, Laith Abualigah, Husam Al Hamad, Hamzeh Alabool, Mohammad Alshinwan, Ahmad M. Khasawneh, "Moth–flame optimiza- tional algorithm: variants and applications", Neural Computing and Applications, October 2019.
3. Celik2018 Emre Çelik and Rafet Durgut, "Performance enhancement of auto- matic voltage regulator by modified cost function and symbiotic organisms search algorithm", Engineering Science and Technology, an International Journal, Volume 21, Issue 5, 2018, Pages 1104-1111.
4. Manipatruni2018 Jaisimha Manipatruni and Narasimha Sampath Vedula, "Design and Implementation of PID Controller using Genetic Algorithm", Volume 07, Issue 11 (November-2018).
5. Celik2018b E. Çelik, "Incorporation of stochastic fractal search algorithm into efficient design of PID controller for an automatic voltage regulator system", Neu- ral Compute. Appl., 2018, 10.1007/s00521-017-3335-7.
6. Mirjalili2016 Seyed Ali Mirjalili and Andrew Lewis, "The Whale Optimization Algorithm", Volume 95, 2016, Pages 51-67.
7. Chatterjee2016 S. Chatterjee and V. Mukherjee, "PID controller for automatic voltage regulator using teaching–learning based optimization technique", Int. J.
8. Electr. Power Energy Syst., 77 (2016), pp. 418-429.
9. Guvencc2016 U. Güvenç, T. Yiğit, A. H. Işık, İ. Akkaya, "Performance analysis of biogeography-based optimization for automatic voltage regulator system", Turk. J. Electr. Eng. Comput. Sci., 24 (2016), pp. 1150-1162.
10. Mirjalili2015 Seyed Ali Mirjalili, "Moth-Flame Optimization Algorithm: A Novel Nature-inspired Heuristic Paradigm", Knowledge-Based Systems, (2015).
11. Gozde2014 H. Gözde, M. C. Taplamacioglu, M. Ari, "Automatic voltage regulator (AVR) design with chaotic particle swarm optimization", International Conference on Electronics, Computers and Artificial Intelligence, 2014, pp. 23-26.
12. Panda2012 S. Panda, B. K. Sahu, P. K. Mohanty, "Design and performance analysis of PID controller for an automatic voltage regulator system using simpli- fied particle swarm optimization algorithm for automatic voltage regulator (AVR) system", J. Franklin Inst., 349 (2012), pp. 2609-2625.
13. Gozde2011 H. Gozde, M. C. Taplamacioglu, "Comparative performance analysis of artificial bee colony algorithm for automatic voltage regulator (AVR) system", J. Franklin Inst., 348 (2011), pp. 1927-1946.12