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# Grey Wolf Optimization Algorithm based PID controller design for AVR Power system

Rvindra kumar Kuri
Department of EE
Rajasthan Technical University
Kota, Rajasthan 324010, INDIA
ravindrakuri099@gmail.com

Deepak Paliwal
Department of EE
Rajasthan Technical University
Kota, Rajasthan 324010, INDIA
dpaliwal.phd17@rtu.ac.in

D. K. Sambariya
Department of EE
Rajasthan Technical University
Kota, Rajasthan 324010, INDIA
dsambariya@gmail.com

***Abstract*—This Article deals with grey wolf optimization algorithm (GWO) detestable on migration demeanors proposed to get the optimum values implementing PID controller for a given automatic voltage regulator system (AVR). In this paper, we briefly described the details about the grey wolf optimization algorithm for proper compatibility of the parameters of PID controllers with integral square error (ISE) using the objective function. the proposed topic simulation outcomes of the response of AVR assimilate with Grey wolf Optimization (GWO), Water Cycle Algorithm (WCA), Monarch butterfly algorithm (MBA), Particle Swarm Optimization (PSO), Chaotic PSO(CPSO), algorithm in terms of peak time, amplitude and settling time with performance check including IAE, ISE, and ITAE function.**

***Keywords—Automatic voltage regulator system (AVR) modelling, PID controller GWO, WCO and MBO.***

## I. INTRODUCTION

The fundamental work of control engineer is to obtain and provide a good design system with good efficiency and economic benefits. Which is always a challenge for control engineer. Numerous control methodology and different structures are used to meliorate the transient response and demote the steady-state errors of disparate industrial operation and proceeding. To preserve the defined voltage level at various load values a voltage regulator system is being formed and employed. For obtaining a good voltage regulator we broadly and pre-eminently use automatic voltage regulator system because of its good excitation control over the synchronous generator to enforce the quality of power and stability of the system in electrical work. The automatic voltage regulator system usually locale in generating units. To conserve the prescribed level of terminal voltage and reactive power of almost all generator AVR system is permanently used [1]-[4].

To generate an optimum result with AVR system we employ PID controller along with it [5]. The PID controller is permanently used controller among the all known controller in the industrial work [6]. Automatic voltage regulator system (AVR) with PID controller used to sense and recognize the generator voltage and keep up to a specific level [7]-[8]. The PID controller with AVR plays a vigorous role to enhance the generator output voltage response, increase the system stability and power quality to satisfy the consumer needs and demands. Moreover, the tuning of a PID controller with automatic voltage regulator is entirely a challenging task to perform. Several techniques have been propounding to match the PID controller parameter [9]. This PID controller parameter is nattily optimized by using various soft computing and conventional techniques such as PSO-PID, ZN-PID, MOL-PID, GWO-PID. To select a better algorithm, many factors are being noticed like performance analysis, cost function and power quality.

In this article, the proposed GWO algorithm has been described, developed by Mirjalli et al 2014, mimics the leadership hierarchy of wolfs which are known for their group hunting. The GWO technique usually used in three stages [11]. (i) Searching (ii)Encircling (iii) Hunting. The simulation results compared with other algorithms with improved responses.

## II. PROBLEM FORMULATION

### *A. AVR configuration*

The main aspect of the power system is to control the reactive power and regulate the terminal voltage profile. The working phenomenon of AVR is to conserve the terminal voltage of the employing synchronous generator despite load variation. AVR captious influence power system security.

The basic model diagram of the AVR with & without PID controller is shown fig. 1 & fig. 2 severally. AVR is usually an amalgamation of several elements namely amplifier, sensor, exciter and generator. Theforemost application of AVR can uphold generators terminal voltage at a preferent level during the period of steady-state and voltage oscillation during transient state has been reduced along with improving the system stability [9].

Eq. (1) explain the transfer function of the amplifier.

$$\frac{V_a(s)}{V_e(s)} = \frac{K_a}{\tau_a s + 1} \tag{1}$$

Eq. (2) explain the transfer function of the exciter.

$$\frac{V_f(s)}{V_a(s)} = \frac{K_e}{\tau_e s + 1} \tag{2}$$

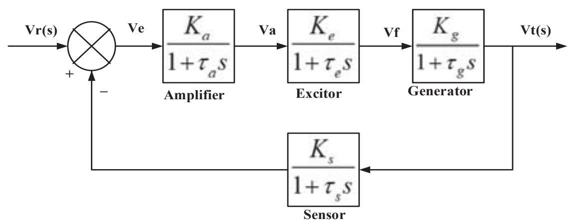

Fig. 1. AVR without PID controller

Eq.(3) explain the transfer function of the generator.

$$\frac{V_t(s)}{V_f(s)} = \frac{K_g}{\tau_g s + 1} \tag{3}$$

Eq. (4) explain the transfer function of the sensor.

$$\frac{V_s(s)}{V_t(s)} = \frac{K_s}{\tau_s s + 1} \tag{4}$$

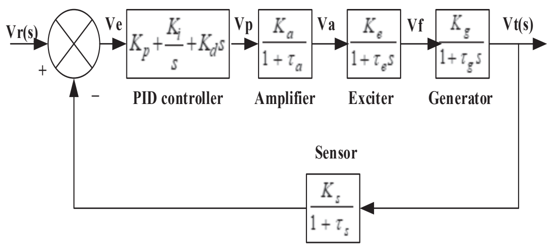


Fig.2. AVR with PID controller

Here, Ka, Ke, Kg, Ks, constant represent the gain and τa, τe, τg, τs constant represents time constant of generator,amplifier, sensor, exciter severally. Various codify of gain, time constant and different used values are present given table 1.

TABLE 1. Range of gain & time constants

| Components | Transfer function | Parameter values |
|---|---|---|
| **Amplifier** | $\frac{V_a(s)}{V_e(s)} = \frac{K_a}{1+\tau_a s}$ | Ka=10<br>τa=0.1 |
| **Exciter** | $\frac{V_f(s)}{V_a(s)} = \frac{K_e}{1+\tau_e s}$ | Ke=1<br>τe=0.4 |
| **Generator** | $\frac{V_t(s)}{V_f(s)} = \frac{K_g}{1+\tau_g s}$ | Kg=1<br>τg=1 |
| **Sensor** | $\frac{V_s(s)}{V_t(s)} = \frac{K_s}{1+\tau_s s}$ | Ke=1<br>τe=0.01 |

## *B. PID Controller*

PID controller is the ubiquitously used control loop feedback controller to enhance the quality response of AVR. PID controller exhibits a short time rise i.e fast response with higher stability. This controller is simple in construction and robust[8].

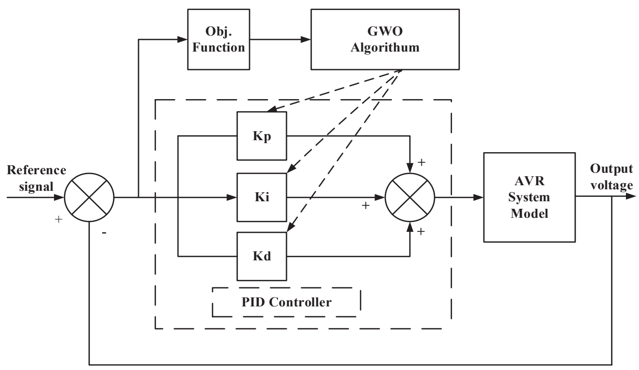


Fig. 3.AVR system using GWO-PID controller

To reduced steady-state error we increase the number of poles indenominator side of integral controller while by employing the derivative controller and adding zero to its numerator side we improve the transient response of plant [8]-[9]. The transfer function is further explained and cover by equation (5).

$$G(s) = K_p + \frac{K_i}{s} + K_d s \tag{5}$$

## *C. . Objective function*

This paper, the basic fundamental objective is to be obtained a describe function with minimum error signa[13]. This evaluated minimize error signals detailed by eq. (6) and (7).

$$J = \int_{t=0}^{T_{sim}} |V_r(t) - V_s(t)^2\, dt| \tag{6}$$

Here Vr(t) is reference signal and Vs(t) referred to feedback signal[13].

$$\begin{aligned} K_p^{\min} &\le K_p \le K_p^{\max} \\ K_i^{\min} &\le K_i \le K_i^{\max} \\ K_d^{\min} &\le K_d \le K_d^{\max} \end{aligned} \tag{7}$$

## III. GREY WOLF OPTIMIZATION

The GWO Algo is progressed by Mirjalili et al in 2014. The Grey wolf (cains lupus) dwells to canidae family. This algorithm mimics the leadership hierarchy system in wolves which are known for their group hunting. Grey wolves are reputed as apex predators i.e top in the food chain[10]. Grey wolves perform living in the back as it is beneficial for them. This pack consist of 9-12 wolves on an average. Here fig. (4) shows the strict social dominant hierarchy.

The social hierarchy is simulated by categorizing the population of search agents into four types based on the fitness.

**Level (1)** -Alpha is the leader most responsible for deciding hunting, rest place and marching etc. Alpha decision is followed by the remaining strictly. Alpha dictated the pack so they also called the dominant wolf.

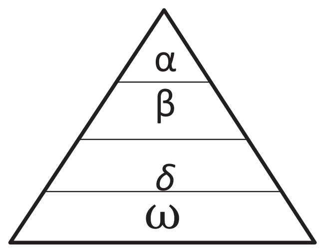


Fig. 4. Hierarchy of grey wolf

**Level (2)**–Beta is subordinate which helps the alpha in decision making i.e works as an advisor to alpha while discipliner for the pack. They refer to the second level in the social hierarchy. Beta level wolves refers to be the best candidatecase of alpha wolves become old or die. The alpha command reinforced by the betathroughout the pack and ensure all subordinate follows the order of alpha[10].

**Level (3)** -Delta is in the third level of strict social dominant hierarchy. They also work as subordinate to alpha & beta. While Delta also dominant the omega and report to the alpha and delta.

**Level (4)** -Omega is the level (4) shows the last level of hierarchy system. They are like the scapegoat in the pack. This level refers as least category.

The search purpose is modelled to mimic the grey wolves behaviour makinguse of three stages namely searching, encircling, and attacking the pray[11].

The first two stages are dedicated to the exploration and the last stage refers to exploitation. This stage mainly consists of three steps.1 Tracking and chasing the pray.2 Encircling and harassing the pray until pray stops movement.3 Attracting the encircled pray.

**A. Mathematical model and Algorithm**

This section explains the mathematical model of a hierarchy consisting of searching, encircling and attacking.

1) Social hierarchy: Here we refer the alpha as fittest result while beta &delta as second and third solution respectively remaining all will refer to omega[12].

2) Encircling preyMathamaticalmode of encircling the pray is explained below in equation (8) and (9).

$$\vec{D} = |\vec{C}\cdot\vec{X}_p(t) - \vec{X}(t)| \tag{8}$$

$$\vec{X}(t+1) = \vec{X}(t) - \vec{A}\cdot\vec{D} \tag{9}$$

Here $\vec{A}$ $\vec{C}$ and both are vector cofficient, t refers to the current iteration. $\vec{X}_p$ is position vector. While $\vec{X}$ it refers to the position of a grey wolf.

For calculating $\vec{A}$ and $\vec{C}$ vectors

$$\vec{A} = 2\vec{a}\cdot\vec{r}_1 - \vec{a} \tag{10}$$

$$\vec{C} = 2\cdot\vec{r}_2 \tag{11}$$

4) Hunting**:** This section mostly refers to recognize the position of pray and track until all the wolves encircle it. The hunt is escorted by the alpha, Sometimes beta and delta also participated in the hunting process. Now the following equation are projected for this respect[13].

$$\begin{aligned} \vec{D}_\alpha &= |\vec{C}_1\cdot\vec{X}_\alpha - \vec{X}| \\ \vec{D}_\beta &= |\vec{C}_2\cdot\vec{X}_\beta - \vec{X}| \\ \vec{D}_\delta &= |\vec{C}_3\cdot\vec{X}_\delta - \vec{X}| \end{aligned} \tag{12}$$

$$\begin{aligned} \vec{X}_1 &= \vec{X}_\alpha - \vec{A}_1\cdot(\vec{D}_\alpha) \\ \vec{X}_2 &= \vec{X}_\beta - \vec{A}_2\cdot(\vec{D}_\beta) \\ \vec{X}_3 &= \vec{X}_\delta - \vec{A}_2\cdot(\vec{D}_\delta) \end{aligned} \tag{13}$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \tag{14}$$

5) Attacking: In this section when the pray stop movementand all the wolves encircled pray. The movement of pray being stopped and makes him unable to run and escape. İn this mathematical model approach, we decrease the value of $\vec{a}$ . İn other words the $\vec{a}$ lies between the value in the interval [-2a, 2a]. Now the fig. 5. shows the attacking pray condition.

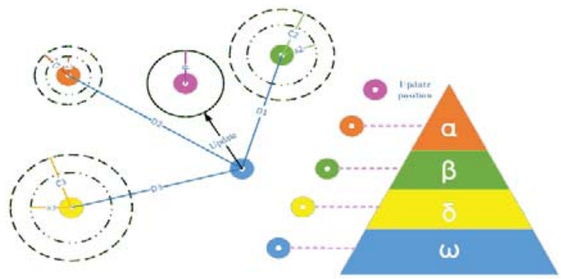


Fig. 5. Position updating in GWO

6) Searching for pray: This section is easy to understand by the fig. 18(a) and 18(b). The condition arises from the wolves for the prey[12]-[13].

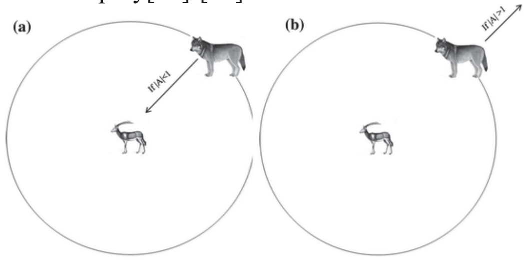


Fig. 6. (a) and 18(b) attacking prey versus searching for prey

Now the pseudo-code of GWO algorithm with all the possibilities consisting all the step shown below

| Algorithm Grey Wolf optimization process |
|---|
| Format the grey wolf people $X_i$ (i=1, 2, 3…….., n)<br>Initialize a, A, and C<br>Compute the health of every individual search agent<br>$X_\alpha$ =the healthiest and robust search agent<br>$X_\beta$ =the endorse 2nd best search agent<br>$X_\delta$=the 3rd best agent<br>While (t<Max number of iterations)<br>For each search agent<br>Contemporize the location of the current search agent using the equation (14)<br>end for<br>Contemporizea, A, and C<br>Compute the health and strength of almost every search agent<br>Modernize $X_\alpha$, $X_\beta$, and $X_\delta$<br>t=t+1<br>end while<br>return $X_\alpha$ |

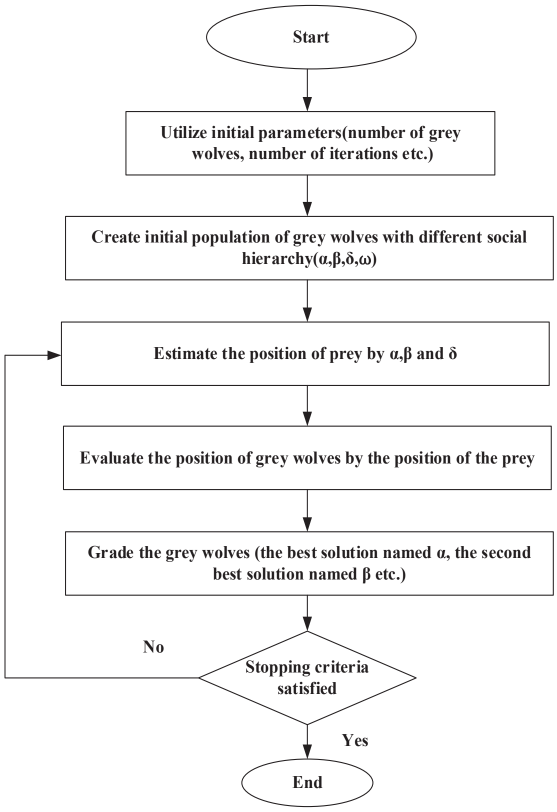


Fig. 7. Flow chart of GWO algorithm

## IV. Simulation Result and Discussion

This section deals with the simulation analysis with PID controller connected with the AVR system. The purposed algorithm GWO and Water cycle, MBA having settling time less than one (<1). So good response make the purposed algorithm is quite better than others.Performance of GWO is based on peak amplitude and settling time.

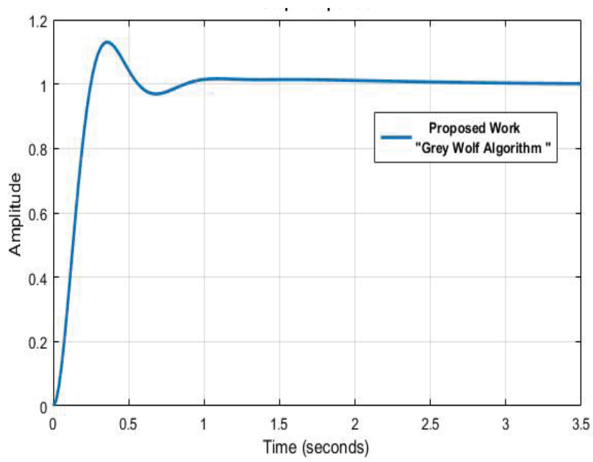


Fig. 8 . Step response of GWO

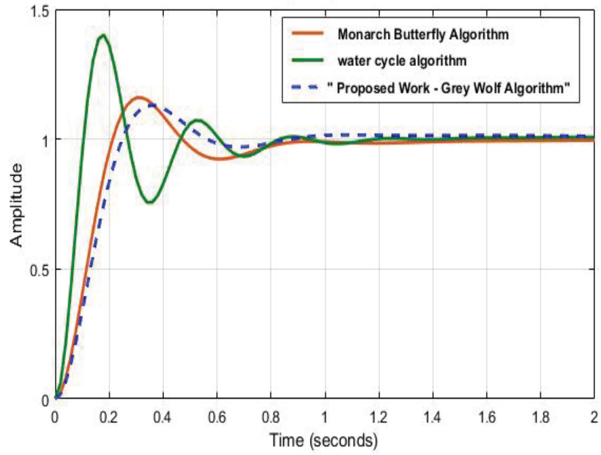


Fig. 9. Step response Comparison between proposed GWO, MBA, WCA

TABLE 2 PID parameter with simulation results

| S. NO. | Controller | PID- Controller Parameter | | |
|---|---|---|---|---|
| | | $K_p$ | $K_i$ | $K_d$ |
| 1 | **PID-GWO (proposed)** | 1.064 | 0.9985 | 0.3971 |
| 2 | **PID-MBO [9]** | 1.2454 | 0.7516 | 0.4821 |
| 3 | **PID-WCA[1]** | 2 | 2 | 1.33 |

TABLE 3 Simulation result with settling time and peak.

| S. No. | Controller | Settling time (sec.) | Peak |
|---|---|---|---|
| 1. | **PID-GWO (proposed)** | 0.7739 | 1.1301 |
| 2. | **PID-MBO [9]** | 0.8276 | 1.1605 |
| 3. | **PID-WCA [1]** | 0.7949 | 1.4023 |

TABLE 4 comprasion On the based on performance indices

| S. No | Controller | ITAE | IAE | ISE |
|---|---|---|---|---|
| 1. | **PID-GWO (proposed)** | 199.2784 | 19.5824 | 20.01743 |
| 2. | **PID-MBO [9]** | 200.6175 | 19.8826 | 20.0528 |
| 3. | **PID-WCA [1]** | 200.6671 | 19.7814 | 20.1536 |

Theabovetableshowsthe hypercritical anatomizing perpetrate by the terms of performance indices. These performance indices usually refers to an integrated time-weighted error(ITAE), integral of squared error(ISE) and integral absolute error(IAE). The detailed explanations of performance indices are given below in question.

$$ITAE = \int_{0}^{T_{sim}} t\,|\,y_0(t) - y_r(t)\,|\,dt \tag{15}$$

$$IAE = \int_{0}^{T_{sim}} |\,y_0(t) - y_r(t)\,|\,dt \tag{16}$$

$$ISE = \int_{0}^{T_{sim}} t\,|\,y_0(t) - y_r(t)\,|^2\,dt \tag{17}$$

## V. CONCLUSION

This paperworkexhibits the property of PID controller associated with AVR using the GWO algorithm is well appropriate tuning &designing using the predefined specific parameters. The output step response is improved by using the mentioned algorithm respectively. The simulation result demonstrates the proposed technique of optimizing GWO algorithm more efficiently employing the PID controller. GWO algorithm improves the system stability & step response of the system namely peak amplitude, rise time, system speed and settling time. It also did a comparative analysis in terms of ITAE, IAE, ISE.

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