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Design and Analysis of a PID Controller for an AVR System Using MOL Optimization Algorithm and Its Comparison with Other Intelligent Algorithms

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ABSTRACT: *Some of the important Automatic Voltage Regulator (AVR) system tasks in power network are generator output voltage regulation, distribution, and reactive power regulation of generators. However, the AVR system without controller does not have a suitable performance. Therefore the Proportional Integral Derivative (PID) controller is used to improve AVR system performance. There are different methods in order to determine PID controller coefficients, by which in this paper a new method called MOL algorithm is getting used. To demonstrate a better performance of MOL algorithm a comparison has been done between this method and other methods like Artificial Bee Colony (ABC), Particle Swarm Optimization (PSO), and Differential Evolution (DE).*

Keywords– *Automatic Voltage Regulator (AVR), Modified Particle Swarm Optimization Algorithm (MOL), PID Controller*

I. INTRODUCTION

As we know all the equipment's connected to power system are designed to work in nominal voltage. Therefore, any type of change in voltage level leads to decrease in desired performance and longevity of connected equipment in power system. Also, the main part of line losses is related to reactive power crossing by which this reactive power is proportionate with voltage. Therefore, in order to line losses reduction, the voltage level must be controlled. A solution for this problem would be control unit called AVR (Automatic Voltage Regulator) [1]. Among different modern control methods such as state feedback and optimized control, LQR (Linear Quadratic Regulator), using of PID controller method in most of cases is recommended due to owing a simple structure and also resistance for system parameters alteration. The problem in optimized design of these PID controllers is high voltage control system degrees for the powerhouses and also their non-linear essence. Therefore some evolutional methods are used for optimization of PID coefficients. The Genetic Algorithm(GA)method is capitalized for PID parameters regulation [2, 3]. Surely, these methods such like GA takes time. Another problem in GA method is disability in optimization of goal functions which coefficients have great correlation. Resultantly after a while the GA method is not able to produce a new population anymore; so the probability of reaching to local optimization increases. Another method which is recently used in PID coefficient design is the PSO (Particle Swarm Optimization) method [4]. This method is powerful in solving non-linear problems and has a less running time and better performance in comparison with other methods. In this paper a modified PSO method which called MOL is used to design controller [5, 6]. This paper proves that small changes in PSO method lead to improved response in comparison with other methods like PSO, ABC (Artificial Bee Colony) [7, 8, and 9], DE (Differential Evolution) [10, 11, and 12]. The simulation results demonstrate better power and efficiency.

In the AVR system, first the output voltage of a generator measures by a voltage sensor then it compares with the reference voltage. The result signal, error voltage, reinforces with an adaptor, and then simulation system applies the output voltage by adjusting the regulator simulation field.

II. LINEAR MODELING OF THE VOLTAGE AUTOMATIC CONTROLLERSYSTEM

As it is shown in Fig. (1), the AVR system has a control ring which is used in order to regulate and apply the generator output voltage. According to Fig. (1)The AVR system is consisting of the four subsystems – namely adaptor, simulator, generator, and sensor.

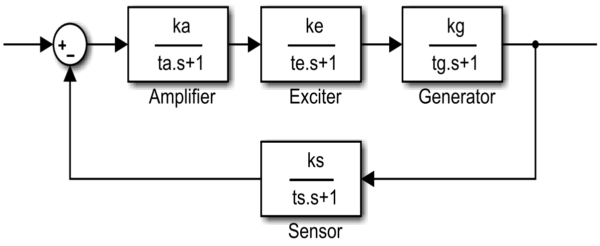

Fig. (1): The Control Block of AVR System

There are convertor functions of eachsubsystem only with parameters ranges in Table (1).

Table (1): The parameters Ranges of AVR System

	Converter Function	Parameters range
Amplifier	$TF_A = \frac{K_a}{1 + ST_a}$	$0.02 < T_a < 0.1$ $10 < K_a < 40$
Exciter	$TF_E = \frac{K_e}{1 + ST_e}$	$0.4 < T_e < 1$ $1 < K_e < 10$
Generator	$TF_G = \frac{K_g}{1 + ST_g}$	$1 < T_g < 2$ $0.7 < K_g < 1$
Sensor	$TF_s = \frac{K_s}{1 + ST_s}$	$0.001 < T_s < 0.06$ $K_s \cong 1$

Using of a PID controller is essential for improvement of dynamic response and output voltage preservation. The Fig. (2) shows the AVR system of the Fig. (1) by a PID controller.

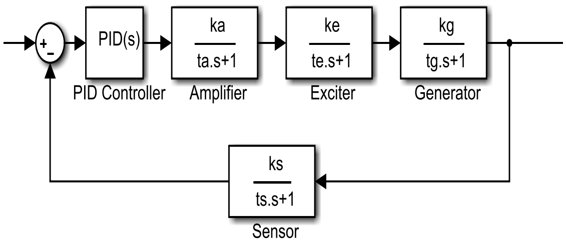

Fig. (2): AVR Package Ring System with a PID Controller

III. INTRODUCTION OF A PID CONTROLLER

The Fig. (3) shows a PID controller which is consisting of three bellow sections:

1) Proportional Coefficient of K_P
2) Integral Coefficient of K_I
3) Differential Coefficient of K_D

Therefore, the convertor function of a PID controller is:

(1): $$TF_{PID} = K_P + \frac{K_I}{S} + K_D S$$

The proportional function leads to decrease of leap-time, even though it cannot decrease the permanent state error. The integral coefficient leads to omission of the permanent state error but makes the transient response worse. For instance a great integral coefficient causes an overshoot and a small one leads to slow system response. A differentiation coefficient causes increment in system stability, overshooting decrease, and transient response improvement [6].

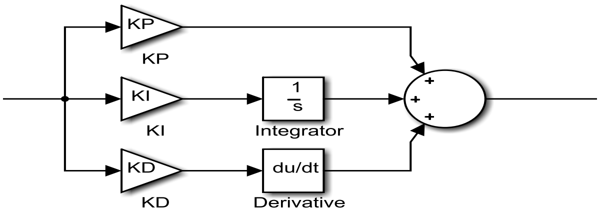

Fig. (3): PID Controller Elements

IV. PID PERFORMANCE ASSESSMENT

Table (2) demonstrates different goal functions that are used for PID controller performance assessment. In these functions V_t is terminal voltage, V_r is reference voltage, andthe'‘t’ is duration of program running time.

Table (2): Goal Functions

1.	$ITAE = \int_0^t t\,\|V_r - V_t\|\,dt$
2.	$ITAE = \int_0^t \|V_r - V_t\|\,dt$
3.	$ITAE = \int_0^t t(V_r - V_t)^2\,dt$
4.	$ITAE = \int_0^t (V_r - V_t)^2\,dt$

V. MOL METHOD

The innovative optimization algorithm of elements group is an evolutional computational method based on the population of responses. As the other innovative algorithms, the above said algorithm is a type of optimization tool that can be used to solve different optimization programs. This is one of the latest innovative methods which were developed by Kennedy and Aberheart in 1995, inspired from social behavior of group of immigrant birds trying to reach an unknown destination. In PSO algorithm the population of responses is called ‘group’ and each response is like a bird in a group of birds called ‘particle’ which is resembled to chromosome in genetic algorithm. All the particles have merit value that is calculating using merit function and it should be optimized. Moving direction of each particle determines by that particle’s speed vector. Unlike the genetic algorithm, in evolution process of this algorithm new birds, or new responses, from previous generation do not produce; however each bird develops its social behavior based on experiences and other birds behavior in group and then improves its movement to the destination by them.

In other words there are not any evolutional operations like intersection and leap in this algorithm. According to the Newton mechanical rules the PSO can express as bellow, by which there is each particle of ‘i’ with mass of ‘m’ in a ‘D’ dimensional searching space.

The particle’s speed and correlation speed is:

(2): $\vec{a} = \frac{d\vec{V}}{dt} = \frac{\vec{F}}{M}$

For practicing the speed and correlation relations in repetitive process:

(3):
$$\vec{V} = \frac{\vec{x}(t) - \vec{x}(t-1)}{\Delta t} \Rightarrow \vec{x}(t) = \vec{x}(t-1) - \vec{v}(t)\Delta t$$
$$\frac{\vec{F}(t-1)}{m} = \frac{\vec{v}(t) - \vec{v}(t-1)}{\Delta t}$$
$$\Rightarrow \vec{v}(t) = \vec{v}(t-1) + \frac{\vec{F}(t-1)}{M}\Delta t$$

Supposing the constant mass of each particle and Δt, the speed and replacement relation for each particle simplifies as equation (4). Now the force on each particle in‘t-1’ time should be obtained. The birds consider total information to determine their direction. Therefore the best global position of group compares with the best global position of particles in each time. The new searching direction is a combination of these two directions and particle previous direction.

(4):
$$\vec{P}_i = (P_{i1}, P_{i2}, P_{i3}, \dots, P_{iD})$$
$$\vec{g}_i = (g_{i1}, g_{i2}, g_{i3}, \dots, g_{iD})$$

In ‘D’ dimensional searching space the best personal position of particle ‘i’ is shown by $P_{i,}$ and the best global position of group is shown by g_i. The force on particle ‘i’ is modeling through the best personal position of particle and the best global position of group as two connected springs to particle by which the first one forces in the best personal experience direction and the second one forces in the best global experience direction. The final relation of particle speed in repetitious time according to Fig. (4) is:

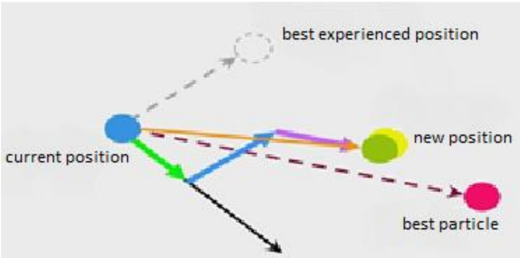

Fig. (4): the particle motion in PSO algorithm

(5):
$$v_{id}(t+1) = wv_{id}(t) + c_1 rand_1 (P_{id}(t) - x_{id}(t)) + c_2 rand_2 (g_d(t) - x_{id}(t))$$

In equation (5), ω is inertia coefficient, and C_1, C2 are Hook spring coefficients or acceleration coefficients. For randomization of particles essence the coefficients of C_1, C2 multiplied in random numbers of $rand_1$, $rand_2$.The MOL algorithm is a simplified form of PSO algorithm. The difference between MOL and PSO algorithms is that the MOL algorithm overlooks particle personal experience, and speed updating is as:

(6):
$$v_{id}(t+1) = wv_{id}(t) + c_2 rand_2 (g_d(t) - x_{id}(t))$$

The Fig. (5) illustrates PID-MOL algorithm as flowchart which represents the program procedure step-by-step. The flowchart is consisting of 5 bellow sections:

1) Random early particle production (problem solution)
2) Merit function calculation (goal function)
3) Particle best experience (g) calculation
4) Next speed and position calculation of each particle by applying speed and replacement relations
5) If convergence condition is true, then the problem is over; else go to the step (2)

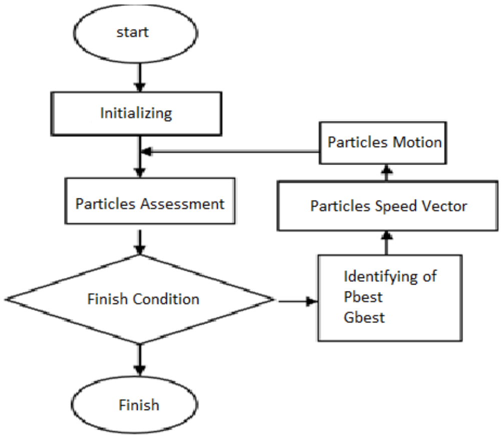

Fig. (5): MOL method flowchart

VI. SIMULATION RESULTS

In first part of simulation we try to get AVR system step-response without the PID controller. The Fig. (6) demonstrates the system's step-response lack of PID controller.

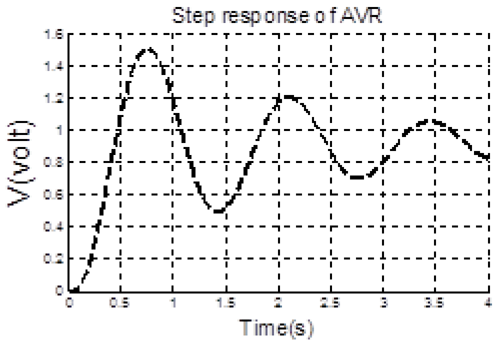

Fig. (6): AVR system step-response without controller

The table (3) presents AVR system step-response specifications without PID controller. To improve dynamic response and output voltage preservation in per unit a PID controller is used.

Table (3): AVR system step-response specifications without PID controller

Delay Time	Overshoot	Session Time	Final Value
0.261	5.1	6.97	0.909

In this step we are going to identify the best goal function from different goal functions introduced in table (2). Hence, the PID coefficients are calculated using different goal functions through MOL algorithm, and the step-response of AVR system obtains. As it is shown in Fig. (7) the best system response is when goal function is considered as ITAE.

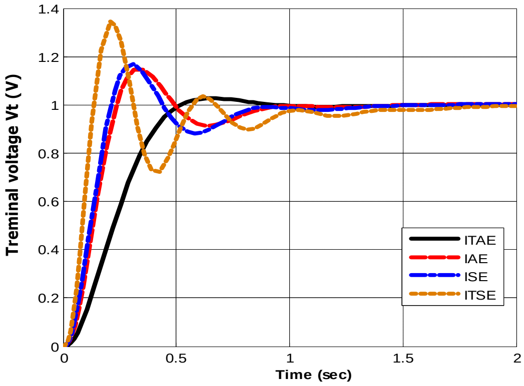

Fig. (7): output terminal voltage different goal functions

These controller coefficients have represented in table (4) for various goal functions.

Table (4): PID coefficients for different goal functions

	ITAE	IAE	ITSE	ISE
Kp	0.5857	0.9931	0.9877	0.9544
Ki	0.4189	0.7461	0.7780	0.9434
Kd	0.1772	0.4249	0.5014	0.9909

In order to demonstrate the efficiency of this method in comparison with other methods a comparison has been done between MOL and other algorithms, including ABC, DE, and even PSO. According to Fig. (8) The best response is from MOL algorithm side. In table (5) the transient response specification is given, and as it is considered the best overshoot and session time is related to MOL algorithm which depicts the excellence of this algorithm to others.

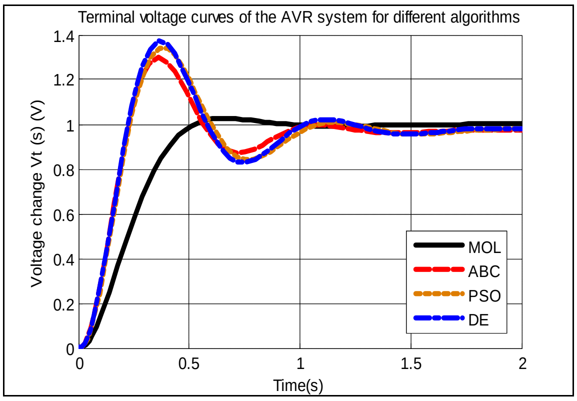

Fig. (8): AVR system step-response for different methods

Table (5): Step-response specification for different algorithms				
Techniqus /error function	*Settling time*	*Maximum Overshoot (pu)*	*Rise Time*	*Peak Time*
Mol/ITAE	*0.5155*	*1.0195*	*0.3433*	*0.7036*
Mol/IAE	*0.8814*	*1.1040*	*0.1644*	*0.3408*
Mol/ITSE	*0.8769*	*1.1143*	*0.1468*	*0.3056*
Mol/ISE	*1.5324*	*1.2481*	*0.0895*	*0.2013*
ABC/ITSE	*3.19*	*1.25*	*0.156*	*0.3628*
PSO/ITSE	*3.5*	*1.3005*	*0.1609*	*0.3908*
DE/ITSE	*2.77*	*1.3281*	*0.1513*	*0.3636*

The Fig. (9) demonstrates AVR system poles and zeros by which their PID controller parameters have regulated by MOL algorithm. In the Table (6) the transform function poles and damping ration by each of methods are presented. As it is shown the poles in all methods are in the left side of pivot; however the AVR system regulated with MOL algorithm has more damping in comparison with other algorithms due to conquering pole far from the ‘jω’ pivot.

The frequency responses of AVR system regulated by MOL algorithm are depicted in Fig. (10). As it is shown in Table (7), the properties of AVR system frequency response regulated by MOL algorithm have relative superiority in comparison with other algorithms, and the best frequency response is related to MOL algorithm.

Table (6): The poles of AVR system package ring with different algorithms			
MOL	*ABC*	*PSO*	*DE*
Closed Loop Poles	*Closed Loop Poles*	*Closed Loop Poles*	*Closed Loop Poles*
-100	*-100.98*	*-101*	*-101*
-2.11	*-4.74*	*-6.26*	*-6.3*
1.06	*-0.25*	*-0.215*	*-0.228*
-4.92+4.72i	*-3.75+8.4i*	*-3.09+7.8i*	*-3.03+8.1i*
-4.92-4.72i	*-3.75-8.4i*	*-3.09-7.8i*	*-3.03-8.1i*

Table (7): The Baud diagram specification obtained from different algorithms				
Different algorithm	Peak gain(dB)	Phase margin(deg.)	Delay margin(s)	Bandwidth
MOL	*0.0*	*180*	*Inf*	*6.3373*
ABC	*2.87(7.51Hz)*	*69.4*	*0.1109*	*12.8791*
PSO	*3.75(1.14Hz)*	*62.2*	*0.103*	*12.182*
DE	*4.20(1.21Hz)*	*58.4*	*0.092*	*12.8*

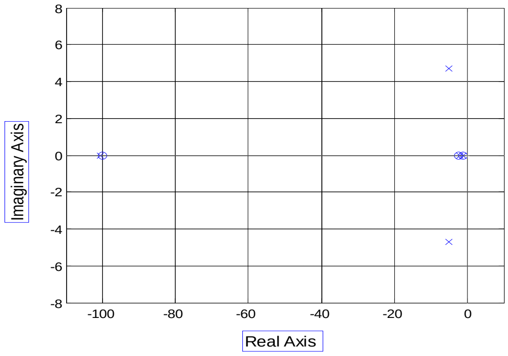

Fig. (9): AVR system poles and zeros using MOL algorithm

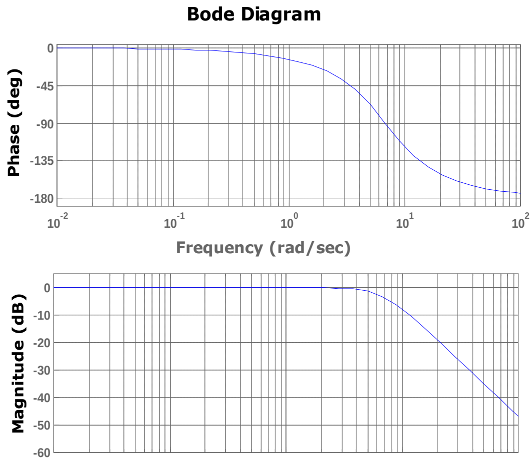

Fig. (10): The Baud diagram with PID coefficients regulation by MOL algorithm

VII. CONCLUSION

The purpose of this paper is to represent a new method, the MOL algorithm, for PID controller design in AVR system. In order to demonstrate better performance of this method than the others, a comparison has been done between MOL algorithm and other methods like ABC, DE, and PSO. From the simulations results like step-response, geometrical location of roots, and baud diagram, we conclude that MOL algorithm has less running time and also better performance in PID controller operation in comparison with other methods, including DE, ABC, and PSO.

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