Speed Control of PMDCM Based GA and DS Techniques

Wisam Najm AL-Din Abed, Adham Hadi Saleh, Abbas Salman Hameed
Department of Electronic Engineering, College of Engineering, University of Diyala, Iraq

ABSTRACT
Permanent magnet direct current motors (PMDCM) are widely used in various applications such as space technologies, personal computers, medical, military, robotics, electrical vehicles, etc. In this paper, the mathematical model of PMDCM is designed and simulated using MATLAB software. The PMDCM speed is controlled using rate feedback controller due to its ability of improving system damping. To improve the controller performance, its parameters are tuned using genetic algorithm (GA) and direct search (DS) techniques. The tuning process based on different performance criteria. The most four common performance criteria used in this paper are JIAE (Integral of Absolute Error), JISE (Integral of Square Error), JITAE (Integral of Time-Weighted Absolute Error), and JITSE (Integral of Time-Weighted Square Error). The results obtained from these evolutionary techniques are compared. The results show an obvious improvement in system performance including enhancing the transient and steady state of PMDCM speed responses for all performance criteria.

Corresponding Author:
Wisam Najm AL-Din Abed,
Department of Electronic Engineering,
College of Engineering,
University of Diyala, Iraq.
Email: wisam_alobaidee@yahoo.com

1. INTRODUCTION
DC motors have been widespread in the industrial control area for a long time, due to its own good characteristics such as high starting torque, good response performance and it is easier to be linear control. It has a good speed-control respond, widespread speed control range. It is extensively used in various speed control systems which need high control requirements [1]. PMDCM is one type of dc motors that used in various applications where simplicity of structures, high efficiency and a lower initial cost are main importance. The PMDCM are used when variable high-speed operation is required. The absence of field winding, make this type of motors lower costs, simpler construction, low starting torque, small air-noise, lower cu losses that increase the motor efficiency. High performance direct current motor drives service PM motors which require accurate complex trajectory tracking for position-speed reference, with improved transient and steady state time specifications for motor response. Control of electric drives is one of the main topics in modern electronics. [2]. High performance PMDCM drives are used in various industrial applications such as process control, vehicles guided, paper and steel rolling mills, and mining and smelting plants. Accurate, fast and effective reference speed tracking with minimum overshoot and undershoot as well as small steady state error are the main important control aims of such a drive system. Conventional control techniques are of a fixed structure, fixed parameter designing hence the optimization or tuning of these controllers are a major challenging and difficult task, mainly under varying load conditions due to parameter changing, and irregular modes of operation [3]. Lastly, Multi Objective Evolutionary Algorithms (MOEA) have confirmed to be extraordinary conveniences for solving different areas optimization problems [4]. Genetic algorithm and direct search techniques implements a special class of direct search called pattern search (PS) [5]. pattern search is a subclass of direct search (DS) algorithms presented by Torczon for
unconstrained problems and prolonged by Lewis and Torczon to problems with bound constraints and a finite number of linear constraints [6]. Genetic algorithm was originally introduced by John Holland (1975). Which are a stochastic global search technique that imitate the process of natural evolution [7].

DC drives control has been the interest of many researchers, due to good torque-speed characteristics, simple control scheme and types variety make them to applicable in different applications. DC motors controllers range from simple traditional PIDs to advanced control algorithms [8]. The PID controller played a vital role in the feedback control system due to its simple structure, ease of use and simple realization. However, the main drawbacks of the PID controllers are the effects of proportional and derivative kick which leads to large overshoot and system oscillation especially when in the presence of load disturbance [9]. This drawbacks of PID controllers represent a real problem in designing the closed loop control system for dc drives.

The proposed solution in this work is to design a rate feedback controller-based GA and DS techniques for optimizing the controller parameters. The motivation for the use of rate feedback controller comes from the fact that, rate feedback controller doesn’t provide a zero into the plant as well as doesn’t decrease the system order (or increase the system dynamics). Rate feedback controller provide the stiffest system, least disturbance sensitivity and It has the attenuation effect which leads to reduce system overshoot and improve its performance. For optimal controller designing, GA and DS techniques are proposed to tune the controller parameters. These strategies have simple search techniques, cover the search space optimally, lower parameters required and avoid entrapped in local optima. These features make them better optimization techniques.

Most of reasearchers focus on the use of PIDs controller in the dc drive control arrangements based several tuning techniques. In 2014 Singh et. Al., [10] proposed PID controller for dc motor speed control-based GA techniques depending on different performance indices. In 2014 Ibrahim et. Al., [11] proposed PID controller-based Ant Colony Optimization (ACO) for separately excited dc motor. In 2014 Ibrahim et. Al., [12] introduce in his article PID controller tuned using Particle swarm optimization (PSO) and Bacterial Foraging (BF) techniques for dc motor control. In 2015 Diego et. Al., [13] present PID controller base ACO for dc motor control in robot arm. In 2016 Suman and Giri [14] proposed PID controller-based GA for dc motor speed control. In 2016 Abdulameer et. Al., [15] present PID controller based- traditional tuning techniques for dcmotor control. In 2018 Shamseldin et. Al., [16] present nonlinear PID controller for speed control of BLDC motor-based GA.

2. MATHEMATICAL DYNAMIC MODEL OF PMDCM

The main advantages of using PMDCM in many applications are safety, more stability, lower cost, easier to control and the ability to run in lower voltages. The equivalent circuit of PMDCM is shown in. The dynamic mathematical model for a PMDCM is derived from both the electrical and mechanical or dynamic equations of motion. The equations describing the PMDC motor characteristics is follow as [17]:

\[
V_a(t) = R_a i_a(t) + L_d \frac{di_a(t)}{dt} + E_b(t)
\] (1)

\[
E_b(t) = K_e \omega_m(t)
\] (2)

\[
T_m(t) = K_i i_a(t)
\] (3)

\[
K_i = K_b = k
\] (4)

\[
T_m(t) = J m \frac{d \omega_m(t)}{dt} + B_m \omega_m(t) + T_L(t)
\] (5)

where; \(V_a\) is the armature voltage (V), \(R_a\) is the armature resistance (Ω), \(i_a\) is the armature current (A), \(K_i\) is the torque constant (Nm/A), \(K_e\) is the back emf constant (V.s/rad), \(J\) is the rotor inertia (kg.m), \(L_d\) is the armature inductance (H), \(E_b\) is the back emf (V), \(B_m\) is the viscous friction coefficient (Nms/rad), \(T_L\) is the load torque (N.m), \(T_m\) is the motor torque (N.m), \(\omega_m\) is the angular speed (rad/s).
3. RATE FEEDBACK CONTROLLER

This type of controller can be achieved by feeding back internally the derivative of the plant output signal using tachogenerator and comparing it with a proportional error signal as shown in Figure 1 [18]. This type of controller doesn’t introduce an additional zero to the plant as some other types of controllers do so it doesn’t increase the overshoot of the system response which means improves the system damping [19].

![Rate feedback controller structure](image)

Figure 1. Rate feedback controller structure [20]

4. DIRECT SEARCH AND GENETIC ALGORITHM OPTIMIZATION TECHNIQUES

Direct search (DS) method is one of important optimization algorithms which challenge to minimize a function by comparing at each iteration, its value is computed by simple mechanisms in a finite set of trial points. DS does not use any derivative information also do not try to indirectly build any derivative approximation type. Pattern search (PS) methods can be understood as DS methods for which the rules of generating the trial points follow stricter calculations and for which convergence for stationary points can be verified from random starting points [21]. The PS optimization is an evolutionary technique which is suitable to solve different optimization problems that lie exterior the space of the standard optimization methods. It has the advantage of possessing very simple concept, easy to implement and computationally efficient. Unlike other heuristic algorithms, PS has a flexible and fine-balanced operator for enhancing and adapting the global and well tune local search. PS algorithm proceeds by computing a sequence of random points that may or may not approaches to the optimal point. The PS algorithm starts by creating a set of points called mesh, around the given point. The current point could be the initial starting point provided by the user or it could be computed from the previous step of the algorithm. The mesh is formed by adding the current point to a scalar multiple of a set of vectors called a pattern. If a point in the mesh is found to improve the fitness or objective function at the current point, the new point becomes the current point at the next iteration. Pattern search optimization algorithm will repeat until it reaches the optimal solution for the minimization of the objective function. Figure 2 shows a flow chart illustrate the pattern search algorithm steps [22].

![Pattern search algorithm flow chart](image)

Figure 2. Pattern search algorithm flow chart
GA is a search mechanism imitates the natural selection and the genetics of living organisms. A typical GA consists of three operators, i.e., reproduction, crossover, and mutation[23]. GA is a powerful and largely appropriate stochastic search and optimization technique and is possibly the greatest widely known type of computational evolutionary methods now days. GA is based on natural evolution and the best chromosome survival. There are three basic variances between genetic algorithm and other classical optimization methods. Firstly, the genetic algorithm works on the problem parameters encoded strings. Each string is the representative of one solution of the problem, and the real values of the parameters are attained from the decoding of these strings. Secondly, the genetic algorithm is a searching technique which works on a search spaces population. This makes the genetic algorithm to explore different search spaces simultaneously and reducing the possibility of being entrapped at local points. Thirdly, the genetic algorithm does not require preceding data from the problem search space such as convexity and derivable. It is only essential to calculate a fitness function. The fitness function expresses the response rate of proximity to the fitness function of the intended algorithm. The genetic algorithm is a technique for solving both constrained and unconstrained optimization problems that is based natural selection, the process that imitate biological evolution. The genetic algorithm recurrently modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at randomly and the present population be parents and uses them to give the children for the next generation. Over recurrent successive generations, the population "evolves" near an optimal solution [24].

Genetic algorithms were originally introduced by John Holland (1975). Genetic algorithms are a stochastic global search technique that imitate the process of natural evolution. Genetic algorithm Procedure is as follows:

1) Population Size
   The first step in the Genetic algorithm is to establish an initial population size, which is normally consists of 20–100 individual strings that represent potential solutions in the search space for global optima. There is not any derived method or rule how to choose the best population size - it is based on trial and error.

2) Reproduction
   Fitness is a measure for evaluating the chromosome suitability. By the survival principle of the fittest, a higher fitness chromosome has a higher probability of contributing one or more offspring in the next generation [25]. The fitness function value of each chromosome is evaluated during the reproduction stage. The fitness value is used in the selection process to offer bias towards fitter individuals. Just like in natural evolution, a fit chromosome possesses a higher selection probability are selected for reproduction stage. There are different types of selection which are based on the same principle that is giving fitter chromosomes a larger probability of selection. Four common selection methods are: Roulette Wheel selection, Stochastic Universal sampling, Normalized geometric selection, and Tournament selection.

3) Crossover
   The next stage after selection is the crossover. Individuals are paired for creating new individuals. Crossover stage involves exchange of genetic materials between two parent chromosomes to create child chromosome. There are many types of crossover such as single-point crossover, two-points crossover, and Uniform crossover.

4) Mutation
   In natural evolution, mutation is a random process that causes one part of a gene to change which produce a new genetic structure. Mutation occurs with a low probability – typically in the range from 0,01 to 0,001 [7]. Genetic algorithm stages are illustrated in Figure 3.
5. SIMULATION AND RESULTS

The PMDCM rated and parameters that are used in this work are illustrated in Table 1. The mathematical model of PMDCM is designed and simulated depending on its dynamic and electric equations as mentioned in section 2. The PMDCM model is built using MATLAB Simulink toolbox. The use of mathematical modelling for the motor give more accurate results for controlling purposes than using transfer function model because transfer function model was built depending approximation for initial conditions.

The permanent magnet direct current motor (PMDCM) closed loop control system is done with rate feedback controller for controlling the motor speed to improve the motor speed response by enhancing the transient and steady state of speed responses. The parameters of rate feedback controller are tuning based direct search and genetic algorithm techniques. The tuning process is done with different performance criteria. The performance criteria used in this work are, JIAE (Integral of Absolute Error), JISE (Integral of Square Error), JITAE (Integral of Time-Weighted Absolute Error), and JITSE (Integral of Time-Weighted Square Error). Each of this performance criteria have its own advantages. The direct search technique and genetic algorithm parameters that are chosen for rate feedback controller tuning are illustrated in Table 2. While the tuned controller’s parameters are listed in Table 3 for all used performance criteria’s.

### Table 1. PMDCM rated and parameters

| PMDCM rated and parameters | Symbol | Unit | Value |
|----------------------------|--------|------|-------|
| Shaft Power                | $P$    | kW   | 5     |
| Armature Resistance        | $R_a$  | Ω    | 0.5   |
| Armature Inductance        | $L_a$  | H    | 0.012 |
| Total Inertia              | $J_m$  | Kg.m²| 0.00471 |
| Viscous Friction Coef.     | $B_m$  | N.m.s/rad | 0.002 |
| Torque Constant            | $K_t$  | N.m/A| 0.5   |
| Back Emf Constant          | $K_b$  | V.s/rad | 0.5   |

### Table 2. Direct search and genetic algorithm parameters

| Direct search technique | Parameters | Genetic algorithm | Parameters |
|-------------------------|------------|-------------------|------------|
| Poll method             | GPS positive basis 2N | Fitness function | JIAE/ JISE/JITAE/JITSE |
| Polling order           | Random     | Population size   | 100        |
| Initial mesh size       | 1          | Crossover fraction| 0.8        |
| Expansion factor        | 1.2        | mutation          | uniform    |
| Correction factor       | 0.5        | Mutation rate     | 0.01       |
| Max. No. of iteration   | 50         | Max. No. of generation | 50        |

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Table 3. Tuned controller parameters

| Direct search technique | K1   | K2   | genetic algorithm | K1   | K2   |
|-------------------------|------|------|-------------------|------|------|
| JIAE                    | 43.5927 | 0.4636 | JIAE             | 812.7630 | 0.2914 |
| JISE                    | 76.9319 | 1.0097 | JISE             | 152.3770 | 0.0962 |
| JITAE                   | 80.0309 | 0.8626 | JITAE            | 1.98917e+04 | 0.6163 |
| JITSE                   | 35.4620 | 0.4441 | JITSE            | 3.7459e+03 | 0.5514 |

Figure 4 shows the PMDCM speed response for rate feedback controller tuned based direct search technique and genetic algorithm with different cost criteria. While Figure 5 illustrate a comparison in the PMDCM speed step responses using four different cost criteria based direct search technique and genetic algorithm respectively.

![Graph A](image1)

![Graph B](image2)

![Graph C](image3)

![Graph D](image4)

Figure 4. PMDCM speed response for controller tuned based GA and DS techniques (a) based JIAE criteria (b) based JISE criteria (c) based JITAE criteria (d) based JITSE criteria

From simulation results it is clearly that the optimization algorithms do well in controller tuning for all used performance indices. The use of proposed controller leads to improving the system transient and steady state performance. The proposed controller-based GA technique leads to fast settling but produce some overshoot due to the large value of forward gain. While the DS techniques give slower settling without any over shoot due to the balance between the feedback and feedforward gain value. Zero steady state error obtained with controller tuned using the the two proposed techniques. So, the two optimization method does well and optimize the controller parameters to meet the system requirements.
Figure 6 and Figure 7 show direct search technique fitness function plot at each iteration and mesh size plot at each iteration respectively. While Figure 8 and Figure 9 show genetic algorithm fitness function plot at each generation and average distance between generations plot at each generation respectively.

From fitness plots for both techniques, it is clear that the fast convergence ability for both optimization strategies. DS technique converge after 10 iterations while GA technique converge after 17 iterations approx. This feature makes these optimization techniques best versus other techniques because the rest need large number of iterations for converge. Both optimization techniques are implemented under the same number of iterations to show its ability under the same conditions.
6. CONCLUSIONS

Rate feedback controller is used widely in different industrial applications due to its simple structure lower complexity cheaper than intelligent controllers and also it has the advantage of improving the system damping over other traditional controllers. In this paper, rate feedback controller is used for controlling the speed of PMDCM. Some evolutionary techniques such genetic algorithm and direct search technique are introduced as controller tuning techniques to improve the controller performance. When comparing the speed response for the two tuning techniques, it is clear that the response obtained when using genetic algorithm tuning method is faster and produce an overshoot for the four mentioned cost criteria. While direct search tuning method produce a response slower than that obtained from genetic algorithm tuning method but eliminate the peak overshoot for all used cost criteria. Both tuning methods improve the system performance by improving the transient and steady state specification for the all used cost criteria. When using genetic algorithm tuning method, the smallest rise, peak and settling time obtained with JITAQE cost criteria while the smallest overshoot obtained with JIAE cost criteria. When using DS tuning method, the smallest rise and settling time obtained with JITAQE cost criteria. So each cost criteria have its own advantages and disadvantages. The tuning algorithms performance can be improved by changing the parameters listed in Table 2.

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**BIOGRAPHIES OF AUTHORS**

The Lecturer Wisam Najm AL-Din Abed received a bachelor's degree in electrical power and machines from engineering college-Diyala University in 2005 and received a master's degree in electrical engineering / power from the University of Technology in 2011. area of research interest in the electric power, machinery and control engineering and artificial intelligence and algorithms. He has more than scientific research published in local and international journals.

Email: wisam_alobaide@yahoo.com

The Lecturer Adham Hadi Saleh received a bachelor's degree in electronic engineering from Diyala University in 2006 and received a master's degree in Electrical Engineering / Electronic from the University of Technology in 2012. Work in SAKAR company - electrical generation station. The area of research interest in the design of systems using VHDL Artificial intelligence and image processing and digital signal processing. He has more than scientific research published in local and international journals.

Email: adham.hadi@yahoo.com

The Lecturer Abbas Salman Hameed received a bachelor's degree in electronic engineering from Diyala University in 2006 and received a master's degree in electronics and communications engineering from Al-Mustansiriya University in 2012. the field of research interest in the image and video signal processing and wireless communications systems. He has more than scientific research published in local and international journals.

Email: abbasfuture@yahoo.com