Optimum Speed Control of DC Motor using Ant Colony Algorithm

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Abstract

The present-dayproblem of control insufficiency, ineffectiveness of meeting the essential demand of control action is dealt with by using optimization techniques for finding optimum parameters for the controllers. As a result, new optimization algorithm Ant Colony Optimization (ACO) is studied in this project. This method used in the tuning of the Proportional Derivative and Integral (PID) controller to achieve optimum speed control for DC motor. This is done by minimizing the nominatedcost functions while retaining a satisfactory limit in terms of physical and technical constraints.System modeling methods for analysis, design and regulation purposes have conventionally employed to provide the dynamic and steady state information required. In this research work, MATLAB are used to carry out the simulation runs and the obtained results were analyzed and discussed then conclusions deduced that good results achieved using the above-mentioned method.

Keywords: DC Motor, Speed Control, Optimum Control, PID Control, Ant Colony Algorithm

I. Introduction

Despite all the advances in control, the most used controller remains the Proportional-Integral-Derivatives (PID) controller for decades. And notwithstanding that advanced control rules are used; it is familiar to have a hierarchical design of the PID control at the lowest rank. Performances of PID are mostly evaluated to control the system power, speed and frequency behavior [1]. The daily use of DC motors, in the industrial environment of automation, makes it a field of research. This leads to an interest of the researchers for its control, specifically the speed control [2]. However, ZieglerNichol's step response has frequently been used, that required long time and effort for the controller parameters tuning, in order to control the DC motor [3]. Therefore, this approach produces a surge and important overshoot [4]. More and more approaches based on clever algorithms, are now used in order to optimize PID parameters [5-11]. The Ant Colony Algorithm (ACO) is a metaheuristic behavior, which based on the swarm intelligence generated by the cooperation in a colony, particularly by pheromone communication between ants on a good path from the colony to a potential food source in an environment [12]. The ACO algorithm is applied to find the optimal parameters of the PID controller for getting the optimum speed of DC motor [13].

II DC motor mathematical model

A DC motor is any of a class of rotary electrical motors that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Larger DC motors are currently used in propulsion of electric vehicles, elevator and hoists, and in drives for steel rolling mills.The transfer function of the DC motor shown in figure (1) can be developed where the second-order effects, such as hysteresis and the voltage drop across the brushes could be neglected.

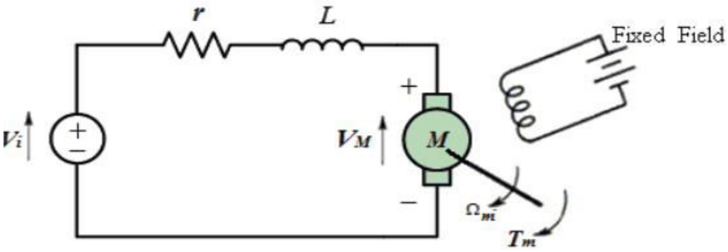


Figure (1) DC motor electric circuit

Applying Newton and Kirchhoff laws to figure 1, the DC motor is commonly described as:

$$L\frac{di}{dt} = V_i(t) - KW_m(t) - r.i(t) \dots\dots \quad (1)$$

$$J\frac{dW_m(t)}{dt} = K.i(t) - b.W_m(t) - T_l \dots\dots \quad (2)$$

Where *$V_i(t)$* is the voltage driven by the source, *$i(t)$* is the armature current; *L* is the armature inductance; *r* is armature resistance, *K* denotes the backelectromotive force constant, *J* denotes theinertia moment of the rotor, *b* denotes the mechanical system damping, *TL* denotes the load torque and W_m(t) denotes the shaft angular velocity.From equations(1 &.1) the motor speed transfer function is given by equation.(3).

$$G_m(s) = \frac{W_m(s)}{V_i(s)} = \frac{K}{L.J.s^2 + (r.J + Lb).s + r.b + K^2} \quad (3)$$

III PID controller

There are a lot of methods to control the speed and position of the motor. PID (proportional-integral-derivative) control is one of the earlier control strategies that have been successfully utilized for industrial process. The PID controller has a simple control structure, system stability, and high reliability. Over years, many techniques have been suggested for tuning the PID controller parameters.With both transient and steady-state responses, its three-term functionality covering treatment proportional-integral-derivative (PID) control offers the simplest and yet most efficient solution too many real-world control problems. Since the invention of PID control in 1910 (largely owning to Elmer Sperry’s ship autopilot), and the Ziegler–Nichols’ straightforward tuning methods in 1942, the popularity of PID control has grown tremendously. With advances in digital technology, the science of automatic control now offers a wide spectrum of choices for control schemes. However, more than 90% of industrial controllers are still implemented based around PID algorithms, particularly at lowest levels [5], as no other controllers match the simplicity, clear functionality, applicability, and ease of use offered by the PID controller. Three-Term Functionality and the Parallel Structure shown in figure (2) of PID controller may be considered as an extreme form of a phase lead-lag compensator with one pole at the origin and the other at infinity. Similarly, its cousins, the PI and the PD controllers, can also be regarded as extreme forms of phase-lag and phase-lead compensators, respectively. A standard PID controller is also known as the “three-term” controller, whose transfer function is generally written in the “parallel form” given by equation (4). Where$K_p$is the proportional gain, $K_i$the integral gain, and K_d the derivative gain.

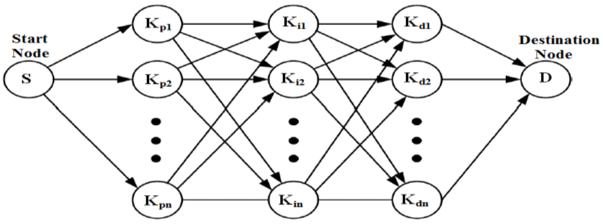
Figure (2) PID controller

$$G(s) = K_p + \frac{K_i}{S} + K_d S \quad (4)$$

One of these modern heuristic optimization paradigms required to provide the PID parameters is the Ant Colony Inspired Algorithm which is used in this research. The origins of ant colony inspired algorithm are in a field called swarm intelligence, which is assigned to study the behavior of some species and use certain properties of them to realize some tasks like optimization. The basic idea underlying ant algorithms is the foraging behavior of real ants [5]

IV. ACO Optimization

Ant colony optimizationalgorithm(ACO) is aprobabilistictechnique for solving computational problems which can be reduced to finding good paths throughgraphs.Artificial Antsstand formulti-agentmethods inspired by the behavior of real ants. The pheromone-based communication of biologicalantsis often the predominant paradigm used. Therefore, the faster the pheromone trails increase on the short path, then the greater the probability that the ants travel this path also. The pheromone trails can deposit unceasingly and evaporate as the time goes on. At the same time, the ants also can unceasingly secrete the pheromone in their travel process, thus the pheromone trails can be updated unceasingly. The pheromone trails on the path which few ants travel decrease more and more, but the pheromone trails on the path which more ants travel increase more and more as shown in figure (3).



Figure(3)Graphical Representation of ACO for tuning PID Speed Controller

Ants move by a stochastic local decision making based on two parameters, called trail of scent and attractiveness. Each ant incrementally constructs a solution to the problem as it moves. When an ant completes a solution or this solution is under construction, the ant evaluates the solution and modifies the trail value of this solution. The pheromone trail will direct the next ant search according to a probability equation given in equation (5):

$$P_{ij}^{k}(t) = \{\frac{\left([\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}\right)}{\sum_{l\in N_i} \quad ([\tau_{il}(t)]^{\alpha}[\eta_{il}(t)]^{\beta})},$$

$$K\ is\ an\ allowed\ selection 0 \qquad Otherwise (5)$$

$\tau_{ij}$is the amount of pheromone deposited for transition from state x to y, 0 ≤ α is a parameter to control the influence of τ_{ij}, η_{ij} is the desirability of state transition ij(*a priori* knowledge, typically 1/d_{ij} where d is the distance) and β ≥ 1 is a parameter to control the influence of η_{ij}. τ_{il}, η_{il}represent the trail level and attractiveness for the other possible state transitions.Ants make the next elections according to this probability equation. A tour or iteration is completed after all the nodes at the problem are visited. At this point, amount of pheromone trace is updated according to the equation (6):

$$\tau_{ij}(t) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}(t) \qquad (6)$$

ρ is the proportion of pheromone trace evaporated (pheromone evaporation factor) between *t* and *t*+1 time period (0 < ρ< 1), and and$\Delta\tau_{ij}(t)$ is the amount of pheromone deposited by th ant is computed by equation (7):

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m} \quad \Delta\tau_{ij}^{k} \qquad (7)$$

V. Simulation Results and Discussion

The parameters of DC motor chosen according to Pittman Model 9234S004 is given in the following Table. Then the transfer function applied in the system using MATLAB program.

Parameter	value
Torque Constant	1.82e-2 Nm/A
Back E.m.f constant	1.82e-2 V/rad/s
Resistance	0.83 Ω
Inductance	0.63 mH
Rotor Inertia	4.2e-6 kgm2/rad
Viscous Damping Co-efficient (B)	2.6e-6 Nms

In order to optimize the parameters of a PID controller with ACO, the PID tuning has to be transformed into combinatorial optimization problem (COP). Firstly Maximum and Minimum values of PID parameters are chosen in such a way that the search space of optimization is not too large. UB and LB are the upper and lower bounds respectively which contain Maximum and Minimum values of PID parameters respectively. All of the values for each parameter (*Kp, Ki, Kd*) are placed in three different vectors. In order to create a graph representation of the problem, these vectors and the values of these vectors can be considered as three nests paths between nests respectively. In the tour, the ant must visit three nests by choosing path between start and end node. The objective of ACO is to find the best tour with the lowest cost function among the three nests.Then the optimal values of PID parameters can be obtained and a step response can be shown as an input function. The ACO algorithm was used to provide the optimum PID values, It is required to trace the system output along a trajectory, a fitness function (cost function) is created to minimize the error that will be comprise along this trajectory. This function is as follows:

$$J = \frac{\sum_{n=1}^{M} \sqrt{(r_n - y_n)^2}}{M} \qquad (8)$$

where*J* is the cost value, n is the order of the data depending on the sampling time, M is the total number of data, r is the input desired DC motor speed and y is the system output speed.For the optimization of PID controller with ACO algorithm a block diagram schema is given in Figure (4).

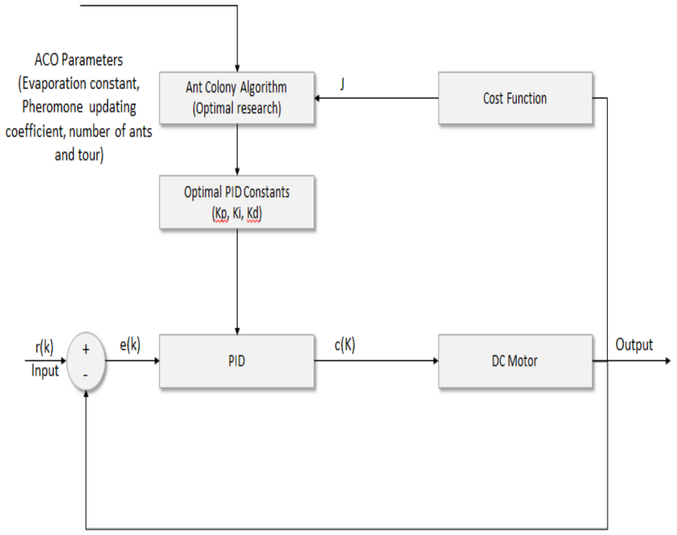


Figure (4) Optimization of the PID Controller using ACO

In the proposed approach each ant updates the pheromones deposited to the path after completing one tour defined as local pheromone updating rule as in equation (9):

$$\tau(t)_{ij} = \tau(t-1)_{ij} + \frac{0.01\theta}{J} \qquad (9)$$

In global pheromone updating rule, pheromones of the paths belonging to the best tour and worst tour of the ant colony are updated as follows:

$$\tau(t)_{ij}{}^{best} = \tau(t)_{ij}{}^{best} + \frac{\theta}{J_{best}} (10)$$

The pheromones of the paths belonging to the best tour of the colony are increased considerably, whereas those of the paths belonging to the worst tour of the iteration are decreased. Then pheromone evaporation allows the ant algorithm to forget its past history, so that ACO can direct its search towards new directions without being trapped in some local minima as equation (11):

$$\tau(t)_{ij} = \tau(t)_{ij}{}^{\lambda} + \tau(t)_{ij}{}^{best} + \tau(t)_{ij}{}^{worst} \qquad (11)$$

Another improvement to the ACO is the adaptation of the pheromone evaporation constant λ, this factor is so important that it has a direct relation to global search ability and convergence velocity in ACO. Such that if there is no appreciable improvement in optimal value after a number of iteration runs, then λ can be adaptively adjusted using equation (12).

$$\lambda(t) = \{0.95\,\lambda(t-1) \;\; if\; 0.95\,\lambda > \lambda_{\min} \;\; \lambda_{min} \quad Otherwise (12\,)$$

This algorithm applied using MATLAB and SIMULINK to provide the best parameters for PID controller. The results of Simulink are divided into three parts: first loading the data to MATLAB workspace then applying the values to ACO algorithm. Second writing a MATLAB program to implement the ACO algorithm and receives the information from workspace to provide the optimum values of PID. Third after optimizing the PID parameters its applied to MATLAB Simulink program to find the optimum speed responseby controlling the applied armature voltage[14 – 15].Then simulation runs carried out with two types of reference speed signals the first one is the standard unit step 100 rad/sec and the second one is a variable speed with unit step changes within the motor rated speed. The attained results were discussed, scrutinized, and presented in the following figures:In figure (5) a Simulink model of Optimized PID for step input speed control of a DC Motor used in the simulation studies and the obtained results offered. The Performance of Optimized PID for step input is depicted in figure (6) and the control action is based on achieving best cost function of optimum PID parameters to improve the transient response and steady state response as presented in figure (7). Figure (8) shows sharp spike in control signal due to extreme case of step change in speed of motor practically this is not the case as the motor speed changes gradually. Error signal between reference speed and output speed is presented in figure (9).

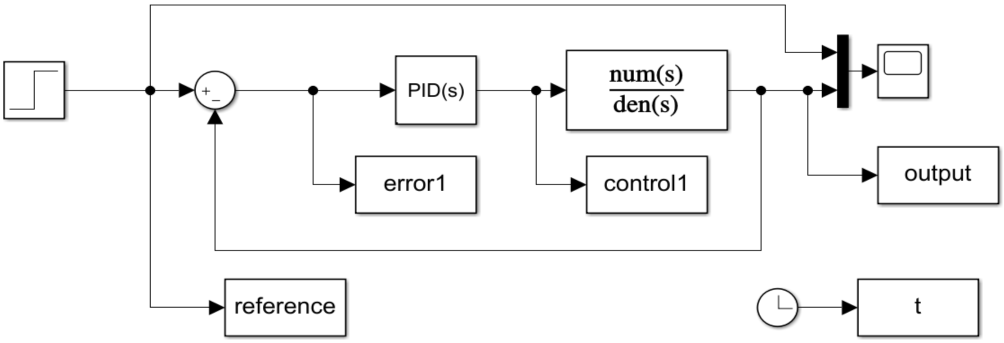


Figure (5) Step reference speed system

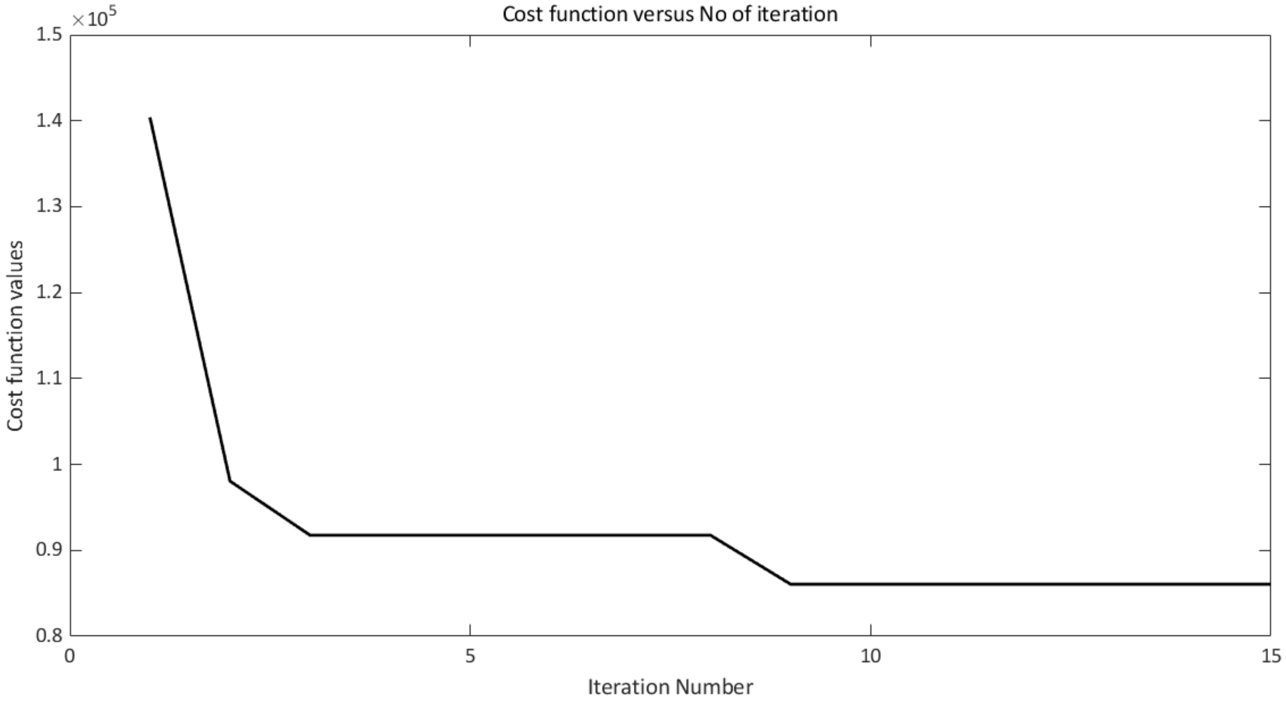


Figure (6) Cost function values versus iteration numbers for step reference speed

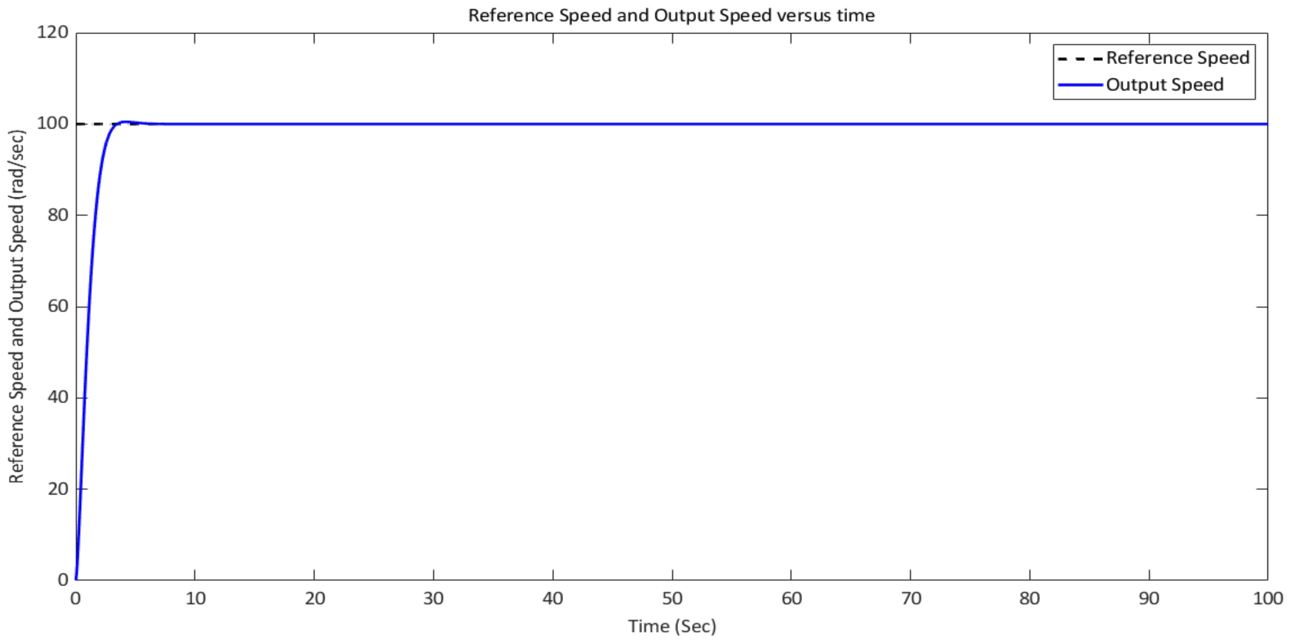


Figure (7) System response for Step Reference speed

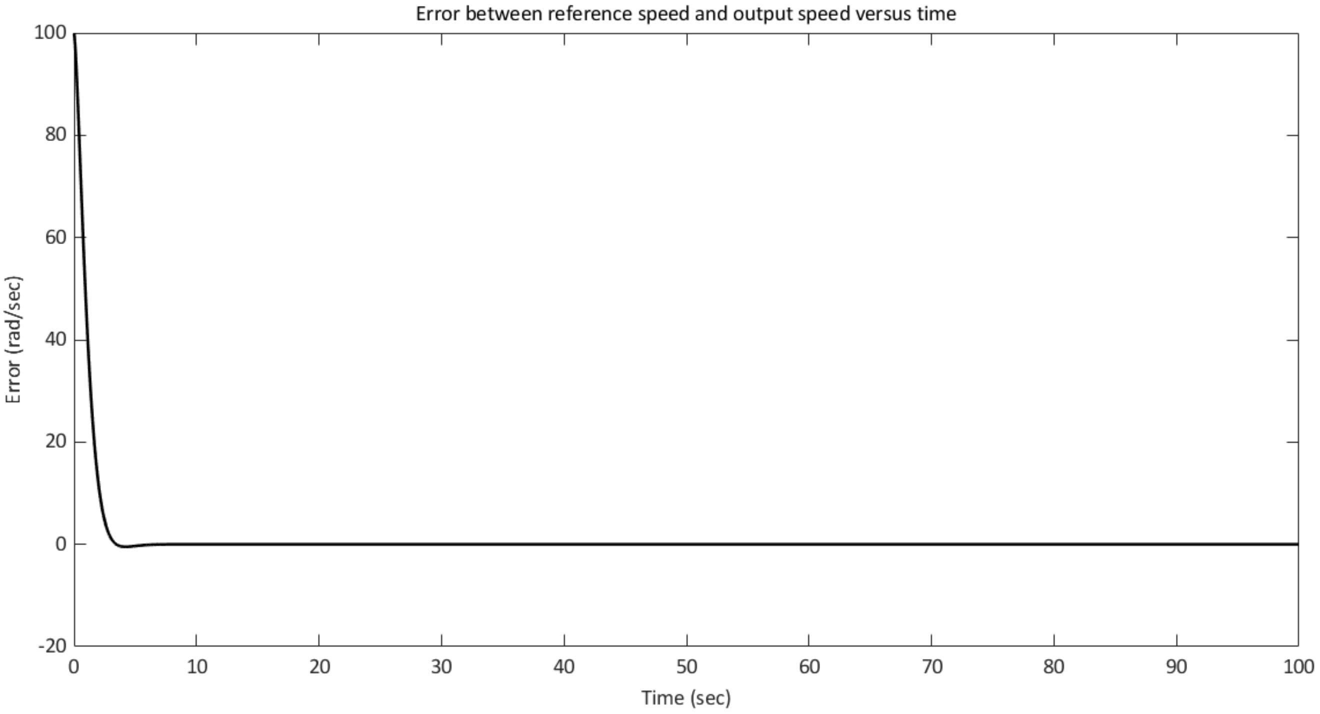


Figure (8) Error signal between Step Reference speed and Output speed

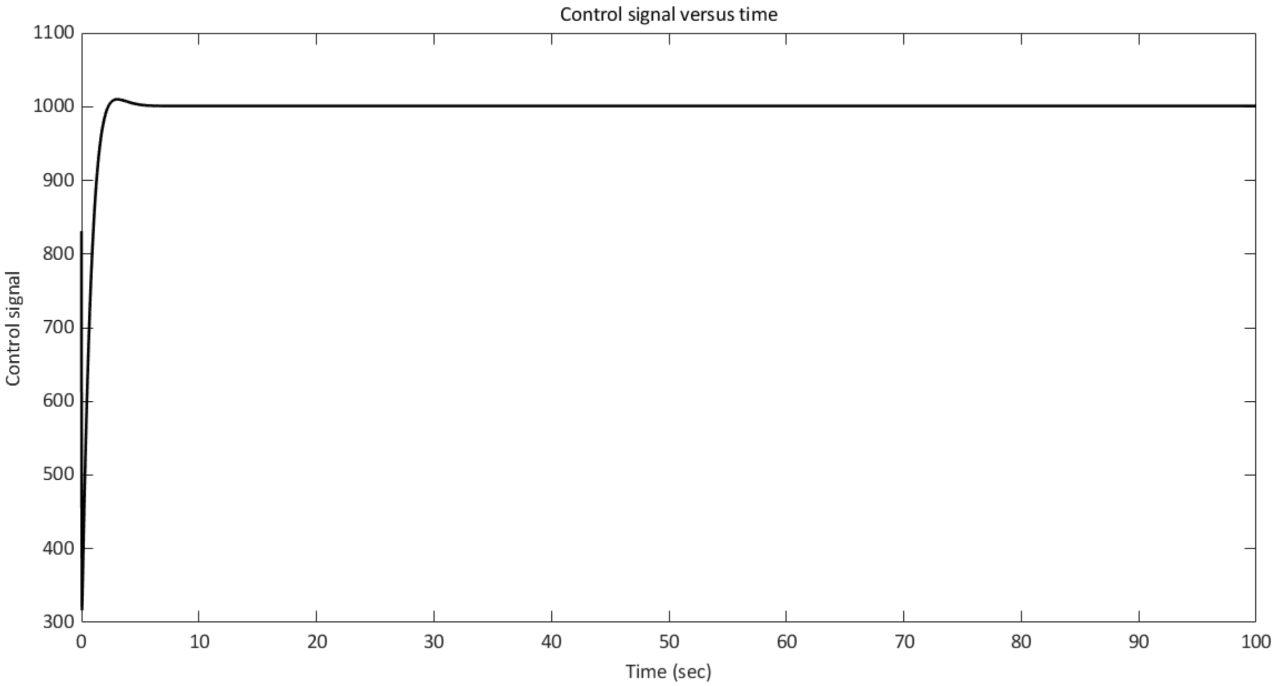


Figure (9Control signalfor Step Reference speed

In order to validate the controller tracking for speed variation a reference signal with step speed changes are included in the simulation studies as depicted in figure (10). Best cost function presented in figure (11) and the obtained results as the Performance of Optimized PID for speed changes tracking are shown in figure (12) which indicate good tracking for step changes in reference speed. Again control signal and error signal between reference speed and output speed with sharp spike due to the extreme case of step change in motor speed as indicated in figures (13& 13) respectively.

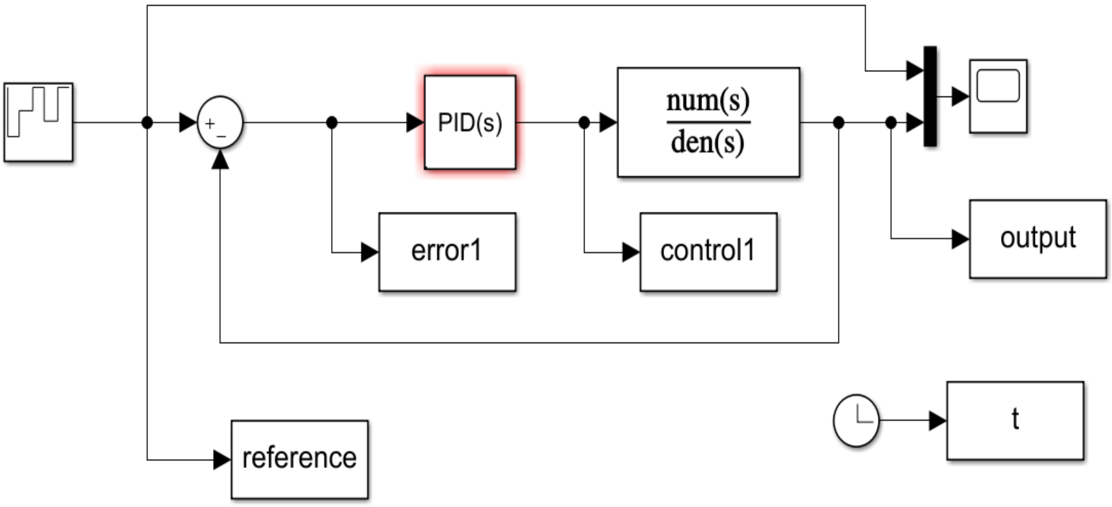


Figure (10) Step variable reference speed system

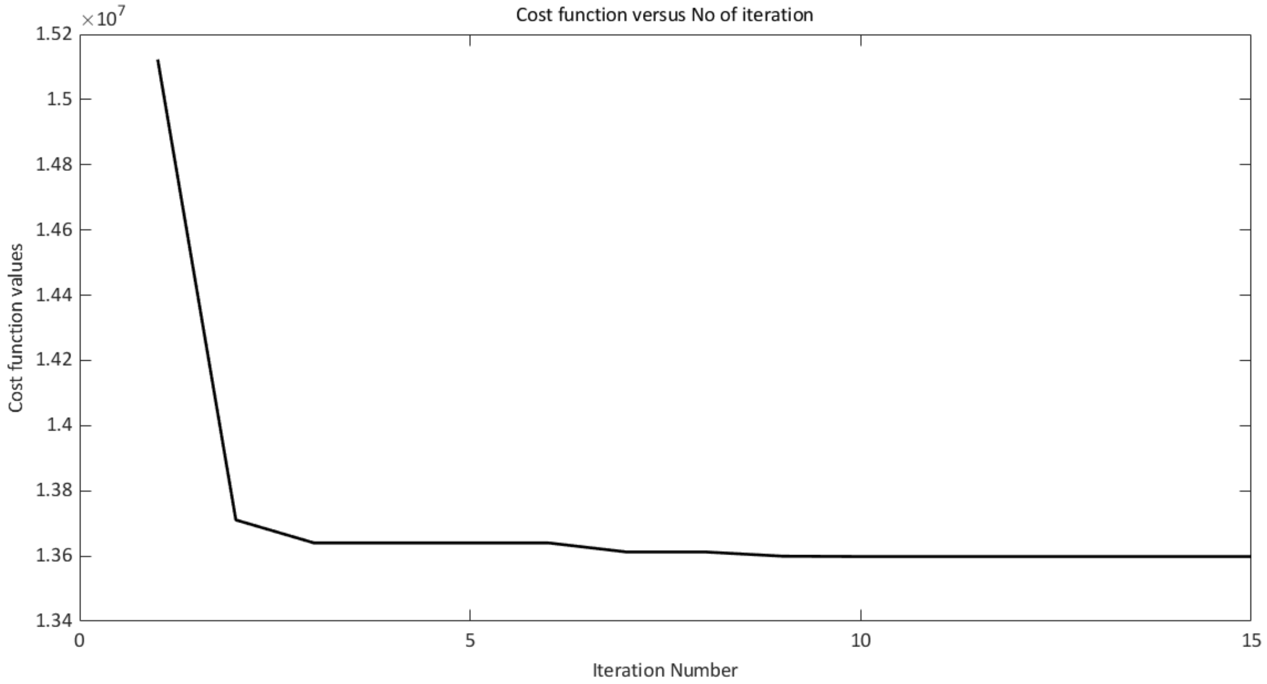


Figure (11) Cost function values versus iteration numbers for variable step reference speed

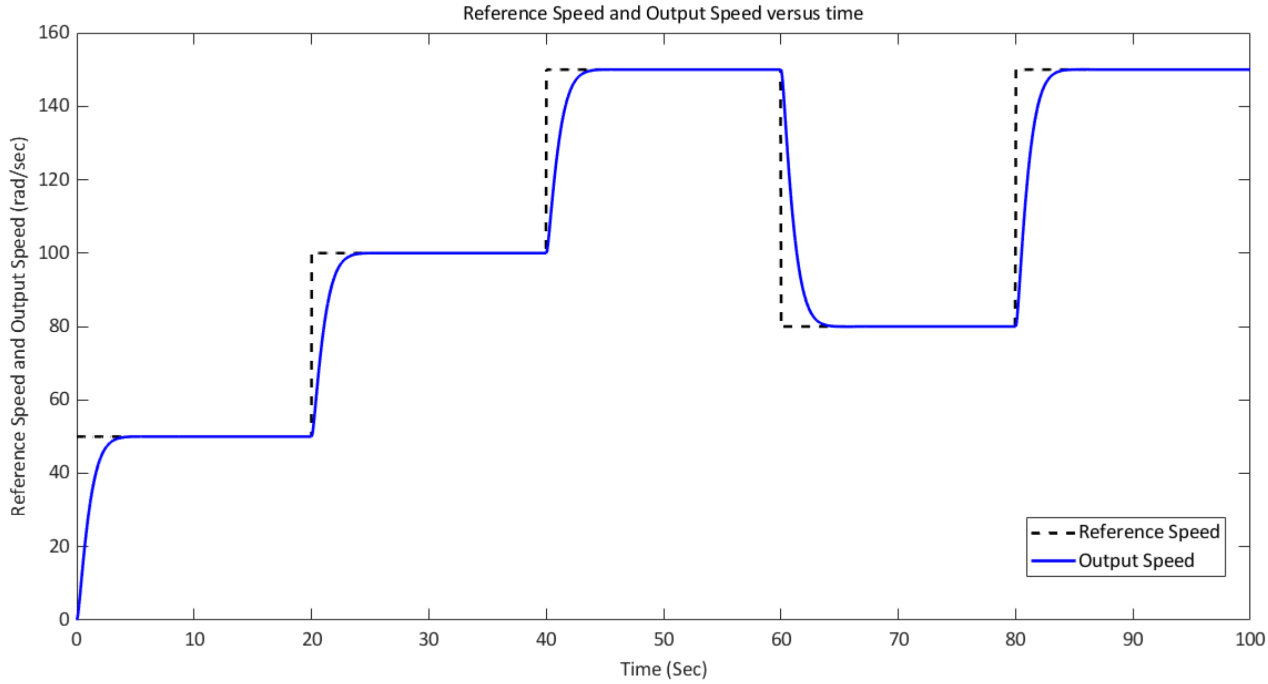


Figure (12) System response for variable Step Reference speed

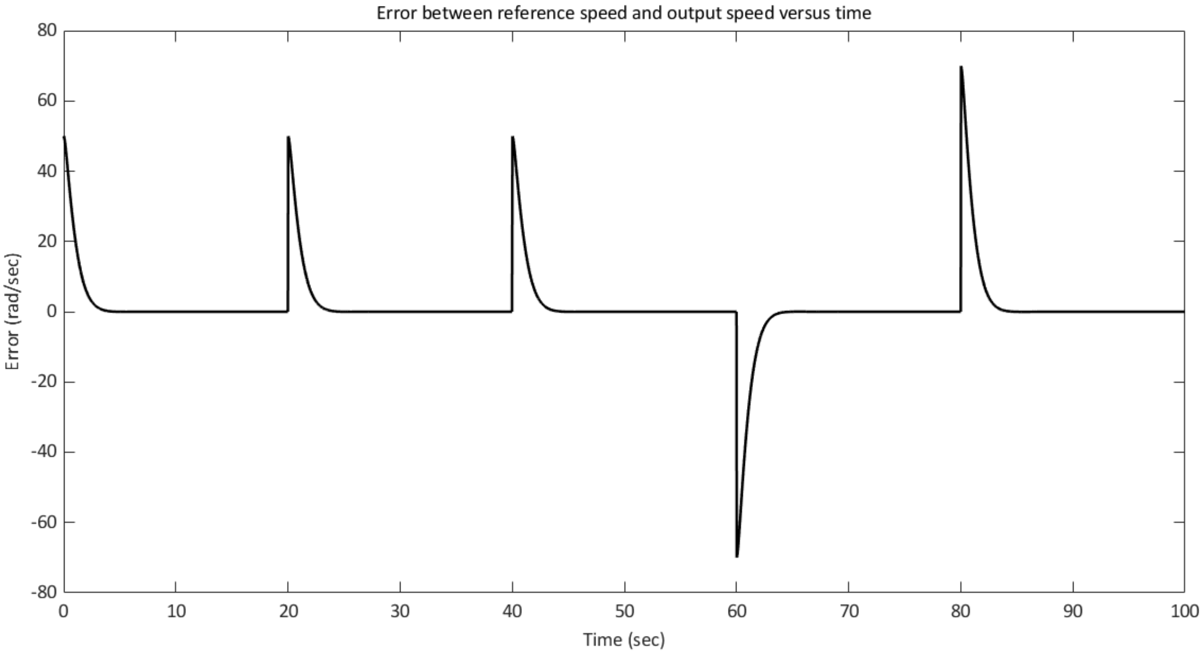


Figure (13) Error signal between variable Step Reference speed and Output speed

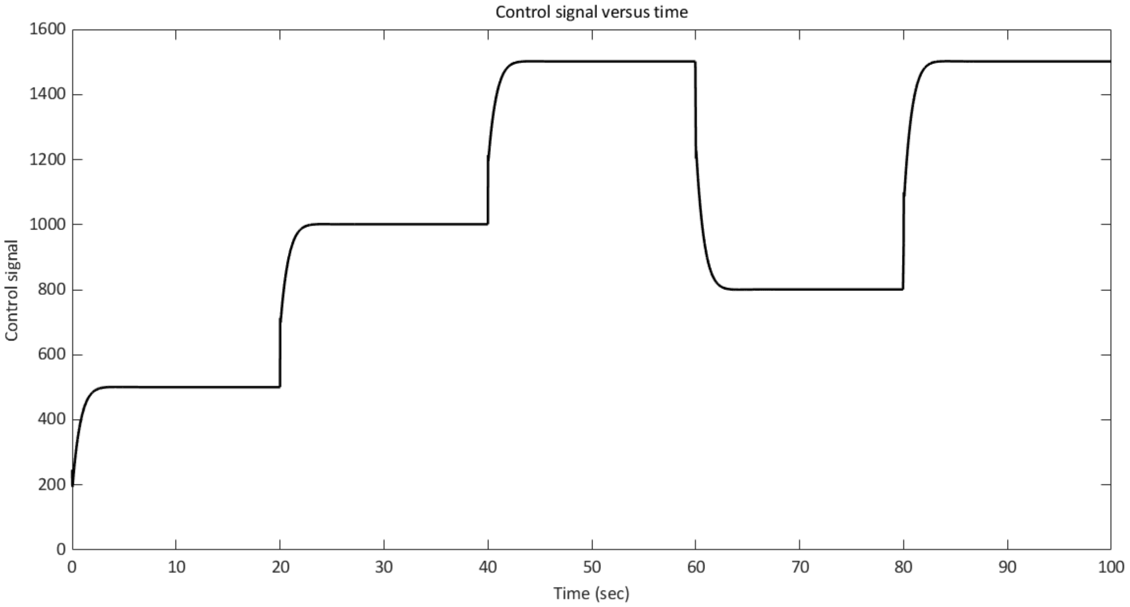


Figure (14) Control signal for variable Step Reference speed

VI. Conclusion

The Matlab and Simulink simulation results obtained from the developed optimized PID were investigated. The presented method successfully controlled the speed of DC motor through simulation studies based on DC motor model system using two types of reference speed signals a step reference speed and a step change variable referencespeed for speed tracking validation purpose. Comparison of the attained results from this simulation studies applying the above mention control technique concluded that good transient and steady state performance were achievedeffectively. Finally the controller in both cases followed the reference speed and tracked the speed changes successfully and the system response with worthy combination of minimum overshoot, fast response, and minimum steady state error.

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