

Speed control of switched reluctance motor using genetic algorithm and ant colony based on optimizing PID controller

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Abstract: - Proportional-Integral-Derivative control is the most used kind of control which provides the simplest and most effective solution to different kinds of control engineering applications. But until now PID controller is poorly tuned in real life and online applications. While most of PID tuning is done manually. Switched reluctance motor (SRM) has highly nonlinear characteristics since the developed/produced torque of the motor has a nonlinear function on both phase current and rotor position. These nonlinearities of the SRM drives make the conventional PID (proportional + integral + Derivative) controller a poor choice for application where high dynamic performance is desired under all motor operating conditions. research paper comes up with two artificial and hybrid techniques involving Genetic Algorithm (GA) and Ant Colony Optimization (ACO). Those techniques were used to tune the PID parameters for the switched reluctance motor (SRM) and its performance were compared with the conventional method of “Ziegler Nichols. The results obtained reflects that, the use of those algorithms based controller improves the performance of the whole process in terms of a fast set point tracking and regulatory changes and also provides an optimum stability for the system itself with a minimum overshoot on the output signal.

Key-Words: - Switched Reluctance Motor, PID Controller, Ant Colony, Genetic Algorithm, Optimization Techniques, speed Control.

1 Introduction

In this research, we show that the control of the switched reluctance motor (SRM) is apparently an easy task but in real world it is difficult to be achieved when using a simple PID controller due to its nonlinear characteristics [1, 15]. So according to that, we use artificial intelligent techniques like Genetic Algorithm and Ant-Colony optimization to be able to achieve a robust steady speed performance under different load circumstances. Also it has some good features, like high power density, high efficiency and no rotor windings. This is one of its major advantages. However, the SRM motor suffers from torque ripples and acoustic noises that prevent its use in high performance drives [14]. A Matlab-Simulink model for the speed control of a 3-phase switched

reluctance motor carried out using different controllers. The Simulink models designed here are the traditional PID, Genetic-PID and Ant Colony-PID controllers which are designed separately and their performance results were compared together. The speed controller applied here is based on the traditional PID Controller and the other one is an artificial intelligent based controller like Genetic algorithm & Ant Colony Controllers. A comprehensive review/research has been done for SRM machine modelling, simulation, analysis and control. The conventional controller design (*i.e.* PID) is based on the mathematical model of the plant, which may often be unknown, ill-defined, nonlinear and complex. The PID controller has fixed gains and is certainly

the most commonly used control algorithm nowadays. The main reason for using it until now is its relatively simple structure which can be easily understood and implemented in real world. The PID controller has traditionally been tuned empirically e.g. by the method described in Ziegler and Nichols. The controller gains once tuned for a given operating point for a specific plant or a system are only suitable for limited operating point changes and this is one of its disadvantages. Therefore, the use of the conventional PID controller does not meet the requirements of a robust & steady speed performance. Various control strategies has been proposed for the speed control of the SRM, such as feedback linearization control, fuzzy logic control and neuro-fuzzy control. While GA and ACO techniques those are based on the behavioral pattern of a living being and are a new artificial methods introduced strongly to control the SRM motor. The objective of this research paper is to show that a 3-phase SRM motor using the conventional PID controller, its values can be obtained and optimized using the artificial techniques of GA and ACO, which gives better results with sudden load changes and system stability.

2 Switched Reluctance Motor

The switched reluctance motor has a passive rotor with a simple construction. While the solution of its mathematical model is relatively difficult due to its non-linear behavior. The SRM is characterized by its geometrical Layout, the characteristic of the magnetic material and electrical parameters

Switched reluctance motor (SRM) drives are of simple construction compared to the induction or synchronous motors. The structure of the motor is very simple that uses salient poles on both stator and rotor but only stator carries winding. The windings on the stator are of simple form. So this apparent simplicity of its design is not very accurate because its construction is simple but controlling the motor itself is difficult. SRM drives has some advantages as it has high efficiency, maximum operating speed, good performance of the motor in terms of torque/inertia ratio, according to that it can be used in variable speed applications with high speed. The performances of switched reluctance motor strongly depend on its applied control. Figure 1 shows the major parts of a switched reluctance motor drive.

There is three main parts identified as follows: the motor itself, the power electronic converter and the controller used. SRM construction consists of the following: There is a single converter per phase; a battery supplies the dc power to the converter. Its operation is simple: When the excitation is given to the stator windings, a force is created by rotor's magnetic reluctance that tries to align the rotor pole with its adjacent stator pole (Fully aligned) in order to maximize the inductance & minimize reluctance of the excited coils. In order to preserve the correct sequence of rotation, the windings of stator pole switches in a sequential order with the help of electronic control system so that the magnetic field of rotor pole was led by the stator pole, pulling towards it production of torque is independent of the direction of current which in-turn reduce the number of switches per phase.

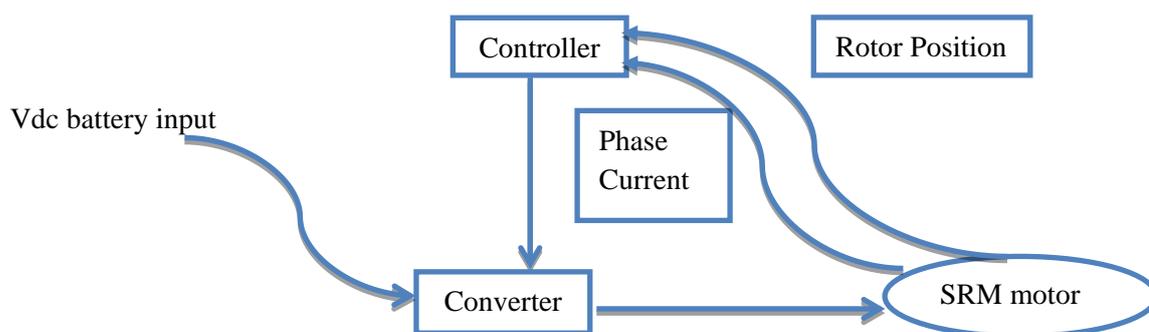


Fig.1 Switched Reluctance Drives System Components

3 SRM Block Diagram

The position of rotor is sensed by the rotor position sensor and it provides its corresponding output to the error detector. Error detector compares reference speed given in RPM and the actual speed feedback from the motor itself to generate an error signal which is given to the controller block. The controller (PID or GA-PID or ACO-PID) gives control signal to the converter according to the error signal value. The speed of the motor is controlled by the converter through proper excitation of their corresponding windings.

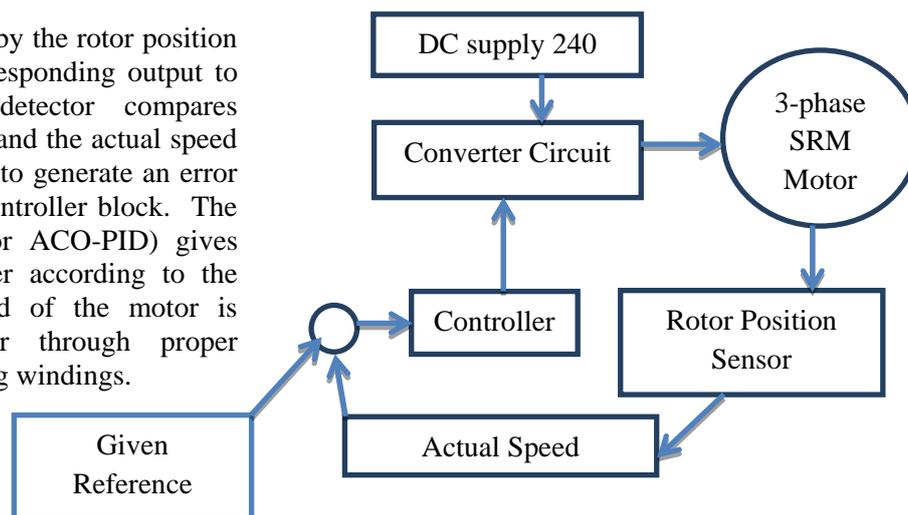


Fig.2 Block Diagram of SRM Speed Control

4 Genetic Algorithms

Genetic Algorithms were invented to try to mimic some of the processes observed with living being [3-5]. The idea with GA is to use the power of natural living ability for evolution to solve hard and very complicated Engineering optimization problems [13]. GA's process starts with no knowledge at all for the correct and accurate solution and depends entirely on responses it receives from the surrounding environment and its internal evolution operators such as reproduction, crossover and mutation to get to the best available solution.

The application of these three basic operations allows the creation of new and better individuals, which may be better than their old parents. This algorithm is repeated for many generations and at the end we stop when we reach for individuals that represent the optimum solution to the problem or we stop at certain number of iterations we initially stated. GA starts with an initial and random chromosome & checks its fitness value. The fittest chromosome are taken as parents for further reproduction also to be crossed over & mutated again. The offspring or their children are checked for the fitness value & depending on it. We can decide either to be taken again or to be neglected from the population [7, 16, 17]. Genetics father is "John Holland" who invented this technique in the early 1970's [6]. GA's is an adaptive artificial

search technique based on the evolutionary ideas of natural selection [7]. In order to use the "GA's" there are two important aspects to follow: chromosome coding and defining the evaluation criteria. Although it appears as a randomized process, GA's is not a completely random process. Instead it develops some historical information to direct the search into the region of better performance within the search space it has. The Basic techniques of the GA's are designed to simulate processes with natural living being which is necessary for evolution as found on the block diagram on Figure 3. Especially those who follow the principles of Charles Darwin "survival of the fittest" Since in nature, competition among individual's results in the fittest individuals dominating over the weaker ones and this is observed and proved its existence in history. GA's can give robust & adaptive response for a system with nonlinearity, parameter variation and load disturbance effect [3-5].

GA's is better than traditional techniques and more robust to sudden load changes and is a very adaptive technique. Unlike old AI systems, they do not break easily if the input changes or noise applied suddenly. Also in searching a large state-space, GA's may offer significant benefits over the typical search of optimization artificial techniques.

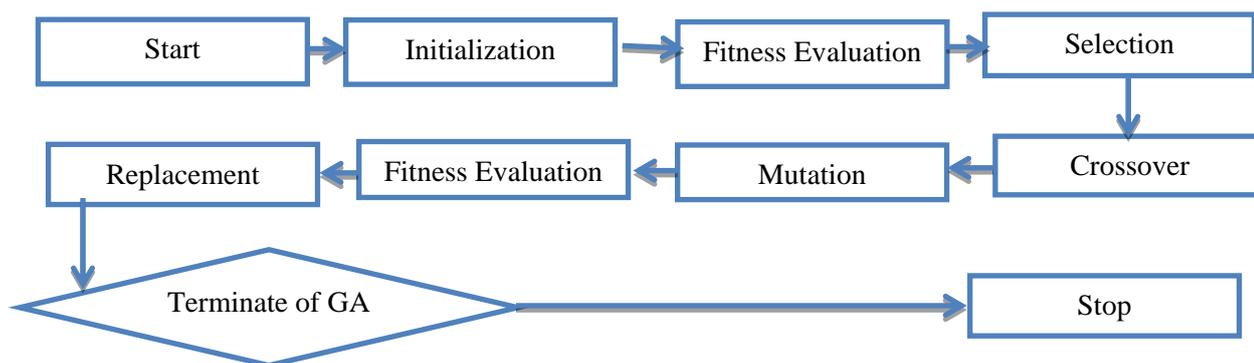


Fig.3 Block Diagram for GA Sequence

5 Ant Colony Optimization

Marco Dorigo and some of his colleagues invented the first ACO concept in the early 90's [8, 9, 10]. The development of these algorithms was inspired by the observation of ant colonies in nature. Ants are social insects with an ability to organize their food obtaining process very accurately. They live in colonies (groups) and their behavior is governed by the goal of colony survival rather than being focused on the survival of individuals. Ant algorithms are adaptive and robust to any complicated engineering problem. The behavior that

provided the inspiration for ACO is the ants "foraging behavior" and in particular, how ants can find the shortest path between food sources and their nest (Home). The main advantages of artificial ants are taken from their natural model. Which are (1) artificial ants exist in colonies of cooperating individuals; (2) they communicate indirectly by depositing pheromone on their way to any expected food sources [11, 12] (3) they use a sequence of local moves to find the shortest path from a starting position which is completely random, to a destination point they apply a stochastic decision

policy using local information only to find the best solution. When searching for food supplies (Sources), ants initially searches the surrounding area or explores it which is near its nest

This is in completely random directions. While moving it leaves a small amount of pheromones behind it on the ground. This is in order for the other ants to smell it during this trip of finding food sources. While other ants search for food it chooses its way in a probability which is according to the amount of pheromones it finds. As soon as an ant finds a food source, it tries to know the quantity and the quality of these sources of food and carries some of it back to its home base. During the return trip the quantity of pheromone it was left over during the trip is evaluated again to try to know the shortest route to its nest. When it reaches its nest other ants will go on the same route to the food source which contains actual food as illustrated on figure 4. It has been shown that, this kind of communications is an indirect one which is built in every ant to get to its nest as soon as possible and in an organized manner also it is called "stigmergy effect" which enables them to find the shortest path between their home base and expected food source.

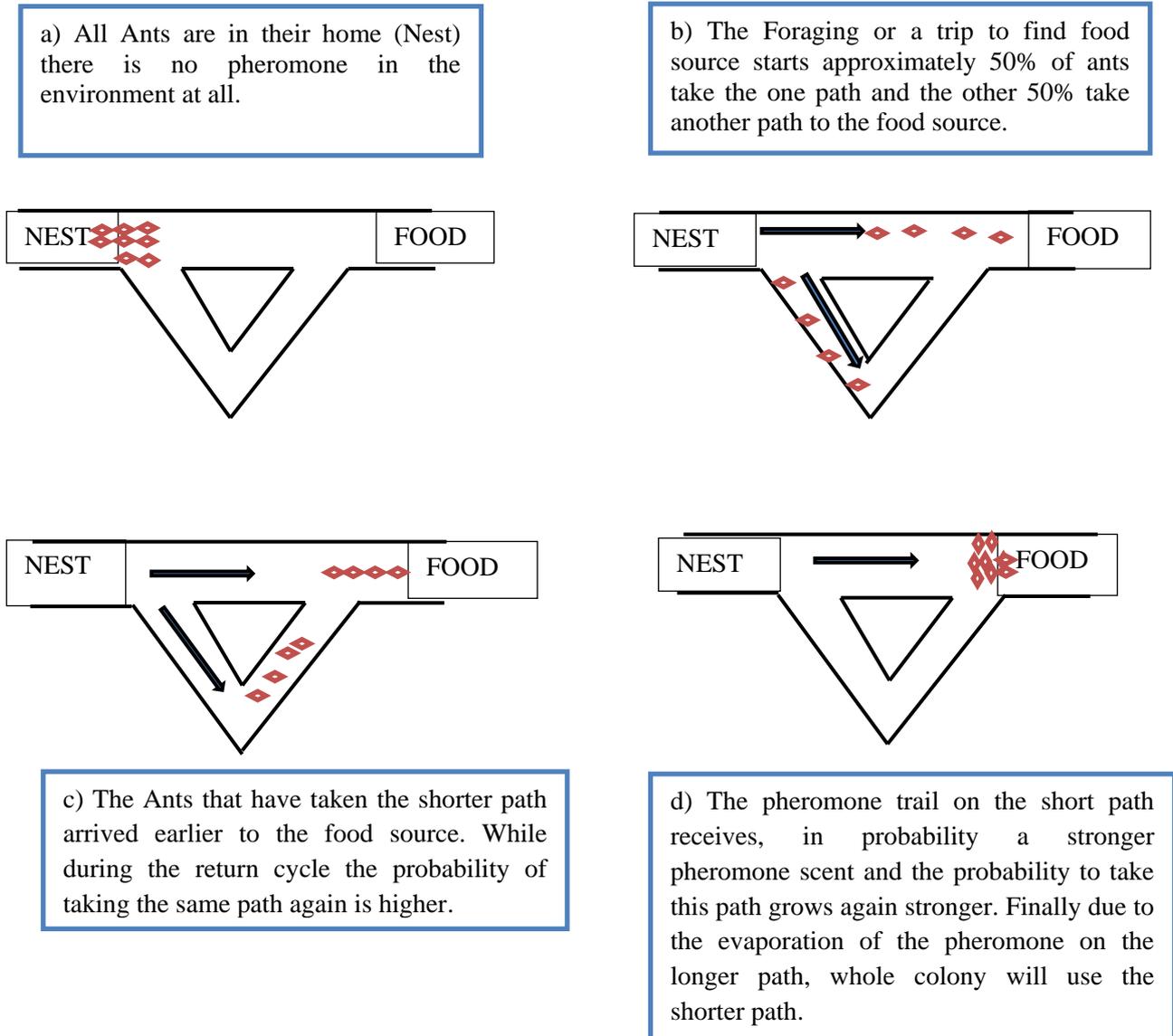


Fig. 4 Experimental setting that demonstrate the Shortest Path Finding Capability of Ant Colonies, between the ants nest and the only food source exist with two paths of different length.

6 Experimental Setup of the SRM Drive Using Matlab-Simulink

The experimental setup is shown on Figures 5, 6. This shows the PID controller optimized by GA's also the same PID controller optimized by ACO technique. We start the simulation by using a 3-phase 60KW SRM motor which is used on this research paper with motor features as found on table 1.

Also it is the same built-in Matlab motor model. Tables 2 and 3 shows the GA's and ACO controller's parameters used after several trials. the response of Kp, Ki and Kd parameters are summarized on table 4 which shows that using the proportional controller "Kp" will have the effect of reducing rise time of the output signal and will reduce the steady state error while the integral controller "Ki" will have the effect of eliminating the steady state error produced by the "Kp" parameter but will have the worst transient response on any system.

While the derivative controller "Kd" will have the effect of increasing the stability of the system, reducing the overall overshoot and improves the transient response of the system. Several simulations were carried out for controlling motor's speed with a different load torque disturbances to explore the effectiveness of the proposed controller's robustness in comparison with the conventional old PID controller.

The results were obtained for cases such as step variable (Input) speed of ranges starts from "1000-1500 RPM" which is our maximum RPM for such motor and under variable load torque "Nm".

Table 1
Matlab built-in Motor Features

Item	Features Description	Value
1	Rotor Pole number "Nr"	6
2	Stator Pole Number "Ns"	8
3	Turn on angle	40 degree
4	Turn off angle	75 degree
5	Number of Phase	3
6	Power in (KW)	60
7	Maximum (Reference) speed (RPM)	1500
8	Stator Resistance (Ohm)	0.05
9	Inertia (Kg.m.m)	0.05
10	Friction (N.m.s)	0.02
11	Source Voltage (Vdc)	240

Table 2
Genetic Algorithm Parameters

Item	Description	values
1	Proportional gain limits Kp	Ranges [0-100]
2	Integral gain limits Ki	Ranges [0-100]
3	Derivative gain limits Kd	Ranges [0-100]
4	Population type	Double vector
5	Population size	100
6	Creation Function	Uniform
7	Mutation rate	0.1
8	Mutation Function	Uniform
9	Selection method "Function"	Uniform
10	Crossover type	Arithmetic

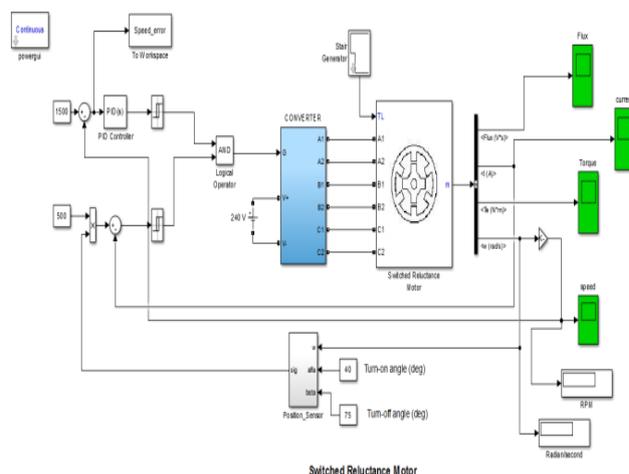


Fig.5 SRM motor speed control with GA-PID Controller.

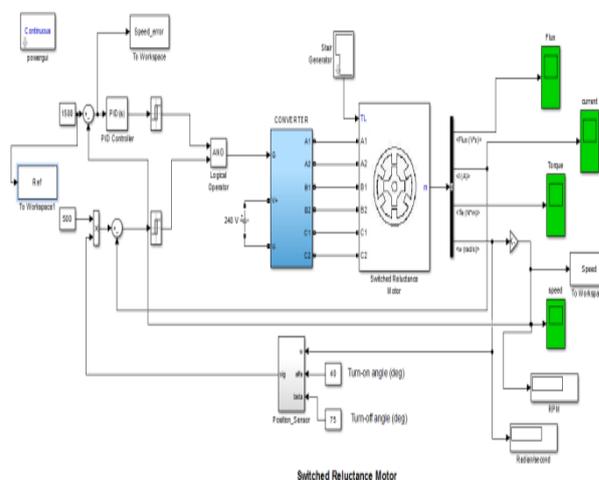


Fig.6 SRM motor speed control with ACO-PID controller

Table 3
Ant Colony Parameters

Item	Description	values
1	Number of Iterations	100
2	Number of Ants	300
3	Alpha	0.8
4	Beta	0.2
5	Evaporation Rate	0.7
6	Number of Parameters	3
7	Lower& upper limits	[000] & [111]

Table 4
Response of K_p , K_i and K_d

Item	K_p	K_i
Rise time	Decrease	Small change
Overshoot	Increase	Decrease
Settling time	Small change	Increase
Steady state error	Decrease	Eliminate
Item	K_p	K_i

7 Simulation Results

To explore the effectiveness of the proposed techniques, a Matlab-Simulink computer simulation has been carried out for the different proposed controllers. The conventional PID, GA-PID and ACO-PID controllers system [i.e. the maximum torque obtained, rotor's position, reference and actual speed values, speed error signal and change in the error signal, input values of torque, produced flux current] can be observed.

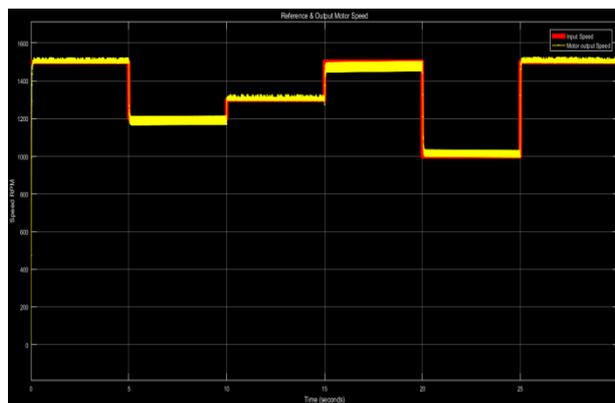


Fig.7 shows the variable step input (Speed) and the motor actual output speed after using Conventional PID controller.

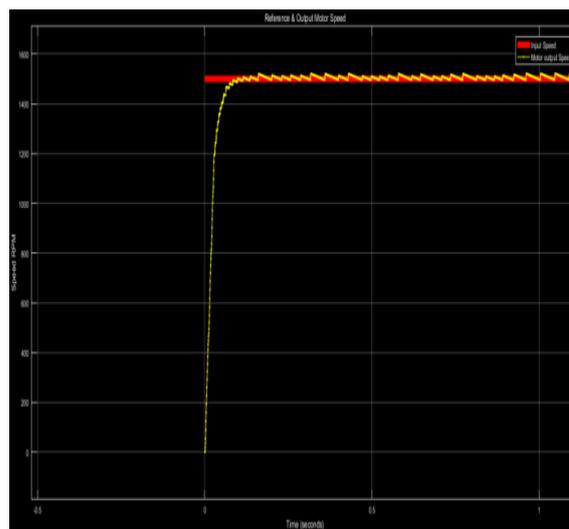


Fig.8 shows the delay on the output (Zoomed in) of the motor with reference step input when using conventional PID controller.

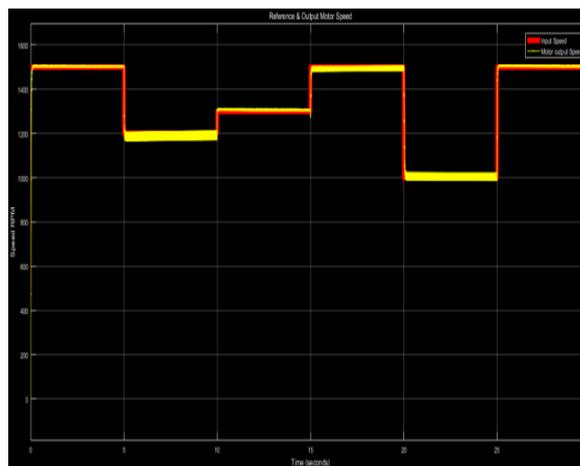


Fig.9 shows the variable step input (Speed) and the motor actual output speed after using the new artificial Genetic algorithm Technique.

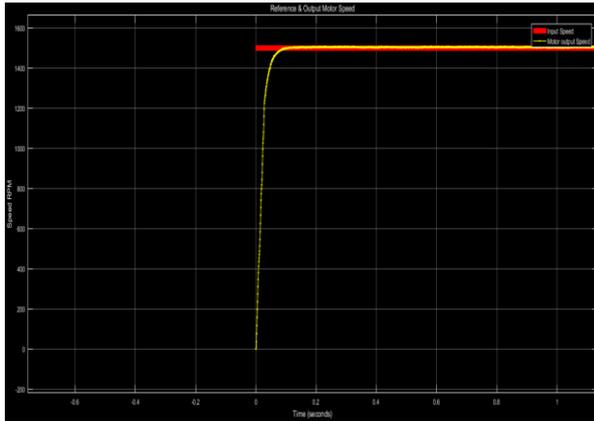


Fig.10 Shows the delay on the output (Zoomed in) of the motor with reference step input when using the Genetic algorithm

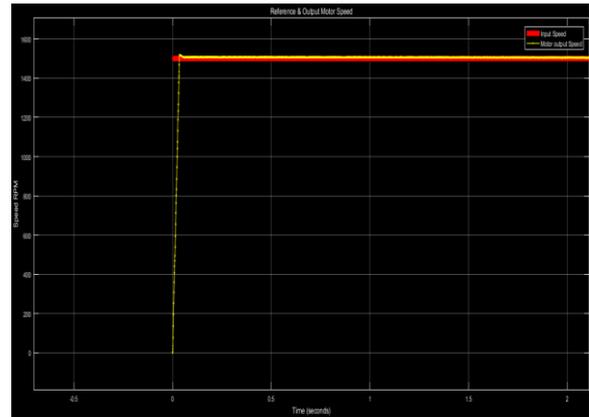


Fig.12 shows the delay on the output of the motor with reference step input when using the Ant Colony technique.

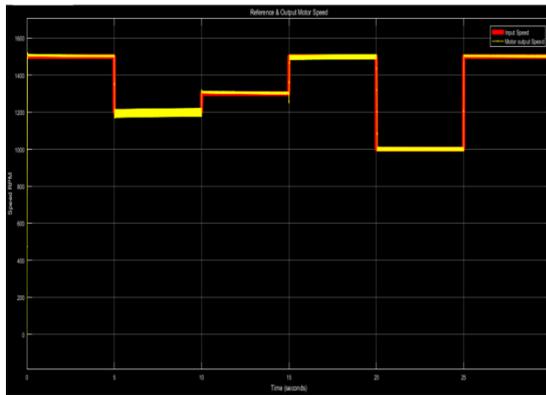


Fig.11 Shows the variable step input (Speed) and the motor actual output speed after using the Ant Colony technique.

8 Future Works

The ACO and GA can be modified for future enhancement such that a new and updated research could and can be focused on each technique disadvantages in order to produce better solution by improving the effectiveness of getting the best solution and reducing its limitations. Research work has been carried out to get the maximum and optimal values for PID controller parameters automatically using GA and ACO artificial optimization techniques as found on figures 9, 10, 11 and 12. Simulation results demonstrate that the tuning methods proposed and used as found on both figures 10 and 12 have a better control performance compared with the conventional ones as found on figure 8 also they have a better steady state response, rise time, settling time, overshoot and a robust control with variable loads as found on table 5.

Table 5
Comparison between the conventional control method (PID) and Heuristic Intelligent artificial methods (GA & ACO)

Tuning Method	PID Parameters			Dynamic Performance Specifications		
	Kp Proportional gain	Ki Integral gain	Kd Derivative gain	Tr Rise time	Ts Settling time	Mp Peak overshoot
ZN	0.95	0.05	0.01	0.070 sec	0.10 sec	1.53 %
GA	282.9	26	2.346	0.060 Sec	0.080 Sec	0.53%
ACO	268.8579	65.86439	0.01	0.036 Sec	0.037 sec	1.2%

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