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J. Electrical Systems 15-1 (2019): 133-141

Regular paper

Journal of Electrical Systems

PID Controller Tuning using Ant Colony Optimization for Induction Motor

This article aims to use the metaheuristic method for continuous variable problems often encountered in the engineering field and their applications. Especially, this approach is used in the electrical machine field for the resolution of proportional integral derivative (PID) controller. In this work we developed the problem of design the PID controller. This latter is applied to resolve parameters variation and to obtain the best possible speed response of induction motor (IM). The gains Kp, Ki,and Kd of the PID controller are tuned by using an algorithm of optimization, named, ant colony optimization (ACO) to eliminate harmonics and speed ripple of new IM. This machine has a new geometry design. The parameters of this motor was identify with finite element method (FEM), which are used to build model in Simulink MATLAB. Two different tuning techniques have been proposed for IM based on manual and intelligent tuning of PID-controller parameters.

Keywords: FE Model; Induction machine; PWM; ACO; PID controller.

Article history: Received 30 November 2018, Accepted 29 November 2018

1. Introduction

Computers advancing technology encounter in real life are transferred into the virtual platform that provide to attain simple and fast solutions. Growing and complicating problems were revealed the notion of the optimal solution and the studies were started in this direction, which have increased the use of induction motors in electrical drives extensively. In most of industrial drive control applications, the standard method to control squirrel cage induction motors is based on the PWM drive in order to achieve the best dynamic behavior. It is observed that, induction motor being a non-linear device, exhibits large parameter variation which requires online tuning of the controller parameters to achieve the best dynamic response at each operating point of the drive system. The proportional-integral-derivative (PID) controller has remained, by far, as the most commonly used controller in practically all industrial control applications. More than 90% of all control loops are PID, with a wide range of applications: process control, motor drives, magnetic memories, automotive, flight control, among others. A technique for tuning of proportional-integral-derivative (PID) multivariable controllers based on a ACO approach is presented in this paper. Due to the simple concept, easy implementation and quick convergence, nowadays ACO has gained much attention and wide application in solving continuous non-linear optimization problems. Due to the problem of accessing real system, second, analytics models are very complex and not accuracy and also depends every stator winding and every rotor bar winding independent model winding. According to these factors, a model for the machine has been built using finite element method for calculating the motor parameters. A library of seven parameters models of IM has been constructed such as rotor time constant, magnetic dispersion coefficient and stator and rotor inductance and mutual inductance [1].

2. Parameters identification of IM with FEM

The three phase machine designed with 36 slots stator and 24 slots rotor. This motor is characteristic by P=1.8kW, f=50Hz, 4 pairs of poles(i.e. p=2), running of a 220 Vrms line-

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to-line, 3 phase supply, implying that it will be running at slightly less than 1500 RPM. The air gap of the induction machine is 0.07 mm. The detailed dimensions presented in Table1. An important feature of the stator is the shape of the slot like presented in figure 2B.

The slots in the engine stator are semi open type and the winding configuration for the machine is divided in three symmetric phases and rotor, the cage rotor constitutes new design, circular bars, as pictured below in Figure1A. To reduce noise and some harmonics during starting and for the accelerating is more uniform, the rotor is constructed so that the conductors are circular with respect to the motor shaft. In order to model electrical rotor asymmetries the full topology of the rotor cage, respectively has to be taken into account. In order to have a good model it is necessary to use a best method.

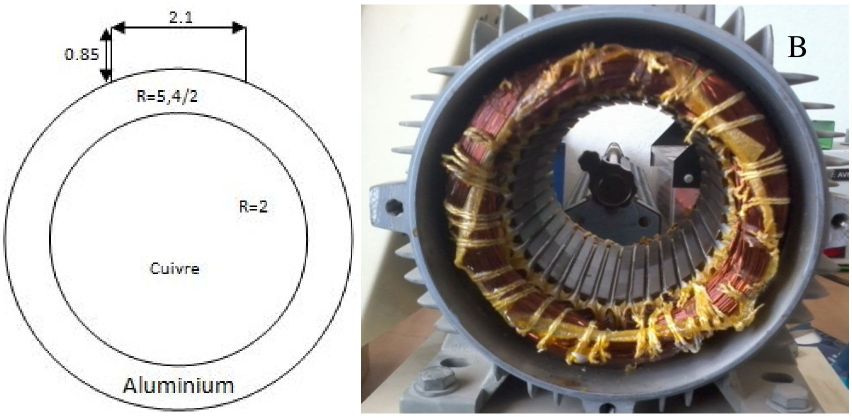


Fig. 1. A.Circular slot type of bars; B. Stator winding

The paragraph presents a finite element (FE) based efficient analysis procedure for induction machine (IM). The study based on finite element models (FEM) offers much more information on the phenomena characterizing the operation of electrical machines than the classical analytical models. This explains the increase of the interest for the finite element investigations in electrical machines. In this paper attempts to present a dynamic model involving Finite Element Analysis. The FE analysis using a two dimensional FEMM software is used to modulate the IM with22800 elements and 11563 nodes as presented in figure 2 a and b[2][3] [4].

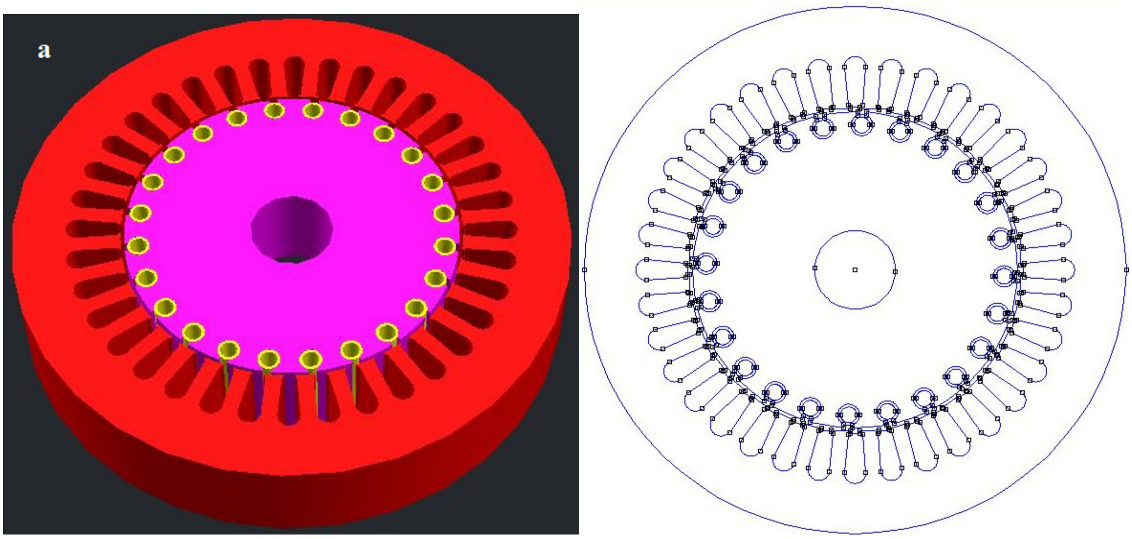
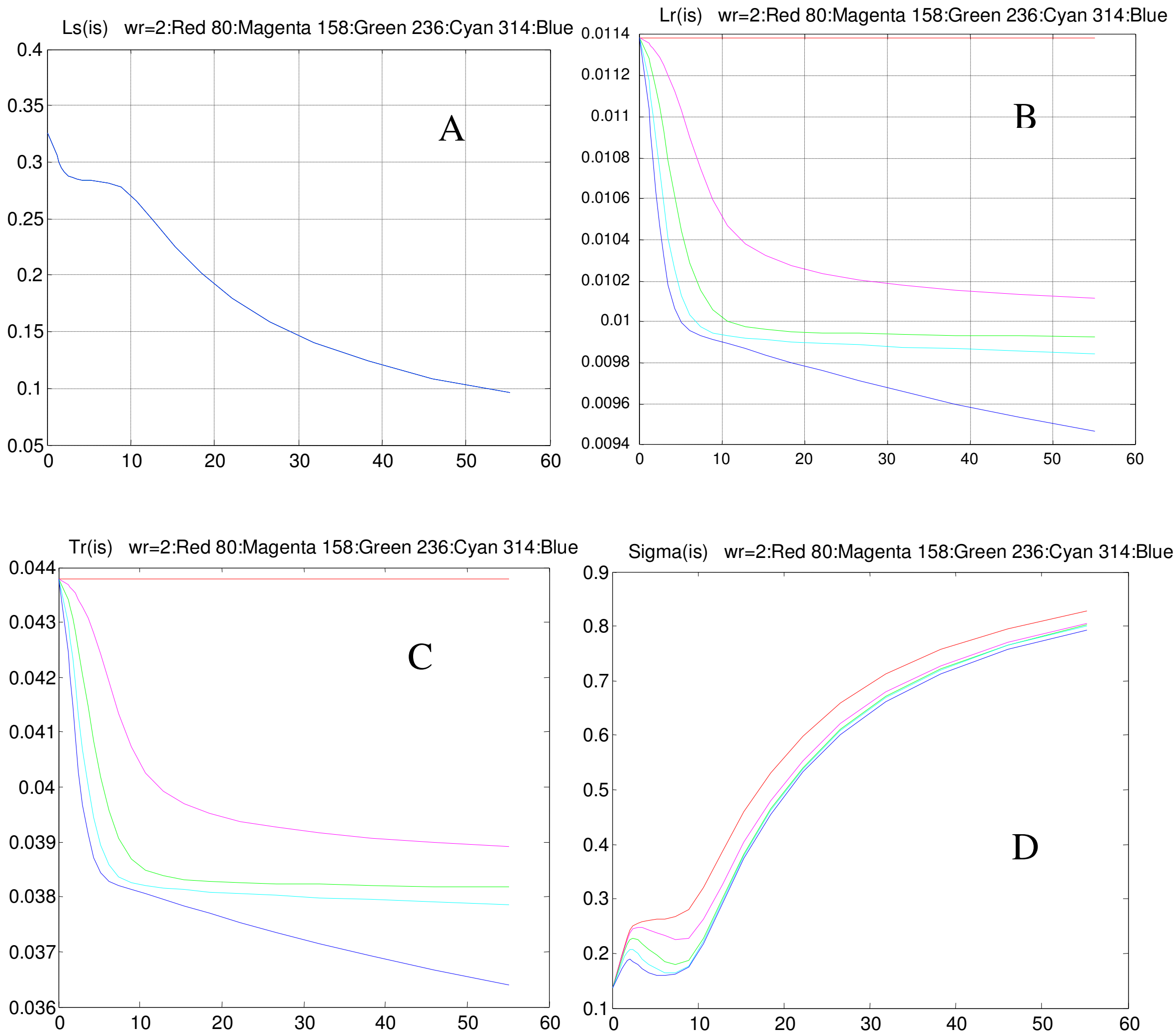


Fig. 2. a: Motor winding configuration; b: FE model with materials identification

FE model has been created, which performed using FEMM to estimate IM parameters like shown in Table 2 to improve efficiency of squirrel cage IM, which used to develop a SMULINK Matlab model. [5]. To calculate the stator induction, the model solved with the simulation were achieved for wide range rotor speeds while different stator current Figure 3A present the stator inductance parameter for rotor speeds equal 2, 5, 12 and 25 rd/s. The same process is adopted for rotor induction while varying stator current up reach high values (0 at 50 A) and for rotor speeds equal 2, 5, 12 and 25 rd/s like Figure 3 B displays. Figure 3C and D shows respectively rotor time constant and magnetic dispersion coefficient, the simulation and FE analysis were achieved with similar manner for wide range rotor speeds equal 2, 5, 12 and 25 rd/s while different stator current(0 at 50 A). The skin effect is clearly present in this case. The amplitude of the current density is much greater at the high value of the rotor speed. Figure 3 E, F and Figure 3 J represent respectively the stator to rotor effect mutual inductance, the rotor to stator mutual inductance and mutual inductance for wide range rotor speed 2, 80, 158, 236 and 314rd/s and with varying stator current up reach high values 0 to 50 A.



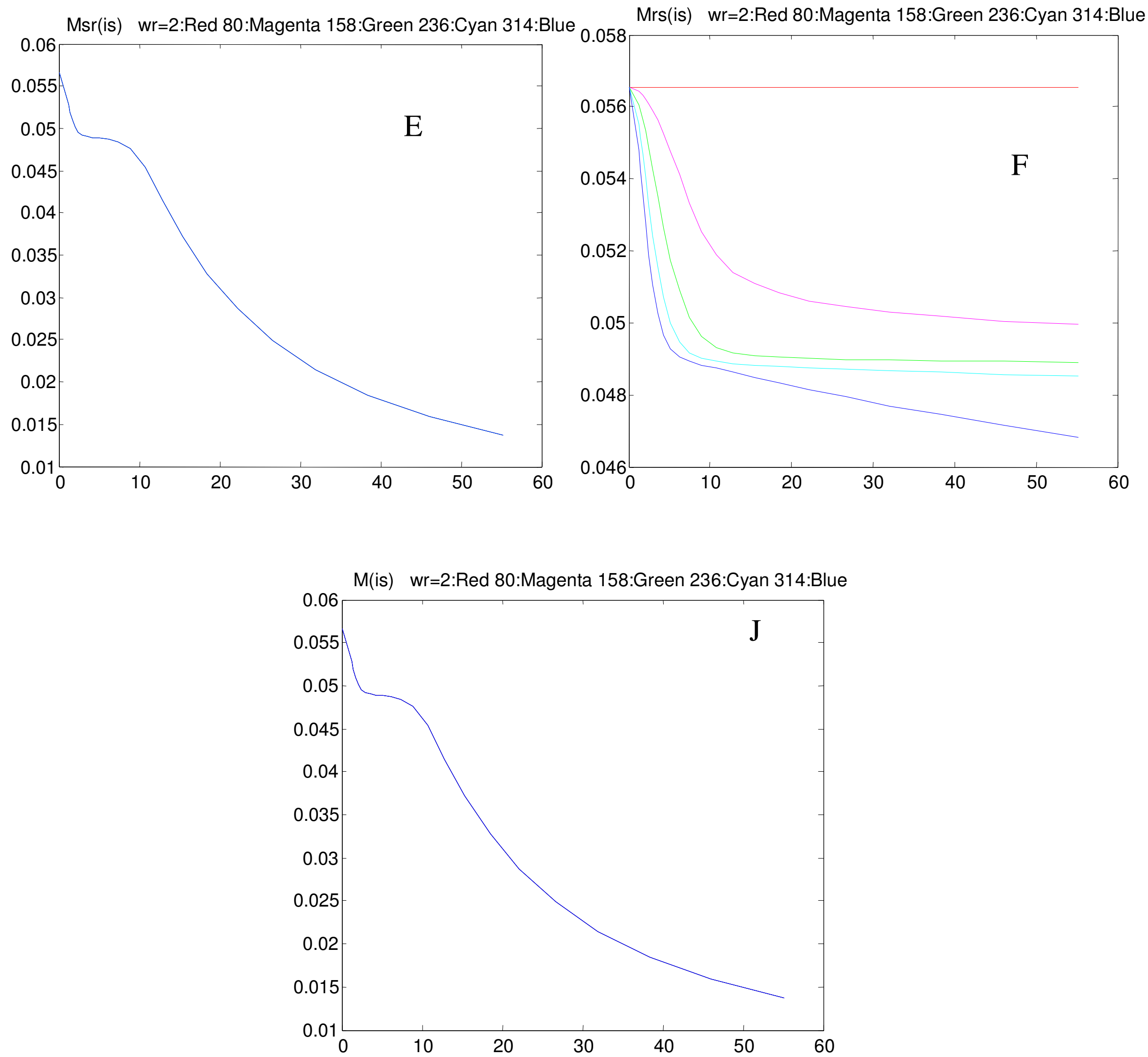


Figure 3 A- Stator inductance, B- Rotor inductance, C- Rotor time constant, D- Magnetic dispersion coefficient, E- Mutual inductance stator to rotor, F- Mutual inductance rotor to stator, J- Mutual inductance

Table 2: Motor Parameters

Parameters	Value
Speed	1468 Rpm
Stator Resistance Rs	1.91 Ω
Rotor Resistance Rr	0.26 Ω
Stator Inductance Ls	0.28105 H
Rotor Inductance Lr	0.0104 H
Mutual Inductance Msr	0.0481 H
Inertia moment J	0.0018

3. PWM Control

Pulse width modulation is a technique in which a fixed input dc voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is most popular method of controlling the output voltage and

this method is termed as pulse width modulation technique. PWM is an internal control method and it gives better result than an external control methods. [6] [7]..
The proposed strategy deals with power switch failures mitigation within a reconfigurable induction motor control The general model of the PWM drive as applied to the three-phase stator d-q frame field components an AC machine is shown in figure 4. [8].

The series controllers are very frequent because of higher order systems. The transfer function of PID controller is defined for a continuous system as:

$$G_c(p) = K_p + \frac{K_i}{s} + K_d s \tag{1}$$

The design implies the determination of the values of the constants Kp, Ki,and Kd, meeting the required performance specifications of the gains Kp, Ki,and Kd of the PID controller.
The first simulation carried with manual tuning parameters of the PID controller. The following speed is presented in figure 5, which has high over shoot value, bad rise time with big time value and the settling time is very worse. The results of new geometry of IM should be ameliorating to validate the system.

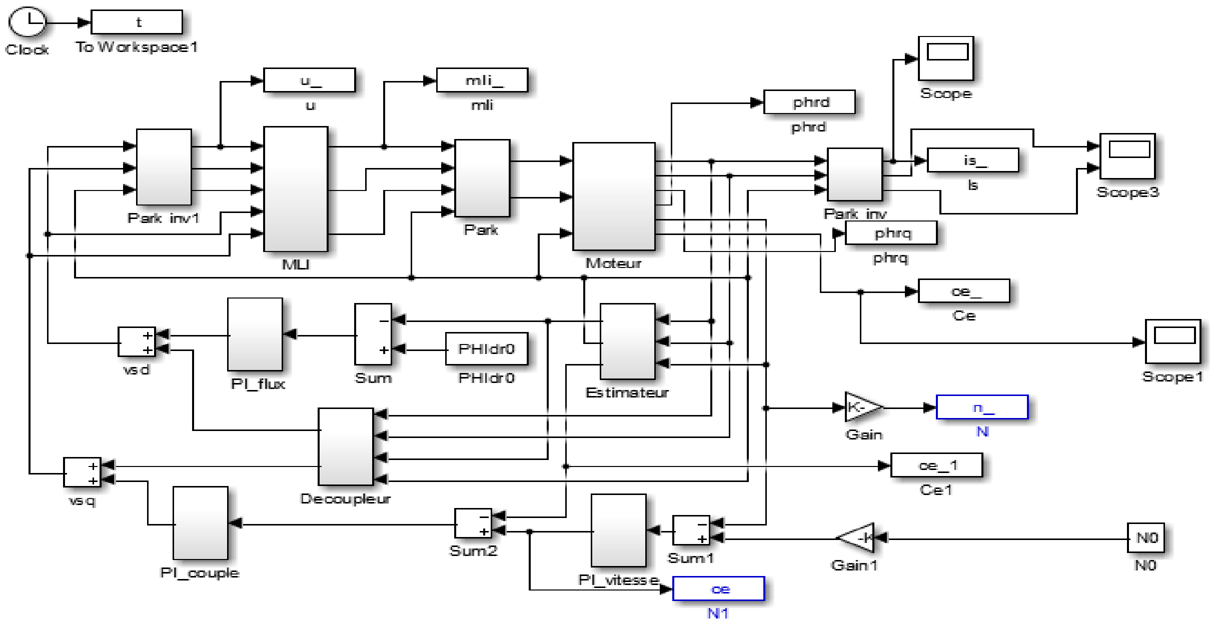


Fig. 4. Matlab Simulink Model

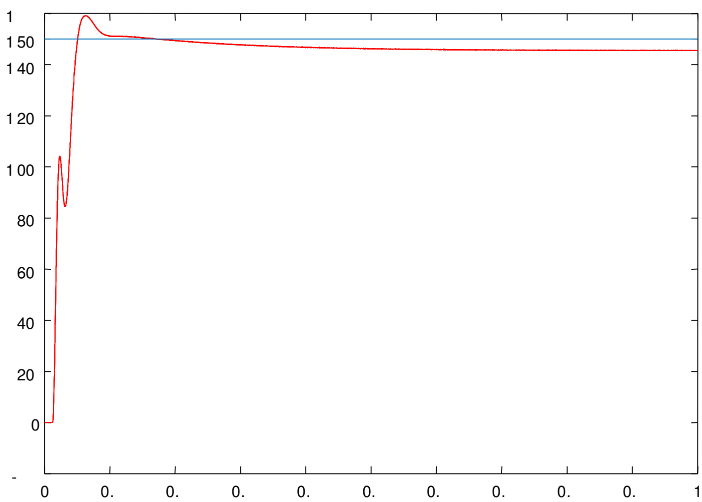


Fig. 5. Speed with manual tuning

4. Ant colony optimization ACO

The ACO algorithm was used to help of some problem and the challenges faced for solving the problems. The ACO discusses about the biological inspiration and behavior of ant colony and then relates with the real life problems. This paper presents an application of an Ant Colony Optimization (ACO) algorithm to optimize the parameters in the design of a type of nonlinear PID controller. The ACO algorithm is a novel heuristic bionic algorithm, which is based on the behavior of real ants in nature searching for food. In order to optimize the parameters of the nonlinear PID controller using ACO algorithm, an objective function based on position tracing error was constructed, and elitist strategy was adopted in the improved ACO algorithm. Detailed simulation steps are presented. This nonlinear PID controller using the ACO algorithm has high precision of control and quick response.

The gains Kp, Ki,and Kd of the PID controller are generated by the ACO algorithm for a given system As shown in Figure 6. [9] [10].

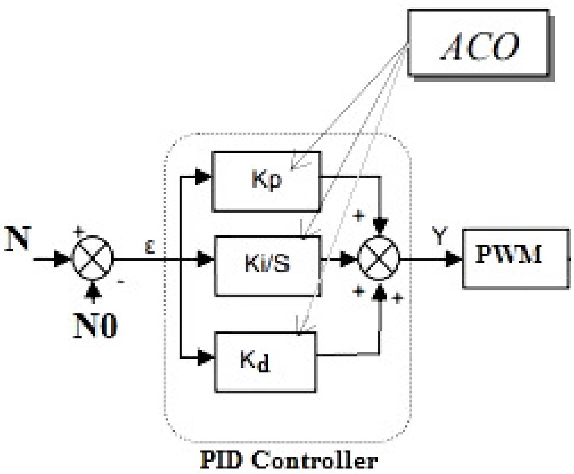


Fig. 6. PID tuning with ACO

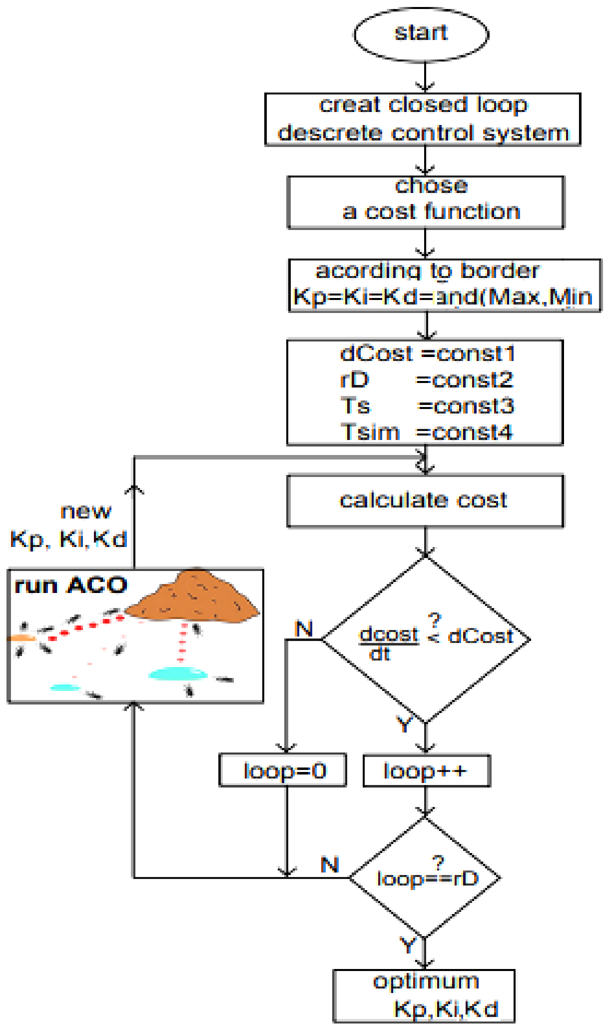


Fig. 7. ACO algorithm

In this study, Kp, Ki and Kd parameters are optimized using the ACO heuristic optimization algorithm. The ACO algorithm should observe the cost value of the control process for the aim of the optimum controller parameter calculation can be realized. The errors ISE, IAE and ITAE discrete time cost functions were used to determine the cost of the control process [11]. Mathematical equations that belong to the cost functions are reflected respectively in Equations:

$$ISE(e) = \sum_{i=1}^{n} e_i^2 \tag{2}$$

$$IAE(e) = \sum_{i=1}^{n} |e_i| \tag{3}$$

$$ITAE(e) = \sum_{i=1}^{n} i|e_i| \tag{4}$$

The optimization process that belongs to the controller parameters can be summarized in the flowchart below, Figure 7. [12]

The ACO is Soft computing technique for solving hard discrete optimization problems, which focused to produce better solution by implementing the effectiveness and reducing the errors [13].

5. SIMULATION RESULT

The ACO is a meta-heuristic method for solving a very general class of computational problems by combining user-given heuristics in the hope of obtaining a more efficient procedure.

The use of ACO method ameliorates the stability of the system and the quality of speed response as presented in figure 8 and Table 3. Which have amelioration in:

- SSE Diminution
- Reduce the over shoot
- Accelerate the Rise time
- Decrease the settling time

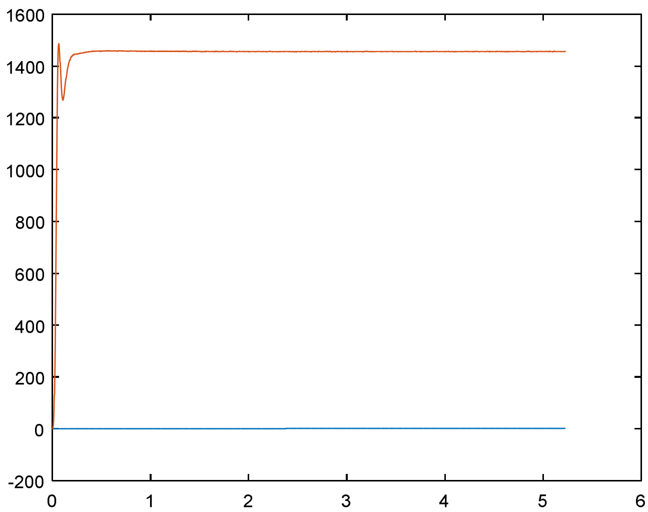


Fig. 8. Speed with ACO tuning

A PID controller improves the transient response of a system by reducing the overshoot and settling time of a system. The main reason to develop better methods to design PID controllers is because of the significant impact on the performance improvement. The performance index adopted for problem formulation is settling time, overshoot and oscillations [14].

The rate of reaching the lowest error value depends on the type of cost function to be selected. As the iteration increases in the optimization process, it is observed that lower over shoot and settlement time result values can be achieved [15] [16].

Table 3: Comparison between ACO method and manual tuning

¨Parameters	Manuel Tuning	ACO Tuning
ITAE	8.795	6.325
IAE	11.5	8.264
ISE	339.5	283.1
SSE	25	0
Rise Time	0.08	0.06
Over Shot	100	10
Settling Time	0.15	0.08

5. Conclusion

The ACO help to resolve the problems and to have the best possible speed response as shown in the table 3. In addition, this meta-heuristic method validates the IM with new geometry, which will be using in electrical vehicle application. Experiments on an induction motor drive and simulations are carried-out to assess performance and effectiveness in speed ripple minimization of IM. Results are presented illustrating the performance of the ACO optimised PID control strategy.

Appendix

Table 1: Motor Dimensions

Dimension	Value
Rotor Radius	81.8/2 mm
Number of stator Slots	36
Number of rotor slots	24
Number of stator turns	46
Coil pitch	65/71mm
Torque	12N.m
Weight	15 Kg
Rated current	4.1A
Peak efficiency	77 %
Power factor	0.85

ACO parameters:
Number of nodes n=10; number of ants m=5; maximum iteration tmax =5; maximum distance for each ant’s tour dmax= 49; Parameter, which determines the relative importance of pheromone versus distance β =0.2;

Acknowledgment

The authors would like to thanks University of Sfax.

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