Hybrid Genetic Algorithm/Bacterial Foraging Techniques Based Single Phase Induction Motor Speed Control

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Abstract

This paper deals with the analysis and design of a speed controller for the single phase induction motor. It uses an evolution programming based on hybrid genetic algorithm bacterial foraging techniques. The proposed technique is used to minimize the error area for the output response. A variable–voltage, variable-frequency (VVVF) control scheme is used (voltage-frequency control strategy) to obtain wide range of speed variations. The controller provides optimize voltage-frequency supply to single phase induction motor through drive circuit. The analysis and simulation results obtained show that the proposed controller designed reduces the computation time in design of speed controller compared to genetic algorithm for same conditions, and it gives a very satisfactory response performance.

Keywords: Bacterial Foraging (BF), Genetic Algorithm (GA), Single Phase Induction Motor(SPIM).

السيطرة على سرعة محرك حثي أحادي الطور بتهجين تقنيتي الجينية وتغذية البكتريا

د. علي حسين أحمد **محمد عبد الجليل سلطان**

الخلاصة

يتناول هذا البحث تصميم وتحليل مسيطر سرعة محرك حثي احادي الطور باستخدام البرمجة المتطورة بالاعتماد على تهجين الخوارزمية الجينية – تغذية البكتريا .التقنية المقترحة تم استخدامها للتقليل من مساحة الخطأ لاستجابة الاخراج .تم استخدام التحكم على الفولتية – التردد المتغير (VVVF) للحصول على مدى واسع من السرع المتغيرة. المسيطر يوفر افضل فولتية– تردد لتغذية المحرك الحثي الاحادي الطور خلال دائرة المسوق. نتائج التحليل والمحاكاة تظهر بأن المسيطر المقترح المصمم يقلل من الوقت اللازم للحساب في تصميم مسيطر السرعة مقارنة بالخوارزمية الجينية لنفس الظروف. وانه يعطي اداء استجابة مرضية للغاية.

1-Introduction

In last few decades, evolutionary algorithms strategies were being used for optimization of various engineering problems. In control systems they were used for reducing the effects of adverse conditions, uncertainties and performance parameters such as: stability, rise-time, overshoot, settling time, steady state tracking etc. Most of the processes are complex and nonlinear in nature, then resulting in poor performance response control by traditional techniques. Single phase induction motors as one of the common systems are widely used in domestic and industrial application (washing machines ,clothes dryers, garbage disposals etc.)[1]. Due to their ruggedness, reliability, low cost and ease electrical installation . Most of the above applications are requiring variable speed drives .In which a single phase induction motors are normally used. The speed of AC squirrel cage motor can be controlled by two methods either by changing the frequency of the supply or its voltage. There are many research works which were dealing with the speed control of such a motor. Each one used a different techniques for example [2] has used Cycloconverter to control the speed of SPIM by applying variable frequency the control system is construct through design calculation to drive the motor in open loop control, the paralleled single phase induction motors driven by VSI based fuzzy was applied by[3] to control the speed of this type of motors .The evolution programming techniques were used by[4] to control SPIM based Frog-Jumping algorithm technique to track the reference speed[5]. Has use Variable voltage-frequency control to drive motor by SHEPWM inverter. The enhancement of conventional genetic algorithm is investigated by[6,7,8] for improving the learning and speed of convergence of the optimization in control system engineering by hybridization with bacterial foraging algorithm .The genetic algorithm used to estimate the parameter of fuzzy PID controller to control the speed of three phase induction motor[9]. The present work proposes a direct hybrid GA-BF technique that mentioned in[6,7,8] to control the speed of SPIM due to lack research works in the field of speed control for this type of motors.

2-System block diagram

The system block diagram is shown in Fig.1. It consists of power converter, single phase induction motor, and controller .

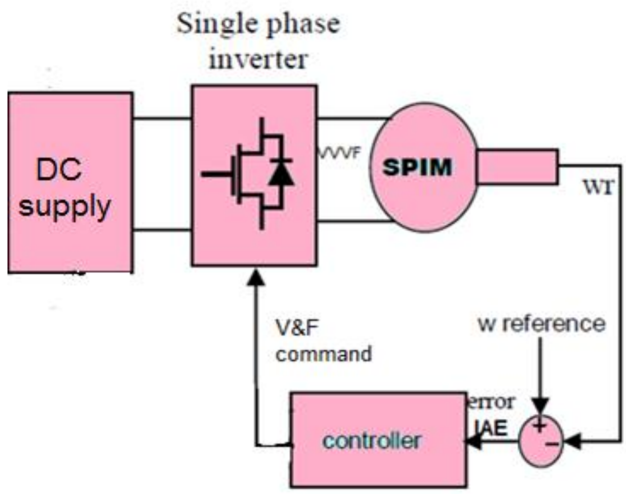


Fig. (1): System block diagram

2-1 Power converter

The power converter consists of DC supply which provide constant voltage level to the inverter from rectifier or battery. The inverter controls the voltage and frequency of the motor supply and feeds the SPIM. The power circuit topology of a single phase full bridge inverter is shown in Fig. 2.

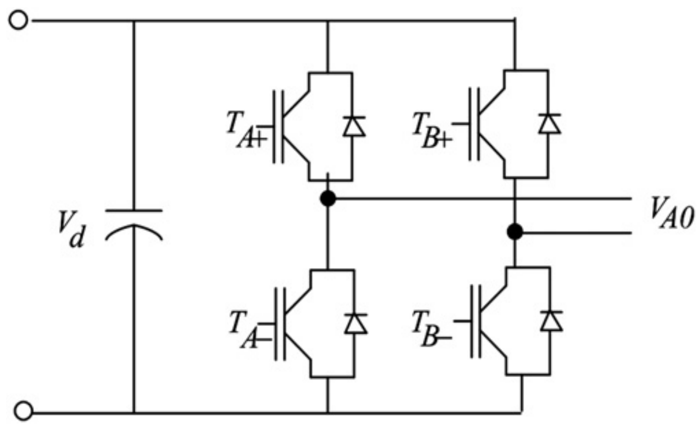


Fig. (2): Single phase inverter

The SPWM technique has been implemented in full bridge inverter by comparing modulating signals with the high frequency triangular carrier wave. The fundamental frequency of the output is decided by the frequency of the modulating signals, the waveforms of inverter is shown in Fig. 3.

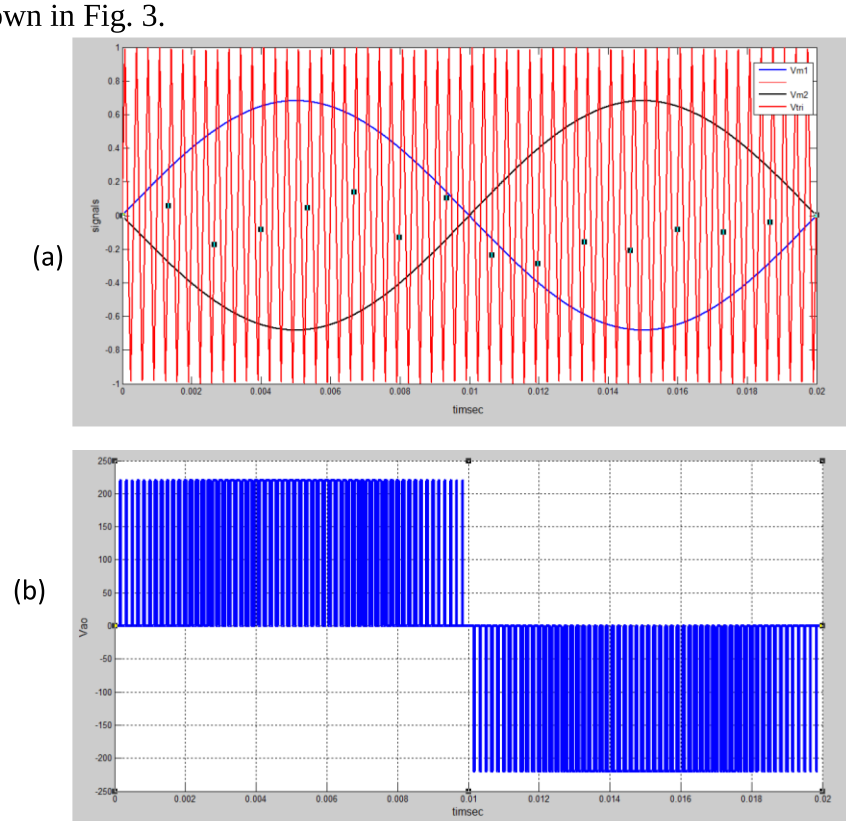


Fig. (3): PWM inverter waveforms. (a) Generation Method (b) Inverter output voltage

2-2 Single phase induction motor

There are several types of SPIMs .They are split phase, capacitor start, capacitor run, and capacitor star-run motors. This motor has main and an auxiliary stator windings displaced by 90 degrees. The capacitor which is connected for improvement in the operation mode[1]. The motor schematic diagram is shown in Fig. 4.

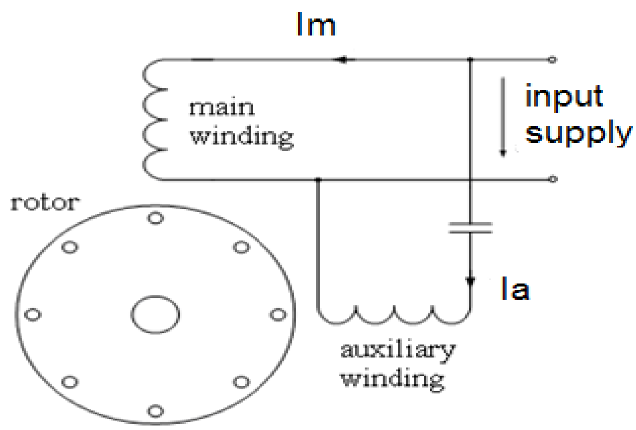


Fig. (4): Single phase induction motor

Mathematical model which describes the motor equation is similar to the unsymmetrical two-phase induction motor with simple modification to describe its behavior[1]. A schematic cross section of a single-phase induction motor is shown in Fig. 5.

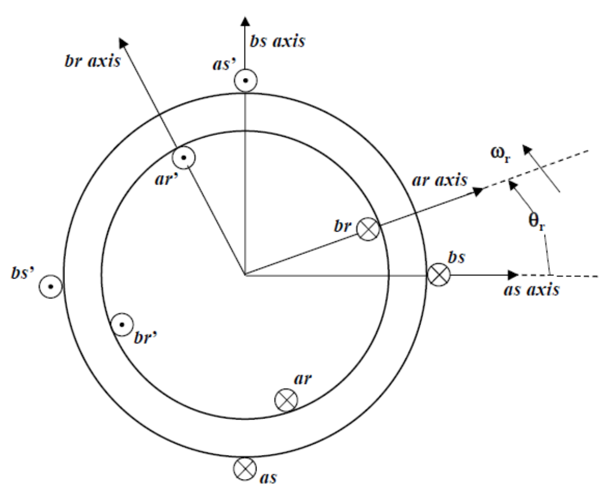


Fig. (5): A schematic cross section of SPIM

The stator and rotor voltage Equations of SPIM are given as[1]

$$v_{as} = r_a i_{as} + p\lambda_{as} \quad (1)$$

$$v_{bs} = r_b i_{bs} + p\lambda_{bs} \quad (2)$$

$$v_{ar} = r_r i_{ar} + p\lambda_{ar} \quad (3)$$

$$v_{br} = r_r i_{br} + p\lambda_{br} \quad (4)$$

The SPIM voltage equations in the q-d stationary reference frame given by:

$$v_{qs} = r_{qs} i_{qs} + p\lambda_{qs} \tag{5}$$

$$v_{ds} = r_{ds} i_{ds} + p\lambda_{ds} \tag{6}$$

$$0 = r'_{qr}\, i'_{qr} - N_{qd}\omega_r\, \lambda'_{qr} + p\,\lambda'_{dr} \tag{7}$$

$$0 = r'_{dr}\, i'_{dr} + N_{dq}\omega_r\, \lambda'_{qr} + p\,\lambda'_{dr} \tag{8}$$

where

$$N_{qd} = \frac{N_q}{N_d} \text{ and } N_{dq} = \frac{N_d}{N_q} \tag{9}$$

The torque and rotor speed are related by:

$$T_e = J\left(\frac{2}{P}\right) p\omega_r + T_L \tag{10}$$

And electromagnetic torque is given as.

$$T_e = \frac{p}{2}(N_{dq}\lambda'_{qr} i'_{dr} - N_{qd}\lambda'_{dr} i_{qr}') \tag{11}$$

Applying 4^{th}-order Rung Kutta method the D.E of single phase induction motor has been solved. The flowchart of the algorithm as shown in Fig. 6.

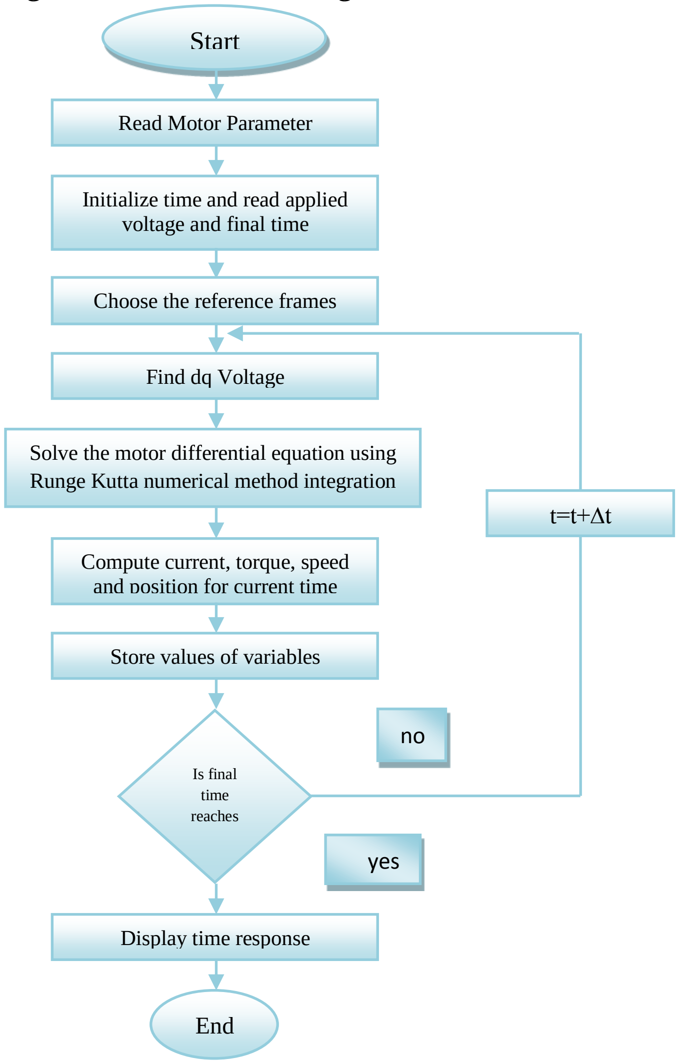
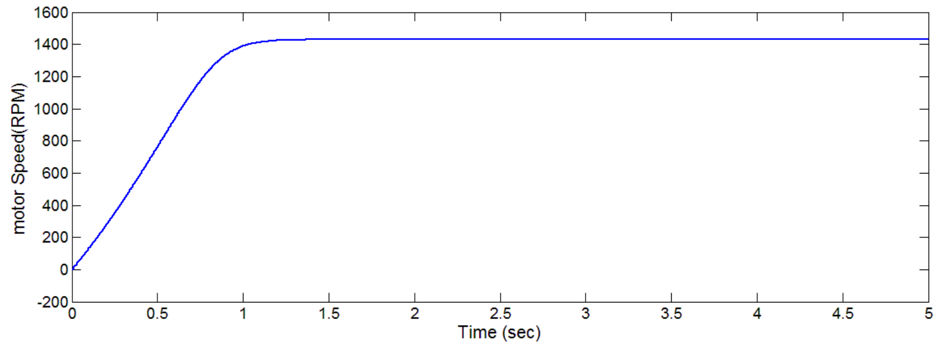
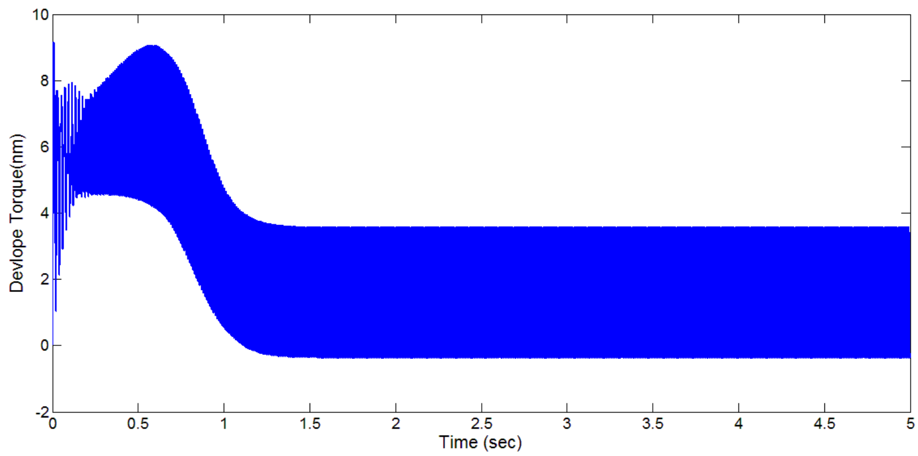


Fig. (6): Rung-Kutta solution of motor equation

The motor responses are shown in Fig.7. Fig.7a shows the motor speed, and Fig. 7b shows the developed torque for the motor (supply voltage = 220 V, supply frequency = 50 Hz, TL = 1.6 N.m)



(a)



(b)

Fig. (7): Motor response at rated load (a) Speed, (b) Develop torque

2-3 Controller

The object of the controller to match between power converter and the motor to meet the requirements . The present work uses an evolution programming technique developed from the hybridization of the genetic algorithm and bacterial foraging. Genetic algorithms are most popular technique in evolutionary programming research. It uses Darwin's theory in natural selection to simulate biological evolution[11]. Due to some limitation of genetic algorithm such as large number of iterations to give the best solution of the problem .The bacterial foraging technique selected to perform the hybridization .The bacterial foraging technique depends on the principle of the Escherichia coli (E-coli) bacteria behaviors ,and consists of four principle mechanisms namely chemotax is, swarming ,reproduction and elimination dispersal[10].

4-Controller Design

The motor speed controller is designed on the bases the error minimization of the output response with respect to the reference. The error is calculated as the performance index, which indicates the "goodness" of the system performance. A control system is considered as an optimal if the values of the parameters are chosen such that the selected performance index is minimum. Integral absolute-error criterion (IAE) is selected as an object function in the controller design which include the performance (rise time, settling time, steady state error) to be optimized.

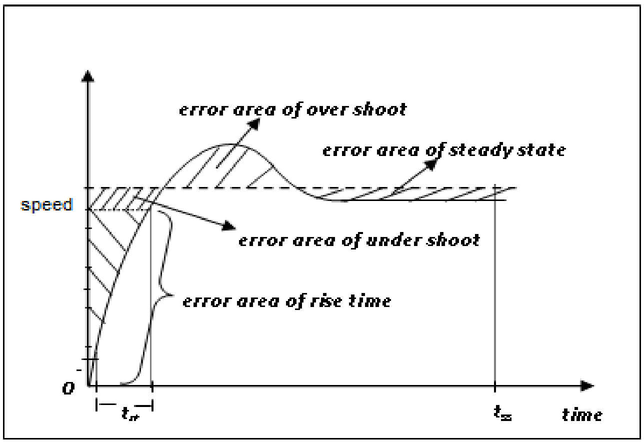


Fig. (8): Area of error for optimization

Where IAE is given by:

$$IAE = \int_0^{tsim} abs(e(t))dt \qquad (12)$$

Then the evolution programming is used to minimize the areas indicated in Fig.8.

In this paper the motor speed controller has been designed in two steps:

3-1-Genetic algorithm controller design

The design procedure using GA can be summarized in the following steps[11]:-

1- Random generation of initial population (search space of solution)
2- Compution of the fitness value for each individual in the current population (IAE for each individual)
3- Selection of certain number of individuals that scored better performance than others according to a specified selection mechanism
4- Generation of new populations from the selected individuals applying genetic operators such as crossover or mutation
5- Repeat from step 2 until a termination criterion is verified (maximum generation or tolerance reached). The flowchart of GA is shown in Fig. 9.

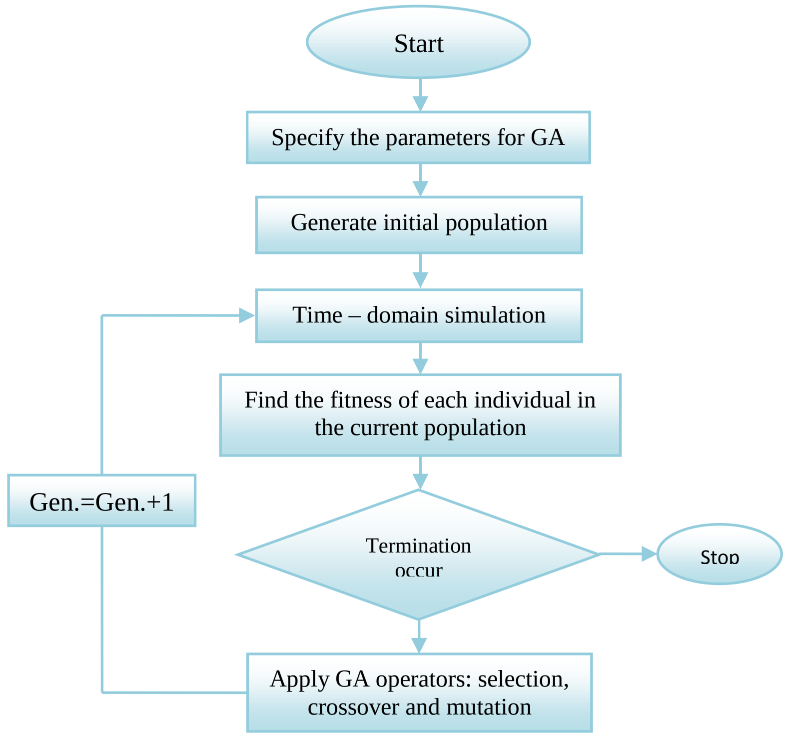


Fig. (9): Flowchart of genetic algorithm

The controller design parameters using GA is shown in table 1.

Table (1): Controller Design Parameters

Reference speed	Load torque	Best voltage	Best frequency	IAE	Population size	Number of generation	Actual speed
1100	0	180	36.81	0,0745	40	20	1095
1100	1	180	38.0644	0.1329	40	20	1094
900	0	160	29.9568	0.0763	40	20	899
900	1	160	31.2337	0.1507	40	20	894
Number of Computing IAE in worse case 800							

The problems of the conventional genetic algorithm is the large number of fitness calculation (number of solution test) and not sure convergence. The fitness calculation indicate to the elapsed time during design calculation.Fig.10 show the effect the number of generation and individuals on elapsed time.

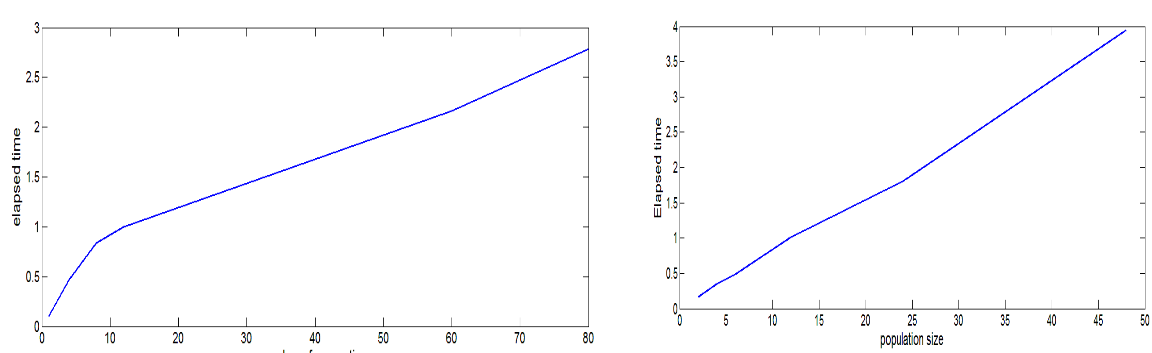


Fig. (10): a) Elapsed time vs number of generation
b) Elapsed time number of individuals

3-2 Hybrid Genetic algorithm -Bacterial foraging

One of the limitation of genetic algorithm is finding the exact global optimum and requirement large number of fitness function evaluations[10]. The Hybrid controller based on GA_BF to make the area of response error as small as possible and tracking the set point with less computional time and mathematic operation and obtain sure convergence optimize data.

The flow chart of proposed hybrid controllers design is shown in Fig.10.

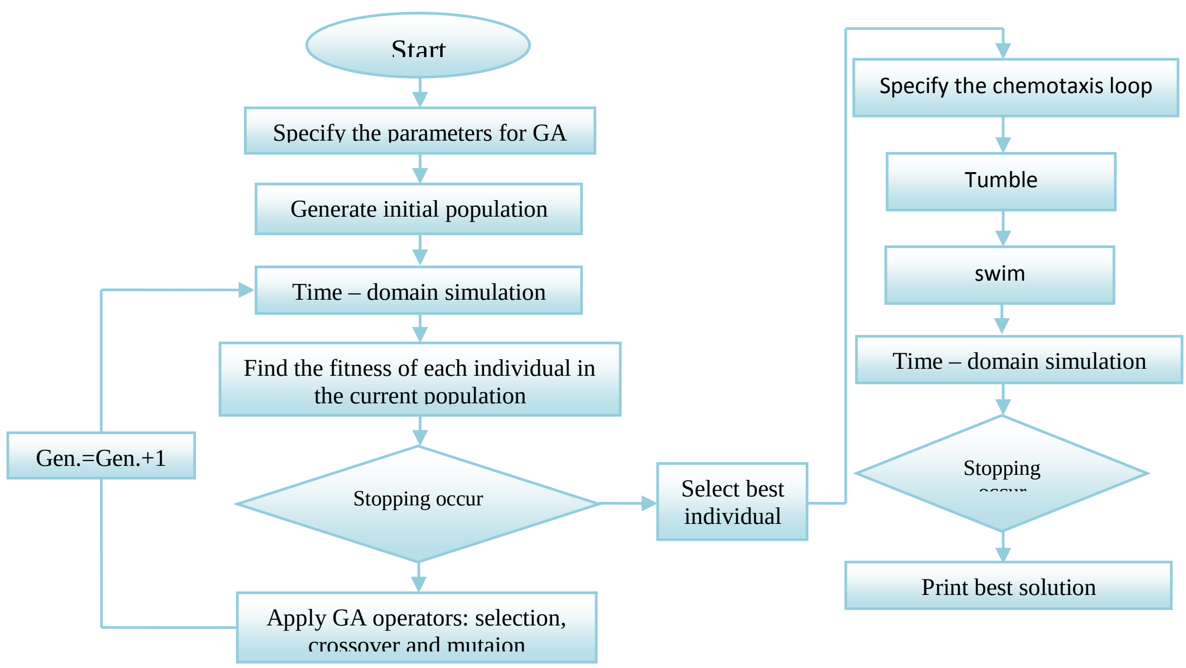


Fig. (10): Flowchart of hybrid controller

In hybrid controller the number of generation and number of individuals in design calculation reduced .The same result in table.1 obtained with reduced the number of generation (No. generation=10) and the number of individuals (No. individuals=15) then the number of computing IAE in worse case for GA-BF controller design equal 190.

Although the simplicity of the basic idea the real time application of evolutionary algorithms for optimization requires dealing with several challenging problems, because it harnesses trial and-error controller directly on the actual process to be controlled. The procedure in real-time by directly commanding the physical hardware can be extremely complex then this type of algorithms in speed controller design in term of real time implementation can used optimized look-up table of the optimized results and it is used to the real time system implementaion[9].

And others used logic protection circuit for this purpose of damage prevention to the physical hardware[7].

4-Result Discussion

This section presents the simulation results of the closed loop control system. The hybrid genetic algorithm-bacterial foraging controller sure convergence optimize data (v,f) supplied to motor through the drive circuit for tracking the speed reference. is shown in Fig.11. The steady state error has been obtained less than (2%) for all values of the speed reference of the SPIM. Fig.12 shows the response of the motor when the controller processing begin after steady state time compared to starting tracking .

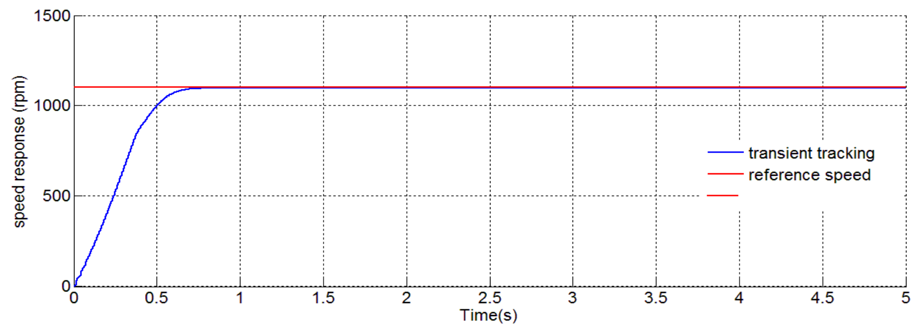


Fig. (11): Closed loop system tracking reference speed

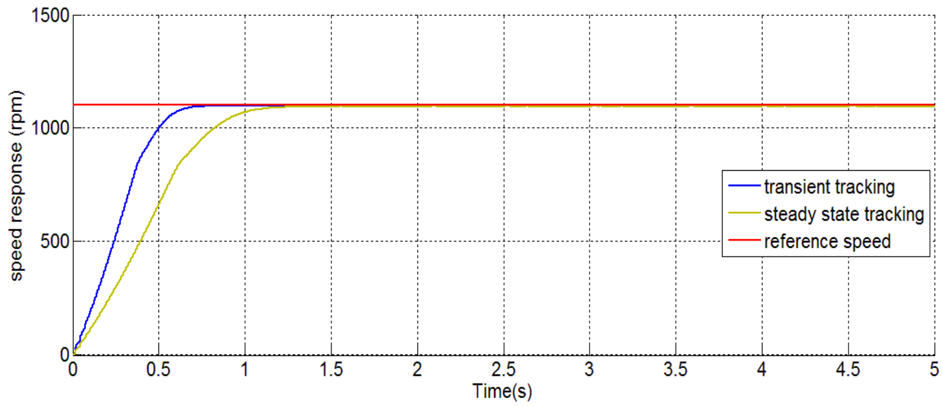


Fig. (12): Processing of controller at different times

Fig.13 and fig.14 shows the two actions of speed controller during different set points and motor subjected to different loads. It is clear there is a very good tracking of the actual speed to the reference speed (1100,900 RPM). Fig.14 shows the speed response of the motor subjected to the different loads . And the controller overcome effect the action to regulate the speed.

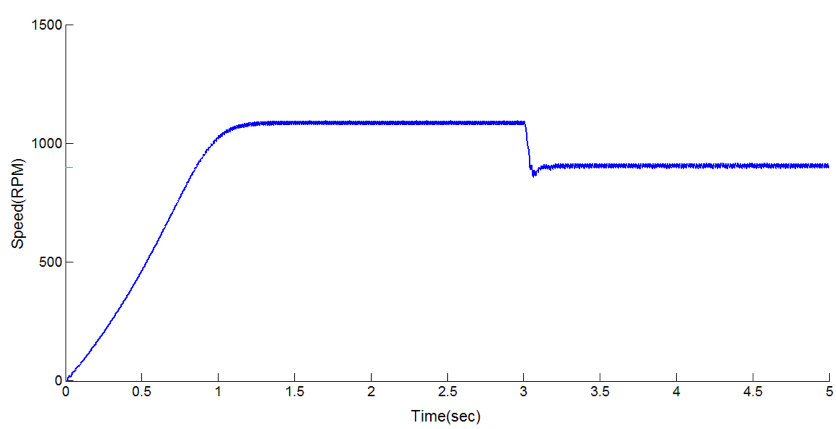


Fig. (13): Change in reference speed (1100 -900 RPM)

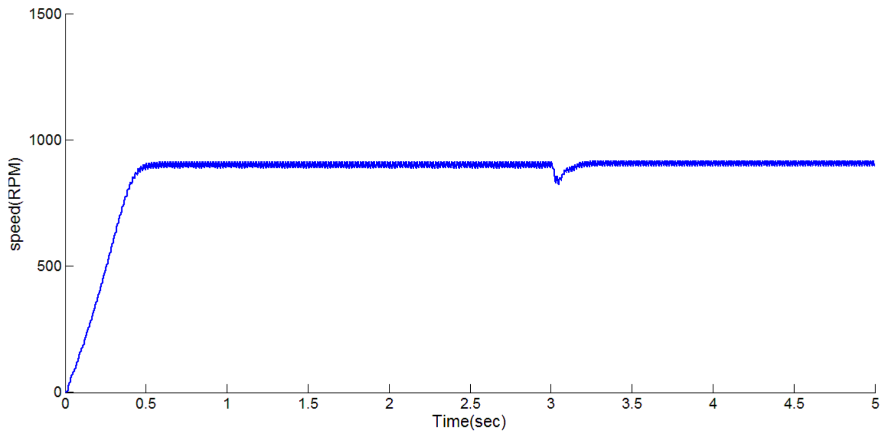


Fig. (14): Motor speed response subjected to load
(900 RPM,1N.m loaded)

6- Conclusion

This paper deals with the design of two types of controllers based on the evolution strategies {genetic algorithm and hybrid genetic algorithm-bacterial foraging} optimization. Applying this technique in the speed control of A SPIM drive system. According to the results of the computer simulation, presented a satisfactory response transient and steady state performances (rise time, settling time Steady state error) has been done as function of error area (IAE). The closed loop system with the proposed controller give good tracking to set point. And the motor operation with variation in loads and reference speed was well regulated too by proposed controller. Due to this hybridization in optimization techniques. improved in genetic algorithm have been investigated, for sure speed convergence to the optimize solution and least time of calculation design.

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Nomenclature

Im	main winding current
Ia	auxiliary winding current
Vm1&Vm2	modulation signals
Vtri	carrier signal
IAE	Integral absolute-error
VAO	inverter output voltage
p	differentiation with respect to time
abs	absolute value
tsim	time of simulation
ra	a-phase stator winding resistance
r_b	b-phase stator winding resistance
r_r	rotor winding resistance
T_e	Electromagnetic torque
T_L	Shaft mechanical torque
J	moment inertia
ω_r	Electrical angular velocity
P	Number of pole pairs
N_q	equivalent turns of phase a-stator
N_d	equivalent turns of phase b-stator
'	denote quantities are referred to the stator
γ	fluxes (stator,rotor)
Gen	generation counter