Research Journal of Engineering Sciences E- ISSN 2278 – 9472
Vol. **5(5),** 9-15, May **(2016)** *Res. J. Engineering Sci.*

A Genetic Algorithm optimized PI Controller for Vector Controlled Drive

Alok Kumar
Department of Electrical Engineering, Bhilai Institute of Technology Durg, C.G., India
alok.kumar@bitdurg.ac.in

Available online at: www.isca.in, www.isca.me
Received 24th February 2016, revised 26th April 2016, accepted 15th May 2016

Abstract

In the present scenario, for high performance industrial, DC machines are used. But with the help of Power Electronics, the same dynamic performance can be obtained for induction motor using vector controlled techniques. An advanced control strategy in the field of adjustable speed drives is the Indirect vector control of an Induction motor. The Indirect vector control strategy is simple with one PI controller. The tuned parameter values obtained by several methods may not perform satisfactorily for variable drive operating condition. In this paper, the Genetic Algorithm is used to optimize the gains of PI controller to enhance the performance of Induction motor drive.

Keywords: Field Oriented Control (FOC), Vector Control (VC), Induction Motor (IM), Proportional-Integral (PI), Genetic Algorithm (GA).

Introduction

The control of AC Motors is considerably complex compared to the DC Motor. The Drive hardware complexity increases, as more and more precise performance specifications are demanded by the user. The complexity increases further because of the variable frequency supply, AC signal processing and relative complex dynamics of AC Machine. The only effective way of producing a variable speed Induction Motor Drive [1] is to supply the Induction Motor with 3-Φ voltages of variable frequency and amplitude.

In the Vector Control scheme, the Motor is analyzed in a synchronously rotating reference frame where all the fundamental AC variables appear as DC quantities. This is also called as "Rotor Flux Oriented Control". The stator current's flux and torque components are identified and controlled independently to get a good dynamic performance. The variables computed in rotating reference frame have to be transformed to stationary reference frame to affect the actual current and voltages. The transformation needs the appropriate flux vector angle, which is calculated by two methods. The method in which the flux vector's angle is calculated as the summation of the slip angle and the measured rotor angle is known as "Indirect Vector Control".

The Indirect Vector Control is a very good strategy, but it needs a sensor for speed for its computations of rotor flux vector position, which reduces its robustness. This problem can be solved by using speed estimators. Such control is known as "Sensorless Indirect Vector Control".

The ordinary method for P-I controller parameters is by hit and trial method which makes the steady-state error zero. But, if the P-I gains are improper, they may affect the system variables. The P-I controllers cause the overshoot and undershoot of the system response. So, the value of gains should be optimized with the help of Optimization Techniques.

The paper is organized as follows: Section–2 describes the function of the various blocks involved in the modeling of the vector controlled I.M drive. Section–3 describes the working of hysteresis band current controller. Section-4 describes about the genetic algorithm. Section-5 gives the simulation results under different drive operating conditions and concluding remarks are given afterword.

Indirect vector control of induction motor

Indirect vector controller is derived from the dynamic equations of the induction machine in the synchronously revolving reference frame where d-axis is attached to the rotor flux-linkage vector.

The torque and flux producing components of stator current phasor and the slip angle, (θ_{sl}) commands is generated when a vector controller accepts torque and flux requests. The command values are denoted with asterisks.

$$i_f^* = \frac{1}{L_m}\left[\psi_r^* + T_r \frac{d\left(\psi_r^*\right)}{dt}\right] \quad (1)$$

$$i_T^* = \left(\frac{2}{3}\right)\left(\frac{2}{P}\right)\left[\frac{L_r}{L_m}\right]\left[\frac{T_e^*}{\psi_r^*}\right] \quad (2)$$

$$\omega_{sl}^{*} = \left(\frac{2}{3}\right)\left(\frac{2}{P}\right)\left[\frac{L_r}{T_r}\right]\left[\frac{T_e^{*}}{\left(\psi_r^{*}\right)^2}\right] \tag{3}$$

The torque angle command is obtained as the arctangent of i_T* (I_d^*) and i_f* (I_q^*). The command slip angle, (θ_{sl}*) is generated by the integration of ω_{sl}*. The summation of command slip angle and rotor angle provides field angle. The angle of stator current phasor is obtained by the addition of the field angle and the torque angle gives us the angle of the stator current phasor, which is used to transform *d-q* axes current commands into *abc* domain. The block diagram of the indirect vector controller is shown in the following figure (Figure-1).

Hysteresis band current controller

Hysteresis-band PWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a hysteresis band. The control circuit generates the sine reference current wave of desired magnitude and frequency, and the actual phase current wave is compared with it. As the current exceeds a prescribed hysteresis band, the upper switch of the inverter is turned off and the lower switch is turned on. As the current crosses the lower limit, the lower switch is turned off and the upper switch is turned on. A lock-out time is provided at each transition to prevent the shoot-through fault. The actual current wave is thus forced to track the sine reference wave within the hysteresis band.

The hysteresis-band PWM technique's simple implementation, fast transient response and, direct limiting of the device peak current makes it very popular. For a three-phase inverter, the control is implemented in all the three phases individually. In hysteresis band current control the fundamental of the actual current wave will suffer a lag in phase that increases at higher frequency. But, still because of its simplicity and easy implementation, this control scheme is being is used vary widely.

Genetic algorithm

Genetic Algorithm is a type of Evolutionary Algorithms (EA) or Optimization Techniques which is employed for optimization quite successfully. It starts with an initial set of parameter values which are randomly selected, instead of minimizing or maximizing the object function. With these parameters the objective function is evaluated and those sets for which the value of the objective function is needed are retained and other sets are rejected. Thus a new set of parameters are evaluated with the help of initial ones and this process is repeated until a "best" choice of parameters are obtained for which the objective function is minimum (or maximum).

In this work, the parameters of PI controller for speed control of Field Oriented Controlled Induction Motor Drive is optimized using GA and study of this method helps in tracking the speed where the demand speed is a time varying function. A MATLAB-SIMULINK model is designed for an induction motor drive. The gain parameters are initially calculated by Ziegler-Nichols's method for a fixed input whose values for gain of GA serves as the range for the generation of algorithm, which optimizes the systems much earlier than what it is supposed to be. The algorithms have been developed in MATLAB 'm-file' and interfaced with SIMULINK model as shown in figure below (Figure-3).

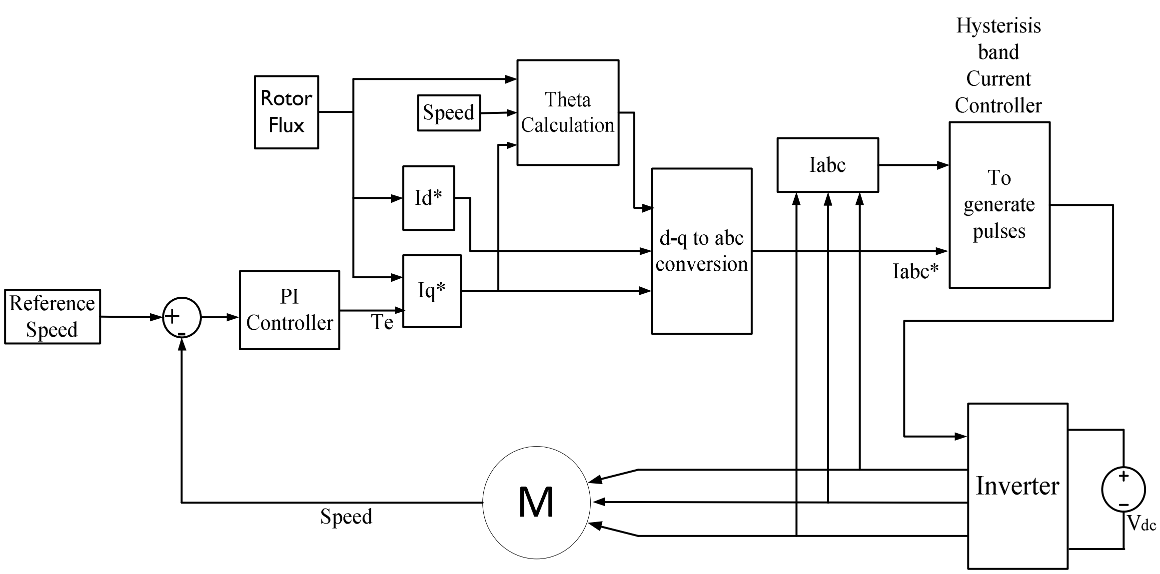

Figure-1
Block Diagram of an In-Direct Vector Controlled IM Drive

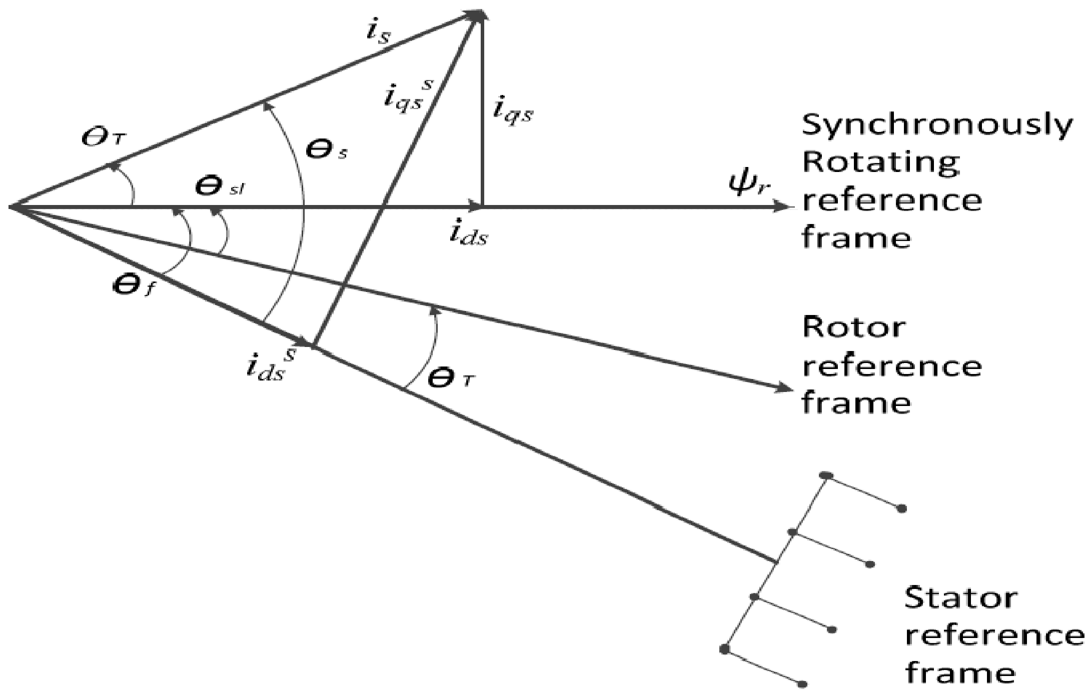

Figure-2
Phasor Diagram of the Vector Controller

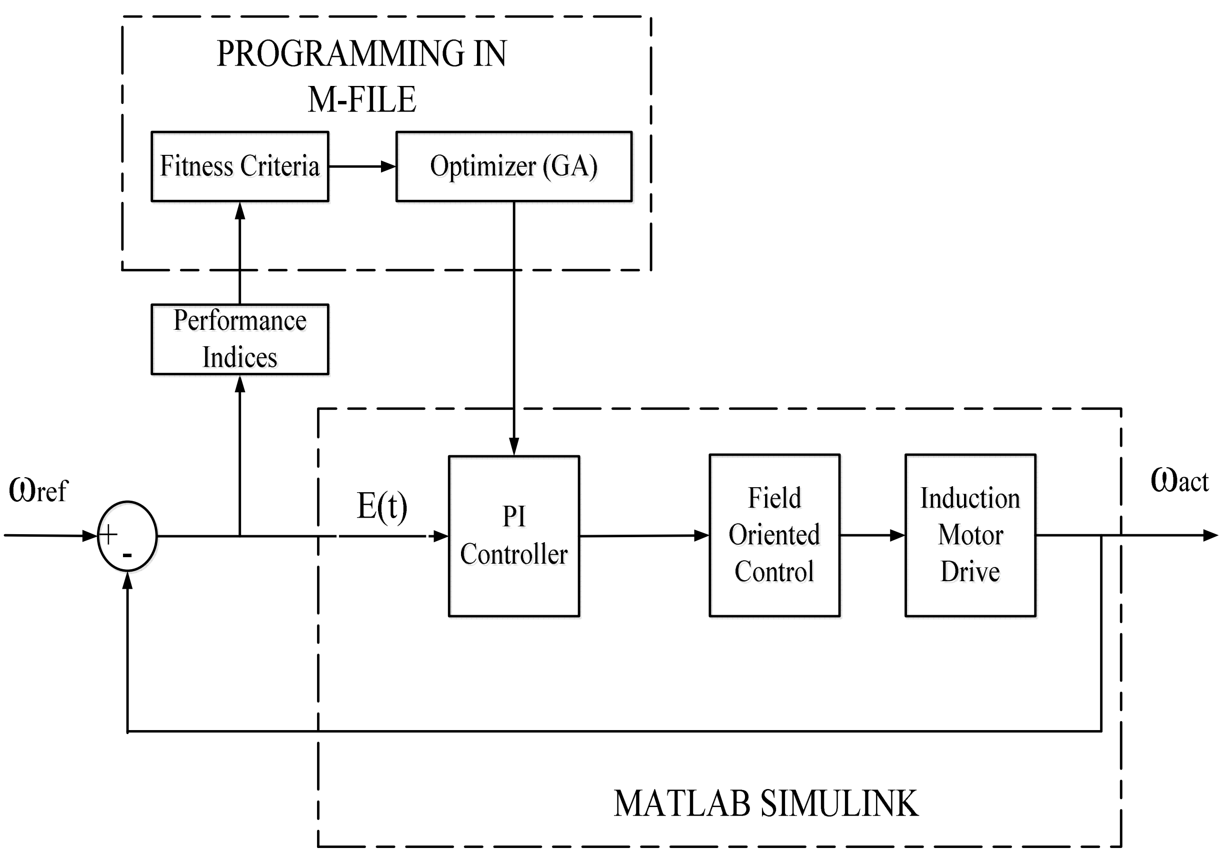

Figure-3
Schematic Diagram of GA based Optimized PI controller for Field Oriented Controlled (FOC) Induction Motor (IM) Drive

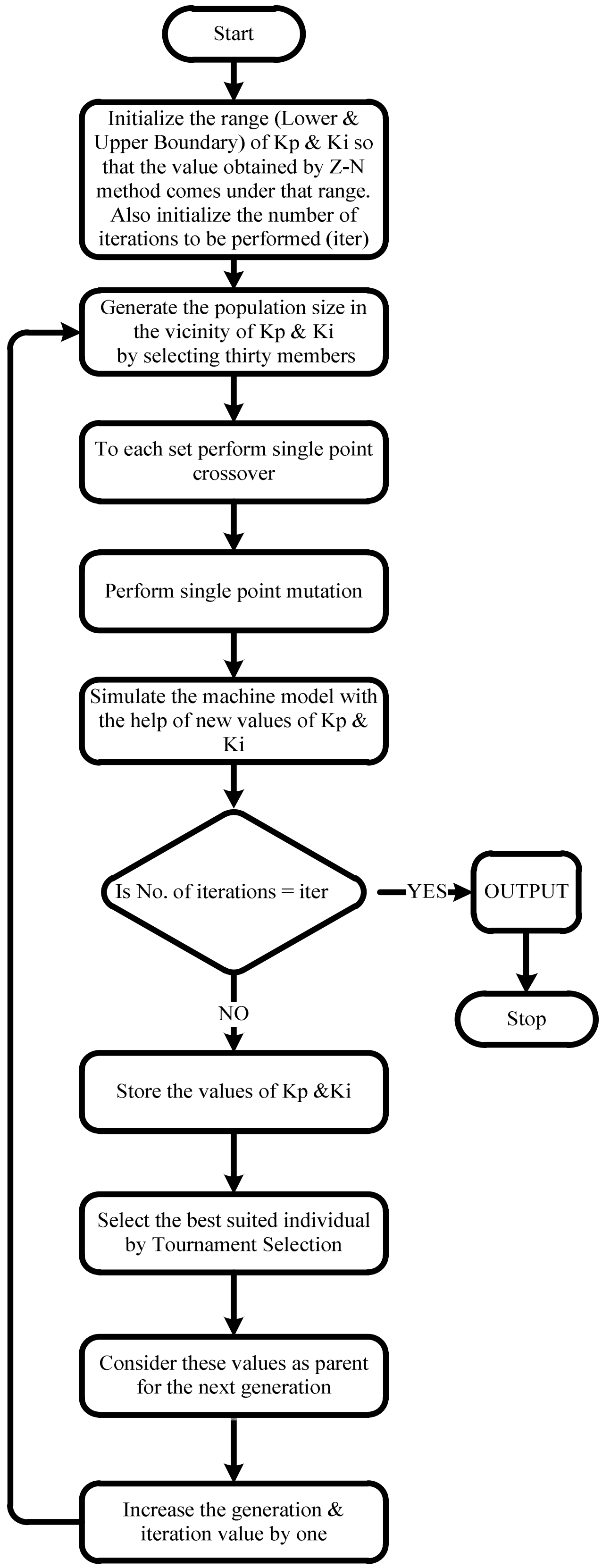

Figure-4
Flow Chart for Optimized PI Controller parameters using GA

Results and Discussion

The convergence characteristics of GA are shown in the figure below. For every performance indices I have performed thirty iterations i.e. for GA.

Outputs of Foc Im Drive Before and After Optimization

It is clear from Figure-6 and Figure-7 that there is an overshoot taking place when the motor reaches nearer to the Reference Speed. Due to this the Settling Time also increases. This overshoot has to be minimized and so the optimization technique was introduced which calculate the optimum value of the gains of PI controller so that the overshoot will be minimized or swiped-off. This can be seen from the figure below clearly. The calculation of overshoot percentage is shown in Figure-6.

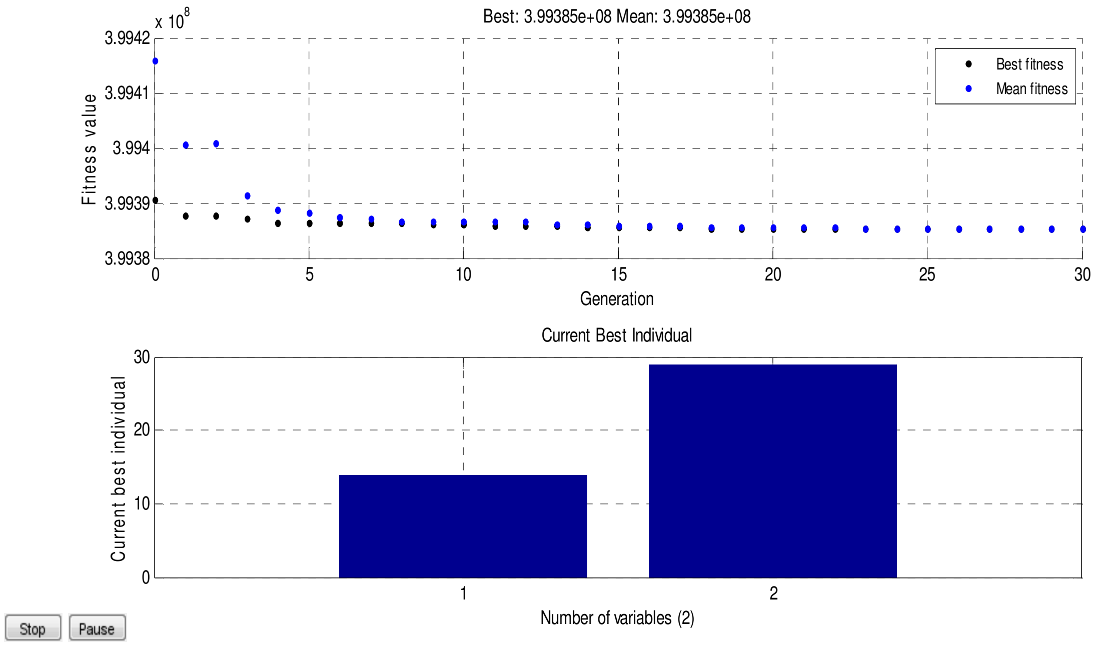

Figure-5
Plot of Fitness Value and Individual Best Gains for a GA optimized FOC IM Drive

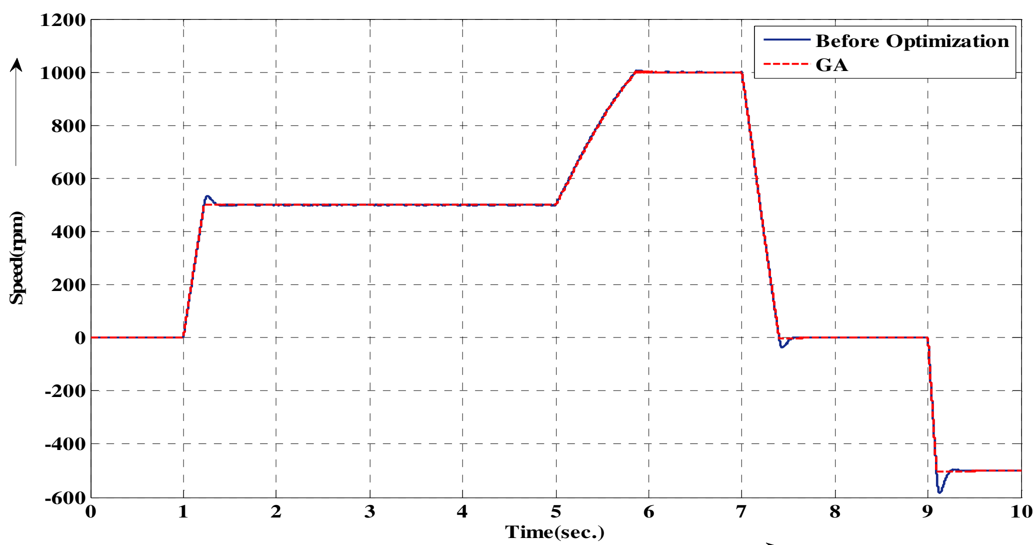

Figure-6
Speed Before and After Optimization for a Variable Speed and Variable Torque FOC IM Drive

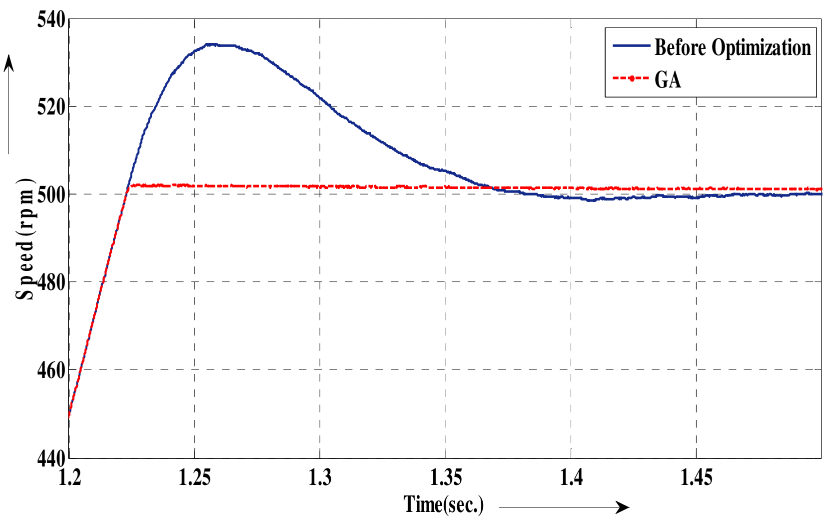

Figure-7
Speed Before and After Optimization for a Variable Speed and Constant Torque FOC IM Drive after Scale Adjustment

From Figure-6 we see that, when Speed and Load Torque are varying, whenever the speed or torque changes overshoot occurs. To overcome this overshoot we apply Optimization Technique using GA.

Figure-7 shows the clear view of one of the overshoot taking place during the operation of the Drive. In this figure the overshoot occurs between 1.2 sec. – 1.5 sec. and the optimized output shows that the overshoot is minimized and compensated to a much greater extent. Table 1 gives the percentage of overshoot compensated with the help of optimization.

$$\text{Percentage Overshoot} = \frac{\text{Motor Speed} - \text{Reference Speed}}{\text{Reference Speed}} \times 100$$

From Table-1, the Percentage Overshoot column clearly Indicate that how much an Optimization Technique is important for minimizing the overshoot. With the help of an Optimization Technique, the overshoot is minimized to a great extent.

Table-1
Percentage Overshoot Calculation for Variable Speed and Variable Torque
Reference Speed taken for overshoot calculation = 500 rpm

Variable Speed and Constant Torque	Actual Motor Speed (rpm)	%age Overshoot
Without Optimization	533.9568	6.79136%
GA	502.0469	0.40938%

The above table (Table-1) shows the percentage overshoot taking place in the Induction Motor. When the optimization technique is not applied to the Vector Controlled Drive, the overshoot is very much higher. But when it is applied to the motor, the overshoot percentage is lowered to a greater extent. This shows that the Optimization Technique is required to properly tune the gains (i.e. Proportional Gain and Integral Gain) of the PI controller through which the machine's speed is getting controlled. So, Optimization Techniques are very much advantageous as compared to conventional method of finding the gains.

The techniques may not be very much helpful for constant Speed – Constant Torque drive but very much useful for Variable Speed or Variable Torque and for both, Variable Speed – Variable Torque drives. Because when the speed changes various no. of times, for every change in speed there is an Overshoot or Undershoot as seen from Figure-6 and Figure-7 but with the help of the Genetic Algorithm (GA), every overshoot or undershoot has been minimized or swiped-off to a much larger extent as seen in the above figures.

Conclusion

Speed control of induction motor drive using Indirect Vector Control is simulated in this paper. There is an overshoot in the speed when the parameters of PI controller are not optimized which we can clearly see from the plots above.

From the above observation we conclude that, with the help of optimization we can reduce or minimize the overshoot taking place during the change in speed. Also the performance of Field Oriented Induction Motor Drive is enhanced with the help of Optimization Technique i.e. GA. From the above plotted graphs or outputs speed has been controlled in a very better way using the PI controller and also the optimization technique used in it.

Also the percentage of overshoot in Speed of an Induction Motor Drive is calculated which helps in knowing that an optimized of PI controller for a Vector Controlled Drive is very much useful when the speed or load varies frequently. This overshoot has been minimized by the work presented in this paper.

Appendix

Machine parameters used for modeling and simulation

Rated Power	=	1 HP (1*746 W)
Number of Poles, P	=	4
Number of Pole Pairs, P	=	2
Rated Stator Voltage	=	415 V
Rotor Resistance	=	7.1750 Ω
Stator Resistance	=	6.3150 Ω
Magnetizing Inductance, L_m	=	0.3855 H
Rotor Leakage Inductance, L_{lr}	=	0.0278 H
Stator Leakage Inductance, L_{ls}	=	0.0278 H
Mechanical Inertia Constant, J	=	0.0118 $kg.m^2$
Friction Constant, b	=	0.0027 N.m.s.
Frequency, f	=	50 Hz.

References

1. Leonhard W. (1988). Adjustable –Speed AC Drives. proc. *IEEE,* 76(4), 455-471.

2. Finch J. W., Atkinson D. J. and Acarnley P. P. (1994). Scalar to vector: General Principles of Modern Induction Motor Control. *IEEE Trans. Ind. Appl.,* 41(2), 201-207.

3. Yen Shin Lai (2003). Machine Modelling and Universal Controller for Vector Controlled Induction Motor Drives. *IEEE Trans. On Energy Conservation,* 18(1), 23-32.

4. Krishnan R. and Bharadwaj A.S. (1991). A review of parameter sensitivity and adaptation in indirect vector controlled induction motor drive systems. *IEEE Trans. on Power Elec.,* 6(4), 695-701.

5. Ashok Kusagur, Kodad S.F. and Shankar Ram B.V. (2009). Modelling of Induction Motor and Control of Speed Using Hybrid Controller Technology. *Journal of Theoretical and Applied Information Technology (JATIT),* 10(2), 117-126.

6. Adel Aktaibi, Daw Ghanim and Rahman M.A. (2016). Dynamic Simulation of a Three-Phase Induction Motor using MATLAB SIMULINK. Currents.

7. Shi K.L., Chan T.F. and Wong Y.K. (1997). Modelling of a Three-Phase Induction Motor Using SIMULINK. *0-7803-3946-0/97, IEEE.* WB3-6.l-6.3.

8. Habibur Rehman (2012). Detuning Minimization for Alternative Energy Vehicular Drive System. *IEEE Trans. on Vehicular Power and Propulsion Conference (VPPC)*, 42-47.

9. Timothy M. Rowan, Russel J. Kerkman and David Leggate (1991). A Simple On-Line Adaption for Indirect Field Orientation of an Induction Machine, *IEEE Trans. On Inds. App.* 27(4), 720-727.

10. Tista Banerjee, Sumana Chowdhuri, Gautam Sarkar and Jitendranath Bera (2012). Performance Comparison between GA and PSO for Optimization of PI and PID controller of Direct FOC Induction Motor Drive. *International Journal of Scientific and Research Publications,* 2(7), 01-08.

11. Ranjith Kumar K., Sakthibala D. and Palaniswami S. (2010). Efficiency Optimization of Induction Motor Drive using Soft Computing Techniques. *International Journal of Computer Applications (IJCA),* 3(1), 06-12.

12. Laatra Yousfi, Amel Bouchemha, Mohcene Bechouat and Abdelhani Boukrouche (2014). Vector control of induction machine using PI controller optimized by genetic algorithms. 16^{th} International Power Electronics and Motion Control Conference and Exposition, 1493-1498, Antalya, Turkey, 21-24.

13. Bose B.K. (2005). Modern Power electronics and AC drives. Pearson Education, Singapore.