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An Evolutionary Algorithm based PI Controller for Performance Enhancement of Vector Controlled Drive

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Abstract: Conventionally for high performance industrial drives, DC machines are used. With the development in the field of Power Electronics, the same dynamic performance can be obtained for induction motor using vector controlled techniques. The Indirect vector control of an Induction motor is an advanced control strategy in the field of adjustable speed drives. The control strategy of Indirect vector control is simple with one PI controller in the outer speed loop. There are several methods which are used to tune the parameter values of the controller. The tuned parameter so obtained may not perform satisfactorily for variable drive operating condition. In this paper the gains of PI controller are optimized with the help of Evolutionary Algorithm to enhance the performance of Induction motor drive.

Keywords*:* Field Oriented Control (FOC); Vector Control (VC); Induction Motor (IM); Proportional-Integral (PI); Evolutionary Algorithm (EA); Particle Swarm Optimization (PSO); Genetic Algorithm (GA).

1. INTRODUCTION

The variable speed Drives are used widely in almost every industries and also in every part of it, such as, transport systems and also for the house-hold purposes e.g., pumps, fans etc. The use of variable speed AC Drives has been further advanced by the development of new power semiconductor devices, and improved Drive control further enhance the performance of the AC Drives. The present widespread trends in the Drive technology convey the belief that AC Drives can have a wide acceptability in future, as compared to other Drives. The major limitations of the DC Motors are commutator and brushes, which require regular maintenance and makes the Motor unsuitable for humid and dirty environments. Due to these drawbacks of DC Motors and the advantages of the Induction Motors, the later have become more widely acceptable than any other electric Motors.

In this paper, the Indirect Vector Control of a 3-phase induction machine in an arbitrary reference scheme is presented. An Indirect Vector Controller accepts the rotor flux linkages and torque as commands and generates the corresponding current references to be followed by the machine. Here, a hysteresis current controller has been used, which allows the current to follow its command value or reference value within a certain band, called hysteresis band. The inverter then generates the required voltages for the induction machine, so as to keep the currents in track with their references. The principle of hysteresis band current control is also discussed in this paper.

The P-I controllers are widely used in industries for high performances of electric drives. The ordinary method for the selection of the P-I gains is by trial and error method. Also, it makes the steady-state error

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zero. But, choosing improper P-I gains may affect the system variables. So, they need to be designed properly. The P-I gains can be designed by modulus optimum method. 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 organized as follows: Section-2 provides an overview of the dynamic modeling of the field oriented vector control drive. Section–3 describes the function of the various block involved in the modeling of the vector controlled I.M drive. Section–4 describes the working of hysteresis band current controller. Section-5 describes about the evolutionary algorithms used. Section-6 gives the simulation results under different drive operating conditions and concluding remarks are given afterword.

2. PRINCIPLE OF VECTOR CONTROL

The dynamic model of the machine to be controlled must be known in order to understand and design vector control drives. Due to the fact that every good control has to face some changes to the plant, it is confirmed that the dynamic model of the machine would be just a good approximation of the real plant. Using a 2-phase motor modeling in direct and quadrature axes, the dynamic model of the induction motor is derived [5, 7]. The concept of power invariance is utilized in the modeling. According to the concept of power invariance, the power in each phase must be equal in the 3-phase machine and its equivalent 2-phase model.

The assumptions are made to derive this model like balanced rotor and stator windings with sinusoidal distributed mmf, uniform air gap, inductance v/s rotor position is sinusoidal & saturation & parameter changes are neglected.

The induction machine's has dynamic or d-q equivalent circuit is shown in Fig 1. One of the most popular models derived from this equivalent circuit is Krause's model.

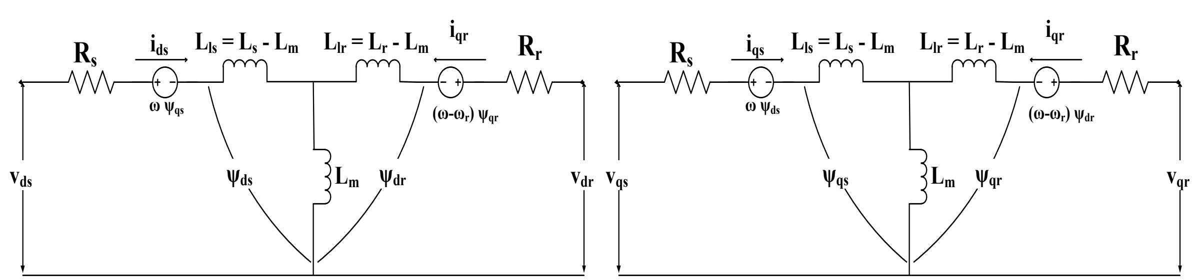

Figure 1: Dynamic or *d-q* equivalent circuit of an induction machine

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \tag{1}$$

$$T_e - T_L = J\left(\frac{2}{P}\right)\frac{d\omega_r}{dt} \tag{2}$$

For a squirrel cage induction machine, v_{qr}, v_{dr} can be set as zero. The inputs to an induction machine are the load torque and the 3-phase voltages. The outputs are the 3- phase currents, the rotor speed and, the electrical torque. Here, ω is the speed of any reference frame, onto which the transformation is carried out, such that the machine can be modeled in any reference frame.

The above equations are implemented in MATLAB-SIMULINK, to obtain the dynamic model of the three phase induction machine.

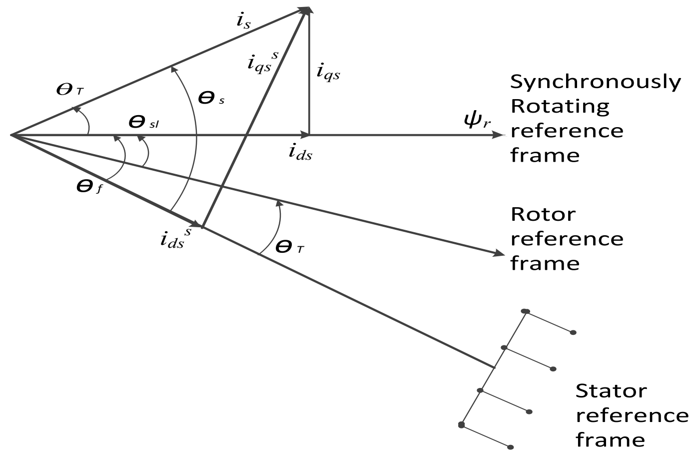

Figure 2: Phasor Diagram of the Vector Controller

3. INDIRECT VECTOR CONTROL OF IM

Indirect vector controller [3, 4, 5] 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.

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

$$i_f^* = \frac{1}{L_m}\left[\psi_r^* + T_r \frac{d\left(\psi_r^*\right)}{dt}\right] \tag{3}$$

$$i_T^* = \left(\frac{2}{3}\right)\left(\frac{2}{P}\right)\left[\frac{L_r}{L_m}\right]\left[\frac{T_e^*}{\psi_r^*}\right] \tag{4}$$

$$\omega_{sl}^* = \left(\frac{2}{3}\right)\left(\frac{2}{P}\right)\left[\frac{L_r}{T_r}\right]\left[\frac{T_e^*}{\left(\psi_r^*\right)^2}\right] \tag{5}$$

The command slip angle, (θ_{sl}*) is generated by the integration of ω_{sl}*. The torque angle command is obtained as the arctangent of i_T* (I_d*) and i_f* (I_q*). The field angle is obtained by addition of both the command slip angle and rotor angle. The summation of the field angle and the torque angle gives us the angle of the stator current phasor [6, 7, 14], 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 (Fig. 3).

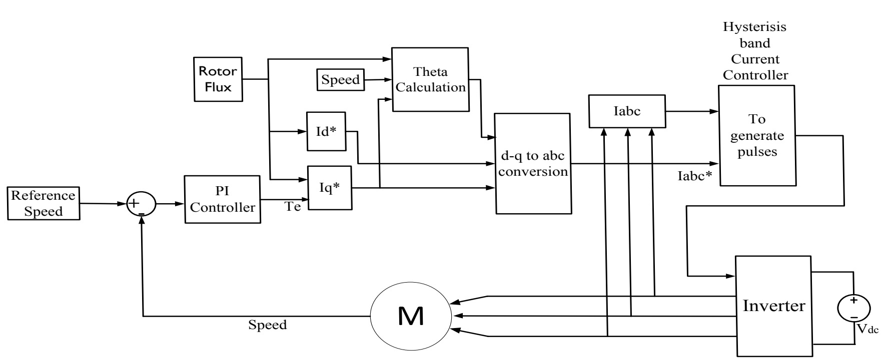

Figure 3: Block Diagram of an In-Direct Vector Controlled IM Drive

4. HYSTERISIS BAND CURRENT CONTROLLER

Hysteresis-band PWM technique is a continuous feedback method for current control using PWM where the actual current tracks the command current continuously within a band. Fig. 4 explains the principle of operation of HCC in contrast to a half-bridge inverter. The control circuit generates the sine wave for current to be taken as reference current (desired magnitude and frequency), and it is compared with the actual phase current. 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 band by back and forth (bang-bang) switching off the upper and lower switches.

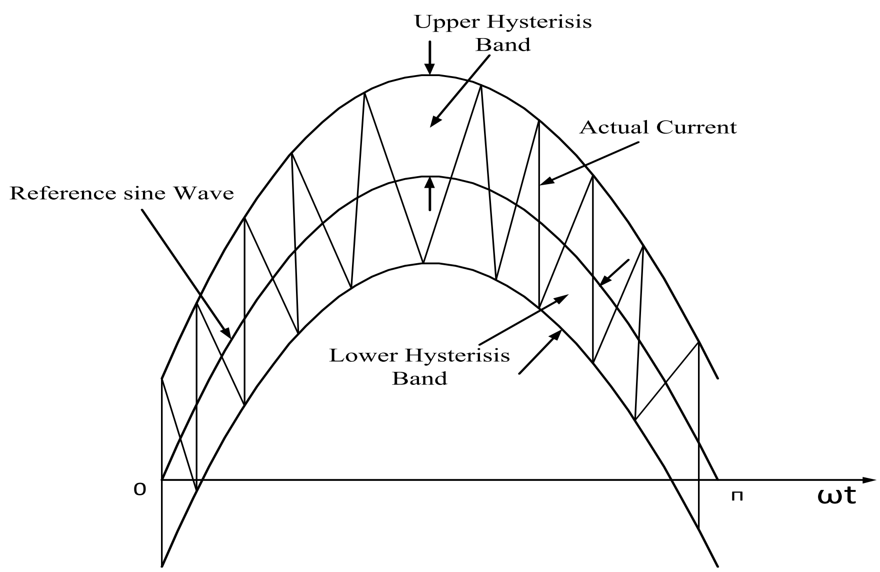

Figure 4: Principle of Hysteresis Band Current Controller

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

5. EVOLUTIONARY ALGORITHM OR OPTIMIZATION TECHNIQUE

Evolutionary Algorithm (EA) now a day has been employed in many cases for solving problems (optimization) quite successfully. Instead of maximizing or minimizing the objective function, it selects an initial set of parameter values randomly. Now with the help of these parameters, the objective function is evaluated and those sets for which the value of the objective function is higher (or lower, as needed) are taken into account and other set of values are manipulated. Thus a new set of parameters are evolved from the initial ones and this process is repeated till a "best" parameter is obtained for which the objective function is maximum (or minimum).

In this paper, optimization of PI controller parameters for speed control of a Field Oriented Controlled Induction Motor Drive has been done using GA and PSO and the study of these two methods where the demand speed is time varying, have been carried out for a speed tracking problem. The design is considered for a 3-phase induction motor in MATLAB-SIMULINK. The gain parameters for a fixed input are initially evaluated by Ziegler-Nichols's method whose values for gain of GA and PSO serves as the range for generating both the algorithms, so as to optimize the system much faster and earlier than what it actually needs [10, 11]. The algorithms are now programmed in 'm-file' and then interfaced with SIMULINK model as shown in figure below (Fig. 5).

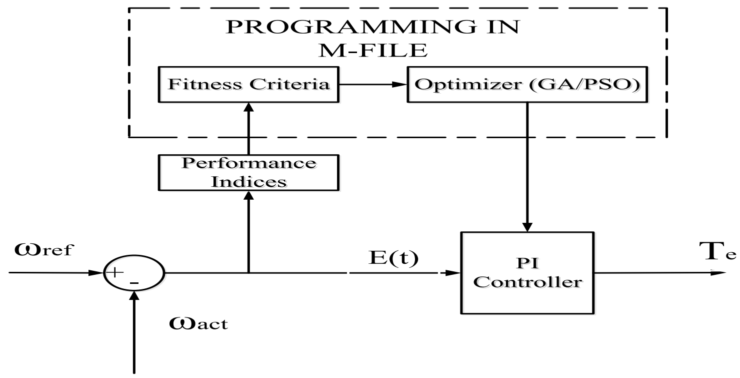

Figure 5: Schematic Diagram of GA and PSO based Optimized PI controller for FOC IM Drive

Table 1
Values taken for GA coding

Terminologies Used in GA Coding	*Values of Terminologies Used*
No. of variables (nvars)	2 (K_p & K_i)
Population size (npop)	30
No. of iterations (iter)	30
Lower boundary for K_p (LB)	0
Upper boundary for K_p (UB)	15
Lower boundary for K_i (LB)	10
Upper boundary for K_i (UB)	30
Elite count (EliteCount)	2

The flow-chart below shows the process of GA clearly,

Table 2
Values taken for PSO coding

Terminologies Used in PSO Coding	*Values of Terminologies Used*
No. of variables (nvars)	2 (K_p& K_i)
Population size (npop)	30
No. of iterations (iter)	30
Lower boundary for K_p (LB)	0
Upper boundary for K_p (UB)	15
Lower boundary for K_i (LB)	10
Upper boundary for K_i (UB)	30

The flow-chart below shows the process of PSO clearly,

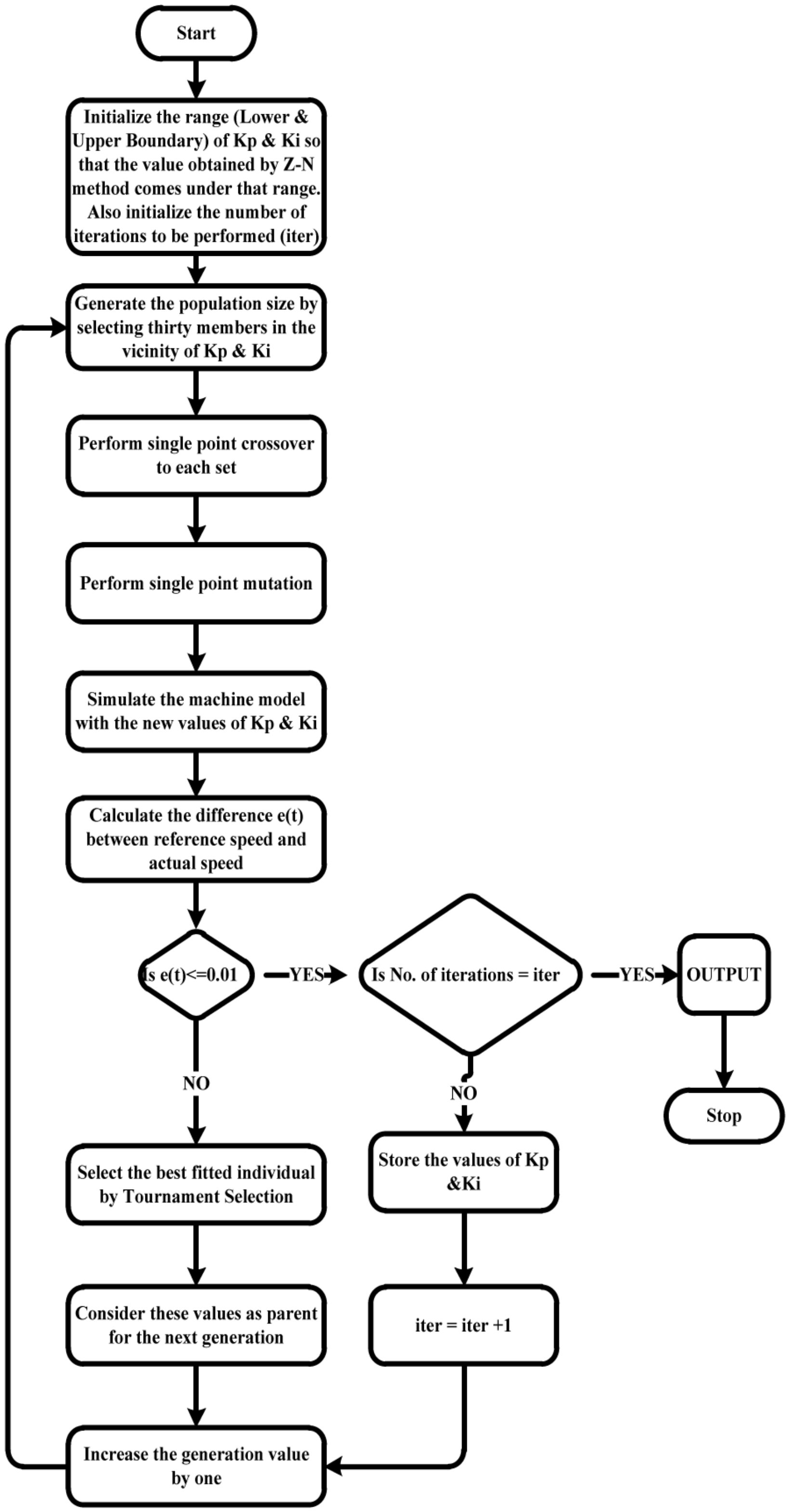

Figure 6: Flow Chart for Optimization of PI Controller parameters using GA

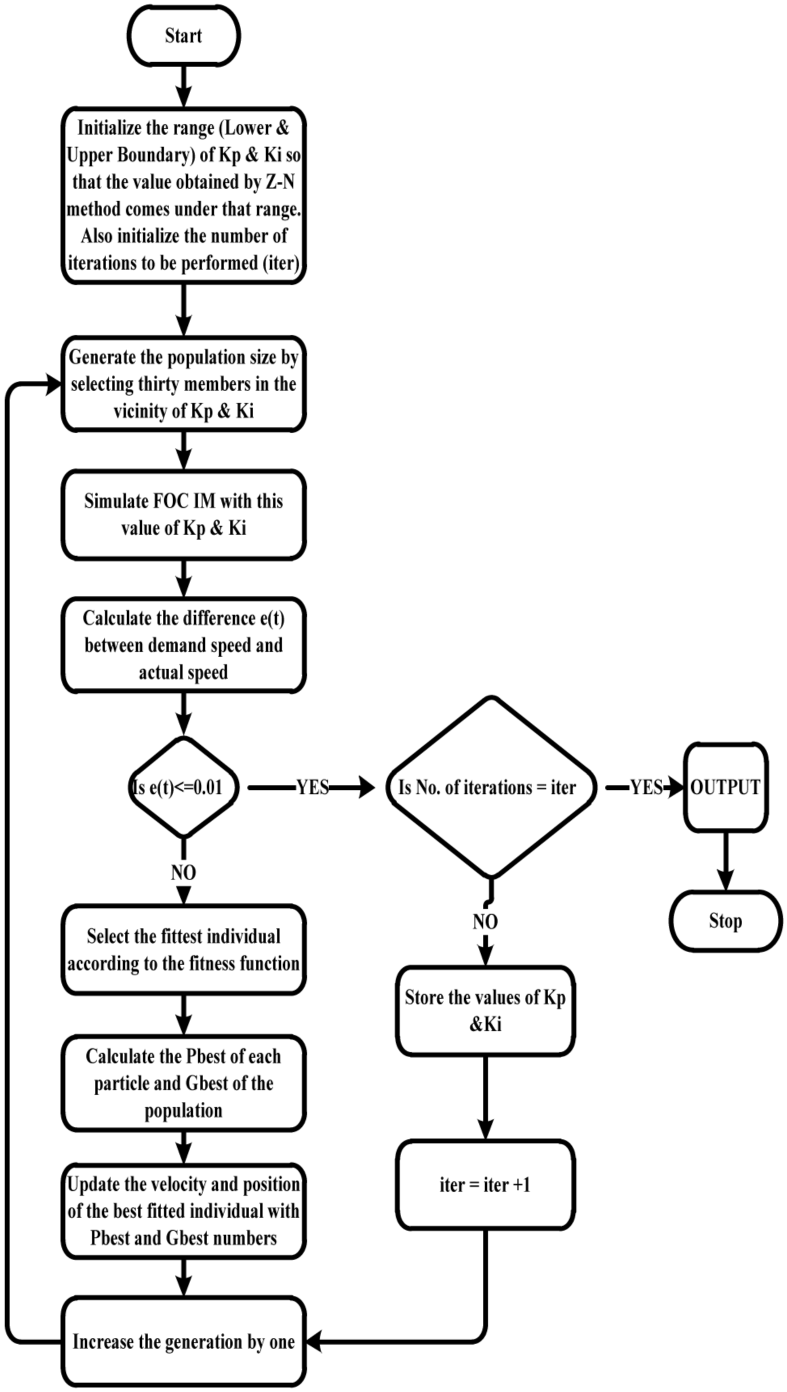

Figure 7: Flow Chart for Optimization of PI Controller parameters using PSO

6. SIMULATION RESULTS

Outputs of FOC IM Drive Before & After Optimization:

It is clear from Fig. 8 and Fig. 9 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 below.

i. When Speed is Variable and Load Torque (T_L) = 2 Nm :-

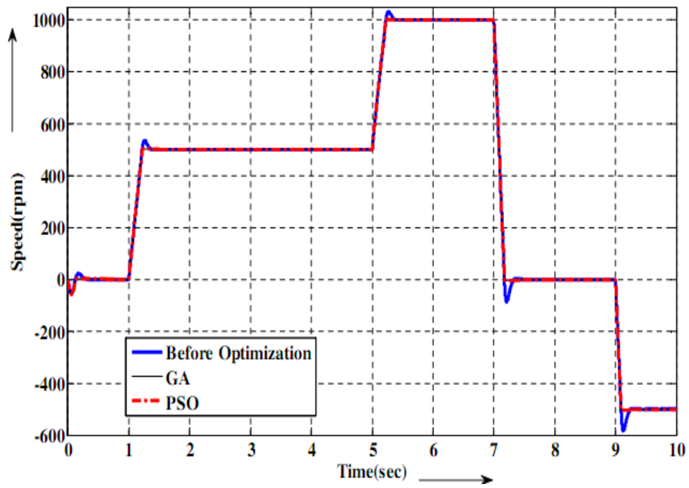

Figure 8: Speed Before & After Optimization for a Variable Speed & Constant Torque FOC IM Drive

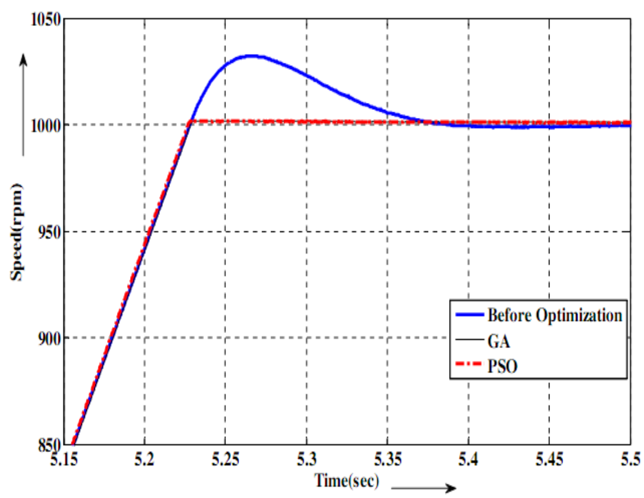

Figure 9: Speed Before & After Optimization for a Variable Speed & Constant Torque FOC IM Drive after Scale Adjustment

From Fig. 8 we see that, when Speed is varying while Load Torque remaining constant, whenever the speed changes overshoot occurs. To overcome this overshoot we apply Optimization Technique using GA and PSO.

Fig. 9 shows the clear view of one of the overshoot taking place during the operation of the Drive. In this figure the overshoot occurs between 5.25 sec. – 5.30 sec. and the optimized output shows that the overshoot is minimized and compensated to a much greater extent. Table 4 gives the percentage of overshoot compensated with the help of optimization.

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

From the below table (Table 3), 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 3:
Percentage Overshoot Calculation for Variable Speed & Constant Torque
Reference Speed taken for overshoot calculation = 1000 rpm

Variable Speed & Constant Torque	*Actual Motor Speed (rpm)*	*%age Overshoot*
Without Optimization	1032.4239	3.24239%
GA	1001.8715	0.18715%
PSO	1001.7793	0.17793%

From Table 3 we conclude that the operation of PSO is much more accurate as compared to GA. All the other plots and tables also clearly indicate that PSO is much more effective than GA in any of the cases discussed.

ii. When Speed = 1000 rpm and Load Torque (T_L) is Variable:

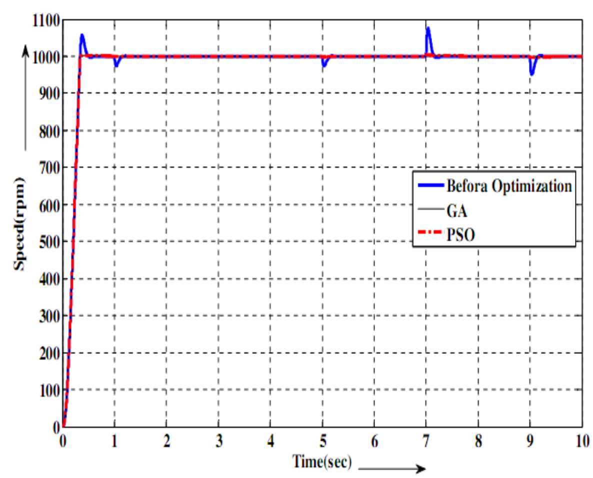

Figure 10: Speed Before & After Optimization for a Constant Speed & Variable Torque FOC IM Drive

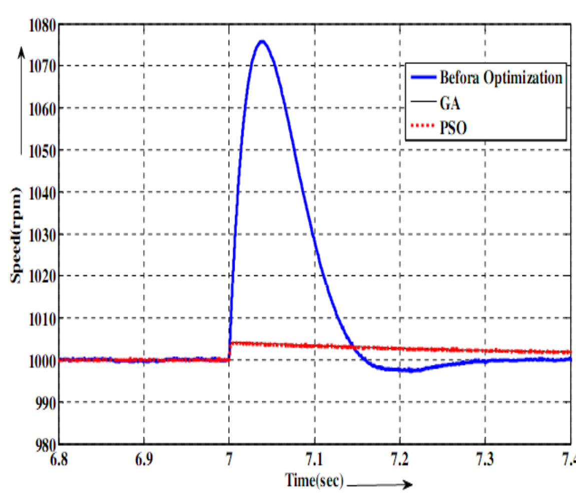

Figure 11: Speed Before & After Optimization for a Constant Speed & Variable Torque FOC IM Drive after Scale Adjustment

Table 4
Percentage Overshoot Calculation for Constant Speed & Variable Torque
Reference Speed taken for overshoot calculation = 1000 rpm

Constant Speed & Variable Torque	*Actual Motor Speed (rpm)*	*%age Overshoot*
Without Optimization	1075.7568	7.57568%
GA	1004.3105	0.43105%
PSO	1004.0839	0.40839%

From the above Fig. 10 it is clearly seen that when the Torque of an Induction Machine changes, the speed fluctuates which causes a high damage to the machine if a significant change takes place sometime. From the observation it is clear that, there are many overshoots taking place in the speed curve but maximum Overshoot occur at around 7.05 sec.

Fig. 11 shows gives a clear view of the overshoot before Optimization & compensation of overshoot after Optimization with a small adjustment in scales of Time and Speed.

The above table (Table 4) 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 & 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 the conventional method of finding the gains.

Although all of the Optimization Technique till studied is very fruitful for the FOC of IM Drive. 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 either in positive speed or in negative speed as seen from Fig. 10 to Fig. 13 but with the help of the Optimization Technique, every overshoot has been minimized or swiped-off to a much larger extent as seen in the above figures.

6. CONCLUSION

Speed control of IM drive using In-Direct Vector Control is simulated in this paper. A new approach has been presented for tuning the parameters of the PI controller using Evolutionary Algorithms. The importance of EA for optimization of PI controller parameters are discussed and the problem of overshoot and undershoot taking place during changes in motor operating condition has been minimized as seen from the results. It is also observed that the performance of the speed controller whose parameter values are tuned by PSO is comparable with that of the speed controller whose parameter values are tuned by GA. Moreover the PSO algorithm requires lesser number of parameters which are to be initialized as compared with the GA.

APPENDIX-A : MACHINE PARAMETERS USED FOR MODELING & SIMULATION

Rated Power	=	1 HP (1*746 W)
Rated Stator Voltage	=	415 V
Number of Pole Pairs, P	=	2
Stator Resistance	=	6.3150 Ω
Rotor Resistance	=	7.1750 Ω

Stator Leakage Inductance, Lls	=	0.0278 H
Rotor Leakage Inductance, Llr	=	0.0278 H
Magnetizing Inductance, Lm	=	0.3855 H
Mechanical Inertia Constant, J	=	0.0118 kg.m^2
Friction Constant, b	=	0.0027 N.m.s.
Frequency, f	=	50 Hz.

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