Enhancing Tracking Performance Parameters of Induction Motor Based on PI-PSO Algorithm

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Abstract - This paper proposes high performance Vector Control to improve the dynamic performance of induction motor. Parameter changes and mechanical interruption may affect the system stability. Systems are unable to overcome these types of error; we need to design a smart controller.The main objective of this work is to improve the speed response of IM at different load and speed conditions. Proportional-Integral (PI) controller based on Particle Swarm Optimization (PSO) technique is used to design such controller. External disturbances were applied to the system to verify the effectiveness of the controller.

Index Terms - Induction motor, Particle swarm optimization (PSO), Proportional plus integral (PI) controller, Vector control.

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1. Introduction

Induction motors are recognized as asynchronous motors they have the following advantagesrobust, less costly, less conservation, high efficiency, good self-starting, high torque to-weight ratio and no collector brooms system.Even though they have few disadvantages such as complex, multivariable and nonlinear of mathematical model [1].

Several control techniques are used to control 3-phase induction motor such as Stator voltage control method, Frequency control method, Rotor resistance control and Vector control method. The vector control method will be discussed in this paper.

Vector control has two types direct method and other is indirect method. With direct method, the field angle is obtained directly by Hall sensors whereas with indirect method, field angle is obtained by rotor position [2].

PI controller has been widely used in industry due to simple implementation, low cost and the ability to apply in a wide range of applications;also, it improves the dynamic response of the system as well as reduces or eliminates the steady state error. Nowadays induction motor drives use heuristic search optimization techniques to tune the [3].

In this paper, Proportional-Integral (PI) controller based on Particle Swarm Optimization (PSO) technique is usedfor the speed control of a direct field oriented control induction motor drive. The results are obtained, compared and proved using MATLAB / SIMULINK.

2. Mathematical model of 3-phase induction motor

The mathematical model of 3-phase induction motor can be described by differential equation with time varying mutual inductances.Axis transformation is applied to transfer the three phase parameters into two–axis frame called (dq-axis stationary frame or park transformation). Park transformation is applied to refer the stator variables to a synchronously rotating reference frame fixed in the rotor.

The per-phase equivalent circuit diagrams of an IM in two-axis synchronously rotating reference frame is shown in Fig. 1 and theequations for the stator and rotor can be written as [4]:

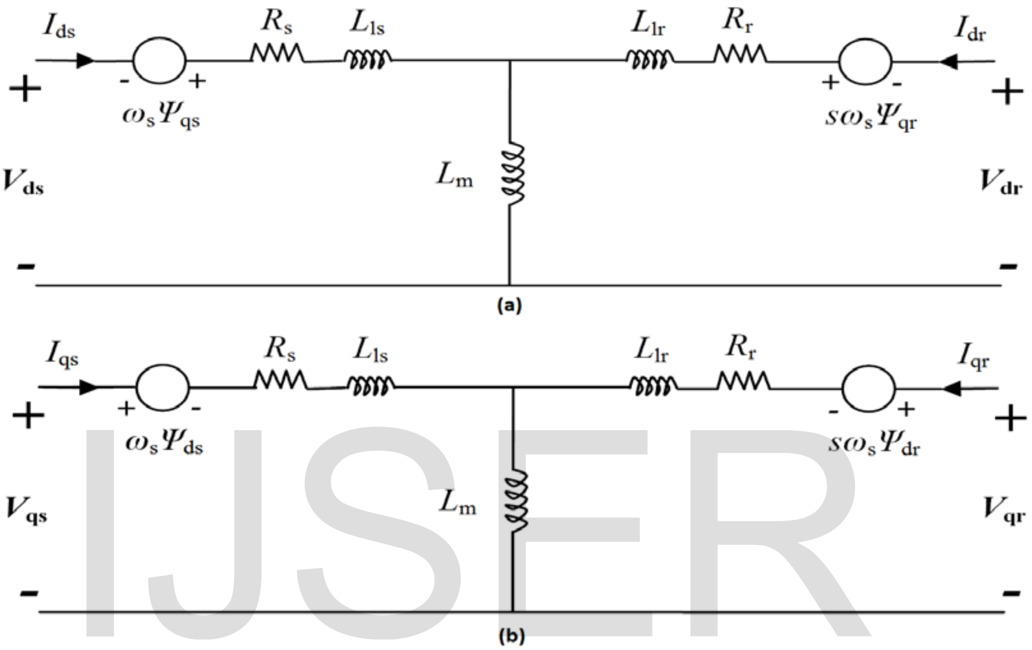

Figure 1: The 3-phase equivalent circuit diagrams of an IM in d - q frame.

- Stator equation:

$$V_{qs}^{e} = R_s * i_{qs}^{e} + \frac{d\varphi_{qs}}{dt} + \omega_e * \varphi_{ds} \qquad (1)$$

$$V_{ds}^{e} = R_s * i_{ds}^{e} + \frac{d\varphi_{ds}}{dt} - \omega_e * \varphi_{qs} \qquad (2)$$

- Rotor equation:

$$V_{qr}^{e} = R_r * i_{qr}^{e} + \frac{d\varphi_{qr}}{dt} + (\omega_e - \omega_r) * \varphi_{dr} \qquad (3)$$

$$V_{dr}^{e} = R_r * i_{dr}^{e} + \frac{d\varphi_{dr}}{dt} - (\omega_e - \omega_r) * \varphi_{qr} \qquad (4)$$

Where:

e: referred to the synchronously rotating reference frame quantities.
V_{qs}^{e} , V_{ds}^{e}: quadrature and direct axes stator voltages.
V_{qr}^{e} , V_{dr}^{e}: quadrature and direct axes rotor voltages.
R_s: stator resistance.
i_{qs}^{e} , i_{ds}^{e}: quadrature and direct axes stator currents.
i_{qr}^{e} , i_{dr}^{e}: quadrature and direct axes rotor currents.
φ_{qs} , φ_{ds}: quadrature and direct axes stator flux.
φ_{qr} , φ_{dr}: quadrature and direct axes rotor flux.
ω_e: electrical rotor angular velocity (rad/sec).
ω_r: rotor speed (rad/sec).

The development torque by interaction of air gap flux and rotor current can be found as:

$$T_e = \frac{3}{2} * \frac{P}{2} * \overrightarrow{\varphi_m} * \overrightarrow{I_r} \tag{5}$$

By resolving the variables into $d^e - q^e$ components:

$$T_e = \frac{3}{2} * \frac{P}{2} * (\varphi_{ds} * i_{qs}^{e} - \varphi_{qs} * i_{ds}^{e}) \tag{6}$$

The stator current can be found by:

$$i_{qs}^{e} = \frac{\varphi_{qs} - \varphi_{qm}}{L_s} \tag{7}$$

$$i_{ds}^{e} = \frac{\varphi_{ds} - \varphi_{dm}}{L_s} \tag{8}$$

$$i_{dr}^{e} = \frac{\varphi_{dr} - \varphi_{dm}}{L_s} \tag{9}$$

$$\varphi_{qm} = \frac{L_{m1}}{L_s} * \varphi_{qs} + \frac{L_{m1}}{L_r} * \varphi_{qr} \tag{10}$$

$$\varphi_{dm} = \frac{L_{m1}}{L_s} * \varphi_{ds} + \frac{L_{m1}}{L_r} * \varphi_{dr} \tag{11}$$

$$L_{m1} = \frac{1}{(\frac{1}{L_m} + \frac{1}{L_s} + \frac{1}{L_r})} \tag{12}$$

Where:

φ_{qm} , φ_{dm} : quadrature and direct mutual flux.
L_s , L_r , L_m : stator, rotor and mutual inductances respectively.

From the previous equations, the dynamic model of an induction motor is simulated as shown in Fig. 2 [5].

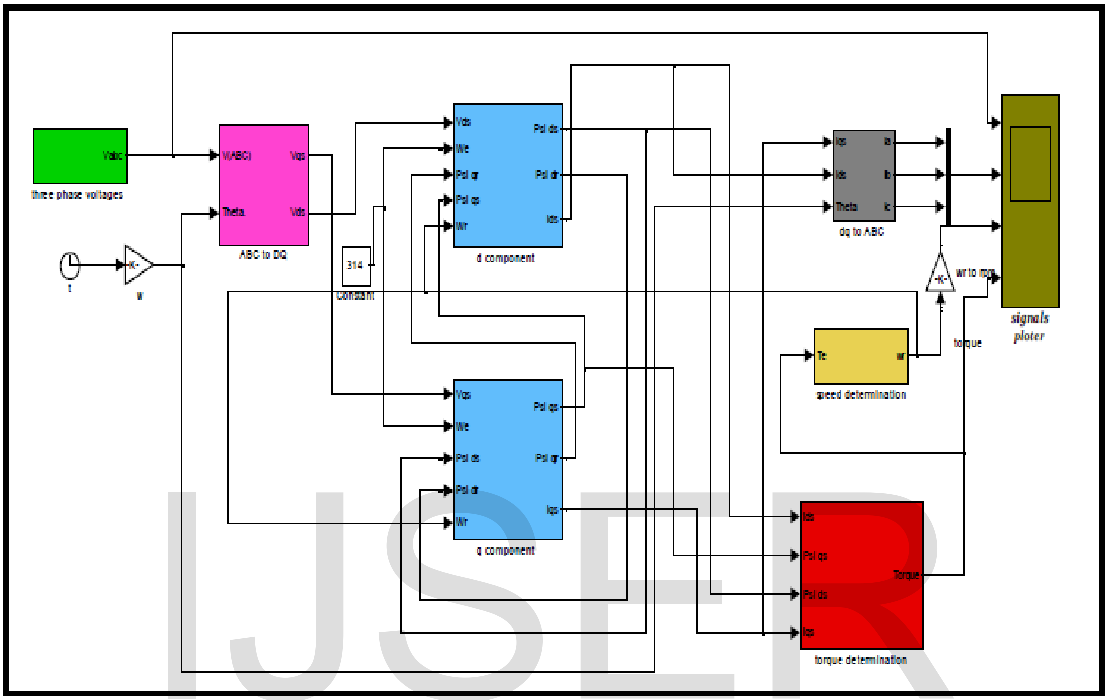

Figure 2: IM dynamic model.

3. Particle Swarm Optimization

PSO is largely developed through simulation of bird flocking in two-dimension space [6].

3.1 Representation of the swarm for problem

If there are n- solutions, the particle position is represented as a vector of length.

$$S_i = (P_{i1}, P_{i2}, \dots \dots . \dots, P_{in}) \; ; \; where \; S_i, is \; the \; position \; vector \qquad (13)$$

3.2 Initialization of the Swarm

Each element of the swarm is initialized randomly within the effective operating limits. The particles begin as given in eq. (14) and the velocity of particles begin as given in eq. (15).

$$P_{intial} = P_{min} + rand * (P_{max} - P_{min}) \qquad (14)$$

$$V_{intial} = V_{min} + rand * (V_{max} - V_{min}) \tag{15}$$

Where, rand = a positiverandom number ranging from[0 to 1].

$$V_{max} = (P_{max} - P_{min}) * 0.5 \tag{16}$$

$$V_{min} = - V_{max} \tag{17}$$

3.3 Moving the particles

With the help of new speeds, the particles in the swarm shift to new positions. The position and the speed of the K^{th} dimension of the i^{th} particle will be as follows

$$V^{K+1} = \omega * V^{K} + C_1 * Rand_1 * (P_{best} - S^{K}) + C_2 * Rand_2 * (G_{best} - S^{K}) \tag{18}$$

$$S^{K+1} = S^{K} + V^{K+1} \tag{19}$$

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} * iter \tag{20}$$

Where, P_{best} is the last bestposition, which leads to the best fitness value for the i^{th} particle; and G_{best} is the best position found by the whole population.C_1 and C_2 are the acceleration constants expressing the weighting of stochastic acceleration terms that pull each particle toP_{best} andG_{best} positions, respectively. $Rand_1$ and $Rand_2$ are two positive random numbers in the range [0, 1].

4. Suggested Controller

PSO is used for the tuning of PI controller parameters as shown in Fig.3, for optimal regulation of rotor speed at the desire speed [7]:

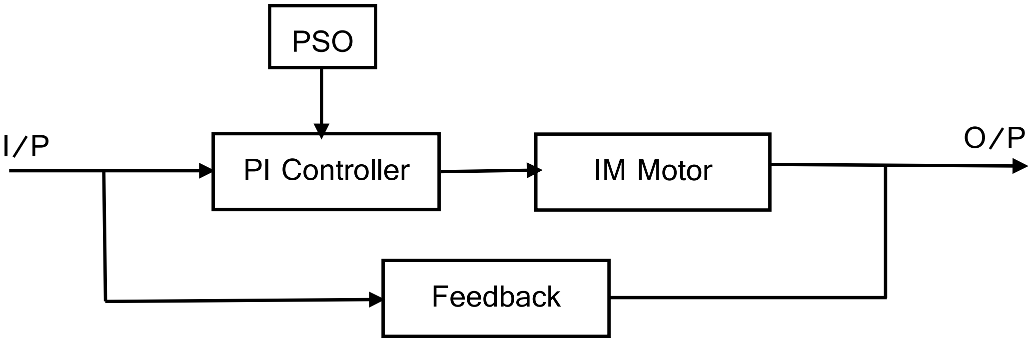

Figure 3: Block diagram of induction motor speed control using PSO.

$$T_{e(n)} = T_{e(n-1)} + k_P * \Delta\omega_{re(n)} + k_i * \Delta\omega_{re(n)} \quad (21)$$

Input can be defining as

$$u(t) = k_P * e(t) + k_i * \int e(t)\, dt \quad (22)$$

That k_P and k_i are proportional coefficient and integral coefficient in PI controller.

In general, the speed error is fed as input to the controllers. These speed controllers process the speed error and give torque value as an input. Then the torque value is given to the limiter, which gives thereference torque final value.

The speed error and variation in speed error at n^{th} instant of time are as follow:

$$\omega_{re(n)} = \omega_{r(n)} - \omega_{a(n)} \quad (23)$$

$$\Delta\omega_{re(n)} = \omega_{r(n)} - \omega_{a(n-1)} \quad (24)$$

In the design procedures of PI controller, the most prevalent performance criteria are integrated of squared error (ISE),integrated absolute error (IAE),integrated of time weight absolute error (ITAE), and the integrated of time weight square error (ITSE) that can be estimated in the frequency domain analytically. In this paper integrated of squared error (ISE) will be used.

5. Vector Control Method

Two types of vector control methods(direct and indirect field oriented control). At direct vector control method, the rotor flux is evaluatedby either using flux sensor in the air gap or evaluating it by sensing stator voltages. At indirect vector control, the rotor flux is evaluatedby field oriented control equations, whichrequireimmediate speed information.At low speed application, the direct vector control is very hard to implement practically.Due to its accuracy over a whole speed range,the indirect field oriented control is more suitablethan direct vector control. Sudden change in load conditions or environmental factors would makeoscillation of the torque, overshoot, long settling time, oscillation of motor speed, andsodeteriorate the drive performance. In addition, the accurate tuning of PI controllers demands the accurate mathematical model of system [7].

6. MATLAB Simulation

6.1 MATLAB Simulation of Vector Control Induction Motor based on PI controller

The simulation of VCIM using PI controller was done as diagram shown in the below Fig. 4. The IM was simulated at four various conditions.

First at reference speed of 120 and no load. Second at speed varied from 120 to 160 after a time $t_1(s)$ and no load. Third by varying the load after a time $t_2(s)$ and keeping the speed at 120.

The final condition being variation of load at a time $t_2(s)$ and variation of speed from 120 to 160 after a time$t_1(s)$. The feedback is given to summer, output of summer error given to PI controller, which change the in output for better result.

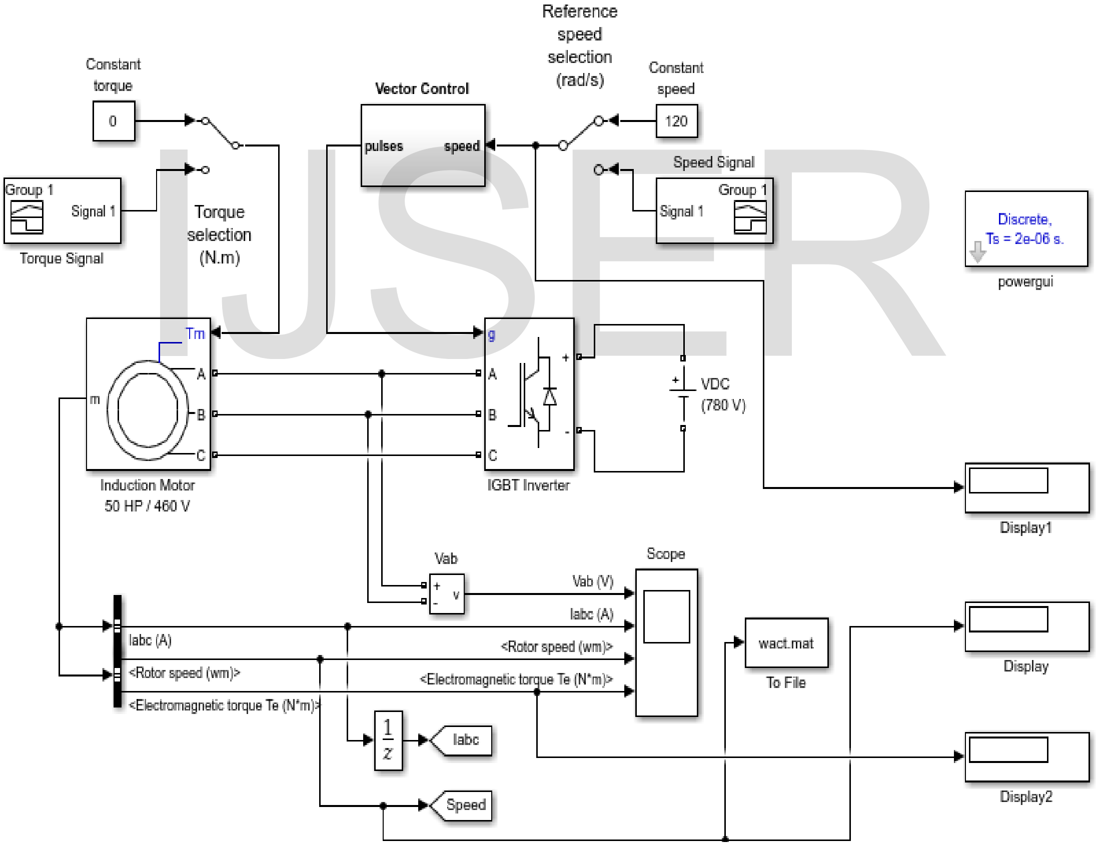

Figure 4: Vector control simulation model of induction motor.

The motor drives a mechanical load distinguished by friction coefficient B, load torque TL, and Inertia J. The motor torque is controlled by the quadrature-axis current reference. Block DQ-ABC is utilized to convert $i_d^*$and i_q^*into current references i_a^*,i_b^* andi_c^* for the current regulator.

7. Results and Analysis

7.1 The Proposed PSO Algorithm

The proposed PSO algorithm are tested for 30 numbers of particles and run on MATLAB to obtain the optimum solution of the proposed PI controller. The simulation results have been obtained with 50 runs.

Table 1: PSO parameters.

No. of particles	**30**
	0.4
	0.9
No. of iterations	**50**

7.2 Performance of Vector Control IM Using PI-PSO Control

The performance characteristic of a 50 HP, 460 V, 60 Hz IM, operating at various conditions with a PI-PSO speed controller was done and the following where the results:

Case 1: At no load and reference speed of 120 rad/s

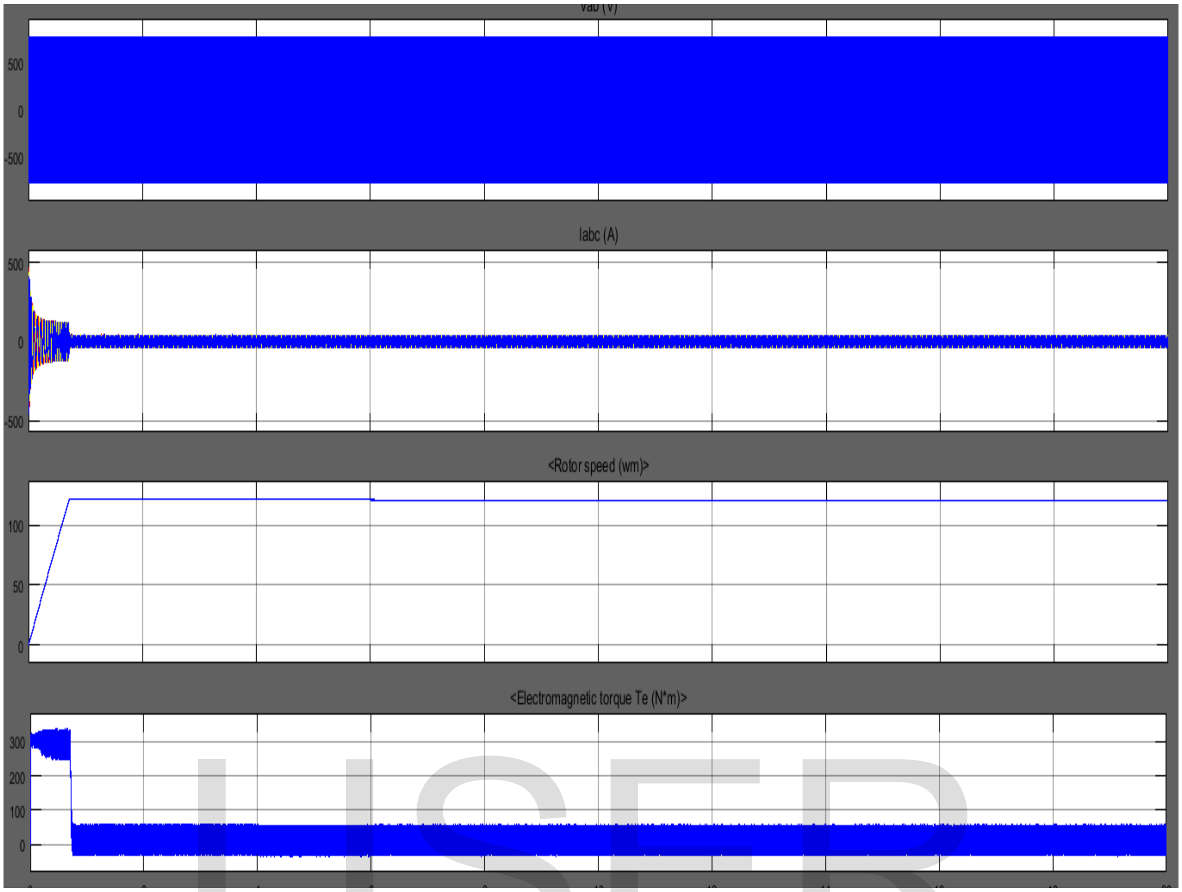

Figure 5: Vector controlled IM characteristic with tuning of PI parameters (k_P=161.7, k_i=17.6).

Voltage, Current, Speed and Electromagnetic Torque curves respectively, through the Fig. 5, it turns out that the Speed at first reaches 120 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 0.741s.

Case 2: Load applied after a time t(s) and speed varying from 120 rad/s to 160 rad/s

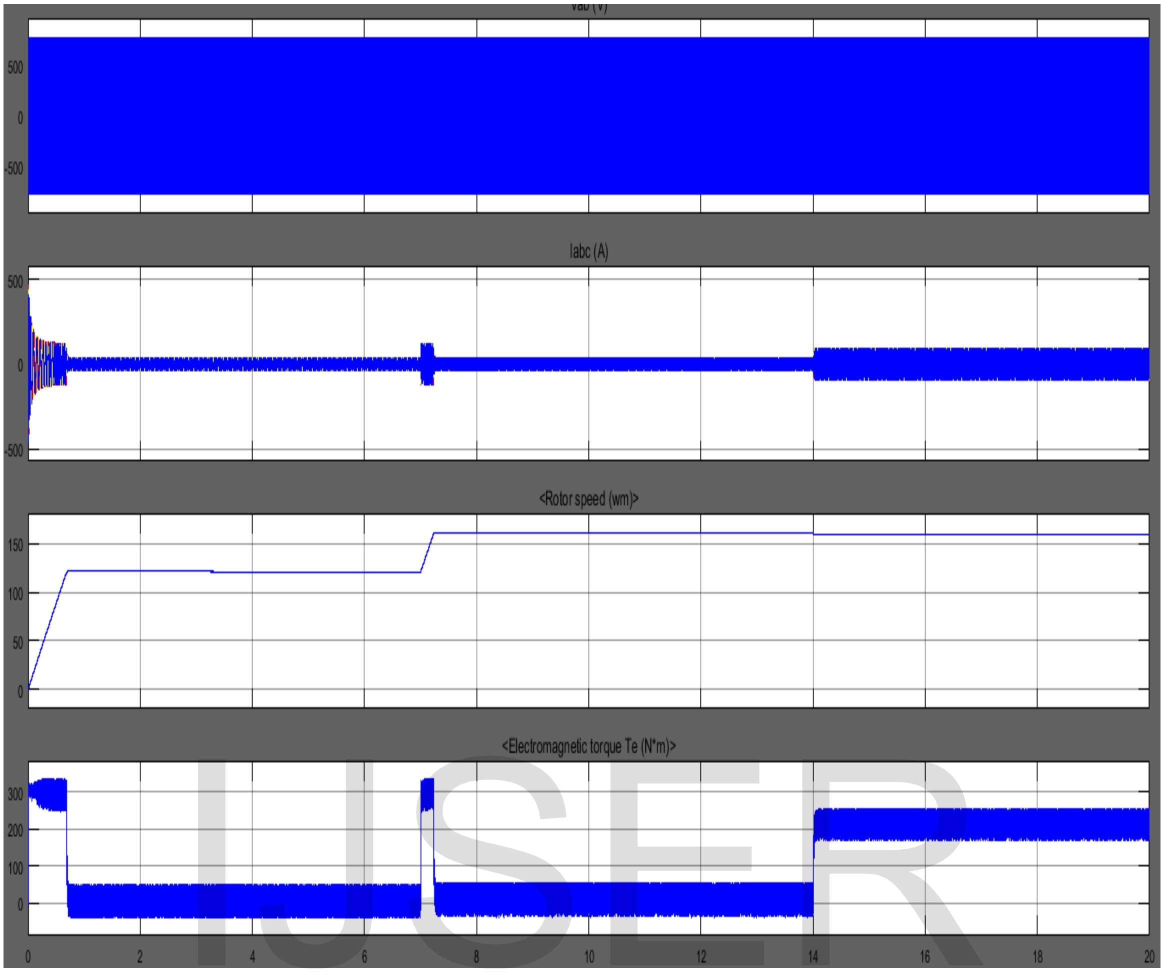

Figure 6: Vector controlled IM characteristic with tuning of PI parameters (k_P=161.7, k_i=17.6).

Fig. 6 shows Voltage, Current, Speed and Electromagnetic Torque curves respectively, through the Fig., it turns out that the Speed at first reaches 120 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 0.741s. Speed is then varied to 160 rad/s after a time t = 7s. After variation the speed reaches 160 rad/s and then reaches the reference speed 160 rad/s. After changing the reference speed to 160 rad/s the steady state speed is obtained at t = 0.303s then the load is applied after a time t = 14s.

Speed after variation dips to 159.4 rad/s and then settles to reference speed 160 rad/s. After applying the load, the steady state speed is obtained at t = 0.066s.

We obtained Optimum solution of k_P = 161.7295 and k_i = 17.6387 using PSO.

7.3 Performance of Vector Control IM Using PI Control

The performance characteristic of a 50 HP, 460 V, 60 Hz IM, operating at various conditions with a PI speed controller was done and the following where the results [8]:

Case 1: At no load and reference speed of 120 rad/s

Voltage, Current, Speed and Electromagnetic Torque curves respectively, through the Fig. 7, it turns out that the Speed at first reaches 140 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 2.2s.

Figure 7: Vector controlled IM characteristic using PI control.

Case 2: Load applied after a time t(s) and speed varying from 120 rad/s to 160 rad/s

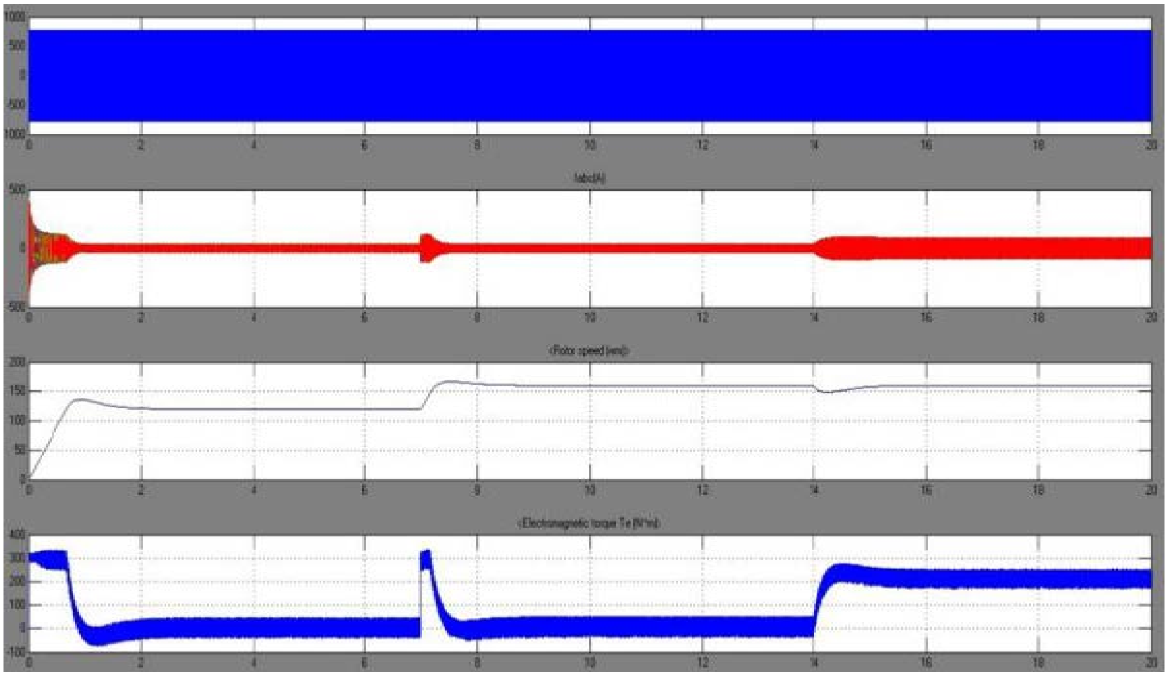

Figure 8: Vector controlled IM characteristic using PI control.

Voltage, Current, Speed and Electromagnetic Torque curves respectively in Fig. 8, it turns out that the Speed at first reaches 140 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 2.1s. Speed is then varied to 160 rad/s after a time t = 7s. After variation the speed reaches 170 rad/s and then reaches the reference speed 160 rad/s. After changing the reference speed to 160 rad/s the steady state speed is obtained at t = 1.4s then the load is applied after a time t = 14s. Speed after variation dips to 150 rad/s and then settles to reference speed 160 rad/s. After applying the load, the steady state speed is obtained at t = 1.1s.

7.4 Performance of Vector Control IM Using FUZZY Control

The performance characteristic of a 50 HP, 460 V, 60 Hz IM, operating at various conditions with a PI-PSO speed controller was done and the following where the results [8]:

Case 1: At no load and reference speed of 120 rad/s

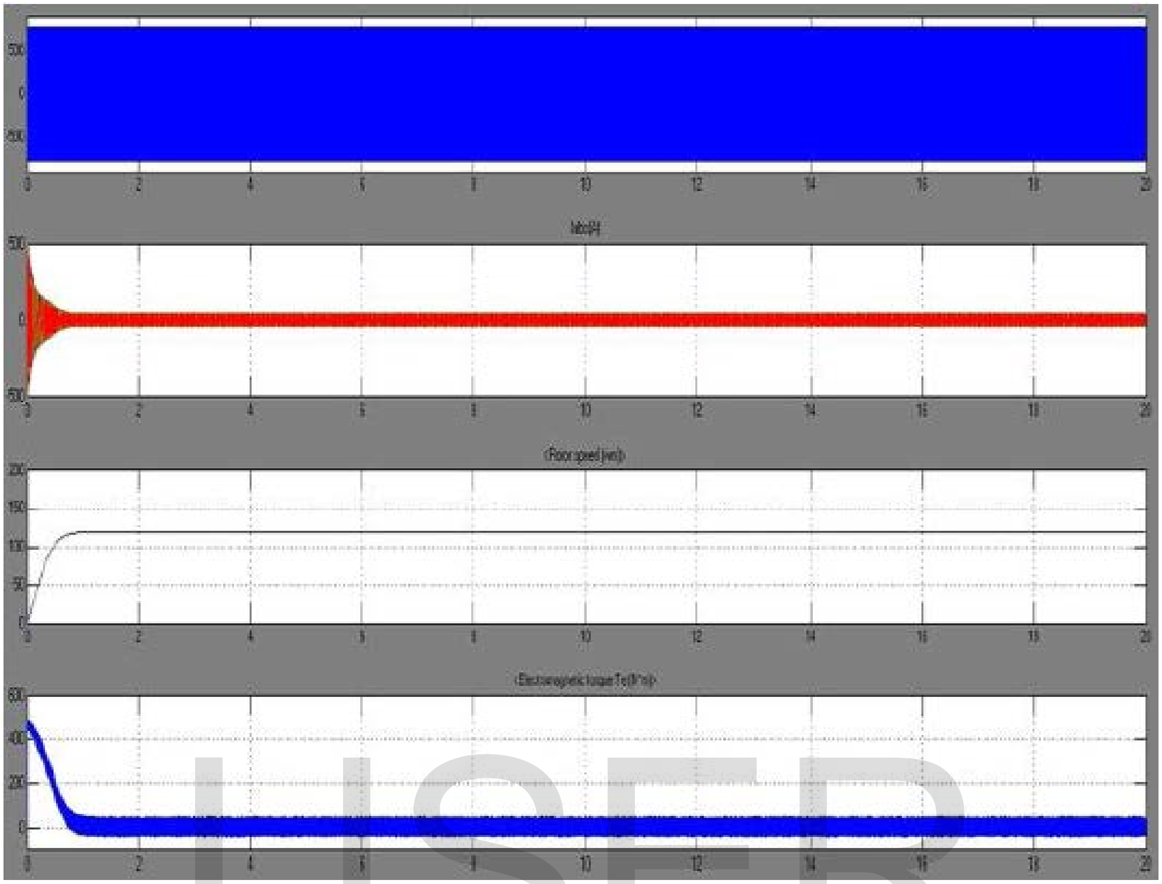

Figure 9: Vector controlled IM characteristic with tuning of PI parameters using Fuzzy control.

Voltage, Current, Speed and Electromagnetic Torque curves respectively,it turns out that the Speed at first reaches 120 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 0.8s that shown in Fig. 9.

Case 2: Load applied after a time t(s) and speed varying from 120 rad/s to 160 rad/s

Voltage, Current, Speed and Electromagnetic Torque curves respectively, through the Fig. 10, it turns out that the Speed at first reaches 120 rad/sec and then settles down at reference speed 120 rad/sec. The speed attains steady state at time t = 0.8s. Speed is then varied to 160 rad/s after a time t = 7s. After variation the speed reaches 160 rad/s and then reaches the reference speed 160 rad/s. After changing the reference speed to 160 rad/s the steady state speed is obtained at t = 0.6s then the load is applied after a time t = 14s. Speed after variation dips to 140 rad/s and then settles to reference speed 160 rad/s. After applying the load, the steady state speed is obtained at t = 0.8s.

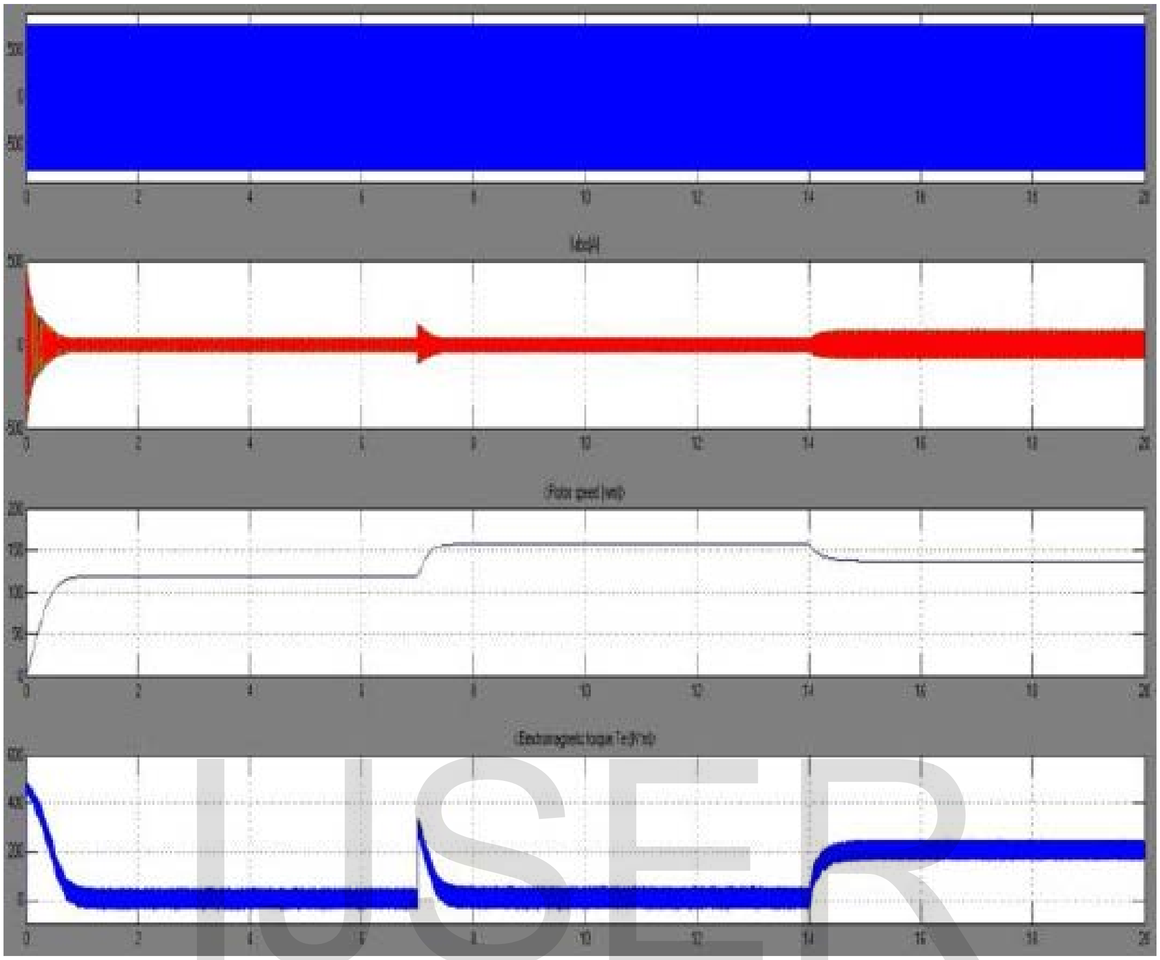

Figure 10: Vector controlled IM characteristic with tuning of PI parameters using Fuzzy control.

7.5 A Comparative Study between Classic PI, FUZZY and PI-PSO parameters

From results, it turns out that PI-PSO Controller is more accurate and better than Classical PI Controller and FUZZY Controller especially when there is load disturbance.

Table 2: The Comparative Study.

	Category		PI Control [3]	Fuzzy Control [3]	The suggested PSO-PI Control
Normal operations	Ref Speed 120 R/S		140 Then 120 R/S	120 R/S	120 R/S
	Settling Time		2.2 S	0.8 S	0.741 S
	Speed Oscillations		16.667 %	0 %	0 %
	Torque Ripples		330 N.m	330 N.m	330 N.m
	Max. Current		460 A	460 A	460 A
Disturbance effect	Speed Oscillations	Ref Speed 160 R/S	170 Then 160 R/S (6.24 %)	160 R/S (0 %)	160 R/S (0 %)
		Applying Load at T= 14 S	150 Then 160 R/S (-6.25 %)	140 Then 160 R/S (-12.5 %)	159.4 Then 160 R/S (-0.375 %)
	Recovery Time	Ref Speed 160 R/S	1.4 S	0.6 S	0.303 S
		Applying Load at T=	1.1 S	0.8 S	0.066 S

		14 S			
	Torque Ripples	**Ref Speed 160 R/S**	**330 N.m**	**330 N.m**	**330 N.m**
		Applying Load at T= 14 S	**254 N.m**	**254 N.m**	**254 N.m**
	Max. Current	**Ref Speed 160 R/S**	**110 A**	**110 A**	**110 A**
		Applying Load at T= 14 S	**95 A**	**95 A**	**95 A**

8. Conclusion

Proportional-Integral (PI) controller based on Particle Swarm Optimization (PSO) technique simulation results show that at different speed references and different loads, speed can follow its reference values without any overshoot at minimum time. PSO is a Powerful algorithm to approximate the PI controller coefficient.The proposed model was successfully modeled and designed using MATLAB/Simulink and its was simulated at various conditions. The two controllers, namely PI, FUZZY [8] were compared with our proposed technique for speed control of vector control of induction motor drive. At different conditions, the load performance of PI-PSO controller was better than that of PI controller and FUZZY controller. Based on simulation results verification, the following conclusions are made:

- The PI-PSO controller is more robust than the PI and FUZZY which has been appeared clearly when load disturbances occurred.
- The PI-PSO controller performance when certain motor parameters (i.e. current and motor torque) were increased by a factor was still quite good and far better than the PI and FUZZY performances when the same parameters.

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