Performance Analysis of Speed Control of Brushless DC motor using Partial Swarm Optimization Technique

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***Abstract* - This paper presents a Particle Swarm Optimization (PSO) technique for determining the optimal parameters of (PI) controller for speed control of a brushless DC motor (BLDC) where the (BLDC) motor is modeled in Simulink in MATLAB. The proposed technique was more efficient in improving the step response characteristics as well as reducing the steady-state error, rise time, settling time and maximum overshoot.**

***Index Terms*—Brushless DC motor; PID controller; Matlab; Particle Swarm Optimization.**

I. INTRODUCTION

There are mainly two types of DC motor used in the industry. The first one is the conventional DC motor where the flux is produced by the current through the field coil of the stationary pole structure. The second type is the brushless DC motor (BLDC motor) where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles [1]. There are many modern control methodologies such as nonlinear control, optimal control, variable structure control and adaptive control have been widely proposed for speed control of a brushless permanent magnet DC motor [2]. However, these approaches are either complex in theoretical basics or difficult to implement [3]. PI controller with its three terms functionality covering treatment for transient and steady-state response offers the simplest and gets most efficient solution to many real world control problems [4]. In spite of the simple structure, optimally tuning gains of PI controllers are quite difficult. Recently, the computational intelligence has proposed bacterial foraging (BF) technique and Particle Swarm Optimization (PSO) technique for the same purpose.

II. BRUSHLESS DC MOTOR (BLDC)

The synchronous electrical motor belongs to the family of electric rotating machines. Other members of the family are the direct current (dc) motor or generator, the induction motor or generator, and a number of derivatives of all these three. What is common to all the members of this family is that the basic physical process involved in their operation is the conversion of electromagnetic energy to mechanical energy, and vice versa. Therefore, to comprehend the physical principles governing the operation of electric rotating machines, one has to understand some rudiments of electrical and mechanical engineering.

No-Load Operation

When the ideal machine is connected to an infinite bus, a three-phase balanced voltage (V1) is applied to the stator winding (within the context of this work, three-phase systems and machines are assumed). As described above, it can be shown that a three-phase balanced voltage applied to a three-phase winding evenly distributed around the core of an armature will produce a rotating(revolving) magneto-motive force (mmf) of constant magnitude (Fs). This mmf, acting upon the reluctance encountered along its path, results in the magnetic flux (Øs) previously introduced. The speed at which this field revolves around the center of the machine is related to the supply frequency and the number of poles, by the following expression:

$$N_s = \frac{120f}{p}$$

Where
f = Electrical frequency in Hz
p = Number of poles of the machine
N_s = Speed of the revolving field in revolutions per minute (rpm)

If a breaking torque is applied to the shaft, the rotor starts falling behind the revolving-armature-induced magnetomotive force (mmf) (Fs). In order to maintain the required magnetizing mmf (Fr) the armature current changes. If the machine is in the underexcited mode, the condition motor in Figure 1a represents the new phasor diagram.
On the other hand, if the machine is overexcited, the new phasor diagram is represented by motor in Figure 1. The active power consumed from the network under these conditions is given by

$$\text{Active power} = V_1 \times I_1 \times \cos \emptyset_1 \text{ (per phase)}$$

If the breaking torque is increased, a limit is reached in which the rotor cannot keep up with the revolving field. The machine then stalls. This is known as “falling out of step,” “pulling out of step,” or “slipping poles.” The maximum torque limit is reached when the angle & equals π/2 electrical. The convention is to define & as negative for motor operation and positive for generator operation. The torque is also a function of the magnitude Ør and Øf. When overexcited, the value of Øf is larger than in the underexcited condition. Therefore synchronous motors are capable of greater mechanical output when overexcited. Likewise, underexcited operation is more prone to result in an “out-of-step” situation

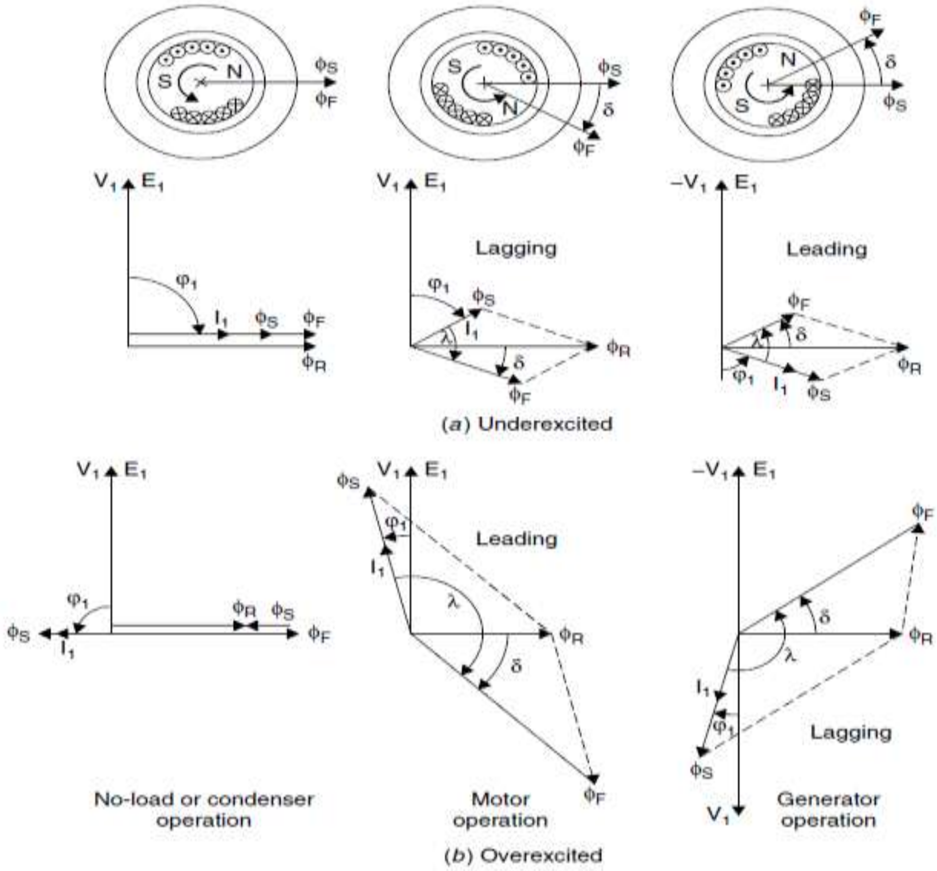


Fig. 1 Phasor diagrams for a synchronous cylindrical-rotor ideal machine

Modern day industry having many advantages compared to the other motors, but it has a limited range of speed normally this drawback can be removed as well as the advantages being maintained as it is and added upon by the use of a BLDC motor system. Some of the notable advantages of a BLDC motor are as given below:

- It has long operation life
- It has higher speed range as well as efficiency
- The speed v/s torque characteristics are superior
- The operation is noiseless to some extent
- Compared with other motors the torque-weight ratio is better

Conventional DC motors have many attractive properties such as high efficiency and linear torque-speed characteristics. The control of DC motors is also simple and does not require complex hardware. However the main drawback of the DC motor is the need of periodic maintenance. The brushes of the mechanical commutator have other undesirable effects such as sparks, acoustic noise and carbon particles coming from the brushes.

Brushless DC BLDC) motors can in many cases replace conventional dc motors. Despite the name, BLDC motors are actually a type of permanent magnet synchronous motors. They are driven by dc voltage but the current commutation is done by solid state switches. The commutation instants are determined by the rotor position and the position of the rotor is detected either by position sensors or by Sensorless techniques.

BLDC motors have many advantages over conventional DC motors like:

- Long operating life
- High dynamic response
- High efficiency
- Better speed vs. torque characteristics
- Noiseless operation
- Higher speed range
- Higher torque-weight ratio

III. .TUNING OF PI CONTROLLER

PI controller has been used widely for processes and motion control system in industry. The transfer function of PI controller is shown in Fig. 5.

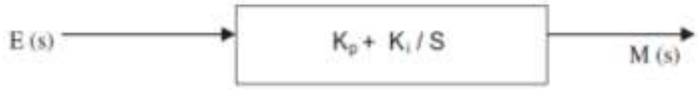


Fig 2. Transfer function of PI controller.

The control system performs poorly in characteristics and even it becomes unstable, if improper values of the controller tuning constants and used. So it becomes necessary to tune the controller parameters to achieve good control performance with the proper choice of tuning constants [6].

where: E(s) is error input signal,M(s) is manipulated output signal. Kp is proportional gain and Ki is integral gain. These parameters Kp and Ki are chosen to meet prescribed performance criteria, classically specified in terms of rise and settling times, overshoot, and steady-state error. In this paper PSO and BF techniques used to find the optimal values of parameters Kp, and Ki of (PI) controller for BLDC motor speed control system. Fig. 3 shows the block diagram of optimal PI control for the BLDC Motor.

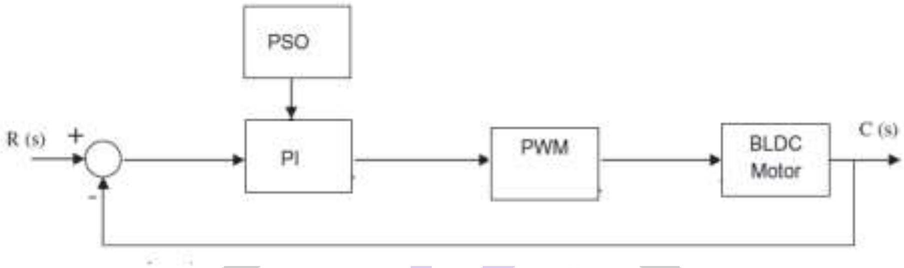


Fig 3. The optimal PI control.

IV. COMPUTATIONAL OR OPTIMIZATION TECHNIQUES

Computational or Optimization Techniques These are techniques which are usually used for data modeling and optimization of a cost function, and have been used in PI tuning. Few examples are neural networks (computational models to simulate complex systems), genetic algorithm and differential evolution. The optimization techniques require a cost function they try to minimize. There are four types of cost functions used commonly

- Integral Absolute Error

$$IAE = \int_0^{\tau} |e(t)|$$

- Integral Square Error

$$ISE = \int_0^{\tau} |e(t)|^2$$

- Integral Time Absolute Error

$$ITAE = \int_0^{\tau} t|e(t)|$$

- Integral Time Square Error

$$ITSE = \int_0^{\tau} t|e(t)|^2$$

Computational models are used for self tuning or auto tuning of PI controllers. Self tuning of PI controllers essentially sets the PI parameters and also models the process by using some computational model and compares the outputs to see if there are any process variations, in which case the PI parameters are reset to give the desired response. The existent types of adaptive techniques are classified based on the fact that if the process dynamics are varying [3], then the controller should compensate these variations by adapting its parameters. There are two types of process dynamics variations, predictable and unpredictable. The predictable ones are typically caused by nonlinearities and can be handled using a gain schedule, which means that the controller parameters are found for different operating conditions with an auto-tuning procedure that is employed thereafter to build a schedule. Different techniques have been used to replace the gain schedule mentioned above.

V. PARTICLE SWARM OPTIMIZATION (PSO)

Particle swarm optimization (PSO) is an optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995. This is population based optimization technique which was inspired by the social behaviour of fish schooling and bird flocking. The basic algorithm of PSO is[9,11]

Step1- At first the mimimum and maximum value of the three controller parameters are being specified. This is done by selecting the population of individual which includes the searching point, its individual best value (p_{best}) and its global best value (g_{best}).

Step2- After that the fitness value is being calculated for each individual using the evaluation function.

Step3- Comparison of each individual is being done which is known as p_{best}. The best value from p_{best} is denoted as is g_{best}

Step 4- After that the member velocity is being modified for each individual k.

$$v_{j,g}^{(t+1)} = \omega * v_j^{(t)} + c_1^* \, rand() * \left(p_{best_{j,g}} - k_{j,g}^{(t)}\right)$$
$$+ c_2^* \, rand() * \left(g_{best_g} - k_{j,g}^{(t)}\right) \qquad (1)$$

Where $j = 1,2,3 \dots \dots .n$, $g = 1,2,3 \dots \dots .n$
where ω is known value. When g is 1 then it represents the change in velocity of controller parameter k_p . When g is 2, then it indicates the change in parameter k_i. Similarly when g is 3 then it denotes the change in parameter k_d.

Step5- If $v_{j,g}^{(t+1)} > V_g^{max}$,then $v_{j,g}^{(t+1)} = V_g^{max}$
If $v_{j,g}^{(t+1)} > V_g^{min}$, then $v_{j,g}^{(t+1)} = V_g^{min}$

Step6- Modified the member of each individual k.

$$k_{j,g}^{(t+1)} = k_{j,g}^{(t)} + v_{j,g}^{(t+1)},$$
$$k_g^{min} \le k_{j,g}^{(t+1)} \le k_g^{max} \qquad (2)$$

Where k_g^{min} and k_g^{max} represent the minimum and maximum, respectively, of member g of the individual. When g is 1,then k_p parameter indicates lower and upper bound which is indicated by k_p^{min} and k_p^{max} respectively. When g is 2, then k_i controller decides the which are indicated by k_i^{min} and k_i^{max} respectively. When g is 3, then the k_d controller indicates the lower and upper bounds which are being indicated by k_d^{min} and k_d^{max} respectively.

Step 7- If the maximum value is reached through number of iteration then proceed to Step 8. or else proceed to Step 2.

Step 8- The latest individual which is now generated becomes the optimal controller parameter.

The Fig 4 shows that the flowchart of parameter optimizing procedure using PSO.

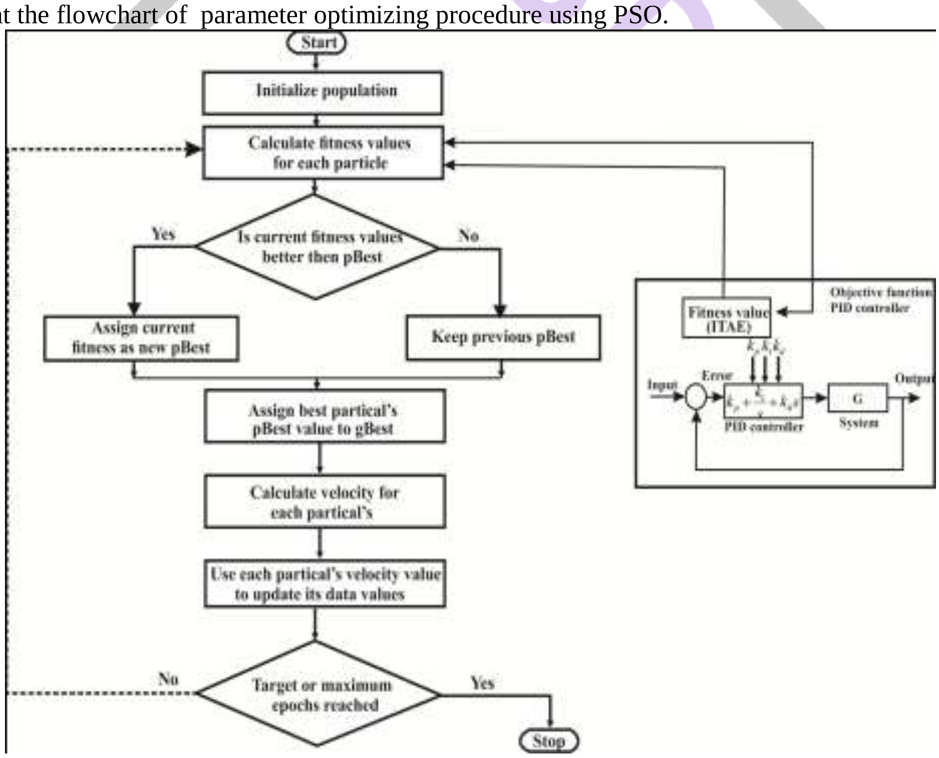


Fig. 4. Flow chart for simulation of PSO based PI controller.

VI. Result and Discussion

CASE I: IAE criteria with Partial Swarm Optimization technique

From the fig 5 graph it is clear that the best fitness value is 7.2798e+6.

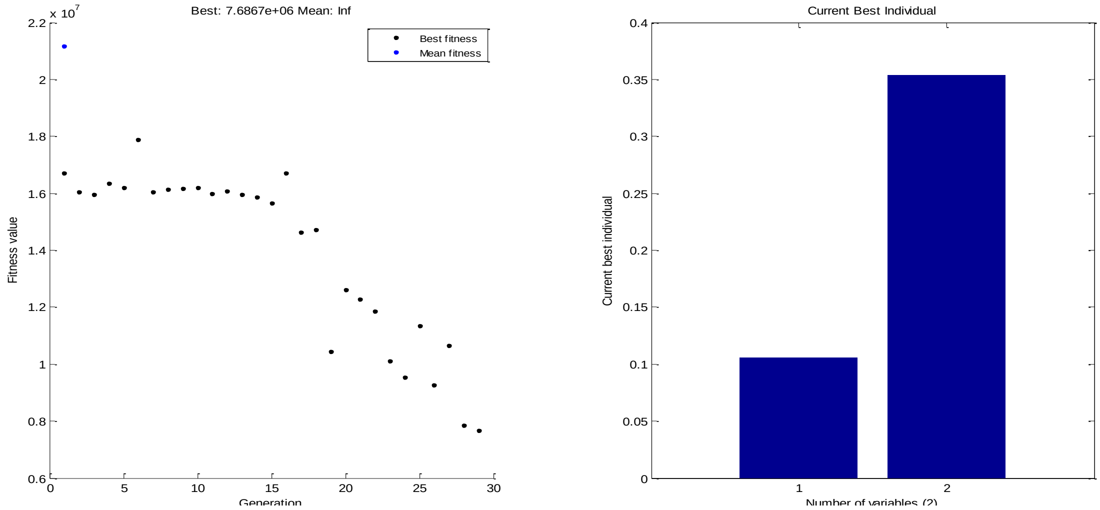


Fig.5. Output of Partial Swarm Optimization technique using IAE

Table1.1 Output parameter of IAE

S.No.	Kp	Ki	Fval
1.	3.5502	18.5479	7.2798e+06

At no load condition the PMSM drive simulink model was evaluated for the wave form of Speed response, motor torque and current by using PI-Controller. The waveforms are presented below. The simulation result for speed reference input of 3000 rpm with controller gains are KP =3.5502, KI = 18.5479with a load torque of 0 Nm, i.e. no load is applied to the motor at 0.1 sec which is shown in fig 6.Under this condition Motor torque is shown in fig.7 at No-load condition.

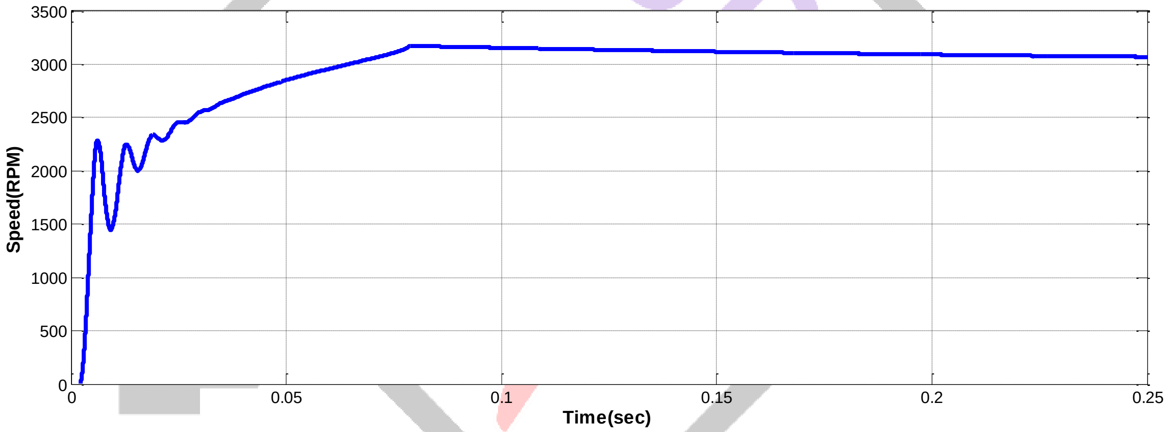


Fig.6 Simulation result of speed response using PI-Controller when no load is applied to the motor at 0.1 sec when TL = 0 Nm, t=0.1 sec.

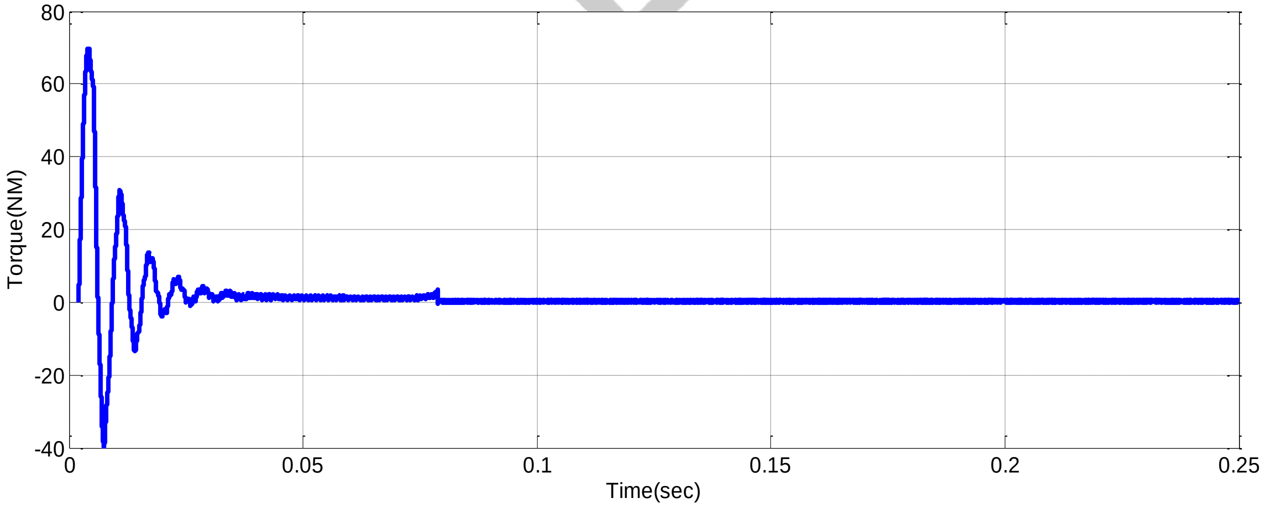
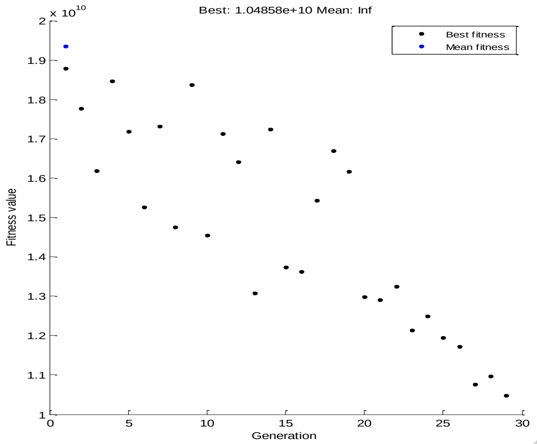


Fig.7.Simulation result of Motor torque using PI-Controller when no-load is applied to motor at 0.1 sec when TL=0Nm, t=0.1 sec.

CASE II: ISE criteria with partial swarm optimization technique

From the fig 8 graph it is clear that the best fitness value is 1.0239e+10.



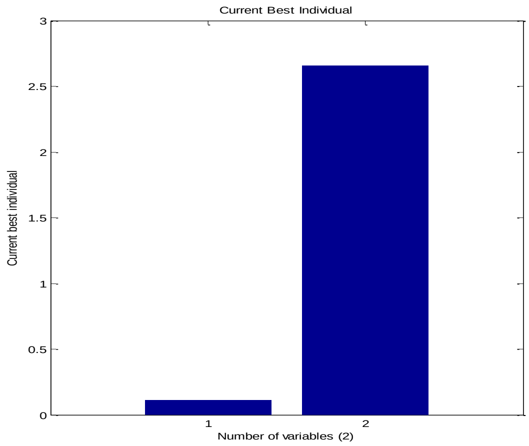


Fig.8. Output of Partial Swarm Optimization technique using ISE

Table1.2 Output parameter of ISE

S.No.	Kp	Ki	Fval
1.	0.7651	4.8748	1.0239e+10

In this condition the PMSM drive simulink model was evaluated for the wave form of Speed response, motor torque and current by using PI-Controller. The waveforms are presented below. The simulation result for speed reference input of 3000 rpm with controller gains are KP =0.7651, KI = 4.8748 with a load torque of 0 Nm, i.e. no load is applied to the motor at 0.1 sec which is shown in fig 9.Under this condition Motor torque is shown in fig.10 at No-load condition.

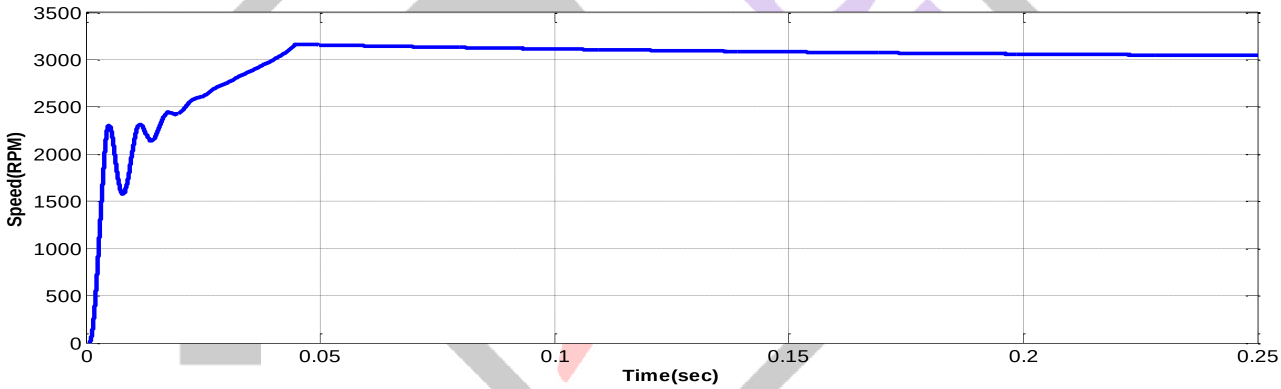


Fig.9 Simulation result of speed response using PI-Controller when no load is applied to the motor at 0.1 sec when TL = 0 Nm, t=0.1 sec.

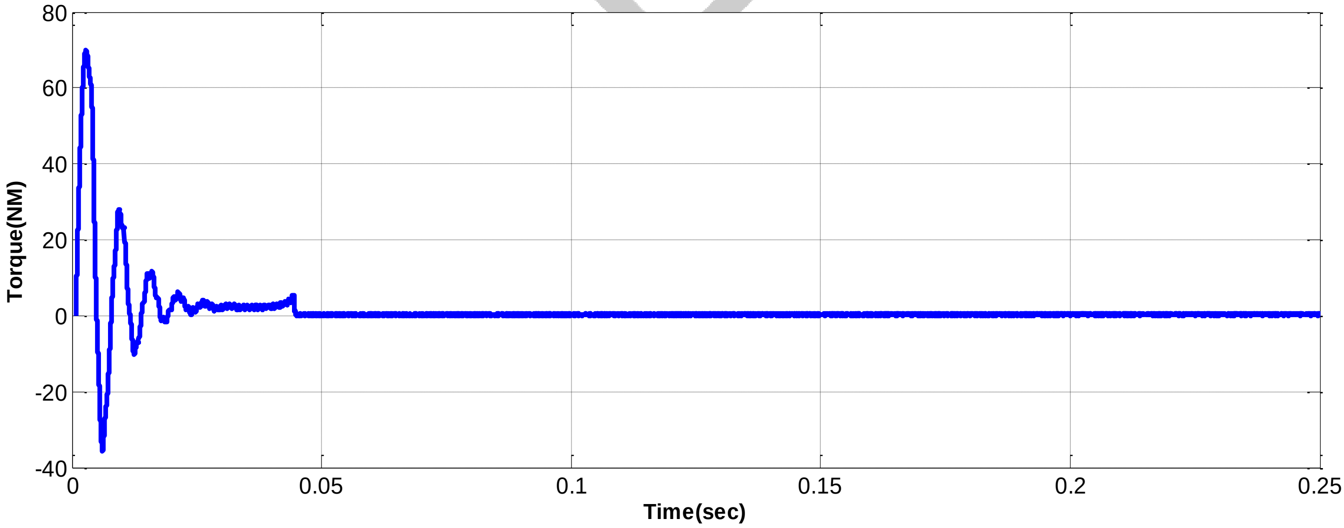


Fig.10.Simulation result of Motor torque using PI-Controller when no-load is applied to motor at 0.1 sec when TL=0Nm, t=0.1 sec.

CASE III: ITAE criteria with partial swarm optimization technique

From the fig 11 graph it is clear that the best fitness value is 1.4577e+05

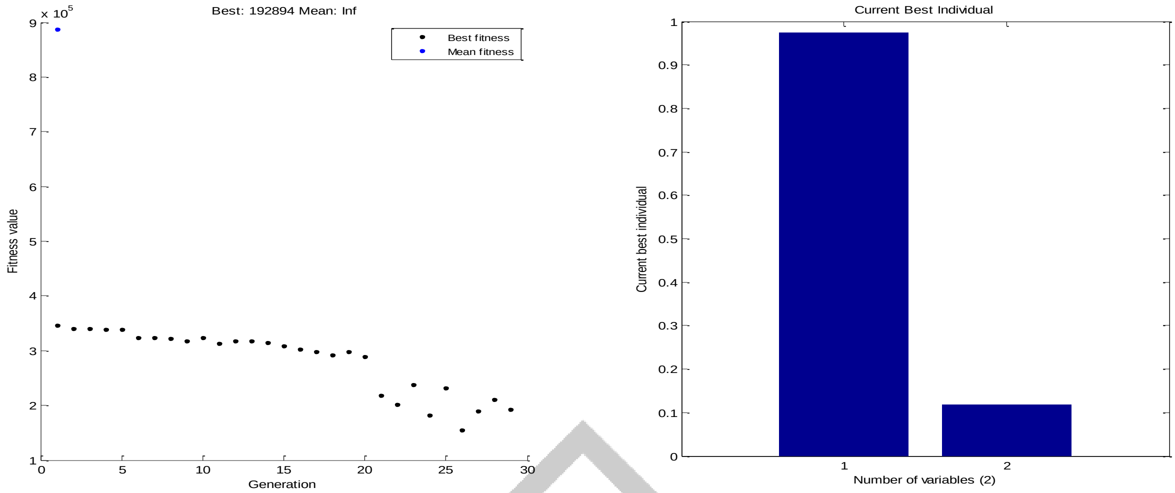


Fig.11. Output of Partial Swarm Optimization technique using ITAE

Table1.3 Output parameter of ITAE

S.No.	Kp	Ki	Fval
1.	7.5015	0.4611	1.4577e+05

In this condition the PMSM drive simulink model was evaluated for the wave form of Speed response, motor torque and current by using PI-Controller. The waveforms are presented below. The simulation result for speed reference input of 3000 rpm with controller gains are KP =7.5015, KI = 0.4611with a load torque of 0 Nm, i.e. no load is applied to the motor at 0.1 sec which is shown in fig 12.Under this condition Motor torque is shown in fig.13 at No-load condition.

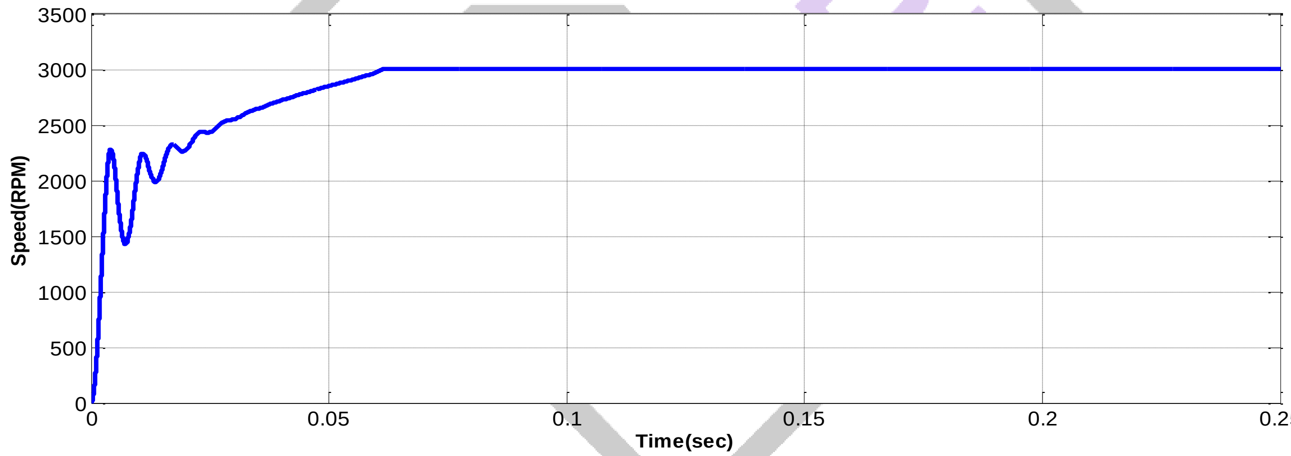


Fig.12 Simulation result of speed response using PI-Controller when no load is applied to the motor at 0.1 sec when TL = 0 Nm, t=0.1 sec.

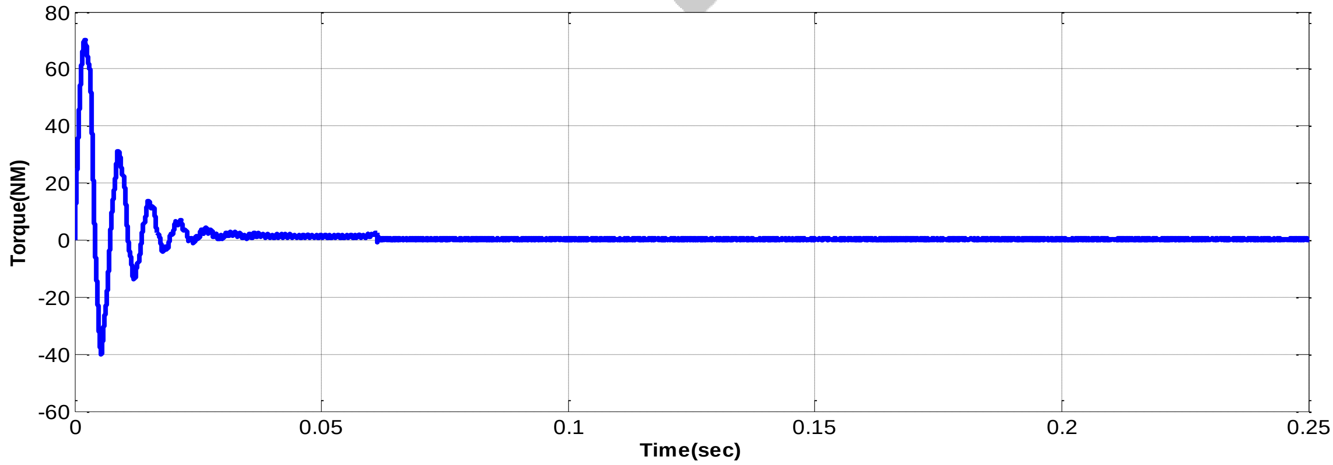


Fig.13.Simulation result of Motor torque using PI-Controller when no-load is applied to motor at 0.1 sec when TL=0Nm, t=0.1 sec.

CASE IV: ITSE criteria with partial swarm optimization technique

From the fig 14 graph it is clear that the best fitness value is 2.4595e+07

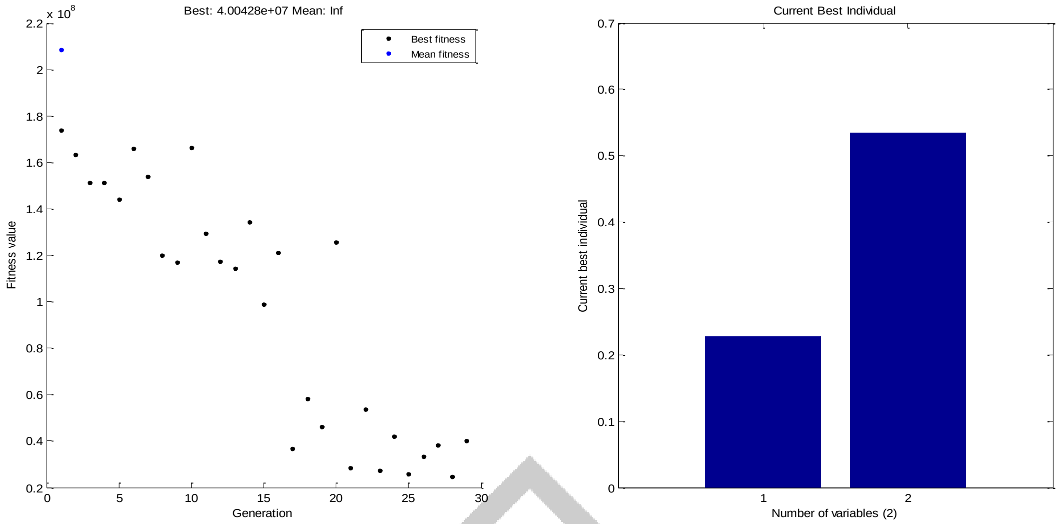


Fig.14. Output of Partial Swarm Optimization technique using ITSE

Table1.4 Output parameter of ITSE

S.No.	Kp	Ki	Fval
1.	0.1431	0.4896	2.4595e+07

At no load condition the PMSM drive simulink model was evaluated for the wave form of Speed response, motor torque and current by using PI-Controller. The waveforms are presented below. The simulation result for speed reference input of 3000 rpm with controller gains are KP =0.1431, KI = 0.4896 with a load torque of 0 Nm, i.e. no load is applied to the motor at 0.1 sec which is shown in fig 15.Under this condition Motor torque is shown in fig.16 at No-load condition.

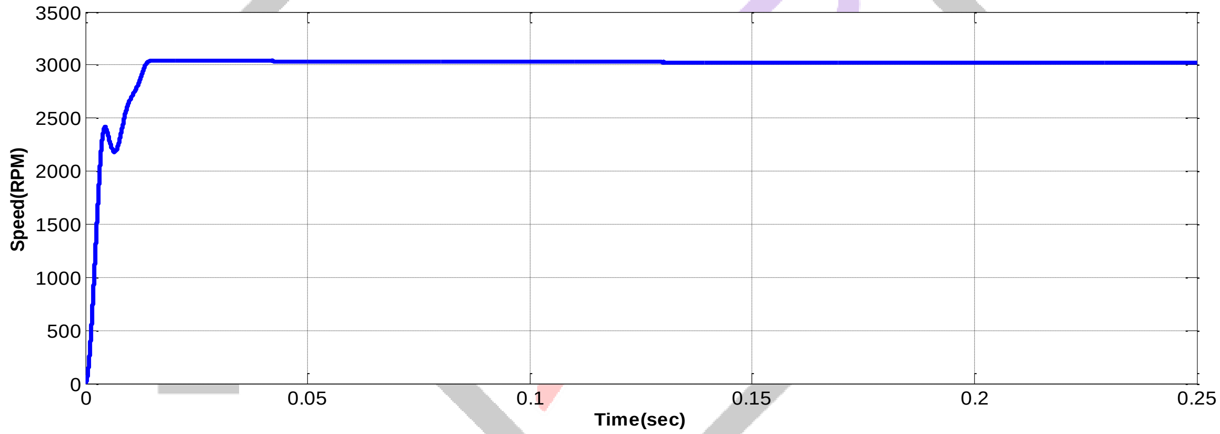


Fig.15 Simulation result of speed response using PI-Controller when no load is applied to the motor at 0.1 sec when TL = 0 Nm, t=0.1 sec.

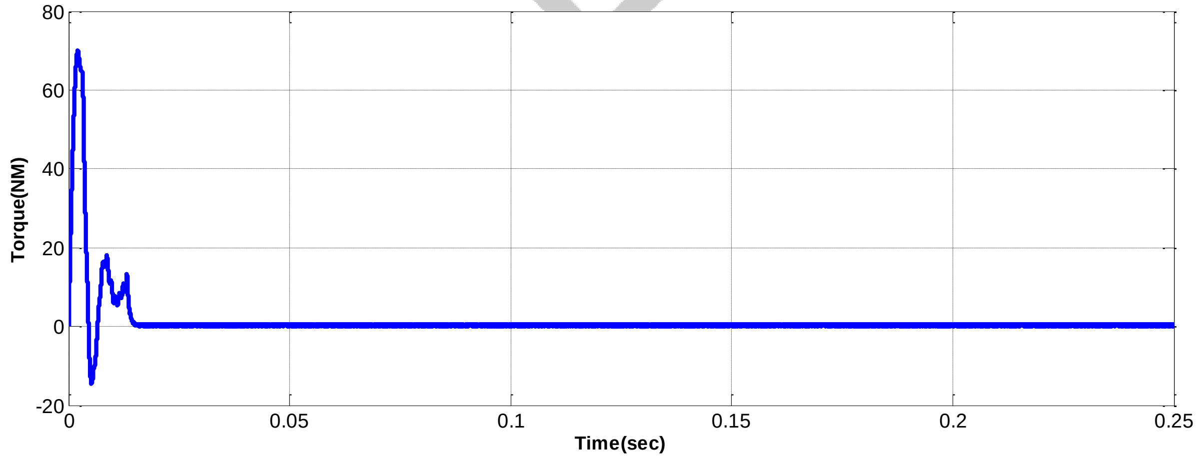


Fig.16.Simulation result of Motor torque using PI-Controller when no-load is applied to motor at 0.1 sec when TL=0Nm, t=0.1 sec.

VII. CONCLUSION

Performance comparison of different criteria has been reviewed and it is found that ITSE is best among the all methods which are used for tuning the parameter of PI controller for which settling time and rise is found to be less. The conventional controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable. Hence, a heuristic approach is required for choice of the controller parameters which can be provided with the help of Bio inspired methods such as Particle Swarm Optimization, where we can define variables in a subjective way.

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