PID Controller Design of Brushless DC Motor by Bacteria Foraging and Hybrid Bacteria Foraging-PSO Optimization

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Abstract - Brushless DC motors are widely used in industries incomparable to DC motors. In this research work transfer function is obtained for brushless DC motor for designing controller gains. The performance is analysed by with and without controller. The design of controller gains is done by bacterial foraging and hybrid bacterial PSO optimization algorithm. The simulation was done by MATLAB /SIMULINK platform and the results are compared for with and without controller. The settling time, steady state error and peak overshoot is better when compared to without controller.

***Key Words*:** PID control, optimization, brushless dc motor, peak over shoot, settling time

1.INTRODUCTION

Brushless direct current motors are widely used in industries. It is used in electric vehicles and other process industries replacing direct current motors. The brushless direct current motors have electronic commutation, uses inverter switches for commutating of other phases, but in DC motor use commutator and brush for its operation. This causes commutation sparking at the brushes and losses in brushes are more. Hence this motor termed as brushless dc motor. This motor is suitable for electric and hybrid vehicles compared to induction motor. The induction motor has poor power factor while in operation and the torque and speed characteristics is not viable for different load spectra. The brushless DC motor has better torque capability at all speeds. The particle swarm optimization is compared with grey wolf optimization shows better performance under different load conditions [1].

The neural fuzzy gives better performance for the motor but the anfis yield superlative result [2]. The position control optimization technique gives superior performance for the brushless dc motor [3]. The fuzz system shows more error in the speed control but combination with optimization algorithm gives better performance [4]. The novel optimal corona virus optimization is specialized for the brushless dc motor speed control [5]. The starting torque of induction motor is less compared to brushless dc motor. Hence for electric vehicle and hybrid vehicle applications it is preferred with good starting torque. The difference between synchronous motor and brushless dc motor is the use of permanent magnets. In industries the variable fed drives play vital role in improving the energy conservation. Hence the brushless dc motor is suitable for industries for energy conservation methods there are two broad classification of permanent magnet brushless dc motor they are trapezoidal and sinusoidal back electromotive force waveform. The rotor has many types out of which there are two basic classifications surface mounted and permanent magnet mounted inside the rotor [16]. In this paper the first part contains the working of brushless direct current motor, the second part consists of obtaining the transfer function for brushless dc motor, the third part is on explaining the algorithm of optimization algorithms. The final part is application of without controller and with controller and its performance analysis in this paper the performance is analyzed with two optimization algorithm named as bacteria foraging optimization algorithm and hybrid algorithm called bacteria foraging particle swarm optimization algorithm, which combines bacteria foraging optimization and particle swarm optimization [7]. This motor is also known as permanent magnet synchronous motor (15]. The performance analysis is obtained by taking into considerations of improving settling time, peak overshoot, rise time and steady state error. This enhancement done with step input and speed is maintained constant when load is applied at a particular time. The performance is compared by without controller and with controllers. The controller gain is obtained from the two optimization techniques.

2. WORKING OF BRUSHLESS DC MOTOR

The brushless direct current motor has better commutation control over conventional direct current motors. The basic principle is similar to direct current motors. The brushless direct current motor has stator windings which are laminated to minimize the eddy current losses. The rotor has permanent magnet as compared to electromagnet in direct current motors. When the stator is energized by suitable inverter circuit and the rotor magnet will be aligned with the stator. This cycle continues for the next stator winding. The speed of the stator and rotor alignment is decided by the switching signals of the inverter. It is understood from this explanation the requirement of brushes is void. Hence it is more efficient than direct current motors. The brushes in direct current motors lead to sparking if commutation is not proper. Brushes have several demerits such as voltage drop during working and high speed causes noisy operation. Hence these conventional direct current motors replaced by brushless direct current motors [13]. In this paper the power electronics circuit is used for the electronic commutation. The topology used in this paper is four switch three phase inverter. The two phase a and c is used with four devices and for the third phase b is utilizing the dc link split capacitors. The two switches cannot conduct at the same instant leads to shoot through fault. The inverter circuit consists of four IGBT switches named as S1, S2, S3 and S4 respectively. The upper switches are S1and S4 while the lower switches are S2 and S3. The upper and lower switches are complementary to each other. The dc voltage is converter to ac voltage by the use of inverter. The inverter switches operate for every 60 degrees and simultaneously the next switches will follow. The speed of the brushless dc motor depends on the switching of the inverters.

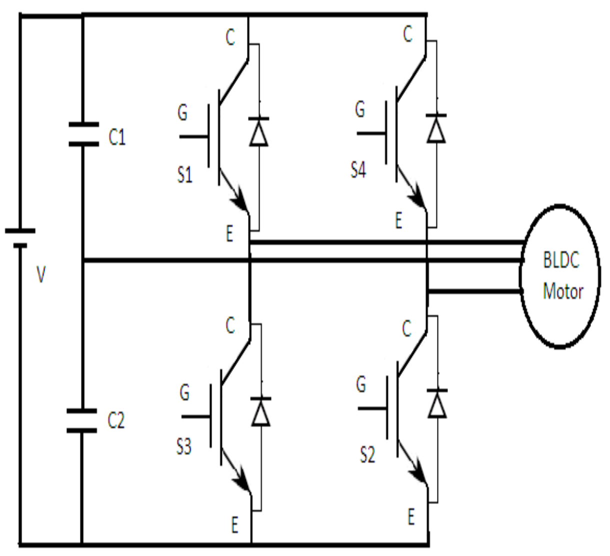

Fig -1: BLDC motor fed four switch inverter circuits

The mathematical model is obtained for the brushless direct current motor and the transfer function is derived from it. The transfer function is defined Laplace transform of output with respect to Laplace transform of input. For the brushless direct current motor, the input is voltage and the output is angular speed of motor [8].

$$G(s) = \frac{\omega_m}{V} = \frac{1/K_e}{\tau_m \tau_e S^2 + \tau_m S + 1} \quad (1)$$

Where τm is known as motor time constant has the value of 0.0161, τe is called as electrical time constant whose value is 151.51X10-6. Ke is called as back emf constant whose value is 0.06902 V-sec/radians, ωm is called angular speed of the brushless direct motor and V is called as input of brushless direct current motor. The input voltage of the motor is 12 volts and speed of the motor is 100 revolutions per minute. The moment of inertia is taken as 82.5 gram -square meter. In open loop control of BLDC Motor, the performance of brushless direct current motor is tested with open loop control using the above mentioned transfer function. The time response analysis is required for taking into account the performance parameters. The performance parameters are settling time, steady state error and peak overshoot. These parameters are to be in specified range for efficient operation. The open loop transfer function wave form is shown in figure2.

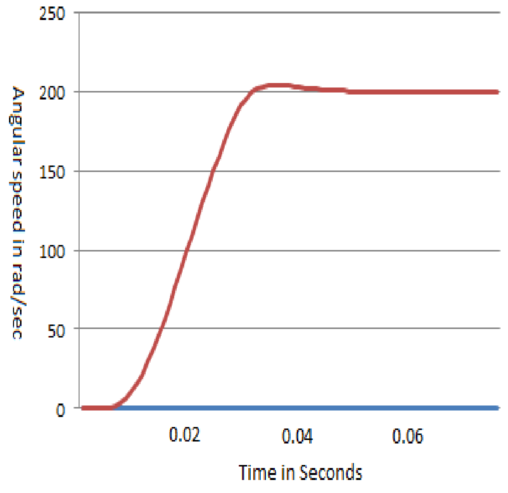

Fig -2: Open loop transfer function waveform

Proportional integral derivative controller is the basic control used in all the process control industries. It is applied in most of the low end applications. The concept of PID control is enhanced by usage of microcontrollers and field programmable gate arrays [4]. The basic function PID controller is reducing the error between the set point and the feedback input. The controller initiates the action by using proportional controller which takes proportional to the error, the integral action taken by integral controller and finally the derivative of error is initiated by derivative controller this also implements to check whether system is stable [10].

The unstable system causes short fall in the effective operation of the brushless direct current motors. Hence suitable controller gain is designed for the effective operation of the BLDC motor. The performance parameters are settling time, peak over shoot and steady state error is considered in this paper for analysis of BLDC motor [9]. The closed loop controller gives good dynamic and steady state performance. The test was conducted by taking the value of proportional controller as one. The performance was resulted with large settling time and high peak overshoot. In the next step the controller gains are obtained using bacteria foraging optimization algorithm and hybrid algorithm of bacteria foraging and particle swarm optimization algorithm. The necessary pulse width modulation technique is employed for the suitable operation of brushless direct current motor. The transfer function obtained is modeled as brushless direct current motor. The load torque is given at some particular time [11]. The performance is analyzed with and without controller for reaching the steady state value after the elapsed time of applied load. In this the optimize values of proportional gain, integral gain and derivative gains to improve the performance parameters like settling time, steady state error and peak overshoot [12].

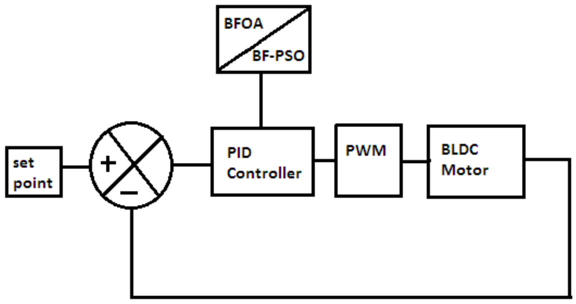

Fig -3: Block diagram of optimization controller of BLDC motor

Bacteria optimization algorithm is the basic science of solving complex and non-linear problems in a simple formulation. This algorithm was formulated by renowned scientist Kevin M Passino. This algorithm was basically obtained from the Darwin's theory of evolution. Different algorithms are available in the literature based on survival of the fittest principle. The algorithms are formulated based on life of animals, birds and other small organisms. The basic idea is to reach the destination in short span of time with more dependent variables. In this algorithm the search space is chosen randomly with controller values of proportional, integral and derivative gains.

In this algorithm the component used for searching the best solution is E.coli bacteria. The property of these bacteria under the condition, when the food is available with good nutrients the actual bacteria grows. When it reaches the certain length it will divide to another bacterium from middle of the bacteria body. When the nutrients available are worse it leads to moving away from the nutrients and moves along the positive gradient direction. The bacterium can be able to swim along in clockwise direction and tumble in anti-clockwise direction. These are the two operations of the bacterium. There are four basic steps for the bacteria foraging optimization algorithm they are chemotaxis operation, swarming operation in which it will swim and tumble depending on the requirements, reproduction operation and elimination operation. The algorithm is listed below.

Initialize the parameters of the bacteria foraging optimization algorithm they are dimension of search space, number of bacteria, number of chemotatic step, limits of length of swim, number of reproductive steps, number elimination and dispersal steps, the number of bacteria reproduction split, probability of elimination, run length and initial positions. The parameters which are required for searching the optimum gains are proportional, integral and derivative gains.

In the chemotatic step depending on the nutrients the flagella will move towards the positive gradient. The flagella will move either in clockwise direction as swimming and counter clockwise direction as tumbling operations. The term Q(i,j,k,l) term represents the total core of the algorithm where i embodies the number of bacteria, j embodies the chemotatic loop, k embodies the reproduction loop and finally l embodies the elimination and dispersal event. The estimate chemotatic step is given below. Where L(i) denotes the step length and Δ denotes vector in random direction from unit value of negative to positive.

$$Q(i,j,k,l) = Q(i,j,k,l) + L(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \qquad (2)$$

The bacteria will be attracting or repelling each other from basic ideology of cell to cell activations. This type of formulation is given below. Where J(Q,P(j, k, l) is the objective function need to be minimized, S is the total number of bacteria, P is the number of variables to be optimized ,Q = [Q1, Q2..] are the points in the search space of the optimization and dattractant, Wattractant, hrepellant,Wrepellant are the different coefficients are chosen properly for the optimized value of the controller gains useful for control of brushless direct current motor.

$$J(Q,P(j,k,l)) = \sum_{i=1}^{S} J(Q,Q^i(j,k,l))$$
$$= \sum_{i=1}^{S} -d_{attractant}\exp(-W_{attractant})\sum_{m=1}^{P}(Q_m - Q_m^i)^2$$
$$+\sum_{i=1}^{S} h_{repellant}\exp(-W_{repellant})\sum_{m=1}^{P}(Q_m - Q_m^i)^2 \qquad (3)$$

Hybrid bacteria foraging particle swarm optimization is the important concept in swarm intelligence. It was invented in 1995 by kennedy and Eberhart. The basic idea of this algorithm the optimized values is obtained with high dimension search space with analogy of ducks moving to the food in less time. This optimization combines both bacterial foraging and Hybrid bacteria foraging particle swarm optimization techniques for enhance of controller gains used in control of brushless direct current motors. Initialize the parameters of bacterial foraging optimization algorithm as shown in section 5. After initializing the parameters and now include the parameter of particle swarm optimization techniques. The basic parameters are current positions, current velocities, and distance between current position and global best position and distance between current position and local best positions. The algorithm is tracked after initializing the parameters of the both optimization algorithms. The chemotatic step is followed by doing the swimming and tumbling operations. At the end of chemotatic step the function to be minimized is applied to particle swarm optimization for finding the shortest distance. The new direction of bacteria is determined and formulated as follows [14].

$$V_1^{m+1} = w * V_1^m + C1 * rand1(LP_1 - CP_1^m)$$
$$+ C2 * rand2(GP_1 - CP_1^m) \qquad (4)$$

Where V is the velocity of the particle, C1 and C2 are the constants, rand1 and rand2 are the random numbers, LP is denoted as local position, GP denoted as global position, CP is denoted as current position and w is denoted as weighting function. When the bacteria have achieved certain optimized

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direction it is initiated with reproduction operation. The process of reproduction operator is that healthier bacteria survive and least healthy bacteria will split into two and maintains the total bacteria in the process in operation. The next event is elimination and dispersal operation in which most of the bacteria does not survive due changes in the environment. The healthier bacteria will evolve and move towards the positive gradient. The remaining bacterium does not survive or it will diminish due to environment conditions. The weighting function is modified for every loop of iteration. The current position and current velocities are updated and to obtain optimum location

3. Results

The simulation results were obtained using MATLAB/ simulink environment. Results were enunciating the performance of brushless direct current motor under operating without controller, with controller and controller with disturbance signal. The performance analysis is compared with bacteria foraging optimization and hybrid algorithm bacterial foraging particle swarm optimization.

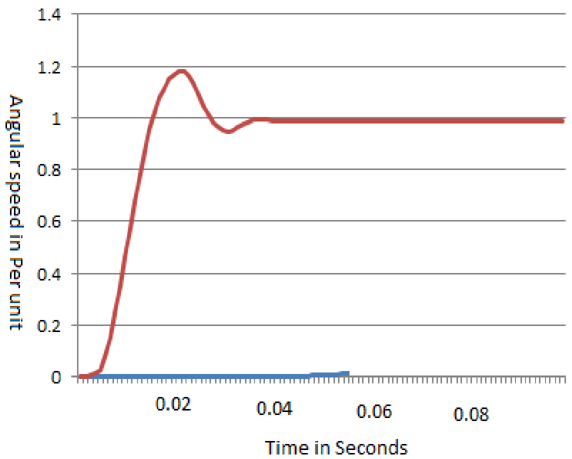

Fig -4: Closed loop control with bacteria foraging optimization

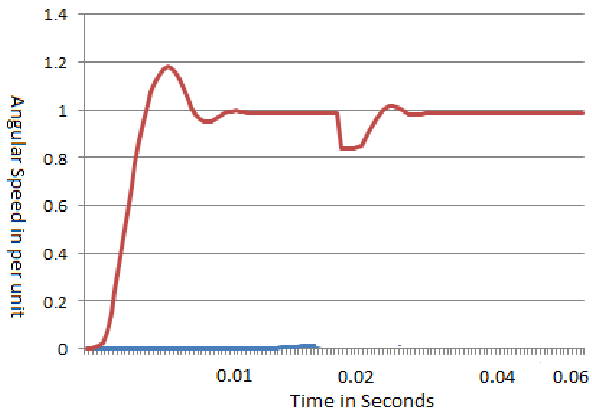

Fig -5: Closed loop control with bacteria foraging optimization with load torque

Table-1
Controller Gains of BFOA controller

BFOA controller	Kp	Ki	Kd
With	5.33	1.02	0.043
Without	1	0	0

Table-2
Performance parameters of BFOA controller

BFOA controller	Settling time	Peak Overshoot	Steady State Error
With	0.003	0.01	0.013
Without	0.005	0.015	0.023

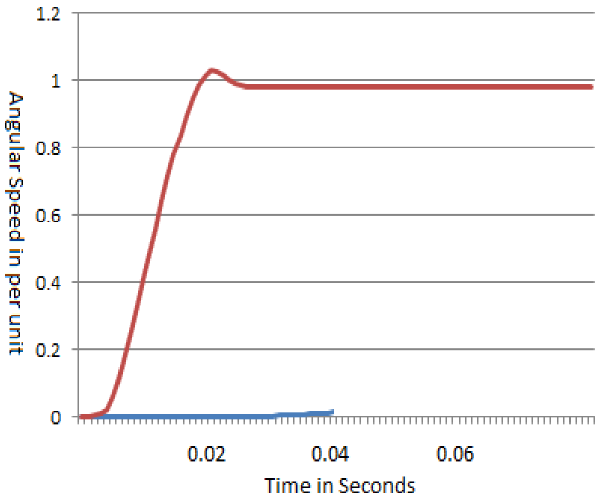

Fig -6: Closed loop control with bacteria foraging particle swarm optimization controller

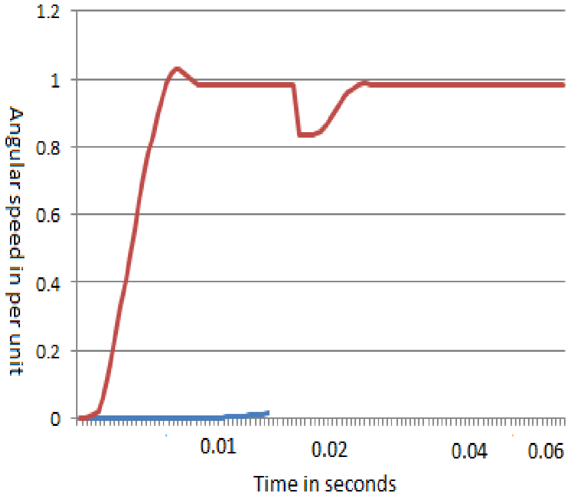

Fig -6: Closed loop control with bacteria foraging particle swarm optimization with load torque

Table-3
Controller Gains of BFO-PSO controller

BFOA controller	Kp	Ki	Kd
With	4.06	0.55	0.001
Without	1	0	0

Table-4
Performance parameters of BFOA controller

BFOA controller	Settling time seconds	Peak Overshoot %	Steady State Error
With	0.026	0.046	0.017
Without	0.005	0.015	0.023

It is inferred that bacterial foraging optimization has less steady state error compared to hybrid bacterial foraging particle swarm optimization. The settling time and peak over shoot is better in hybrid bacterial particle swarm optimization. The load torque is applied at 2 milli seconds for both the controller. The settling time is better after application of load torque in hybrid bacterial foraging particle swarm optimization at 1.5 milliseconds compared to bacterial foraging optimization at 2.2 milli seconds.

4. CONCLUSIONS

The brushless direct current motor dynamic performance requires good control strategies to minimize the errors in the system. The performance is enhanced by both bacterial foraging optimization technique and hybrid algorithm of bacterial foraging particle swarm optimization technique. It is inferred that by comparing the two optimization techniques hybrid algorithm of bacterial foraging particle swarm optimization is better compared to bacterial foraging optimization technique. The future scope of the work can be implemented with hardware realization to enhance the operating characteristics of the motor.

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