Mathematical modeling and speed control of BLDC Motor Using GA and PID

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***Abstract* - This paper presents the modeling of three phase brushless DC motor along with the speed regulation scheme with trapezoidal back-emf consideration. Permanent magnet synchronous motor with a trapezoidal back EMF waveform shape is conventionally called as Brushless DC motor (BLDC). In this project, GA tuned is better than PID is shown which results in a better optimization of the process.**

***Index Terms* - BLDC, PID controller, GA controller.**

I. INTRODUCTION

A motor that retains the characteristics of a dc motor but eliminates the commutator and the brushes is called a Brushless DC motor. Brushless DC (BLDC) motors can in many cases replace conventional DC motors. They are driven by dc voltage but current commutation is done by solid state switches i.e., the commutation is done electronically. BLDC motors are available in many different power ratings, from very small motors as used in hard disk drives to large motors in electric vehicles. Three phase motors are most common but two phase motors are also found in many applications. The BLDC motors have many advantages over brushed DC motors. A few of these are:

- Higher speed ranges
- Higher efficiency
- Better speed versus torque characteristics
- Long operating life
- Noiseless operation
- Higher dynamic response [2].

A three phase BLDC Motor has three phase stator winding on stator and permanent magnet rotor. The torque developed in BLDCM is affected by the waveform of back- Emf waveform. Usually the BLDCM has trapezoidal back- Emf waveform and stator is fed by rectangular stator current and theoretically it gives a constant torque but the torque ripple exists due to emf waveform imperfection, current ripple and phase current commutation[3].

Brushless DC motor is one of a small-scale motor used in small electric devices like CD players, hard disk drives, or even small electric cars. Its rotor is mounted with permanent magnet. There is no need for extra field excitation. BLDC is well-known and popular for position and speed control drive applications [1].This presents a BLDCM Model with the trapezoidal and sinusoidal back-EMF waveform. The block diagram of BLDC Motor control system is shown in fig.1

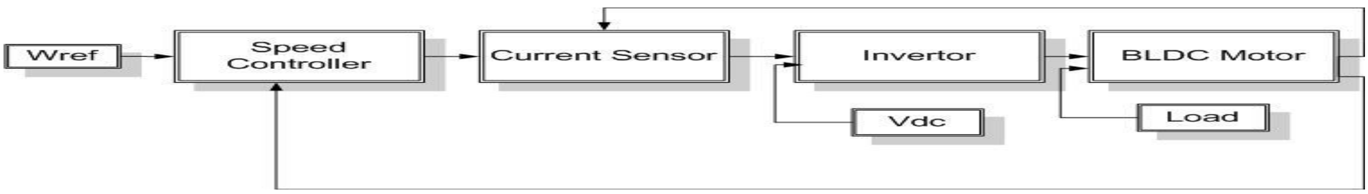

Fig 1. Block diagram of Speed Control of BLDC Motor

II. PRINCIPLES OF THE BLDC MOTOR

2.1Mathematical Model of BLDC Motors

Modeling of a BLDC motor can be developed in the similar manner as a three-phase synchronous machine [1, 2]. Since rotor of this motor is mounted with a permanent magnet, some dynamic characteristics are different. Flux linkage from the rotor is dependent upon the magnet. Therefore, saturation of magnetic flux linkage is typical for this kind of motors. As any typical three-phase motors, one structure of the BLDC motor is fed by a three-phase voltage source as shown in Fig. 1. The source is not necessary to be sinusoidal. Square wave or other wave shape can be applied as long as the peak voltage is not exceeded the maximum voltage limit of the motor. Similarly, the model of the armature winding for this motor is expressed as follows:

$$V_a = Ri_a + L\frac{di_a}{dt} + e_a \qquad (1)$$

$$V_b = Ri_b + L\frac{di_b}{dt} + e_b \qquad (2)$$

$$V_c = Ri_c + L\frac{di_c}{dt} + e_c \qquad (3)$$

in the compact matrix form as follows:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R+pL & 0 & 0 \\ 0 & R+pL & 0 \\ 0 & 0 & R+pL \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (4)$$

where, $L_a = L_b = L_c = L = L_s - M[H]$

L_s is armature self-inductance

M is Mutual inductance

$R_a = R_b = R_c = R$ are the armature resistance in ohm

V_a, V_b, V_c are the terminal phase voltages in volts

i_a, i_b, i_c are the motor input currents in amp.

e_a, e_b, e_c are the motor back emf in volts

p is the matrix represents $^{d}/_{dt}$

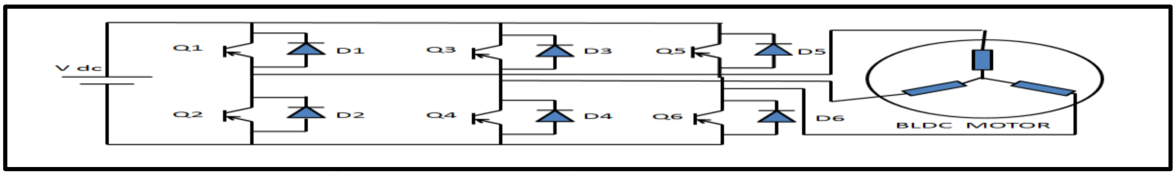

Fig. 2 BLDC Motor Control System

Due to the permanent magnet mounted on the rotor, its back emf is trapezoidal as shown in Fig. 2. The expression of back emf must be modified as expressed in (5) – (7).

$$\mathrm{e_a(t) = K_E * \phi(\theta) * \omega(t)} \qquad (5)$$

$$\mathrm{e_b(t) = K_E * \phi\left(\theta - \frac{2\pi}{3}\right) * \omega(t)} \qquad (6)$$

$$\mathrm{e_c(t) = K_E * \phi\left(\theta + \frac{2\pi}{3}\right) * \omega(t)} \qquad (7)$$

where K_E is the back emf constant and ω(t)is the mechanical speed of the rotor.

The permanent magnet also influences produced torques due to the trapezoidal flux linkage. Given that K_T is the torque constant. The produced torques can be expressed as describe (8).

$$\mathrm{T_E = (e_a i_a + e_b i_b + e_c i_c)/\omega} \qquad (8)$$

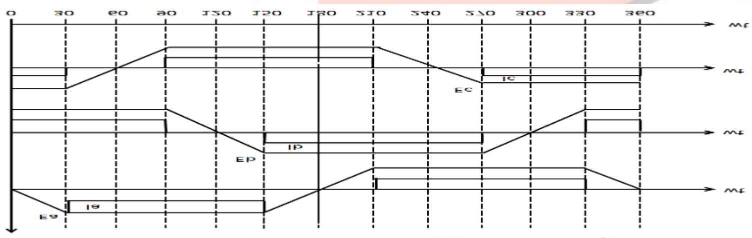

Fig. 3 BLDC Motor back emf and the motor phase currents

Substitute (5) – (7) into (8), the resultant torque, T_E, can be obtained by the following expressions.

$$\mathrm{T_a(t) = K_T * \phi(\theta) * i_a(t)} \qquad (9)$$

$$\mathrm{T_b(t) = K_T * \phi\left(\theta - \frac{2\pi}{3}\right) * i_b(t)} \qquad (10)$$

$$\mathrm{T_c(t) = K_T * \phi\left(\theta + \frac{2\pi}{3}\right) * i_c(t)} \qquad (11)$$

$$\mathrm{T_E(t)} = T_a(t) + T_b(t) + T_c(t) \qquad (12)$$

With the Newton's second law of motion [5], the angular motion of the rotor can be written as follows.

$$\mathrm{T_E(t) - T_L(t)} = J\frac{d\omega(t)}{dt} + B * \omega(t) \qquad (13)$$

where, T_L is load torque in N-m

J is rotor inertia in kg-m^2

B is damping constant

III. PID Controller

PID controller consists of Proportional Action, Integral Action and Derivative Action. It is commonly refer to Ziegler-Nichols PID tuning parameters. It is by far the most common control algorithm [1].

In proportional control,

$P_{term} = K_P$ X Error (14)

It uses proportion of the system error to control the system. In this action an offset is introduced in the system.
In Integral control,

$I_{term}= K_i \times \int Error\, dt$ (15)

It is proportional to the amount of error in the system. In this action, the I-action will introduce a lag in the system. This will eliminate the offset that was introduced earlier on by the P-action.
In Derivative control,

$D_{term} = K_D \frac{dError}{dt}$ (16)

It is proportional to the rate of change of the error. In this action, the D-action will introduce a lead in the system. This will eliminate the lag in the system that was introduced by the I-action earlier on.

$\frac{M(S)}{E(S)} = K_P + \frac{K_I}{S} + K_D S$ (17)

Where: E(s) is error input signal,

M(s) is manipulated output signal.

K_P is proportional gain,

K_I is integral gain and

K_D is derivative gain.

These parameters K_P, K_I and K_D are chosen to meet prescribed performance criteria, classically specified in terms of rise and settling times, overshoot, and steady-state error. Block diagram of optimal PID control for the BLDC motor is shown in *Fig.4*.

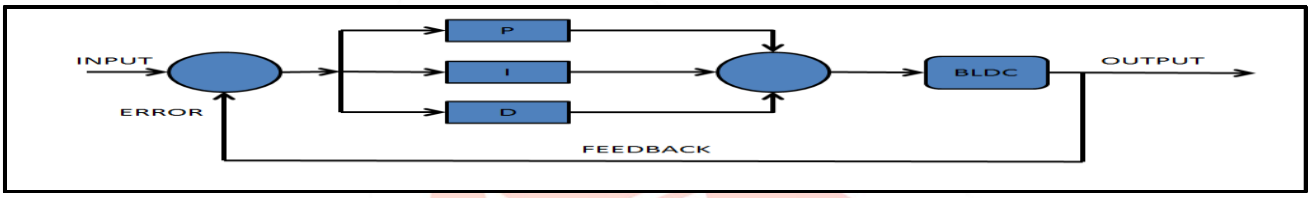

Fig.4 Block diagram of PID control of BLDC motor.

IV. GENETIC ALGORITHEM

Genetic Algorithms (GA.s) are a stochastic global search method that mimics the process of natural evolution. It is one of the methods used for optimization. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions.
Genetic Algorithms are search and optimization techniques inspired by two biological principles namely the process of natural selection and the mechanics of natural genetics.

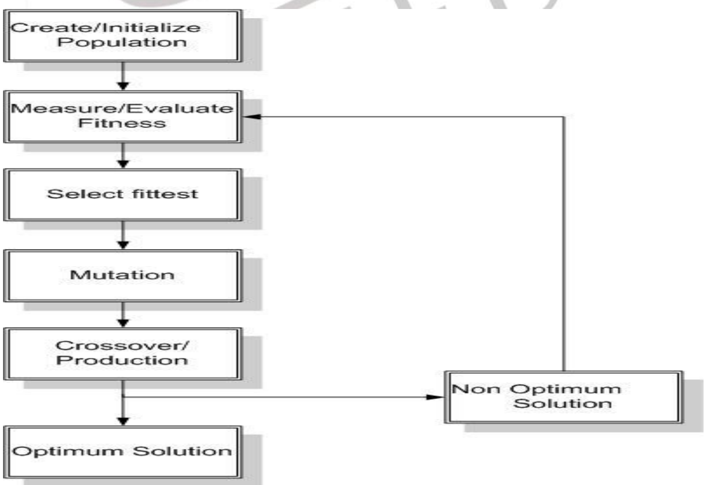

Fig 5. Genetic Algorithm Process Flowchart

V. SIMULATION RESULTS

This chapter is concerned with the simulation results of the closed loop control of the BLDC Motor drive system using PI controller and PI tuned GA. Modeling and Simulation of a 3 phase, 8 poles, 1.4 N-m permanent magnet BLDC motor is carried out using MATLAB/SIMULINK. The performance characteristics are shown here. Specifications of the BLDC motor are given in APPENDIX-A. The purpose of the simulation is to evaluate the performance of the BLDC drive system when PID speed controller is used and comparing its performance when GA controller is used. The performance of BLDC motor drive was investigated with conventional inverter and comparing their speed response for a required reference speed.

5.1 PERFORMANCE WITH PID CONTROLLER AT NO LOAD CONDITION

DC bus voltage simulation results is shown in Fig 5.1:

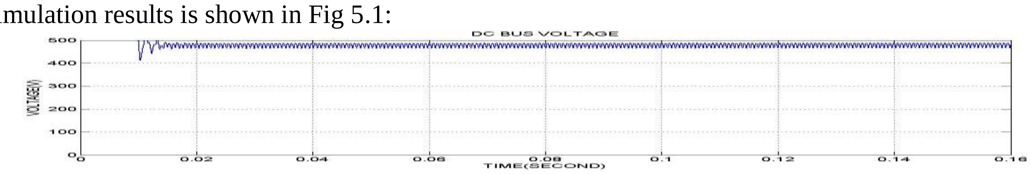

Fig. 6 Simulation result of DC Bus Voltage using PID-Controller

The Ea are the Electromotive forced of the model. It is observed that the phase displacement between the emfs are 120 degree. Their simulation results shown in Fig. 7.

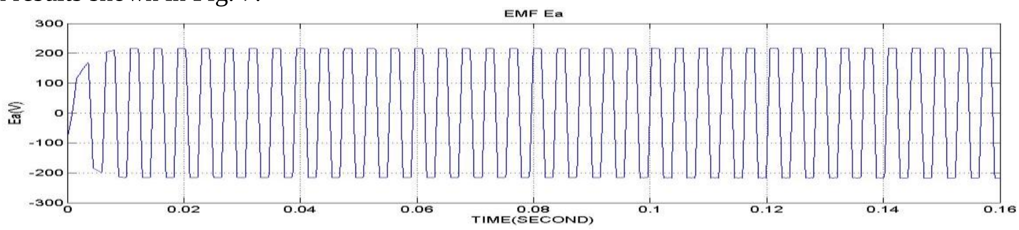

Fig.7 Simulation result of EMF Ea using PID-Controller

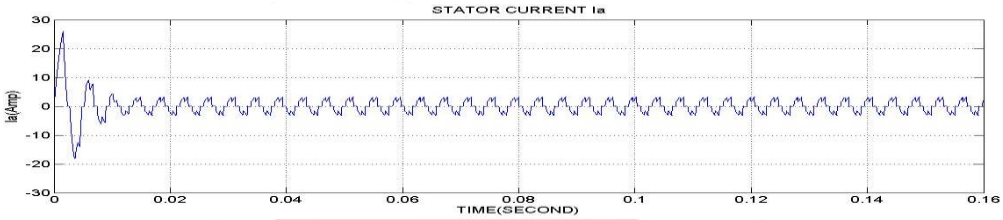

Fig. *8 Simulation result of Stator Current Ia using PID-Controller*

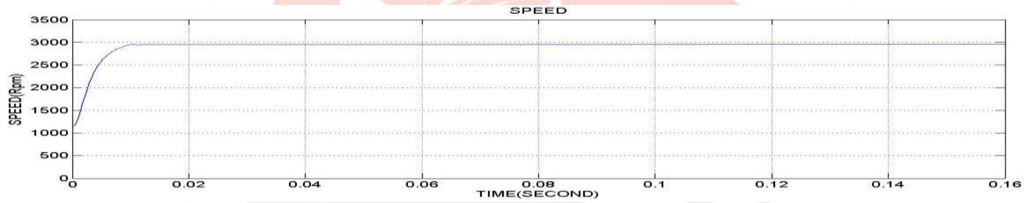

Fig. 9 Simulation result of Speed using PID-Controller

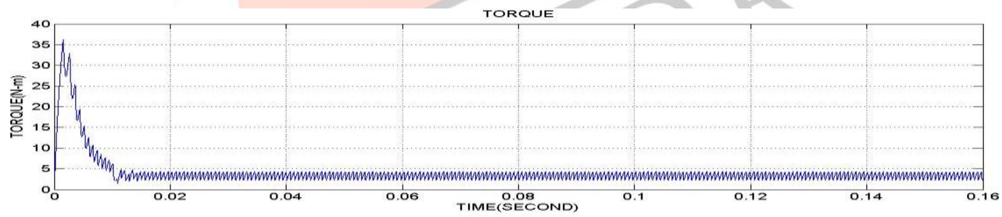

Fig. 10 Simulation result of Torque using PID-Controller

5.2 PERFOMANCE WITH GA CONTROLLER

Based on the system configuration shown in Fig. 5.9 the simulation of BLDC motor with GA tuned PID controller and current sensor loop is performed. The simulation result for reference speed input of 3000 RPM.This will helps to understand that GA is more efficient than the traditional methods.

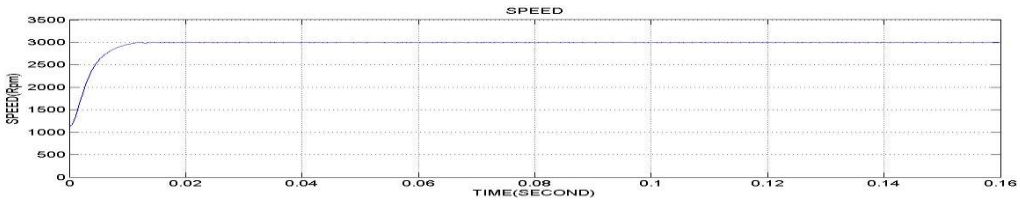

Fig. 11 Simulation result of speed using GA-Controller

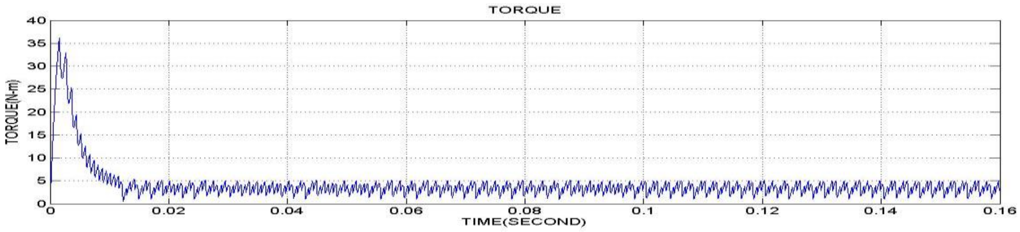

Fig. 12 Simulation result of Torque using GA-Controller

VI. CONCLUSION

The steady state error is approximately 5% but in the case of GA it is about 0.1%.We have seen that the in PID controller the overshoot is high and setting time take more time to settle down to overcome. So we can conclude from here that the tuning PID with soft computing techniques (GA) reduce manual error and also improve the performance dramatically. It can be seen that GA tuned system as compared to Ziegler-Nichols tuned system for PID, has less settling time and Rise time at no load condition.

FUTURE SCOPE

- In future we shall improve transient state.
- Steady state contains 0.01% harmonics, so we will try to implement with more advance heuristic algorithms.
- PSO can be implemented in future for better performance on loaded and unloaded condition.

Table 1PARAMETERS OF THE BLDC

Parameter	Symbol	Data
Stator Inductance	L	$8.5*10^{-3}$ H
Stator Resistance	R	2.8750 Ω
Rotor Inertia	J	$0.8*10^{-3}$kgm^2
Damping Constant	B	0.005 N-m-s
Back EMF Constant	K_E	0.175 V-s
Proportional Gain	k_p	8
Integral Gain	k_i	9
Derivative Gain	kd	0.02

VII. ACKNOWLEDGMENT

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