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Adaptive Speed Control of Permanent Magnet Brushless DC Motor by Implementing PSO Algorithm

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Abstract:
The Brushless DC (BLDC) motors are one of the most intriguing motors, not only because of their efficiency and torque characteristics, but also because they have the benefits of being powered by direct current (DC), while avoiding the drawbacks of brush or the conventional DC motors. A BLDC motor has excellent speed to torque characteristics, as well as high dynamic responsiveness, high efficiency, long life, and noiseless operation. This research paper includes a simulation for closed loop speed control of BLDC motor, the design and implementation of Particle Swarm Optimization (PSO) tuned PID controller for speed control of Brushless DC (BLDC) motor. The simulation is done by using MATLAB software.

Key Word*: PSO algorithm, BLDC motor, MATLAB, Simulink, PID Controller.*

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I. Introduction

Environment degradation and emissions of greenhouse gases are growing at an alarming rate because of consumption fossil fuel. In these scenarios electric vehicles (EVs) got more attention from different countries in comparison with internal combustion engine cars, due to their Null pollutants, great efficiency, and reliable Stability. Permanent magnet motors are widely utilized in a variety of electric drive applications, including traction drives, electric cars, fans, submersible pumps, and so on. The use of a motor with outstanding dynamic performance and great efficiency minimizes energy consumption and improves the system's overall performance. Controlling the speed of the motor is essential to a lot of applications to get accurate speed with smooth response and reduced torque ripples to avoid bearing damage, noise reduced lifetime .There are two types of BLDC motor control algorithms, the first one is Hall Effect sensor control and the other is senseless control [3] . Senseless control reduces the cost and needs fewer interconnects between the motor and the drive, but it has a lot of disadvantages such as uncertain position of rotor that may causes vibration at zero startup .Sensor less control method also has a major drawback that when there is no back EMF generated in case of not turning (stationary) this will lead to lack of important information needed to properly control the motor. In addition to that sensor less control is not suitable for low-speed rates. So, in this work the Hall Effect sensor control method will be used as it is more effective. The brushless DC machine are widely used, and this is due to the new and high technologies of the electronic control solutions[4]. Therefore, several control methods were exposed in order to control this machine. PID control is the most basic and provides a good response in transient and steady state, and its control result is effective, but it has some drawbacks (large overshoot, slow response, and poor dynamic performance), so it will be combined with artificial intelligent optimization techniques to provide reduced overshoot, fast speed response, high static precision, and improved dynamic performance. Particle Swarm Optimization (PSO) is simple to implement and does not require the gradient information of the response of a system. Particle swarm optimization algorithm is a searching technique using a population of particles, corresponding to each particle. Each individual or particle represents a solution to the problem and has more efficiency to find the problem solution. PSO is generally used to obtain PID parameters but with no response consideration designed, only to get the best PID parameters to minimize overshoot and rise time.

II. Brushless DC Motor Modelling

The Brushless DC motor is much identical to Conventional DC motor. The intuition between the Brushless DC motor and Conventional DC motor is the absence of brushes. It utilizes Hall sensor and inverter to commutate electrically and generate a trapezoidal back emf. The brushless DC motors are generally controlled using a three-phase inverter bridge circuit[4]. The motor needs a Hall sensor for starting and proper commutation sequence to turn on the power devices in the inverter bridge circuit. Based on the rotor position, the power devices are commutated sequentially for every 60 degrees. Instead of commutating the armature current using brushes, electronical commutation is used hence it define as electronic motor with dc source. This eliminates the problems associated with the brush-commutator assembly.

Mathematical Formulation of Three Phase BLDC Motor

The BLDC motor conduct in many phases system, but the most common is the 3-phase system. The 3-phase system has better efficiency. It has some cost implications but still the 3-phase has a very good precision control, and helpful in terms of the stator current.

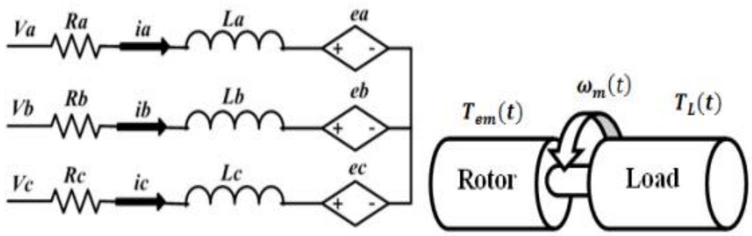

Figure no 1. BLDC motor model represents electrical and mechanical components

According to the concept of stator winding excitation, the inverter circuit energize two windings at the same time. Therefore, the motor input voltage is defined as the terminal voltage between two windings, with a magnitude equal to the supply voltage. Hence the three-phase voltage equation of BLDC motor is given as,

$$V_{ab} = R(i_a - i_b) + L\frac{d(i_a - i_b)}{dt} + (e_a - e_b) \quad (1)$$
$$V_{bc} = R(i_b - i_c) + L\frac{d(i_b - i_c)}{dt} + (e_b - e_c) \quad (2)$$
$$V_{ca} = R(i_c - i_a) + L\frac{d(i_c - i_a)}{dt} + (e_c - e_a) \quad (3)$$

Where, L= Per phase inductance of stator winding (Henry).
R = Per phase resistance of stator winding (Ohms).
V_a, V_b, V_c = Phase voltages of stator winding.
I_a, I_b, I_c = Phase currents of stator winding.
e_a, e_b, e_c = Back emf of stator winding.

The mechanical component is expressed as,

$$T_{em} = k_f\, w_m + J\frac{dw_m}{dt} + T_l \quad (4)$$

Where, T_{em} = Electromotive torque.
k_f = Viscous friction constant.
w_m = Angular speed of the motor.
J = moment of inertia.
T_l = Load torque.

Transfer function of BLDC motor

One of the most significant aspects of control theory is the transfer function. In the subject of automatic control, the transfer function based on a mathematical model is commonly utilized. The transfer function of a BLDC motor is extremely important for system control design and performance analysis. Unlike traditional DC motors, the stator windings of BLDC motors are energized based on the rotor position, and BLDC motors are typically constructed in three-phase or multi-phase configurations. Because of the mechanisms of back emf and electromagnetic torque for each phase winding conduction are identical to those of a conventional DC motor, the same analysis are taken into consideration.

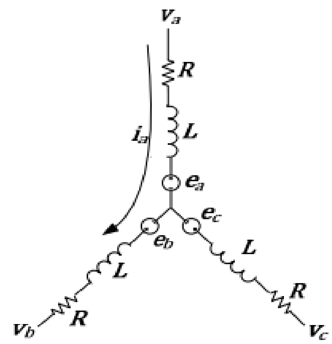

Figure no 2. Conducted two-phase windings (phase A and phase B)

According to Fig 2, when phase A and phase B are conducted, it can be formulated that

$$i_a = -i_b = i \qquad (5)$$

$$\frac{di_a}{dt} = -\frac{di_b}{dt} = \frac{di}{dt} \qquad (6)$$

Assuming the system in a steady state condition, e_a and e_b are same in magnitude but opposite in direction. Hence equation (1) can be rewritten as,

$$V_{ab} = 2R\,i + 2L\frac{di}{dt} + (e_a - e_{b)} \qquad (7)$$

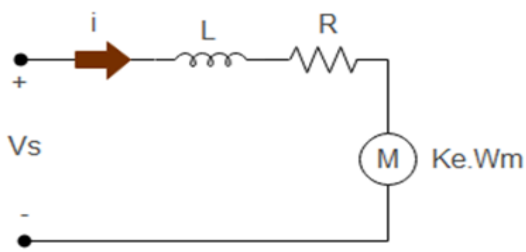

Figure no 3 Equivalent circuit of BLDC Motor.

From Fig 2,

Vs = $R\,i + L\frac{di}{dt} + k_e\,w_m$ (8)

$$k_t\,i - T_l = J\,\frac{dw_m}{dt} + k_f\,w_m \qquad (9)$$

Assume T_l = 0,

$$i = \frac{J}{k_t}\,\frac{dw_m}{dt} + \frac{k_f}{k_t}w_m \qquad (10)$$

Substitute equation (9) in equation (8)

$$Vs = R\left(\frac{J}{k_t}\frac{dw_m}{dt} + \frac{k_f}{k_t}\,w_m\right) + L\,\frac{d}{dt}\left(\frac{J}{k_t}\frac{dw_m}{dt} + \frac{k_f}{k_t}\,w_m\right) + \,k_e\,w_m \qquad (11)$$

$$Vs = \frac{L\,J\,d^2w_m}{dt^2} + \frac{R\,J + w_m}{k_t}\,\frac{dw_m}{dt} + \frac{R\,w_m + k_e\,k_t}{k_t}\,w_m \qquad (12)$$

Applying Laplace transform to equation (12) we get,

$$G(s) = \frac{k_t}{s^2JL + sk_fL + S\,R\,J + k_f\,R + k_e\,k_t} \qquad (13)$$

Table no 1 Parameters of BLDC Motor

Rating	Symbol	Units	Value
Nominal voltage	V	Volts	300
Nominal speed	w_m	RPM	1530
Nominal current	I	Amp	2.50
Nominal power	P	Watt	200
Nominal torque	T	Nm	5.9
Armature resistance	R (Ω)	Ohms	2.8750
Inductance	L	mH	8.5
Torque constant	k_t	mNm/A	21.65
Rotor inertia	J	gcm^2	90.52
Electrical torque	k_e	v-sec/rad	1.60
No. of phase	p		3

III. PI Controller Tunning

Proportional – Integral - Derivative controller (PID controller) is a commonly used conventional controller used for various applications to control parameters like speed, temperature, flow, pressure and other process variables. Zero state errors can occur with PID controllers. The system's response can be improved to achieve a faster response, oscillations in the system can be removed, and the system's stability can be improved. To phase out overshoot and oscillations in the system, a derivative of the output response is frequently added to a PI controller.

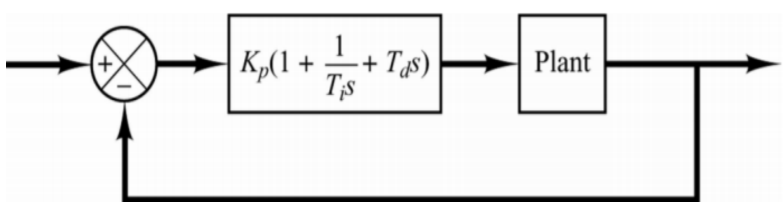

Figure no 4. PID Controller Block Diagram

The proportional controller recurrently reduces the rise time and frequently reduces the steady-state error of the system, but it never completely eliminates the error. On the other hand, the integrated control completely removes a system's permanent status error. A derivative control nevertheless enhances the system's stability, reduces overflow, and improves the system's transient response[4]. It in no way alters the system's constant state error The equation of pi controller is given as,

$$P_{out} = K_p\,e(t) + K_i\int e(t) \qquad (14)$$

The derivative controller responds to the rate of variation in error, however noise is form due to this action [7]. As a result, this paper refers only Proportional Integral (PI) Controller to control the speed of a BLDC motor as defined by the equation. The only problem is related to the optimal PI parameters values finding. Actually, this is can be resolved using the PI parameters adjusting tool as Nickels or the other tools. However, this does not guarantee the performance of the subsystem. Therefore, we try to resolve this problem using the optimization technic noted PSO.

IV. Particle Swarm Optimization Algorithm

PSO refers as an advanced optimization algorithm that inspired from swarm intelligence. PSO algorithm was implemented as simulating animal's social activities like insects and birds, Due to its structural simplicity, superior optimization capacity and rapid reaction, heuristic algorithms are commonly utilized in process management. It can be easily adapted to the current traditional controller design techniques due to their versatility. PSO algorithm was firstly introduced in 1995 by J. Kennedy and R.C. Eberhart [8]. Then, in 1998, this algorithm was modified to improve the performance of PSO itself by adding a new parameter, called inertia weight [11].

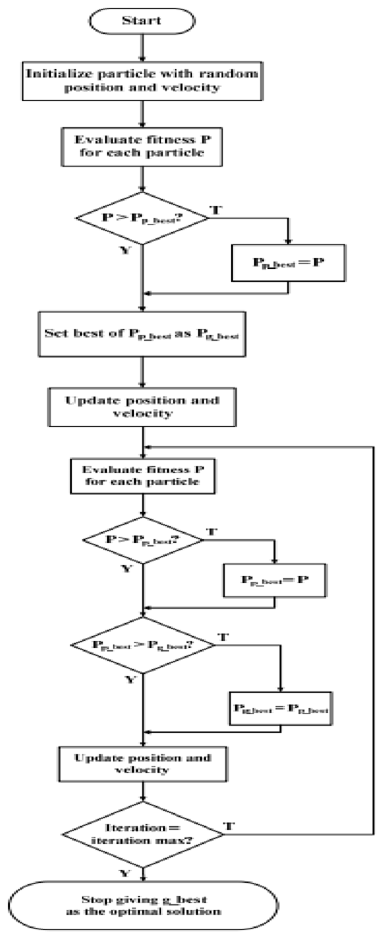

Figure no 5. Flow Chart of PSO Algorithm

Individuals in PSO are called particles. Each of particles is presented in D-dimensional space. The swarm concept could be adopted in engineering as yet another technique for determining optimized values in a multivariable framework, such as finding optimized values of PI controller. The particles in the swarm are the individual elements in the group that are responsible for moving to their personal best values (pbest) and the overall swarm's best values (gbest), all the while constantly searching for better values than what they currently initialize. The particles (potential solutions) are randomly initialized, and the initial population is evaluated in the

PSO method. If the terminating criterion is met, the operation is terminated. Otherwise, these particles will update their velocities and positions, and a new swarm will be evaluated.

The implementation of PSO is illustrated with this algorithm demonstrate in Figure and the optimization process are described as follows: First: Initialize the search points xi(0) and velocities vi(0) of each particle which are generated randomly in the specified given range. Current search position is set to pbest for each particle. The best evaluated value of pbest initialize to gbest and the particle number with the best value is declared. Then, the objective function value is calculated for every particle. If the value is better than the current pbest of the agent, the pbest value is replaced by the current value. If the best value of the pbest is better than the gbest, the current gbest is replaced with the best value of pbest, and the particle number with the best value is preserved. The third step is to modify each searching point and the current searching point of each agent is changed using the first and second steps, and then the exit condition must be checked; if the number of iterations surpasses the determined maximum iteration, the agent must exit. Or else, proceed to the second step.

The velocity of particle is calculated by the formula given below,

$$V_{id}^{t+1} = w\, V_{id}^{t} + c_1\, ran_1\, (P_{best\ id}^{t} - X_{id}^{t}) + c_2\, ran_2\, (G_{best\ id}^{t} - X_{id}^{t}) \quad (15)$$

The position of each particle is to be updated by the given formula,

$$X_{id}^{t+1} = X_{id}^{t} + V_{id}^{t+1} \quad (16)$$

The parameter used for implementation in PSO algorithms for this paper is mentioned in Table

Table no 2. Parameters of PSO Algorithm

Parameter	Value
No. of particles	20
No. of iteration	50
Cognitive factor (c1)	2
Exploration factor (c2)	2
Proportional Gain (Kp)	8.38
Integral Gain (Ki)	410.86

V. Simulink Model of BLDC Motor with PI Controller

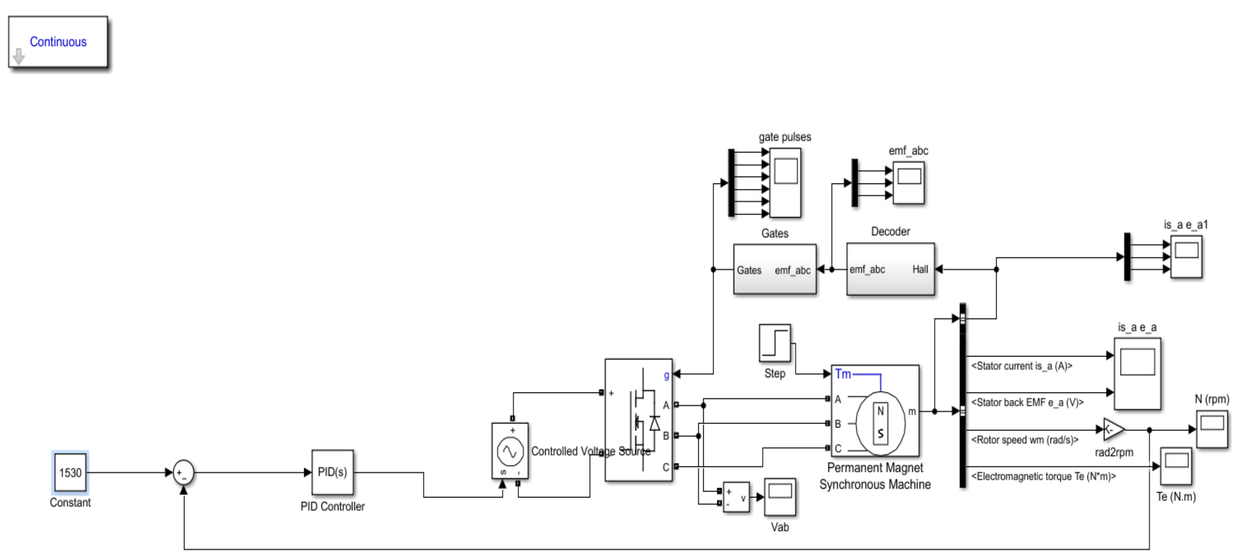

Figure no 6. Simulink Model of BLDC Motor

VI. Simulation Result and Analysis

The MATLAB /Simulink model for the BLDC motor is implemented for the PI control on the speed of the motor with reference speed of 1530 rpm. In MATLAB, during simulation the step load is applied on the BLDC drive system. Furthermore, noise is added to the control system in order to replicate the practical process. The process is continuous in practical online mode, without shutting off or resuming. . A fixed number of iterations to evaluate the control system are now provided for the convenience of simulation. The position values of the particles in the search space indicate the values of Kp and Ki parameters of the PI speed controller for the BLDC drive system.

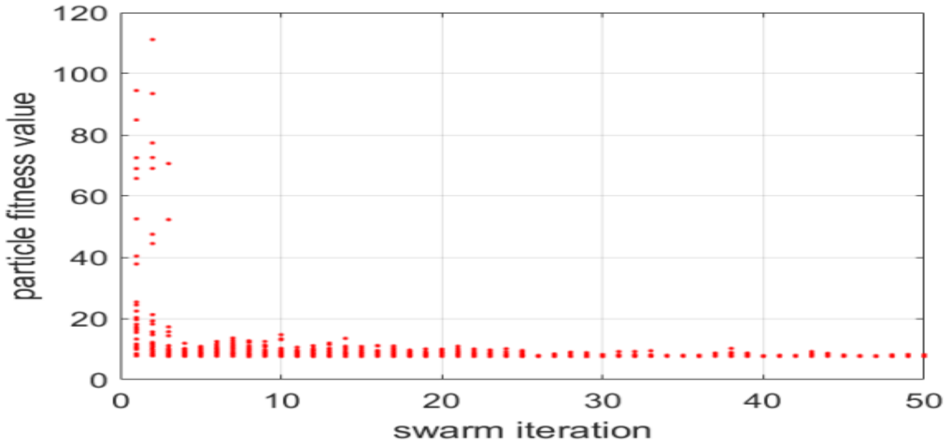

Figure no 7. Values of Fitness Function

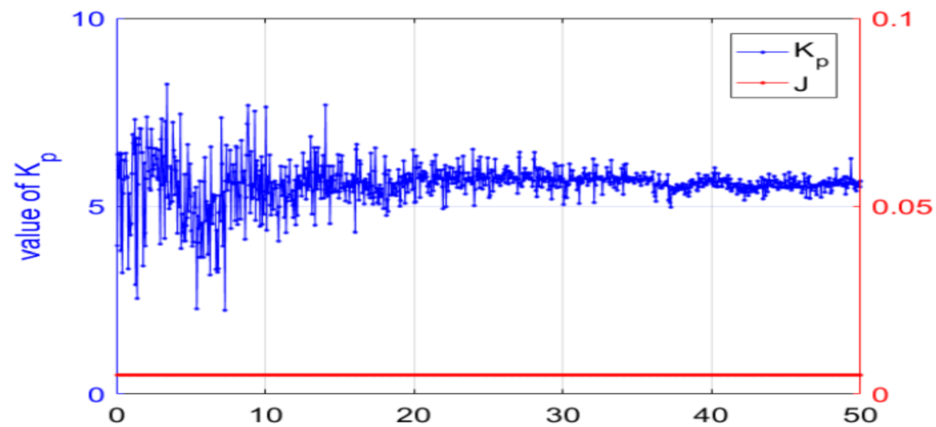

Figure no 8. Value of Proportional Gain (Kp)

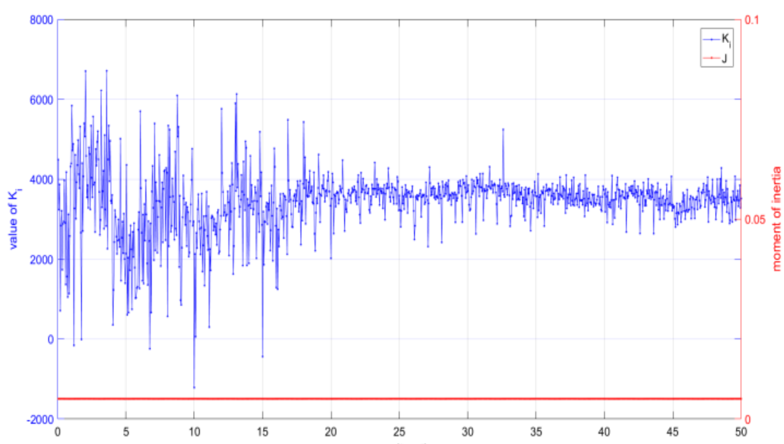

Figure no 9. Value of Integral Gain (Ki)

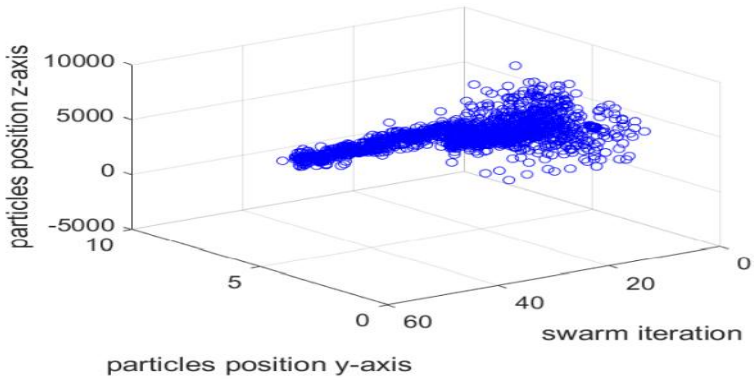

Figure no 10. Position of the Particles

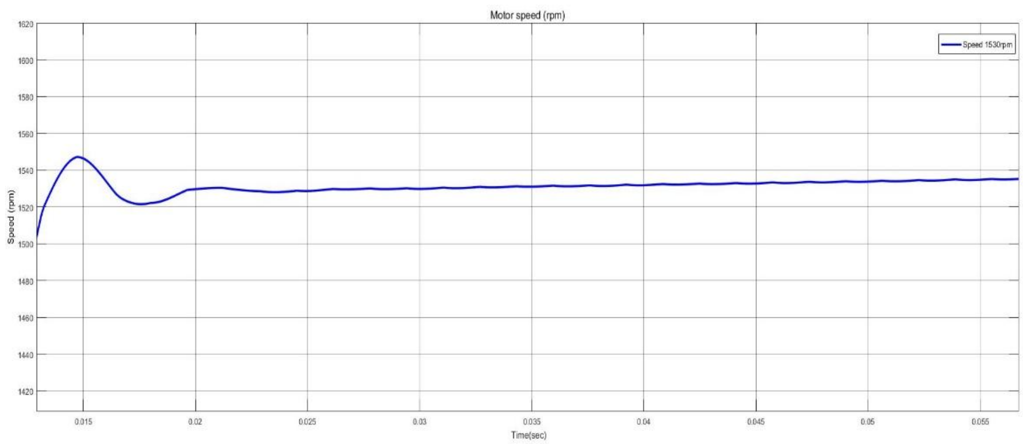

Figure no 11. Speed- Time Characteristic of the motor

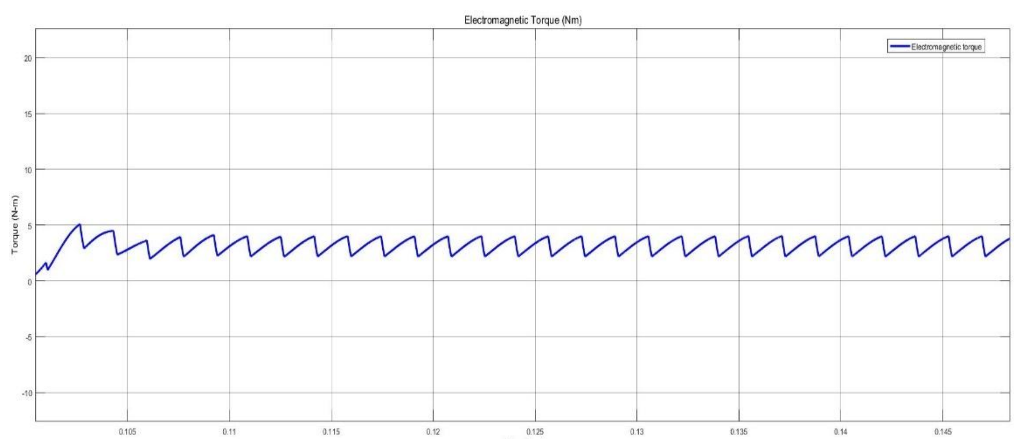

Figure no 12. Torque- Time Characteristic of the motor

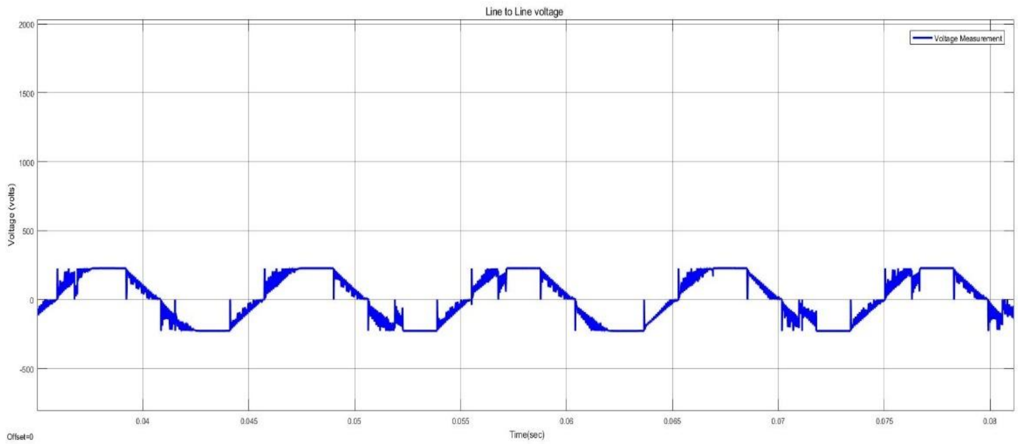

Figure no 13. Line to Line Voltage waveform of the motor

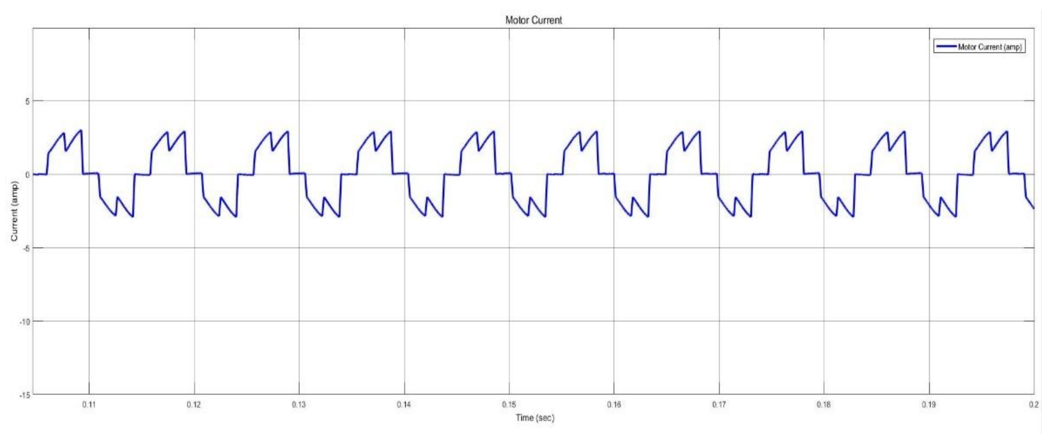

Figure no 14. Current Waveform of motor

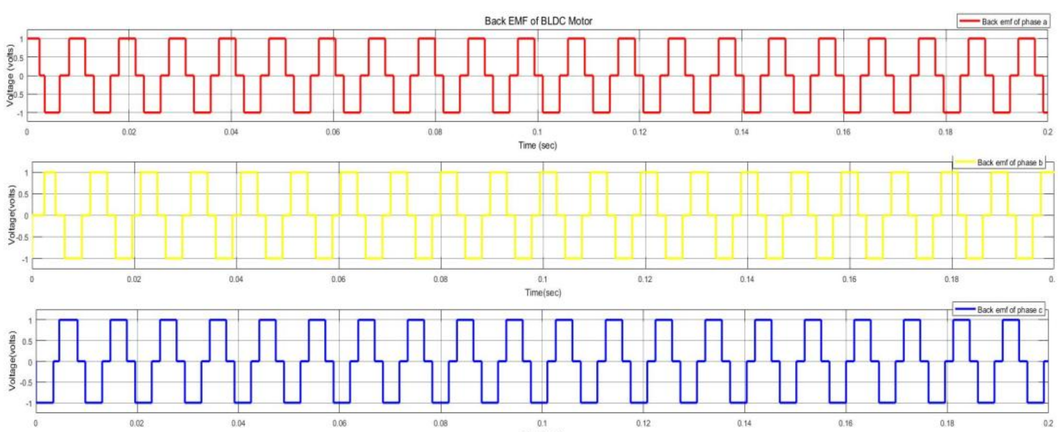

Figure no 15. Back EMF waveform of motor

Fig 7,8,9,10 represents the value of Kp and Ki gain of PI controller for tunning the BLDC motor in order to get the desired speed control. Fig 11. shows that the maximum desired speed is achieved at the shaft end of the motor which concludes that the speed control is optimize and desired value is achieve that is 1530RPM. Fig 13 represent the line-to-line voltage waveform having the magnitude of 300 volts. Fig 15 shown the back emf of bldc motor which is 120 degrees apart from each other because of hall sensor effect which operates only two phases at a one time.

VII. Conclusion

The aim of this paper is to propose an efficient algorithm to control the speed of PMBLDC motor such that it operates effectively at variable speeds. Results of speed control of BLDC motor have been designed by adopting PSO algorithm. After iteration, PI Controller's parameters are obtained with optimized values which are used in further processing of speed control of motor. The Simulation is performed by using MATLAB/SIMULINK. The PID controller is tuned using PSO algorithm which shows an improvement in the time response with lower overshoot and faster settling time. For future work, a new innovation in PSO algorithm can be proposed to provide better optimal values after convergence so that the PID control is more efficient. Further to this, the simulation work can be implemented on real-time hardware.

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