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Performance enhancement of BLDC motor using PID controller

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ABSTRACT

Mainly the DC motors are employed in most of the application. The main objective is to Regulate the DC motor system. A motor which displays the appearances of a DC motor but there is no commutator and brushes is called as brushless DC motor. These motors are widespread to their compensations than other motors in relationships of dependability, sound, efficiency, preliminary torque and longevity. To achieve the operation more reliable and less noisy, brushless dc motors are employed. In the proposed work, dissimilar methods of speed control are analysed. In real time submission of speed control of BLDC motor, numerous strategies are executed for the speed control singularity. The modified approaches are the employment of PI controller, use of PID controller and proposed current controller.

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1. INTRODUCTION

BLDC motors have an outsized number of applications in industries. The only difference between a BLDC motor and a permanent synchronous motor is the back EMF [1], [2]. The back EMF in a permanent synchronous motor is of sinusoidal form and in a BLDC, machine is of trapezoidal form. Commutation is the process of interchanging the current through the coil which make the motor to spin. The commutation of the currents is done with the help of automatically changes DC to AC which is basically supplied by a DC source.

The currents which induced in the rotating part can be failed due to very high resistivity of mutually stainless steel and magnet. Damping winding should be of very less value because due to this only magnetic flux got decreases [3], [4]. The BLDC Motor is run on DC supply rather than AC Supply. The DC voltage is converted into 3-phase AC voltage, which is then supplied to the motor. AC source can also be used and then it can be converted into DC but the main disadvantage of converting AC to DC is that it will cause new problems like THD, poor power factor, poor quality etc. that’s why BLDC motors are run on DC source and not on AC [5], [6]. The DC source can be directly connected or it can be given by connecting it across any of the converters like DC-DC converter, SEPIC converter etc. BLDC fed with diode bridge rectifier has poor power factor. By using different converter techniques Voltage can be controlled and power factor can be improved [7], [8].

Different simulations are performed by researchers to analyse the performance and process of the procedure to get the better speed regulation and higher starting torque of the motor. The researchers are working on tuning PID controllers by performing iterations, trying PSO algorithms, experimenting using Fuzzy logic controllers and also trying the conventional methods [9], [10]. Speed control theatres a necessary role in the current world. The speed control offers many advantages such as higher reliability, higher efficiency, high starting torque and reduced electrical noise. The speed control is of two types: open and closed loop. In this first system, there is no response path and the desired speed may/may not be obtained. The machine parameters and gate pulses sequences are considered, which needed to be chosen more carefully while designing the system. The closed loop system is the one in which a feedback loop is always present and the speed control is easy. The desired speed can be obtained using this mechanism [11], [12]. The closed loop system employed here is the dual closed loop system.

2. PROPOSED TERMINOLOGY

2.1. Reference speed

The input speed to the motor is given by the reference speed. It is the motor speed that is to be obtained [13]. The reference speed will be compared with the actual speed of the motor. The difference between the actual and reference speed is denoted as error. The enchanced performance of the motor is based the zero error from the actual and reference speed.

2.2. Actual speed

It is the speed at which the motor rotates. It is obtained from the machine after running the motor with initial variables. Initially, this speed is obtained on the basis of the machine parameters and the torque given to the motor. The output speed of the motor in the MATLAB Simulink software is expressed in rps. It is converted into RPM by multiplying it by gain (k= 30/pi) [14], [15].

2.3. Load torque

The BLDC Motor needs an external initial load torque so that the motor can run if the current is not sufficient enough to start the motor. In these simulations, the load torque is given as a constant value [16]. Based on the constant value of torque given, performance of the torque response will be analysed for BLDC motor. The BLDC motor require external intial torque during starting of the motor.

2.4. Rotor position

This block gives the information about the position of the rotor. This uses the hall sensors which send signals corresponding to the position of rotor with signal for each phase. This plays a very important role in triggering of gate pulses of 3-phase inverter.

2.5. Controlled voltage source

The input to the circuitry is a DC Supply. A controlled voltage source is used which has a fixed amplitude but keeps changing with the change in the error speed. The error speed is defined by the difference between the actual and reference speed. If the actual speed of the motor varied, the error speed will be different. The amplitude of voltage source will be varied due to the change in the acyual speed.

2.6. Three phase inverter

It is used to convert the DC supply into the 3-phase AC supply, which serves as input to the motor. MOSFET's are used as switching devices. The gate pulses for these switches are obtained from a closed loop system for the operation of the inverter [17].

2.7. Decoder

The function of this block is to convert the hall signals into EMF signals corresponding to each phase. The Hall Sensors send the signals corresponding to each phase in the motor. The Hall Effect signals are given by Ha, Hb and Hc. These signals are converted into EMF signals represented by emf_a, emf_b and emf_c. The decoder can be designed based on this truth table by either using a MATLAB function or by traditional methods of using gates [18], [19].

2.8. Firing signal generator

The function of this block is that it provides the gate pulses for the switching of the MOSFET's in the 3-phase inverter. This receives the input from the decoder and gives the output as pulses. The number of outputs from this block depends on the number of MOSFET switches present in the inverter. The signals then operate the inverter in either 120-degree conduction mode or 180-degree conduction mode, depending on the requirement [20].

3. OPERATION PRINCIPLE

The BLDC Motor works on the principle based on the feedback from internal shaft or rotor. Unlike brushed DC motors, where feedback is maintained using commutator and brushes, the brushless DC motor uses certain feedback sensors to attain the position of the rotor [21]-[23]. For the three phase BLDC motor, the back EMF is of trapezoidal form and there is a phase difference of 120-degree [24]-[26]. The model of BLDC motor is illustrated in Figure 1. The output waveforms for the back EMF [27], [28] and the output currents is shown Figure 2.

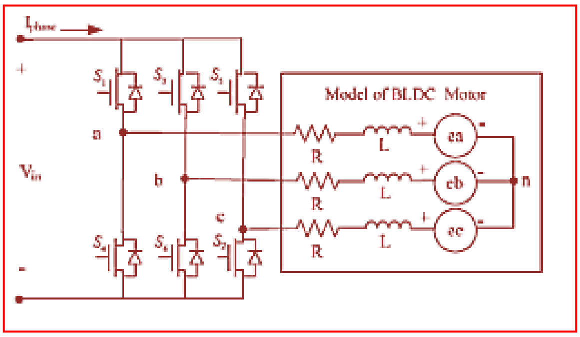

Figure 1. Model of BLDC motor

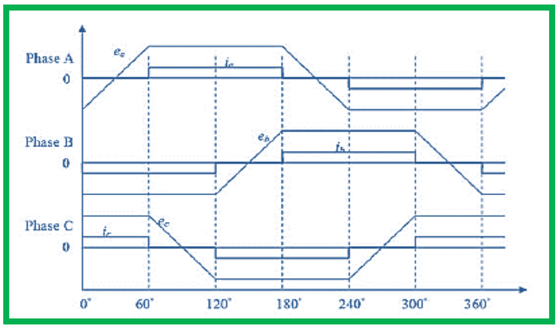

Figure 2. Output waveforms of back EMF and currents

4. PROPOSED METHOD

The methods used for the speed control of the BLDC Motor use the dual closed loop speed control in which the one loop is used to limit the current or govern the current control or for the control of the gate pulses. The other loop is for speed control which is used to get the desired speed as per the requirement. The required speed can be either set as an integer value or can be given as step input. The reference speed is given as a constant value which can be changed based on the requirement and accordingly the desired speed can be obtained. The methods used in this paper are namely speed control using PI controller, using Current Controller and a CUK converter based dual closed loop speed control. These methods are compared based on the values of current total harmonic distortion (THD), output current (RMS value) and on the values of rise time and settling time of the speed response of various methods.

4.1. PI control

This method is a dual closed loop speed control in which the PI controller is used for controlling the speed of BLDC motor. In this method, the feedback speed from the motor is compared with the reference speed. The error speed is then passed through the PI controller which then is given directly to the controlled Voltage Source. The voltage source is a DC Voltage Source which gives supply to the MOSFET bridge. The bridge converts the DC supply into the 3-phase AC supply which is then given to the motor. The motor gives various outputs including stator currents, Hall Effect signals, back EMF voltages, electromagnetic torque and speed of the rotor (in rps). The output from the Hall Sensors is then used to determine the position of the rotor of the motor. These signals form a closed loop in which these signals are converted into the EMF signals and again converted to the gate signals using different topologies and is converted to the gate signals based on the number of switches connected in the MOSFET bridge. These signals serve as the gate signals for controlling the voltage which in turn control the input voltage to the motor which in turn helps in controlling the speed of the motor. The PI controller is used as it helps in eliminating the steady state error. The main disadvantage of the PI controller is that the oscillations cannot be removed and also, rise time cannot be decreased by use of this controller. The PI controller gives the output based on the sum of proportional gain and integral gain. Mathematically:

$$\text{Output}= Kpe(t) + Ki\int_0^t e(t)dt \quad (1)$$

The block diagram depicting the circuitry of the system is shown in Figure 3. The truth table depicting the operation of the firing signal generator block is depicted in Table 1. The 3-phase inverter operates in 120degree conduction mode, which is why at a time only two of the switches' conducts.

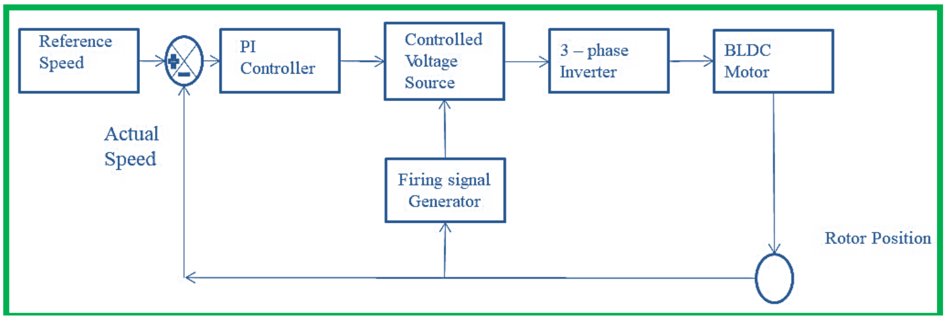

Figure 3. Block diagram using PI control

Table 1. Firing signal generator truth table

Emf_a	Emf_b	Emf_c	Q1	Q2	Q3	Q4	Q5	Q6
Zero	zero	Zero	Zero	Zero	Zero	Zero	Zero	zero
Zero	-1	VH	Zero	Zero	Zero	VH	VH	zero
-1	VH	Zero	Zero	VH	VH	Zero	Zero	zero
-1	zero	Zero	Zero	VH	Zero	Zero	VH	zero
VH	zero	-1	VH	Zero	Zero	Zero	Zero	one
VH	-1	Zero	VH	Zero	Zero	VH	Zero	Zero
Zero	VH	-1	Zero	Zero	VH	Zero	Zero	VH
Zero	zero	Zero	Zero	Zero	zero	Zero	Zero	Zero

4.2. PID controller

This method of speed control using PID controller is implemented as it has many advantages as zero steady state error, no oscillations, higher rate of response and providing more stability to the system. This controller is used as it helps in eliminating the overshoot and the oscillations occurring in the system's output. The output in a PID controller is the sum of proportional gain, integral gain and derivative gain as illustrated in Figure 4.

$$\text{Output}=Kpe(t) + Ki\int_0^t e(t)dt + Kd * d/dt(e(t)) \quad (2)$$

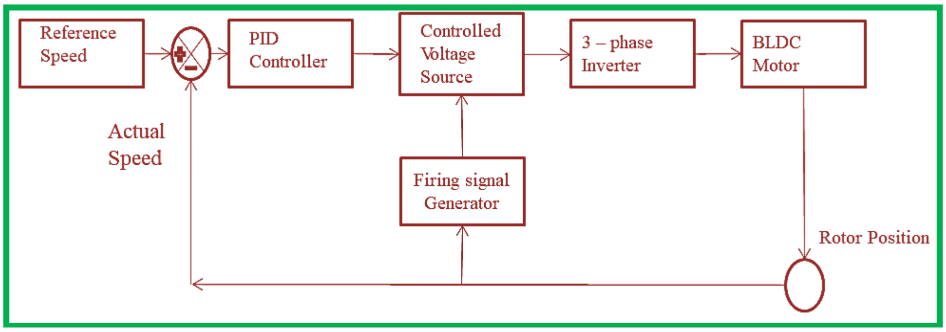

Figure 4. Block diagram of PID controller

4.3. Proposed current control

The novelty of the work is based on the proposed current controller which is used to control the switching states of the MOSFET bridge. This method takes the Phasor current from the input supply to the motor and is compared with a reference value the signals are converted in the form of 0's and 1's. The Hall effect signals from the hall sensors which determine the position of the rotor give the position in the form of 0's and 1's. These signals are converted into EMF signals of the form -1, 0, +1. These signals are obtained based on the decoder truth table. The signals are then compared with the current signals which generate 6 gate pulses for the MOSFET Bridge. This method helps in controlling the input supply to the motor, indeed controlling the speed of the motor. This also uses the dual closed loop system, one loop for controlling the switching of the MOSFET and the other loop for controlling the speed output. The reference speed and actual speed are compared and the output signal is given directly to the controlled DC voltage source. The block diagram depicting this circuitry of this method is as under Figure 5.

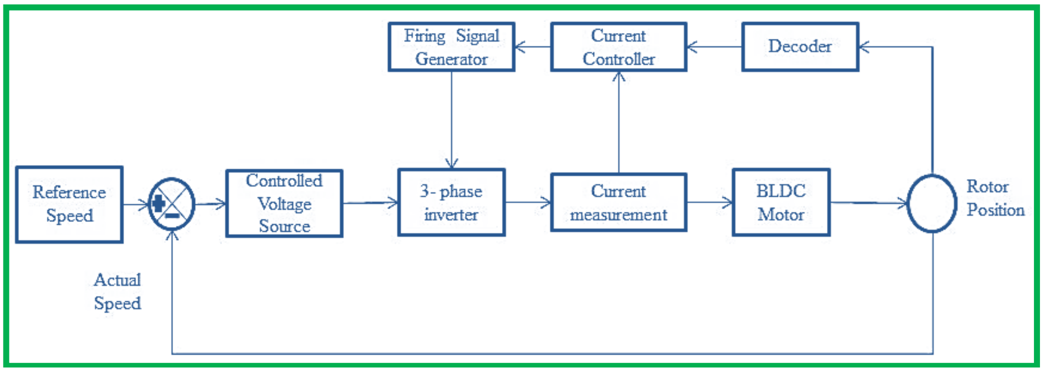

Figure 5. Block diagram of current controller algorithm

5. RESULTS AND DISCUSSION

The simulations are carried on a model of BLDC motor. The parameters of the machine are mentioned below with their standard values as shown in Table 2. The simulations are performed in MATLAB/Simulink software and the outputs are obtained for different models and are given below. Frequency analysis is also performed for all the models. It is done in order to know which model is better and which shows less distortion while operating at a certain frequency. This also allows to know which method is advantageous over other in terms of both efficiency and economically. The hardware implementation of model which is much better than the others is also done.

Table 2. Machine parameters

Parameters	Value
Stator Phasor resistance (Rs)	0.7 ohm
Armature inductance	2.72e-3 H
Flux linkage established by magnets	0.105 Wb
Voltage constant	87.9646 (V/krpm)
Torque constant	0.84 (N/A)
Inertia	08e-3 J
Viscous damping	1e-3
Pole pairs	4
Static friction	0
Number of phases	3
Back EMF	Trapezoidal
Mechanical Input	Torque
Back EMF flat area (degrees)	120º

5.1. Speed control using PI controller

The speed control is achieved by proportional and integral controller. The stator current, back EMF, speed and electromagnetic torque performance are analysed. The output waveforms for different characteristics are shown above from Figures 6 to 10. These characteristics of the BLDC motor can help in determining which method is best among these three. In order to reduce the harmonics the current control methodsis proposed and enhanced speed performance compared to the conventional methods. The 5% error is allowed for the error in the value of the actual speed, as the error may occur due to the switching states, friction force in the machine or due to the operation under variable frequency.

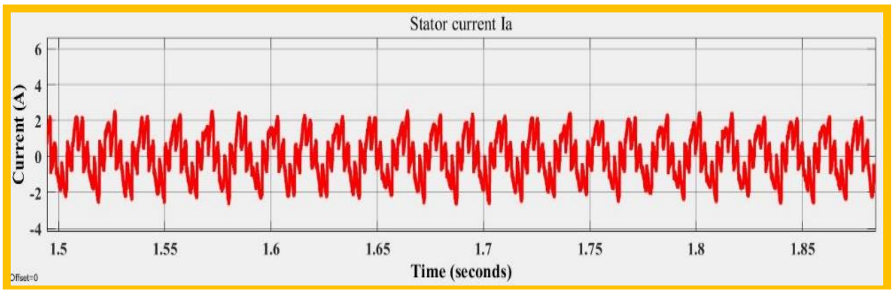

Figure 6. Output stator current

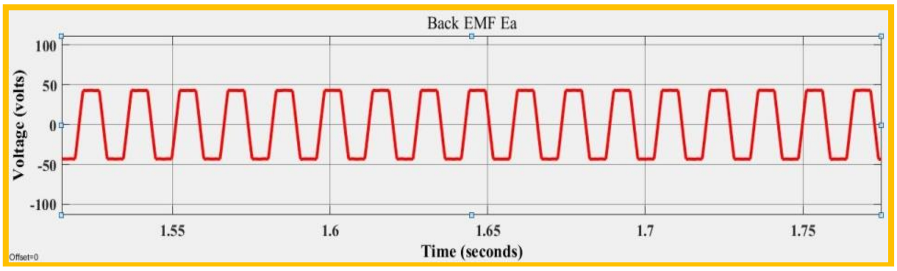

Figure 7. output back EMF

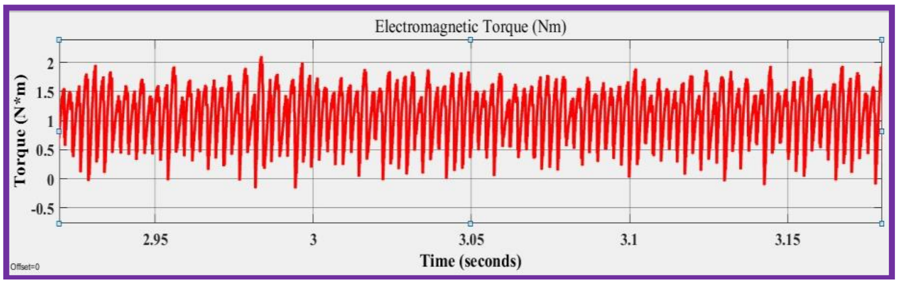

Figure 8. Output electromagnetic torque

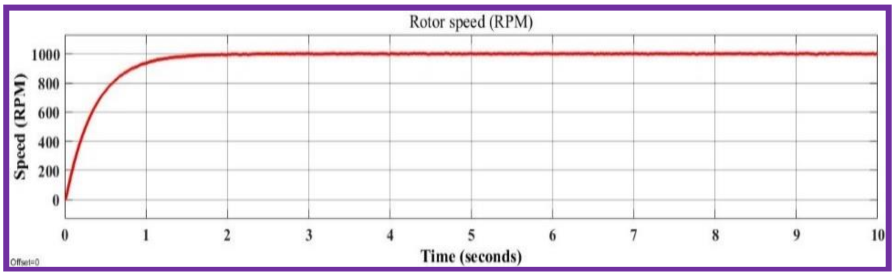

Figure 9. Output speed

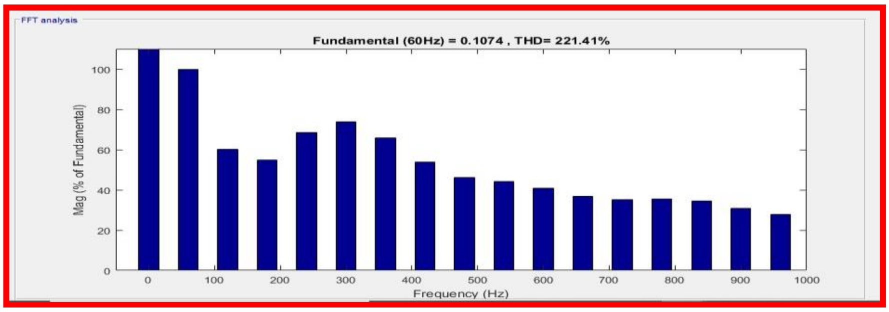

Figure 10. Frequency analysis at fundamental frequency of 50 H

5.2. Speed control using PID controller

The speed control is achieved by proportional, integral and derivative controller. The stator current, back EMF, speed and electromagnetic torque performance are analysed. The output waveforms for different characteristics using PID controller are depicted from Figures 11 to 15.

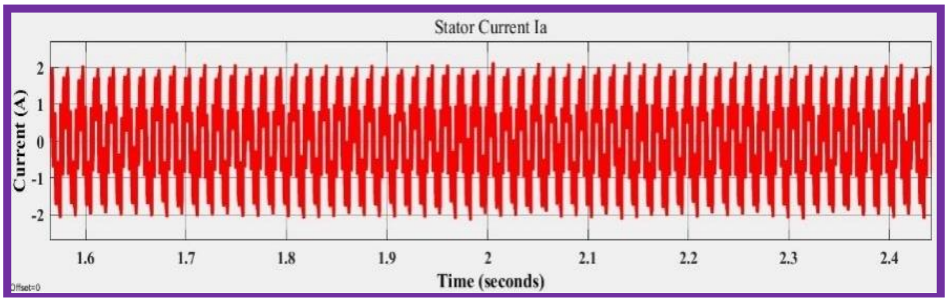

Figure 11. Output current

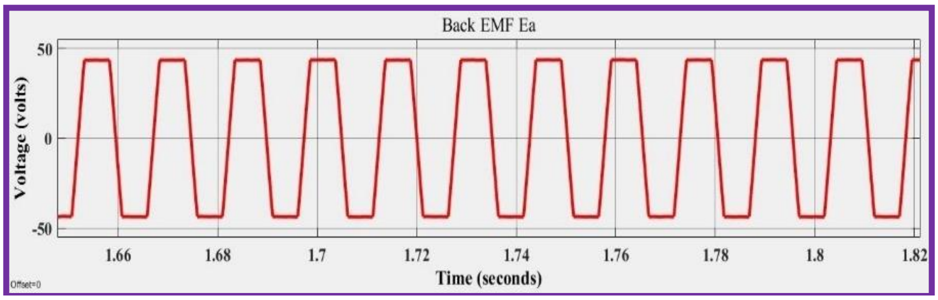

Figure 12. Back EMF

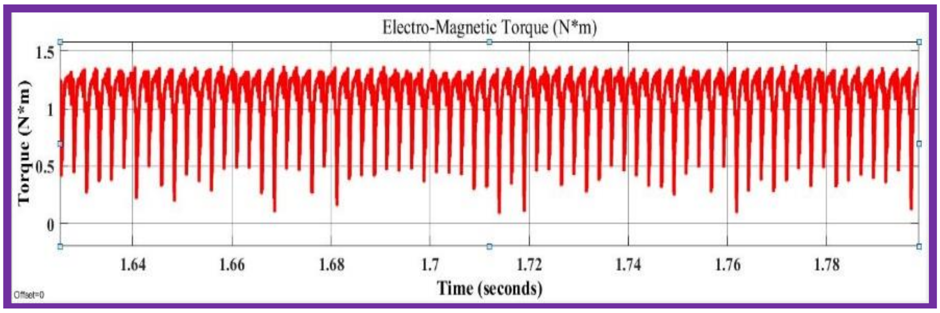

Figure 13. Output electromagnetic torque

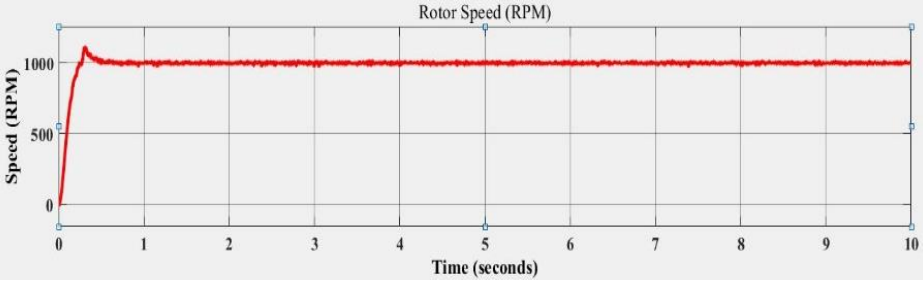

Figure 14. Output speed

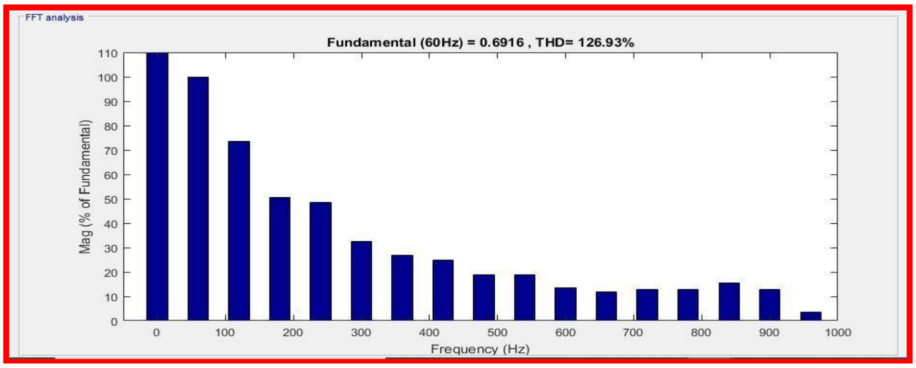

Figure 15. Frequency analysis at fundamental frequency of 50 Hz

5.3. Speed control using proposed current controller

For a reference speed of 1000 RPM, the actual speed is obtained among different control methods. The 5% error is allowed for the error in the value of the actual speed, as the error may occur due to the switching states, friction force in the machine or due to the operation under variable frequency. The reduced harmonics and improved performance of BLDC motor using proposed current controller are depicted Table 3 and also from Figures 16 to 19.

Table 3. Performance analysis

Performance	PID controller	PI controller	Current controller
Output Speed	1002RPM	1002 RPM	1002 RPM
Current THD	126.93 %	221.41 %	87.12 %
Signal ripple	Medium	Very high	Low
Rise time (seconds)	0.2	0.75	0.02855
Settling time (seconds)	0.6	1.8	0.1

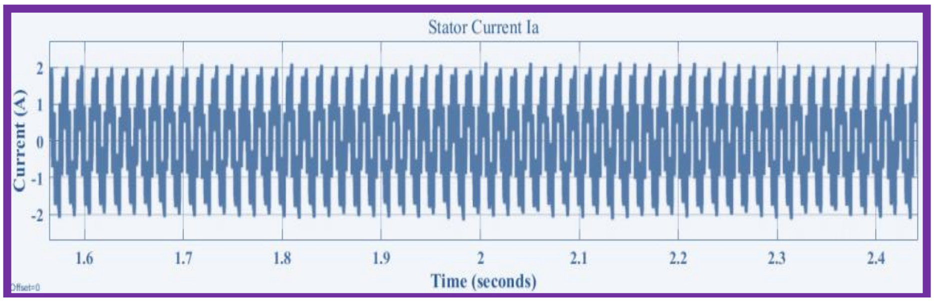

Figure 16. Output current

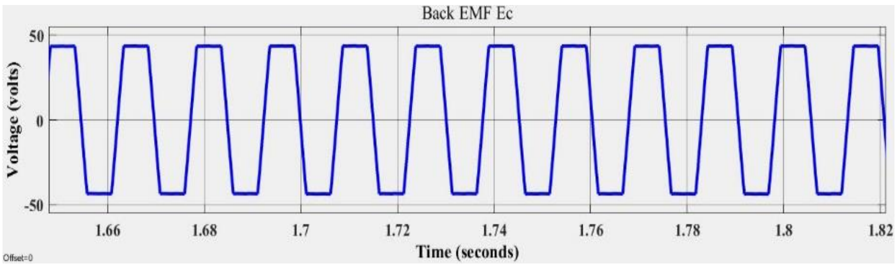

Figure 17. Back EMF

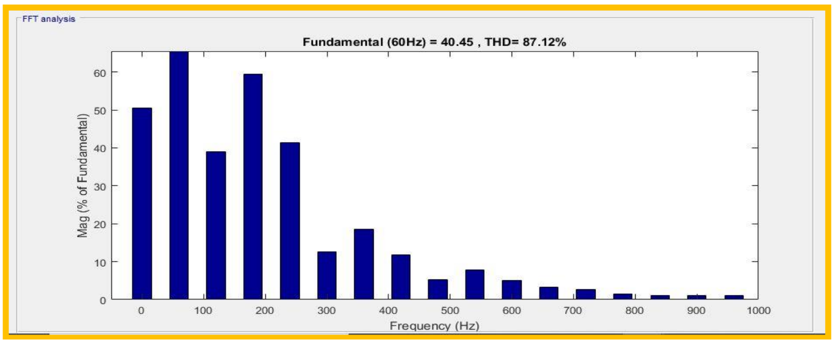

Figure 18. FFT analysis of BLDC motor using proposed current controller

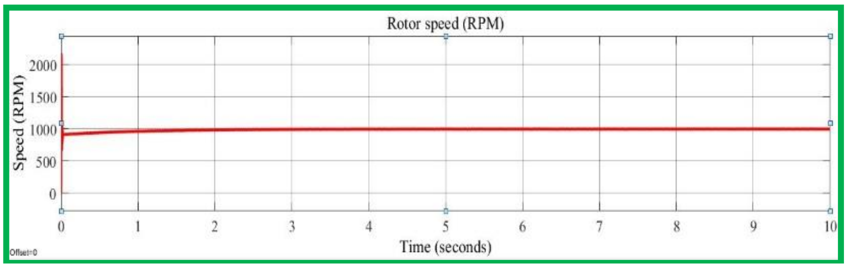

Figure 19. Speed response of BLDC motor using proposed current controller

6. CONCLUSION

Different methods of speed control are discussed. These methods implement the use of PI controller and use of PID controller. These models were modeled in MATLAB/Simulink and the outputs were obtained for different parameters like stator Phasor current, Back EMF voltages, output speed, electromagnetic torque and FFT analysis. Different parameters were compared so as to conclude the method more efficient among the three. Frequency analysis was done with the fundamental frequency of 50Hz on the stator current (Ia) which showed the THD in the machine. FFT analysis is done on all of the controller techniques and the results were obtained. The PID controller at fundamental frequency of 50 Hz showed THD of 87.12% whereas the PI controller at fundamental frequency of 50 Hz showed THD of 221.41%. This showed that PID controller is the most suitable option among these control techniques. The machine was run for a total of 10 seconds and the corresponding waveforms were obtained. Rise time and settling time of the output speed of the machine were also calculated. The simulation results showed that the use of PID controller for the speed control of BLDC motor proves to be more efficient?

REFERENCES

[1] P. Pillay, and R. Krishnan, "Modeling, simulation, and analysis of permanent-magnet motor drives. II. The brushless DC motor drive," in *IEEE Transactions on Industry Applications*, vol. 25, no. 2, pp. 274-279, March-April 1989, doi: 10.1109/28.25542.
[2] P. Pillay, and R. Krishnan, "Modeling of permanent magnet motor drives," in *IEEE Transactions on Industrial Electronics*, vol. 35, no. 4, pp. 537-541, Nov. 1988, doi: 10.1109/41.9176.
[3] A. M. Niasar, A. Vahedi, and H. Moghbelli, "Speed control of a brushless DC motor drive via adaptive neuro-fuzzy controller based on emotional learning algorithm," in *2005 International Conference on Electrical Machines and Systems*, Vol. 1, 2005, pp. 230-234, doi: 10.1109/ICEMS.2005.202518.
[4] J. Moreno, M. E. Ortuzar, and J. W. Dixon, "Energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks," in *IEEE Transactions on Industrial Electronics*, vol. 53, no. 2, pp. 614-623, April 2006, doi: 10.1109/TIE.2006.870880.
[5] A. Rubaai, A. Ofoli, and M. Castro, "dSPACE DSP-based rapid prototyping of fuzzy PID controls for high performance brushless servo drives," in *Conference Record of the 2006 IEEE Industry Applications Conference Forty-First IAS Annual Meeting*, 2006, pp. 1360-1364, doi: 10.1109/IAS.2006.256707.
[6] R. Civilian, and D. Stupak, "Disk drive employing multi mode spindle drive system," US patent 5471353, Oct 3, 1995.

[7] G. H. Jang, and M. G. Kim, "A bipolar-starting and unipolar-running method to drive an HDD spindle motor at high speed with large starting torque," in *APMRC 2004 Asia-Pacific Magnetic Recording Conference*, 2004, pp. 36-37, doi: 10.1109/APMRC.2004.1521938.
[8] E. Grochowski, and R. F. Hoyt, "Future trends in hard disk drives," in *IEEE Transactions on Magnetics*, vol. 32, no. 3, pp. 1850-1854, May 1996, doi: 10.1109/20.492876.
[9] J. D. Ede, Z. Q. Zhu, and D. Howe, "Optimal split ratio for high-speed permanent magnet brushless DC motors," in *ICEMS'2001. Proceedings of the Fifth International Conference on Electrical Machines and Systems (IEEE Cat. No.01EX501)*, vol. 2, 2001, pp. 909-912 doi: 10.1109/ICEMS.2001.971826.
[10] S. X. Chen, M. A. Jabbar, Q. D. Zhang, and Z. J. Liu, "New challenge: electromagnetic design of BLDC motors for high speed fluid film bearing spindles used in hard disk drives," in *IEEE Transactions on Magnetics*, vol. 32, no. 5, pp. 3854-3856, Sept. 1996, doi: 10.1109/20.539195.
[11] T. Kenzo, and S. Nagamori, *Permanent magnets and brushless DC motors*, Tokyo: Sogo Electronics, 1984.
[12] S.W. Cameron, "Method and apparatus for starting a sensorless polyphase dc motors in dual coil mode and switching to single coil mode at speed," U.S. Patent 5455885, Nov. 28, 1995.
[13] T. Gopalarathnam, and H. A. Toliyat, "A new topology for unipolar brushless DC motor drive with high power factor," in *IEEE Transactions on Power Electronics*, vol. 18, no. 6, pp. 1397-1404, Nov. 2003, doi: 10.1109/TPEL.2003.818873.
[14] B. Singh and S. Singh, "State of art on permanent magnet brushless Dc motor drives," *Journal of Power Electronics*, vol. 9 no. 1, pp. 1-17, 2009.
[15] B. K. Bose, "Power electronics and motion control-technology status and recent trends," in *IEEE Transactions on Industry Applications*, vol. 29, no. 5, pp. 902-909, Sept.-Oct. 1993, doi: 10.1109/28.245713.
[16] B.-K. Lee, T.-H. Kim, and M. Ehsani, "On the feasibility of four-switch three-phase BLDC motor drives for low cost commercial applications: topology and control," in *IEEE Transactions on Power Electronics*, vol. 18, no. 1, pp. 164-172, Jan. 2003, doi: 10.1109/TPEL.2002.807125.
[17] R. Carlson, M. Lajoie-Mazenc, and J. C. d. S. Fagundes, "Analysis of torque ripple due to phase commutation in brushless DC machines," in *IEEE Transactions on Industry Applications*, vol. 28, no. 3, pp. 632-638, May-June 1992, doi: 10.1109/28.137450.
[18] J. L. Castro, "Fuzzy logic controllers are universal approximators," in *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 25, no. 4, pp. 629-635, April 1995, doi: 10.1109/21.370193.
[19] C. Xia, Z. Li, and T. Shi, "A control strategy for four-switch three-phase brushless DC motor using single current sensor," in *IEEE Transactions on Industrial Electronics*, vol. 56, no. 6, pp. 2058-2066, June 2009, doi: 10.1109/TIE.2009.2014307.
[20] C. Weitian, "Sufficient conditions on fuzzy logic controllers as universal approximators," in *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, vol. 31, no. 2, pp. 270-274, April 2001, doi: 10.1109/3477.915352.
[21] D. Kim, K. Lee, and B. Kwon, "Commutation torque ripple reduction in a position sensorless brushless DC Motor Drive," in *IEEE Transactions on Power Electronics*, vol. 21, no. 6, pp. 1762-1768, Nov. 2006, doi: 10.1109/TPEL.2006.882918.
[22] K. Swapnil, J. Anjali, A. Mohan and D. Shantanu, "Modeling andcontrol of a permanent-magnet brushless DC motordrive using afractional-order proportional-integral-derivative controller," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 25, no. 5, pp. 4223-4241, 2017, doi: 10.3906/elk-1612-277.
[23] M. V. Rajkumar, G. Ranjhitha, M. Pradeep, M. Fasil PK, and R. Sathish Kumar, "Fuzzy based speed control of brushless DC motor fedelectricvehicle," *International Journal of Innovative Studies inSciences and Engineering Technology (IJISSET)*, vol. 3, no. 3, pp. 12-17,2017.
[24] M. Singirala, D. Krishna, and T. A. Kumar, "Improving performance parameters of PMBLDC motor using fuzzy sliding mode controller," *International Journal of Recent Technology and Engineering*, vol. 8, no. 4, pp. 3684-3689,2019, doi: 10.35940/ijrte.D7942.118419.
[25] S. M. A. Motakabber, T. Rahman, M. I. Ibrahimy, and A. H. M. ZahirulAlam, "PLL-based 3φ inverter circuit for microgrid system operatedby electrostatic generator," *IIUM Engineering Journal*, 2019, vol. 20, no. 1, pp. 177-193, doi: 10.31436/iiumej.v20i1.1071.
[26] T. Rahman, S. M. A. Motakabber, M. I. Ibrahimy, and A. 'Aini, "APWM controller of a full bridge single-phase synchronous inverter formicro-grid system," in *IOP Conf. Series: Journal of Physics*, 2017, pp. 1-7, doi: 10.1088/1742-6596/949/1/012020.
[27] S. M. A. Motakabber, N. Amin, and M. A. Mohd Ali, "Computer aided design of an active notch filter for HF Band RFID," *Frequenz*, vol. 64, no. 1-2, pp. 23-25,2010, 10.1515/FREQ.2010.64.1-2.23.
[28] E. Can, and H. H. Sayan, "The performance of the DC motor by the PID controlling PWM DC-DC boost converter," *Tehničkiglasnik*, vol. 11, no. 4, pp. 182-187, 2017.