Dogo Rangsang Research Journal
ISSN : 2347-7180
UGC Care Journal
Vol-10 Issue-12 No. 01 December 2020

Comparative Studies of open Loop Control of BLDC Motor with Load and No Load

Dr.V Kannan, Associate Professor, Department of Electrical Engineering, NM Institute Of Engineering & Tech, Bhubaneswar
Suvrakanta Pal, Assistant Professor, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Pratyush Ranjan Mohapatra, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Samim Ahamad Taher, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar

Abstract: **A Brushless DC Motor (known as BLDC) is a Permanent Magnet Synchronous Electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system instead of a mechanically commutation system. In this paper, Open Loop Control system of BLDC motor drives is presented in detailed. MATLAB Simulation is done under Load and No Load condition, the change in speed and torque due to the variations of applied voltage is observed. Then Load and Unload condition of Open Loop control of BLDC motor are compared. Moreover, Frequency Analysis using Fast Fourier Transform is also done to calculate the Current THD (Total Harmonic Distortion) under different load and unload conditions. Then the results are compared. From the frequency analysis it is find out that current THD (Total Harmonic Distortion) and operating frequency are changing with varying load. The main purpose of this paper is to examine whether Open Loop Control system of BLDC motor is preferable for industrial used or not.**

Keywords: Brushless DC motor; Open loop model; Inverter; load and no load; Simulation; Frequency Analysis.

I: INTRODUCTION

Brushless DC motors (BLDC) find many applications in industries due to their high power density and ease of control. Since BLDC motor does not have brush, it has -longer life, higher efficiency, higher speed and maintenance free. Therefore, BLDC Motors become a significant contributor of the modern drive technology. They gain popularity rapidly in the fields of Consumer Appliances, Automotive Industry, Industrial Automation, Chemical and Medical, Aerospace and Instrumentation and the range is increasing day by day. The ratio of Torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors [1 - 15].

Stator and Rotor are the main part of the BLDC motors like Brush DC motor. Hall sensor may be considered as one part of BLDC motor since most of them are sensor by Hall Effect signal. Hall sensors work on the hall-effect principle that when a current carrying conductor is exposed to the magnetic field, charge carriers experience a force based on the voltage developed across the two sides of the conductor. If the direction of the magnetic field is reversed, the voltage developed will reverse as well. For Hall-effect sensors used in BLDC motors, whenever rotor magnetic poles (N or S) pass near the hall sensor, they generate a HIGH or LOW level signal, which can be used to determine the position of the shaft. The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor [1, 6, 10, 11, 12].

The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. Instead of commutating the armature current using brushes, electronic commutation is used that is why it is called as an electronic motor.

For Each commutation sequence, one winding is energized to positive, the other winding is energized negative and the next is in a non-energized condition. Torque is produced due to the interaction between the two magnetic fields generated by the stator coils and the permanent magnets. Ideally, the peak torque is observed when these two fields are in quadrature to each other. In order to keep the motor running, the magnetic field generated by the windings should shift their position, as the rotor moves to catch up with the moving stator field [1, 2, 10]

The open loop speed control of BLDC motor can be carried out in a similar way to that of a conventional DC machine, by changing the equivalent conceptual “brush” position and varying the sensor position with respect to the rotor frame. Open Loop Control is simple and easy to construct and cheaper in comparison to Closed Loop Control system. However, the output cannot be monitor

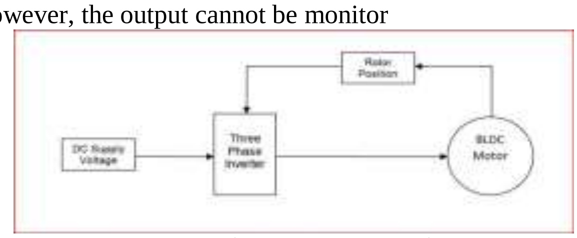

Fig. 1: Block Diagram of Open Loop Control of BLDC motor.

since there is no feedback. The Speed can be increase or decrease by increasing or decreasing the supply voltage as the speed is the function of the supply voltage. And the Torque is directly proportional to current. Current is depending on the load. Therefore, in case of Open Loop control the output is mainly depend on supply voltage and load condition.

The block diagram of Open Loop Control is shown in Fig. 1. It has three main blocks such as Voltage Source, Inverter and the BLDC Motor [4].

VOLTAGE SOURCE: The Voltage source is used to supply DC voltage to the BLDC motor. The speed of BLDC motor is increased with increase in voltage. Voltage source is the main controller, no other controller is used in this control. The speed is fully depends on the supply voltage since the supply voltage is the function of the speed. The applied voltage should not be more than the rated of the motor; therefore square or sinusoidal wave shape can be applied as the input voltage [6].

INVERTER: An Inverter is a circuit which converts a DC power into an AC power at desired output voltage and frequency. This conversion can be achieved either by controlled turn-on and turn-off devices (e.g. BJTs, MOSFETs, IGBTs, MCTs, SITs, SITHs) or by forced commutated Thyristor, depending on applications. Inverters are mainly classified as voltage source inverter and current source inverter. The Voltage Source Inverter (VSI) consists of stiff voltage source with negligible internal impedance whereas Current Source Inverter (CSI) typically consists of a stiff current source which is DC in nature. The transition of firing pulses from one power switch to another in a defined sequence is termed as a step. Each step is of 60-degree duration in a cycle of 360-degree. There are mainly two modes of conduction, viz. 180-degree and 120-degree mode but in both the modes the gating pulses are present for 60-degree of the output voltage wave.

In case of 120-degree operation of VSI: Two switch are put on at the same time; Every switch is put on for 120-degree. This operation is very similar with the operation of BLDC motor in which - Two phases are energized at a time; Every phase is energized till 120-degree electrical degrees; After each 60-degree, the commutation sequence is changed. Therefore, 120-degree operation of VSI is used in BLDC motor control [4].

II: MATHEMATICAL MODELLING

In modeling a BLDC motor a, b, c, phase variable model is preferred as the mutual inductance between stator and rotor is non-sinusoidal. Before formulating the equations following assumptions are made in modeling the BLDC motor.

- The motor is not saturated.
- Resistances of all the stator windings are equal, self and mutual inductances are constant.
- The power semiconductor devices are ideal.
- Iron losses are negligible.

There are two possible methods to model a BLDC motor, one is a, b, c phase variable model and the other is d-q axis model. BLDC motor has the permanent magnet with trapezoidal back EMF whereas synchronous motor has sinusoidal back EMF. So transforming to d-q axis does not provide any added benefit, thus a, b, c phase variable model is chosen. The equivalent diagram of the BLDC motor is as shown in the Fig.2 [3, 5, 8, 12].

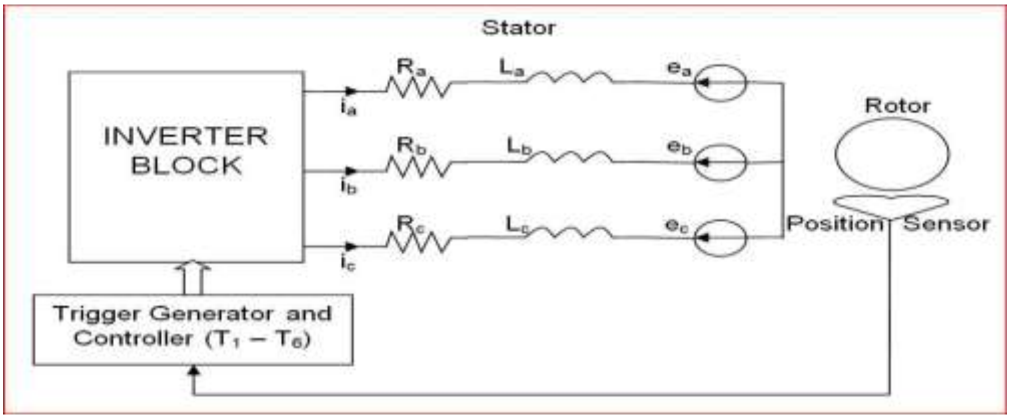

Fig.2: Three-phase BLDC motor equivalent circuit.

The voltage equations of BLDC motor are:

$$V_a = R_a i_a + L_a \frac{d}{dt} i_a + e_a \quad (1)$$

$$V_b = R_b i_b + L_b \frac{d}{dt} i_b + e_b \quad (2)$$

$$V_c = R_c i_c + L_c \frac{d}{dt} i_c + e_c \quad (3)$$

where,
$L_a = L_b = L_c = L$, are the self inductance [H].
V_a, V_b, V_c, are the per phase stator voltages [V].
$R_a = R_b = R_c = R$ are the per phase stator resistance [Ω].
i_a, i_b, i_c, are the per phase stator currents [A].
e_a, e_b, e_c, are the induced back-emf [V].

In the 3-phase BLDC motor, the back-EMF is related to a function of rotor position and the back-EMF of each phase has 120° phase angle difference so equation of each phase should be as follows:

$$e_a = \frac{K_e}{2} * F(\theta_e) * \omega_r(t) \quad (4)$$

$$e_b = \frac{K_e}{2} * F(\theta_e - \frac{2\pi}{3}) * \omega_r(t) \quad (5)$$

$$e_c = \frac{K_e}{2} * F(\theta_e + \frac{2\pi}{3}) * \omega_r(t) \quad (6)$$

where,
K_e is the back emf constant of one phase[V/rad.s^{-1}]
ω_r is the mechanical speed of the rotor [rad.s^{-1}]
θ_e is electrical rotor angle [° elect.]

The electrical rotor angle is equal to the mechanical rotor angle θ_m multiplied by half of the number of poles P :

$$\theta_e = \frac{P}{2}\theta_m \qquad (7)$$

The function $F(\theta_e)$ gives the trapezoidal waveform of the back – emf. One period of this function can be written as follow:

$$F(\theta_e) = \begin{cases} 1 & 0 < \theta e < \frac{2\pi}{3} \\ 1 - \frac{6}{\pi}(\theta e - \frac{2\pi}{3}) & \frac{2\pi}{3} < \theta e < \pi \\ -1 & \pi < \theta e < \frac{5\pi}{3} \\ -1 + \frac{6}{\pi}(\theta e - \frac{2\pi}{3}) & \frac{5\pi}{3} < \theta e < 2\pi \end{cases} \qquad (8)$$

The Electromagnetic Power equation is:

$$P_e = (e_a i_a + e_b i_b + e_c i_c) \qquad (9)$$

By neglecting the stray and mechanical losses; the electromagnetic power is completely converted to kinetic energy, so

$$P_e = T_e \omega_r \qquad (10)$$

Therefore electromagnetic torque equation is:

$$T_e = \frac{1}{\omega_r}(e_a i_a + e_b i_b + e_c i_c) \qquad (11)$$

Also,

$$T_e = \frac{Kt}{2}[F(\theta_e) i_a + F(\theta_e - \frac{2\pi}{3}) i_b + F(\theta_e + \frac{2\pi}{3}) i_c] \quad (12)$$

where,
T_e is the electromagnetic torque
K_t is torque constant
The equation of mechanical part (equation of motion) is:

$$J\frac{d}{dt}\omega_m + B\omega_m = T_e - T_l \qquad (13)$$

where,
B is friction coefficient [Nms.rad^{-1}].
J is moment of inertia of rotor and coupled shaft [kgm^2].
T_l is load torque [Nm].
ω_m is rotor speed [rad.s^{-1}].

III: SIMULATION RESULTS AND DISCUSSIONS

The simulation is done using MATLAB R2018b with Auto (Automatic solver selection) Variable-step type solver. The simulation time is 2 second. The simulink model is shown in Fig. 3.

The BLDC Motor block is taken from Sim-Power System tool box and configurations are altered as Trapezoidal back EMF and the BLDC motor parameter is set as given in Table 1 below:

Parameter types	Values	Units
Stator phase Resistance	2.8750	Ohm
Stator phase inductance	8.5e-3	H
Flux linkage established by magnet	0.175	V.s
Voltage constant	65.3127	V
Torque constant	1.4	N.m
Back EMF flat area	120	Degree
Inertia	0.8e-3	J(kg.m^2)
Viscous damping	1e-3	F(N.m.s)
No. of Pole pairs	4	
Static friction	0	TF(N.m)

Table 1: BLDC motor Parameter

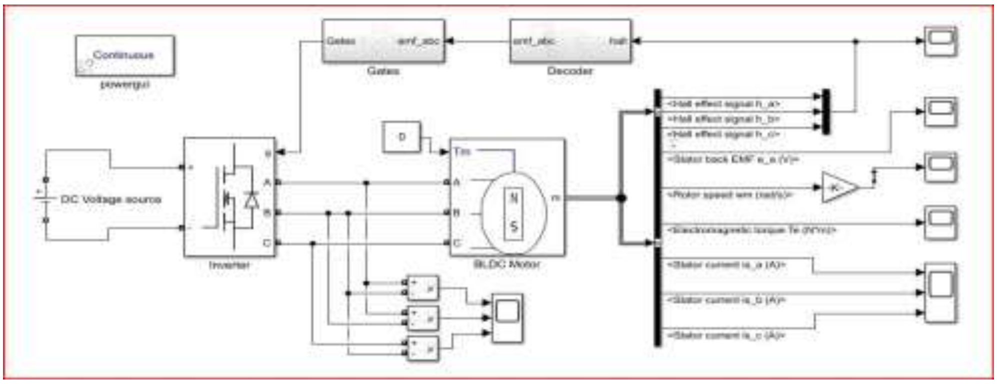

Fig. 3: Simulink Model of Open Loop Control of BLDC motor

The inverter is configured from universal bridge of Sim-Power System tool box and the configuration parameters are: Snubber resistance R_s is 5000 ohms; Snubber Capacitance C_s is 1e-6F; R_{on} is 1e-3 ohm ohms; choosing the MOSFET as switches.

This inverter is trigger by the gating signal which is controlled by the GATE block. This Gates generates six pulses from the hall effect signals through the Decoder to control the Inverter switches. The gate signal is generated by providing Hall Effect sensor decoder and then Commutation Sequence is decided by this Gate signals. Depending upon the signal generated by this gate, the switches (MOSFET) in an inverter are put ON/ OFF sequencially.

Depending on the position of rotor, hall signal is generated by hall sensor which is embedded on the stator of BLDC motor. This generated hall signal is not usable directly to trigger an inverter, it is required to decode first, so Hall signal is decoded by DECODER block using the AND, OR, and NOT logic the gate signal is generated. The output of the decoder is used to generate six pulses through the

Gate block. Therefore, Inverter is controlled by the rotor position and the applied voltage [13].

The simulation is done without load starting from 50V and then applied voltage is increased step by step with an interval of 50V till 250V. The simulation is repeated by giving a load of 1Nm, 1.5Nm and 2Nm. The results are tabulated in table 2. The waveforms of Speed and Torque at supply voltage 150V are shown in Fig. 4 to Fig. 13.

Fig. 14&15 shows speed and torque characteristics at various supply voltage at 1.5Nm load. Step response is also shown in table 3.

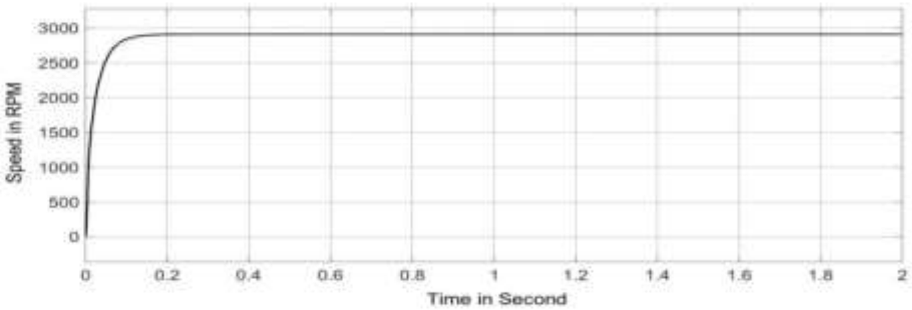

Fig. 4: Speed Characteristics of BLDC motor without load.

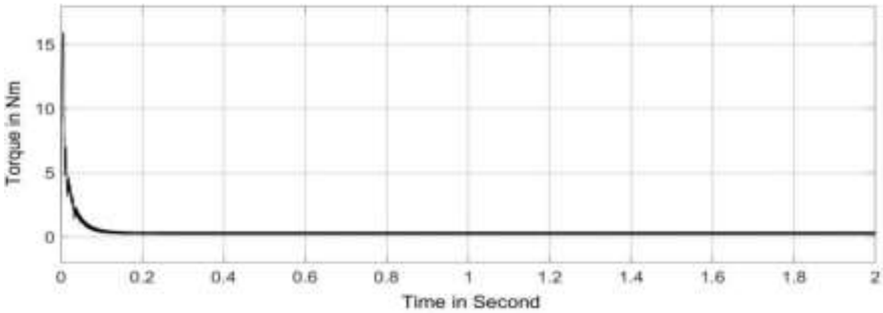

Fig. 5: Electromagnetic Torque Characteristics of BLDC without load.

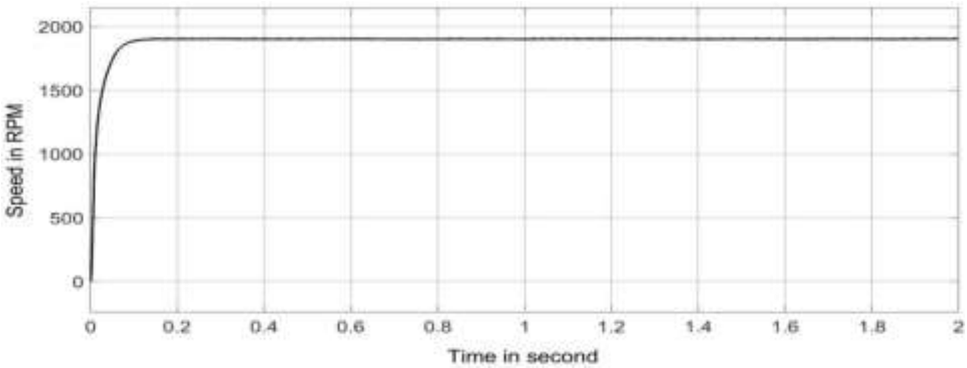

Fig. 6: Speed Characteristics of BLDC motor applying 1Nm load.

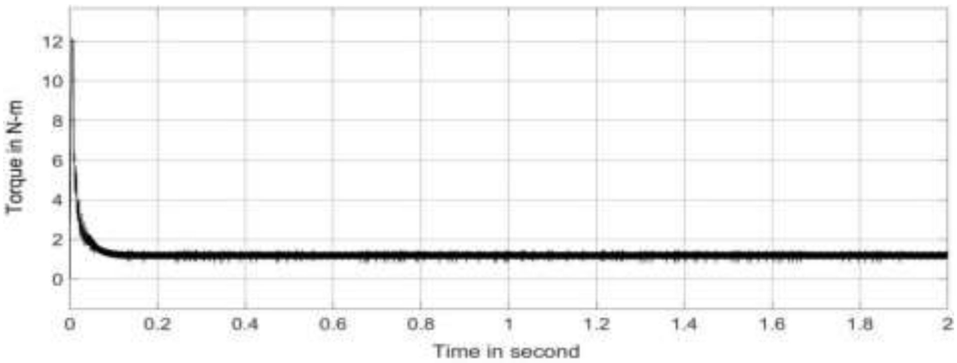

Fig. 7: Electromagnetic Torque Characteristics of BLDC applying 1Nm load.

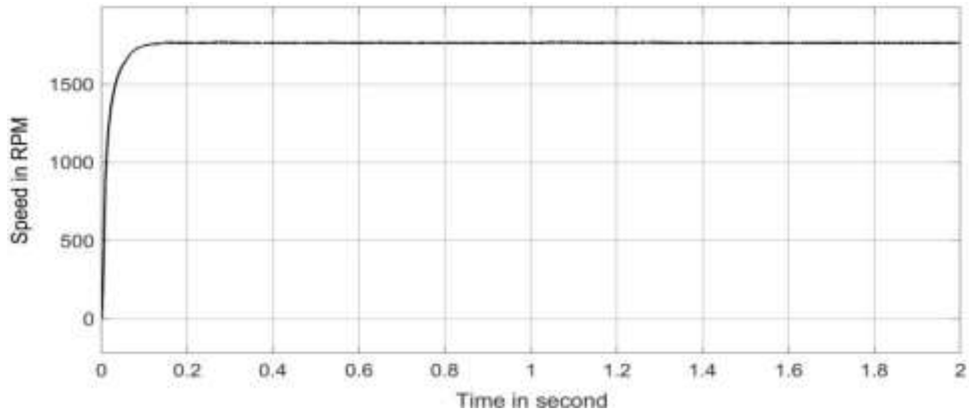

Fig. 8: Speed Characteristics of BLDC motor applying 1.5Nm load.

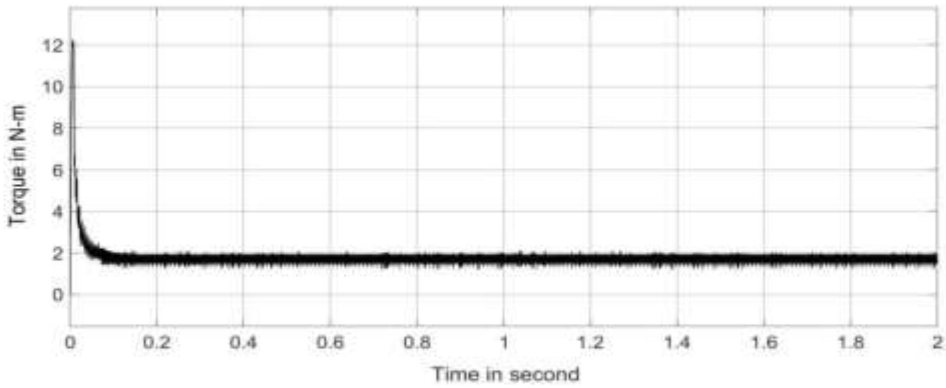

Fig. 9: Electromagnetic Torque Characteristics of BLDC applying 1.5Nm load.

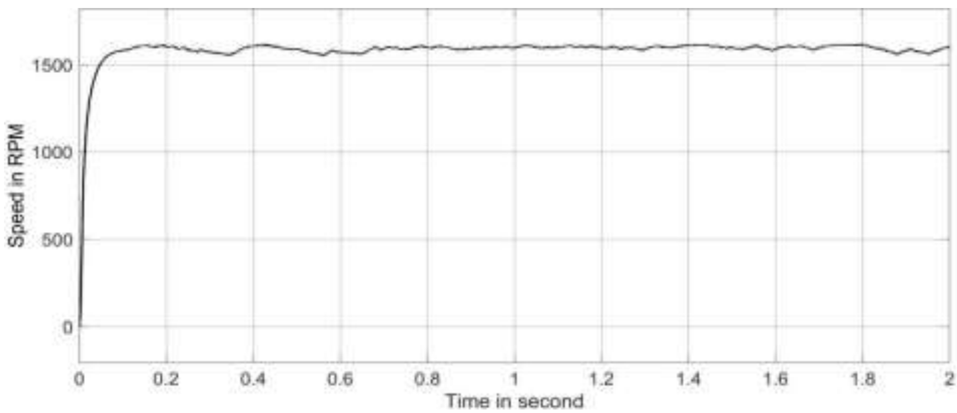

Fig. 10: Speed Characteristics of BLDC motor applying 2Nm load.

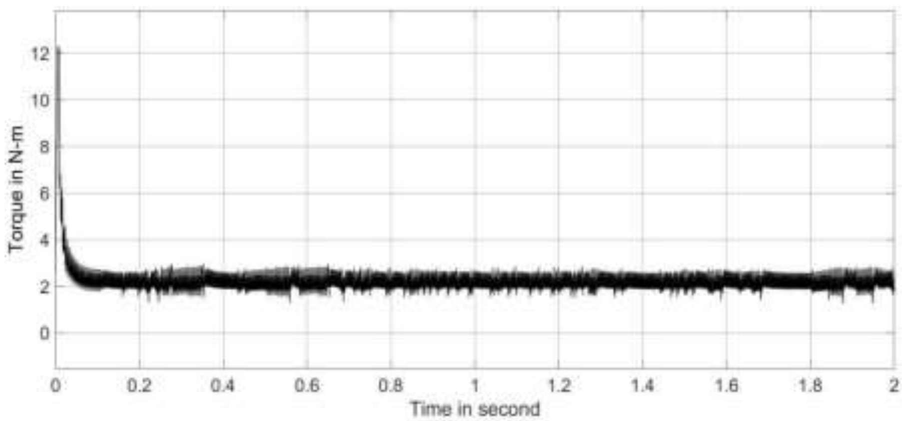

Fig. 11: Electromagnetic Torque Characteristics of BLDC applying 2Nm load.

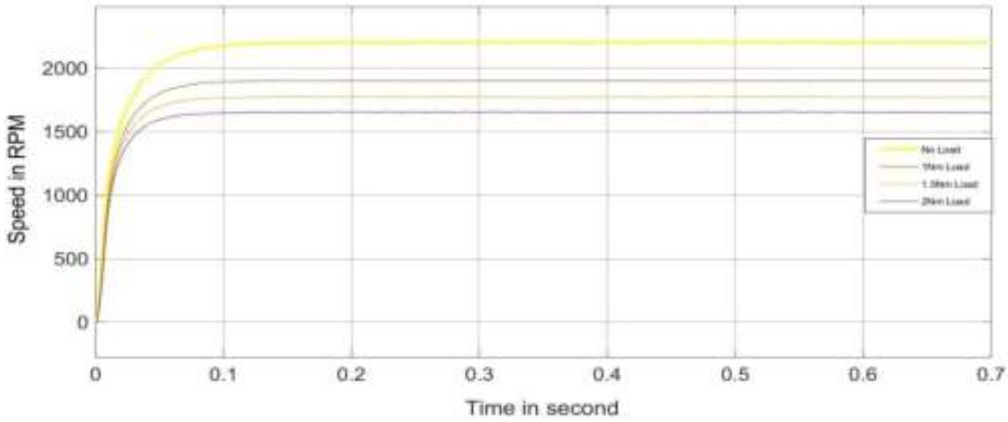

Fig. 12: Speed response at various load conditions.

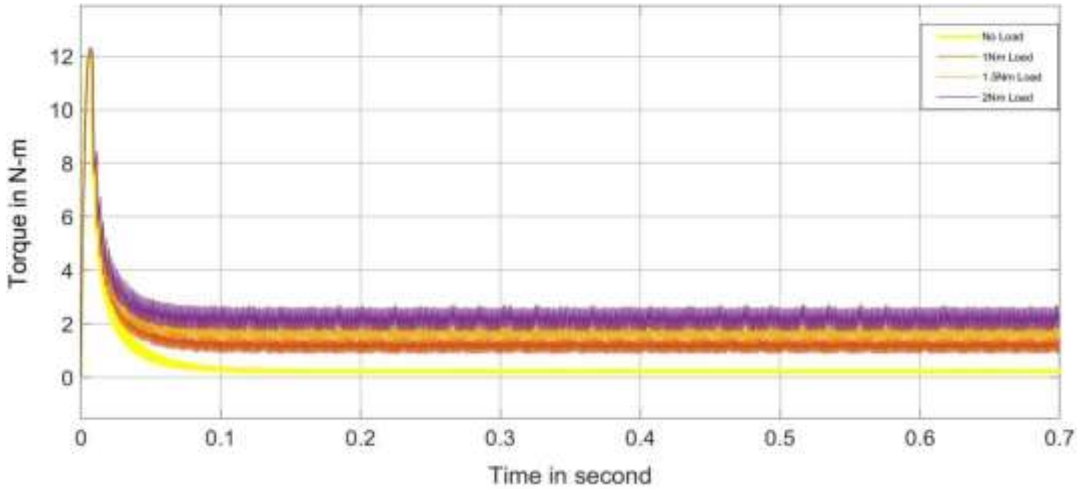

Fig. 13 : Electromagnetic Torque at various load conditions.

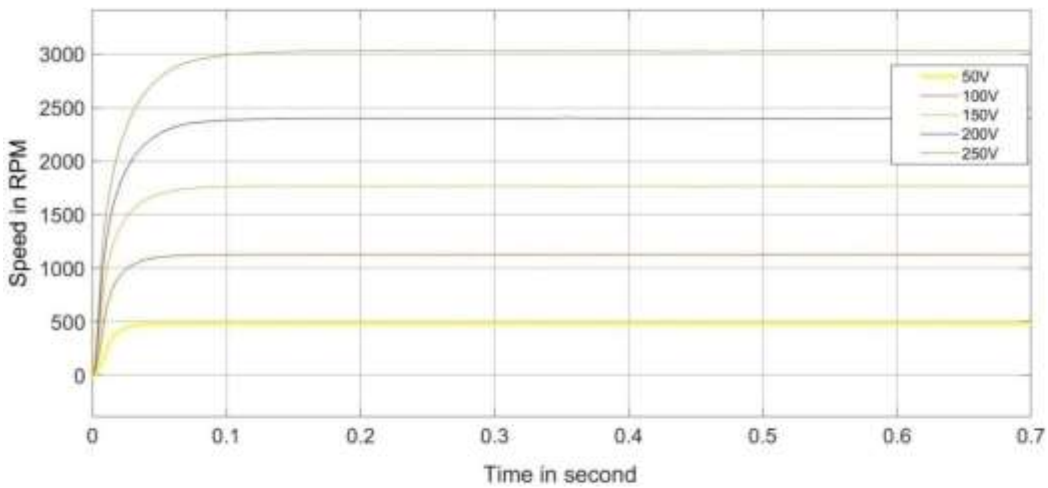

Fig. 14: Speed response at various supply voltage at 1.5Nm load.

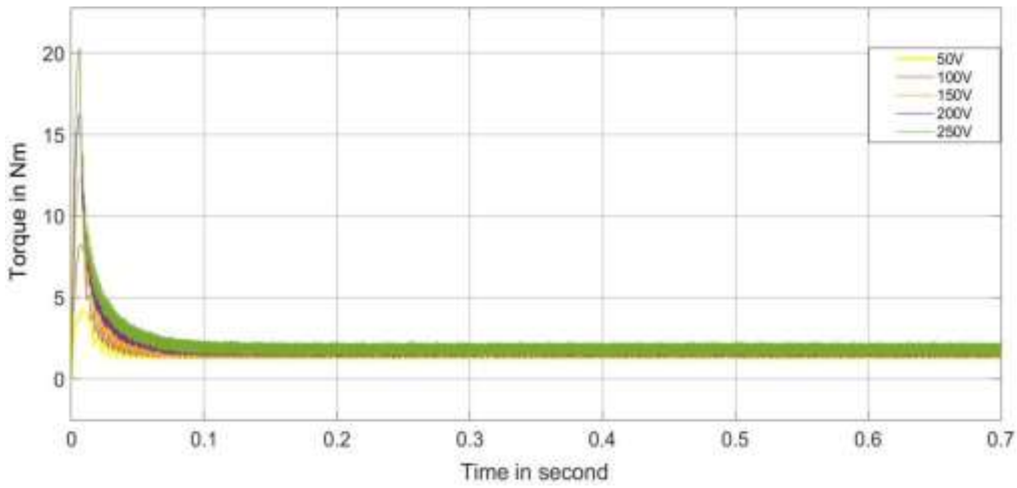

Fig. 15 : Electromagnetic Torque at various supply voltage at 1.5Nm load.

Sl. no	Input Voltage (V)	Without Load		With Load of 1.0 N-m		With Load of 1.5 N-m		With Load of 2.0 N-m	
		Speed (RPM)	Torgue (N-m)	Speed (RPM)	Torgue (N-m)	Speed (RPM)	Torgue (N-m)	Speed (RPM)	Torgue (N-m)
1	50	750	4	560	4	500	4	420	4
2	100	1500	8	1300	8	1150	8	1010	8
3	150	2200	12	1900	12	1780	12	1600	12
4	200	2900	16	2550	16	2400	16	2100	16
5	250	3600	20	3200	20	3000	20	2630	20

Table 2: Speed and Torque at different input Voltage at different load

Bilevel Measurement	Without Load	With Load of 1Nm	With Load of 1.5 Nm	With Load of 2.0 Nm
Preshoot (%)	0.505	0.505	0.505	0.505
Overshoot (%)	0.483	0.361	0.220	0.165
Undershoot (%)	1.998	1.964	1.943	1.902

Table 3: Table showing Step Response of BLDC motor when supply voltage is 200V.

In case of Open Loop Control, as we can see from the above table and waveform, it is clear that both speed and peak torque are increased as increasing input supply voltage in both cases of load as well as without load condition. This proved that the speed is the function of the applied voltage. The change in peak torque is same both on under load condition and without load condition, but the torque in steady state condition is increasing with load at any supply voltage. The speed is reducing with increasing the load. There is no change in Preshoot when load is increasing. However, there is a small change in Overshoot and Undershoot, both are slightly decreased with increased in load.

V: FREQUENCY ANALYSIS

Frequency Analysis is done for better comparison of no load and load condition. The BLDC is nonlinear load having trapezoidal current and voltage waveform, due to which it will produce significant harmonics in the power line system. Total Harmonic distortion is a measure of closeness in shape between the output voltage waveform and its fundamental component. It is defined as the ratio of the rms value of its total harmonics component of the output voltage and the rms value of the fundamental component. It is a dirty power which is usually linked with industrial plants that used adaptable power supplies, speed drives, and other equipment's which use solid-state switching. Therefore, total harmonic distortion should be reduced as far as possible in drive system since it increases the operating temperature of the motor, thereby reducing its life. There are several methods to find out total harmonic in the drive system, Fast Flourier Transform is chosen as it is easy to implement [2, 5].

In this analysis Current Frequency Spectrum is plotted using Matlab Software. FFT (Fast Fourier Transform) Analysis is used and the graph is plotted between Harmonic order versus Percentage of Fundamental Frequency. The Total Harmonic Distortion (THD) at various load conditions at 150 V supplied is tabulated in table 4 below.

Load Condition	Operation Frequency (Hz)	Current THD (%)
At No Load	180	75.22
At 1 Nm Load	160	72.07
At 1.5 Nm Load	150	64.16
At 2 Nm Load	130	83.77

Table 4: Current THD and Operation Frequency at various Load conditions.

Fig. 16 to Fig. 16 show Phase Current (I_a) Frequency Spectrum at various load conditions at 150 V supply voltage.

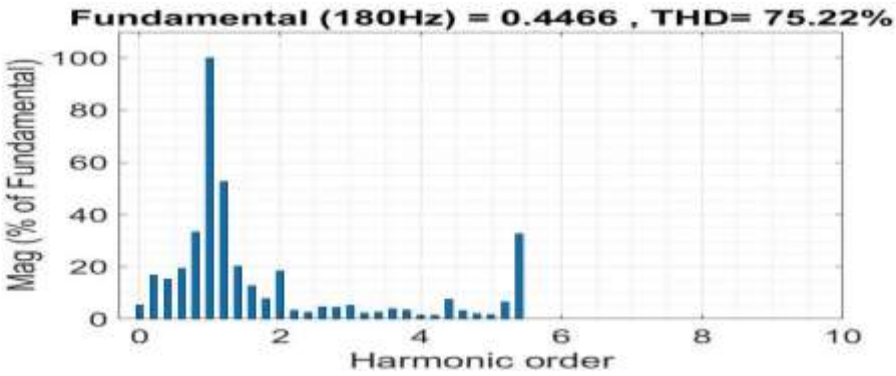

Fig. 16: Frequency Spectrum of Current at No-Load.

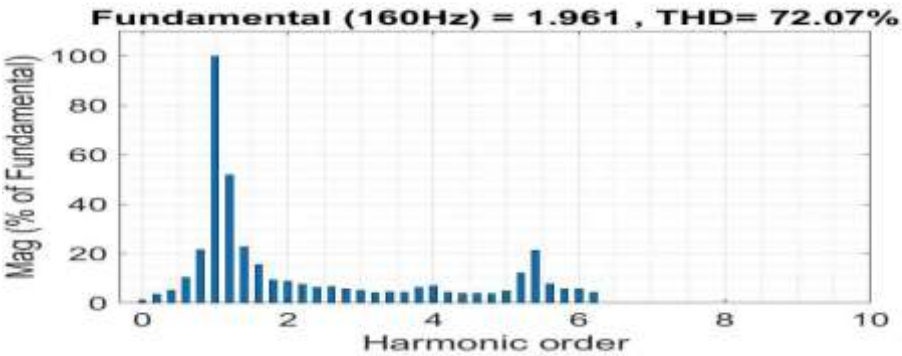

Fig. 17: Frequency Spectrum of Current at 1Nm Load.

Fig. 18: Frequency Spectrum of Current at 1.5Nm Load.

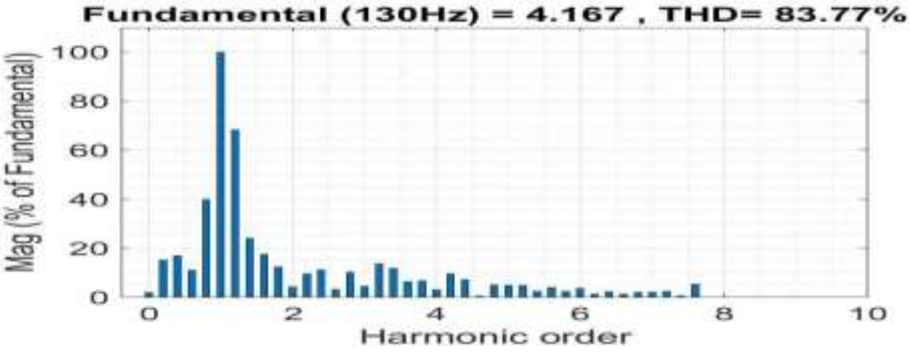

Fig. 19: Frequency Spectrum of Current at 2Nm Load.

The fundamental frequency is 180 Hz and THD is 75.22 % at no-load as it is shown in Fig.16. The THD is varying as load is changing and the switching frequency is decreasing with increase in load as shown in Fig. 17 to Fig. 19.

VI: CONCLUSION

In this paper, the open loop control of BLDC motor at no-load and at various load is performed. The speed and torque are increasing with increasing the supply voltage. When the load is applied the speed is reduced while the peak torque is constant. The Frequency analysis is implemented using FFT analysis and found out that Open Loop control has uncontrolled switching frequency and the harmonics of the fundamental frequency are quite strong which is the main drawback of open loop control since it makes difficult to filter the undesired harmonics. Therefore, open loop control may not be preferable for industrial use.

REFERENCES

[1] Chang-liang Xia, "Permanent Magnet Brushless DC Motor Drives and Control", John Wiley & Sons, First Edition, ISBN 978-1-118-18833-0, 2012.

[2] Stefan B., "BLDC motor modelling and control a Matlab/ Simulink implementation", Master thesis in Electrical Power Engineering, Chambers University of Technology, Gothenburg. Sweden, (May 2005).

[3] Shirish Vasantrao Gadewar and A.M.Jain, "Modelling and Simulation of Three Phase BLDC motor for Electric Braking using Matlab/ Simulink", International Journal of Electrical, Electronics and Data Communication, pp 48-53, July 2017.

[4] Upama Das and Pabitra Kumar Biswas and Sanjeev Parek, "Performance Analysis for Open Loop Brushless DC Motor Drive", International Journal of Engineering and Advanced Technology (IJEAT), pp 1220-1228, Volume-8, Issue-6, August 2019.

[5] Adel A. Obed and Abbas K. Kadhim, "Speed and Current Limiting Control Strategies for BLDC Motor Drive System: A Comparative Study", International Journal of Advanced Engineering Research and Science (IJERS), pp 129-130, Vol-5, Issue-2, Feb 2018.

[6]] Hayder Salim Hameed, "Brushless DC motor controller design using MATLAB applications" IEEE, 1st International Scientific Conference of Engineering Sciences, pp 44-49, 2018.

[7] M. Vignesh kumar, "Speed Control Of Three Phase BLDC Motor Using Four Switch Inverter", International Journal of Scientific & Engineering Research, pp 351-356, Volume 4, Issue 5, May-2013

[8] R. M. Pindoriya and S. Rajendran and P. J. Chauhan, "Speed Control of BLDC Motor using PWM Technique", International Journal of Advance Engineering and Research Development, pp 1-6, ETCEE-2014 Issue, March 2014.

[9] SK.Sharmila, K.Esther Rani, A.Anil Kumar and T.Naveen, "Comparison of different Control Strategies for BLDC motor Drive", International Journal of Electrical Engineering and Technology, pp 24-36, March-April 2018.

[10] Anurak Dwivedi, A.N.Tiwari, "A Review: Speed control of brushless DC motor" IJBSTR Review Paper, Vol. 1, Issue-6, June 2013.

[11] Lokesh Kumar Agrawal and Bhavesh Kumar Chauhan and G. K. Banerjee "Speed Control of Brushless DC Motor Using Conventional Controllers" International Journal of Pure and Applied Mathematics, pp 3955-3961, Volume119, No.16, 2018

[12] MS. Juli Singh, "Analysis the speed control of BLDC drive using sensors", International Journal of Engineering Research and Applications, pp 2868-2884, Vol.-2, Issue-3, May-June 2012.

[13] Ravi Maraviya, "Simulation and Analysis for Different Speed Control Methods of BLDC Motor Drive", International Journal of Advance Research in Engineering, Science & Technology, pp 677-682 , Volume 4, Issue 4, April-2017.

[14] Anjali Hingmire and B.B. Pimple, "Simulation and Analysis Studies of Speed Control of Brushless DC Motor Using Hall Sensors", International Conference on Smart Electric Drives & Power System, 2018.

[15] Nguyen Thi Thanh Nga, Nguyen Thi Phuong Chi and Nguyen Hong Quang, "Study on Controlling Brushless DC Motor in Current Control Loop Using DC-Link Current", American Journal of Engineering Research (AJER), Volume-7, Issue-5, pp-522-528, 2018.