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Cob-Web Building Controller for Reduced Torque Ripples in BLDC Motor Drive

Rinki Roy Chowdhury[1], Sandhya P[2]
[1]*PG Scholar, Electrical and Electronics Engineering, Mar Baselios College of Engineering and Technology, Kerala, India*
[2]*Assistant Professor, Electrical and Electronics Engineering, Mar Baselios College of Engineering and Technology, Kerala, India*

Abstract: The BLDC motors have become a very common choice for most of industrial applications because of its reliability and other characteristics of improved efficiency, high torque output, better power factor and simple controller designs. Here the mutual torque which is caused due to coupling of rotor magnetic field and stator currents are responsible for pulsating torque or torque ripples occurring in the motors. To remove the ripples several methods are conventionally used. Here a new biologically-oriented controller design is proposed in this work. The cob-web building activity of spider is utilized to build an algorithm to reduce torque ripples in BLDC motor. A MATLAB/SIMULINK design of proposed system is being compared to conventional methods to show the effectiveness of this method.
***Keywords**: Biological-oriented controller, BLDC motor, Cob-web controller, Controller design, Torque ripples, Total harmonic distortion (THD).*

I. INTRODUCTION

The BLDC motors can be either sensored or sensorless depending upon the presence of hall-effect sensors and their absence. If sensored then they are electronically commutated motors that have hall sensors at the rotor of the system where the feedback signals are fed to the controller in order to check the rotor position corresponding to stator position based on which the commutation of the switches of inverter feeding the BLDC motor operates and hence BLDC runs. If sensorless then the back-emf of the motor is directly used to commutate the inverter switches based on relational operators. The mutual torque which is responsible for the torque ripples has to be reduced and for this a new biologically oriented controller design is used to produce the pulses for inverter.

There has been many previous works that are present which provides many different analysis and methods to reduce torque ripples. In the work [1], a buck converter analysis can be used to analyse the torque ripples but the absence of the capacitor shows the presence of the torque ripples. In [2], using the model, constant speed operation of a BLDC motor drive operated without a DC link capacitor is analyzed. In [3], a large capacitor is designed to compensate the torque ripples. The disadvantages of large capacitance is that its capacitance changes with change in temperature, also if the capacitor gets spoiled, the whole system will get affected and will stop working. To avoid all these disadvantages, we prefer the new work proposed in this paper, where a small a capacitor and switch is utilized instead of a large capacitor. The pulses given to this switch is also obtained from the controller we introduce. The biologically oriented technique works similar to that of the cob-web building method of a spider. Here a sensorless BLDC motor with its back-emf as the feedback from the rotor is considered instead of hall sensor signals to generate the pulses for the inverter.

II. PROPOSED METHODOLOGY

Here as the fig 1. shows the basic block diagram of the control scheme of BLDC motor. Here the single phase AC input is given to the diode bridge rectifier which then is converted to DC output and this output is fed to the inverter that produces the required AC supply to feed the BLDC motor. Using the back-emf of BLDC motor the cob-web building controller produces the pulses that is given to the switches of inverter and the switch controlling capacitor.

From [1] the buck model analysis of BLDC motor shows that the torque produced as output of motor is analysed using two regions. In region 2, the torque ripples seems to be at the highest value. Hence the capacitor can be made to discharge at region 2, when motor back emf is greater than the inverter output. Other time the capacitor is left to charge. This operation of charging and discharging of capacitor is done by the swich placed along with it. The duty cycle of switch is changed by comparing the back emf and output voltage of inverter. This duty cycle of pulse generated by the cob web controller is fed to the switch placed along with capacitor that controls the capacitor charging and discharging. Since capacitor used only at region 2, the size of capacitor chosen is also very small compared to large capacitor in [3].

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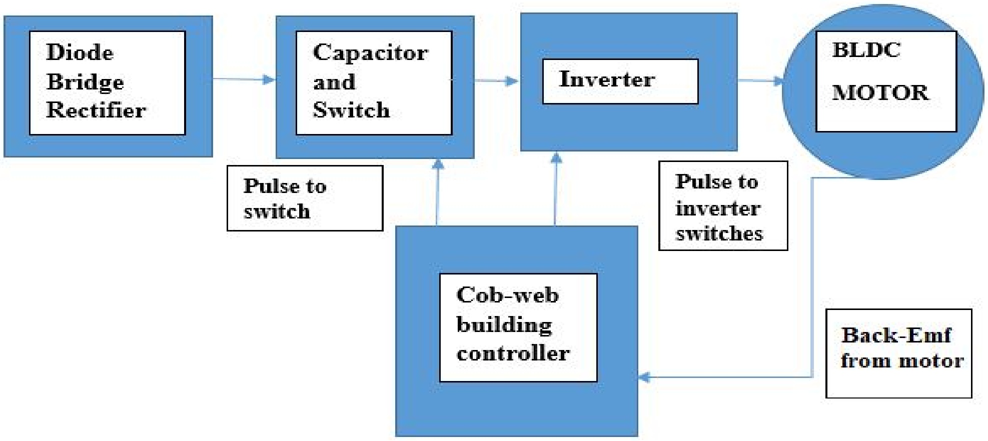

Fig 1. Basic block diagram of the cob-web building controller for BLDC drive

III. BLDC MODELLED USING EQUATIONS

A three-phase star connected trapezoidal back-emf type BLDC motor [4] is considered with no power losses, no armature reaction, and concentrated windings in stator . There are mainly five blocks which has to be designed using five equations. The back-emf generation block uses the following equation (1). Rotor position function is a unit function generator which has a maximum value of +1 or -1.The back emf has a phase difference of 120 between each phase.

$$e_a = k_w f(\theta_e)\omega$$
$$e_b = k_w f(\theta_e - 2\pi/3)\omega$$
$$e_c = k_w f(\theta_e + 2\pi/3)\omega \quad (1)$$

Where k_w is back EMF constant per phase[V/rad.s^{-1}], θ_e is electrical rotor angle [° el.], ω is rotor speed [rad. s^{-1}]. Now for current generation block we use (2),

$$V_a = Ri_a + L\frac{d}{dt}(i_a) + e_a$$
$$V_b = Ri_b + L\frac{d}{dt}(i_b) + e_b$$
$$V_c = Ri_c + L\frac{d}{dt}(i_c) + e_c \quad (2)$$

where R is the resistance of each phase (Ω), L is the self-inductance of each phase (H), V_a, V_b, V_c are the stator phase voltages (V), i_a, i_b, i_c are the stator phase currents in (A), e_a, e_b, e_c are the back emf signals (V) of BLDC motor. The equation of electromagnetic torque is given by (3), used to generate the electromagnetic torque block.

$$T_e = \frac{1}{\omega}(e_a i_a + e_b i_b + e_c i_c) \quad (3)$$

The mechanical torque is given by (4), Where J is the moment of inertia of drive ,B is the damping constant ,T_L is the load torque.

$$T_m = J\frac{d\omega}{dt} + B\omega + T_L \quad (4)$$

The angular position and angular speed of the motor are related by (5), where P is the number of pole pairs of the BLDC motor. This is used for theta generation block.

$$\frac{P}{2}\omega = \frac{d\theta_e}{dt} \quad (5)$$

The table I shows the BLDC motor parameters of the chosen model with which the work has been done here . The rated power of this motor is 2.5KW.

Table-I
Parameters of motor used

MOTOR PARAMETERS	VALUES
Stator inductance per phase	2 m H
Stator resistance per phase	0.56Ω
Moment of inertia, J	0.0725 kgm^2
Friction coefficient, B	$0.055 Nm.s.rad^{-1}$
Back emf constant	$0.72 V/rad.s^{-1}$
Rated speed	2300 rpm
Input voltage	305V

IV. COMPENSATING FOR THE TORQUE RIPPLE

To remove torque ripples the designing of a capacitor has to be obtained for the sizing of the capacitor component. Conventionally [5], desigining of capacitor value for the above mentioned 305V BLDC input voltage, we use (6).

$$C = \frac{I_{DC}}{6 * \omega * V_{DC}} \quad (6)$$

where V_{DC} is the amount of permitted ripple in the voltage across the DC link capacitor, I_{DC} is the DC current of inverter input, ω is the speed at minimum and rated conditions, by substituting values for capacitor the minimum value of capacitor obtained is taken as the DC voltage link capacitor. Here a value of 480μF is obatined from (6) .In this work the value of capacitor [3] is calculated using (7).

$$T = \frac{1}{2\pi f}\sin^{-1}\frac{E}{V_m} \quad (7)$$

Where T is the time taken for V_m to reach E from 0 V. V_m is the voltage (V) , f is the frequency (Hz) . At the rated condition of motor E =60 V and V_m=305 V.

$$T = \frac{1}{2\pi * 50}\sin^{-1}\frac{60}{305} = 0.619ms \quad (8)$$

The value of C_{small} is selected such that it is capable to provide the required reference current when V_m < E to maintain current at reference value, where I_{avg} is the average current drawn to the motor from the DC bus to maintain $i_{m(t)}$ at I_{ref}. Let I_{avg} be 12A.

$$C_{small} = \frac{2T I_{avg}}{V_m - E} \quad (9)$$

$$C_{small} = \frac{2 * 0.619 * 10^{-3} * 12}{305 - 60} = 16\mu F \quad (10)$$

V. COB-WEB BUILDING ALGORITHM

The algorithm used here is bio-oriented and has the utilisation of the cob-web building methodology to generate the pulses for the inverter switches and the pulse for the the switch placed along with the capacitor. There are two main steps utilised to generate the pulses.

At first the back-emf produced by the BLDC motor is calculated using (1) and then the commutation of inverter swicthes based on a particular sequence is obtained using relational operator. The upper and lower bridge of inverter has one switch each operating at a particular time based on commutation sequence, of which one is chopping while other remains on throughout. Hence the spider is jumping between two positions based on duty cycle of the switches. The spider jumps between two positions by either making a new web or by eating the old web.

In the second step the spider compares the back-emf value with the input voltage of inverter and whenever the value of the back-emf falls below input voltage the capacitor has to discharge hence a pulse generated and fed to switch placed along with capacitor. The switching on and off of the switch is based on the cob-web building method by either making a new web or eating the old web based on duty cycle of pulse generated.

VI. RESULT AND DISCUSSION

The overall simulation diagram of the whole system is shown in fig.2 , here we analyse the torque ripples produced at output of the motor and also the current ripples produced at the output of the motor using total harmonic distortion method using FFT analysis technique and compare the values to cases where a large capacitor of 480µF is used and also without a compensation capacitor case. For the analysis the capacitor used by us is 16µF as obtained in (10) and also an IGBT switch placed along with it . The switching pulses are generated at 20KHz. The switching losses at such high frequencies are neglible hence this method is preferrable.

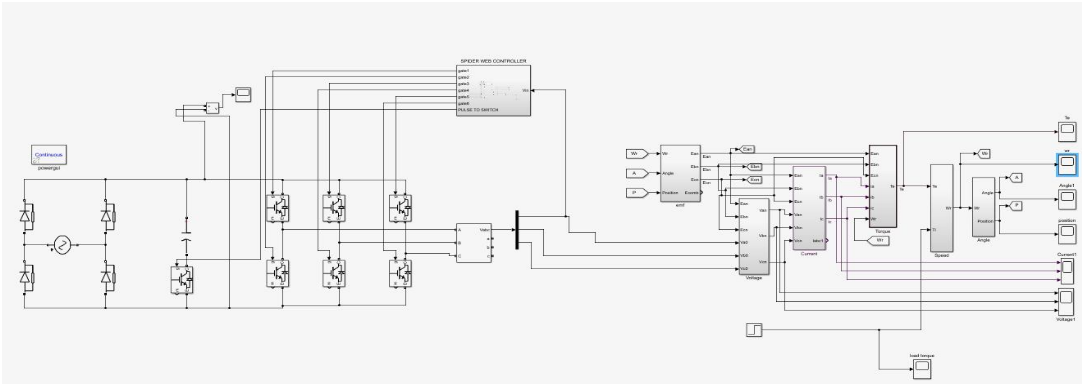

Fig.2. Overall simulation diagram of proposed system

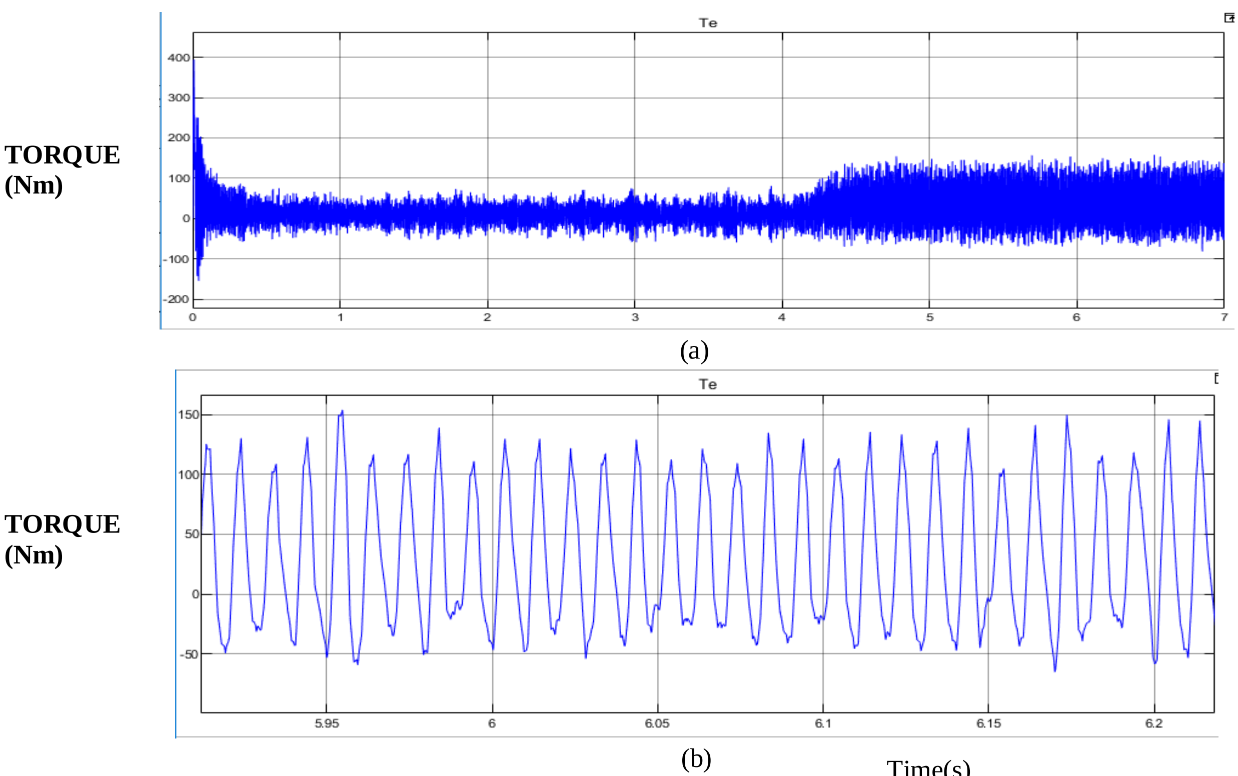

Fig 3(a) Torque ripple when no compensation capacitor is used (b) Enlarged section of torque ripple.

Here in fig.3(a) shows the torque ripple when no compensation capacitor is placed, hence fig.3 (b) shows the enlarged section of this torque ripple for calculation using (11) [6]. Also the ripples of output current of motor is calculated using FFT analysis and given in fig.4 , here the values of ripples are seen to be maximum for this case. A load torque at 4s of 28Nm is applied.

$$T_{ripple} = \frac{T_{high} - T_{low}}{T_{high} + T_{low}} * 100\% \quad (11)$$

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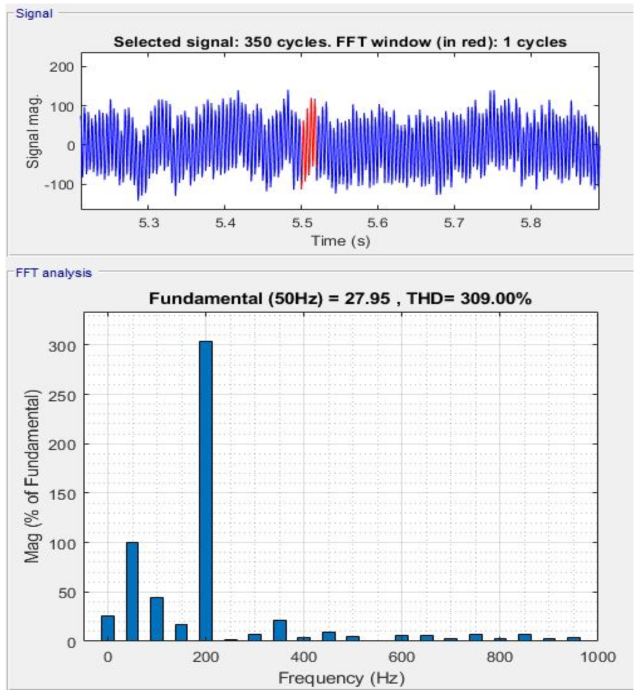

Fig.4 Total harmonic distortion of output current with no capacitor

Here in the following fig.5(a) shows the torque ripple when large compensation capacitor 480µF is placed, hence fig.5(b) shows the enlarged section of this torque ripple for calculation using (11) [6]. Also the ripples of output current of motor is calculated using FFT analysis and given in fig.6. Here the large capacitor is seen to compensate the ripples. But the large capacitor makes the system bulky and costly. A load torque at 4s of 28Nm is applied.

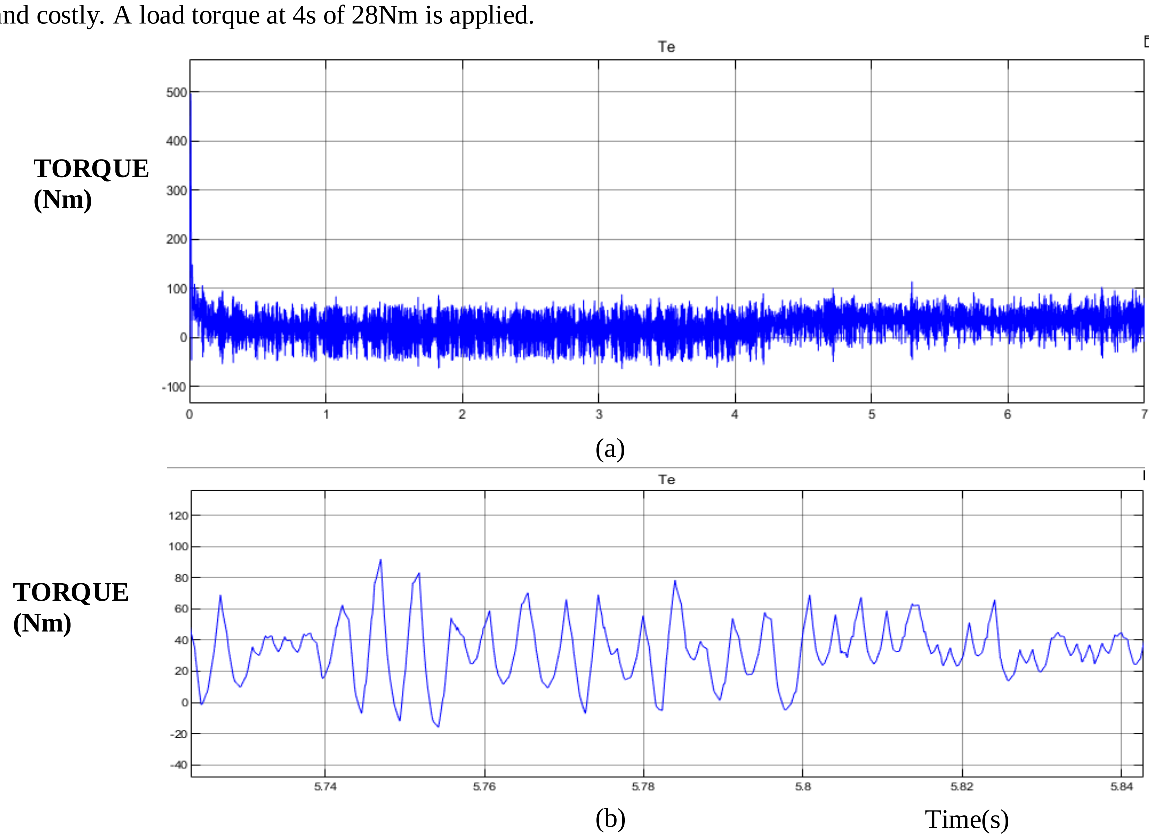

Fig 5(a) Torque ripple when large compensation capacitor is used (b) Enlarged section of torque ripple

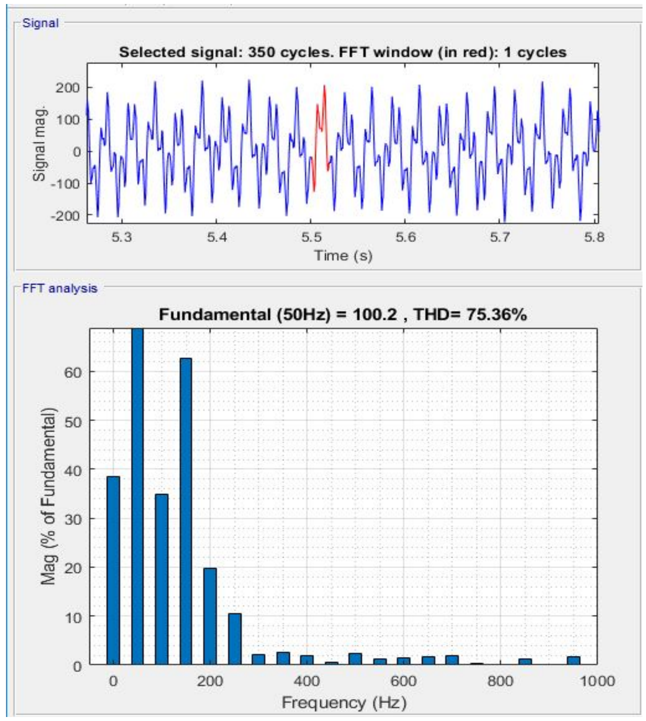

Fig.6 Total harmonic distortion of output current with large capacitor

Here in the following fig.7 (a) shows the torque ripple when small compensation capacitor 16μF is placed, hence fig.7(b) shows the enlarged section of this torque ripple for calculation using (11) [6]. Also the ripples of output current of motor is calculated using FFT analysis and given in fig.8. Here the small capacitor and switch is seen to compensate the ripples. Using cob-web building algorithm the generation of pulses occur. A load torque at 4s of 28Nm is applied. Here the least value of torque ripple is seen and THD is also reduced.

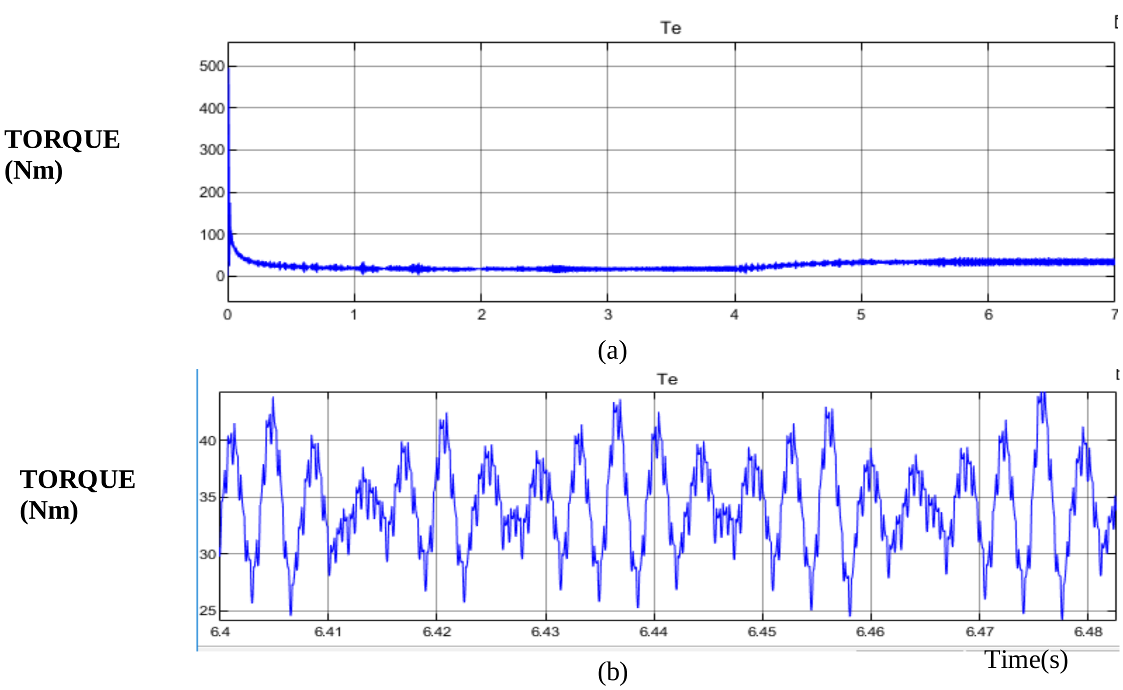

Fig 7(a) Torque ripple when cob-web building method is used (b) Enlarged section of torque rippl

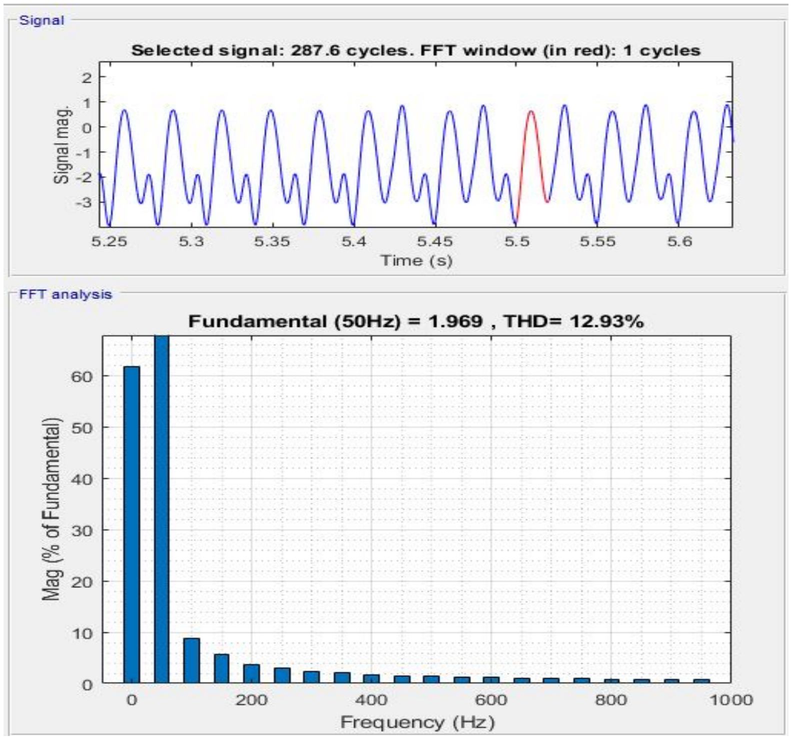

Fig.8. Total harmonic distortion of output current with cob-web building method

The table II shows the calculated torque ripples and THD obatined for each cases. On comparing the values we see that the torque ripples in cob-web building algorithm is considerably reduced as that of the large compensation capacitor and no compensation capacitor cases. This method can be used because of its simplicity and ease of control in desigining. Also hall sensors may not be needed in the BLDC motor being used.

Table II
Analysis Of Torque Ripples And Thd

Cases	Torque ripple	THD of output current
With Cob- web building algorithm	33.33%	12.93%
With large capacitance	150%	75%
With no compensation	200%	309%

VII.CONCLUSION

Here the three cases has been analysed with different methods to see reduction of ripples in the system. A reduction to 12% from 75% is seen in torque ripples at same load torque of 28Nm, similarly a THD reduction is seen from 150%to 33.33%. The fundamental frequency used at FFT analysis is 50Hz. Only 1 cycle taken at time 5s to analyse the THD of output current. The cob-web building activity of spider is taken as the algorithm procedure which helps to reduce size of capacitor. For a sensorless BLDC motor this method can be considered as a very simple controller to reduce the uneccessary ripples in the system.

VIII. ACKNOWLEDGMENT

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