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REDUCTION OF TORQUE RIPPLE AND SPEED CONTROL IN BLDC MOTOR USING BRAIN EMOTION-BASED INTELLIGENT CONTROLLER

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Abstract: The main aim of this project is speed control and torque ripple reduction in BLDC motor using brain emotion-based intelligent controller. It is a very difficult process to achieve smooth drivers for the motor operating under variable speed mode. In Brushless Direct Current Motor (BLDCM) when back electromotive force waveform is of trapezoidal type, the developed torque is constant in ideal conditions. However, practically, torque ripple is present in the output torque because of the physical design of the motor and its parameters. Also, the produced ripples are associated with the control and driver side of the motor. In the previous literature, the drive without a dc-link capacitor is presented but the torque ripple reduction is not effective. Hence in another work, the usage of the small capacitor is recommended and the results are improved. In this work, the quick stabilization with torque ripple reduction is presented using Brain Emotional Learning Based Intelligent Controller (BELBIC) is built to generate the pulse width modulation signals applied to the inverter and the control signal applied to the capacitor. The effect of utilizing small dc-link capacitor, on the torque ripple reduction and speed control is investigated. The performance is also compared with the case of large capacitor utilization and without a capacitor case. The proposed control strategy is verified by MATLAB/SIMULINK environment.

Keywords: Brushless DC Motor (BLDCM), Torque ripple, Brain Emotional Learning Based Intelligent Controller (BELBIC)

I.INTRODUCTION

Artificial intelligence (AI) techniques are one of the rapidly growing interesting topics for industrial applications [1, 2]. AI techniques usage is widely accepted from guiding of autonomous vehicles to identifying of human emotions. Development of AI techniques for complex non-linear systems replaces conventional controllers since accuracy of AI techniques in finding solution is high with faster reaction time. Various approaches are used to design intelligent controllers such as Neural Network, Fuzzy Logic Control, Evolutionary computation, Bayesian probability and many more. Since last decade, researchers focused on metaheuristic approaches to develop AI algorithms [3–6]. The modern AI techniques are developed by mimicking mammalian brain. Modern AI techniques with different architectures are developed by mimicking the functionalities of mammals because of their inherent intelligence [7–9]. The mammalian brain analyses the information collected from different structures and linkages of organs to solve the tasks efficiently. The problem-solving nature of brain can be used to develop intelligent systems. These intelligent systems are capable to take decision inspiring human but understanding and developing of human capability is one of the most challenging tasks [10]. Numerous attempts have been made by neuroscientists to elucidate the mechanism of different parts located in the brain [11–13]. There are three main divisions within the brain that include Cerebrum, Cerebellum and Brain Stem [14–16]. Each part has specific function and their combined effort provides an optimal solution on problem leads to effective decision. These parts can be used to develop a computational model to introduce newer AI techniques to attain optimal solution. These models are programmed and form as controller for a machine to develop an AI device. Since last decade many researchers have been working on modelling of brain by understanding the neuro-scientific behaviour of individual parts i.e., Cerebrum, Cerebellum and Brain stem. The computational model for Cerebrum is modelled with limbic system by Moran and Balconies and tested for fear and stress [17]. The developed computational has been applied as controller by Caro Lucas et al. [11] and named as Brain Emotional Learning Based Intelligent Controller (BELBIC). Further, BELBIC is modified and applied many of the engineering applications [9, 10]. The Cerebellum, another part of brain actively participates in decision making process, whereas the computational model is developed by Marr Albus and named as Cerebellum Model Articulation Controller (CMAC) [18]. Structure of CMAC is modified and applied on many of potential engineering applications [20–24]. Some neuroscientists recognize the benefits that are to be expected from infusion of engineering ideas with their Feld and anticipating the symbolic relationship between modelling and experimental research [16, 17]. It has been observed that the Cerebrum and Cerebellum parts of brain involve in cognition. The output information from Cerebrum and Cerebellum passes through various elements of brainstem in order to obtain optimal performance on the given task. There is a multi-modular joint between Cerebrum and cerebellum with Red Nucleus (RN) of brain stem to process the sensory information. Cerebellum has a connection with Deep Nucleus (DN) and forwarded to RN [19, 25–27]. Cerebrum and Cerebellum connections with brainstem from RN and DN can be realized to develop a computational model. In view of the above, the Cerebrum is responsible for emotions whereas Cerebellum for motor movements. The information collected from Cerebrum and Cerebellum is processed in Brain stem and sends the signals to the organ to take a decision. The individual controllers for Cerebellum (BELBIC) and Cerebrum (CMAC) are developed and implemented successfully in many of the applications. As per neurobiological connections the brain will process sensory signal in both Cerebrum and Cerebellum simultaneously and the brain stem generate an activating signal to perform the task. In order to develop a controller, the connection is established among Cerebrum, Cerebellum, and brain stem to as per brain anatomy Multi Modular Joint connection with Red Nucleus (RN) in brain stem and Deep Nucleus (DN) in Cerebellum. In this paper, neural connections of brain parts especially with DN and RN from Cerebrum and Cerebellum parts are inspired to develop a computational model. Cerebellum and Cerebrum relate to RN in brainstem, the point of connection is multi modular joint and developed controller inspiring connections termed as Multi modular Joint-Brain Controller (MMJ-BC). In design of MMJ-BC, Cerebrum and Cerebellum controllers are developed separately and combined with DN and RN. Individually, the Cerebrum based controller i.e., BELBIC is designed by inspiring Limbic system and associated parts and Cerebellum based controller is designed by adopting layer approach. MMJ-BC is designed by forwarding the output of Cerebellum with DN and further processed in RN with BELBIC output [19]. The developed MMJ-BC performance is verified by testing on different plants such as position control of Aircraft system and speed control of Brushless DC (BLDC) motor.

In this project the proposed BEC technique also concerns the issue of torque ripples in the BLDC motor and attempted to lessen the torque ripple causes with small dc-link capacitor. This method also introduces a control method to reduce the ripples without affecting the motor speed. The contribution of this work is the effective reduction of torque with more stabilization in the motor speed which is illustrated in the curves presented in the results section.

II. PROPOSED SYSTEM

The figure.1 shows the proposed BEL based controller for torque ripple minimization. In the proposed work, the torque ripple compensation method is presented for a BLDC motor at low cost. The configuration uses a small dc-link capacitor in place of a bulkier capacitor for torque ripple reduction. The capacitance value of the smaller dc-link capacitor connected in this configuration is about 3% of the normally used heavier capacitor. The mathematical equations of the BLDC motor and the developed torque are given below. To produce the switching sequence, Brain emotion learning based controller is employed.

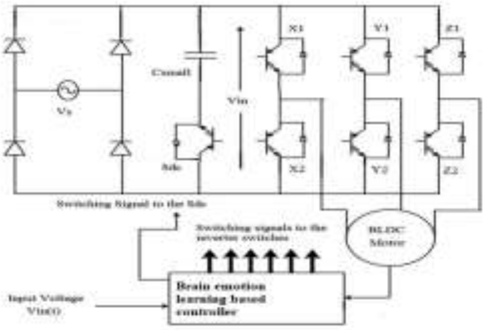


Fig 1 Proposed BEL based controller for torque ripple minimization

BLDC Motor Operation

The pulsating dc is applied to the stator field windings in the BLdc motor. There three pole pairs are considered which are denoted as X, Y, and Z. When dc pulse passes through pair X, the pole X1 magnetizes as south and the pole X2 magnetizes as north. Then the current applied to pole pair X is turned OFF and the pulsated dc passes through pole pair Y and then similarly through pole pair Z. Thus, by giving the pulse to the stator pole pairs sequentially, the magnet will continuously rotate in a clockwise direction.

A six-step inverter is employed in the driver side of the motor to work as three-phase supply and the rotating field is created through the electronic commutation of the three pairs of stator coils. In a three-phase BLdc motor, only two phases are energized at a particular instant, the switches of another phase kept in “OFF” state. Thus, in a particular instant, only two switches of the inverter are kept in “ON” state. In order to control these two switches, the PWM signals are generated from the controller circuit. The controller circuit is able to operate in two modes namely, torque control or speed control mode [39], [40]. However, in this proposed configuration, the used dc-link capacitor is the small capacitance. Hence, another strategy is proposed for this kind of configuration by controlling only one switch and keeping another switch in “ON” state for the whole interval. Thus, the obtained switching sequence is given in the table. The switch existing in “ON” state gives a freewheeling path to the inductive current during the “OFF” state of the controlled switch. The Hall sensor outputs are denoted as Hx, Hy, and Hz.

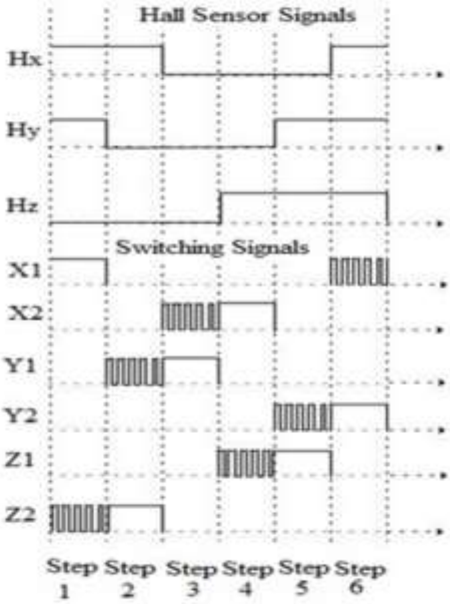


Fig. 2. Hall sensor signals and switching signals.

In Fig 2, the waveforms of Hall sensor output, switching pulses are given along with the rotor position, denoted by φr. By taking below assumption, the BLdc motor model is analyzed. 1) BLdc motor is an unsaturated type. 2) The resistances of the stator winding in all the three phases are equal and the inductance (self and mutual) is constant. 3) The semiconductor switches are considered ideal and negligible iron losses are considered. 4) Back-EMF waveforms of all phases are equal. The dynamic equation models are obtained by considering the equivalent circuit of the BLdc motor and VSI system depicted in Fig 2

$$V_x = RI_x + (L-M)\frac{di_x}{da} + e_x \qquad 1$$

$$V_y = RI_y + (L-M)\frac{di_y}{da} + e_y \qquad 2$$

$$V_z = RI_z + (L-M)\frac{di_z}{da} + e_z \qquad 3$$

where

Vx, Vy, Vz Stator phase voltages.

ix, iy, iz Stator phase current.

ex, ey, ez Phase back-EMF.

L Self-inductance.

M Mutual inductance.

R Phase resistance.

a Time instant.

The motion equation is defined a

$$\frac{ds_m}{dt} = \left(\frac{P}{2J}\right)\left(\tau_e - \tau_L - F s_r\right)$$ 4

$$\frac{d\phi}{dt} = s_r$$ 5

τe Electromagnetic torque. τL Load torque (Nm). J moment of inertia (kgm2). F Friction coefficient (Nms/rad). sm Rotor speed in mechanical (rad/s). sr Rotor speed in electrical (rad/s). Electrical and mechanical speed of the motor are related by

$$Ps = \frac{d\phi_r}{da}$$ 6

where P is the number of pole pairs.

III. PROPOSED BELBIC

Fig 3 displays the simulation model of BELBIC. In the PMBLDC, motor control signals are taken as actual sources of information. Emotional signals rely upon performance parameters. BELBIC depends on an intelligently influenced computational model (Lucas, Shahmirzadi, and Sheikholeslam 2004). It has been used for various modern applications and control drives. BELBIC is an emotional control based on physical sources of info and reward signals (Jamali et al. 2009). Model output MO is the reference voltage (V*) delivered by BELBIC.

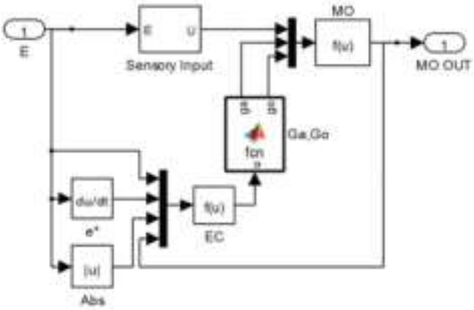


Figure 3 Basic circuit of BELBIC

ES is the emotional signal named emotional cue determined utilizing existing speed error, loads, and model output (Lotfi, Rezaee, and Belbic 2019). Indications of ES choose the additions to be shifted, which selects model output. The output of BELBIC is a controlled DC voltage for an inverter. This closed-loop control circuit produces controlled speed with the least error (Subramaniam et al. 2016). The presentation of the PMBLDC motor drive is explored at diverse speed conditions and several load-changing conditions. The model output can be computed as follows

$$E = \sum_{i=0}^{n} Ai \sum_{i=0}^{n} Oi\{\text{comprising Ath}\}$$ 7

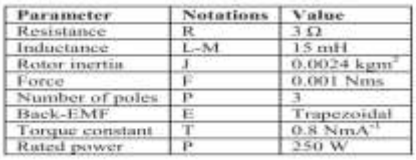
$$E' = \sum_{i=0}^{n} Ai - \sum_{i=0}^{n} Oi\{\text{excluding Ath}\}$$ 8

The Simulink model of BELBIC is developed using the equations from (5.6) to (5.7). Updating the adaptive weights in the orbitofrontal cortex is almost like the amygdala rule. The distinguishing point is that the orbitofrontal weights must be changed for tracking the inappropriate response from the amygdala. The 'A' nodes produce their outputs proportionally to their contribution in predicting the reward or stress, while the 'O' nodes prevent the output of 'E' if necessary. The model output is the difference between the output of the amygdala and orbitofrontal nodes.

IV. SIMULATION RESULTS

In order to evaluate the proposed control algorithm, the topology and the algorithm are implemented in MATLAB. The simulation diagram of the proposed scheme is presented in Fig.4 The performance of the proposed strategy is also analyzed and compared with the capacitor case, without the capacitor case, and small capacitor case. The parameters set to the BLdc motor in this work are displayed in Table 1. The Hall effect sensors are mounted in the motor to give the rotor position to the PWM controller. In the PWM controller, the BEL-based control algorithm to generate the switching signals to the inverter switches. Fig.5 (a) and (b) provides a comparison of the phase current (im) without a dc-link capacitor nd with a dc-link capacitor. Fig. 5(c) and (d) illustrates the phase current with the small capacitor and with the spider control algorithm. Fig.6(a) and (b) provides a comparison of the torque without a dc-link capacitor and with a dc-link capacitor. Fig.6(c) and (d) illustrates the torque with the small capacitor and with the existing spider control algorithm. Fig. 7(a) and (b) provides a comparison of the speed without a dc-link capacitor and with a dc-link capacitor. Fig.7(c) and (d) illustrates the speed with the small capacitor and with the spider control algorithm.

TABLE 1 ; MOTOR SPECIFICATIONS



Parameter	Notations	Value
Resistance	R	3 Ω
Inductance	L-M	15 mH
Rotor inertia	J	0.0024 kgm^2
Force	F	0.001 Nms
Number of poles	P	3
Back-EMF	E	Trapezoidal
Torque constant	T	0.8 NmA^{-1}
Rated power	P	250 W

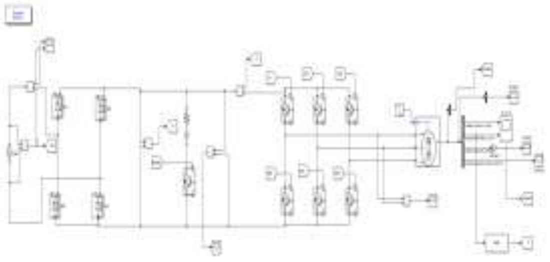
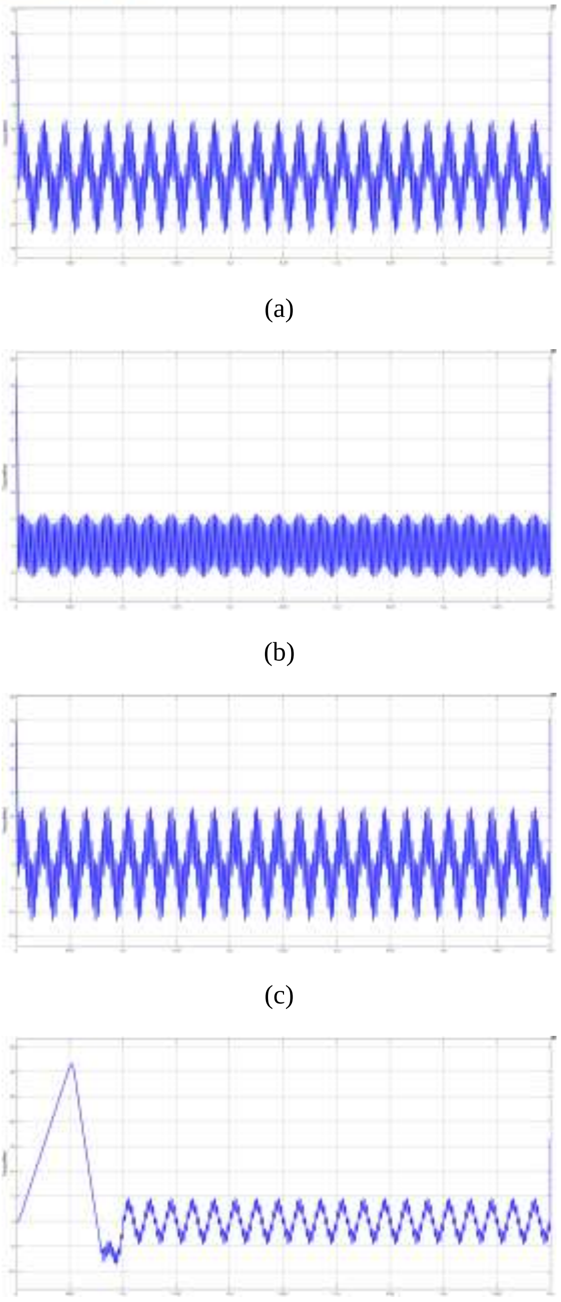


Fig.4 MATLAB/SIMULINK circuit diagram of the system

A) EXISTING RESULTS



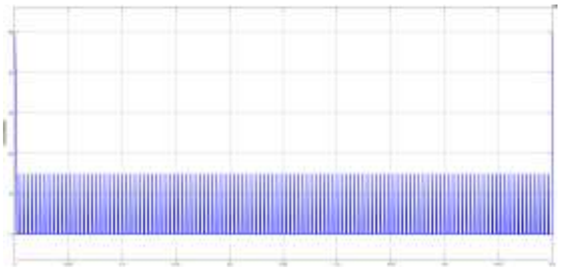
(a)

(b)

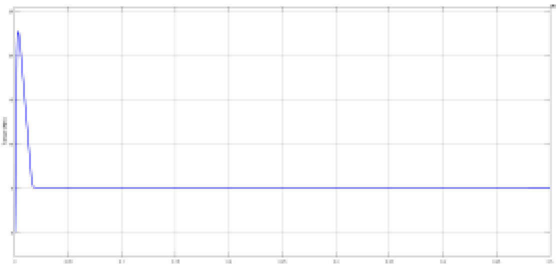
(c)

(d)

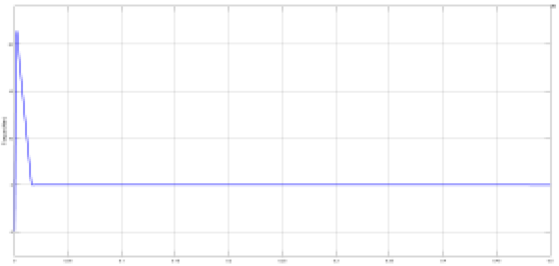
Fig.7.2 im compensation. (a) Im (A) - without capacitor. (b) Im (A) - with capacitor. (c) Im (A) - with small capacitor. (d) Im (A) - with spider.



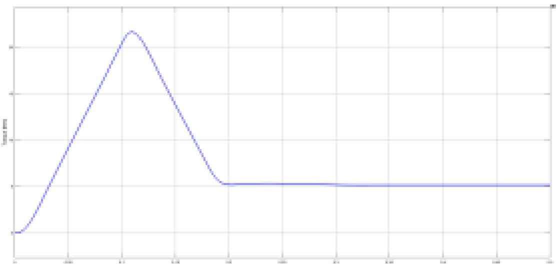
(a)



(b)

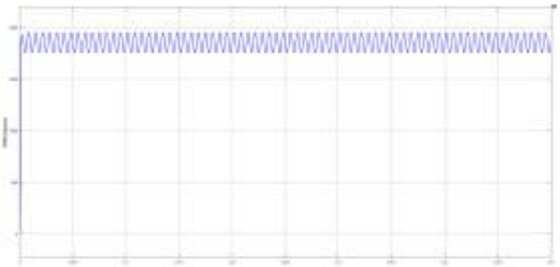


(c)

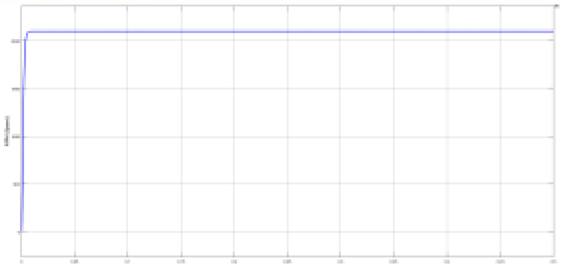


(d)

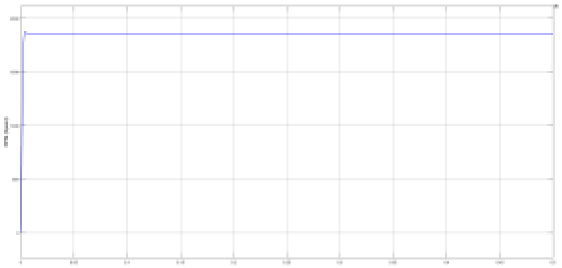
Fig.5 Torque comparison. (a) Torque (Nm) - without capacitor. (b) Torque (Nm) - with capacitor. (c) Torque (Nm) - with small capacitor. (d) Torque (Nm) - with spider.



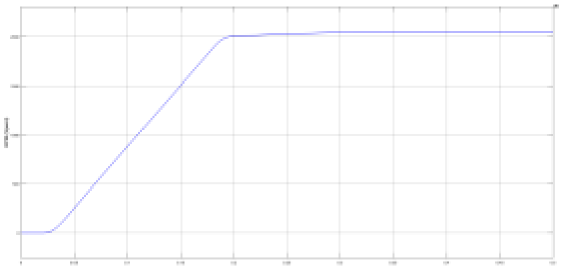
(a)



(b)



(c)



(d)

Fig.6 Speed comparison. (a) RPM (speed) - without capacitor. (b) RPM (speed) - with capacitor. (c) RPM (speed) - with small capacitor. (d) RPM (speed) - with spider.

B) EXTENSION RESULTS

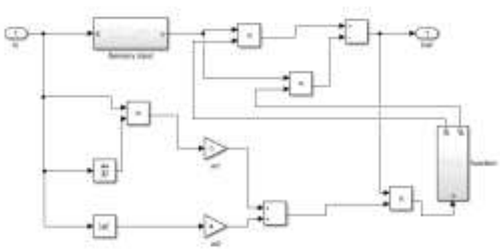


Fig .7 Subsystem of Brain emotion controller

Fig 7 shows the brain emotion controller. Fig.8 displays the phase current (im) with proposed controller. Fig.9 illustrates the torque with the proposed control algorithm. Fig. Fig.10 illustrates the speed with the proposed control algorithm. By observing the proposed results the torques ripples are reduced compared to existing controller.

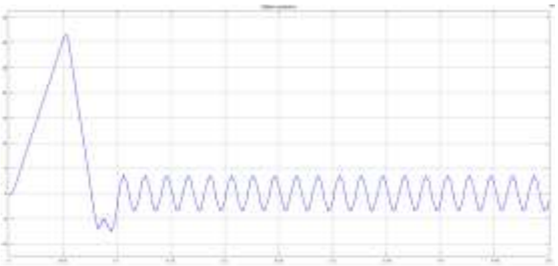


Fig. 8 Current

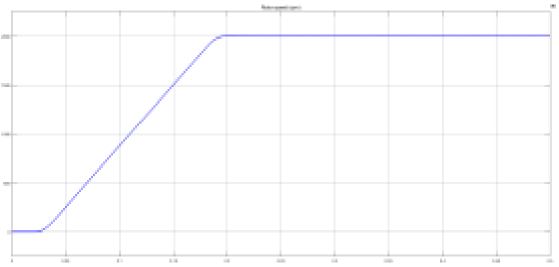


Fig.9 Speed

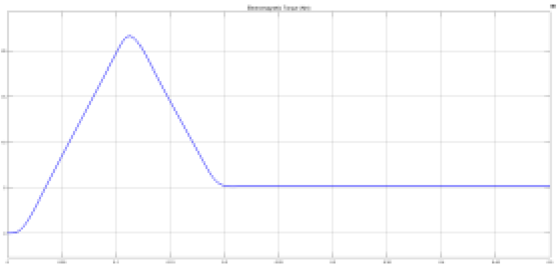


Fig.10 Torque

COMPARISION TABLE

Case	THD%
With small capacitor	**105.5%**
With spider-based controller	**98.93%**
With brain emotion controller	**83.95 %**

CONCLUSION

The method of designing a three-phase BLDC motor drive by using a single-phase voltage source is presented with the intention of employing small dc-link capacitor. In addition, the strategy for reducing torque ripple concern which is generally presenting in BLDC motor is considered in the work. The mathematical equations are developed to determine the capacitor rating and the parameters are set in the simulation to validate the theoretical results. The utilization of a small dc-link capacitor is evaluated by assessing the torque compensation waveform and current compensation waveform with the capacitor-less case and large capacitor case. Besides, the application of Brain Emotion Learning Based Intelligent Controller (BELBIC) in generating the necessary switching control pulses are observed by comparing waveforms with the spider-based control algorithm also with the capacitor and without capacitor case. The utilization of BELBIC control algorithm to develop the control pulses make the system to be more stabilized with respect to its speed. Though the scheme has a switch and a small capacitor as additional components, the total price of the drive is reduced. Similarly, the control process used for the switches is simple, extra components are not used. When the large capacitors are used, the motor reliability is reduced since the large capacitors are rated for the small period only. In addition, the simulation results are validated by MATLAB/SIMULINK environment

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