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Commutation Torque Ripple Reduction strategy for BLDC Motor using Novel NIBFE

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ABSTRACT: This paper is based on commutation torque ripple reduction strategy for BLDC Motorusing Novel NIBFE. BLDC Motor are used in many applications due to high efficiency, high power density, high starting torque. The commutation torque ripple is produced in commutation period due to phase current which is not undergoing commutation. By maintaining noncommutation phase current constant in commutation period torque ripple can be minimized. The commutation torque ripple cause vibration and noise, will reduce high performance operation of BLDC motor. BLDCM normally operates in two phase conduction mode which is considered as non commutation period and three phase conduction region is considered as commutation Period. BLDC motors do not have brushes and commutator rather commutation is done by electronic switches. They use Hall sensors to sense rotor position. In this work Novel NIBFE called as Non inductive boost front end formed using Diode, MOSFET and capacitor is used. The output of NIBFE is given to BLDC motor using an Inverter. A Closed loop feedback controller circuit is used to generate PWM gate pulse by using proper switching sequence of four switching vectors in commutation and noncommutation period have reduced the commutation torque ripple. The components are simulated in MATLAB 2019b software and the simulation results of Open loop and Closed loop are presented.

KEYWORDS: BLDC Motor, Commutation torque ripple reduction, Hall sensors, NIBFE, Switching Vectors.

I.INTRODUCTION

BRUSHLESS DC motors (BLDC Motor) is used in many applications due to their simple structure and high torque density.The commutation torque ripplemaximum may reach 50% ofaverage torqueproduced in the commutation process,Torque ripple occurs as during phase current commutation period phase current control is lost.[2] The major problem of commutation torque ripple is it cause noise and vibration which reduce the high-performance operation of BLDCM [1][3].Two phase modulation mode during both commutation and noncommutation period simplifies modulator design where PWM are modulated in non commutating phase[5]. To reduce commutation torque ripplethreesegment modulation strategy is used which divides each PWM period into three segments and analyseduration of each segment according to both constant noncommutation phase current and minimum commutation time.[4] Results showed modulation on outgoing phase in the high-speed regionand noncommutation phase in low-speed region are selected. When machine operates at low speed range with PWM technique torque ripple can be minimized. It is not effective to minimize torque ripple at high speed with PWM scheme at rated condition due to Inverters limited DC source voltage.At high speed range to minimize the commutation torque ripple DC to DC converter is added in front end which would increase Inverter voltage during the commutation period.[6]The SEPIC converter is employed to adjust the voltage required in commutation period, where DC source and SEPIC converter are selected to supply motor during noncommutation and commutation periods. A Cuk converter is presented to reduce commutation torque ripple in [7], where two operation modes are employed to regulate the voltage during the noncommutation and the commutation period, respectively. However, few power switches and inductors are required in these DC–DC converters, which greatly increases both the size and cost of the motor drive system.

II.PROPOSED SYSTEM

In this project a unified commutation torque ripple reduction using Switching Vectors is proposed with a designed noninductive boost front end (NIBFE). Input DC voltage is given to NIBFE output is fed to Inverter then to BLDC motor and Closed loop feedback controller circuit with proper switching sequence to generate gate pulse for inverter

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switches will be used. By maintaining noncommutation phase current constant in commutation period the commutation torque ripple can be reduced.

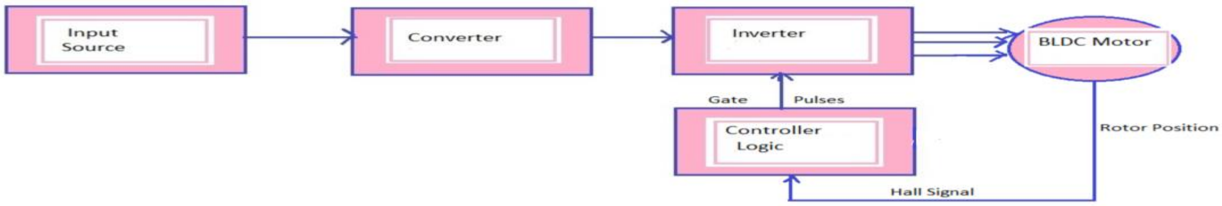


Fig. 1 Block diagram of BLDC Motor using NIBFE

A.NIBFE

Here novel NIBFEis Non inductive boost front end simply a Diode, MOSFET, DC-link capacitor. Here C is DC-link capacitor,D8 is DC link diode, Switches S1-S7 are MOSFET ,D1-D7 are antiparallel diode.NIBFE output is given to Inverter.

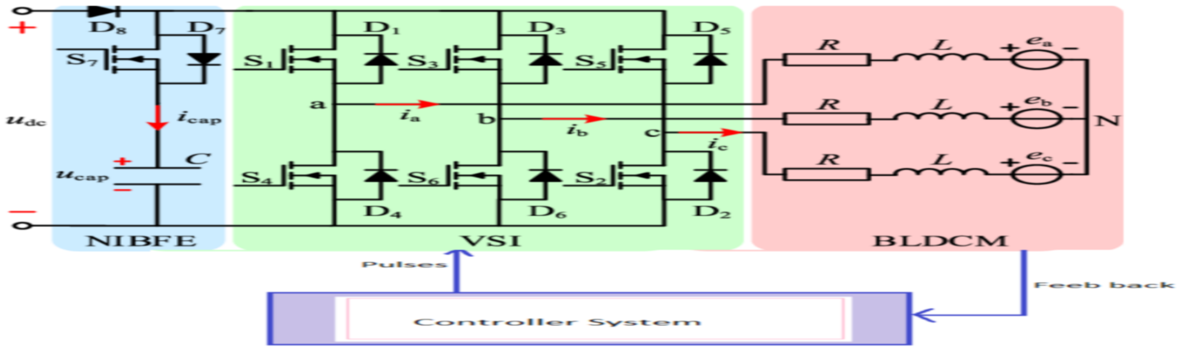
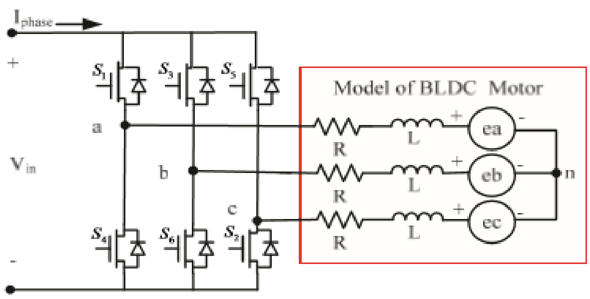


Fig. 2Detailed diagram of BLDCM drive system using NIBFE

B. BLDC MOTOR DRIVE SYSTEM

BLDC motor needs input as AC so Inverter is input to BLDCM which converts DC-AC.VSI is used for achieving an electronic commutation of BLDC motor based on the rotor position. Electronic commutation happens every sequentially 60 degrees rotation of rotor. The BLDCM has three stator windings and a permanent magnet rotor on the rotor. We consider three phase star connected balanced system. Assume Eddy current, hysteresis losses are neglected.



Parameters	Values
Input voltage	100 V
Poles	12
Stator inductance, L	2.2 m H
Stator resistance, R	0.4Ω
Friction coefficient, B	0.0015 Nm.s/rad
Moment of inertia, J	0.00024 kgm2
Back emf constant ,Kb	0.0248 V/rad/s
Rated Power	1 KW

Fig. 3 Parameter of BLDC Motor

Voltage equation of 3 phase windings.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_v \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

where Va,Vb,Vc are stator phase voltages, R stator resistance per phase, ia,ib,ic stator phase currents, L self-inductance of each phase,M mutual inductances between phases, ea,eb,ec phase back electromotive forces

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$$V_a = i_a R + L\frac{di_a}{d_t} + e_a$$
$$V_b = i_b R + L\frac{di_b}{d_t} + e_b$$
$$V_c = i_c R + L\frac{di_c}{d_t} + e_c \quad (2)$$

It has been assume that back EMF ea,eb,echave trapezoidal wave displaced by 120.

$$e_a = \omega_m \lambda_m f_{as}(\theta_r)$$
$$e_b = \omega_m \lambda_m f_{bs}(\theta_r)$$
$$e_c = \omega_m \lambda_m f_{cs}(\theta_r) \quad (3)$$

where ωm angular rotor speed in radians per seconds, λm flux linkage, θr rotor position in radian and fas(θr) ,fbs(θr), fcs(θr) trapezoidal functions have same shape as ea,eb,ec with a maximum magnitude of ±1 phase displaced by 120.

Electromagnetic toque equation in Newton's defined as

$$T_e = [e_a i_a + e_b i_b + e_c i_c] / \omega_m \quad (4)$$

Motion Equation

$$J\frac{d\omega_m}{dt} + B\omega_m = (T_e - T_l) \quad (5)$$

where J moment of inertia, B friction coefficient, Tl load torque, ωm angular velocity. The electrical rotor speed and position are related by

$$\frac{d\theta_r}{dt} = \frac{p}{2}\omega_m \quad (6)$$

where p number of poles pairs

III.COMMUTATION TORQUE RIPPLE REDUCTION WITH PROPOSED SYSTEM

Table 1 shows Current conduction of Positive and Negative phases.

H_a H_b H_c	1 0 1	1 0 0	1 1 0	0 1 0	0 1 1	0 0 1
Sector	⑤	④	⑥	②	③	①
(p,n)	(a,b)	(a,c)	(b,c)	(b,a)	(c,a)	(c,b)

"H_a," "H_b," and "H_c" are denoted as the Hall signals of three phases.

Table. 1 Current conduction of Positive and Negative phases

The proposed control strategy requires four Switching Vectors.Two main Vector (Vm0,Vm1) and two Auxiliary Vectors (Va0,Va1) ,switching sequence of 6 Inverter switches and NIBFE switch for each Sector is shown in Table 2.

	V_{m0}	V_{m1}	V_{a0}	V_{a1}
	S_{pH} S_{nL} S_7	S_{pH} S_{nL} S_7	S_{pH} S_{nL} S_7	S_{pH} S_{nL} S_7
④, ②, ①	1 1 0	1 1 1	0 1 x	0 0 0
⑤, ⑥, ③			1 0 x	

Table. 2 Proposed strategy using four switching Vectors

A. NONCOMMUTATION PERIOD STRATEGY

Noncommutation period modulation strategy used in Noncommutation period itsswitching pattern of each sector is shown in Table 3.

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|| Volume 10, Issue 5, May 2021 ||

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Sector	$U_{ref} \le U_{cap} < U_{ref} + w_0$			$U_{cap} < U_{ref}$		
	S_{pH}	S_{nL}	S_7	S_{pH}	S_{nL}	S_7
④, ②, ①	d_1	1	0	d_2	d_2	0
⑤, ⑥, ③	1	d_1	0			

"1" is ON: "0" is OFF. The switches not listed in the table are OFF

Table. 3 Non commutation Period Modulation strategy

B. COMMUTATION PERIOD STRATEGY

Commutation period modulation strategy used in Commutation period its switching pattern of each sector is shown in Table 4.

Status	Sector					
	⑤	④	⑥	②	③	①
d_{cmt}	S_6	S_1	S_2	S_3	S_4	S_5
1	S_1	S_2	S_3	S_4	S_5	S_6
1	S_7					

Table. 4 Commutation Period Modulation strategy

C. CLOSED LOOP ANALYSIS

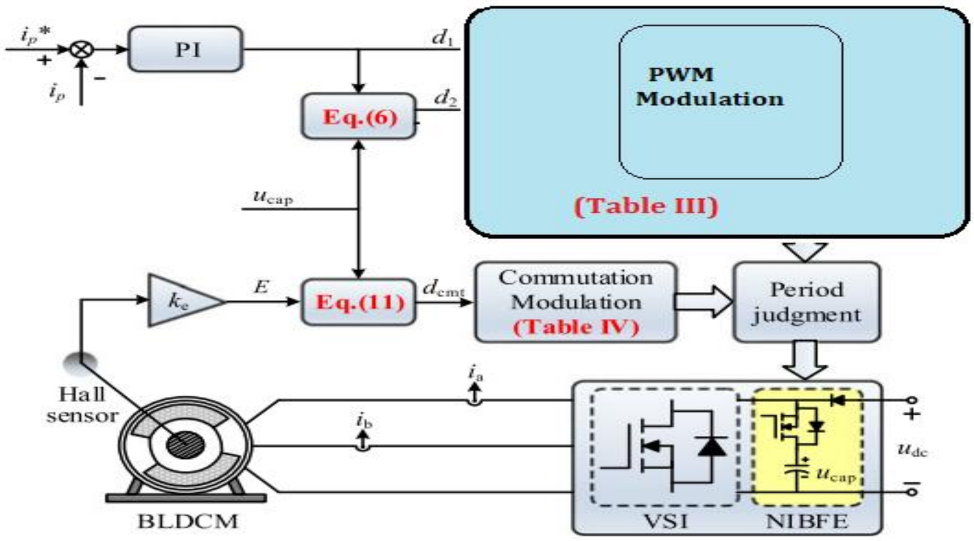

Fig. 4 Closed loop Proposed control strategy of BLDCM drive system using NIBFE

In closed loop operation of NIBFE fed VSI fed BLDC motor speed is compared with reference speed and actual speed of BLDC motor that error is given to Speed PI controller and its output is given to current PI controller, duty cycle d1,d2 is acquired and given to Noncommutation block .The duty cycle of commutation period is acquired given to Commutation block.Period Judgement block decides which period for Commutation period select Commutation modulation strategy (Table 4) and Noncommutation period select Noncommutation modulation strategy (Table 3).PWM Gate signals are generated and given to 6 Inverter switches and NIBFE capacitor switch.

$$d_2 = \frac{d_1 U_{dc} + U_{cap}}{U_{dc} + U_{cap}} \quad (7)$$

$$d_{cmt} = 0.5 + \frac{2E}{U_{cap}} \quad (8)$$

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$$C \leq \frac{2LI^2}{U_{\text{ref}}^2 - (U_{\text{ref}} - \Delta U)^2} \quad (9)$$

where C=2300MF is the capacitor value , d1, d2 are duty cycle of non commutation period and dcmt is duty cycle of commutation period

Torque ripple rate is calculated as

$$K_{\text{rT}} = \frac{T_{\text{high}} - T_{\text{low}}}{T_{\text{high}} + T_{\text{low}}} \times 100\% \quad (10)$$

where Tlow is minimum torque and Thigh is maximum torque over a period of time.

IV.SIMULATION

The Mathematical modelling of Brushless DC motoris shown in Fig 5.

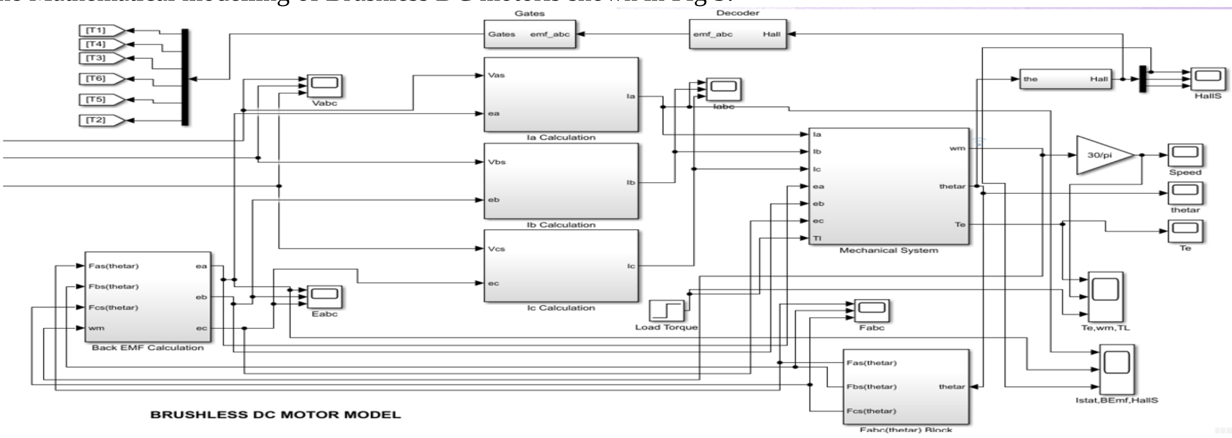

Fig. 5 Simulation of Mathematicalmodelling of Brushless DC motor

A. OPEN LOOP

The simulation of NIBFE-VSI-BLDC motor whole system in Open Loopis shown in Fig .Input Voltage of 100Vfrom DC voltage source with duty cycle of 0.2 is applied to NIBFE Capacitor switch ,Load Torque of 0Nm is given to BLDC motor and results are obtained.By sensing the position of rotor, hall sensors produce hall signals and send it to logic circuit in which decoder is placed to produce gate signals for the inverter of BLDC motor drive circuit. According to hall signals gate triggering of electronic inverter is done in Open Loop.

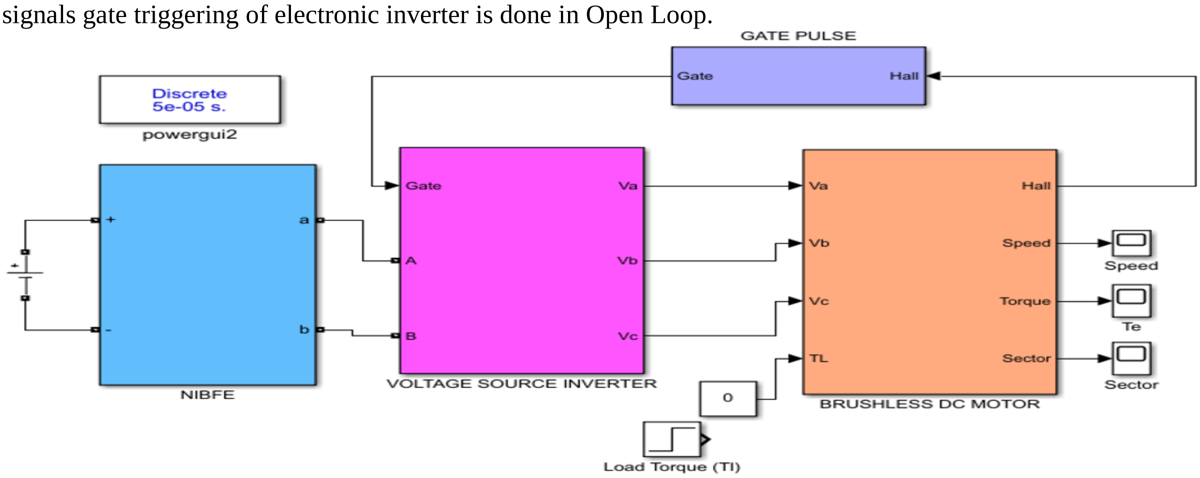

Fig. 6 Simulation of NIBFE-VSI-BLDC motor whole system in Open Loop

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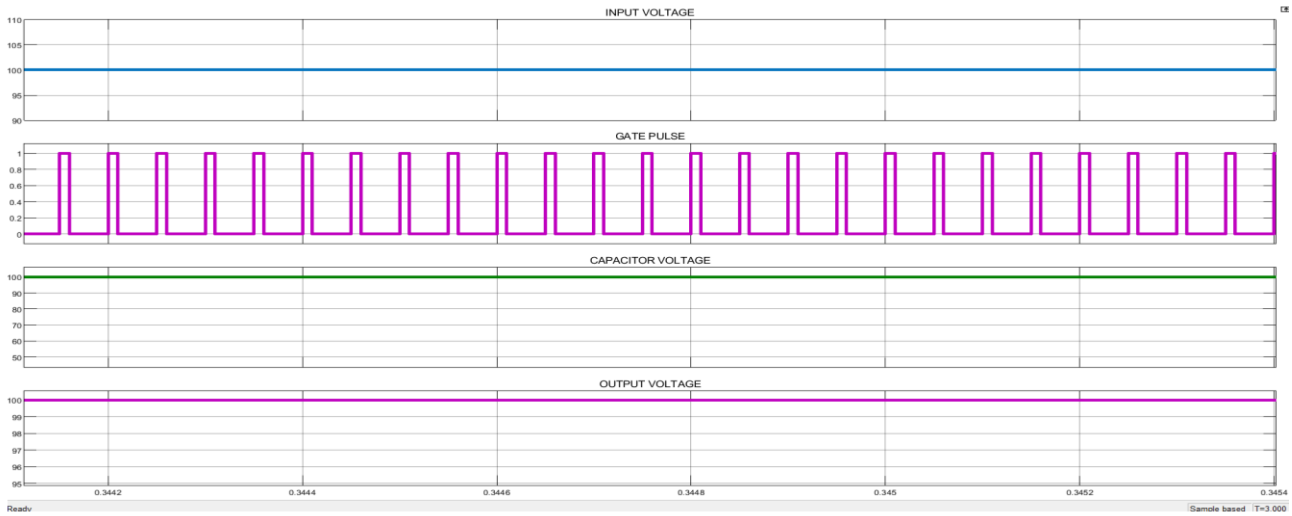

Fig. 7 NIBFE Input,Output ,Capacitor Voltage, Gate pulse waveform of NIBFE-VSI-BLDC motor system

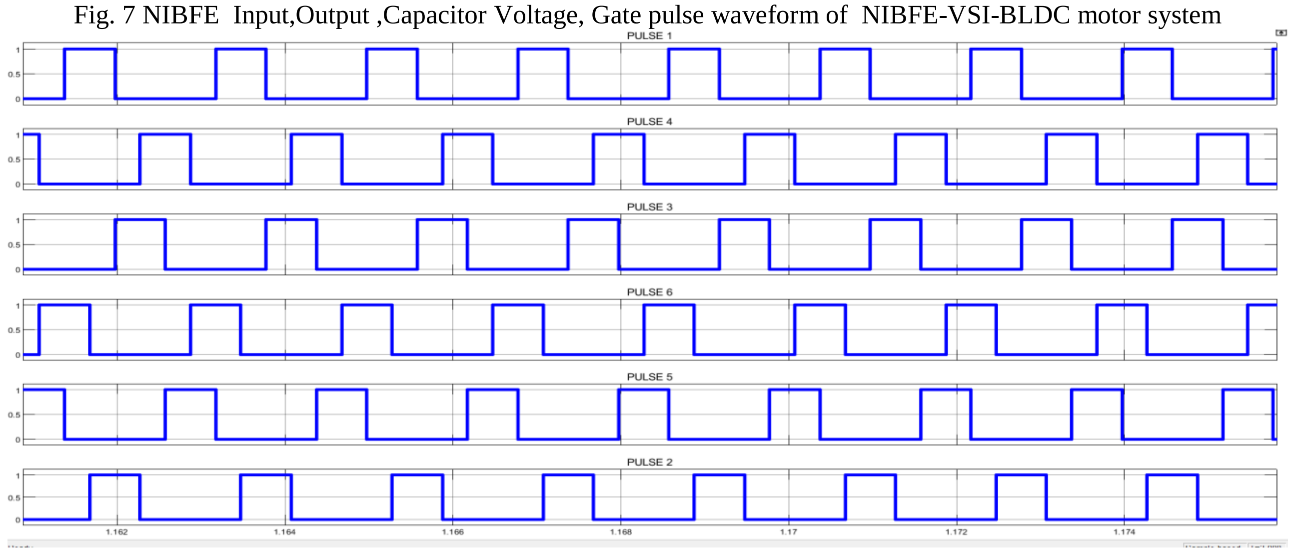

Fig. 8 Inverter Gate pulse waveform of NIBFE-VSI-BLDC motor system

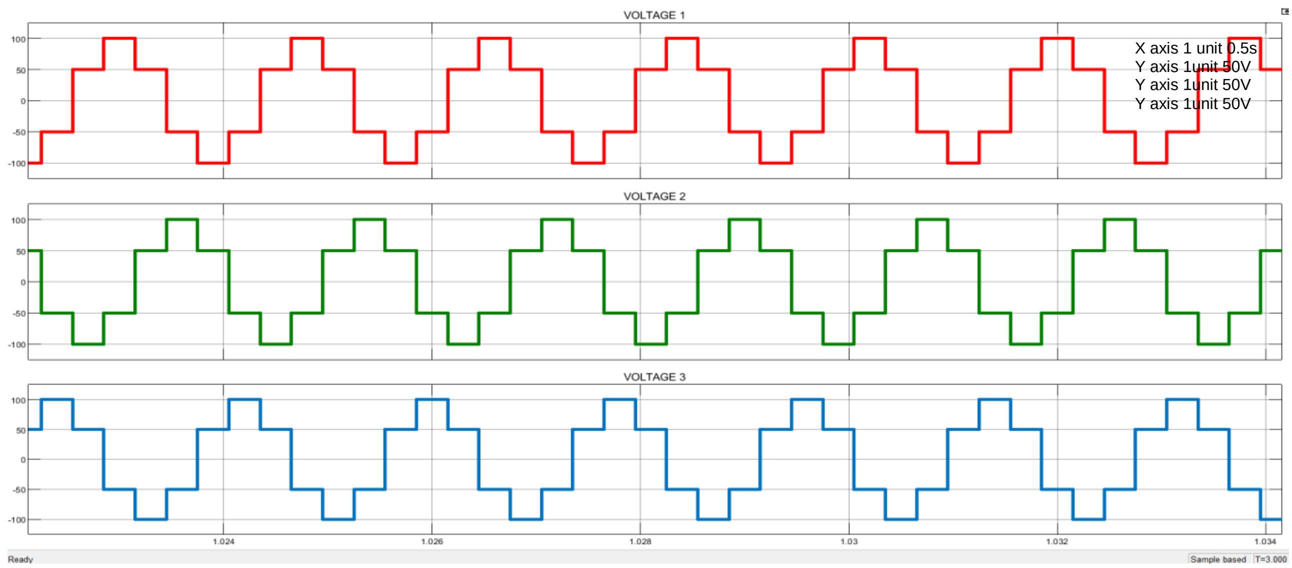

Fig. 9 Inverter Voltage waveform of NIBFE-VSI-BLDC motor system

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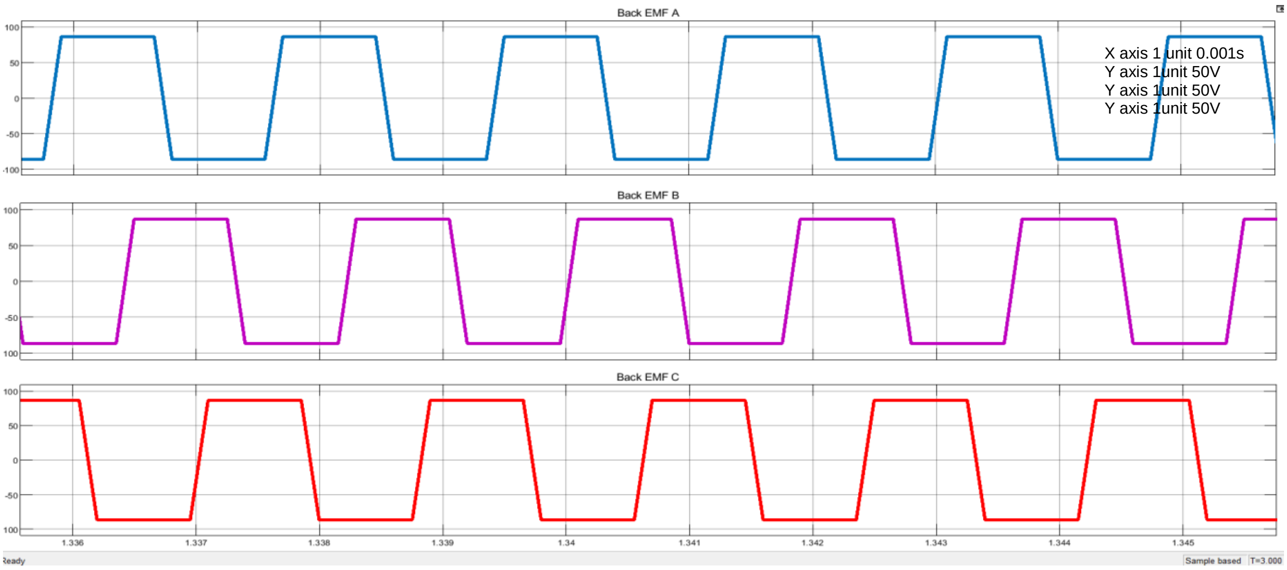

Fig. 10 Back EMF waveform of NIBFE-VSI-BLDC motor system

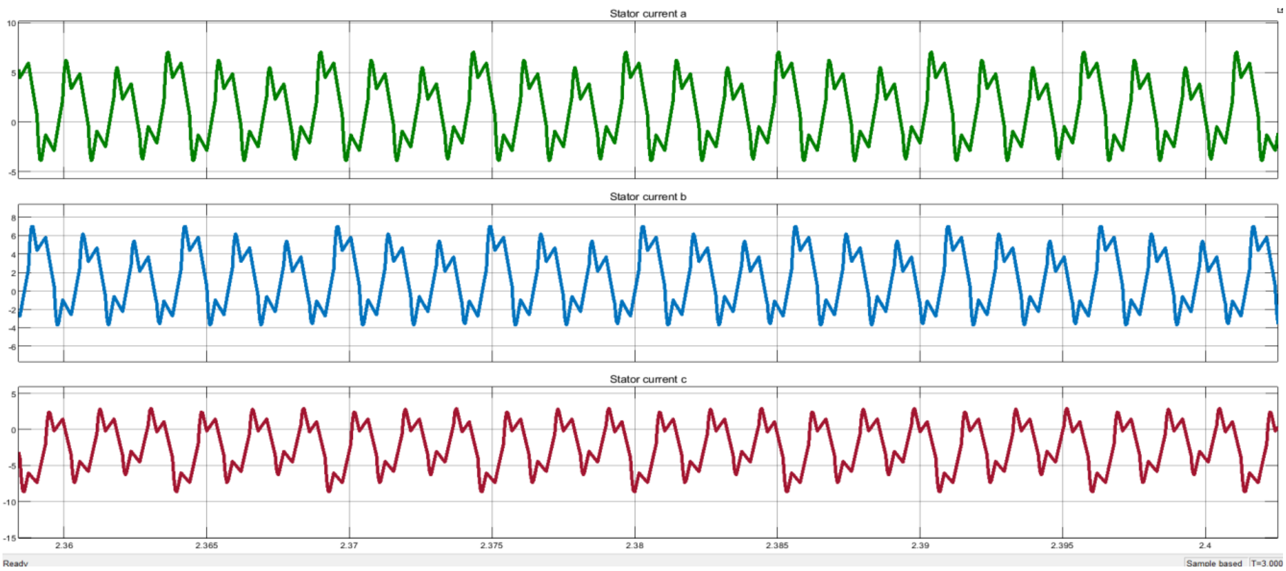

Fig. 11 Stator Current waveform of NIBFE-VSI-BLDC motor system

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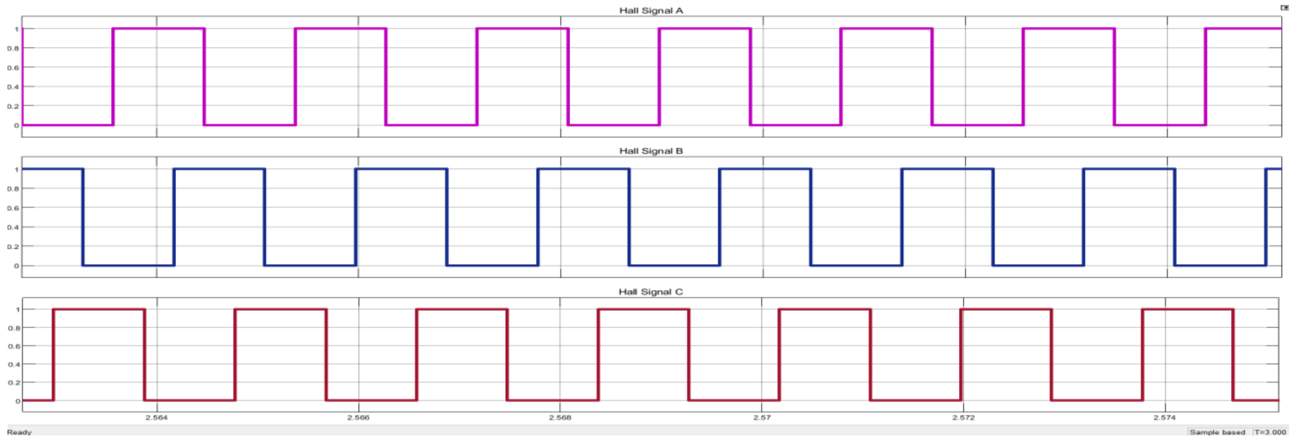

Fig. 12 Hall Signal waveform of NIBFE-VSI-BLDC motor system

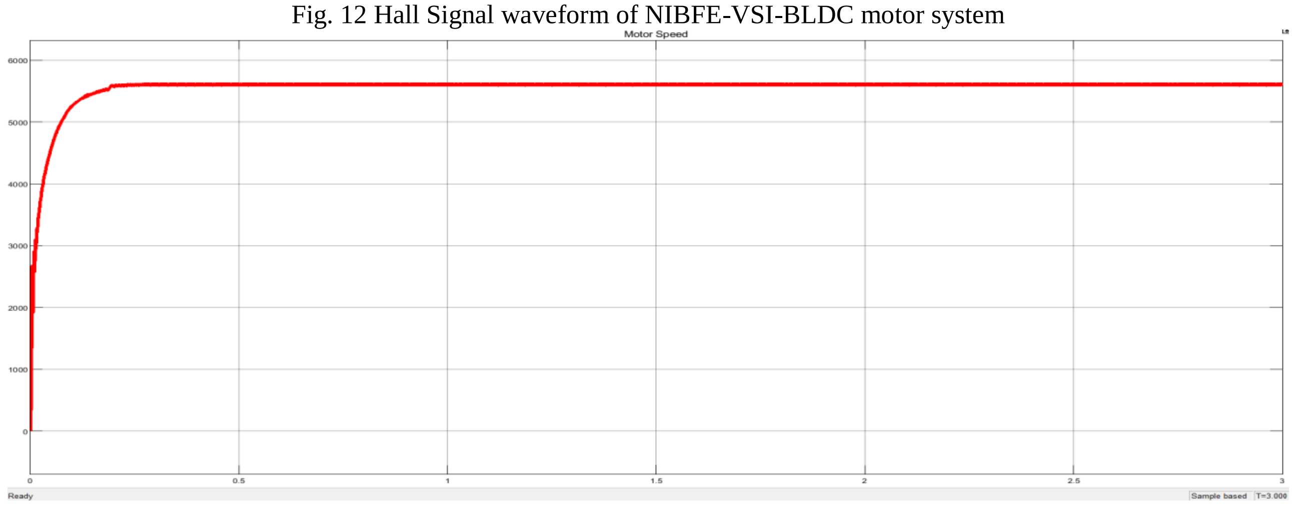

Fig. 13 Speed waveform of NIBFE-VSI-BLDC motor system

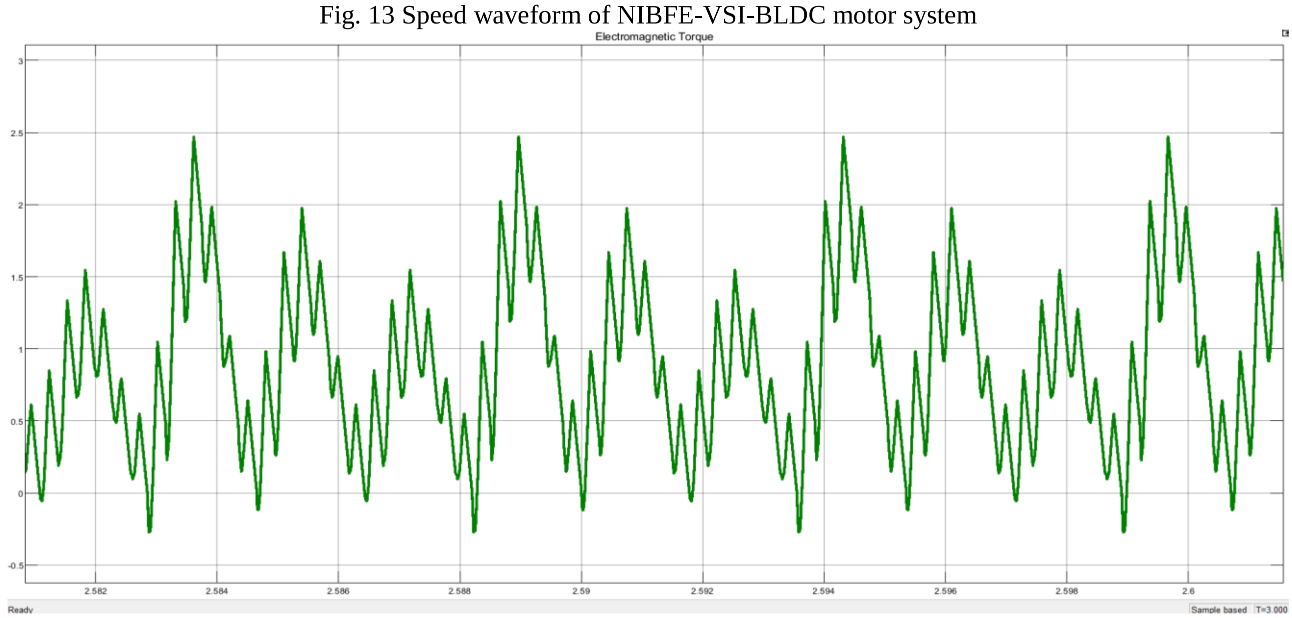

Fig. 14 Torque waveform of NIBFE-VSI-BLDC motor system

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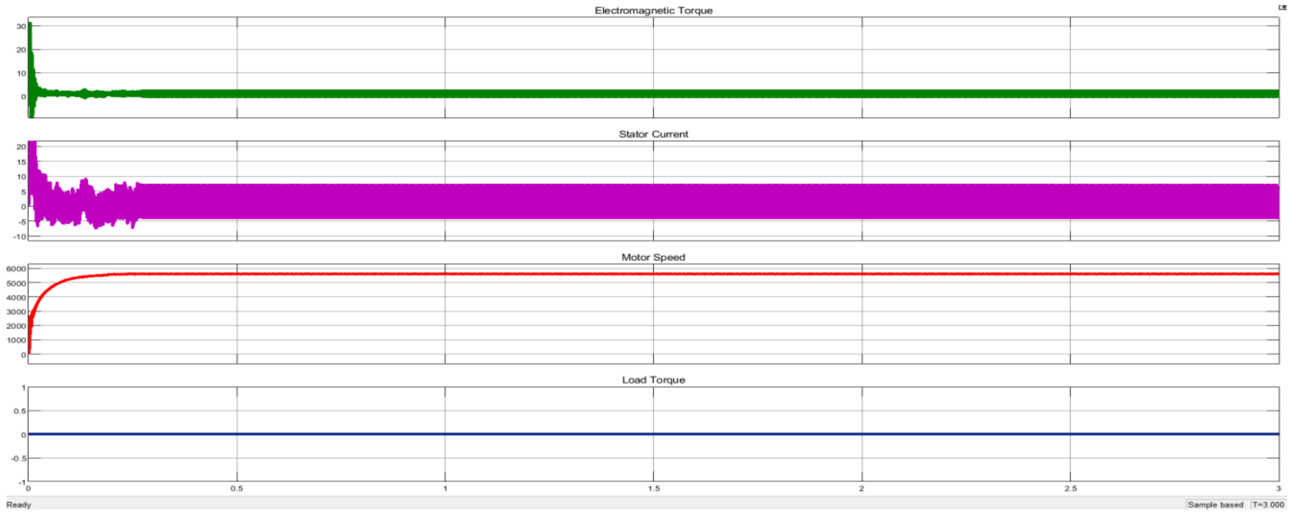

Fig. 15 Torque,stator current,Speed waveform of NIBFE-VSI-BLDC motor system

Now step Load Torque of 0Nm till 1.5sec and from 1.5sec onwards till 3sec Load Torque of3Nm is applied.

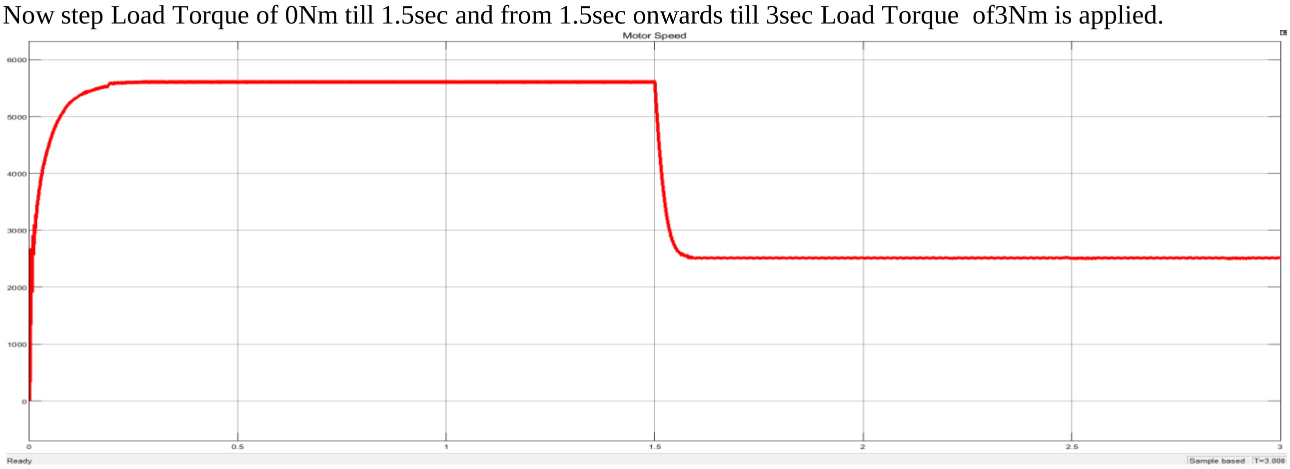

Fig. 16 Speed waveform of NIBFE-VSI-BLDC motor system

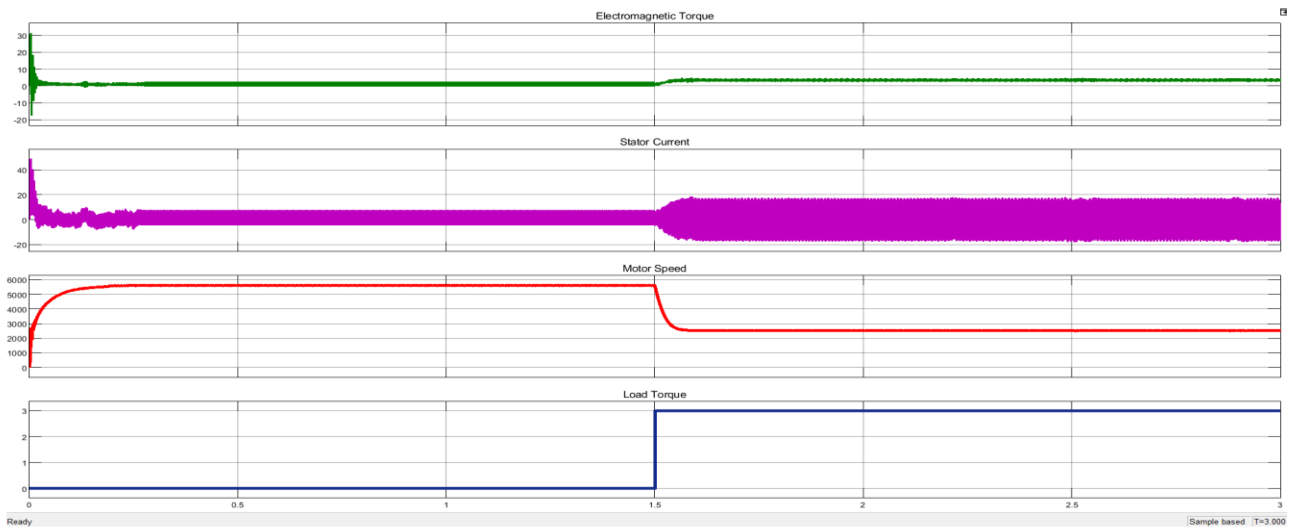

Fig. 17 Torque,stator current,Speed waveform of NIBFE-VSI-BLDC motor system

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A. CLOSED LOOP

The simulation of NIBFE-VSI-BLDC motor whole system in Closed Loop is shown in Fig 18.Input Voltage of 100V from DC voltage source is applied to NIBFE,Load Torque of 0Nm is given to BLDC motor.Inverter gate pulse to 6 switches and gate pulse to NIBFE capacitor switch is generated from closed loop feedback controller.

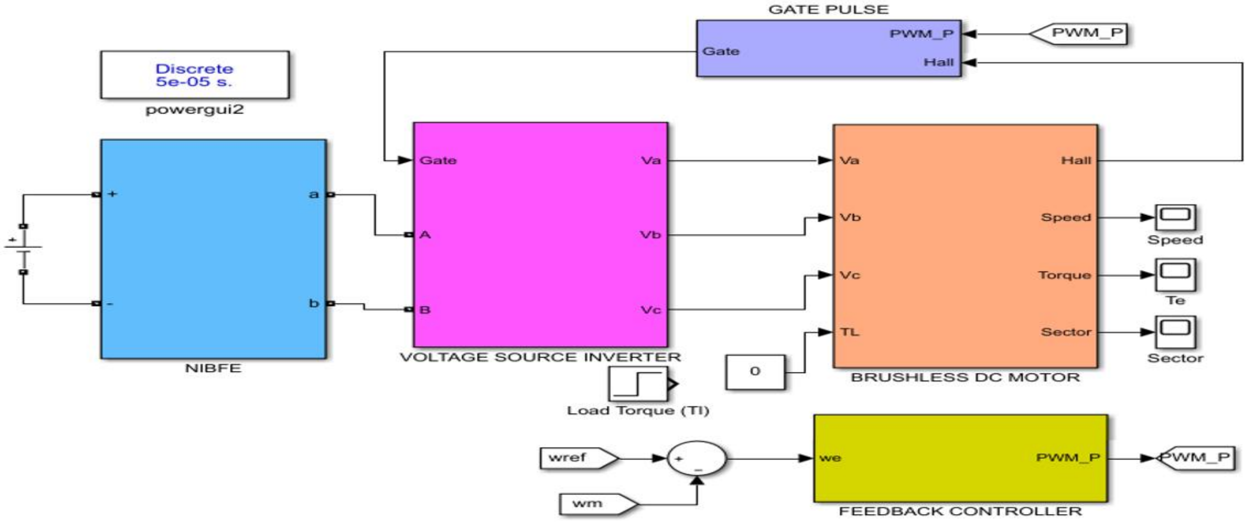

Fig. 18 Simulation of NIBFE-VSI-BLDC motor whole system in Closed Loop

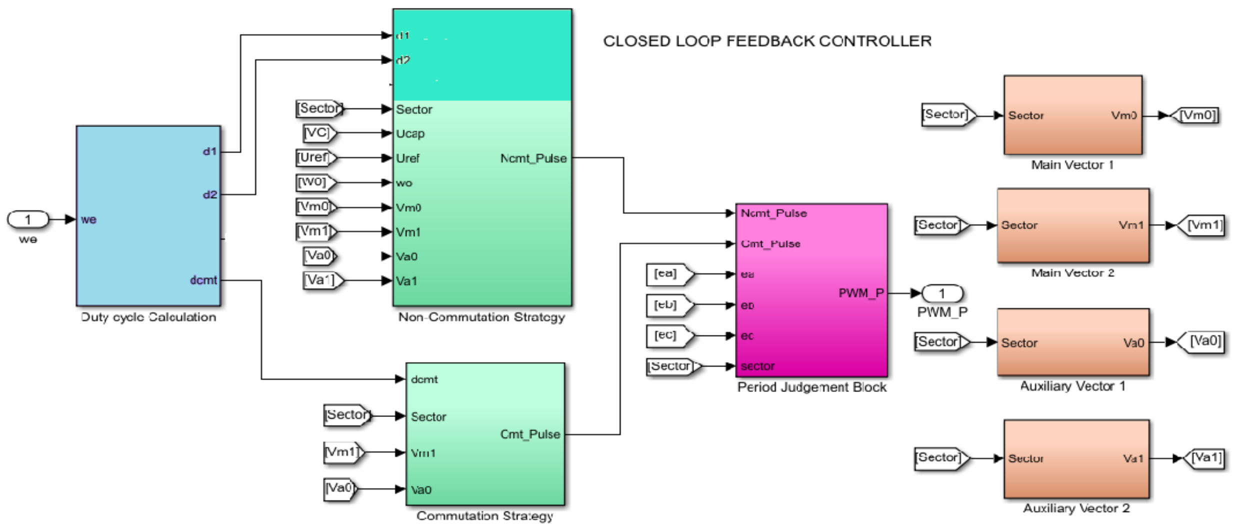

Fig. 19 Closed loop feedback controller

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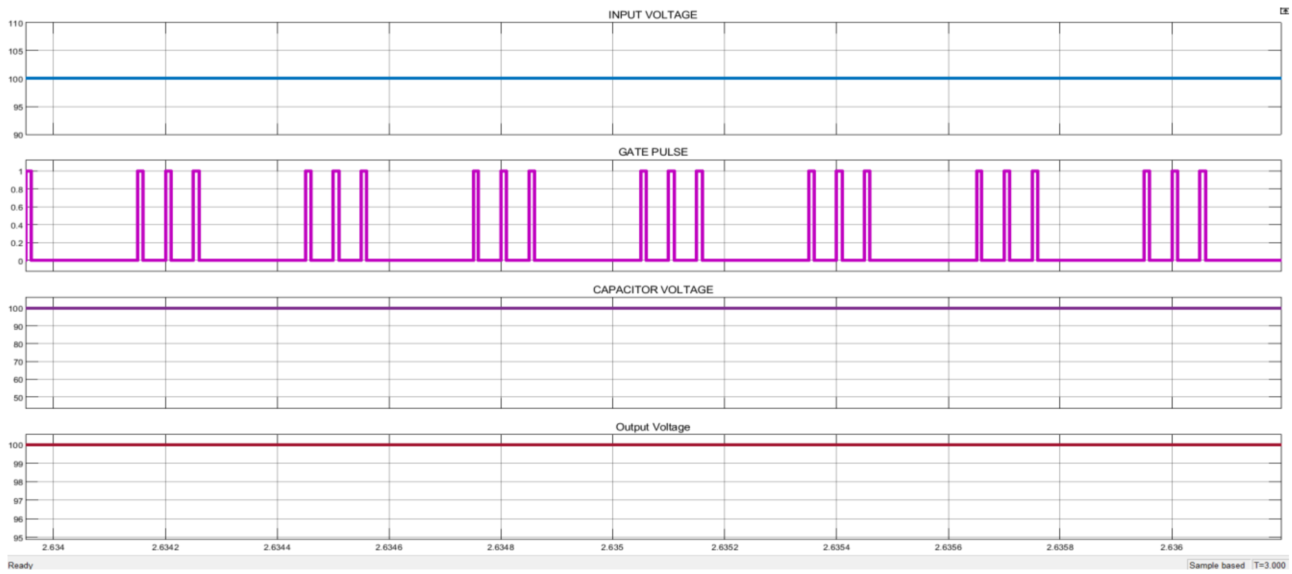

Fig. 20 NIBFE Input,Output,Capacitor Voltage, Gate pulse waveform of NIBFE-VSI-BLDC motor system

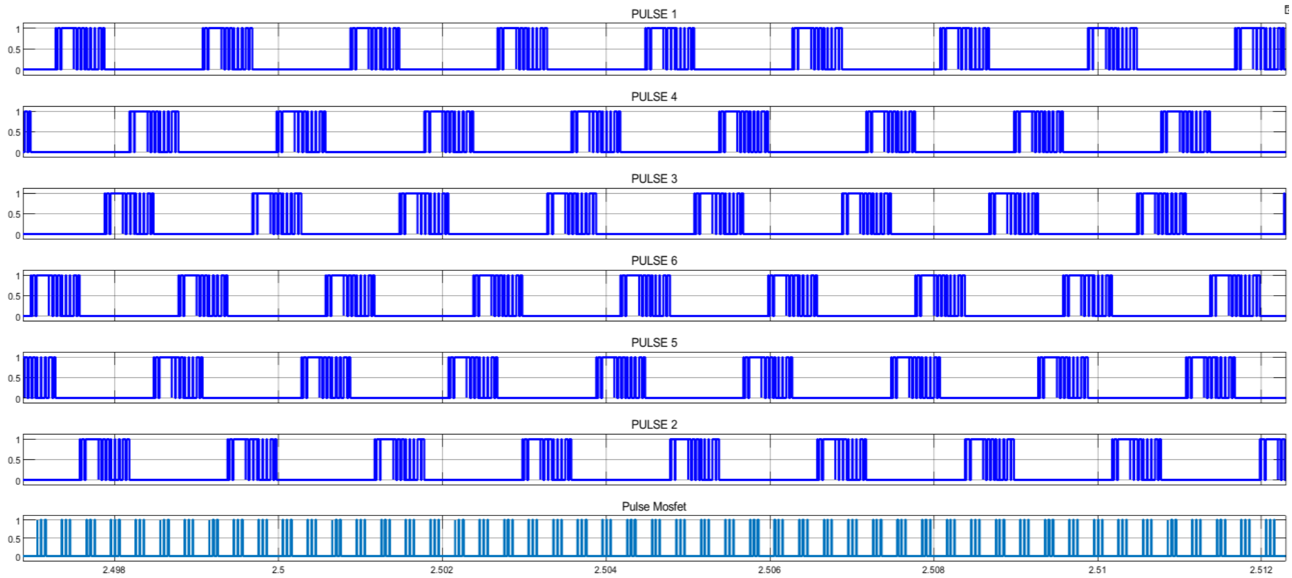

Fig. 21 Inverter Gate pulse waveform of NIBFE-VSI-BLDC motor system

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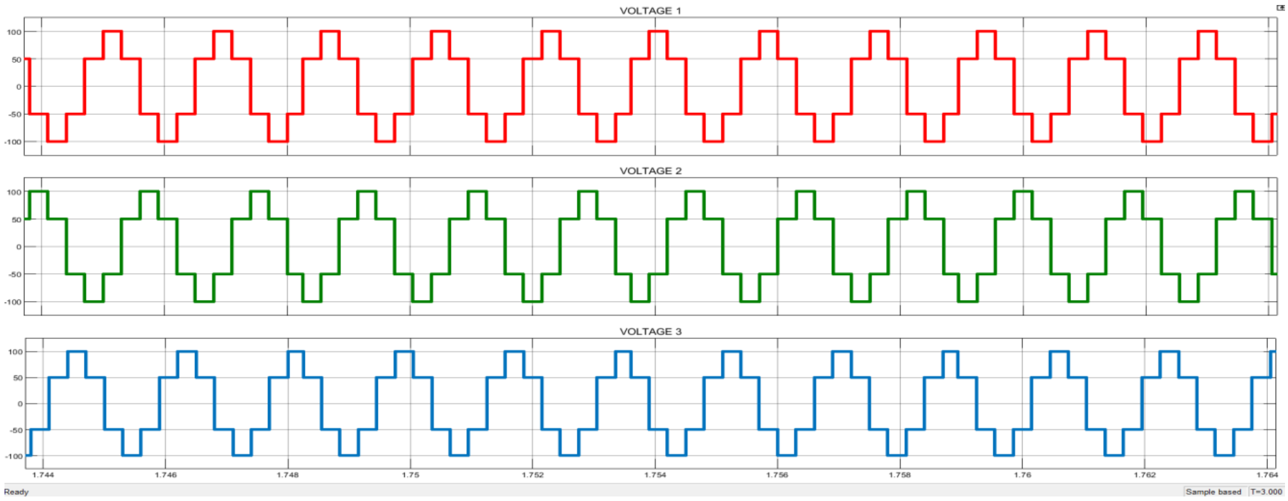

Fig. 22 Inverter Voltage waveform of NIBFE-VSI-BLDC motor system

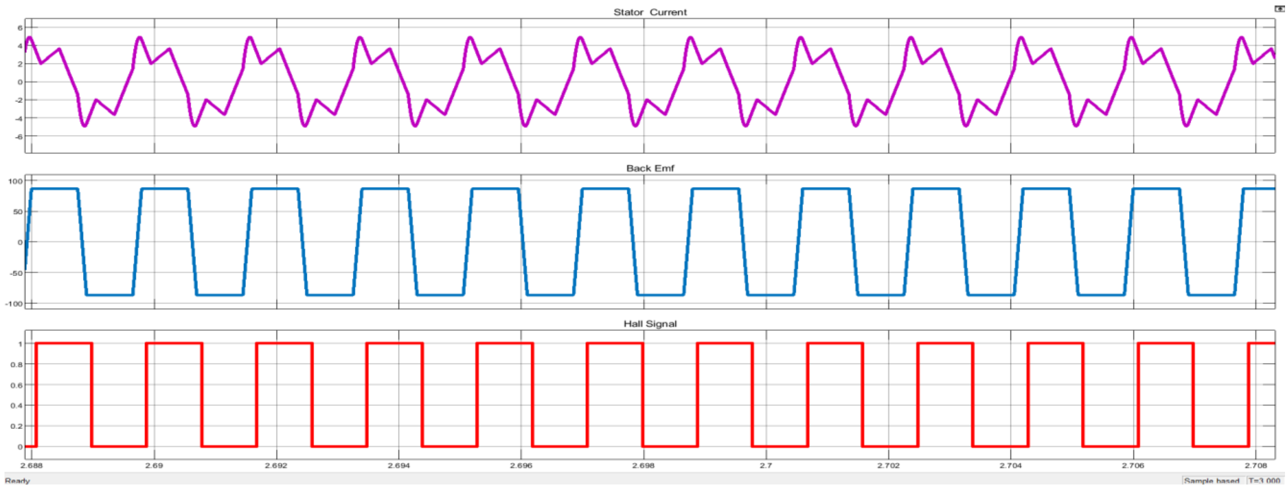

Fig. 23 Stator Current, Back EMF, Hall signal waveform of NIBFE-VSI-BLDC motor system

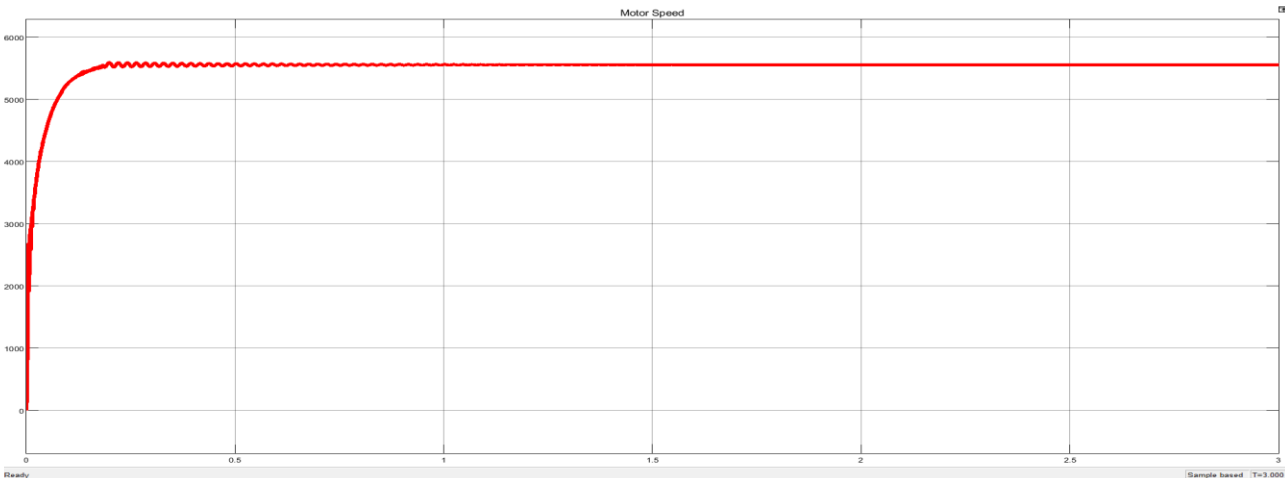

Fig. 24 Speed waveform of NIBFE-VSI-BLDC motor system

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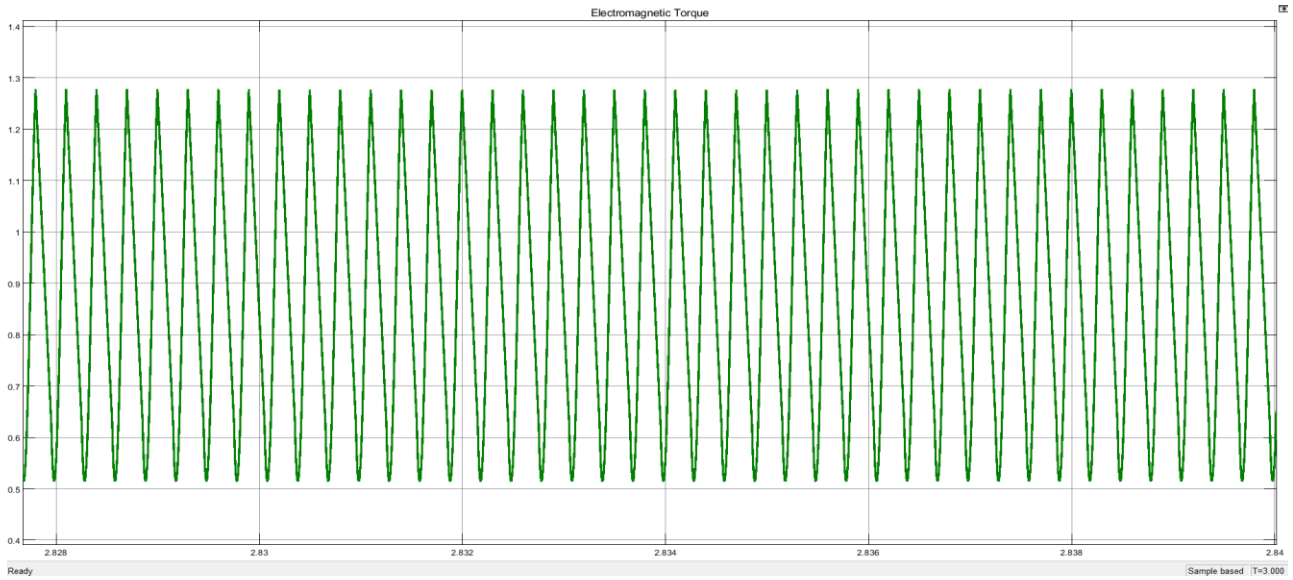

Fig. 25 Torque waveform of NIBFE-VSI-BLDC motor system

Fig. 26 Torque,stator current,Speed waveform of NIBFE-VSI-BLDC motor system

Now step Load Torque of 0Nm till 1.5sec and from 1.5sec onwards till 3sec Load Torque of 3Nm is applied

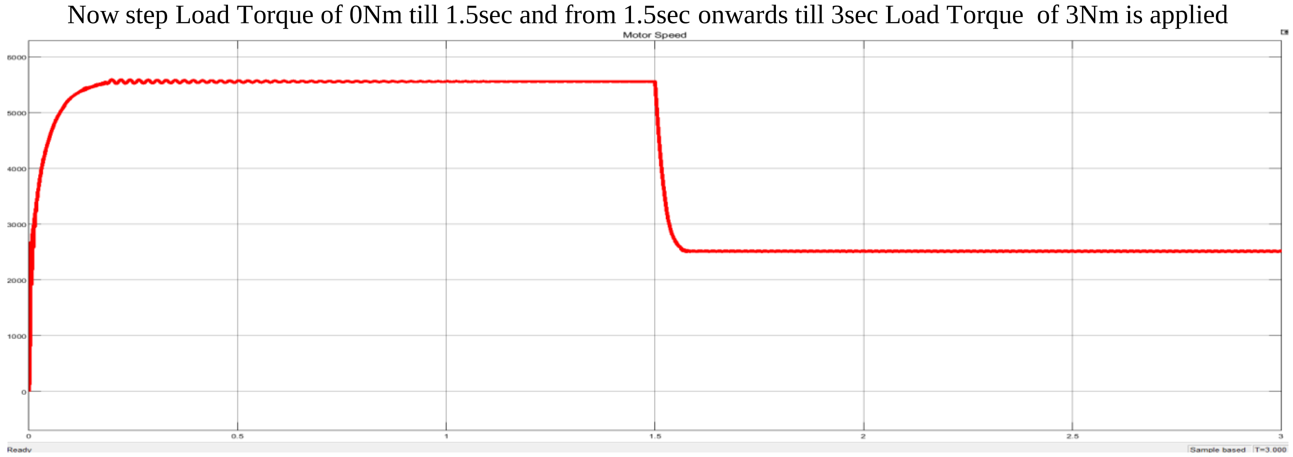

Fig. 27 Speed waveform of NIBFE-VSI-BLDC motor system

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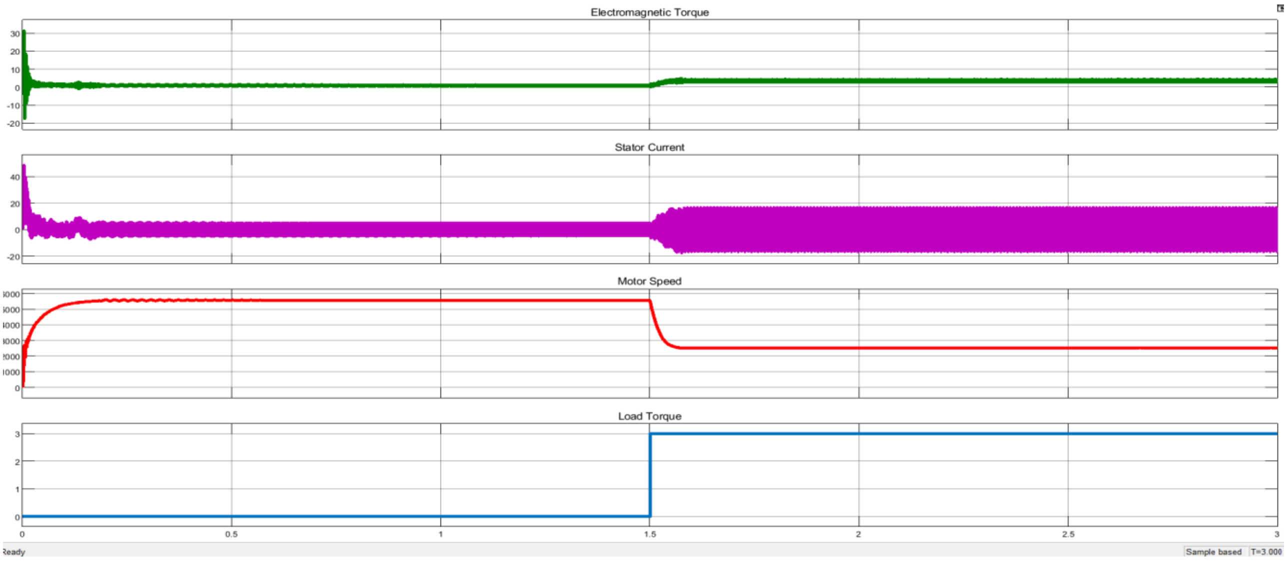

Fig. 28 Torque,stator current,Speed waveform of NIBFE-VSI-BLDC motor system

BLDCM has trapezoidal back-Emf waveform of magnitude of 86V which is 120 degree displayed and stator is fed by quasi square stator current of magnitude 5A. Hall sensors placed in stator produce 3 hall signals 120 degree apart . Torque waveform is having small ripple due stator current ripple.Speed of BLDC motor at no load torque is 5500rpm. The stator current of BLDC motor is proportional to Torque.Back EMF is proportional to Speed.When step Load Torque of 0Nm till 1.5sec and from 1.5sec onwards till 3sec Load Torque of 3Nm is applied as load torque is increased speed is reduced , back emf is reduced , stator current is increased.Speed is increasing and attaining steady state so initially there is some torque.Under steady state the electromagnetic Torque will be same as load torque.

V. RESULT AND DISCUSSION

From Result it is observed that commutation torque ripple of NIBFE fed BLDC motor from 127.9% in Open loop is reduced to 42.22% in closed loop ,torque ripple is reduced in closed loop with Proposed control method strategy.

Mode	Open Loop	Closed Loop
Torque Ripple %	127. 9%	42.22%
Torque Ripple	2.15	0.76
Thigh	2.45	1.28
Tlow	-0.3	0.52

Fig. 29 Result analysis of Torque ripple of Open and Closed loop

VI.CONCLUSION

In this Project work with the designed NIBFE commutation torque ripple reduction strategy is proposed.By using proper switching sequence of switching vectors in commutation and non commutation period have reduced the commutation torque ripple. This proposed is simple, as NIBFE have less components and no inductors present have reduced system size and cost.

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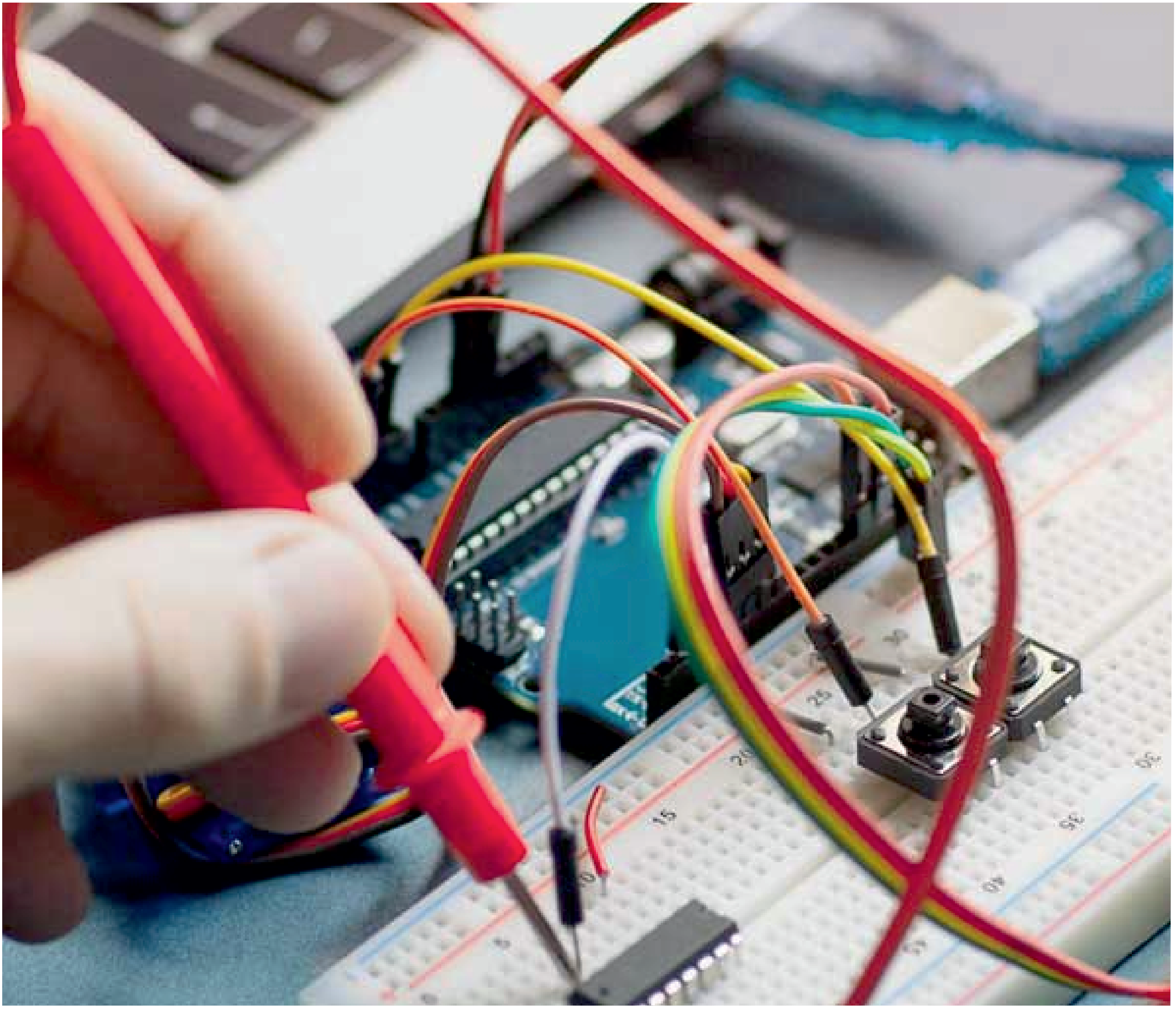

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