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Modeling and Simulation of Indirect Back EMF Detection Based Sensor Less Operation of PMBLDC Motor Drive

Manoj D. Patil, Rajendra B. Madake, Sonali L. Sawant

***Abstract*: This paper represents advance techniques of speed control by using MATLAB simulation and FPGA controller to controlled speed of PMBLDC motor require rotor position sensing. To achieve sensor-less speed control of this motor use zero crossing detection method and FPGA controller with hardware set-up is adopted by replacing hall effect sensor which is used to sense the position of rotor. For back EMF detection zero crossing detection method is used. Hence, It is most preferable technique because sensor is not used then cost is effective and it is efficient for size reduction and maintenance.**

***Index Terms*: Six switch inverter, back EMF, RC network, Zero crossing detection method, Sensor-less Brushless DC motor.**

I. INTRODUCTION

In Japan and USA design the permanent magnet (PM) motor drives for different applications. Japan design variable speed drive which is used in air conditioner and refrigerators and USA design cheap induction motor drive which has around 10% lower efficiency. These both designed are used for energy saving applications. The PM motor drives are also called BLDC motor. Now a day's variable speed PM motor drives are high demanded because the increase in energy price, high demanded areas such as automobile industries based on hybrid drives, demand for high efficiency PM motor drive. The BLDC motor has better performance and linear characteristic between current & torque, voltage & speed. [1] BLDC motor drive is electronically controlled commutation system which is better than brushed motor for instead of having a mechanical commutation. In BLDC PMs are rotate and armature remains static and electromagnets do not moves because of the problem is create, how transfer current for moving armature. [2] To overcome this problem brush that is commutator part of the motor is replaced by an electronic controller, it has same power distribution as a brushed DC motor.

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Manoj D. Patil, Department of Electrical Engineering, Annasaheb Dange College of Engineering and Technology, Ashta, Sangli, Maharashtra, India. Email: mdpatileps@gmail.com
Rajendra B. Madake, Department of Electrical Engineering, Annasaheb Dange College of Engineering and Technology, Ashta, Sangli, Maharashtra, India. Email: rbm@ele@adcet.in
Sonali L. Sawant, Department of Electrical Engineering, Annasaheb Dange College of Engineering and Technology, Ashta, Sangli, Maharashtra, India. Email: sonalisawant2121@gmail.com

The BLDC motor current waveforms are quasi square waveform. PM motors are windily used in because their high power density reliability and silent operation. For proper commutation of currents in stator windings are require proper rotor position of BLDC motor, for sense the position used the position sensors but it has some limitations. [3]
Because of limitations developed the sensor-less control technology of PMBLDC motor drive. In that technology normally used direct back EMF detection method & indirect back EMF detection method, but in this work use only indirect back EMF detection method.
The PMBLDC motor drive is a self synchronous machine. It has a stator and rotor, Stator is like same as induction motor and rotor is same as lasting magnet which is surface mounted. The winding is fitted on stator is called as stator winding which is always stationary and permanent magnet fitted on rotor is known as rotor winding which is always rotating. The polarity of current is changed by using commutator and brushes. But in this motor no brushes and commutator. So, the polarity of current is changed by MOSFET, IGBT switches. But it is required this switches is in synchronization and it is similar to rotor position therefore sensored BLDC motor to sense the position of rotor uses position sensors. [4]
The speed control of BLDC motor is not easy because it's required to make more reliable power electronics and electrical drives advancement in microcontroller over the decade and for adjustable speed application cost.
There are many advantages of BLDC motor which is used in home appliances. It is reliable for changing the conventional motor and cost effective solution. Then also BLDC motor is used in washing machine, electrical vehicles, refrigerator, dish washer, vacuum cleaner and room air conditioner etc. The important application is in space and weight is critical especially in aerospace.
By using zero crossing detector of back emf method rotor position is selected and which is vary at 120^0. During the operation each commutation cycle there are two phases and by third phase obtaining back emf through ZCD.

II. MODELLING OF PMBLDC MOTOR & UNCONTROLLED PHASE CURRENT BASED SSI

2.1 Modelling of PMBLDC motor drive

In Fig.1 shows the equivalent circuit of PMBLDC Motor drives for phase A.

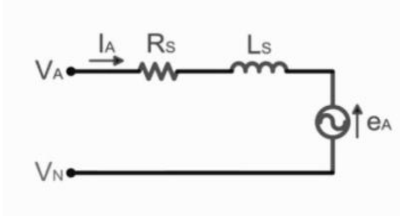

Fig.1. For Phase A PMBLDC motor Equivalent circuit

$$V = I_A \cdot R_s + L_s \cdot \frac{dI_A}{dt} + e_A \quad \ldots\ldots\ldots (1)$$

Where, For phase A,

R_s, L_s, & e_A are stator winding resistance, Stator winding Inductance and back emf of motor respectively in eq^n (1)

By using KVL,

$$Va = R_a I_a + L_a \frac{dI_a}{dt} + M_{ab}\frac{dI_b}{dt} + M_{ac}\frac{dI_c}{dt} + e_a \quad \ldots\ldots.. (2)$$

$$Vb = R_a I_b + L_a \frac{dI_b}{dt} + M_{ba}\frac{dI_a}{dt} + M_{bc}\frac{dI_c}{dt} + e_b \quad \ldots\ldots.. (3)$$

$$Vc = R_c I_c + c\frac{dI_c}{dt} + M_{ca}\frac{dI_a}{dt} + M_{cb}\frac{dI_b}{dt} + e_c \quad \ldots\ldots.. (4)$$

Where,

V_a, V_b &V_c are three phase stator winding voltages, R_a, R_b&R_c are resistances, I_a, I_b &I_c are three phase stator winding currents, L_a, L_b&L_c are the self inductances, $M_{ab}, M_{ac}, M_{ba}, M_{bc}, M_{ca}$&$M_{cb}$ are the mutual inductances .e_a, e_b&$e_c$are the back emf's.

The voltage equation is written in matrix form,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} L_a & M_{ab} & M_{ac} \\ M_{bc} & L_b & M_{bc} \\ M_{ca} & M_{cb} & L_c \end{bmatrix}\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad \ldots\ldots.. (5)$$

The stator self inductances and mutual inductances both are independent on rotor position.

Assume, self inductances are equal which is denoted by L (i.e L_a=L_b=L_c=L) and mutual inductances are inductances are denoted by M. Similarly, three phase resistances denoted by R which is consider balance three phase system (i.e R_a=R_b=R_c=R) that is both are equal.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix}\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad \ldots\ldots.. (6)$$

The following equation represents electromagnetic torque, speed and load torque equation.

$$T_e = j\frac{d\omega}{dt} + B\omega + T_l \quad \ldots\ldots\ldots (7)$$

Where,

Te = Electromagnetic Torque in Newton-meter

J = moment of inertia

B = coefficient of friction

ω = speed

T_l = load torque.

2.2 Modelling of uncontrolled Phase current based SSI

By using three phase converter with six step commutation drive BLDC motor. The conventional six switch analogy shown in fig.2 below.[5]

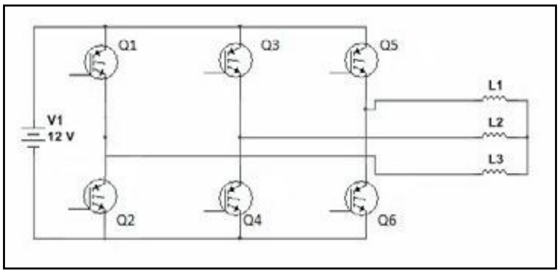

Fig.2. Six Switch Three Phase Inverter

For real time application implement the algorithm for control the scheme shown in fig.3

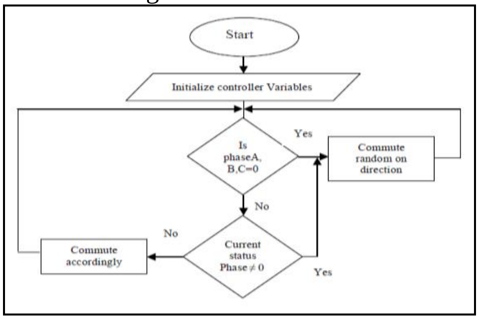

Fig.3. For logical control of sensorless drive algorithm designed

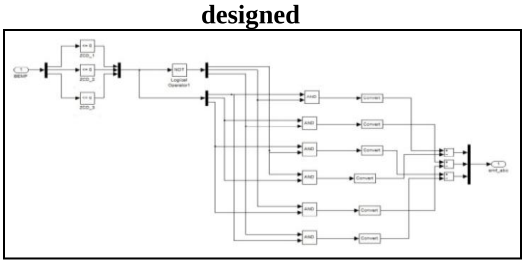

Fig.4. Using ZCD MATLAB/SIMULINK model of commutation logic

With the help of BEMF detection BLDC motor is drive which is required quasi square waves. The quasi square waves needs to drive gates which having conducting at 120^0 & 60^0 non-conducting regions. For obtaining a output of constant steady torque the waveforms should be synchronized with back emf. The operating of FSIPI system is basically divided in six different mode which is depend on active phases and conducting switches.

III. PRAPOSED WORK

Fig.5 shows equivalent circuits diagram for phase A of PMBLDC motor drive

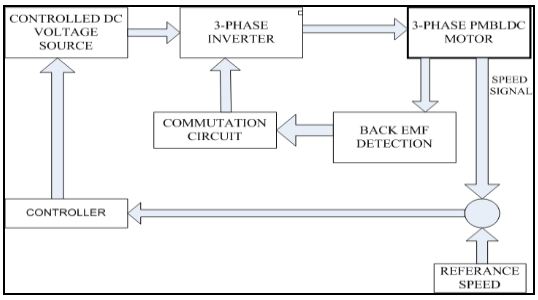

Fig.5. PMBLDC Motor Speed Control by Using BEMF ZCD method

By using back emf detection method rotor position is sensed and above fig. 5 shows the by using back emf ZCD for control the speed of PMBLDC motor.

Three phase inverter is connected in between control DC voltage source and three phase PMBLDC motor. The voltage source inverter is operates at 120^0 displacement. The three phase inverter has 2 switches one from upper leg and other from lower leg therefore, at the time of operation when supply is start to flow because of this two switches curving of motor will be energized.

When motor winding of motor are energized then it obtains speed of motor. The ω is real speed which is compared to ω_r known as reference speed. The real speed achieved by three phase BLDC motor and reference speed and result will be produced by ω_e that is error signal. The error signal given to the controller as a input. The function of controller is to generate PWM signals given to the inverter switches. If the vary voltage of pulsed supply which is from the inverter then current is flows in stator winding changes, force on the rotor pole and rotor speed also varied.

3.1 Sensorless BLDC Motor drives

To convert electrical energy into mechanical energy BLDC motor is used in which permanent magnet motor is placed. Fig. (6) shows the typical sensorless BLDC motor drive. In these motor drive circuit there are three phases which is denoted by three different colors like A phase denoted by red color, B phase denoted by green color, C phase denoted by blue color and N is neutral point which is denoted by pink color.

A non linear magnetic saturation characteristic of stator iron motor is used to determine the initial position of stator. For a certain time DC voltage is applied then stator is energized then magnetic field will be produced and which is flow with a fixed direction. Due to this inductance difference the current responses are different because of this deverification of the current responses obtained rotor position information.[8]

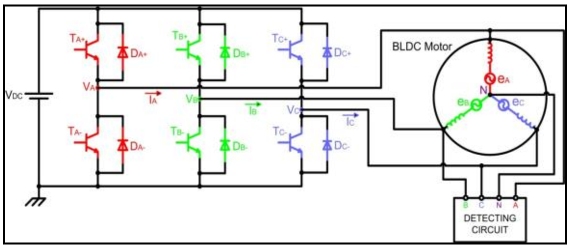

Fig.6. Sensor-less BLDC motor drive

3.2 Back-EMF Zero Crossing Detection method

Back EMF ZCD method known as incurable voltage sensing method. It is easy technique. The back EMF is crosses unexated phase that instant is detected. If to give trigger a timer that time which may be RC time consistent and because of this occurs next sequential inverter commutation at the end.

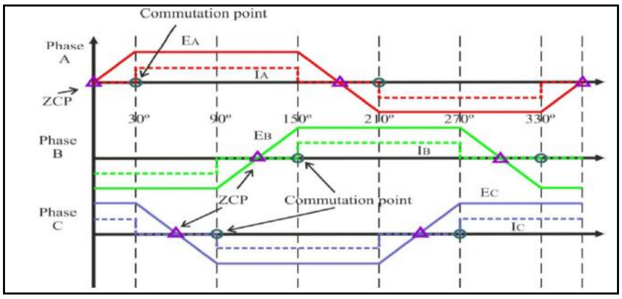

Fig.7. ZCP of the back-EMF and phase current commutation points

From this operation, current in each phase and back EMF should be aligned to generator consistent torque. Fig (8) shows the point A, the current commutation of phase and back EMF which is required to drive BLDC motor. Commutation point occurs at 30^0 phase shift by using six step commutation schemes through a three phase inverter at the 120^0 conduct the inverter of phase. From fig. the phase A and phase B are conducted at any time and phase C is floating so, phase A and phase B conduct current at any time. At the 60^0 produce maximum torque because of this current and back EMF both are in phase.[6-8]

When the particular phase current is zero then to detect ZCD and by using low pass filter terminal voltage is filtered. Also by using three low pass filters voltage reduces harmonics in terminal voltages which is possible by inverter switching. To reduce high frequency components and design BLDC motor. For floating phase that is C is given by Equation,

$$V_c = e_c + V_N = e_c + \frac{V_{CE} - V_F}{2} - \frac{e_A + e_B}{2} \qquad \text{...... (7)}$$

Where,

e_c presents back EMF at phase C

V_N is voltage of motor neutral point

V_{CE} & V_F is forward voltage drop of transistor & diodes

There are two conducting phases such as phase A and phase B. If has opposite sing but amplitude is same.

The result of phase B is written by equation,

$$e_A = -e_B \rightarrow V_c = e_c + \frac{V_{CE} - V_F}{2} = e_c + \frac{e_A + e_B}{2} \qquad \text{...... (8)}$$

$$V_{CE}^{A+} \approx V_{CE}^{B-} \rightarrow V_c = e_c + V_{CE}^{B-} + V_{DC} - V_{CE}^{A+} \approx e_c + \frac{V_{DC}}{2}$$

...... (9)

IV. SIMULATIOM MODEL & RESULTS

In MATLAB simulation model of PMBLDC motor is completed. In fig. 8 shows simulation using back EMF zero crossing detection method of PMBLDC motor drive.

This is the new proposed method to speed control of motor without using sensor that is also called sensorless. The simulation parameter used here are reference speed 1500 rpm, in PI controller proportional gain=6.61 and Integral gain= 0.013, step input is used to provide load to motor.[9-11]

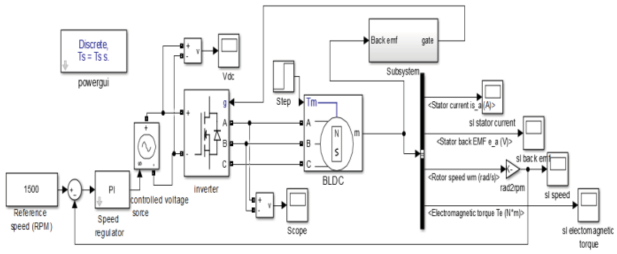

Fig.8. Simulation model

Using indirect back EMF ZCD Method

Motor drive Specification

- No. of poles- P= 4
- Moment of Inertial- J= 8*e-04
- Stator phase Inductance (H) Ls= 0.0085
- Stator Phase Resistance (ohm) Rs= 2.875
- Torque Constant Tc = 1.4

PI Controller Specification

- Integral gain: 16.61
- Proportional gain: 0.013

Above fig.8 shows the simulation for PMBLDC Motor drive Speed Control of motor drive using BEMF ZCD method. Simulation contains controlled voltage source, three phase inverter, three phase BLDC motor, controller, reference speed block and PI controller. In this method, the gate pulses are generated by using back EMF which is detect by zero crossing detection method to control switching of inverter switches. The three phase BLDC motor is supplied by the controlled voltage source through three phase inverter. Controller output gives gate signals to inverter, to maintain the synchronism between winding energizing and rotor position to developed constant torque. Comparator compares ω_r and ω and produce error signal that is ω_e proportional to error speed. Then this error signal gives to the PI controller. PI controller gives the signal to controlled voltage source to vary the input voltage to maintain the constant speed of BLDC motor. [12]

4.1 No Loading Condition

At No loading condition the step input initial value and final value is zero (0).The load to motor is Zero (0). The output results are shown in below figures from fig.9 to Fig.13.

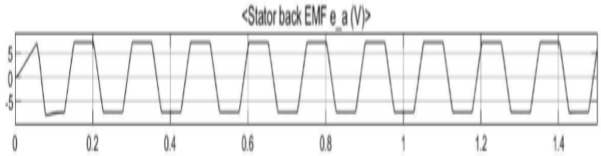

Fig.9. Back EMF Vs Time

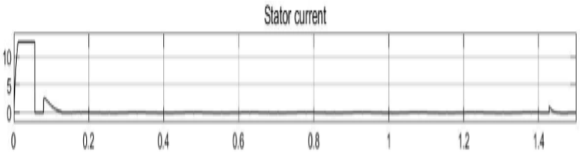

Fig.10. Current of stator

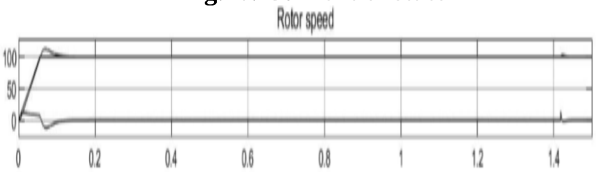

Fig.11. Speed of Rotor

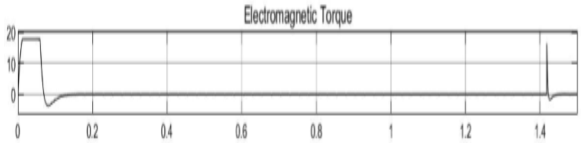

Fig.12. Electromagnetic Torque

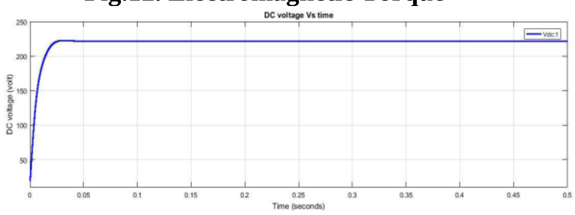

Fig.13. DC Voltage

4.2 Full Loading Condition

At full load condition, the step input initial value is set to zero (0) and final value is set to Four (4) to apply load on the motor. The output results are shown in below figures from fig.14 to Fig.18.

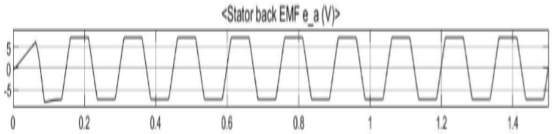

Fig.14. Back EMF Vs Time

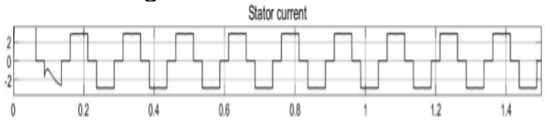

Fig.15. Current of Stator

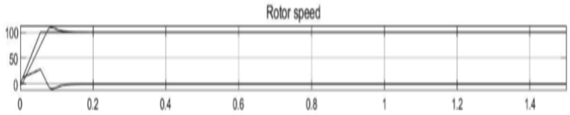

Fig.16. Speed of Rotor

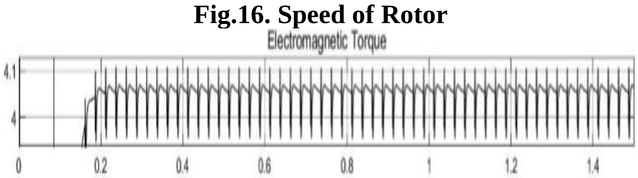

Fig.17. Electromagnetic Torque

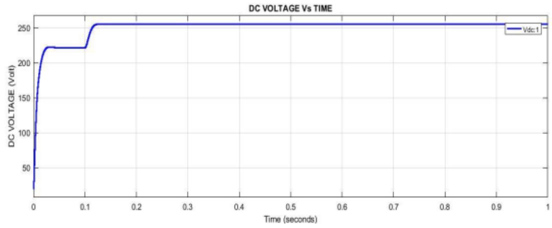

Fig.18. DC Voltage

From above no loading condition and full loading condition simulation results, the back emf is constant for no load and full load condition. The stator current increases at full load condition as compare to no load condition. The rotor speed is remains constant at both loading conditions to reference speed. It is slightly disturbed when load applied and archive references speed in few seconds. Electromagnetic torque increases in loading condition. The DC voltage of controlled voltage source increases at full load condition.

V. HARDWARE SETUP

By using controller that is FPGA is used to control PMBLDC motor drive. The hardware setup is constructed by using FPGA controller, power module, PMBLDC motor, auto transformer and interface card.

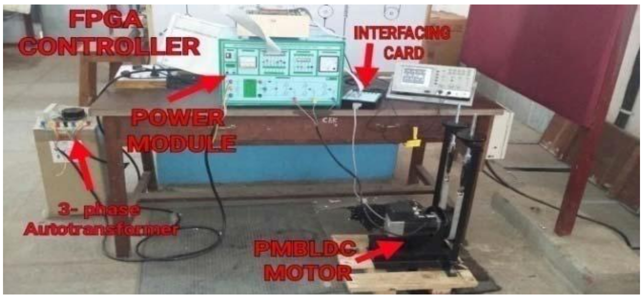

Fig.19. Control by using FPGA controller PMBLDC motor drive

Waveforms:-

Gate pulse waveforms

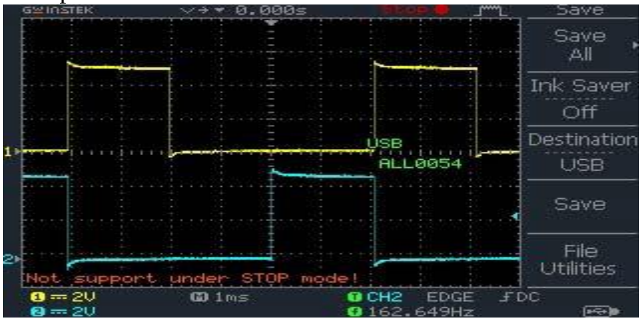

Fig.20. Gate pulse

Feedback signal

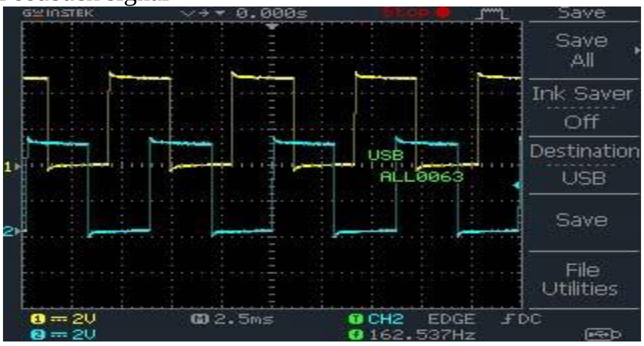

Fig.21. Feedback signal

Back EMF waveforms are fig.22 and fig. 23, is nature trapezoidal.

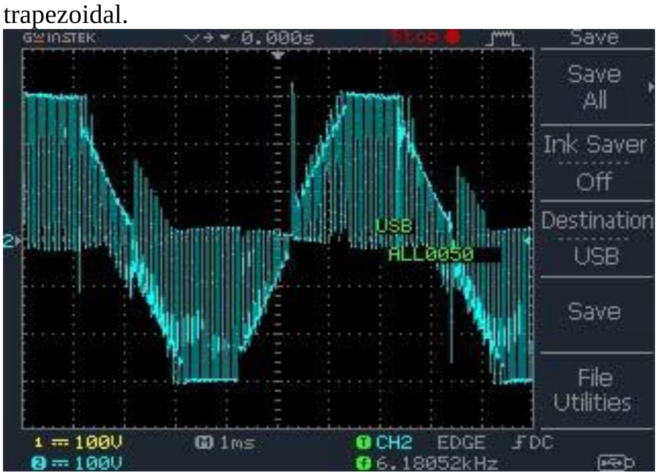

Fig.22.Back EMF VRB

Fig.23. Back emf VRY and VYB

Stator current

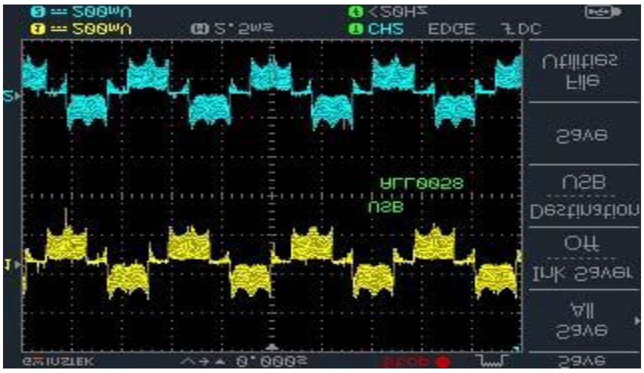

Fig.24. IR and IY stator current

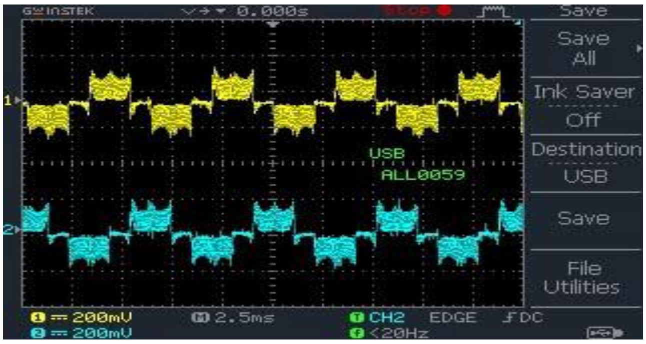

Fig.25. IR and IB stator current

Table 1. Open loop condition

DC Link Voltage Vdc (volt)	Condition of Load	Current of Stator (Amp)	Speed (rpm)
315 v	No load	0.4	4610
315 v	Full load	4.6	2837

Table 2. Closed loop condition

DC Link Voltage Vdc (volt)	Condition of Load	Current of Stator (Amp)	Speed (rpm)
315 v	No load	0.27	4005
315 v	Full load	4.53	4005

VI. CONCLUSION

In this paper improving speed control method of PMBLDC motor by BEMF detection by using ZCD method at different loading conditions. The results of MATLAB simulation detects rotor speed, current of stator, Back EMF and electromagnetic torque, DC current which is within operating condition. Also at different loading condition testing results will be shows in hardware results. By using this method reduces cost and size and increases the reliability of motor. In this technique hall effect sensor is removed that is sensorless PMBLDC motor is modulate.

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