Abstract—This paper presents the implementation of sensorless PMBLDC motor involving the back emf detection. Along with the back emf detection respective zero-crossing points are identified which is based on detecting the instant at which the back-EMF in the unexcited phase crosses zero. These zcp can be used for the generation of pulses for electronic commutation of inverter switches to achieve sensorless operation of permanent magnet brushless DC (PMBLDC) motor. Performance analysis is carried out in comparison with a sensed motor. The simulation model has been developed in MATLAB/SIMULINK environment.

Index Terms—Permanent magnet brushless DC (PMBLDC) motor, electromotive force (emf), voltage source inverter (VSI), zero crossing point (ZCP)

I. INTRODUCTION

BLDC motors from micro to large size are extensively used for applications in many types of motion control apparatus and systems as adjustable speed drives.

The BLDC motors are typically permanent synchronous motors, they are well driven by dc voltage. They have a commutator that is done mainly by electronics application. Some of the many advantages of a brushless dc motor over the conventional brushed dc motors are highlighted below:

1. Better speed versus torque characteristics
2. High dynamic response
3. High efficiency
4. Long operating life
5. High speed ranges
6. Low maintenance (in terms of brushes cleaning which is peculiar to the brushed dc motor).

Basically PMBLDC motor drive uses one or more sensors to have positional information which results in a higher drive cost so sensorless techniques are keen desire. Fig. 1 shows basic inverter topology employed:

One of the most common methods used for inverter switching is pulse width modulation (PWM) techniques.

II. MATHEMATICAL MODELING OF PMBLDC MOTOR

For a three phase star connected PMBLDC motor, per phase voltages \( V_{an}, V_{bn}, V_{cn} \) can be given as:

\[
\begin{bmatrix}
V_{an} \\
V_{bn} \\
V_{cn}
\end{bmatrix} =
R_s
\begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix} + \begin{bmatrix}
L & M & M \\
M & L & M \\
M & M & L
\end{bmatrix}
\begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix} + \begin{bmatrix}
e_{an} \\
e_{bn} \\
e_{cn}
\end{bmatrix}
\]

(1)

Where \( R_s \) is stator phase resistance, \( L \) is stator phase inductance, \( M \) is mutual inductance between the phases, \( i_{an}, i_{bn}, i_{cn} \) are stator current and \( v_{an}, v_{bn}, v_{cn} \) are phase voltage of the stator’s winding and \( p \) is derivative operator.

For a three phase star connected PMBLDC motor, \( i_{an} + i_{bn} + i_{cn} = 0 \)

(2)

\[
\begin{bmatrix}
V_{an} \\
V_{bn} \\
V_{cn}
\end{bmatrix} =
R_s
\begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix} + \begin{bmatrix}
L & 0 & 0 \\
0 & L & 0 \\
0 & 0 & L
\end{bmatrix}
\begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix} + \begin{bmatrix}
e_{an} \\
e_{bn} \\
e_{cn}
\end{bmatrix}
\]

(3)

Using Eq. (3), we have current derivative as:

\[
p_i\begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix} = \left( \begin{bmatrix}
L & 0 & 0 \\
0 & L & 0 \\
0 & 0 & L
\end{bmatrix}^{-1}\begin{bmatrix}
V_{an} \\
V_{bn} \\
V_{cn}
\end{bmatrix} - \begin{bmatrix}
e_{an} \\
e_{bn} \\
e_{cn}
\end{bmatrix} - R_s \begin{bmatrix}
i_{an} \\
i_{bn} \\
i_{cn}
\end{bmatrix}\right)
\]

(4)

The electromagnetic torques can be given as:

\[
T_e = \sum (e_{cn}i_{cn}) / \omega_e
\]

(5)
Where $\omega_r$ represents the rotor speed, $x$ represent the phase a, b and c while $n$ represent the neutral terminal. Since back emf is a function of flux and rotor position, it can be expressed as:

$$e_{xn} = f_{xn}(\theta)\lambda_n \omega_r$$  \hspace{1cm} (6)

Where $\lambda_n$ represents the flux linkage and $f_{xn}(\theta)$ have the same shape as of the back emf. Substituting Eq. (6) in Eq. (5), we have:

$$T_e = \lambda_n \sum f_{xn}(\theta)i_{xn}$$  \hspace{1cm} (7)

The equation of motion for simple system is:

$$J \frac{d\omega}{dt} + B\omega = T_e - T_l$$  \hspace{1cm} (8)

Where, $T_e$ is electromagnetic torque, $T_l$ is load torque, $J$ is motor inertia and $B$ is damping constant. The relation between angular position (electrical) and angular mechanical velocity is given by:

$$\frac{d\theta_e}{dt} = \frac{(P/2)\omega}{\omega}$$  \hspace{1cm} (9)

Eq. (1)-(9) represents the dynamic model of the PMBLDC motor. The trapezoidal back EMF waveform and the phase current of the PMBLDC motor are shown in the Fig. 2. The graph is presented for one complete cycle of 360 degrees.

In this method ZCP of the back EMF is detected directly. For typical operation of a BLDC motor, the phase current and back EMF should be aligned to generate the constant torque. The commutation point can be estimated by the ZCP of back EMF. The conducting interval for each phase is 120 electrical degrees. Therefore, leaving the third phase floating, only two phases conduct current at any time. The inverter should be commutated every 60° by detecting zero crossing of back EMF on the floating coil of the motor in order to produce maximum torque, so that current is in phase with the back EMF.

![Diagram](Fig.3 Back EMF and Phase current waveforms of PMBLDC motor)

### III. Simulation Results and Analysis

Simulation for the discussed technique has been carried out in MATLAB/SIMULINK environment and experimental model modelled as shown in Fig. 3. All the respective parameters for techniques are mentioned in appendix. Various wave-form for current, back emf, speed and torque and inverter pulses has been obtained at no load as well as on load condition having load of 3 N-m and the respective wave-form obtained are as follow:

![Diagram](Fig.2 Back EMF and Phase current waveforms of PMBLDC motor)
Fig. 4 Response for No Load Condition

Fig. 5 Pulses for No Load Condition
Fig. 6 Response for Load Condition

Fig. 7 Pulses for Load Condition
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Based on various results following analysis has been made:

**TABLE I. ANALYSIS FOR SPEED RESPONSE**

<table>
<thead>
<tr>
<th>Method</th>
<th>Setting Time (s)</th>
<th>Maximum transient overshoot (r/min)</th>
<th>Speed Ripple (Peak to Peak) under steady state (r/min)</th>
<th>Physical Condition</th>
<th>Response and stable</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEMF ZCD</td>
<td>0.07</td>
<td>3096</td>
<td>3 (2999-3002)</td>
<td>Excellent</td>
<td></td>
</tr>
</tbody>
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**TABLE II. ANALYSIS FOR SPEED RESPONSE**

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**IV. CONCLUSION**

The aim of the work was to introduce sensorless operation of PMBLDC motor. Based on discussed procedure, simulation model has been developed and response is shown in different figures along with inverter pulses for no load as well as on load condition. With respect to various results conclusion can be drawn that at no load as well as on load condition Back EMF approach implies excellent and same response as compared to sensored machine.

**APPENDIX**

A. **PMBLDC Motor Specifications[16]:**
- Power: 1 Kw
- Speed: 3000 rpm
- Vdc: 500V
- Stator phase resistance Rs: 2.875 ohm
- Stator phase inductance Ls: 0.0085 h
- Flux linkage: 0.175 V.s
- Voltage Constant: 146.6077
- Torque Constant: 0.49
- Back EMF flat area (degrees): 120
- Inertia, J: 0.00012 kg.m²
- Friction factor F: 0.001 N.m.s
- Pole Pairs P: 4
- Back EMF waveform: Trapezoidal
- Mechanical input: Tm

**REFERENCES**

[16] Matlab 7.10.0 (R2010a) Mathwork Inc.

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