Sensorless Speed Control of BLDC Motor Using Different Back EMF Techniques

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Abstract: For both domestic and industrial applications, the BLDC motor is widely being used. They are popularly used due to its reliability, controllability and compact size. BLDC motor is normally operated with one or more rotor position sensors or position encoders. This paper provides exceptional Sensorless strategies for Permanent Magnet Brushless DC (PMBLDC) motor. The BLDC automobiles have an internal stator again EMF that is trapezoidal waveform with the help of this BEMF the method is proposed. This proposed technique will gives a wide range of speed. The indirect BEMF are two types they are third harmonic voltage detection and BEMF integration method. In 3rd harmonic BEMF method, the back EMF component is extracted from phase voltages (stator), third harmonic signals was filtered and it is fed as triggering pulse for the inverter. Even though this method provides a better speed performance than exiting one, it requires heavy filtering devices and a power quality issue arises. To overcome all these we are going for the Indirect BEMF integration method. In this method, the BEMF are extracted from the stator and it was send across the conditioning & integrating circuit to reduce the PQ issues. This method provides as wide range of speed control, reduced PQ disturbance and better efficiency. But, the dynamic performance of the method is not effective. So we proposing Direct BEMF method, which is highly effective than that of indirect methods. The simulation results of these methods are discussed in the below chapters. The simulation for proposed systems are done using MATLAB/SIMULINK software package (R 2014).

Keywords: BEMF integration, BLDC Motor, Direct BEMF, Sensorless control, third harmonic BEMF method, ZCD

INTRODUCTION

The permanent magnet brushless DC (PM BLDC) motor is extensively being used at laptop processor, aerospace, army, automobile technology, business and household merchandise due to its great torque, compactness, and excellent efficiency. The brushless DC motor is inherently electronically managed and requires a rotor position statistics for correct flip-off currents. To elucidate this problem effectively will open the manner for full penetration of this motor power into all low price, excessive reliability, and big scaled programs.

Recently the permanent magnet automobiles are widely used for a lot of packages because of the emergence of speedy virtual controllers. Even although the benefits consisting of higher efficiency, excessive pace operation, high torque to extent ratio, noiseless operation, and long running lifestyles and many others. Make BLDC motor as a quality desire for lots programs starting from servos to traction drives [1-2]. However, the location sensors cause numerous troubles that the fee of motor manage device is raised, the extent of the motor system will increase and the reliability hassle of the sensor exists [3]. Therefore, the Sensorless power algorithms constantly have evolved.

Among the present Sensorless techniques, the most distinguished class is the returned-EMF primarily based method. The BEMF sensorless scheme is first off proposed by way of Kenichi Iizuka by means of extracting the lower back-EMF 0 crossing points [4] of the voltage. On this ground, many sensorless scheme primarily based on the terminal voltage had been advanced, and to get favorable performances inside the precise programs [5-6].

Detecting the unfastened-wheeling diode conduction inside the open segment offers the 0-crossing point of the lower back EMF waveform [7]. This mechanism of rotor-position sensing operates over a finite speed range, specifically as a minimum velocity. The predominant demerits of this strategy is the want of six more strength resources for the comparator circuits to hit upon modern-day flowing thru the loose-wheeling diode. In this paper, sensorless BLDC motor the usage of the direct BEMF technique, right here stator voltage changed into filtered and it changed into exceeded through the converter unit, then the gating pulse can be send to the Inverter unit. The open loop manage turned into simulated the use of respective simulation software program [8-9].

In this paper, we proposed the indirect BEMF method of sensorless method of the BLDC motor. There are techniques viable; they may be 0.33 harmonic voltage and Back EMF integration technique. Here the Closed loop manage was accomplished at outer loop side. The stator deliver become delicate the use of LC conditioner and it changed into exceeded through the BEMF converter phase, then the gating pulse could be given to the Inverter unit. In first technique, the 0.33 harmonic voltage element changed into extracted from the stator voltage and it changed into filtered and carried out to converter circuit, primarily based on that firing pulse of inverter became managed. In 2nd technique the stator voltage element turned into implemented to integrator and filter circuit then the signal turned into converted as triggering pulse of inverter. By using above stated technique speed and torque response of the BLDC motor is stepped forward with the reference pace. Then the Proportional and Integral controller applied inside the closed loop manage of system. It was used to reduce the constant state error and to improve the dynamic performance of the system. The simulation outcomes are compared all three cases and achieved the use of MATLAB/SIMULINK software bundle of version (RA 2014).

II.BLDC MOTOR AND MODELLING

The brushless DC motor is a synchronous AC motor with permanent magnets at the rotor and winding coils at the stator poles. Permanent magnets create the rotor flux. The energized stator windings make electromagnetic poles. The rotor is titillated via the energized stator section, generating a rotation. An everyday BL motor has everlasting magnets that rotate around a hard and fast armature, associated with connecting modern-day to the transferring armature.

A. Equivalent Circuit

For a three-Phased Brushless DC motor, the electrical circuit model is shown within the Figure 1. In this circuit, the resistance of the stator winding is denoted as R and the inductive component of the stator phase winding is denoted as L. Ea, eb and ec are the lower back-EMFs of three phases. Because the resistance &inductance values are inconsiderable for the BLDC motor, the section currents required to be confined to gain a higher efficiency. Normally, pulse width modulation method is employed for BLDC motor manipulate, and a small range cycle is prepared in the course of setting out.

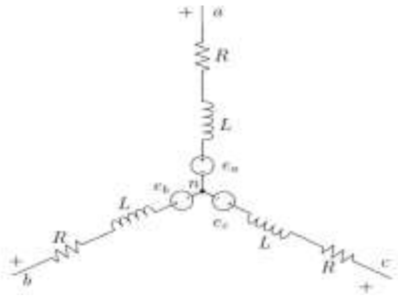

Figure 1. Electrical circuit of BLDC motor.

B. MODELLING OF BLDC MOTOR

The modeling of BLDC motor for the three phase stator coils of a BLDC motor, the electrical relationships will be represented by the below shown equation (1):

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} . \quad (1)$$

Where

V_{an}, V_{bn} and V_{cn} are the phasor voltages with referenced to the motor neutral voltage,

i_a, i_b and i_c are the phasor currents,

e_a, e_b and e_c are the phase lower back- EMFs, R is the stator resistance,

L_{aa}, L_{bb} and L_{cc} are the self-inductances,

L_{ab}, L_{ba}, L_{ac}, L_{ca}, L_{bc} and L_{cb} are the mutual inductances respectively.

If three phases are symmetrical and the rotor reluctance is equal with electrical angle (degree), all the 3 self-inductances are same and the 6 mutual inductances are equal to one other as shown below:

$$Laa = Lbb = Lcc = Ls \quad (2)$$

$$Lab = Lba = Lac = Lca = Lbc = Lcb = M \quad (3)$$

The inductance L can be derived as follow:

$$L = Ls - M \quad (4)$$

Considering that the phasor currents are identical, that is

$$ia + ib + ic = 0 \quad (5)$$

Then the electrical relations can be interpreted and the BLDC motor can be modeled as follow (6):

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = R \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} . \quad (6)$$

III. EXISTING METHOD

There are numerous styles of sensorless control scheme; however, the most famous type is based totally on lower back electromotive forces or back-EMFs. For everyday operating of a BLDC motor, the phase voltage and BEMF need to be aligned so that you can produce consistent torque. The contemporary commutation factor, may be predicted with the help of the zero crossing point (ZCP) of returned-EMFs and a 30° (degree) segment shift, the use of a 6 step commutation technique thru a three-phase inverter for running the BLDC motor. The wearing out degree of every section is 120° electric powered stages. Therefore, only behavior at any time, leaving the third segment floating. Due to the problem of low order harmonic present day and velocity range troubles we are shifting toward Back EMF methods.

IV. PROPOSED METHOD

The conduction of the freewheeling diodes is based on lower back-EMFs fee, detection of the rotor role at sluggish speeds is tough to comprehend, so a starting system is carried out. The most important disadvantage of this Freewheeling Diode Conducting State Detection method is that for detection of modern-day owing in every freewheeling diode, a separate strength deliver for the comparator circuit is required. Hence we trending toward the 3rd harmonic voltage signal detection approach and BEMF integrations methods. Here under we provided the certain description of the both strategies and simulation outcomes and comparative outcomes among these direct & oblique lower back EMF strategies additionally stated as observe.

A. THIRD HARMONIC BACK EMF METHOD

The sensorless pace manage proposed in this paper is primarily based on the evaluation of the air hole flux through the 3rd harmonic issue of the stator segment voltages. The block diagram of the proposed device changed into proven in Figure 2. The stator third harmonic voltage of the PMBLDC motor discussed on this paper is based totally at the symmetrical three stages big name-linked motor with airgap flux distribution. The sum of the stator phase voltages results inside the reduction of all poly phase components and all the function harmonics components. The 0 crossings of the third harmonic thing arise at 60^{o} electric ranges, exactly at each applicable current commutation immediately. Figure 3, depicts the motor internal voltage similar to returned-EMF, third harmonic sign, vital sign, and commutation sign. The trapezoidal waveforms of the BLDC motor includes again-EMFs, fundamental and better order harmonics. After summing the 3 terminal voltages, the 0.33 harmonic thing of returned-EMF waveforms is acquired as follow,

$$V_{result} = V_{an} + V_{bn} + V_{cn} \quad (7)$$

$$= \left(R + L\frac{d}{dt}\right)(i_a + i_b + i_c) + e_a + e_b + e_c \quad (8)$$

$$= e_a + e_b + e_c \approx 3\, e_3 \sin(3\theta_r) \quad (9)$$

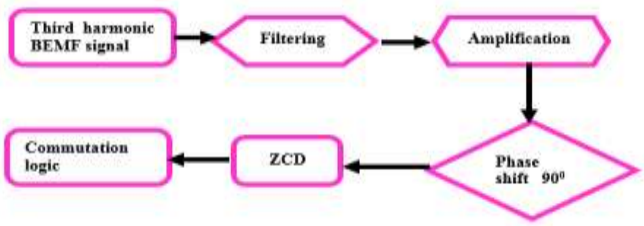

Figure 2. Block diagram of proposed system

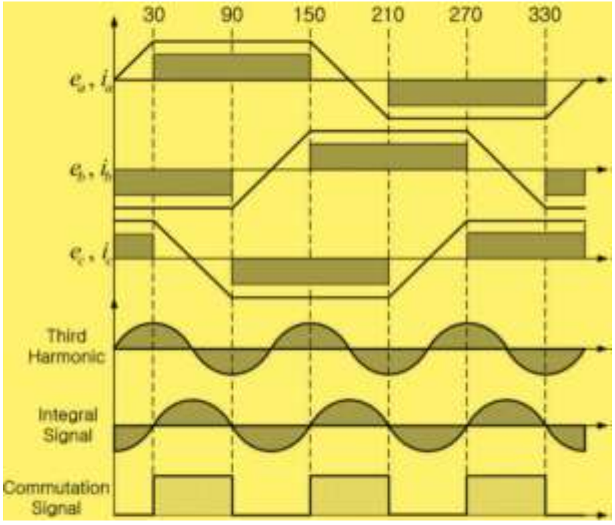

Figure 3. Trapezoidal waveforms with commutation signal using 3rd harmonic signals

By using this technique the various velocity range of BLDC motor can be obtained. The closed loop topology became performed using Proportional and Integral controllers. In the 3rd harmonic BEMF approach, the 0.33 harmonic element became extracted from the stator returned EMF, then it changed into filtered and exceeded throughout 0 crossing detector. The output of ZCD changed into transformed into gate signal for the inverter. Due to insensitivity in filtering delay, this technique can work over a much wider pace variety. Theoretically, this sensorless method is appropriate for a large velocity stages. But it can't paintings at dynamic load changing situations and harmonic component problems also arises.

B. BACK EMF INTEGRATION METHOD

In the BEMFs 0-crossing points, returned-EMFs vary approximately linearly with time. The integration mechanism will begin if the BEMF within the floating section attains its zero-crossing points. The integration end result Vint may be calculated as:

$$V_{int} = \int_0^t \frac{e(t)}{k}dt = \frac{mt^2}{2k} \quad (10)$$

Where k is the combination benefit regular, t is the mixing finishing time, e(t) is the again- EMF and m is the slope range of the again-EMF waveform. The integration system will prevent when Vint reaches the predefined thresh antique. As the BEMF value quantity is in proportion to the motor rotating speed, while the motor speeds raises or fall, the conduction durations will down or increase due to the constant predefined threshold voltage as proven in Figure 4.

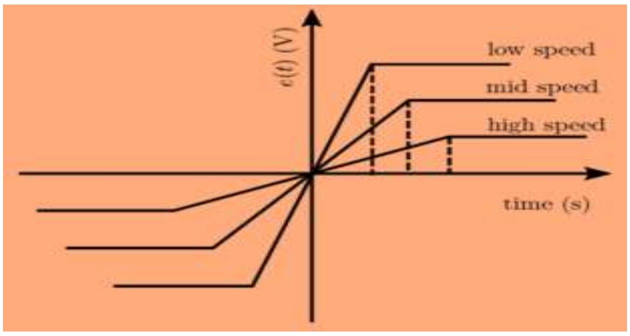

Figure 4. Integrated areas of the back-EMF signal

By the usage of this technique the various pace and load range of BLDC motor may be obtained. The closed loop control changed into carried out the usage of PI controllers. In the BEMF integration technique, the stator lower back EMF is filtered, then surpassed throughout zero crossing detector. The output of ZCD was compared in the integrator circuit and then it was transformed into gate sign for the inverter.

C. PI CONTROLLER

Proportional & Integral control is more prominent because of its capability to maintain actual set value. Simulation is done by using MATLAB R14a software.

The PI controller gives an output along with bilinear terms, one is directly proportional to errors signal and another is inversely proportional to the dynamic change in difference signal. The proportional component is imposed for following the desired set-factor at the same time as the vital part accounts for the accretion of existing error. In spite of simplicity, they can be used to resolve even a very complicated trouble managing, especially whilst combined with distinctive practical blocks, filters (compensators or correction blocks), selectors, and many others.

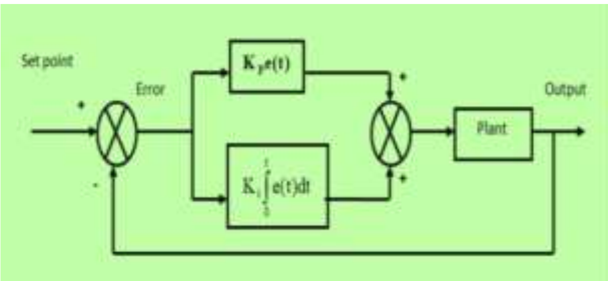

Figure 5. Structure of PI Controller

The PI controller output is given as

$$u(t)=Kp.e(t)+Ki\int e(t)dt \quad (11)$$

$$P = Kp\ ep + Kp\ Kt\ p\ dt + pt\ (0) \quad (12)$$

Whereas K_p is proportional gain constant and K_i is integral gain constants respectively.

V. SIMULATION RESULTS

A. Simulation Model of BLDC Motor Using 3rd Harmonic BEMF Method with PI Controller

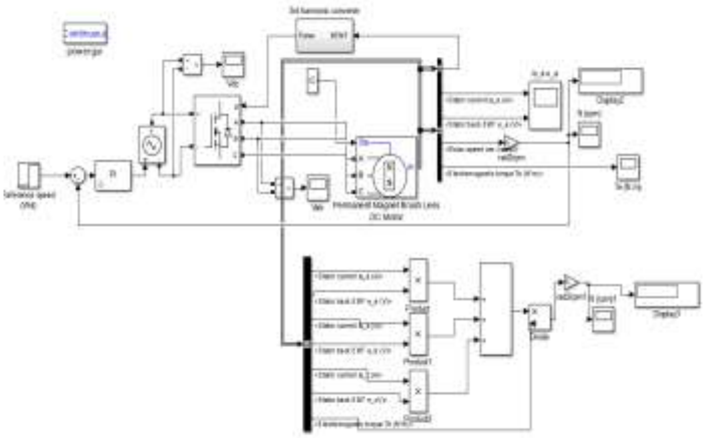

Figure 6. Simulink diagram of closed loop control of BLDC motor using 3rd harmonic BEMF Method with PI controller

The above diagram Figure 6, indicates the Simulink model of the closed loop manipulate of BLDC motor the usage of third harmonic BEMF approach with PI controllers. The input voltage will is 250V, that's controlled voltage source. Figure 6a shows the stator BEMF and stator contemporary of section A. The Back EMF of stator Ea is 189 V and stator modern ia of 2.52 A. The nominal speed of motor is in comparison with set speed (ie.3000 RPM). The compared output errors sign is ship to Proportional-Integral controller. Then, the sign output is ship as input to variable voltage provider (outer loop). The velocity of the motor is around 2721 RPM that's shown in Figure 6b. The torque is at range of 2.16 Nm which is shown in Figure 6c.

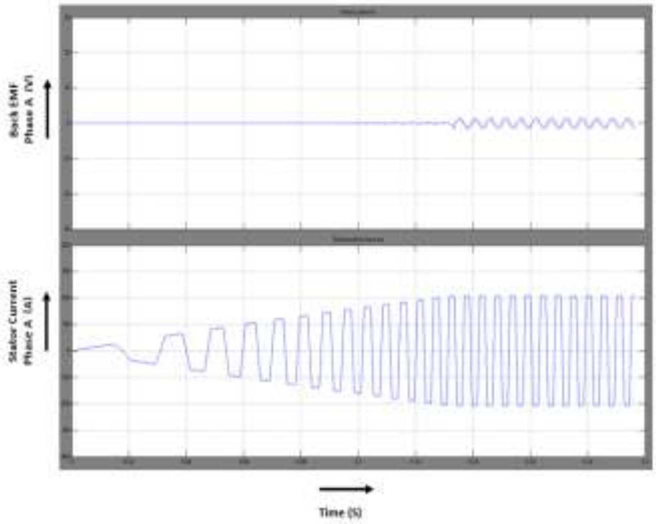

Figure 6a. Stator current and Back EMF of Phase ‘A’

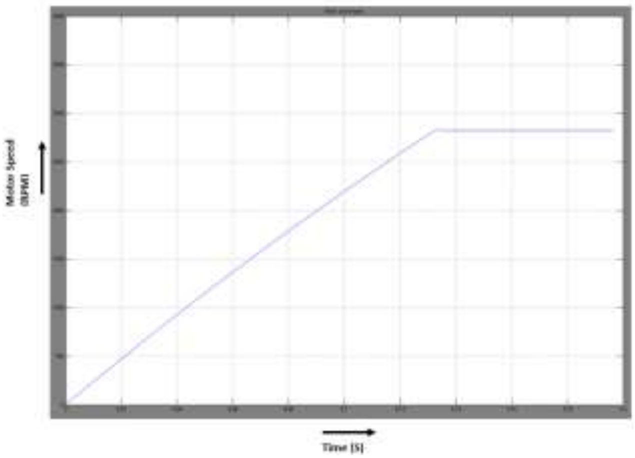

Figure 6b. Output motor speed

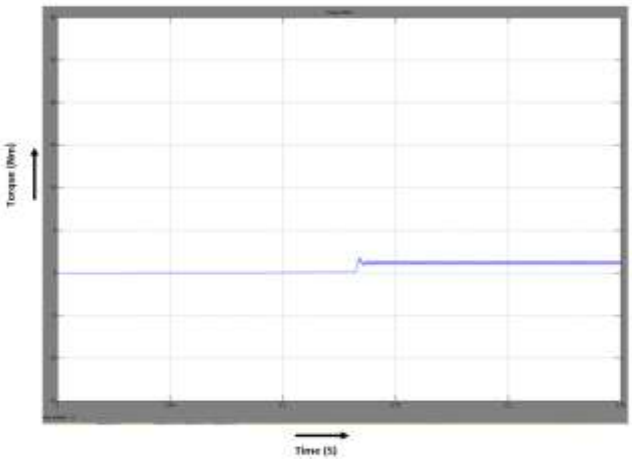

Figure 6c. Output Torque

B. Simulation model of BLDC motor using BEMF integration method with PI controller

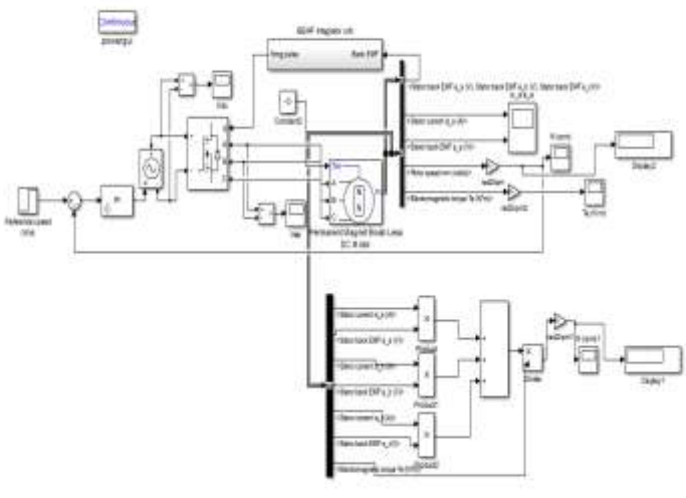

Figure 7. Simulink diagram of closed loop control of BLDC motor using BEMF integration method with PI controller

The above diagram Figure 7, shows the Simulink model closed loop manipulate of BLDC motor the usage of BEMF integration technique with PI controllers. The supply voltage may be around 250 Volts, that's managed voltage source. Figure 7a suggests the stator phase A BEMF and stator cutting-edge of segment A. The stator Back EMF Ea of 203 V and stator current Ia of 1.91 A. The sluggish velocity of motor is compared with 3000 RPM, i.e. the reference or set speed of BLDC motor. The compared output mistakes signal is send to Proportional-Integral controller. Then, the output of PI controller is send as input to controlled voltage supply.

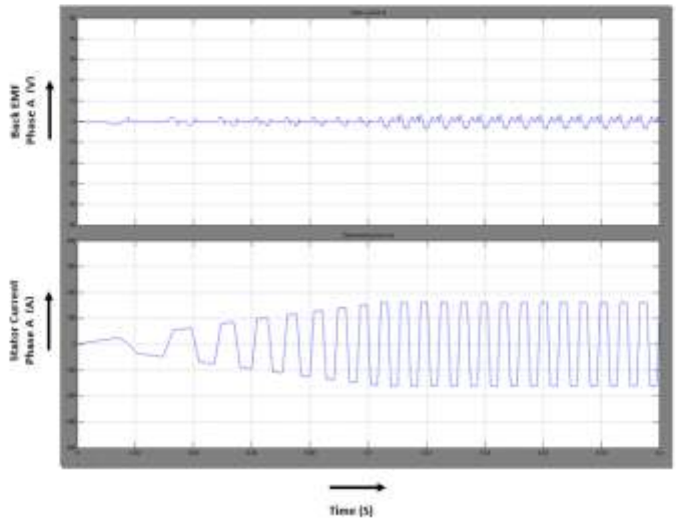

Figure 7a. Stator current and Back EMF of Phase 'A'

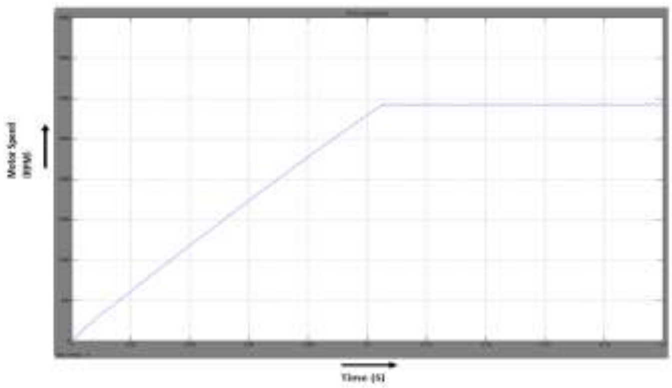

Figure 7b. Output motor speed

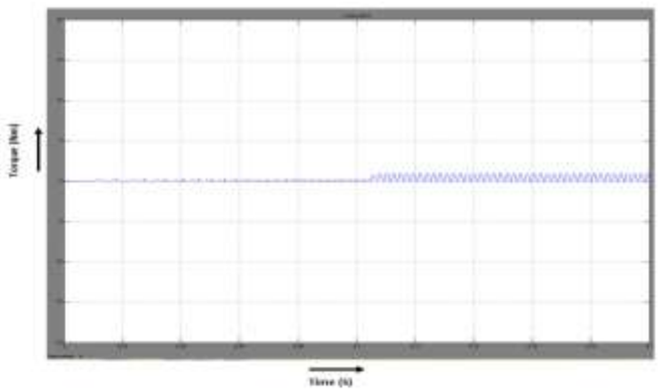

Figure 7c. Output Torque

The speed of the motor is around 2785 RPM which is shown in Figure 7b. The torque is at range of 1.91 Nm which is shown in Figure 7c. The simulation parameter are shown in **Table 1.**

S.No	Simulation parameters	Range / value.
1	Voltage source	250V
2	MOSFET	Rs=5KΩ, Cf=1μF
3	Stator resistance Rs	2.7650 Ω
4	Stator Inductance Ls	8.5 mH
5	Torque constant	1.38
6	Motor Inertia J	0.0008 Kg.m2
7	Max. speed wm	4000 RPM
8	Friction factor	0.001 N.m.s
9	No. of Poles	4
10	Reference speed wref	3000 RPM

The comparative results of various closed loop control of BEMF methods was shown in the table 2.

Table 2: Comparison of different sensorless techniques of BLDC motor control.

BLDC motor speed control method	Input DC Voltage (V)	Stator Back EMF (V)	Stator current (A)	Motor speed (RPM)	Torque (Nm)
3rd harmonic BEMF	250	189	2.52	2721	2.16
Back EMF integration	250	203	2.31	2785	1.91
Direct BEMF	250	210	2.02	2820	1.78

From the above Table 2, we are able to take a look at that the proposed sensorless Direct BEMF approach offers the excessive speed output than that of current technique. The everyday speed turned into additionally proved that, the increase in the velocity will growth the lower back EMF and decrease the Torque & present day issue. The difference within the pace variety of closed loop changed into around 180RPM. These closed loop using PI scheme turned into performed at the set pace range of 3000 RPM. The torque level also implies the powerful operating of the BLDC drive the use of this sensorless approach.

VI. CONCLUSION

In this paper, the sensorless speed control strategies for BLDC motor has been presented. The fundamentals of several techniques had been added, in particular sensorless oblique back-EMF scheme. The evaluation of the previous sensorless technique with this approach will implies the importance of the proposed technique. The closed loop manipulate simulation consequences are discussed above. The Proportional and Integral controller is used in the closed loop manipulate which offers the higher performance than that of existing manipulate. The Simulation results proves that the Direct BEMF method gives the higher velocity than that of traditional pace control of BLDC motor. Due to the simplistic nature of this technique and it has the functionality to be finished in a low-fee software. The dynamic traits of the BLDC motor is better through the usage of proposed technique. It additionally provides a huge velocity variety and control.

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