CLOSED LOOP SPEED CONTROL OF SENSORLESS BLDC DRIVE USING DIRECT BEMF METHOD WITH PI CONTROLLER

R. Gobi[1], S. Raja[2]

[1]PG scholar, Department of EEE, Sri Chandrasekharendra Saraswathi Viswa Maha Vidyalaya, Kanchipuram, Tamilnadu, India.
[2]Assistant Professor, Department of EEE, Sri Chandrasekharendra Saraswathi Viswa Maha Vidyalaya, Kanchipuram, Tamilnadu, India.

---***---

Abstract - *This paper represents a technique for deployment of the sensor less Permanent Magnet Brushless DC (PMBLDC) motor force gadget. BLDC motor is commonly operated with one or greater number of rotor sensors. It is acceptable in any kind of system to use a technique that's less dependable on the sensors and complex circuits, so on this paper a sensor less technique is used to commutate and trigger the inverter linked to BLDC motor. A proposed sensor less scheme is used to overcome the risks of sensored scheme. The rotor position detection can be anticipated even at standstill and walking situations. In this precise method, the returned EMF thing is extracted from the stator section voltages. The ensuing BEMF signal keeps a constant section courting with the rotor flux for any motor phase and load condition, and is nearly free of noise that can be brought by way of the inverter switching, making this a sturdy sensing technique. In contrast with indirect sensing methods based totally on detection of the lower back-EMF signal that require heavy filtering, those direct BEMF sign needs only a small quantity of filtering to take away the switching frequency and its aspect bands. This paper presents the development of sensor much less control system for brushless DC motor the use of direct lower back-EMF approach without the usage of any function sensors which includes hall sensors or encoders. The modeling of open loop and closed loop scheme became proposed for direct BEMF methods. The simulation outcomes with hall sensor, direct BEMF techniques are shown in comparison. The simulation for proposed drive is done the use of MATLAB/SIMULINK software program package.*

***Key Words*: PMBLDC Motor, Sensor less control, BEMF Sensing, ZCD, Filters, Inverter and Motor speed.**

1. INTRODUCTION

BLDC vehicles are higher than induction drive and brushed DC drive in lots of regions. Firstly, BLDC motors are smaller in size, and have better performance because of no losses within the rotor. Secondly, due to the elimination of brushes, BLDC motors have better excessive speed functionality, and they do no longer need any brush protection [1].

However BLDC motor have many difficulties while such forms of role sensors are used. The major difficulty is the hike size of the motor and require unique format for mounting the sensors [2].

All of the electric vehicles that do not require an electrical connection (made with brushes) among stationary and rotating elements can be considered as brushless everlasting magnet (PM) machines [3], which can be categorized primarily based on the PMs mounting and the again-EMF shape. The PMs can be floor hooked up on the rotor (SMPM) or established internal of the rotor (IPM) [4], and the returned-EMF shape can either be

Sinusoidal or trapezoidal. According to the again-EMF shape, PM AC synchronous vehicles (PMAC or PMSM) have sinusoidal again-EMF and Brushless DC automobiles (BLDC or BPM) have trapezoidal returned- EMF. A PMAC motor is typically excited by way of a 3-phase sinusoidal current, and a BLDC motor is normally powered via a fixed of currents having a quasi-square waveform [5] [6].

In the ZCP approach the lower back emf can't be received while the BLDC motor is at standstill or running nearly 0 velocity as discussed by way of Yen- Shin Lai and Yongkai Lin [7]. Therefore, a special manipulate is needed for smooth and reliable sensorless manipulate operation of BLDC motor [8].

In this paper we proposed the sensorless approach of the BLDC motor using the Direct BEMF method. Here the Closed loop control was done implemented at controlled voltage source. The stator voltage was filtered using LC filter and it was send across the BEMF converter circuit, then the firing pulse will be given to the Inverter. The open and closed loop control was simulated here.

2. BLDC MOTOR AND MODELLING

The BLDC motor is an AC synchronous motor with everlasting magnets at the rotor (shifting component) and windings on the stator. Permanent magnets create the rotor flux. The energized stator windings create electromagnet poles. The rotor is attracted via the energized stator phase, producing a rotation. A usual brushless motor has everlasting magnets which rotate around a fixed armature, casting off troubles related to connecting modern to the transferring armature. A digital controller replaces the brush/commentator assembly of the brushed DC motor, which always switches the segment to the windings to preserve the motor turning. The controller plays similar timed power distribution by using the use of a solid-state circuit as opposed to the brush/commutator gadget.

2.1 EQUIVALENT CIRCUIT

For a 3-Phase BLDC motor, the electrical circuit model may be shown in Fig-1. In this circuit, R represents the resistance component of the stator winding and L represents the inductive factor of the stator phase winding. ea, eb and ec are the section back-EMFs. Because the resistance and inductance are very small for the BLDC motor, the phase currents want to be limited throughout commencing. Normally, PWM method is implemented for BLDC motor control, and a small obligation cycle is ready all through starting up.

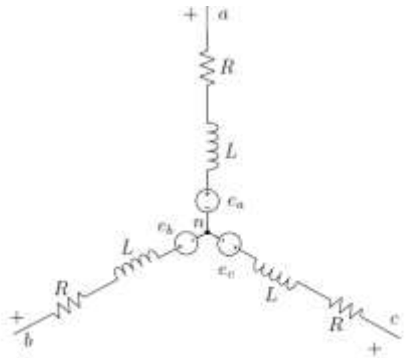

Fig-1: Equivalent circuit of BLDC motor.

2.2 MODELLING OF BLDC MOTOR

The BLDC motor modeling for the 3 stator windings of a BLDC motor, the electric relationships may be represented with the equation under:

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

------ (1)

Where Van, Vbn and Vcn are the phase voltages referenced to the motor neutral voltage, ia, ib and ic are the phase currents, ea, eb and ec are the phase lower back- EMFs, R is the segment stator resistance that is identical for 3 levels, Laa, Lbb and Lcc are the self-inductances, Lab, Lba, Lac, Lca, Lbc and Lcb are the mutual inductances. If three levels are symmetric and the rotor reluctance is equal with the alternate of electrical angle, the 3 self-inductances are identical and the six mutual inductances are equal to every different as:

$Laa = Lbb = Lcc = Ls$ ------- (2)
$Lab = Lba = Lac = Lca = Lbc = Lcb = M$ ------- (3)
The equivalent inductance L can be calculated as:
$L = Ls - M$ ------- (4)
Assuming that the phase currents are symmetric, that is
$ia + ib + ic = 0$ ------- (5)
Then the electrical relationships can be simplified and the BLDC motor can be modeled as:

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

----- (6)

2.3 CONVENTIONAL SPEED CONTROL METHOD

Fig-2 shows the fundamental block diagram for an ordinary BLDC motor manage gadget. Three hall sensors are used which are placed a hundred and twenty degree aside from every different.

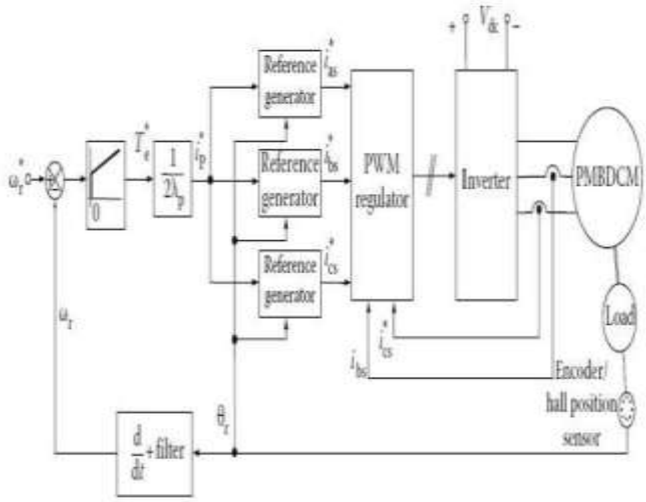

Fig-2: A complete BLDC speed control system with hall sensor for position Information

As shown in Fig-2, hall role sensors offer the information of rotor function from which rotor speed can be calculated. The inner loop enforces modern-day command and outer loop enforces speed command. Rotor speed is in comparison with the reference or commanded pace to provide some error pace that is to begin with same to reference pace and equals 0 at ideal steady country. The errors is processed with a PI controller with suitable proportional and integral constants to provide the reference torque for the power. The commanded modern-day is observed from the reference torque from equation. Rotor positions extracted from Hall sensors are translated to three exceptional states (1, zero, -1) depending on the rotor on the spot positions. These states have the exact in shape with the states of the respective lower back EMFs, and consequently improved with the commanded present day to produce reference contemporary vectors which might be as compared to the actual currents respectively (hysteresis control). The error sign made out of this evaluation is used as a reference for a PWM generator block which affords 6 gate pulses for the three phase inverter.

3. PROPOSED TOPOLOGY

If a PM motor needs electric measurements with none requirements for a position sensor, it is known as a sensorless drive. There are many varieties of sensorless drives for BLDC motor. Among them, again electromotive force (BEMF) based totally techniques are the most commonly used class. Conventional back-EMF primarily based strategies utilize the terminal voltage inside the floating phase, detection of the conducting state of freewheeling diode inside the floating phase, 3rd harmonic components of BEMF waveforms and integration of the floating phase back-EMF. However, again-EMFs values are zero at standstill, and it is tough to hit upon the 0-crossing factors from noises if the motor phase is low, so the low pace performance is constrained. For methods based totally on BEMFs, a beginning procedure is normally required to speed up BLDC motor to a surprisingly better pace, after which motor can be managed with the aid of sensorless drives. Fig-3, indicates the various sensorless approach in BLDC motor.

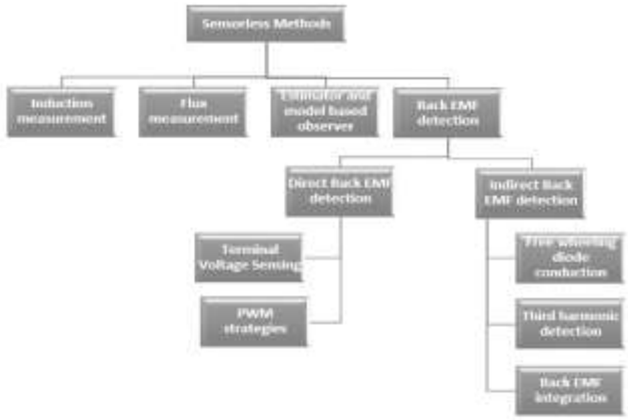

Fig-3: Types of sensorless methods in BLDC motor

3.1 DIRECT BACK-EMF DETECTION METHOD

The BLDC motor presents an appealing candidate for sensorless operation because the character of its excitation inherently offers a low-cost manner to extract rotor function statistics from motor-terminal voltages. In the excitation of a three-phase BLDC motor, except for the phase-commutation intervals, most effective two of the 3 phase windings are carrying out at a time and the no carrying out phase consists of the BEMF. There are many classes of sensorless control strategies; but, the most popular class is based totally on lower back electromotive forces or returned-EMFs. Sensing back-EMF of unused phase is the most price efficient method to reap the commutation collection in megastar wound automobiles. Since lower back-EMF is 0 at standstill and proportional to hurry, the measured terminal voltage that has large signal-to-noise ratio can't discover 0 crossing at low speeds. That is the cause why in all again-EMF-based sensorless techniques the low-velocity overall performance is constrained, and an open-loop starting method is needed.

Generally, a brushless DC motor includes a PM synchronous motor that converts electrical energy to mechanical energy, an inverter corresponding to brushes and commutators, and a shaft position sensor. In this figure, every of the 3 inverter levels are highlighted in a different coloration, together with the impartial point: red phase A, green phase B, blue phase C, and pink impartial point N. The stator iron of the BLDC motor has a non-linear magnetic saturation feature, that's the idea from which it's miles viable to determine the preliminary function of the rotor. When the stator winding is energized, applying a DC voltage for a positive time, a magnetic field with a hard and fast route may be mounted. Then, the modern-day responses are unique because of the inductance distinction, and this transformation of the present day responses consists of the statistics of the rotor role. Therefore, the inductance of stator winding is a characteristic of the rotor role. BLDC motor sensorless circuit scheme are proven in Fig-4. Detail circuit diagram of proposed system is proven in Fig-5.

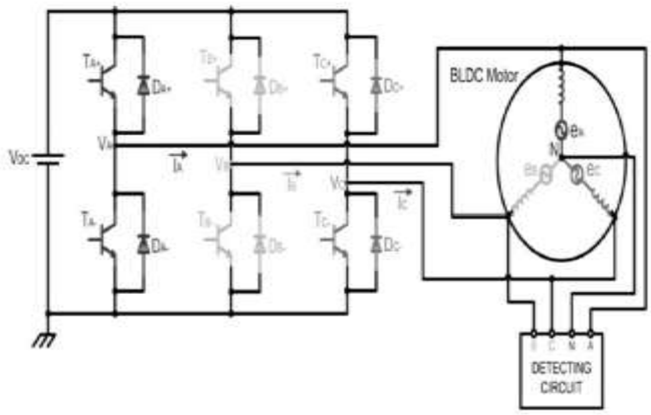

Fig-4: Sensorless circuit scheme

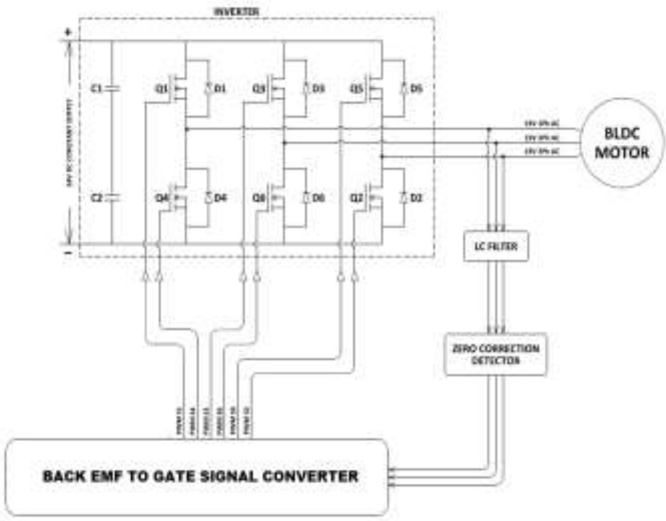

Fig-5: Detail circuit diagram of proposed system

3.2 BACK-EMF ZERO CROSSING DETECTION

The zero-crossing technique is one of the simplest methods of returned-EMF sensing method, and is primarily based on detecting the on the spot at which the returned-EMF inside the unexcited phase crosses 0. This zero crossing triggers a timer, which may be as easy as an RC time consistent, so that the subsequent sequential inverter commutation takes place at the give up to this timing interval.

For normal operation of a BLDC motor, the segment cutting-edge and returned-EMF must be aligned to generate constant torque. The cutting-edge commutation point proven in Fig-6, can be anticipated with the aid of the zero crossing point (ZCP) of back-EMFs and a 30° segment shift, using a six-step commutation scheme via a three-segment inverter for riding the BLDC motor. The carrying out c programming language for every phase is one hundred twenty electric ranges. Therefore, simplest levels behavior modern at any time, leaving the third segment floating. In order to produce most torque, the inverter should be commutated each 60° by means of detecting 0 crossing of again-EMF at the floating coil of the motor, so that contemporary is in phase with the BEMF.

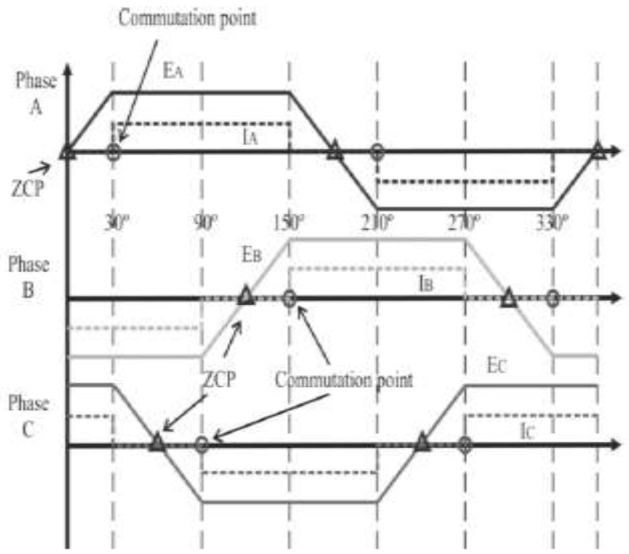

Fig-6: Trapezoidal waveform diagram of BLDC motor back EMF

This approach of delaying 30° (electric ranges) from 0 crossing instant of the returned-EMF isn't affected a great deal through speed changes. To locate the ZCPs, the section again-EMF must be monitored during the silent phase (while the particular segment cutting-edge is 0) and the terminal voltages need to be low-skip filtered first.

3.3 CONTROLLERS TECHNIQUES

PI CONTROLLER

PI control is becoming more popular because of its ability to maintain exact set point. This chapter aims at establishing the design and implementation of the conventional PI controllers. Simulation is done by using MATLAB R14a and the controller is subjected to various disturbances of input voltage and load changes.

PI CONTROL MODES

The PI controller produces an output signal along with two terms, one proportional to errors signal and the alternative proportional to the essential of blunders signal. The proportional component is responsible for following the desired set-factor at the same time as the vital part accounts for the accumulation of past mistakes. Fig-7, shows the primary structure of Proportional Integral (PI) controller. In spite of simplicity, they can be used to resolve even a very complicated manage trouble, especially whilst combined with distinctive practical blocks, filters (compensators or correction blocks), selectors, and many others.

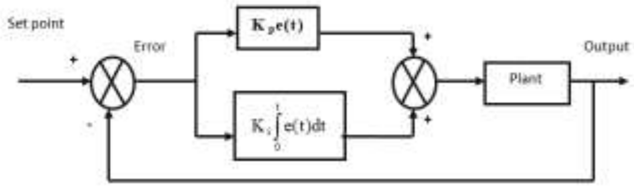

Fig-7: Structure of PI Controller

The PI controller output is given as

$u(t)=Kp.e(t)+ Ki\int e(t)dt$ ---------------------- (8)

$P = Kp\ ep + Kp\ Kt\ p\ dt + pt\ (0)$ --------------------- (9)

Where Kp and Ki are proportional and integral constants respectively.

The controller output is provided through a sum of proportional plus essential action that eventually leaves the mistake at 0. The proportional element is obviously simply a picture of the error.

The proportional action will increase the loop advantage and makes the device less sensitive to versions of machine parameters. The integral motion eliminates or reduces the constant kingdom errors. Zeigler and Nichols proposed a method to set the PI controller parameters.

4. SIMULATION RESULTS AND DISCUSSION

4.1 OPEN LOOP CONTROL OF BLDC MOTOR USING DIRECT BEMF METHOD

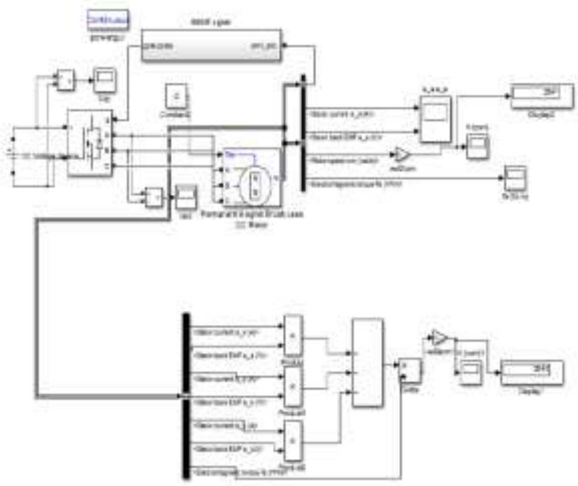

Fig-8: Simulink diagram of open loop control of BLDC motor using Direct BEMF Method

The above diagram shows the Simulink model of open loop control of BLDC motor in Fig-8. The input voltage will be around 250V, which is constant in the model. The three inverter was powered by the DC source. Then the inverter output was given to BLDC motor. The Direct back EMF signal was converted into gating signal for inverter with the help of ZCD technique. The switch used is MOSFET device. Fig-9 shows the stator BEMF and stator current of phase A. The stator Back EMF of 157V and current of 3.35A.

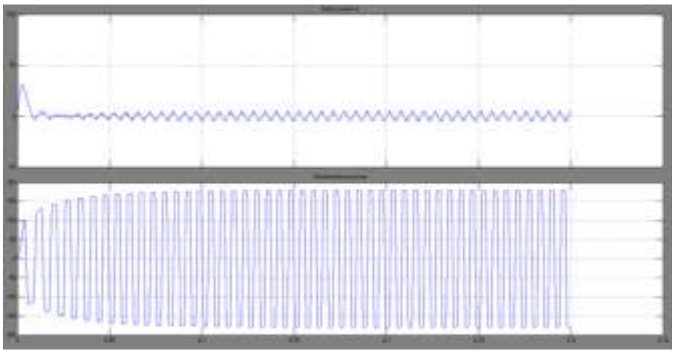

Fig-9: Stator current and Back EMF of Phase 'A'

The speed of the motor is around 2140 RPM which is shown in Fig-10. The torque is at range of 2.32 Nm which is shown in Fig- 11.

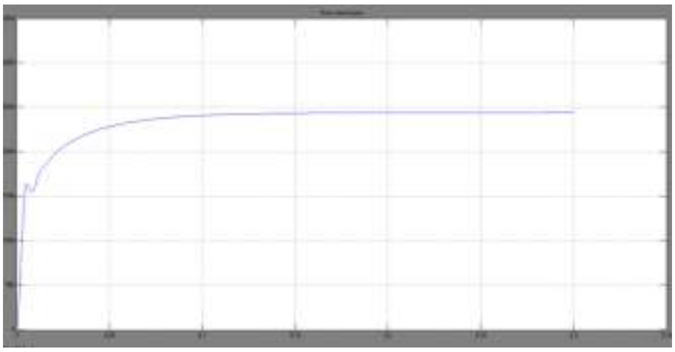

Fig-10: Output motor speed

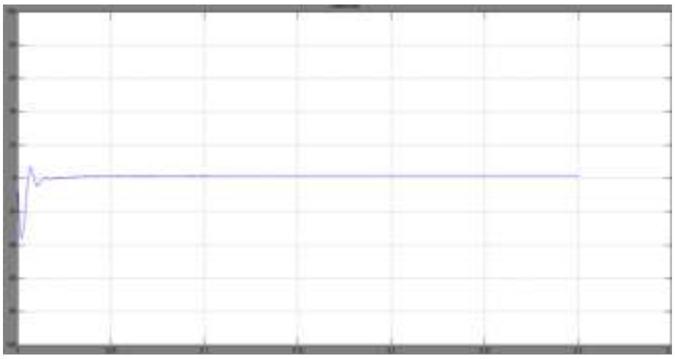

Fig-11: Output Torque

The Simulink model of the BLDC motor without the help of Hall sensor is modeled above. The simulation parameters are described in the below table 1. The model was developed at the average speed of 3000 RPM. But the output results of the open loop control was not satisfies the required limit. In order to overcome these problem, we using the PI controller. The PI controller produces an output signal consisting of two terms, one proportional to error signal and the other proportional to the integral of error signal. The proportional part is responsible for following the desired set-point while the integral part accounts for the accumulation of past errors. The values of the Kp and Ki was tuned in order to get the optimized results from the set or reference values,

4.2 CLOSED LOOP CONTROL OF BLDC MOTOR USING DIRECT BEMF METHOD WITH PI CONTROLLER

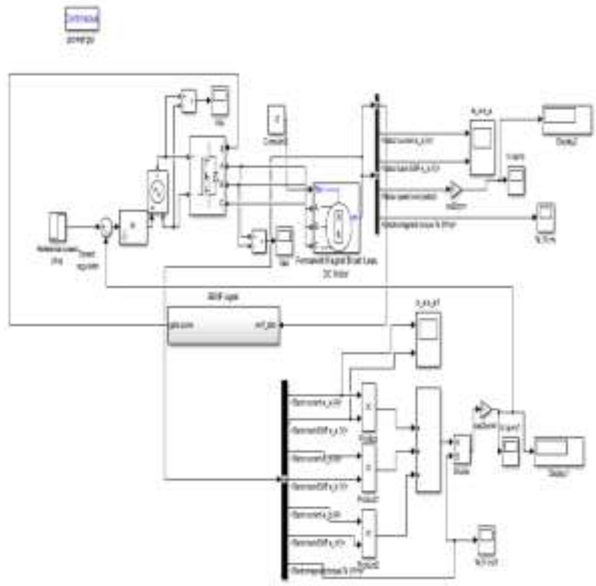

Fig-12: Simulink diagram of closed loop control of BLDC motor using Direct BEMF Method with PI controller

The above diagram Fig-12, shows the Simulink model closed loop control of BLDC motor using Direct BEMF method with PI controllers. The input voltage will be around 250V, which is controlled voltage source in the model. Fig-13 shows the stator BEMF and stator current of phase A. The stator Back EMF of 210 V and current of 2.02 A. The actual speed of motor is compared with the reference or set speed of 3000 RPM. The compared error signal is send to Proportional-Integral controller. Then, the optimized signal is send as input to controlled voltage source.

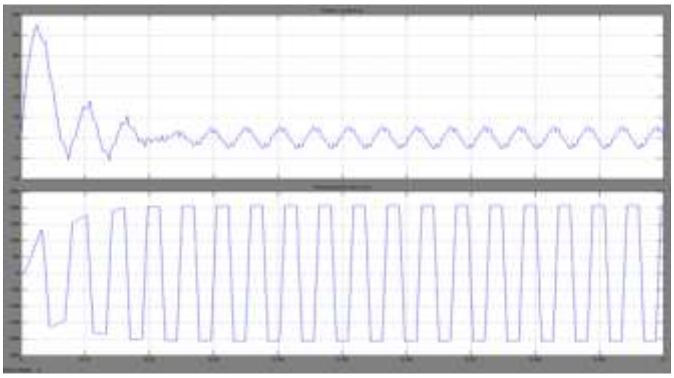

Fig-13: Stator current and Back EMF of Phase 'A'

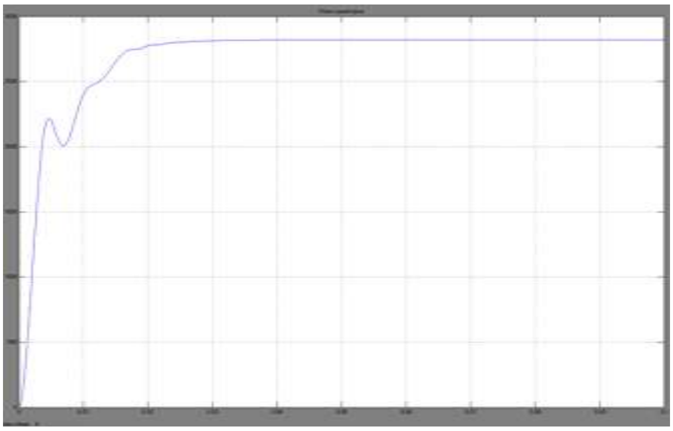

Fig-14: Output motor speed

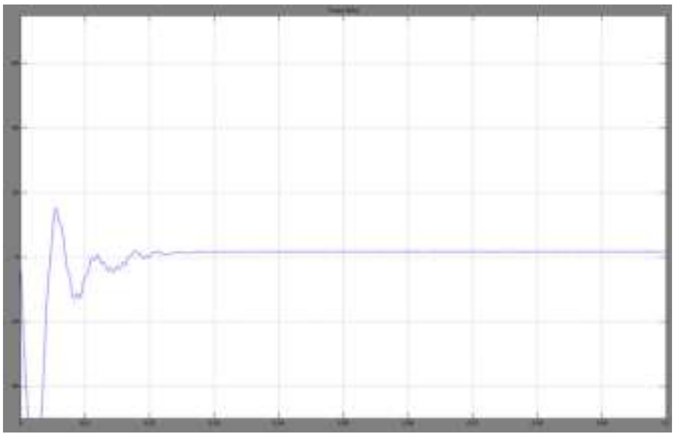

Fig-15: Output Torque

The speed of the motor is around 2820 RPM which is shown in Fig- 14. The torque is at range of 1.78 Nm which is shown in Fig- 15. 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.m^2
7	Max. speed w_m	4000 RPM
8	Friction factor	0.001 N.m.s
9	No. of Poles	4
10	Reference speed w_{ref}	3000 RPM

The comparative results of open loop and closed loop control of direct BEMF method and sensored method was shown in the table 2.

Table 2: Comparison of sensored and sensorless techniques of BLDC motor control.

BLDC MOTOR WITH METHOD		Input DC Voltage (V)	Stator Back EMF (V)	Stator current (A)	Motor speed (RPM)	Torque (Nm)
WITH HALL SENSOR	Open loop	250	124	3.80	1690	3.5
	Closed loop with PI	250	202	2.32	2766	2.07
SENSORLESS DIRECT BEMF	Open loop	250	157	3.35	2140	2.32
	Closed loop with PI	250	210	2.02	2820	1.78

From the above table 2, we can observe that the proposed sensorless Direct BEMF method was gives the high speed output than that of sensor based method. The normal speed law was also proved that, the increase in the speed will increase the back EMF and decrease the Torque and current component. The difference in the speed range of open loop and closed loop was around 680RPM. These closed loop scheme was done at the reference speed range of 3000 RPM. The torque parameters also implies the efficient operation of the BLDC drive.

5. CONCLUSIONS

In this paper a evaluate study of sensorless speed control strategies for BLDC automobiles has been offered. The basics of numerous strategies have been added, mainly sensorless direct back-EMF scheme. The evaluation of the sensorless method with the sensor primarily based technique will implies the significance of the proposed technique. The open & closed loop control simulation results are discussed above. The Proportional and Integral controller is used within the closed loop control which offers the better performance than that of Open loop control. The Simulation consequences broadcasts that the Direct BEMF control offers the higher velocity manipulate than that of conventional sensored velocity manipulate of BLDC motor. Due to the simplistic nature of this manage; it has the capability to be carried out in a low-price software-precise included circuit.

REFERENCES

[1] Harith Mohan1, Remya K P2, Gomathy S3, "Speed Control of Brushless DC Motor Using Fuzzy Based Controllers", International Research Journal of Engineering and Technology (IRJET), Volume: 02 Issue: 04 | July-2015.

[2] Becerra RC, Ehsani M, "High-Speed Torque Control of Brushless Permanent Magnet Motors", IEEE Trans. Ind. Electron. 1988; 35:402–406.

[3] Bonfe M, Bergo M. "A Brushless Motor Drive with Sensorless Control for Commercial Vehicle Hydraulic "Pumps. Proceedings of the IEEE International Symposium on Industrial Electronics (ISIE 2008); Cambridge, England. July 2008; pp. 612–617.

[4] Bianchi N, Bolognani S, Jang JH, Sul SK. "Comparison of PM Motor Structures and Sensorless Control Techniques for Zero-Speed Rotor Position Detection". IEEE Trans Power Electron. 2007; 22:2466–2475.

[5] Su GJ, McKeever JW. "Low-Cost Sensorless Control of Brushless DC Motors with Improved Speed Range". IEEE Trans. Power Electron. 2004; 19:296–302.

[6] Damodharan P, Vasudevan K. "Indirect Back-EMF Zero Crossing Detection for Sensorless BLDC Motor Operation. "Proceedings of the International Conference on Power Electronics and Drives Systems (PEDS 2005); K L , Malaysia. November 2008; pp. 1107–1111.

[7] Lai Y.-S and Lin Y.-K., " The unified approach to zero crossing point detection of back EMF for Brushless DC motor drives without current and hall sensors", IEEE Trans. Power Electron. 26(6), (2011)

[8] P. Damodharan and Krishna Vasudevan, " A Brushless DC Motor Drive Based on the Zero-Crossing Detection of Back Electromotive Force (EMF) from the Line Voltage Difference", IEEE Trans on energy conversion, vol. 25, September 2010.

[9] Sreepriya R and Ragam Rajagopal, "speed control of three phase BLDC motor drive with improved flux observer", 2013 International Conference on Control Communication and Computing (ICCC).2014.

[10] Dariusz Swierczyúski, "Direct Torque Control with Space Vector Modulation (DTC-SVM) of Inverter-Fed Permanent Magnet Synchronous Motor Drive", 2005.

[11] T. Cicily Antony, M. Beena Varghese, Anish Gopinath, "Poly Phase BLDC Motor Drive with Ten Step Commutation", IEEE 2014 Annual International Conference on Emerging Research Areas: Magnetics Machines and Drives (AICERA/ICMMD), 2014.

[12] D. Mahayana, S. Anwari, "Brushed DC Motor Controller Using Robust Indirect Adaptive Control", IEEE 2009 International Conference on Electrical Engineering and Informatics, vol. 1-2, pp. 242-246, 2009.

[13] C. Umayal, D. Saranya Devi, "Modeling and Simulation of PFC SEPIC Converter fed PMBLDC Drive for Mining Application", International Journal of Advanced Trends in Computer Science and Engineering, vol. 2, pp. 203-208, 2013.

[14] R. Carlson, M. Lajoie-Mazenc, C.D.S. Fagundes, "Analysis of torque ripple due to phase commutation in brushless DC machines", IEEE Trans. On Industry Applications, vol. 28, pp. 632-638, 1992.

[15] A. Barkley, D. Michaud, E. Santi, A. Monti, D. Patterson, "Single stage brushless DC motor drive with high input power factor for single phase applications", IEEE trans on Power Electronics Specialists Conf. 2006, pp. 1-10.

[16] M. R. Feyzi, M. Ebadpour, S. A. KH. Mozaffari Niapour, Arshya Feizi, R. Mousavi Aghdam, "A New Single Current Strategy for High-performance Brushless DC Motor Drives", International Conference on Electrical and Computer Engineering IEEE CCECE 2011, pp. 419-424.

[17] S.K. Safi, P.P. Acamley, A.G. Jack, "Analysis and simulation of the high-speed torque performance of brushless DC motor drives", IEE Proceedings-Electric Power Applications, vol. 142, no. 3, pp. 191-200, May 1995.