www.ijaceeonline.com ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 2, Issue12, December 2017, pp. 8–14

A Novel Approach to Sensorless Control for a Low Cost BLDC Motor

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Abstract: *Brushless Direct Current (BLDC) motors have made a successful entrance into various sectors of industry such as aerospace, automotive and home appliances due to its simple structure. Nowadays, many studies have been focused on how to reduce the cost of BLDC motor and its control system without performance degradation. The accurate knowledge of the rotor position is required for good performance of BLDC motors. The need for rotor angle information in BLDC has been satisfied by the use of some form of position sensor. The position sensors used in BLDC drives have many disadvantages such as additional cost, electrical connections, mechanical alignment problems, and being inherent source of unreliability. This paper proposes a sensorless control approach with Back-Electro Magnetic Field (EMF) detection for the low cost BLDC motor based on Proportional Integral (PI) controller using back EMF as the control feedback. Simulation and results have been carried out for the verification of the proposed control scheme.*

Keyword: *Back EMF; BLDC motor; PI controller; rotor angle.*

1. INTRODUCTION

The BLDC motors have been widely used because of the developments in power electronics, manufacturing technology and high performance magnetic fields. The brushless motors which also known as permanent magnet synchronous motors being without a collector have an increasingly important use. These motors have been widely used due to its high power density, large torque to inertia ratio and high efficiency. BLDC motors which are controlled electronically, mainly requires the rotor position information. There are several techniques for the control and the detection of rotor position. Sensors are also used in the detection of electromotive force which is relatively expensive. The problem that includes the cost and reliability factor can be overcome by the development of BLDC motor without sensors [4].

The BLDC motor can be chosen mainly due to high reliability, high efficiency and high power to volume ratio. BLDC motor is a high performance motor which can provide large amount of torque over a vast speed range. Both the brushless and brushed DC motors share the same speed performance and torque. The use of brushes serves the difference between the two. The brushless motors generally increase the performance and reliability of the motor. The brushes are not available in BLDC motors and hence are electronically commutated [4] [8].

2. SENSORLESS DRIVE TECHNOLOGY

Among the various sensor control techniques used in various technology, the sensorless control is used mainly to reduce the cost, increase the performance of the motor and to increase the reliability. The sensorless BLDC motor is mainly rotated with the effect of back EMF detection method in which the motor neutral voltage is not needed to measure the back EMFs. Since the back EMF is proportional to the terminal voltage it reduces the switching noise.

The position of the rotor can be detected by the use of sensors that include the Hall Effect devices (HFD). This HFD enables an electronic device which is called as drive to commutate the motor. BLDC motor is also used in inverter operation with their trapezoidal electromotive force [9]. For the inverter operation, the back EMF requires the six discrete rotor positions. These are mainly generated by the HFD switch sensors which are placed within the motor. These hall sensors are mainly temperature sensitive, and limit the operation of the motor. Due to this, the reliability of the system is reduced. [1] [2].

Cite this paper:

Laavanya Periyasamy, Senthil Ganesh Ramasamy, "A Novel Approach to Sensorless Control for a Low Cost BLDC Motor", International Journal of Advances in Computer and Electronics Engineering, Vol. 2, No. 12, pp. 8-14, December 2017.

www.ijaceeonline.com ISSN: 2456 - 3935
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The Hall Effect theory states that if an electric current carrying conductor is placed in a magnetic field, to rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to detect the rotor position by the use of Hall sensors which is embedded in stator. The Hall sensors that are embedded with the stator are a very complex process. If the Hall sensors and the stator are not embedded in a proper manner it may result in the error in the detection of the rotor position [12]. In order to overcome this problem, the mounting of Hall sensors on to the stator can be varied with the rotor, in addition to the rotor magnets. The photoelectric sensors are widely used in the transmission of light. Due to its complex installation, use of photoelectric sensors becomes increasingly smaller in use.

Hence these types of sensors have number of drawbacks which includes the high cost complex installation and so on. So, nowadays we are using the sensorless BLDC motor in modern technology mainly to reduce the cost and increase the reliability. The usage of sensorless BLDC motor has been increased in the medical system design.

The HFD's are mainly used to provide the feedback from the motor. This is not used in sensorless BLDC motor. Instead, it uses the back EMF detection method to determine the method of commutation. The most common technique that is used in the detection of rotor position is the ramp-up pattern mainly to energize two motor phases and the third phase is for back EMF which is to be monitored. When the motor speed increases, a proportionate amount of back EMF is produced by the motor on the non energized phase. If this amount of back EMF is sufficient enough for the motor drive to detect the position of the sensor, then the ramp up technique will switch over to the next which is called as back EMF zero crossing technique [15].

3. BLDC MOTOR USING SENSORS

The BLDC motors using sensors requires a rotor position sensor for starting. These are generally controlled by using a three phase inverter. This is because the three phase inverter provides proper commutation sequence which is used to control the speed of the motor. The position sensors used generally will increase the cost and reduce the reliability. The sensors need special mechanical arrangements for mounting. This makes the system installation more complex [5] [8].

The position sensors used in BLDC motor is Hall sensors to detect the rotor position. The hall sensors are mainly used in high speed operation and to measure larger current. But this may get affected by the external magnetic field. They are temperature sensitive and hence the operation of motor limited to below 75˚C. The Hall sensors used in the BLDC motor mainly increase the cost; reduce the reliability of the system [5].

The BLDC motor with the position sensor is shown in the Figure 1 which shows the performance of the sensors in rotor position detection and the importance of the usage of sensorless BLDC motor in modern control technology. The BLDC motor is driven with the three phase inverter in which the power input is given. The sensors shown are used to detect the position of the rotor. The rotor position is again feedback to the inverter which produces the back EMF.

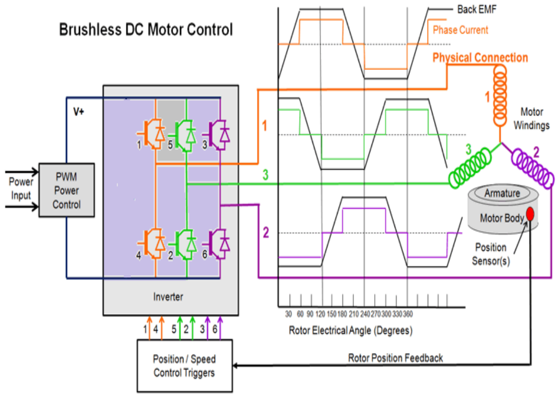

Figure 1 BLDC motor with position sensor [11]

In summary, the BLDC motor drives require a sensor to detect the position of rotor and to perform the phase commutation, but this includes several drawbacks. The main drawback includes the increase in size of motor and cost, and a special arrangement to be made for mounting the sensors. The Hall sensors are also temperature sensitive and hence limit the operation of the motor which could reduce the system reliability. In order to reduce the cost and to increase the reliability such position sensors can be eliminated. To overcome these limitations, the sensorless schemes can be used for the BLDC motor.

4. TECHNIQUES AND ADVANCES IN SENSORLESS CONTROL

The position sensors used can be eliminated thus reducing the cost and size of the motor. Some control methods such as back EMF detection and integration method and current sensing provide enough information to estimate the position of the rotor and to operate the motor with the synchronous phase currents [3]. The main technique used in this sensorless control strategy is back EMF detection method in which the commutation is performed by various methods to limit the performance of the speed. This method increases the reliability and the performance of the motor.

The BLDC motor has an increasing importance in sensorless operation which offers a low cost way to

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extract the rotor position from the motor terminal voltages. There are many sensorless control strategies; of these the most popular strategy includes the back EMF detection method. This method which is used for unused phase is the most cost effective method. At the standstill condition, the back EMF is zero and proportional to speed. Hence, the measured terminal voltage which has the large signal to noise ratio cannot defect the zero crossing at low speeds. Hence in BLDC motor with the back EMF detection method, the speed performance is limited and an open loop strategy is required [13].

The BLDC motor consists of permanent magnet synchronous motor that converts the electrical energy into mechanical energy. The initial position of the rotor can be detected by the usage of stator iron of the BLDC motor which has a non linear magnetic saturation characteristic. This stator winding when energized by applying a DC voltage, a certain magnetic field will be established [10]. Due to this, the current responses are different this variation provides the information of the rotor position.

5. IDEAL BACK EMF METHOD

The BLDC motor includes the types with sensors and sensorless control methods. Similarly the back EMF signal of the motor includes sinusoidal and trapezoidal. Sensor signals are mainly used to generate the PWM sequence of three phase inverter. These sensor signals are detected by using the Hall Effect sensors low resolution requirements and optical encoder for high resolution requirements [6]. The BLDC motor with the back EMF method is shown in the Figure 2.

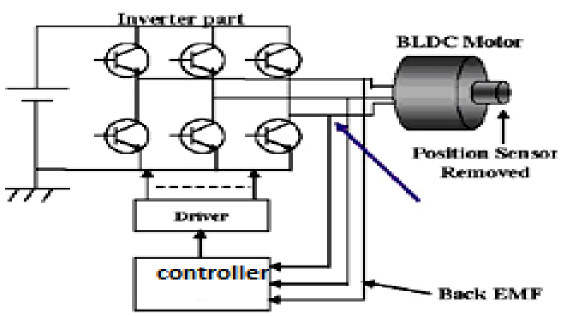

Figure 2 BLDC motor with Back EMF method [16]

Initially the three phase inverter is used as a voltage source. The rotor position is detected and the commutation is performed by the back EMF detection method. In this type, the trapezoidal commutation is performed which increases the performance of the motor. However at very low speed the back EMF will be very low. This indicates that the back EMF is proportional to speed. This back EMF is generated to the controller which includes the proportional plus integral (PI) controller to limit the speed [14]. Hence the motor should be operated in open loop mode until the sufficient speed is generated for the rotation. Finally the MATLAB code is written for the rotation of the motor with the back EMF detection method.

6. DISCUSSION OF SIMULATION RESULTS

The simulation for both the conventional and sensorless control of BLDC motor is shown and hence the results of the proposed method are compared with the conventional method.

6.1. Simulation results of conventional method

A three BLDC motor is fed to the inverter bridge and it is connected to controlled voltage source. The inverter gates signals are produced by decoding Hall Effect signals. The three phase output of the inverter is applied to the motors stator windings. From the supply voltage divider is connected, and a compare to zero circuit to produce the back EMF for three phases [2].

TABLE I BLDC MOTOR SPECIFICATIONS

Parameter	Specifications	
	Conventional method	Sensorless method
Voltage	220 V	500 V
Current	0 A	0 A
Speed	3000 rpm	3000 rpm
Inertia	0.8e-3 J(kg.m^2)	0.8e-3 J(kg.m^2)
Torque	3.5 Nm	4.5 Nm
Resistance	2.875 ohm	2.875 ohm
Inductance	8.5 mH	8.5 mH

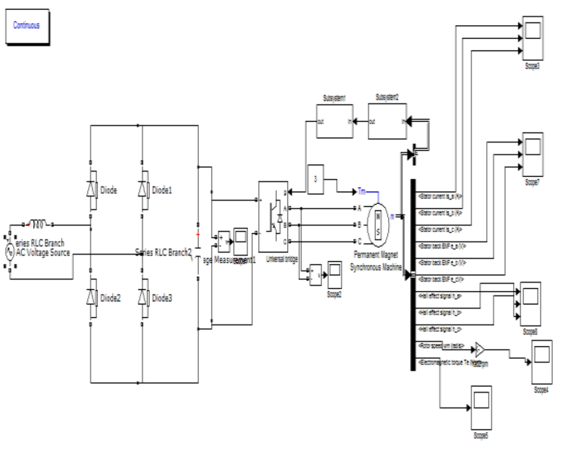

Figure 3 Simulation of BLDC motor using sensors

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International Journal of Advances in Computer and Electronics Engineering
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With the specification provided for the BLDC motor which is shown in the Table I, a power supply is given to the inverter. The simulation of the conventional method with the diode rectifier and PI controller is shown in the Figure 3 and 4. The three phase output of the inverter is applied to the motors stator windings. From the supply, voltage divider is connected, and a zero crossing detector circuit to produce the back EMF for three phases. To drive the BLDC motor, an electronic commutation circuit is required.

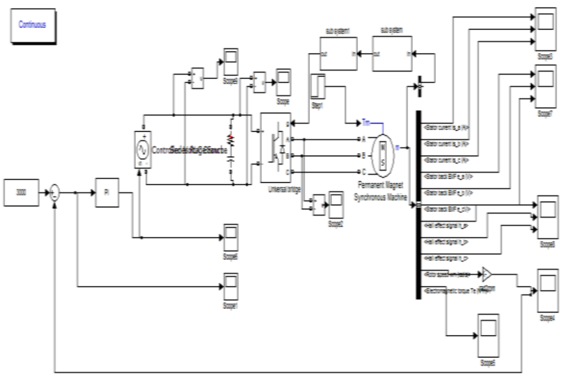

Figure 4 Simulation of BLDC motor with PI controller using sensors

The simulation results of the conventional method are shown with the comparison results of diode rectifier and PI controller. The Stator current waveform with the diode rectifier and PI controller is shown in the Figure 5 and 6. The stator current reads 2.5 A for diode rectifier and hence this tends to increase in case of PI controller which results in 3A as shown in the Figure 6.

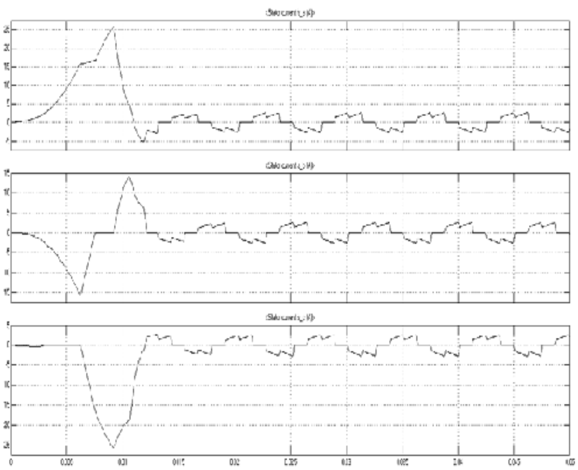

Figure 5 Stator current waveform for diode rectifier

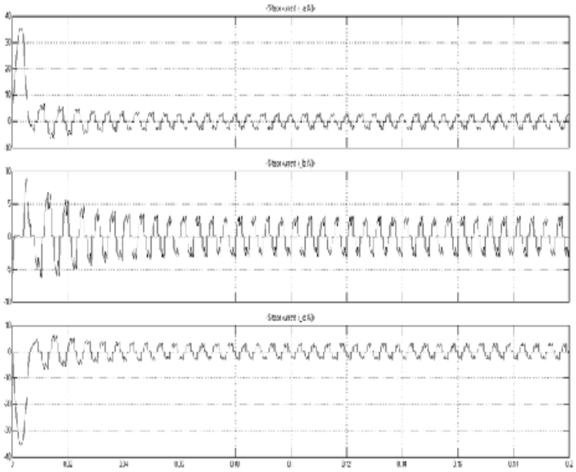

Figure 6 Stator current waveform for PI controller

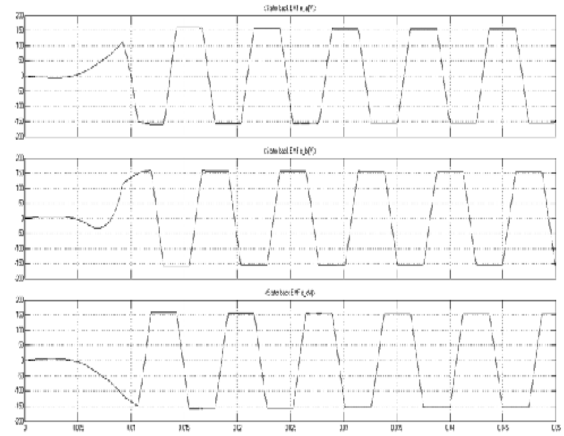

Figure 7 Back EMF for diode rectifier

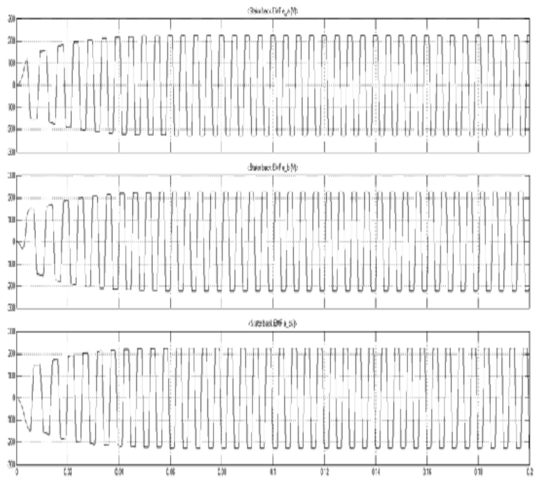

Figure 8 Back EMF waveforms for PI controller

When the voltage is applied to the inverter the BLDC motor starts to rotate. This rotation makes each winding to generate the back EMF which opposes the main voltage supplied to the windings. Hence the polarity of the back EMF will be in opposite direction.

The rotor magnetic field and the number of turns in the winding remains constant when the motor starts

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to rotate. The back EMF is governed by the angular velocity or the speed of the rotor [8]. Hence, when the speed increases the back EMF also increases. The back EMF for the determined speed can be estimated by the motor technical specifications which give a parameter called the back EMF constant.

The back EMF waveform is shown in the Figure 7 and 8 where for diode rectifier the back EMF is 160 V and for PI controller 200 V.

The speed waveform obtained for both the diode rectifier and the PI controller are varied with the variation in the reference speed. The speed waveform is shown in Figure 9 and 10. The speed shown is the reference speed which is set initially in the simulation process. The speed obtained as 2200rpm with the diode rectifier and 3000 rpm with the simulation of PI controller.

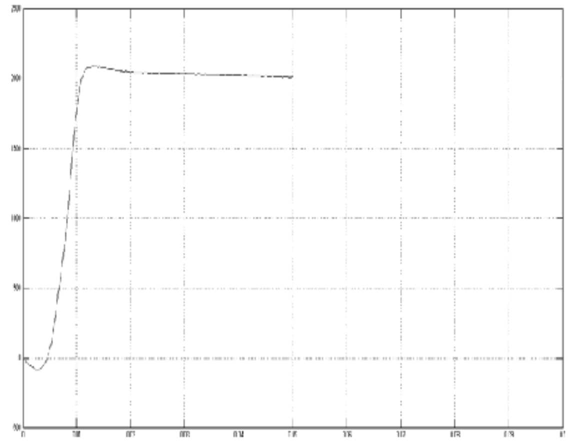

Figure 9 Speed Waveform for diode rectifier

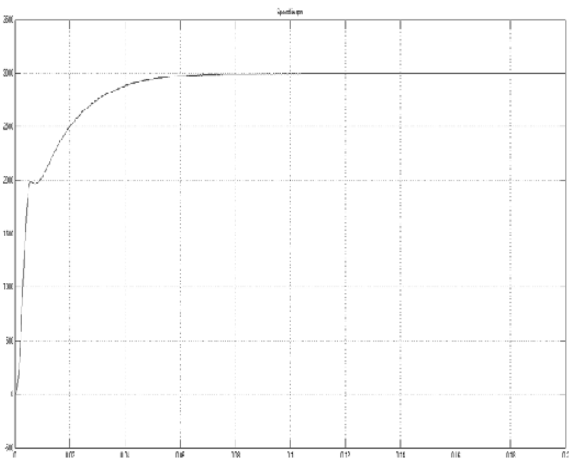

Figure 10 Speed Waveform for PI controller

6.2. Simulation results of proposed method

The simulation has three main blocks. They are BLDC motor, controller block, and inverter block. Each main block has several sub-blocks. The inverter block is the MOSFET and as internal diode in parallel with a series RC snubber circuit. When the signal is applied to the MOSFET, it conducts and acts as a resistance in both directions with the generation of back EMF waveform [2].

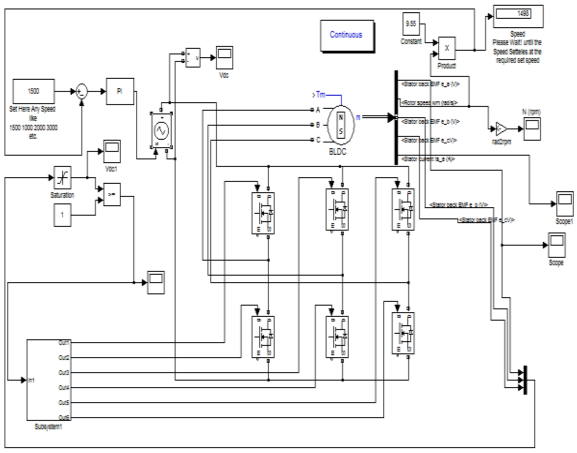

Figure 11 Simulation diagram of sensorless control

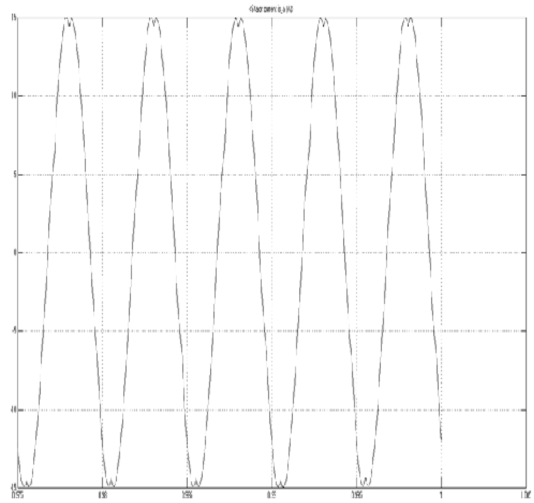

Figure 12 Stator Current waveform of sensorless control

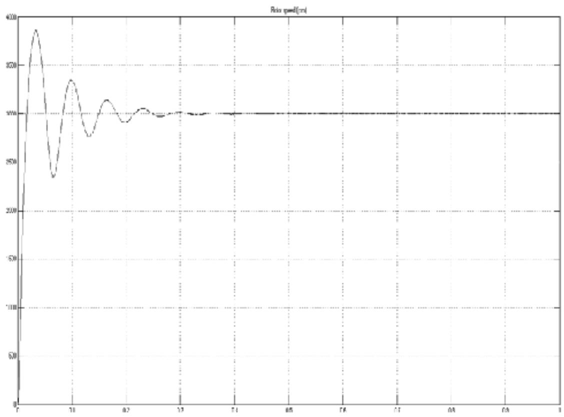

Figure 13 Speed Waveform of sensorless control

The controller block includes voltage control source which converts the input signal derived from the three phase inverter to an equivalent voltage source [7]. The simulation starts with the speed that settles at the required speed for the initialization. The stator back EMF with the bus selector is fed to the subsystem which is used as the control feedback with the back EMF detection. The generation of the signal with the three phase inverter (used as the MOSFET) generates the sensorless BLDC motor with the desired speed and back EMF output waveforms.

The simulation results are shown in the figure which includes the stator current waveform as shown in the Figure 12. This provides the 15 A which shows an increase when compared to the conventional method of PI controller.

The Speed waveform is shown in the Figure 13. This provides the value of 3000 rpm that is set initially during the simulation. This is the reference speed which shows the appropriate response with the simulation as shown in Figure 13.

The back EMF is shown in the Figure 14 which shows the increase in the sensorless control when compared with the conventional method. The back EMF results in 220 V which is clearly shown in the Figure 14.

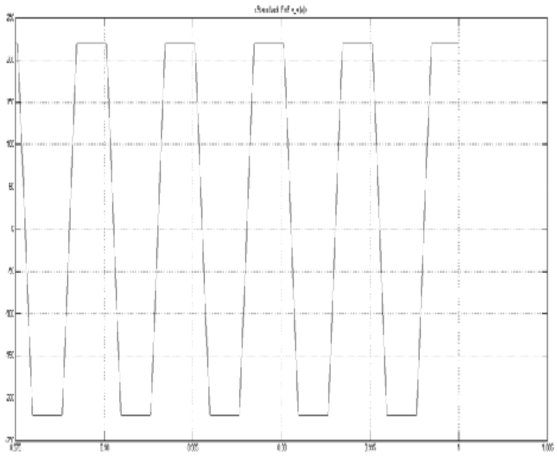

Figure 14 Back EMF waveform

TABLE II COMPARISON TABLE

Parameter	**Comparison**	
	Conventional method	**Sensorless method**
Initial Amplitude	220 V	500 V
Reference Speed	3000 rpm	3000 rpm
Back EMF	200 V	220 V

Finally the simulation results are shown for the conventional and proposed method. Hence the results of both the method are compared for better understanding which is shown in the Table II.

7. CONCLUSION AND FUTURE WORK

BLDC motor is mainly chosen due to its high efficiency, high speed ranges when compared to other motor types and high power density. In this paper BLDC motor with the sensorless control in which the back EMF detection method is used to detect the rotor position. This proposed method is simulated in MATLAB. This simulation results with the diode rectifier and PI controller are shown with the change in parameters in which the demerits of the convolution system is rectified by the sensorless control back EMF method.

The machine parameters can be varied to evaluate the performance characteristics of the BLDC motor. This variation in the parameters provides useful information based on performance and reliability.

The simulation results demonstrate that the simulated waveforms fit theoretical analysis well. Through the modularization design, a lot of time spent on design can be saved and the design efficiency can be promoted rapidly. The second method proposed in this paper provides a novel and effective tool for analyzing and designing the control system of brushless DC motor. The future work of the BLDC motor can be carried out with the artificial neural network which includes the fuzzy logic.

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Cite this paper:

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