Modeling and Performance Analysis of Sensorless Brushless DC Motor Using PWM Control Technique

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Abstract

This paper proposes a new position senseless drive for brushless DC (BLDC) motors. Typical senseless control methods such as the scheme with the back-EMF detection method show high performance only at a high speed range because the magnitude of the back-EMF is dependent upon the rotor speed. This paper presents differentsenseless control method. In the proposed method, a trapezoidal back-EMF is modeled as an unknown input and the proposed unknown input observer estimating a line-to-line back-EMF in real time makes it possible to detect the rotor position. Simulations andresults have beencarried out for the verification of the proposed control scheme.

Keywords: BLDC motor, full speed range, senseless control.pwm.

1. Introduction

Brushless DC (BLDC) motors have the advantage of higher power density than other motors such as induction motors because of having no copper losses on the rotor side and they do not need mechanical commutation mechanisms as compared with DC motors, which results in compact and robust structures. Owing to these features, BLDC motors have become more popular in the applications where efficiency is a critical issue, or There spikes caused by mechanical commutation are not allowed. A BLDC motor requires an inverter and a rotor position sensor to perform commutation process because a permanent magnet synchronous motor does not have brushes and

commutator in DC motors. However, the position sensor presents several disadvantages from the standpoints of drive's cost, machine size, reliability, and noise immunity. As a result, many researches have been reported for senseless drives that can control position, speed, and/or torque without shaft-mounted position sensors [1, 2]. Conventional senseless control methods can be classified into four categories. First, the open phase current sensing method [3] is a technique for detecting the conducting interval of freewheeling diodes connected in antiparallel with power transistors. It has the advantage that the synchronous process is simpleand the control characteristic has high performance atlow speeds. However, rotor position resolutionconspicuously decreases at high speeds. In particular,for realization of this method, it has the defect thatadditional isolated power needs to supply to acomparator for detecting the freewheeling current.Secondly, the method detecting the third harmonic ofback-EMF [4,5] is the technique to remove all thefundamental and other polyphase components througha simple summation of three phase voltages. There isa reduced filtering requirement for the integrationfunction performed on a signal, which has a frequencythree times that of the fundamental signal. Eventually,the filter has a much smaller capacity than the fluxdetection method using back-EMF; it is not sensitiveto filtering delays and achieves high performance overa wide speed range. However, a neutral point that isnot considered in the manufacturing process of themotor is required to measure phase voltages. Also, thethird harmonics detection is difficult at a low speedrange. Thirdly, the back-EMF integrating method [6, 7]is a technique applying the principle that integration isconstant from Zero Crossing Point (ZCP) to 30°.There is the advantage that the operation of the mainprocessor decreases, seeing that it is not necessary tocalculate an additional conversion point of theSwitching mode. This method does not synchronizethe phase current with the back-EMF at the senseless drive. Besides, the flux-weakening drive is impossible. Finally, the open phase voltage sensing method [8-11] is a scheme estimating the rotor position indirectly byusing the ZCP detection of open phase's terminal voltage. It is the most commonly used senseless control method. However, this method has a deteriorated response at transient state and requires high operational speed enough to detect the ZCP of terminal voltages.

2. Modeling of BLDC Motors

The BLDC motor drive block diagram is shown in Figure 1. Assuming that the stator resistances of all the windings are equal, and also self and mutual inductances are constant, the voltage equation of the three phases can be expressed as (1) [18]. In this equation, magnets, stainless steel retaining sleeves with high resistivity, and rotor-induced currents are neglected and no damper windings are model led.

$$\begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix}\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$
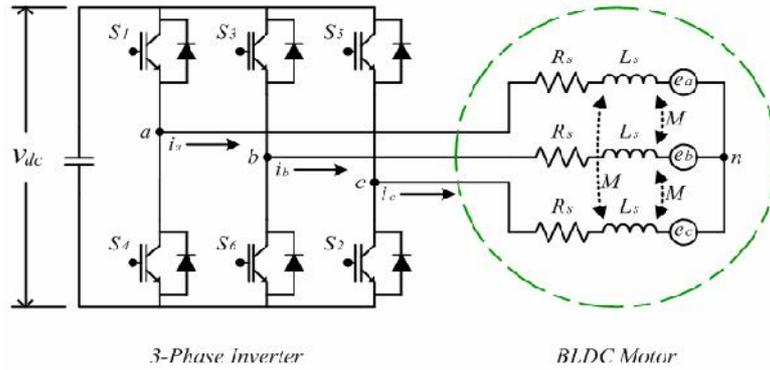
Figure 1: Block diagram of a BLDC motor drive.

The electromagnetic torque is given by:

$$T_e = \frac{(e_a i_a + e_b i_b + e_c i_c)}{w_r} \tag{2}$$

Whereva, vb, and vc are phase voltages. Rs is a stator resistance. ia, ib, and ic are phase currents. Ls is a statorinductance. M is a mutual inductance. Where, hereinafter L represents Ls – M. ea, eb, and ec are phase back-EMFs. ωm is a mechanical angular velocity. Figure 2 shows that the torque ripple can be minimized and the stablecontrol is achieved when the phase current with square wave form is injected into the part where the magnitude of back-EMFs is fixed.
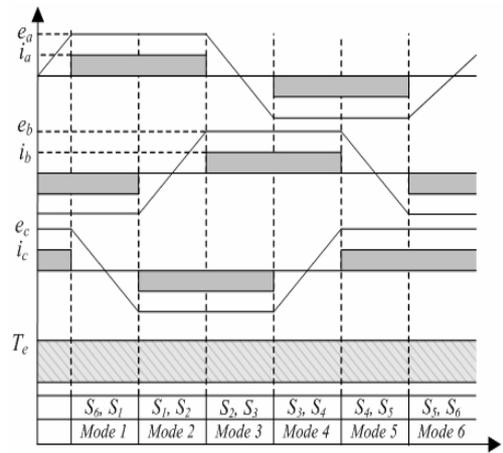
Figure 2: Waveforms of a back-EMF, a phase current and a torque of BLDC motor

3. Proposed Sensorless Control Method

The proposed senseless control method is based on the fact that the rotor position can be detected by using a trapezoidal back-EMF of BLDC motors. Since a back-EMF of the BLDC motor is not measured directly, it is estimated by the unknown input observer. The different senseless control method is given below.

3.1 Commutation function

The senseless control method that decides commutation instances of switching devices by detecting ZCP of back-EMF has been commonly used. However, this method cannot detect ZCP at a lowspeed range. In order to solve this problem, the sensitive commutation function defined by using the line-to-line back-EMF observer is proposed to improve the performance of the senseless control scheme as shown in Figure 4 and the commutation functions (CF) are defined as below:

$$\text{Mode 1 and 4: } CF(\Theta)_1 = \hat{e}_{bc} \backslash \hat{e}_{ca} \quad (3)$$

$$\text{Mode 2 and 5: } CF(\Theta)_2 = \hat{e}_{ab} \backslash \hat{e}_{bc} \quad (4)$$

$$\text{Mode 3 and 6: } CF(\Theta)_3 = \hat{e}_{ca} \backslash \hat{e}_{ab} \quad (5)$$

As shown in Figure 4, the commutation function for the mode conversion from mode 6 to 1 is represented by the fractional equation consisted of the numerator ($\hat{e}_{bc}$) having a constant negative magnitude and the gradually decreasing denominator ($\hat{e}_{ca}$). Before mode change, this commutation function instantaneously changes from negative infinity to positive infinity and this moment is considered as the position signal so that this feature can be certainly distinguished from noises by selecting a relevant threshold magnitude. Although a similar commutation function has been reported [20], the commutation functions of the proposed scheme have the characteristic of less noise sensitive.

Figure s 5 and 6 represent the proposed commutation function and the existing commutation function, respectively. In Figure 5, the lower noise ①than threshold (th) 1 does not affect position detection of the rotor, however, the bigger noise ②than th 1 can be regarded as commutation signal and generate error of a rotor position. Also, in case of commutation function such as ③due to variation of back-EMF, the th voltage level should be increased to achieve the exact commutation signal, as in case the noise ②exists.
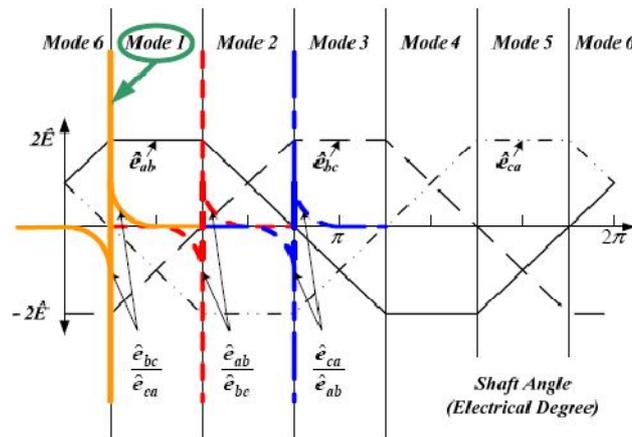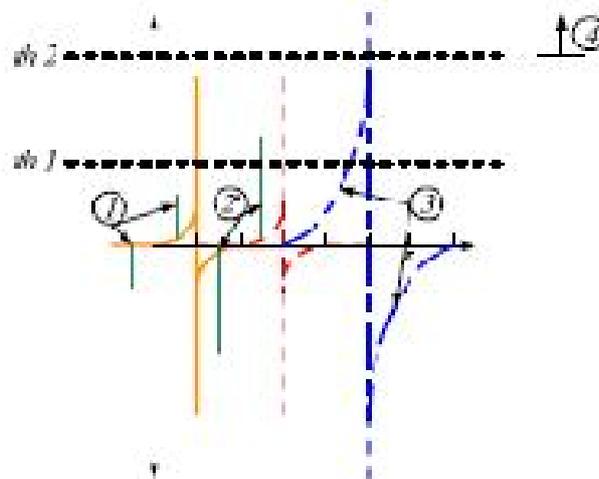

Figure 4: Proposed commutation functions.

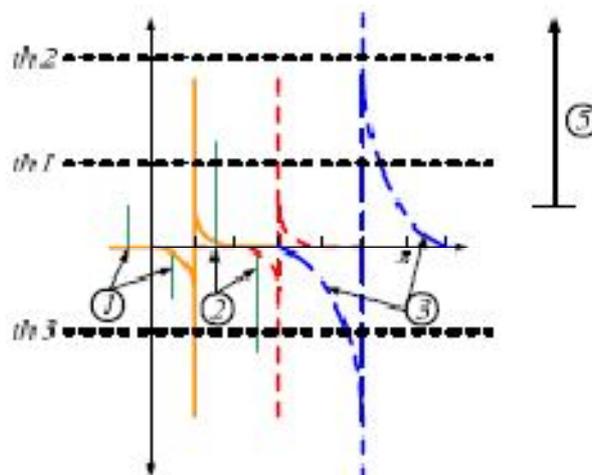**Figure 5**: Commutation function using the existing method.

Figure 6: Commutation function using the proposed method.

On the other hand, as shown in Figure 6, the bigger signal than th 1 or th 3, such as ② and ③, are not regarded as commutation signal in the proposed method since it is generated in the point before negative infinity, namely, the signal after passing negative infinity (th 3) and satisfying the bigger magnitude than th 1 is regarded as the commutation signal. Finally, the existed method is sensitive to the noise, and the calculation of commutation point can be delayed because it should select the bigger voltage level th than th 2 (④). But the proposed method can generate the exact position information in the lower th voltage level as ⑤.

3.3. The estimation of speed and position

If the estimated magnitude of a back-EMF is defined, the rotor position and the speed can be calculated by simple arithmetic. The relationship between the speed and the magnitude of a back-EMF in BLDC motors is:

$$E = K_e w_e \qquad (6)$$

Where E is a back-EMF magnitude, K_e is a back-EMF constant, and ω_e is an electrical angular velocity.

As shown in Figure 7, the magnitude of the back-EMF is estimated by the maximum magnitude of the lineto-line back-EMF that the unknown input observer offers. Therefore, the speed can be calculated by using the estimated magnitude of the back-EMF as follows:

$$We = E \backslash Ke \qquad (7)$$

3.4. Starting procedure

It is necessary to have the process start up in senseless control because it has difficulty detecting the rotor position at standstill. The simple 'align and go' scheme [3], which is a widely used method in commercialized BLDC senseless controller, has been adopted for the starting procedure for the proposed scheme. In this method, the controller aligns the rotor with a predetermined position by conducting two phases of a motor before rotations, and then rotates the rotor according to a given switching sequence with incensement of the rotor speed. In conventional senseless methods such as detecting the ZCP of terminal voltages, the closed loop control starts from a relatively high speed, since they need a high speed enough to achieve a certain level of voltage signals. On the contrary, the proposed method can determine the motor position within a 60° motor

Revolution. Since the proposed method detects the commutation instance by using commutation functions, which are based on estimated line-to-line back-EMFs with 60° resolution and shown in (13-15). After detecting the first commutation point, torque and speed are controlled with a senseless algorithm with the estimated speed calculated by the time interval of commutation points.

3.5. The overall black diagram of the proposed sensorless scheme

Figure 8 illustrates the overall structure of the proposed sensorless drive system. The line-to-line voltage is calculated based on the DC-link voltage and switching status of the inverter. As described above, the back-EMF observer provides the estimated line-to-line back-EMF (12). The commutation function (13-15), the speed (18), and the rotor position (19) are calculated from the estimated line-to-line back-EMFs. The commutation signal generation block generates commutation signals based on the calculated rotor position and the commutation function. Each phase current is controlled by the hystersis current controller using the commutation signals.
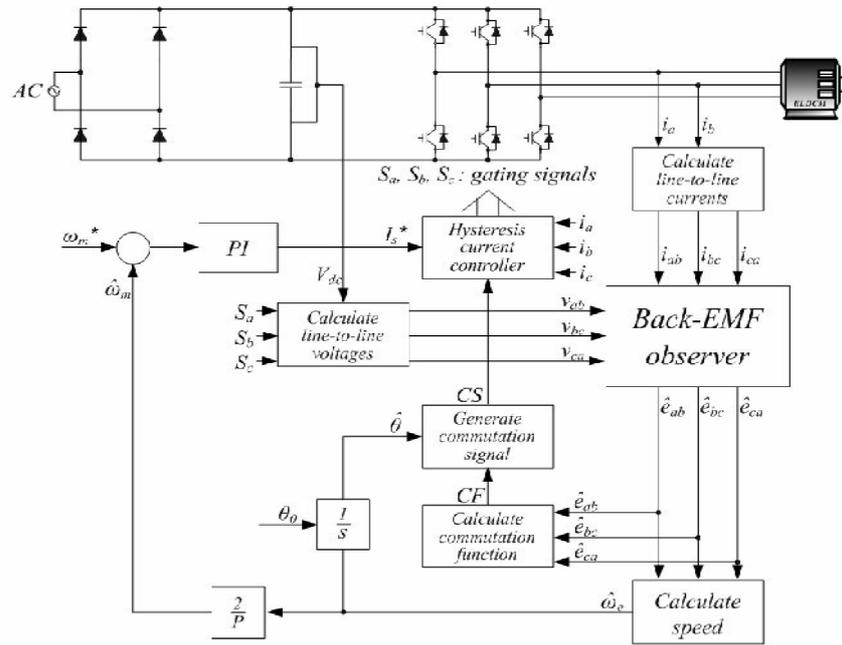
Figure 8: Overall structure of the proposed sensorlessdrive system.

4. Simulation

Simulations have been performed on the BLDCmotor that has the ratings and parameters as shown in Table 1. The Matlab/Simulink environment was usedfor the simulations.
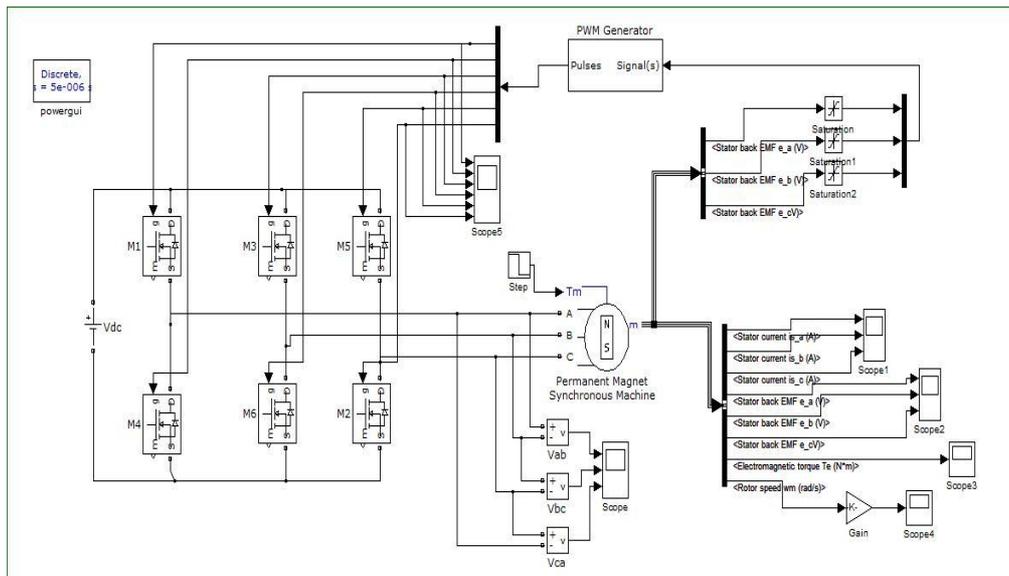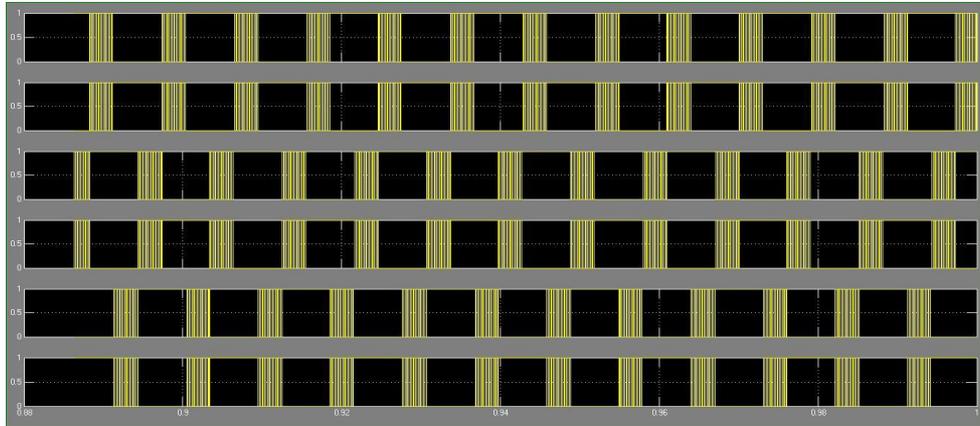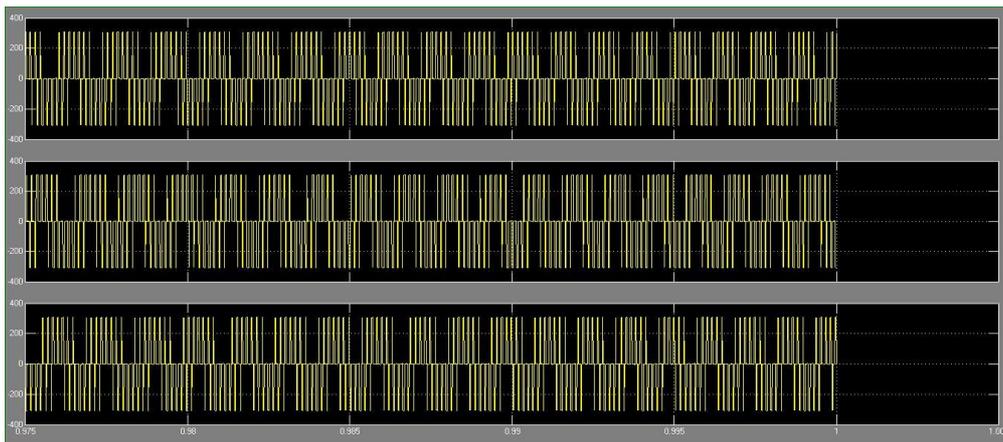

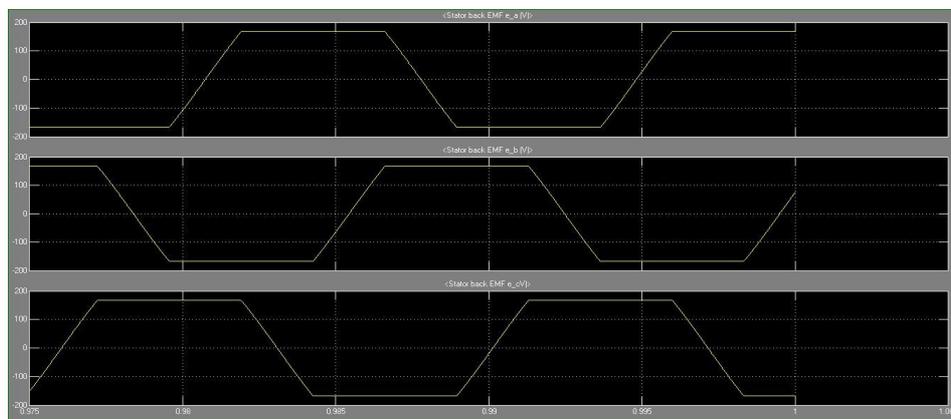**Figure 9**: Simulation of BLDC in sensorless mode of operation.

5. Simulation results

Figure 10: Commutation signal of pwm generator.

Figure 11: stator voltage (Vab Vbc Vca).

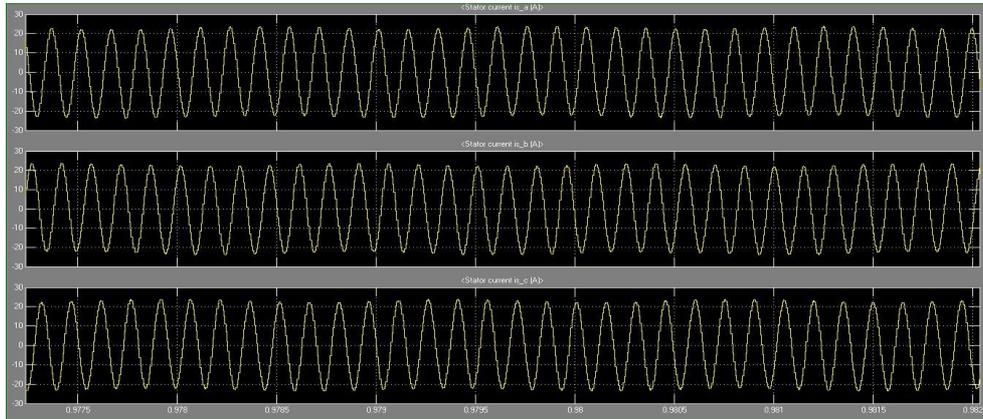

Figure 12: Back EMF (Ea Eb Ec).

Figure 13: Stator phase current (ia ib ic).
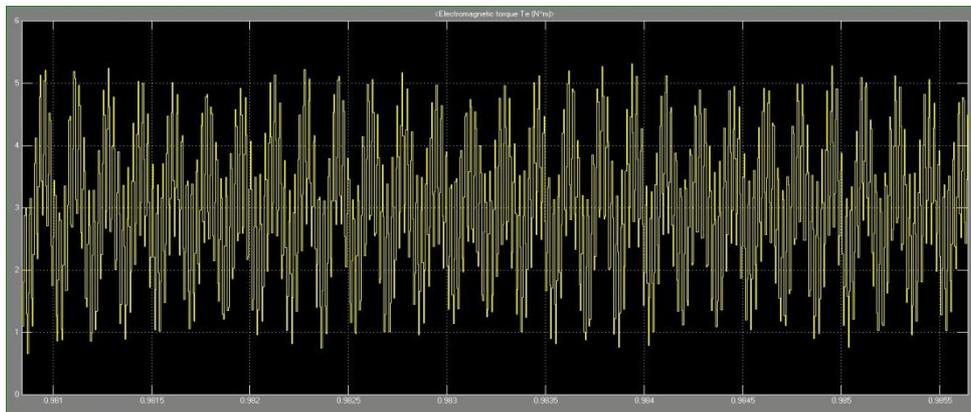

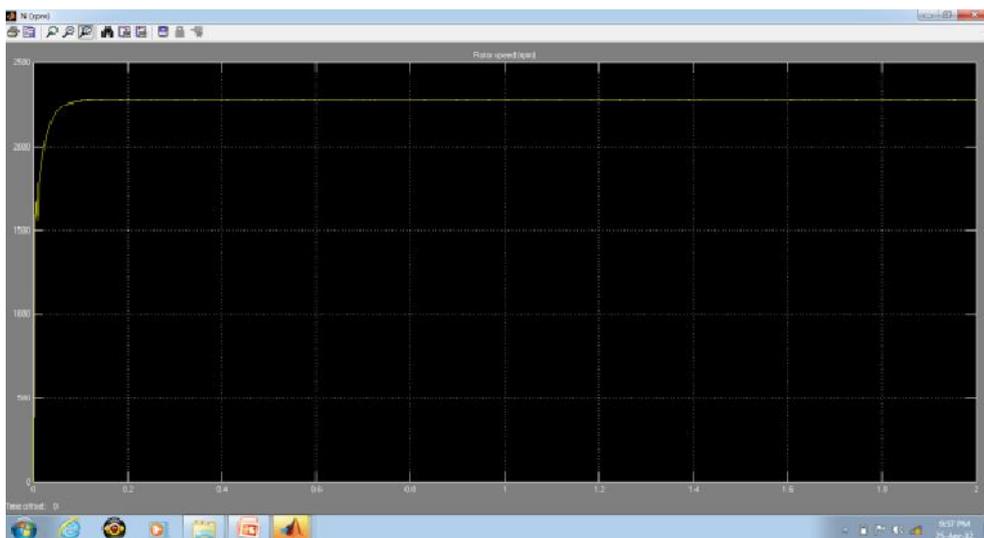**Figure 14**: Electromagnetic torque (Te).

Figure 15: Rotor speed.

Conclusion

This shows the speed control of position sensorless brushless DC motor. The rotor position is determined by the state of back- EMF. The circuit has been constructed and simulated using Matlab-Simulink and desired results were obtained.

Figure in 13 shows the Stator current, Figure in12 showthe back EMF generated, Figure in 15 shows Speed of the motor, Figure in 14 shows the Electromagnetic Torque of the motor. These were the results analyzed using simulation

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