Speed Control of Brushless DC motor using Third Harmonic Back EMF

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Abstract : In the recent past years, power electronics have been the area of interest of many researchers. In this particular area, a lot of work is going on Brushless DC (BLDC) motors which are quite popular due to their different advantages over the conventional dc motors. It is due to this reason that they are being used in many applications. This paper presents the sensorless speed control of PMBLDC using Third harmonic back EMF sensing technique. The simulation has been done using MATLAB/SIMULINK platform. The simulation results compare the performance of motor with Fuzzy Logic Controller (FLC) and PI controller.

***Index Terms* – BLDC motor, FLC, Third Harmonic, PI Controller**

I. INTRODUCTION

The Brushless DC (BLDC) motor has become very popular in the last two decades due to the several advantages which it offers. Some of the advantages over the conventional dc motors are improved speed torque characteristic, better efficiency, higher speed ranges, noiseless operation. Due to all these advantages it is being widely used in the various domestic and industrial applications [1] - [3]. Also, there has been a growing interest in the various research areas related to BLDC motors. Permanent magnet motors are classified into Permanent Magnet Synchronous Motors and Permanent Magnet Brushless dc or simply Brushless DC (BLDC) motors .The former class of motors have the sinusoidal back EMF whereas the latter have the trapezoidal back EMF. In contrast to the brushed DC motors, the commutation of a BLDC motor is electronically controlled. In order to know the rotor position accurately, hall effect sensors are used which are placed in the stator. These sensors sense the rotor position and give output to generate the signals for the converters.

However, there are certain disadvantages associated with these Hall sensors such as cost, reliability etc. Due to these demerits the researchers are working hard on the sensorless methods of speed control of BLDC motors. Sensorless techniques eliminates the drawbacks associated with the methods which makes use of sensors. There are various different techniques of the sensorless control which exist in literature. Some of these techniques are zero crossing back EMF technique [4], method based on flux linkage estimation [5], third harmonic back EMF sensing using zigzag transformer [6]. In [7] a hybrid drive combining PWM and PAM is introduced and a new sensorless control method based on the virtual neutral voltage has been proposed. Tashakori and Ektesabi [8] proposed a new sensorless drive for BLDC motor. They have implemented a digital PWM technique with a PI duty cycle controller. In [9], a novel microcontroller based sensorless system is proposed which is based on extracting the back EMF signal without sensing the neutral point of the motor. This method has been applied for automotive fuel pump systems. Kim and Ehsani [10] have proposed a sensorless technique for the operation of BLDC motors from near-zero to high speed by defining a new flux linkage function which is speed independent. Their method does not require the measurement of back EMF. Ogasawara and Akagi [11] have proposed a sensorless drive which is based on detecting the conducting the free-wheeling diode. This method works well for detecting the rotor speed for a wide range of speed. In [12] a Fuzzy Logic Controller is used for speed control of PMBLDC motor.

In sensorless mode of operation Hall sensors which are used to detect the position of rotor are not employed and some sensorless technique is employed to run motor. A PMBLDC motor is fed with a three-phase inverter whose switching depends upon accurate detection of commutation instants of current. In this paper a Third Harmonic Back EMF technique is proposed to detect the actual commutation instant of phase current. The advantage of this scheme over other scheme such as Indirect Back EMF Detection using line voltage difference method is that this scheme accurately determines the exact commutation instant which is not possible in other Indirect Back-Emf sensing methods, where only approximate estimation of Zero Crossing Point (ZCP) is possible and a delay circuit is designed to detect the exact commutation instants.. The proposed method is applicable when the motor is running at low speeds.

In this paper, the use of Fuzzy Logic Controller (FLC) and a PI controller has been made to compare their relative performance. The design of a controller by classical methods becomes troublesome if the structure of the plant is not known or quiet complex. Fuzzy Logic Controllers offers advantages in these situations since plant structure need not to be known if we are using FLC. One more advantage by using the FLC is the significant reduction of the required time for controller design. However, the rule base for FLC and its tuning plays a crucial role in performance improvement of the system.

The paper is organized as follows. Section I gives the background of PMBLDC motor, various problems associated with control using sensors, merits of sensorless control. Section II describes the System Configuration of BLDC drive motor. Section III describes the third Harmonic back EMF detection technique for sensorless operation of motor Section IV describes the design of Fuzzy Logic based Speed Controller. In Section V Simulation Results are shown and in Section VI Conclusion is discussed.

II. SYSTEM CONFIGURATION

BLDC motor consists of a three-phase star connected stator and a permanent magnet rotor. A three-phase inverter (operating in 120^0 mode) is used for supplying the stator. At any particular time two-phase conduct while the third phase is floating. The triggering of switches are made by utilizing the exact rotor position. In our case, sensorless technique is used for detecting the rotor position which is based on knowing the ZCP's of back EMF from the difference of line voltage. Either a PI controller or a FLC can be used as a speed controller. There is a outer speed controller and inner current controller in the control loop. Fig. 1 shows the overall configuration for speed control of motor. Table 1 gives details of PMBLDC motor specifications.

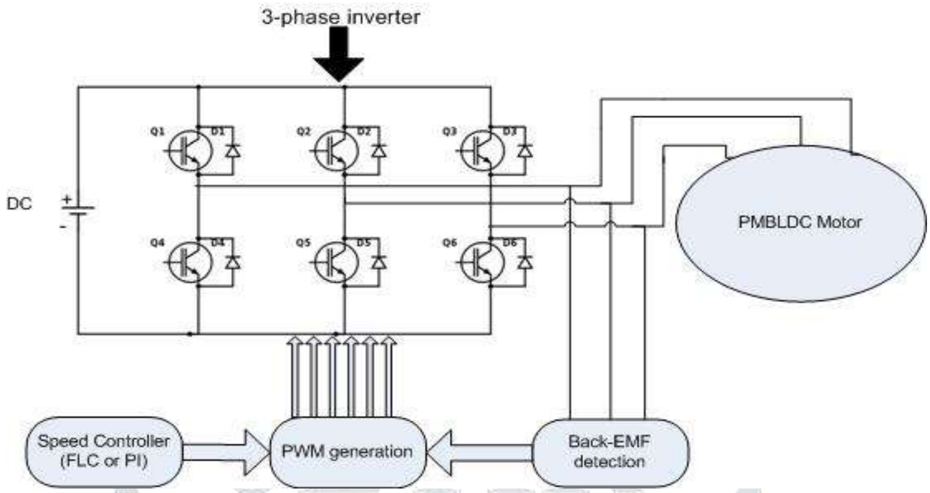


Fig. 1: VSI fed PMBLDC motor with back EMF detection

Table 1: The PMBLDC motor specifications

Parameters	Value	Units
No. of Phases	3	-
Torque constant	0.042	N-m/A
Poles	4	-
Back-EMF-constant	0.42	V/rad/s
Resistance per phase (R)	2.90	Ohm
Inductance per phase (L)	2.80	mH
Viscous Damping (B)	0.00009	N-m/(rad/s)
Rotor Inertia (J)	0.0005	Kg-m^2
DC link voltage	300	V

III. THIRD HARMONIC BACK-EMF SENSING USING ARTIFICIAL NEUTRAL

The basic principle behind third harmonic back EMF sensing technique is that if the three phase voltages of stator in a star connected trapezoidal air gap flux PMBLDC motor are added, then only the terms containing third harmonic components and its multiples are present whereas the fundamental and the remaining higher order harmonics are removed. The rotor flux position and the commutation instants are estimated using these third harmonic components and eventually the suitable switching instants for the inverter are obtained. Although this technique works satisfactorily over a wide range of speed but the only problem is that the motor neutral should be accessible. Mostly it is difficult to access the neutral and therefore in such cases, a virtual neutral is required to be created for the detection of third harmonic.

The stator voltage equation for phase 'a' for a three phase motor is given by

$$V_{as} = Ri_{as} + (L-M)\frac{d}{dt}i_{as} + E_{as} \ldots\ldots\ldots\ldots (1)$$

The internal back EMF of BLDC motor has triplen harmonics other than fundamental as given by equation 2.

$$E_{as} = E_m(\cos\omega_e t + 3n\cos 3\omega_e t + 5n\cos 5\omega_e t + \ldots\ldots) \ldots\ldots (2)$$

The third harmonic back EMF voltage v_{ns} can be obtained by creating a virtual neutral 'n' with the help of a resistor bank as shown in Figure 2. The voltage v_{ns} between motor neutral 's' and artificial neutral 'n' contains triplen harmonics and its multiples as given by equation 3.

$$v_{ns} = (E_{as} + E_{bs} + E_{cs})/3 = (e_3 + e_9 + e_{15} + \ldots\ldots) \ldots\ldots\ldots (3)$$

where e_3, e_9 and e_{15} are the magnitudes of third, ninth and fifteenth harmonic voltages.
For determining the appropriate commutation instants, we need to process only third harmonic voltages. Other triplen harmonics should be eliminated by using a low pass filter or a band pass filter. The third harmonic back EMF voltage v_{ns} has a frequency three times that of fundamental and integration of this third harmonic back emf voltage as given by equation 4 gives exact commutation instants of current as shown in Figure 3. The determination of these commutation instants are utilized for generating switching signals for the inverter. Figure 2 shows the control circuit used in this method.

$$\lambda_3 = \int v_3 dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

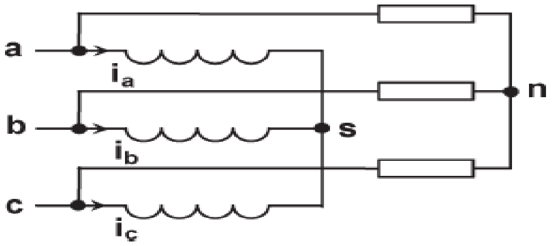


Fig.2 Control circuit for third harmonic Back EMF Sensing (virtual neutral n)

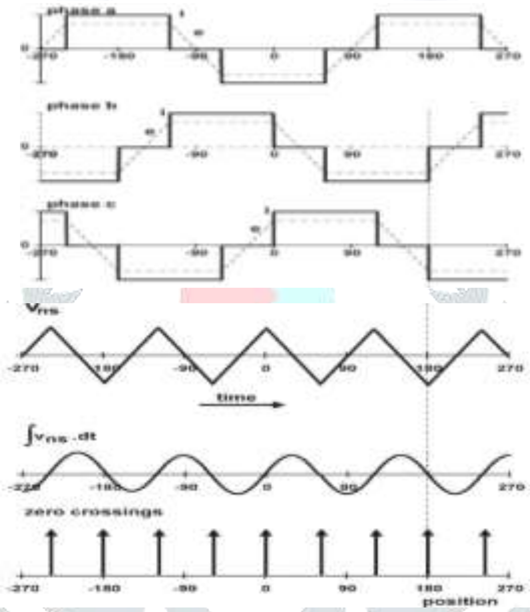
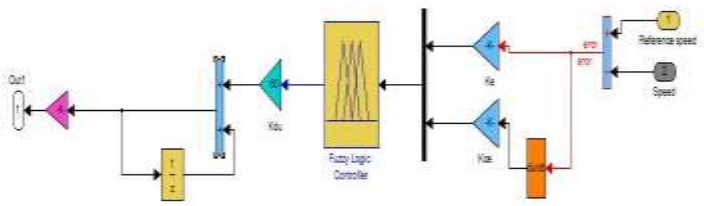


Fig. 3 Derivation of current commutation signals from third harmonic of motional EMF in a trapezoidal BLDC motor

IV. IMPLEMENTATION OF FUZZY LOGIC BASED SPEED CONTROLLER

As shown in Figure 4, to design a FLC, we need two inputs namely error (**e**), change in error (**Δe**) and an output (**Δz**) where e and Δe are determined by comparing motor speed with set point speed or desired speed. Five linguistic variables are used to derive fuzzy rules for FLC. These fuzzy rules are used for building fuzzy inference system as shown in Table 2. Three scaling factors K_e, K_{ce} and K_{du} are used for tuning FLC. These scaling factors cannot be changed every time once membership functions and rule base is defined. Hence we have to tune these scaling factors to get the optimal response. The FLC chosen has 25(5x5) Fuzzy rule base system. A larger rule base system can also be chosen but studies have shown that a larger rule base system does not necessarily improves the performance. Fig. 5 and 6 gives the membership functions of input and output variables.



. Fig.4 Fuzzy Logic based speed controller

Table 2: Rule table for Fuzzy inference system

Δe / e	NB	NS	Z	PS	PB
NB	NVB	NB	NM	NS	Z
NS	NB	NM	NS	Z	PS
Z	NM	NS	Z	PS	PM
PS	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PVB

Meaning of variables: NVB= Negative very big, NB= Negative Big, Z= Zero, PS= Positive Small, PB= Positive Big. PS = Positive Small, PB= Positive Big, PVB= Positive very big.

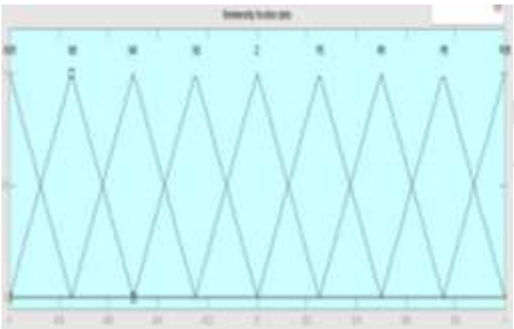


Fig. 5: Membership function for output vaiable Δz

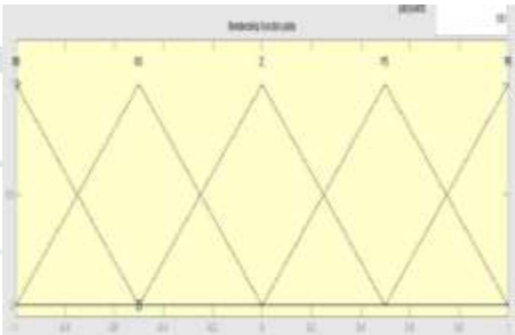


Fig.6 Membership function for input variable e and Δe

V. SIMULATION RESULTS AND DISCUSSION

This section describes the various simulation results obtained such as motor speed, phase current and back EMF along with Hall signals when motor is running in sensorless mode. The determination of the exact instant of shifting to sensorless mode from the sensor control is a problematic task. This is done by first exciting two phases out of three for a fixed period. At the end of this period motor have moved from an unknown position to a predetermined position. The motor performance is simulated using third harmonic voltage detection technique, because of oscillating neutral this technique is difficult to implement when compared with other sensorless techniques such as line voltage difference method which does not employ neutral in estimation of commutation instants. Fig. 7 shows the third harmonic voltage v_{ns}. Fig. 8 shows integrated third harmonic voltage which shall give exact commutation instants for switching of the inverter.

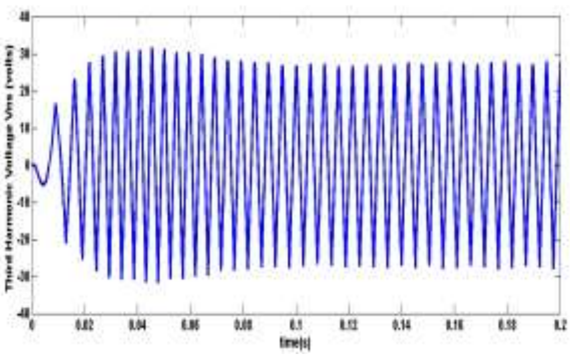


Fig.7 Third harmonic voltage v_{ns}

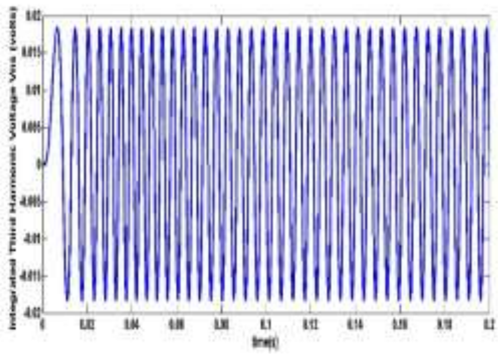


Fig.8 Integrated Third harmonic voltage v_{ns}

Figure 9 shows that integration of third harmonic voltage v_{ns} gives exact commutation instants for generation of virtual Hall signals. The commutation point of current of phase a exactly coincides with the zero crossing point of integrated third harmonic voltage v_{ns}. Fig. 10 and 11 shows the real hall signal and virtual hall signals respectively. It can be clearly seen from above that both these signals matches with each other which means that the motor operates satisfactorily in sensorless mode.

The performance of motor with PI controller in sensorless mode is also shown in this section. Fig.12 shows the speed response of the motor with PI Controller. Load torque of 1 Nm is applied at t=0.2s. It can be seen that speed is reduced to 194 rad/s from set point speed of 200 rad/s at t=0.2s.

Although the motor speed again reaches the original speed but after a significant delay of 0.3 seconds. Fig. 13 and Fig. 14 shows the speed response of the motor with FLC. Same amount of load torque i.e 1Nm is applied at t=0.2 second. The speed response clearly shows that there is a negligible reduction in speed of the motor on the application of the load torque at t=0.2 second which helps us to understand that a properly tuned FLC performs better than a PI controller. We had seen earlier that for the same amount of load torque, a PI controller took more time to get back to the same reference speed. The speed response of motor using FLC in case of a sudden change in reference speed is from 200 rad/s to 300 rad/s is shown in Fig. 15.

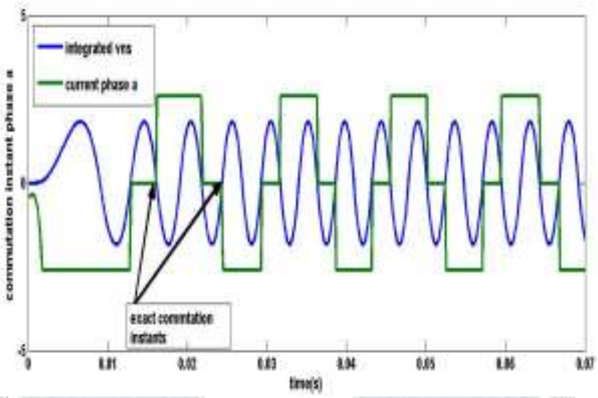


Fig.9 Exact commutation instants determined by third harmonic voltage, phase a

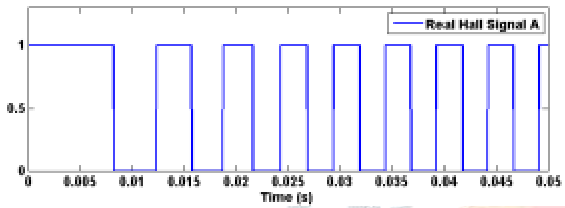


Fig.10 Real Hall Signal

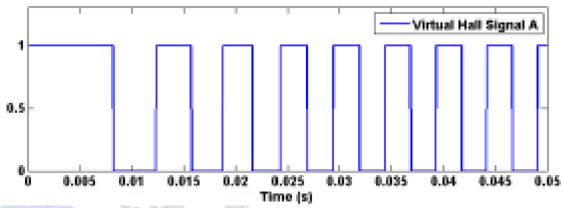


Fig.11 Virtual Hall Signal

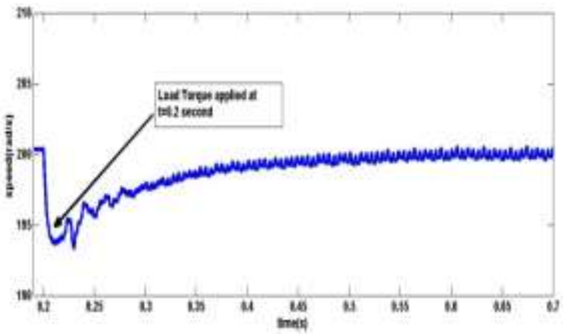


Fig.12: Delay in tracking set point speed with PI controller

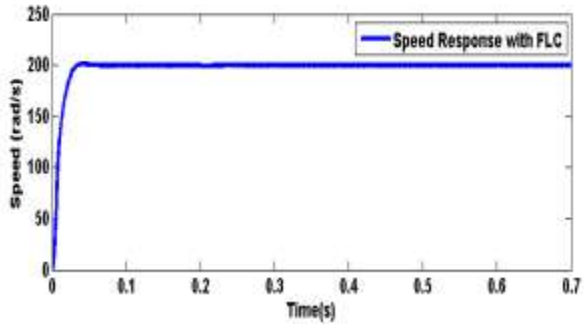
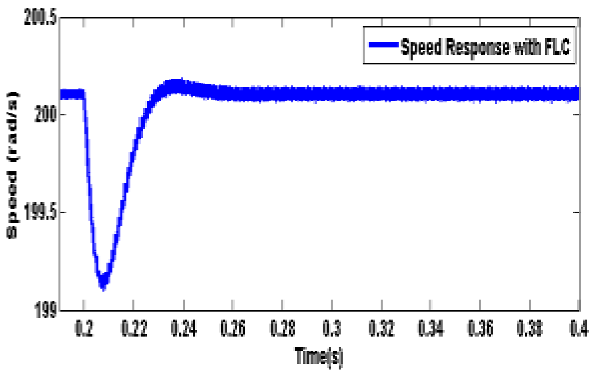


Fig. 13: Speed response with FLC (Tl=1Nm)



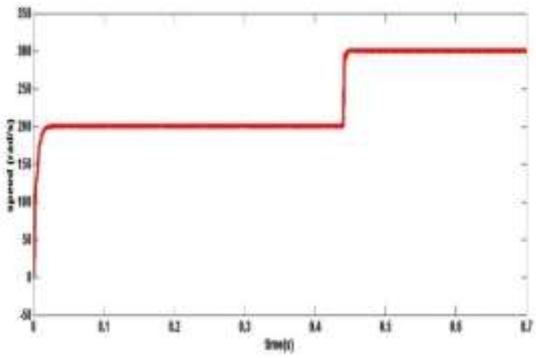


Fig. 14: Speed response with FLC (T_l=1Nm) Fig. 15: Set point speed increased from 200 rad/s to 300 rad/s with FLC.

The trapezoidal waveform of back EMF current of phase a is shown in Fig. 16 and 17 respectively. Fig. 18 and Fig.19 shows the waveforms of rotor position of motor in radians and electromagnetic torque developed.

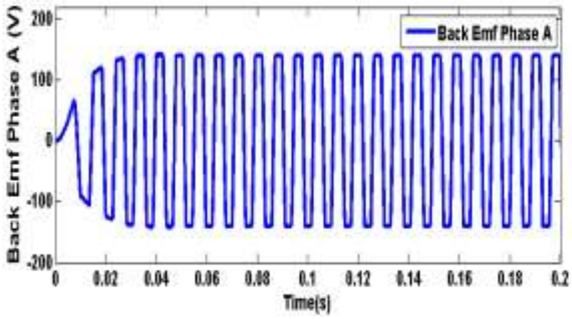


Fig 16: Back EMF phase a

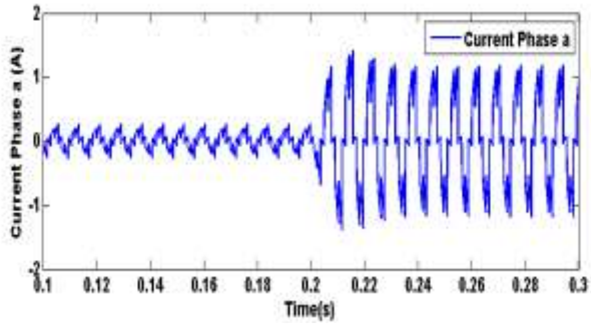


Fig. 17: Current of phase a

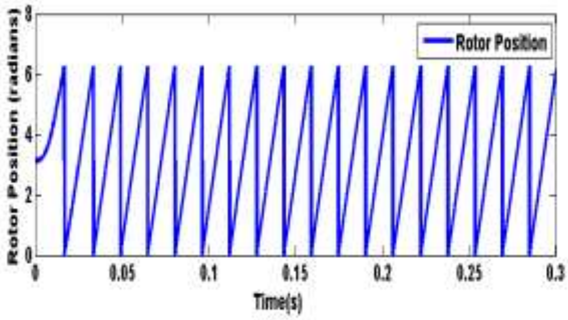


Fig.18 Rotor position in radians

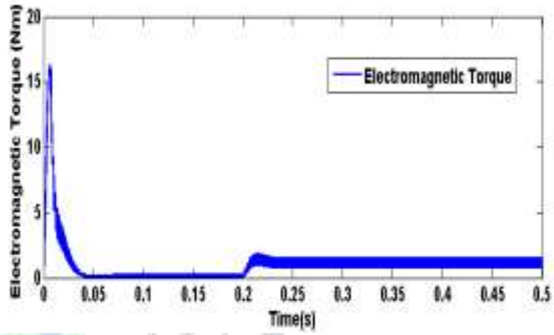


Fig. 19: Electromagnetic Torque developed

VI. CONCLUSION

The sensorless operation of the PMBLDC motor i.e. without hall sensors is considered. The speed is controlled by using both FLC and PI controller. A MATLAB/Simulink model of the motor has been developed and various results such as back emf, rotor position, phase currents have been shown. The use of FLC has reduced the rise time and settling time of the speed response of the motor. Hence a tuned Fuzzy controller performs better than a conventional PI controller. In sensorless control using voltage difference estimation method filter characteristics plays an important role in determining the exact zero commutation instants, each time when speed transition takes place filter characteristics need changes because previous zero crossing instant changes and at new set point speed they will not correspond to exact commutation instants. In third harmonic voltage-based technique which is used in this paper there is minimal requirement of filtering if integral of v_{ns} is used in detecting the commutating instants. This technique allows us to detect the signal at low speeds because the frequency of third harmonic signal is three times higher than the fundamental EMF, resulting in a wider speed range operation. However, the main advantage of using Hall sensors is that motor design remains simple, and no extra circuitry is needed.

REFERENCES

[1] Tae-Won Chun , Quang-Vinh Tran , Hong-Hee Lee , Heung-Geun Kim, "Sensorless Control of BLDC Motor Drive for an Automotive Fuel Pump Using a Hysteresis Comparator" , IEEE Transactions on Power Electronics Volume: 29, Issue: 3, pp 1382 - 1391 ,March 2014.

[2] Anand Sathyan , Mahesh Krishnamurthy, Nikola Milivojevic , Ali Emadi , "A low-cost digital control scheme for Brushless DC motor drives in domestic applications" , IEEE International Conference on Electric Machines and Drives, 3-6 May 2009.

[3] A. Sundaram , Dr. G.P. Ramesh, "Sensor less Control of BLDC Motor using Fuzzy logic controller for Solar power Generation", International Journal of MC Square Scientific Research Vol.9, No.2 , 2017.

[4] R.M. Pindoriya, A.K. Mishra, B.S. Rajpurohie and R. Kumar, "Analysis of Position and Speed Control of Sensorless BLDC Motor using Zero Crossing Back-EMF Technique," IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES-2016).

[5] Alireza Siadatan, Elnaz Yasoubi, Sam Ghasemi, Majid Hojjat, "Design and Simulation of new method of a sensorless control of BLDC motor by using of speed and rotor position method" , International Symposium on Power Electronics, Electrical Drives, Automation and Motion, 2016.
[6] Aakanksha Girolkar and G. Bhuvaneswari, "Control of PMBLDC Motor Using Third harmonic back emf sensing with zigzag transformer", IEEE 2nd International Conference on Electrical Energy Systems (ICEES), 2014.
[7] Chenium Cui, Gang Liu, Kun Wang and Xinda Song Sensorless, "Drive for High-Speed Brushless DC Motor Based on the Virtual Neutral Voltage", IEEE Transactions on Power Electronics (in press).
[8] A. Tashakori, M. Ektesabi , "Stability analysis of sensorless BLDC motor drive using digital PWM technique for electric vehicles", IECON 2012.
[9] J. Shao, D. Nolan. Teissier, and D. Swanson, "A novel microcontroller based sensorless brushless DC (BLDC) motor drive for automotive fuel pumps," IEEE Trans. Ind. Appl., vol. 39, no. 6, pp. 1734–1740, Nov./Dec. 2003.
[10] T.-H. Kim and M. Ehsani, "Sensorless control of BLDC motors from near-zero to high speeds," IEEE Trans. Power Electron., vol. 19, no. 6, pp. 1635–1645, Nov. 2004.
[11] S. Ogasawara and H. Akagi, "An approach to position sensorless drive for brushless DC motors", IEEE Trans. Ind. Appl., vol. 27, no. 5, pp. 928–933, Sep./Oct. 1991.
[12] Mohammad Zaid, Zeeshan Sarwer, Farhan Ahmad, Mukul Pandey, "Speed Control of PMBLDC motor using Fuzzy Logic Controller in Sensorless Mode with Back-EMF Detection", Applications of Artificial Intelligence Techniques in Engineering. Advances in Intelligent Systems and Computing, vol 698, pp 439-447, Springer, Singapore.