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Sensorless Speed Control of B-4 Inverter Fed Three Phase BLDC Motor using Fuzzy Logic Controller

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***Abstract*—Brushless DC motors have gained popularity in electric drives applications such as industrial automotive equipment's, instrumentations, aerospace etc due to its higher efficiency, greater reliability, good dynamic response and very low maintenance. This paper presents speed control of four switch three phase inverter fed BLDC with fuzzy logic implementation. Cost saving is achieved by reducing the number of components in the inverter circuit by implementing four switch topologies.The sensorless techniques based on the back EMF difference estimation method is suggested. The design analysis and simulation of the proposed system is done using MATLAB/SIMULINK software. Also, simulation results of sensor drive using PI controller and sensorless drive using fuzzy logic controller are analysed.**

***Index Terms*— Brushless dc moto; Hall sensor drive; PI controller; Back EMF sensorless drive; Fuzzy logic controller.**

I. INTRODUCTION

Brushless dc (BLDC) motors have been used for small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the control complexity of variable speed controls and the high cost of the electric drive is the limitations of the widespread use of brushless dc motor in industries. Over the last decade, microprocessors/logic ICs, adjustable speed drivers (ASDs) control schemes and permanent magnet brushless electric motor production have combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. Household appliances are expected to be one of fastest-growing end-product market for electronic motor drivers (EMDs) over the next five years.

A standard three phase voltage source inverter consists of six switches to three legs called Six Switch Three Phase Inverter (SSTPI). A reduced switch count is designed for voltage source inverter consists of four switches i.e. Four Switch Three Phase Inverter (FSTPI) uses only three legs, with four switches and two capacitors is employed.

In BLDC motor mechanical position sensor is used to detect the rotor position, but today cost of mechanical rotor position sensor is expensive than low power rating BLDC motor. Low power rating BLDC motors are gaining huge popularity in home appliances, hospital instruments, office equipment's, and in industrial machines. Usually these applications have very small investment. In such case in order to decrease the cost of the total system, mechanical sensor is avoided, and to detect the rotor position, instead of mechanical sensors, electronic sensor is used and thus the operating cost decreases. Some drawbacks of mechanical sensors are:

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they are affected at high operating temperature and harsh environment and complex problems involving motor assemblers in production, and wiring between a sensor board and a drive circuit. Therefore, overall drive system size will be increased.
In this paper, sensorless control of BLDC motor using an indirect Back EMF zero crossing detection is included. Here information about the rotor position is obtained from the line voltage difference of the stator coil rather than from the mechanical position sensor. The back EMF signal is directly related to the speed of the motor. Some of the advantages obtained by avoiding this mechanical sensor in control system of BLDC motor are: Lighter in weight, Compactness in size, Reduction in overall cost, Reliable during operating condition.
This paper develops to remove the drawbacks associated with sensor control, reduced number of switches and use of traditional controllers by using zero crossing point (ZCP) of Back electromotive force (Back-EMF).Also, sensorless control is implemented with fuzzy logic controller. The sensorless control requires good reliability and various speed ranges with the high starting torque for BLDC motor drive system. To satisfy these requirements, this paper proposes an efficient sensorless speed control to avoid high energy prices.

II. Four Switch Inverter Fed Three Phase BLDC Motor

A BLDC motor needs quasi-square current waveforms, which are synchronized with the back EMFs to generate constant output torque and have 120 degree conduction and 60 degree non-conducting regions. Also, at every instant only two phases are conducting and the other phase remains inactive. Compared with the conventional six-switch three-phase inverter for the BLDC motor, the whole working process of the four switch inverter fed three phase BLDC motor is divided into six modes. Phase c involves four modes, including modes 2, 3, 5, and 6. Only one switch should work in the four modes. These modes are divided into two sub operating modes. In modes 1 and 4, phases a and b have current owing through them, and I_c should be zero. Figure 1 shows four switch three phase inverter fed BLDC motor.

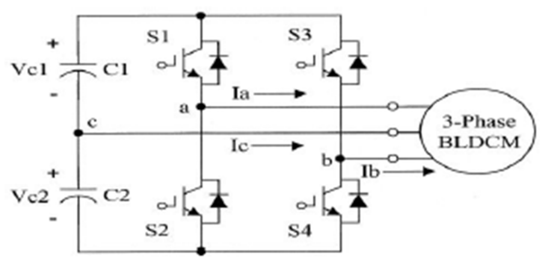

Fig.1: Four switch inverter fed three phase BLDC motor

III. Proposed Sensorless Control Of FSTPI Fed BLDC Motor

In the proposed method, rotor position can be detected by using a trapezoidal Back-EMF of BLDC motors. Since Back-EMF of the BLDC motor is not measured directly, it is estimated by the comparator with zero crossing detection technique and fuzzy logic intelligent controller is used for efficient speed control.

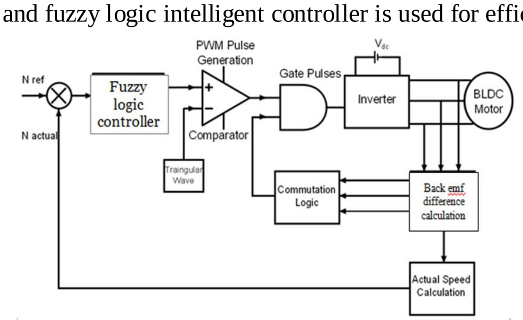

Fig 2: Block diagram

A. Conventional back emf detection method

The zero-crossing approach is one of the simplest methods of back-EMF sensing technique, and is based on detecting the instant at which the back-EMF in the unexcited phase crosses zero. This zero crossing triggers a timer, which may be as simple as an RC time constant, so that the next sequential inverter commutation occurs at the end to this timing interval. For typical operation of a BLDC motor, the phase current and back-EMF should be aligned to generate constant torque. The current commutation point can be estimated by the zero crossing point (ZCP) of back EMFs and a 30 phase shift, using a six-step commutation scheme through a three phase inverter for driving the BLDC motor. Figure 3 depicts the zero crossing points of back emf. The conducting interval for each phase is 120 electrical degrees. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated at every 60 degree by detecting zero crossing of back-EMF on the floating coil of the motor, so that current is in phase with the back-EMF.

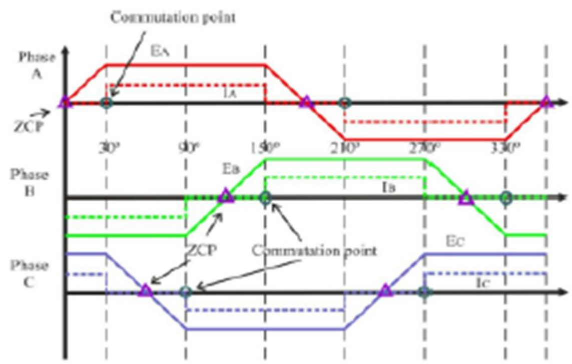

Fig 3: Zero crossing points of the back-emf and phase current commutation points

This technique of delaying 30 (electrical degrees) from zero crossing instant of the back-EMF is not affected much by speed changes. To detect the ZCPs, the phase back-EMF should be monitored during the silent phase.

B. Proposed back emf difference estimation method

Instead of using phase BEMF, the proposed method utilizes difference in BEMF of two phases. In the proposed method the commutation can be done at the ZCP itself which is depicted in figure 4. Thus the optimal performance is guaranteed and phase current commutation points without any phase shift by using this signal for commutation. The ZCP of the terminal voltage difference is identical to the ZCP of the BEMF difference and thus it can be used as commutation signal directly without phase compensation. Commutation sequences in BEMF difference method is illustrated in table 1.

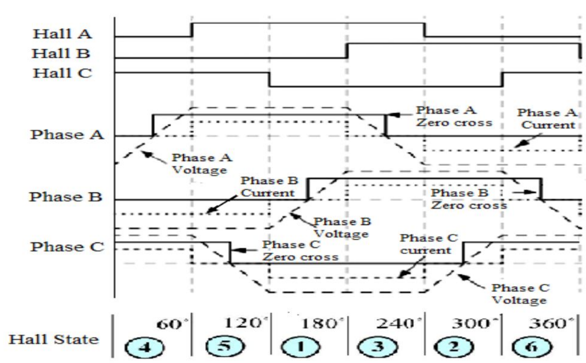

Fig 4: Zero crossing points of the back-emf difference

TABLE I. COMMUTATION SEQUENCE IN BACK EMF DIFFERENCE ESTIMATION METHOD

e_{ac}	e_{ba}	e_{cb}	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
1	-1	1	1	0	0	0	0	1
1	-1	-1	1	1	0	0	0	0
1	1	-1	0	1	1	0	0	0
-1	1	-1	0	0	1	1	0	0
-1	1	1	0	0	0	1	1	0
-1	-1	1	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0

IV. DESIGN OF FUZZY CONTROLLER

The generated signals are employed in fuzzy controller and PWM signals which in gate driver circuit is produced for control system. The fuzzy controller is composed of the following four elements fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification. Figure 5 shows the basic structure of a fuzzy logic controller.

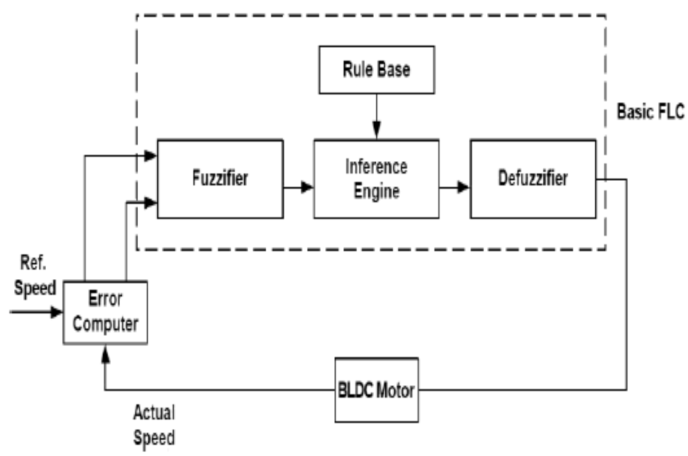

Fig.5: Basic structure of a fuzzy logic controller

Error (e) and change in error (ce) are the inputs for the fuzzy controller whereas the output of the controller is change in duty cycle (Δdc). The error is defined as the difference between the ref speed and actual speed, the change in error is defined as the difference between the present error and previous error and the output, the Change in duty cycle which **c**ould be either positive or negative and added with the existing duty-cycle to determine the new duty-cycle. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable in to a linguistic variable is called fuzzification. Fuzzy logic linguistic terms are most often expressed in the form of logical implications, such as If-Then rules. These rules define a range of values known as fuzzy membership functions. Fuzzy membership functions may be in the form of a triangle, a trapezoid or a bell.
Fig. 6 illustrates the membership function of fuzzy logic controller that used the fuzzification of two input values and defuzzification output of the controller. There are seven clusters in the membership functions, with seven linguistic variables defined as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB).. The min-max compositional rule of inference and the center of gravity method have been used in the defuzzification process.

TABLE II. MEMBERSHIP FUNCTION

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

V. SIMULATION CIRCUIT AND ITS RESULTS

Fig. 6 shows the MATLAB simulation diagram of fuzzy logic controller used for the speed control of Four switch three phase inverter fed BLDC motor.

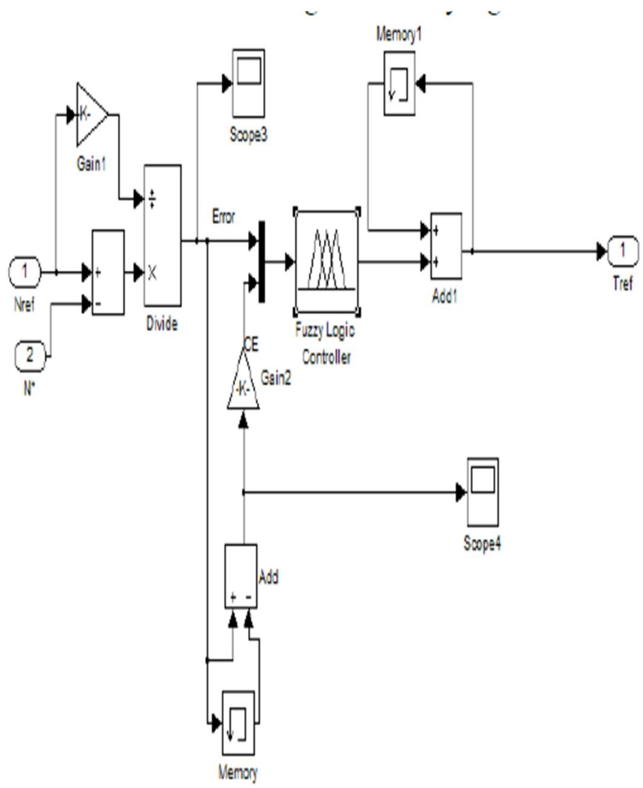

Fig 6: MATLAB simulation diagram of fuzzy logic controller

In order to validate the control strategies as described, digital simulations were carried out for the BLDC motor drive system using MATLAB/SIMULINK. Simulation studies were carried out to evaluate the performance of both sensored and sensorless based speed control of BLDC motor. The output waveform of back EMF figure 9. The speed response for sensored drive using Proportional integral controller and sensorless drive using Fuzzy controller are observed. Also, electromagnetic torque of the PI and Fuzzy intelligent controllers are analysed under comparator with zero crossing back EMF sensorless drive technique.

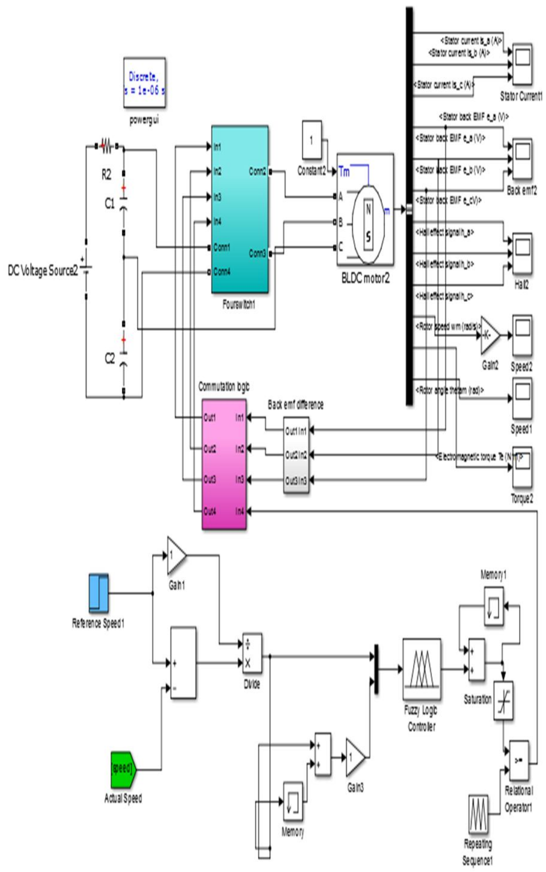

Fig 7:Simulation circuit for sensorless speed control of FSTPI fed BLDC using FLC

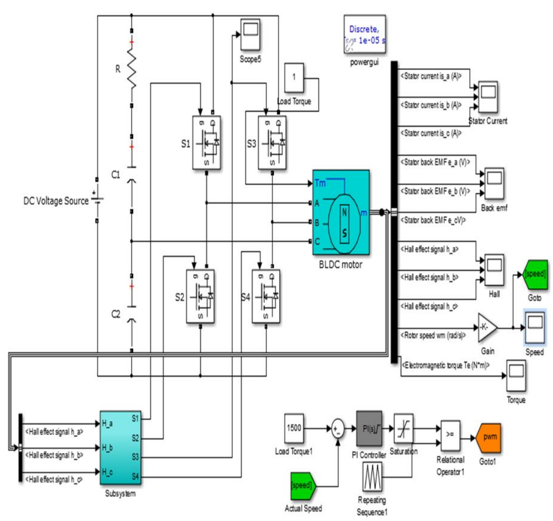

Fig 8: Simulation circuit for sensorless speed control of FSTPI fed BLDC using PI controller

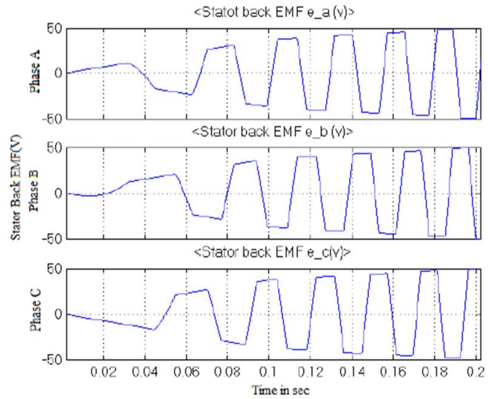

Fig 9:Variation of Back EMF signal with reference set at 1500rpm with PI controller

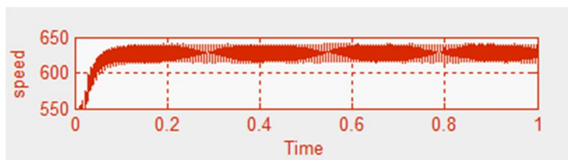

Fig 10:Variation of speed signal with reference set at 630rpm with PI controller

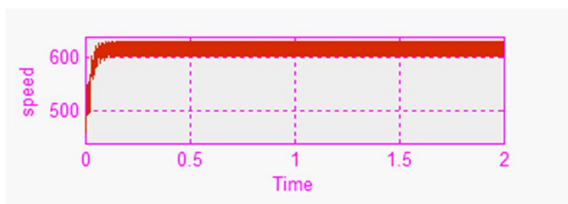

Fig 11:Variation of speed signal with reference set at 630rpm with fuzzy controller

Fig.10 shows actual speed attains reference speed at 0.2 sec and Fig.11 shows that the sensorless drive with proposed FLC method improves settling time to 0.1sec. The sensorless drive using PI controller and proposed model using fuzzy controller are analyzed.

VI. CONCLUSION

Sensorless speed control of four switch three phase inverter fed BLDC motor drive with fuzzy logic implementation based on comparator with zero crossing detection have been experimented using MATLAB/SIMULINK and evaluation of results are observed. The simulation results have shown that speed response of the BLDC motor can be controlled without sensors and also reduces the torque ripple. The results obtained from sensorless speed control of BLDC motor demonstrates that the system is less cost compared to sensored control and also good dynamic performance is obtained. This makes the motor suitable in application such as fuel pump, robotics and industrial automation. The proposed speed control scheme is robust, efficient and easy to implement in place of sensored applications.

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