# A FLC Based Four- Switched Converter Controller for a 3- Phase BLDC Motor Drive

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***Abstract*- Brushless DC (BLDC) motor is attracting much interest due to its high efficiency, performance and ease of control for many applications. Moreover, reducing of the drive components is more attractive for low cost applications. The paper presents the comprehensive study on the controllability and generated torque ripple of phase commutation in Four Switch Three Phase Inverter (FSTPI) Brushless DC (BLDC) motor drive which is suitable for low cost application. The conventional techniques for controlling the phase current in a FSTPI brushless DC drive are practically effective in low speed and cannot reduce the commutation torque ripple in high speed range. For effective utilization of the developed system, a novel direct current controlled PWM scheme is designed and implemented to produce the desired dynamic and static speed–torque characteristics. The simulation results are obtained using MATLAB/SIMULINK software.**

***Keywords* - BLDC motor, four switch inverter, Fuzzy controller.**

## I. INTRODUCTION

The BLDC motor is a rotating electric motor consisting of three- phase armature windings on the stator and permanent magnets on the rotor. The mechanical structure of BLDC motor is the conventional permanent magnet brushed DC motor (PMDCM) inside out, the rotor contains permanent magnets and the motor windings are mounted on the stator. The BLDC motor does not have any brushes, those required in the commutation of PMDCM. There fore the maintenance free motor drive system is possible with BLDC motor. The permanent magnets on the rotor of the BLDC motor provide a constant rotor magnetic field and makes possible a highly efficient, high torque-per volume, and low moment of inertia [1]. The BLDC motor is an electronically commutating permanent magnet DC motor. Because of this motor's inherent variable speed drive nature, its applications are growing, in automobile and machine building industries. Some work has also been done on a sensored four switch BLDC motor drive. An asymmetric PWM scheme for a four-switch three-phase BLDC motor drive to make six commutations and produce four floating phases to detect back electromotive force. The position information of the rotor can be acquired based on the crossing points of the voltage of controllable phases. Virtual Hall sensor signals are made by detecting the zero crossing points of the stator terminal voltages, and there is no need to build a 30◦ phase shift, which is prevalent in most of the sensored algorithms. [7] A four-switch three-phase BLDC motor drive is proposed to simplify the topological structure of the conventional six-switch inverter. The uncontrollable phase current causes unsymmetrical voltage vector and its waveform is much of distortion from rectangular. The direct current control based on hysteresis avoids this problem and it senses currents of phases A and B individually by two current sensors and then switches them separately [1] [2] [4].

## II.DESCRIPTION OF PMBLDCM DRIVE

Fig.1 describes the basic building blocks of the PMBLDCM drive. The drive consists of speed controller, reference current generator, pulse width modulation (PWM) current controller, position sensor, the motor and a IGBT based voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in PI speed controller. The output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents. The reference current generator block generates the three phase reference currents ($ia^*$, $ib^*$, $ic^*$) using the limited peak current.

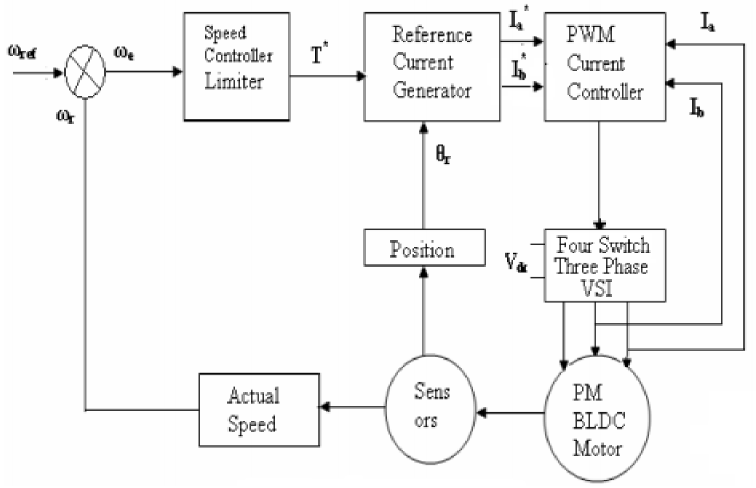



Fig.1 PI-Speed Controller

The PI controller is widely used in industry due to its ease in design and simple structure. The rotor speed ωr(n) is compared with the reference speed ωr(n)∗ and the resulting error is estimated at the nth sampling instant as

$$\omega_e(n) = \omega_r(n)^* - \omega_r(n) \tag{1}$$

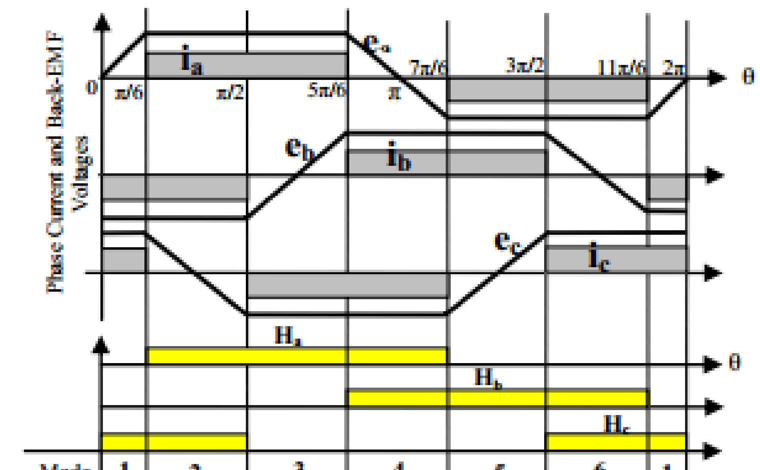
The new value of torque reference is given by

$$T(n) = T(n-1) + K_P \omega_e(n) - \omega_e(n-1) + K_1 \omega_e(n) \tag{2}$$

Where, ωe(n − 1) is the speed error of previous interval, and ωe(n) is the speed error of the working interval. KP and KI are the gains of proportional and integral controllers respectively. By using Ziegler Nichols method the KP and KI values are determined [1].

***A. Reference Current Generator:***

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. The magnitude of the reference current ($I^*$) is determined by using reference torque ($T^*$) and the back emf constant (Kb); $I^* = T^* / Kb$. Depending on the rotor position, the reference current generator block generates three-phase reference currents ($ia^*, ib^*, ic^*$) considering the value of reference current magnitude as $I^*$, −I* and zero. The reference current generation is shown in Fig.2.




| Mode | 1 | 2 | 3 | 4 | 5 | 6 | 1 |
|---|---|---|---|---|---|---|---|
| Conducting Switches | $S_4$ | $S_4 S_1$ | $S_1$ | $S_3$ | $S_3 S_2$ | $S_2$ | $S_4$ |

Fig.2 Back EMF, current profile, modes, conducting switches in the four-switch converter for three-phase BLDC motor drives.

Terminal voltages of a BLDC motor in the four switch inverter with respect to the mid-point of the dc bus are as follows:

$$V_{ao} = Ri_a + L\frac{di_a}{dt} + e_a + V_{no} \quad (3)$$

$$V_{bo} = Ri_b + L\frac{di_b}{dt} + e_b + V_{no} \quad (4)$$

$$V_{co} = Ri_c + L\frac{di_c}{dt} + e_c + V_{no} \quad (5)$$

## III.OPERATIONAL PRINCIPLE OF DIRECT CURRENT CONTROLLED PWM

From the motor point of view, even though the BLDC motor is supplied by the four-switch converter, ideal back-EMF of three-phase BLDC motor and the desired current profiles can be described as shown in Fig. 2. From the detailed investigation of the four-switch configuration and back-EMF and current profiles, we could come up with a PWM control strategy for the four-switch three-phase BLDC motor drives as follows: Under a balanced condition, the three-phase currents always satisfy the following condition

$$I_a + I_b + I_c = 0 \quad (6)$$

Then, (1) can be modified as

$$I_c = -(I_a + I_b) \quad (7)$$

In the case of the ac induction motor drive, at any instant there are always three phase currents flowing through the load, such as

$$I_a \neq 0;\ I_b \neq 0;\ I_c \neq 0 \quad (8)$$

However, in the case of the BLDC motor drive, (3) is not valid anymore. Note that in Fig. 2 phase A and B currents are only controllable and phase C is uncontrollable. According to the operating modes, one can derive the following current equations: Table I implies that due to the characteristics of the BLDC motor, such as two-phase, only two phases (four switches) needed to be controlled, not three phases. Therefore, based on Table I, one can develop a switching sequence using four switches as follows:

**Table 1. Rotor position signal Vs reference current**

| Rotor Position Signal $\theta_r$ | Reference Currents $(i_a^*, i_b^*, i_c^*)$ | | |
|---|---|---|---|
| 330°-0° to 0°-30° | 0 | –I* | I* |
| 30° - 90° | I* | –I* | 0 |
| 90° -150° | I* | 0 | –I* |
| 150° - 210° | 0 | I* | –I* |
| 210° - 270° | –I* | I* | 0 |
| 270° - 330° | –I* | 0 | I* |

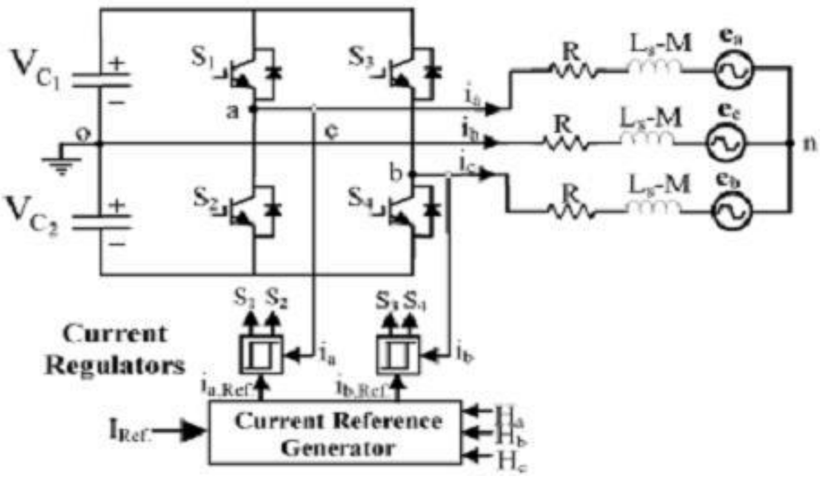



Fig.3 proposed four-switch converter topology for three-phase BLDC motor.

As shown in Table II, the two-phase currents need to be directly controlled using the hysteresis current control method by four switches. Hence, it is called the direct current controlled PWM scheme. Based on the direct current controlled PWM, implementation of the switching sequence and current flow are depicted in Fig. 6

Table 2. Switching Sequence of Four switch BLDC motor

| MODES | ACTIVE PHASES | SILENT PHASES | SWITCHING DEVICES |
|---|---|---|---|
| Mode 1 | Phase B and C | Phase A | $S_4$ |
| Mode 2 | Phase A and B | Phase C | $S_1$ and $S_4$ |
| Mode 3 | Phase A and C | Phase B | $S_1$ |
| Mode 4 | Phase B and C | Phase A | $S_3$ |
| Mode 5 | Phase A and B | Phase C | $S_2$ and $S_3$ |
| Mode 6 | Phase A and C | Phase B | $S_2$ |

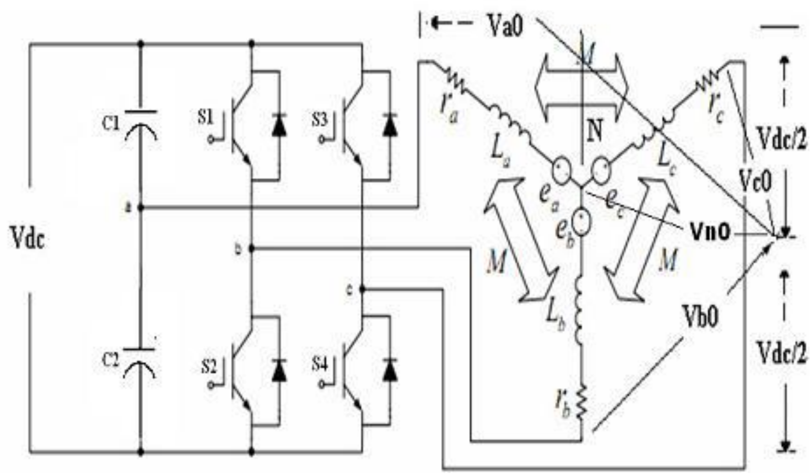



Fig.4 Inverter circuit with PMBLDCM drive

***A. Current Regulation:***

Based on the switching sequences in Table II, the current regulation is actually performed by using hysteresis current control. The purpose of regulation is to shape quasi square waveform with acceptable switching (ripple) band. Using mode II and mode III, the current regulation can be explained as follows: In mode II, Ia and Ib currents (Ia>0 ,Ib<0) flow and Ic=0. Therefore, mode II is divided into two cases, such as dia/dt>0, dib/dt<0 and dia/dt<0,dib/dt>0. In this mode, as shown in Fig. 5(b), switches

S1and S4 are used. Until Ia(Ib) reaches the upper (lower) limit, S1 and S4 are turned on for supplying dc link energy to increase the current. When the current reaches to the upper limit, S1and S4 are turned off to decrease the current through the anti-parallel diodes D2 and D3.

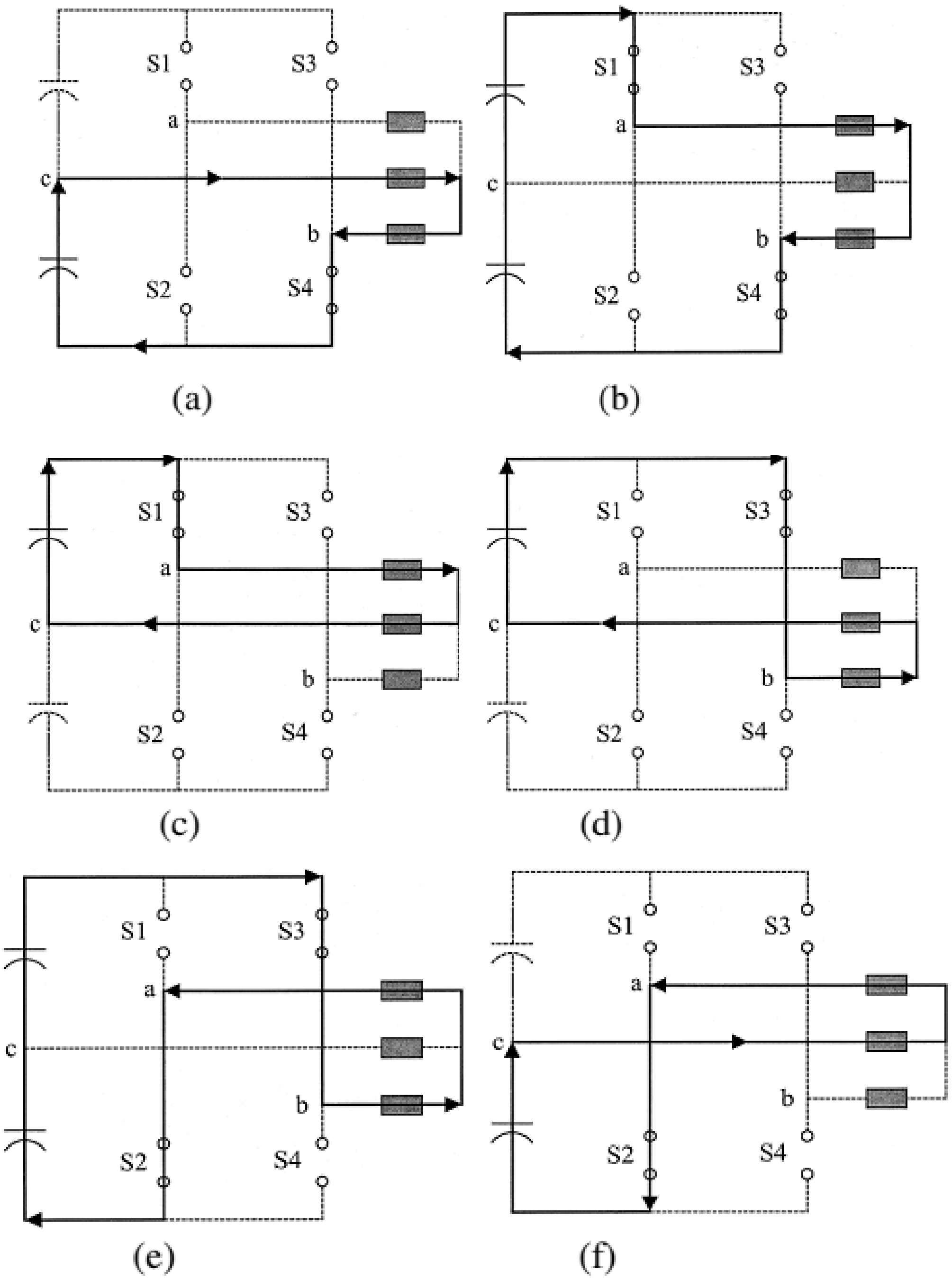



Fig. 5. Implementation of the direct current controlled PWM strategy. (a) Mode I (S4). (b) Mode II (S1 and S4). (c) Mode III(S1). (d) Mode IV (S3). (e) Mode V (S3 and S2). (f) Mode VI (S2).

At that time, the reverse bias (negative dc-link voltage) is applied to the phases, resulting in decreasing the current. On the other hand, in mode III, only one current (Ia) can be controllable. It means that only switch S1 can be used as shown in Fig. 5(c). However, the same principle as used for mode II is applied to mode
III. When Ia increases, S1 is turned on and other case S1 is turned off.

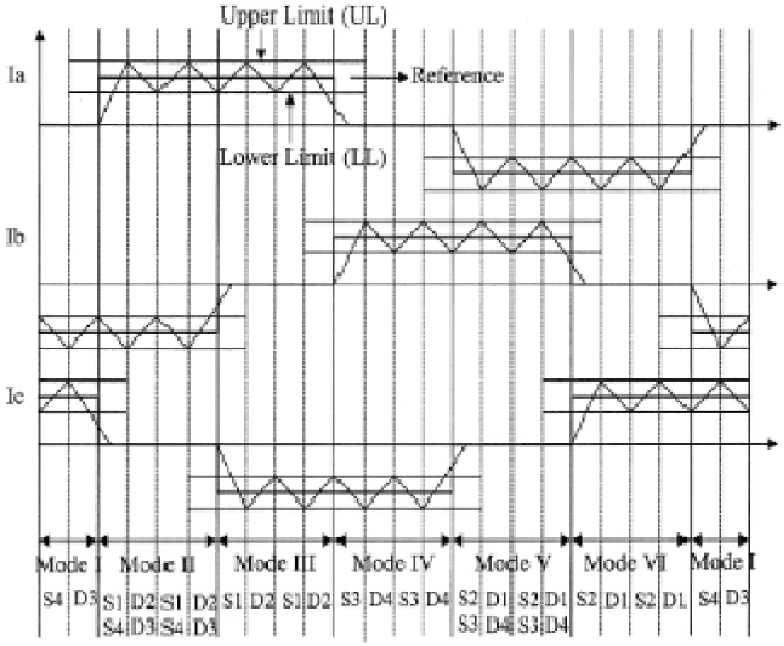



Fig.6 Current regulation and detailed switching sequences.

## IV.INTRODUCTION TO FUZZY LOGIC CONTROLLER

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. MATLAB/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of propose controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig 7 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

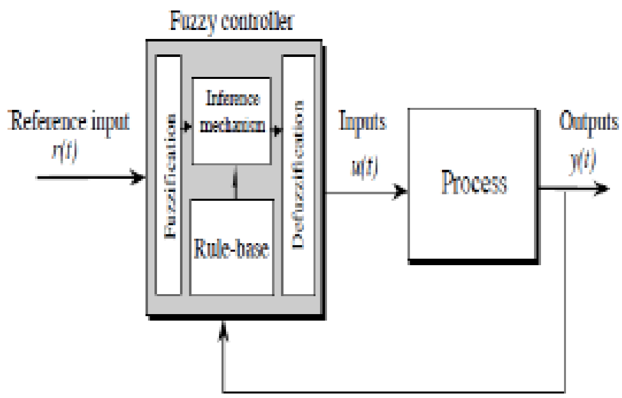



Fig.7. General Structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

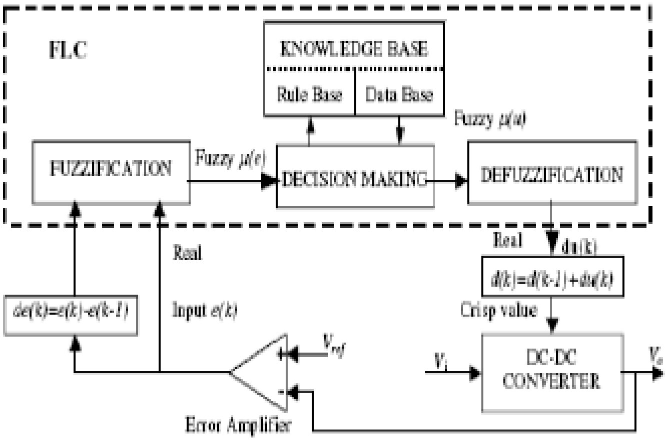



Fig.8. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

A. ***Fuzzy Logic Membership Functions:***

The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are d esigned based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

***B. Fuzzy Logic Rules:***

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

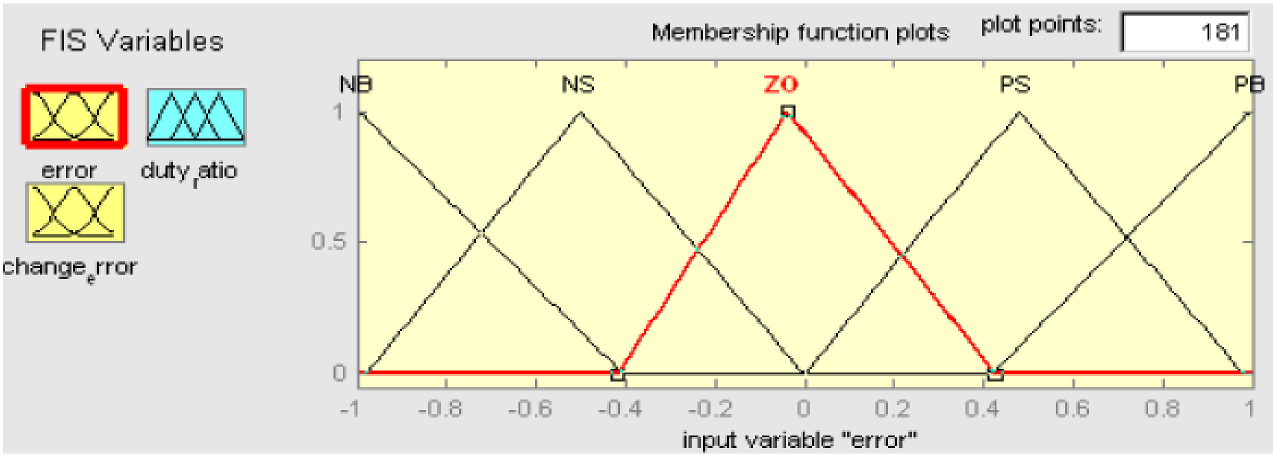



Fig. 9.The Membership Function plots of error

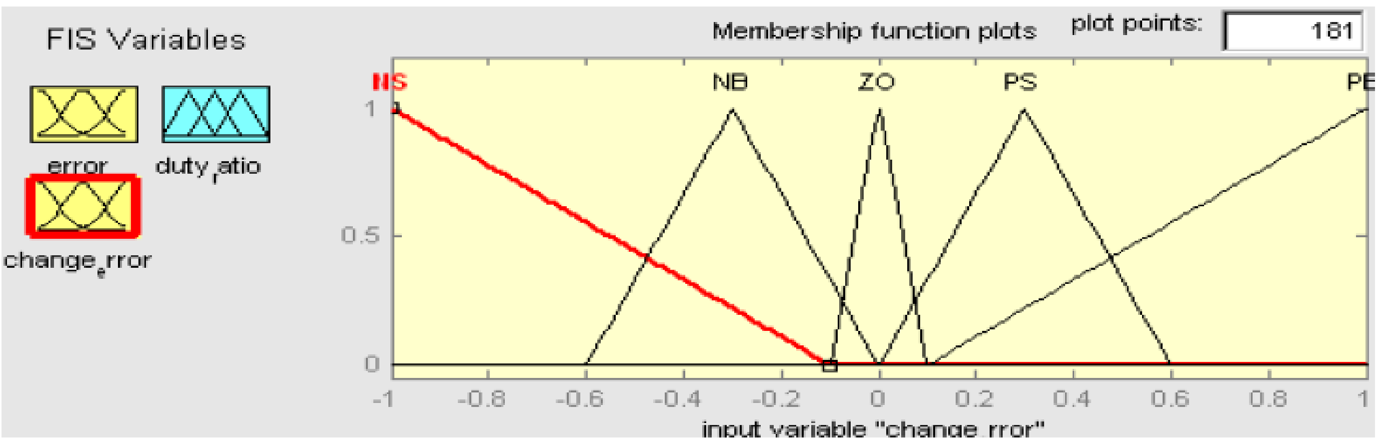


Fig.10. The Membership Function plots of change error

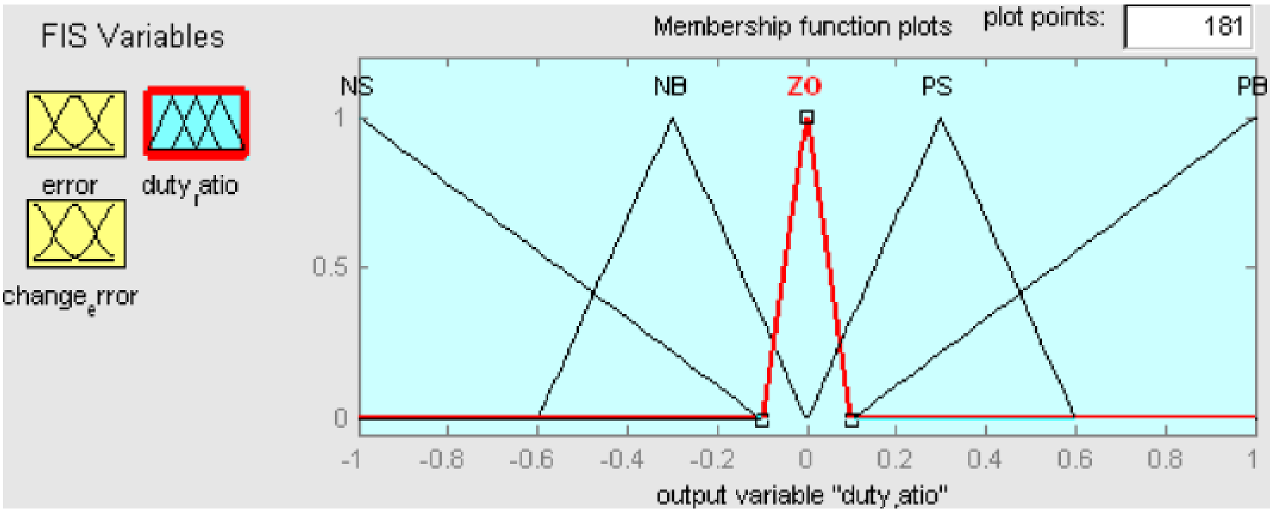



Fig.11. the Membership Function plots of duty ratio

Table II Table rules for error and change of error

| (de) \ (e) | NB | NS | ZO | PS | PB |
|---|---|---|---|---|---|
| NB | NB | NB | NB | NS | ZO |
| NS | NB | NB | NS | ZO | PS |
| ZO | NB | NS | ZO | PS | PB |
| PS | NS | ZO | PS | PB | PB |
| PB | ZO | PS | PB | PB | PB |

## V.MATLAB MODELING AND SIMULATION RESULTS

Here simulation is carried out in two different cases, in that 1). Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller. 2). Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller.

*Case 1: Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller*

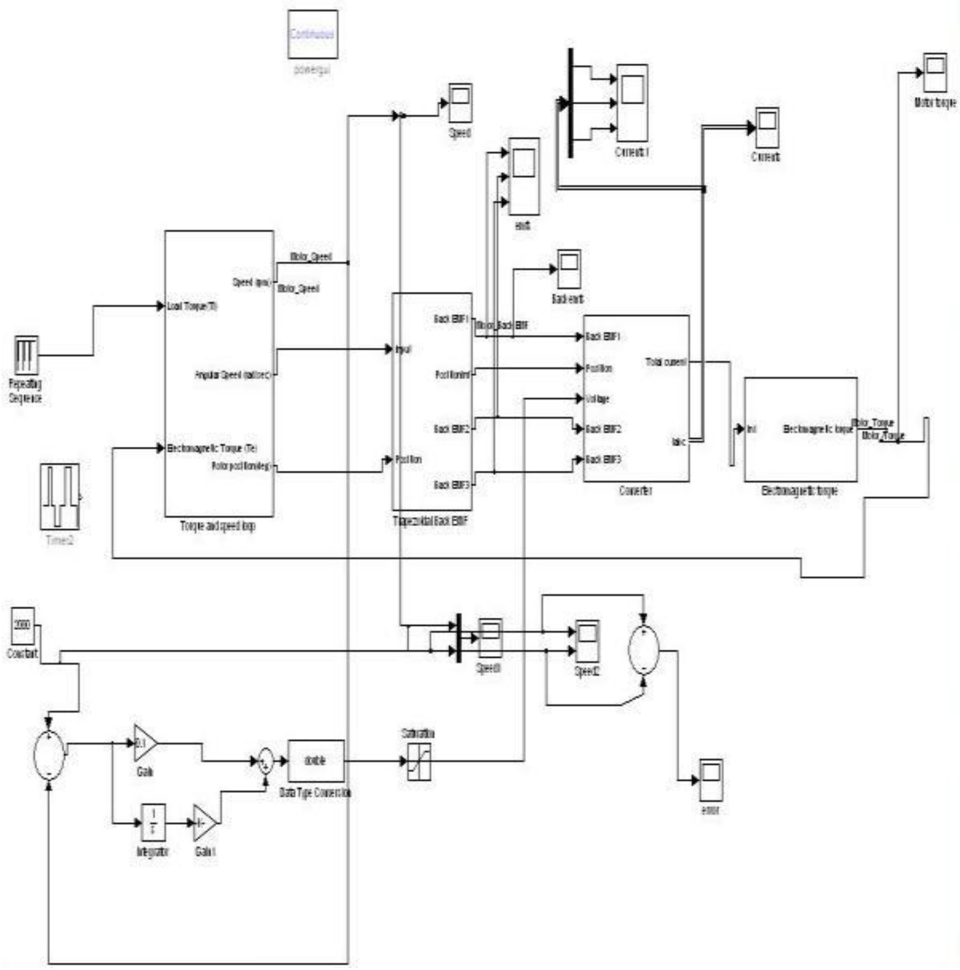
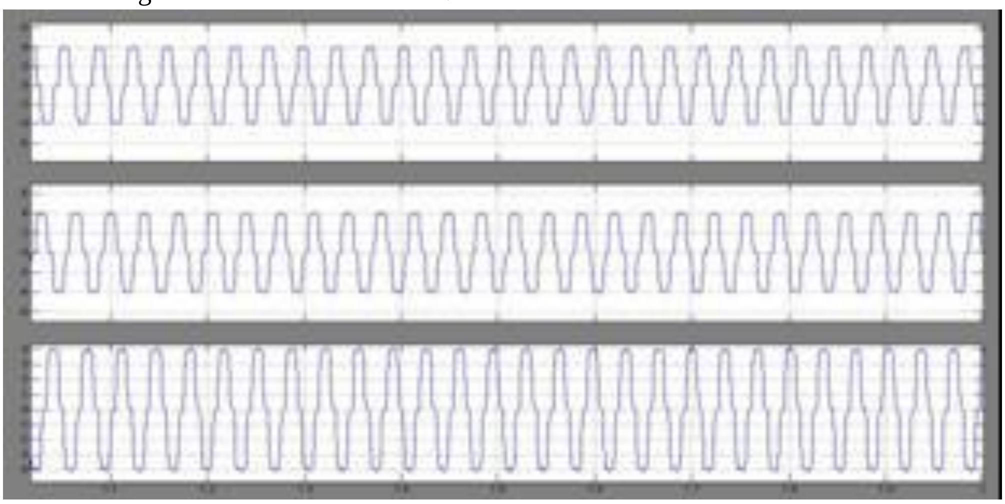
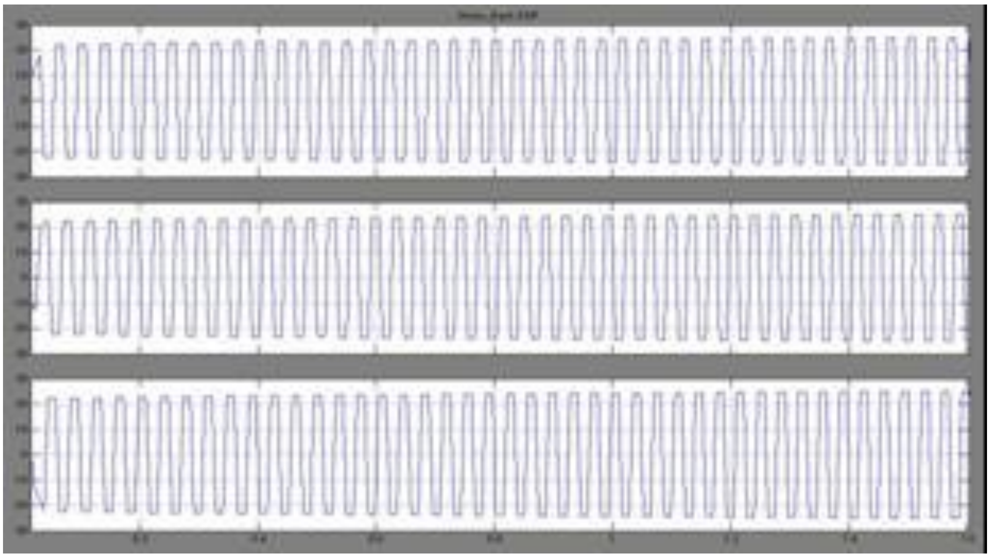



Fig.12 Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller

Fig.12 shows the Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller using Matlab/Simulink Platform.



(a)



(b)

Fig.13 (a)Stator Current & (b) Back EMF

Fig.13 shows the Stator Current & Back EMF of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller.

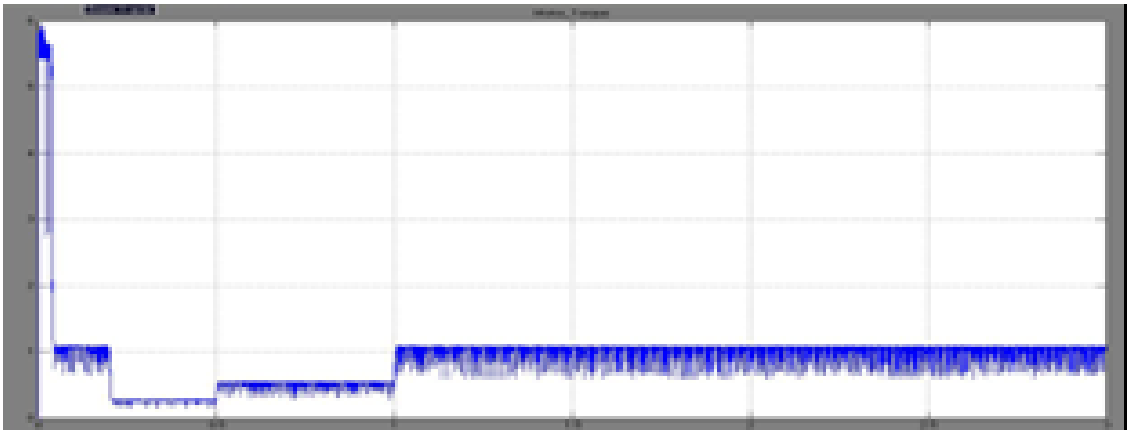


Fig.14 Torque curve for Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller

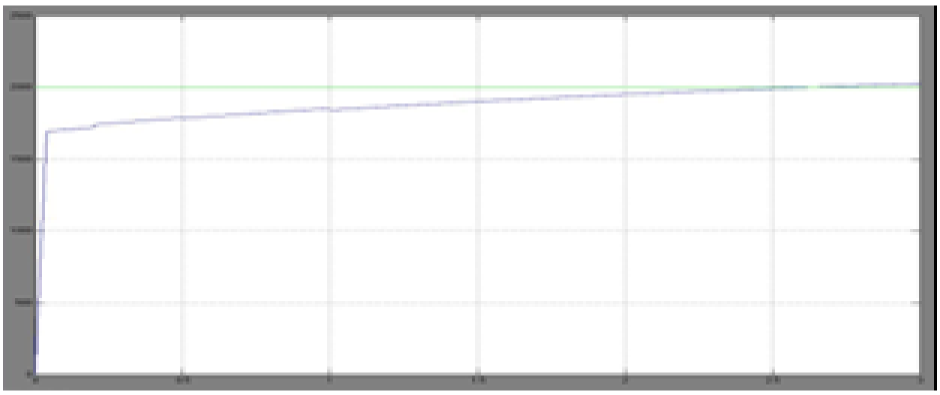


Fig.15 speed with reference curve for Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller

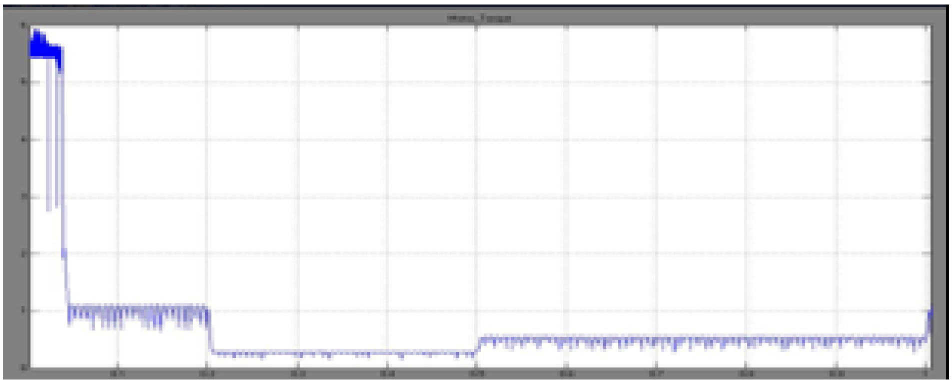


Fig.16 Electromagnetic Step Torque

Fig.16 shows the Electromagnetic Step Torque of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Conventional Controller.

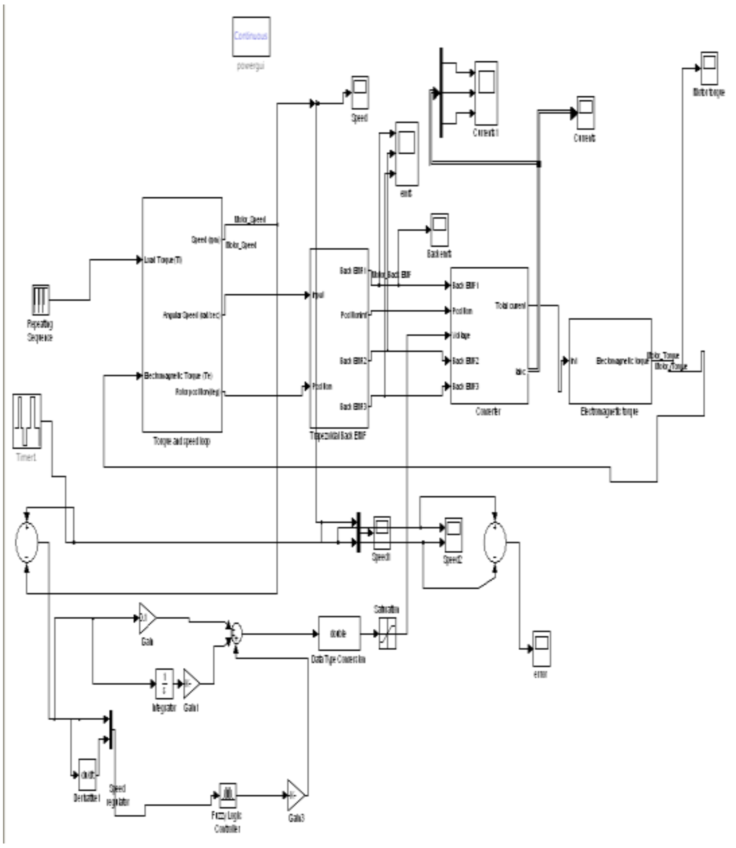
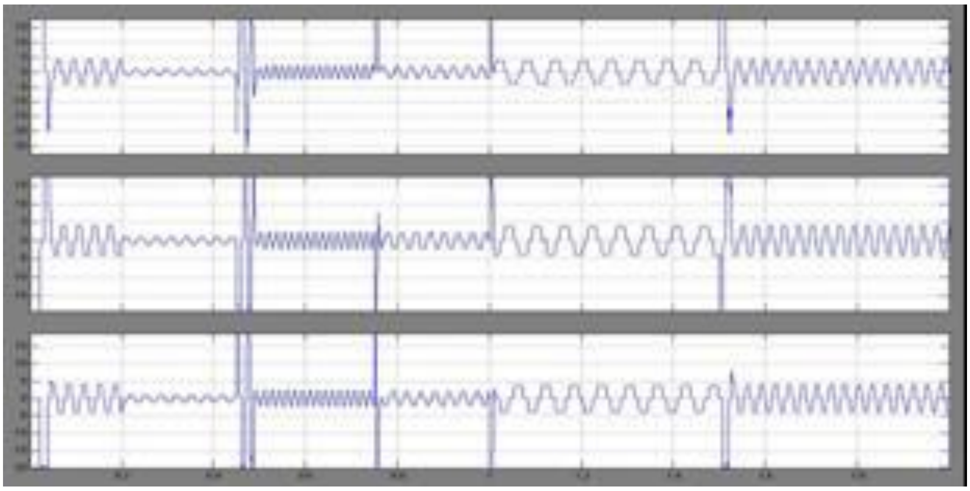


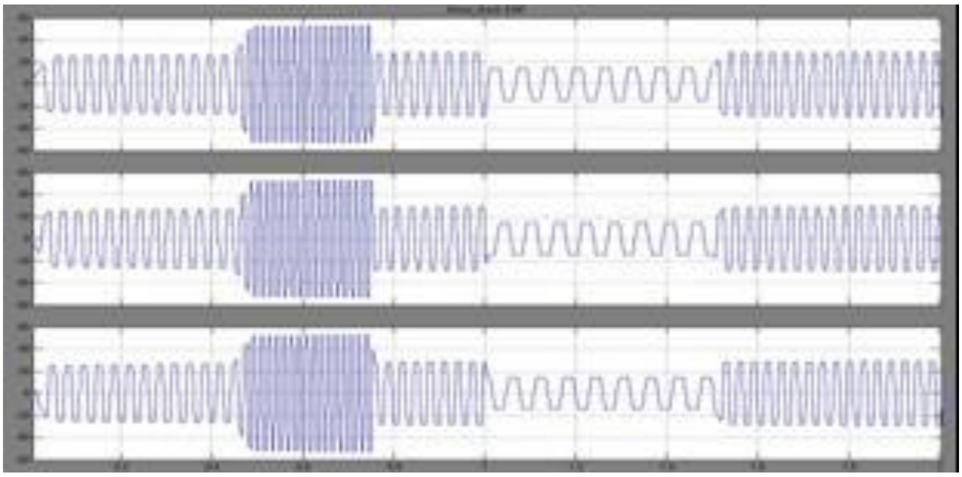
Fig.17 Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller

*Case 2: Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller*

Fig.17 shows the Matlab/Simulink Model of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller using Matlab/Simulink Platform.



(a)



(b)

Fig.18 (a)Stator Current & (b) Back EMF

Fig.18 shows the Stator Current & Back EMF o Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller.

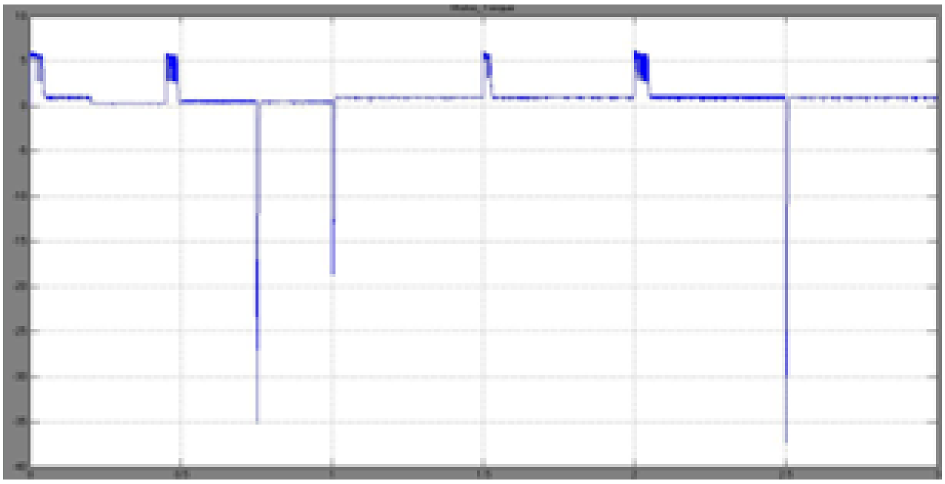
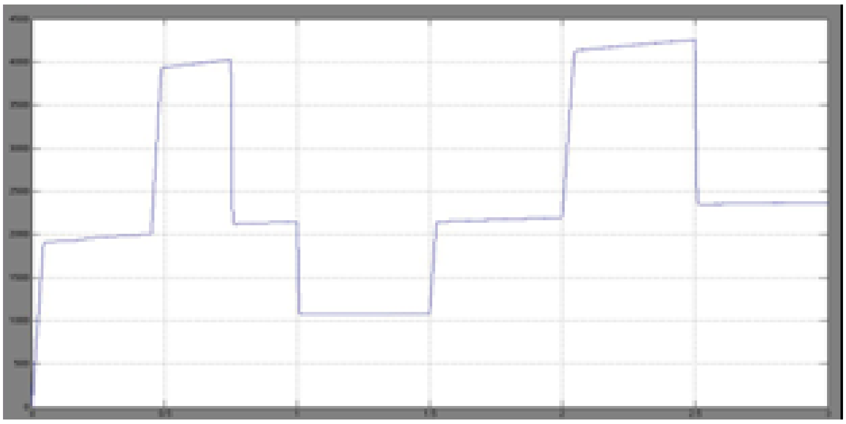
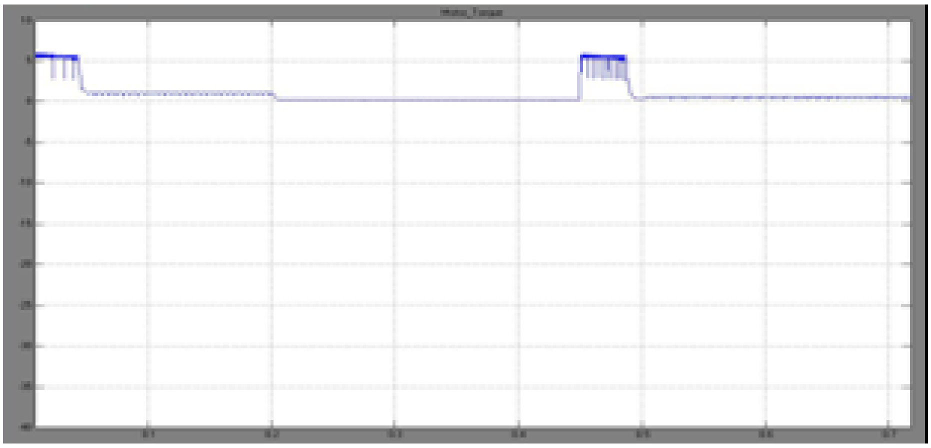


Fig.19 Shows the Motor Torque

Fig.19 shows the Motor Torque of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller.



(a)



(b)

Fig.20 Speed & Electromagnetic Step Torque

Fig.20 shows the Speed & Electromagnetic

Fig.20 shows the Speed & Electromagnetic Torque of Proposed Four Switch Three Phase Inverter Fed BLDC Motor using Intelligence Controller.

## VI.CONCLUSION

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic closed loop appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances. With respect to their successful methodology implementation, control closed loop converter and opened loop converter will compare the efficiency of the converters. The simulation model of the BLDC motors drive system with PI control based four switch three phase inverter on MATLAB/Simulink platform is presented. The performance of the developed algorithm based speed controller of the drive has revealed that the algorithm devises the behaviour of the PMBLDC motor drive system work satisfactorily. And also n this paper, the four switch inverter topology is studied using conventional controller as well as fuzzy controller to provide a possibility for the realization of low cost and high performance three-phase BLDC motor drive system.

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