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THREE LEVEL THREE PHASE DRIVES FOR BLDC MOTOR FOR AEROSPACE APPLICATIONS

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ABSTRACT

The success of spacecraft mission is highly dependent on the performance and robustness of attitude control system. Actuators are the key element for attitude control. Electromechanical actuators are replacing electrohydraulic actuators for attitude control owing to the inherent advantages of lower cost and weight, maintenance free, higher efficiency and fault tolerance. For high power actuators of range 200KW requires improved motor drive for BLDC motor. This paper presents position control of BLDC motor fed by three level three phase inverter with space vector pulse width modulation (SVPWM) for aerospace application. SVPWM improves DC BUS utilization, reduced THD in the output which leads to excellent output performance, high efficiency and reliability compared to other modulation techniques.

Keywords:Brushless DC motors, Multi-level inverter, Position control, Space vector pulse width modulation.

I.INTRODUCTION

In present trend, in the field of aerospace spacecraft attitude control is an active research topic. The rocket produces pitch and yaw motions by gimballing the exhaust nozzle gimbal angle (refer Figure 1) so that the rocketcan be launched in the defined path.

The thrust vector control (TVC) is comprised of actuator and power components for controlling the nozzle direction and thrust to steer the vehicle. In today's scenario, in the spacecraft electromechanical actuation system offers an attractive alternative to the hydraulic system thus it improves safety, efficiency, reliability and maintainability [1]. For electromechanical actuation system, based on BLDC motors we need to develop improved motor drives with increased efficiency.

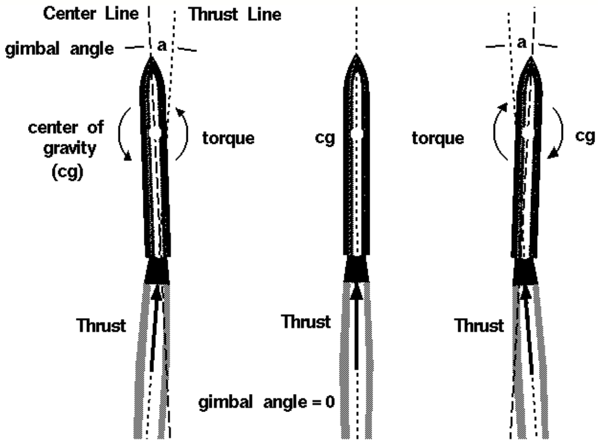

Figure 1: Thrust control in rockets by Gimballing

BLDC motor is used for actuators as it has several advantages over other motors. It has no mechanical commutation and associated problems, increased efficiency due to use of permanent magnets, noiseless operations due to absence of brushes, high speed of operation and long operating life as no inspection and maintenance is required.

BLDC motor needs an inverter to feed power. Studies are carried for meeting the requirement of inverter such as reduced harmonic content in the output, switching frequency of the inverter and better consumption of available dc voltage. In order to get higher efficiency, reduced harmonic distortion, higher voltage requirement for the motor drives; three level three phase motor drives with space vector pulse width modulation is developed. The inverter which produces output voltage or current of two different levels of ±V is known as two level inverters. The two level inverters operate at high switching frequency having high switching losses and rating constraints for high power and voltage applications. There is also problem of harmonic distortion, EMI and high *dv/dt* stress.To avoid this problem, now-a-days, multilevel inverter topologies have received great attention in the field of high power& high voltage applications [4]. The multilevel inverter topology concept has been introduced in the early 1975 with three level converters. It is possible to increase the power rating with high number of voltage levels in the inverter. Thus, it reduces switch rating in the inverter.They improve output waveform quality of the voltage source inverter by increasing waveform steps and reduce the voltage stress across switches. There are mainly three types of multilevel converter topologies- cascaded H-bridge converter, neutral point clamed or diode clamped inverter and flying capacitor. Among these topologies neutral point clamped three level topologies are showing great attentions in the field of power electronics and being extensively used in various industrial and commercial applications. As it possess low electromagnetic interference, high efficiency and voltage across the switch is only half of the dc link voltage. These topologies uses clamping diodes thus it helps to limit the voltage stress of power electronics devices. In three phase modulation technologies SVPWM for 3-level converter has an advantage over sinusoidal PWM in voltage utility as SVPWM has 15% higher voltage utilization than that of sinusoidal PWM. The purpose of this is to design 3-level 3-phase motor drives using SVPWM and to control the position of BLDC motor. In section-II, implementation of space vector PWM is shown; section-III details the position control of BLDC motor for aerospace application; section-IV gives simulation and results; section-V provides the conclusion.

II.IMPLEMENTATION OF 3-LEVEL SVPWM

Nabae proposed the topology called neutral point clamped converter (NPC) [5] as shown in Figure 2 for three level. Various PWM techniques for three level converters have been studied. The most widely used PWM is Space vector PWM among all due to its better performance with high output quality. Though the complexity increases in three level SVPWM than the two level but it has less harmonic injection in the output waveform and thus inverter performance increases. It is an efficient switching technique for various applications of drives. It is naturally accepted that three level SVPWM is an extension of the 2-level SVPWM.

2.1 Principle of SVPWM: - The main circuit for three level neutral point clamped converter is shown in fig-2. It consists of four switches in each leg and it has three kinds of switching states which is represented by P, O, N (2 1 0) as tabulated in Table 1.

Table 1

Symbol	**Switching States**				**Terminal Voltage**
	S_{1X}	**S_{2X}**	**S_{3X}**	**S_{4X}**	
P (2)	ON	ON	OFF	OFF	V_{DC}
O (1)	OFF	ON	ON	OFF	0
N (0)	OFF	OFF	ON	ON	$-V_{DC}$

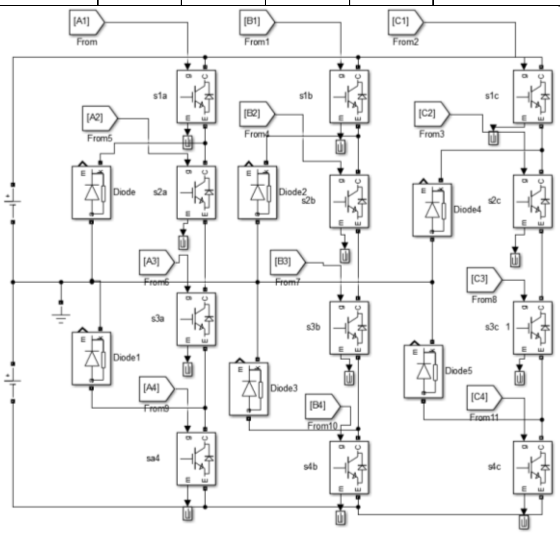

Figure 2: circuit diagram of three level three phase inverter

In three level phase converter total 27 switching states or switching vectors exist. The space vector of three level converters for 27 vectors is shown inFigure 3. There are 24 active vectors including 12 short vectors, 6 medium vectors and 6 long vectors and the remaining three vectors are zero vectors (000 111 222) which lie at the Centre of the Hexagon. The area of hexagon is divided into six sectors (1 to 6) and each sector is divided into four regions (1to 4).

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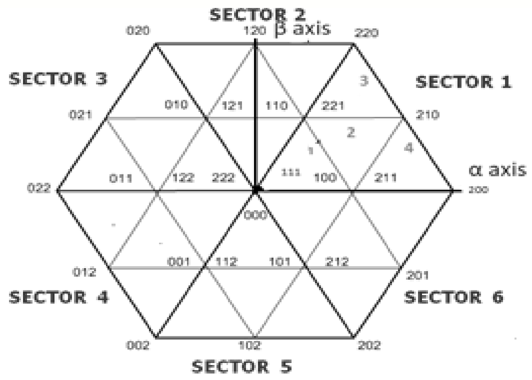

Figure 3: space vector diagram of three level

The space vector is represented as:

$V\alpha = Va\cos 0^0 + Vb\cos 120^0 + Vc\cos 240^0$ and

$V\beta = Va\sin 0^0 + Vb\sin 120^0 + Vc\sin 240^0$.

In SVPWM scheme, the three phase output voltage is represented by a reference vector given by $Vref = (V\alpha^2 + V\beta^2)^{1/2}$ and $\Theta = \tan^{-1}(V\beta/V\alpha)$ where Θ is reference vector angle; which rotates at an angular speed of $\omega = 2\pi f$. The aim of space vector modulation is to use the combination of switching states to approximate the locus of Vref.

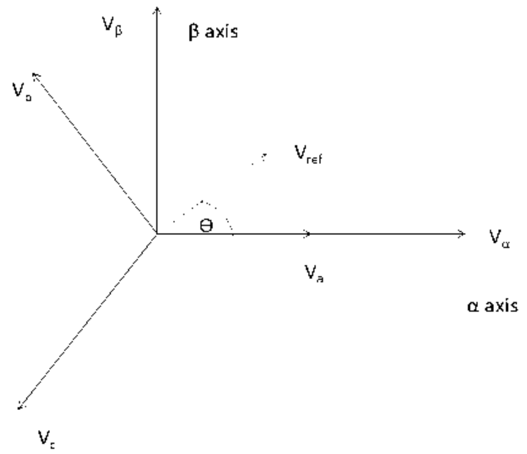

Figure 4: Coordinate representation

Analysis of three level SVPWM inverter can be done in following steps:

- Determination of sector and corresponding region of the sector.
- Selection of switching vector.
- Determination of the applying times of switching vectors.
- Determination of switching times of each phase.

The sectors are divided into 60^0 each. There are total 6 sectors and each sector has 4 regions; 1, 2, 3, 4. On the basis of sector and region in which Vref is lying, we determine the corresponding switching vectors. By using sector 1, as an example the calculation for three level SVPWM algorithm is demonstrated. Suppose reference voltage vector is lying in the region 2, it is composed of voltage vectors V1, V2 & V8. During Sampling time (Ts), the equation for on time of the voltage vector can be given as

$\overrightarrow{V_{ref}} = \overrightarrow{V_1}\overrightarrow{t_1} + \overrightarrow{V_8}\overrightarrow{t_2} + \overrightarrow{V_2}\overrightarrow{t_3}$ …… (i)

$t_1 + t_2 + t_3 = T_s$ …… (ii)

From the above equations, the on time of voltage vectors can be given as

$$\left.\begin{aligned} t_1 &= T_S - 2k\sin\theta \\ t_2 &= 2k\sin(\pi/_3 + \theta) - T_S \\ t_3 &= T_S - 2k\sin(\pi/_3 - \theta) \end{aligned}\right\} \quad \text{….. (iii)}$$

Where, $k = \frac{2mT_S}{\sqrt{3}}$ and $m = \frac{V_{ref}}{2/_3 V_{dc}}$

Using the same procedure, the dwelling time in other region in Sector-A can be calculated.

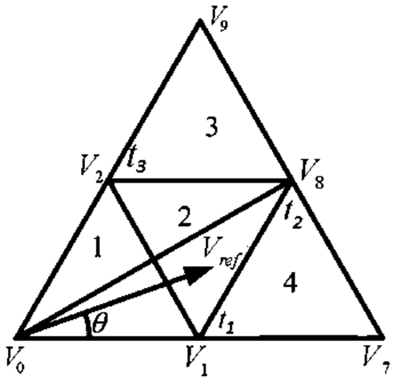

Figure 5: sector 1 representation

2.2 Switching Sequence arrangement: - If on times are calculated, then the switching sequence has to be determined. Switching sequence can be determined keeping the objective that there should be minimum switching losses or minimum total harmonic distortion. In order to achieve this following switching sequence is adopted. Switching sequence in the regions of sector-1 is given as

Region 1→221→211→111→110→100 & return.

Region 2→221→211→210→110→100 & return.

Region 3→221→220→210→110 & return.

Region 4→211→210→200→100 & return.

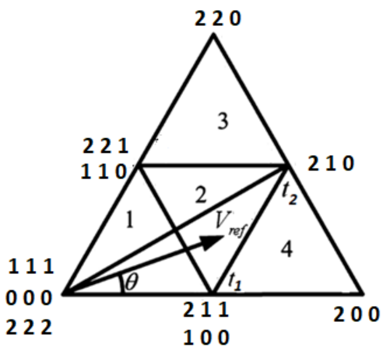

Figure 6: vectors representation of sector 1

In all switching states transition, we see only one inverter leg changing between 0, 1 & 2.

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1.3 Generation of PWM: - The PWM signals can be generated using PWM generators to fire the switches.The switching sequence in region 2 is shown in Figure 7, so that the symmetrical PWM signals can be easily generated. As each phase has three level, so it requires two PWM generators to produce.

From the Figure 8, for phase b, we have PWM fixing time as below

S1b = t3/4 and S2b = (Ts/2 – t1/4)

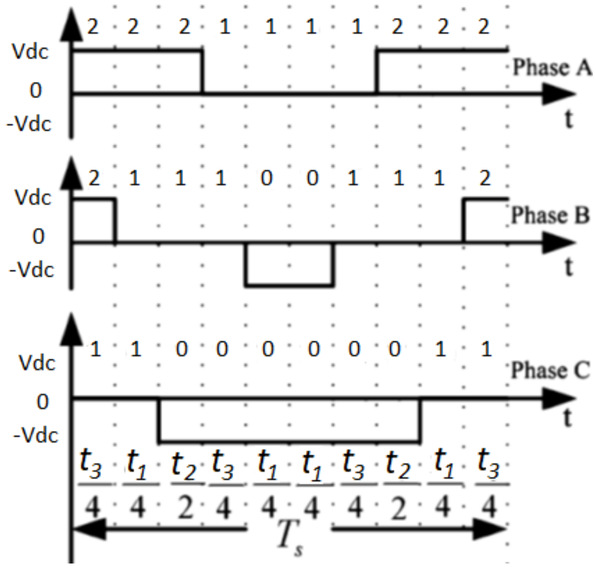

Figure 7: Switching sequence arrangement

Similarly for other phases of region 2, PWM fixing time can be calculated. Above realization procedures in sector1 can be applied to other sectors and similarresults will be obtained. The calculation flow chart is given in Figure 9:

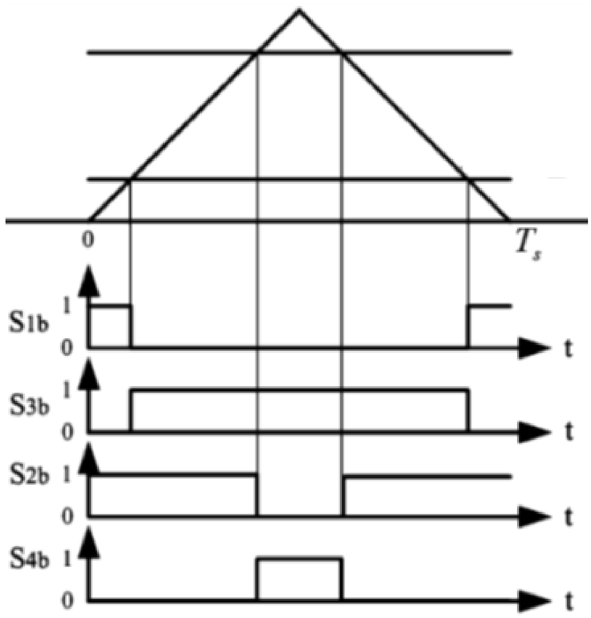

Figure 8: PWM firing time

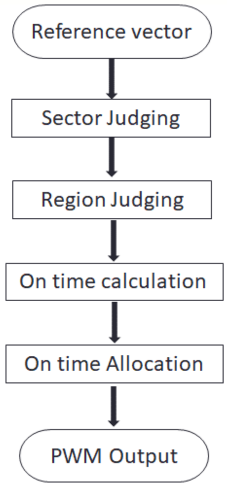

Figure 9: flow chart

III.POSITION CONTROL OF BLDC MOTOR

The rocket gimbal angle control of pitch and yaw axis during electromechanical (EM) stage is more important for orientation of the spacecraft. This will be achieved by using engine gimbal control (EGC) system. The block diagram of the EM EGC system is shown in Figure 10. The linear electromechanical actuators are mounted orthogonally for pitch and yaw axis control.The drive bar of the actuator is rigidly connected to the nut of the ball-screw and is attached to the engine with a gimbal. A Brushless DC motor is the driving element of the actuator. With the help of BLDC motor, nozzle is moved to the required command angle. The motor is driven by pulse width modulator power amplifier. The actual position of nozzle is sensed by the LVDT embedded in the actuator. The output of the position sensor is the feedback which is compared with the reference command to generate the error signal. The error signal is fed to the controller which provides stability and robustness to the system.

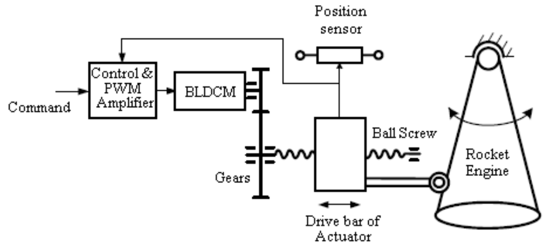

Figure 10: Electromechanical EGC System

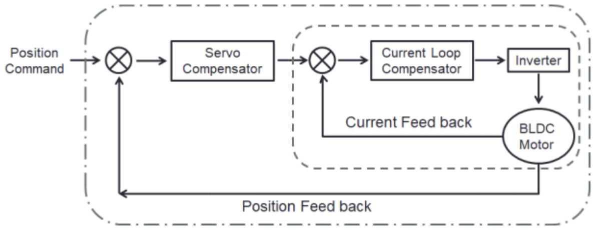

Figure 11: Position control of BLDC motors

IV.SIMULATION AND RESULTS

Figure 12&Figure 13 shows the simulink model of gate pulse generation for three level three phase inverter using space vector pulse width modulation and three level inverter fed BLDC motor.

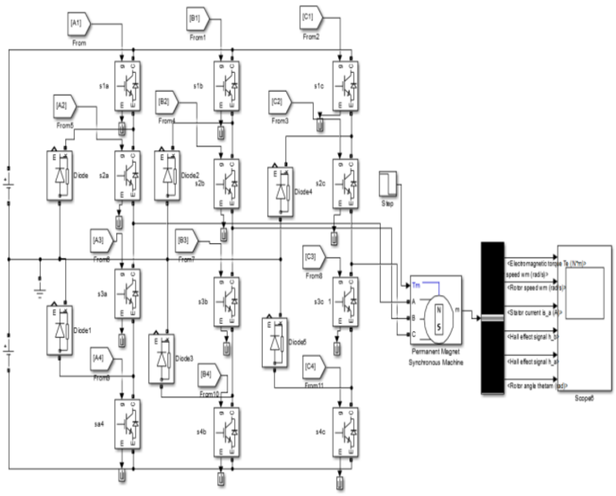

Figure 12: Simulink Model of three phase three level inverter fed BLDC motor

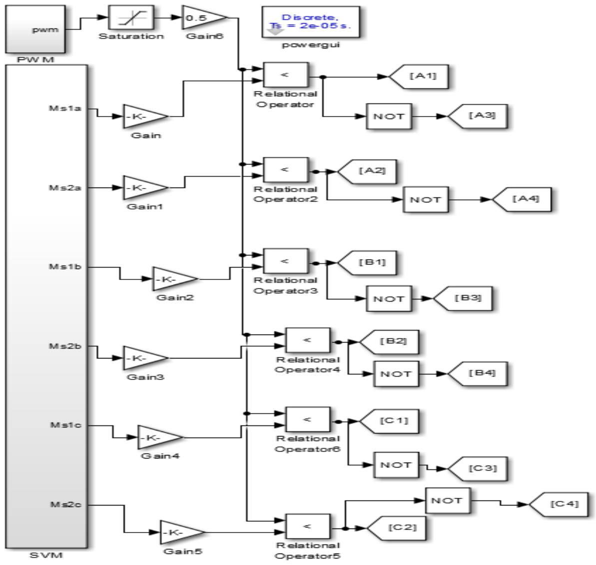

Figure 13: Simulink Model of gate pulse generation using SVPWM

The simulation results of output voltage, load current, electromagnetic torque and rotor speed are given below in Figure 14 toFigure 18.

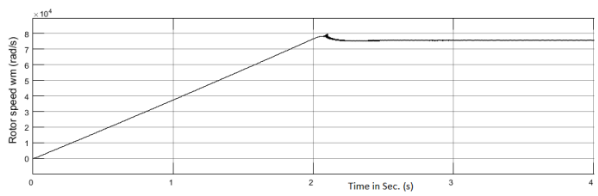

Figure 14: Rotor speed of motor

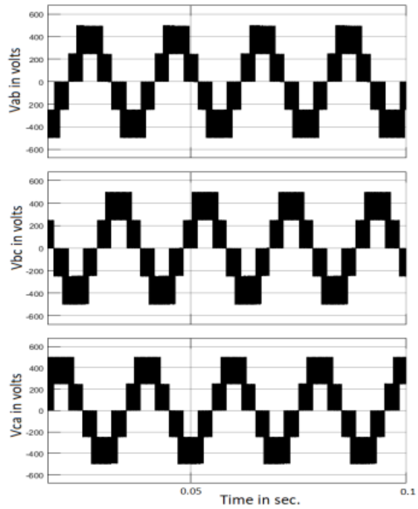

Figure 15: Line to line output voltages

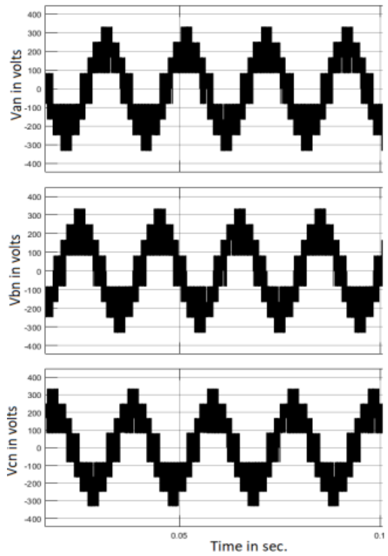

Figure 16: Line to neutral output voltages

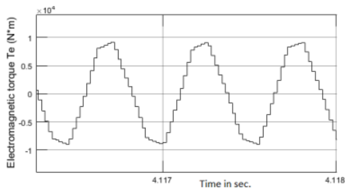

Figure 17: Electromagnetic torque of motor

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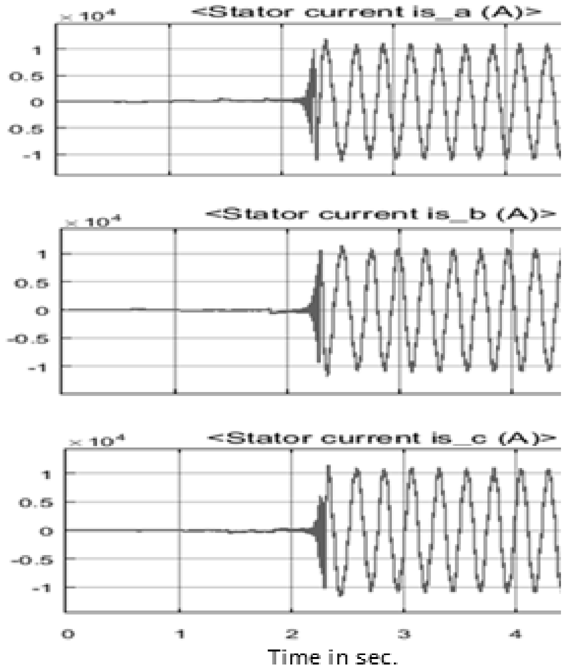

Figure 18: Load current waveforms

In order to realize position control of motor, it includes two closed control loops i.e. current and position feed-back loops. The position control of three phase BLDC motor is done by using PI controllers. The simulation results are shown below in Figure 19 to Figure 20.

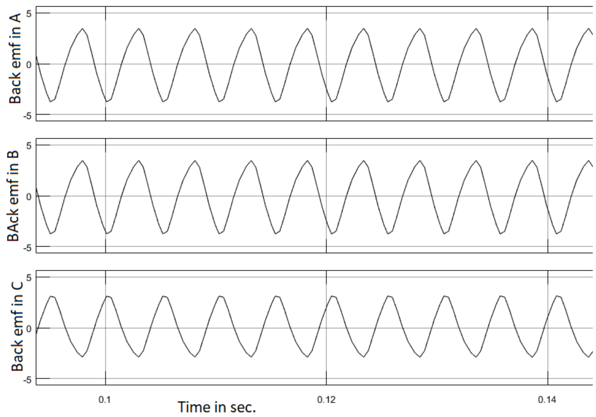

Figure 19: Back emf waveforms for 3-phase

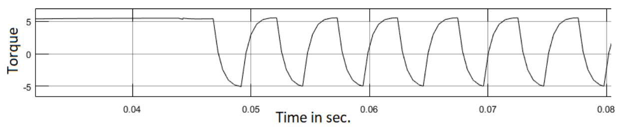

Figure 20: Electromagnetic torque

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The position controls for different angles are shown in Figure 21 and Figure 22.

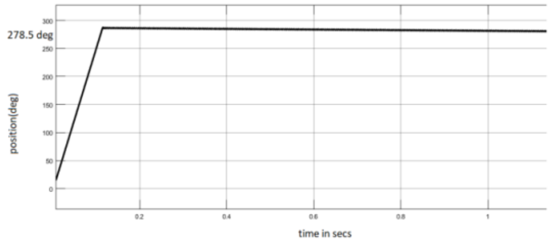

Figure 21: rotor position at angle 278.5 degrees

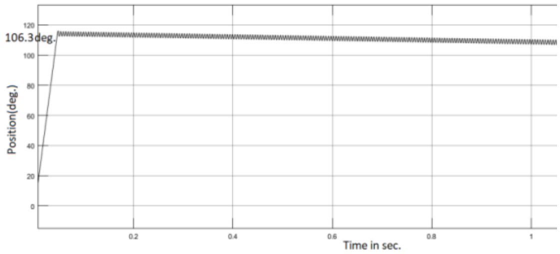

Figure 22: Rotor position at angle 106.3 degrees

FFT Analysis of load current and load voltage for 2-level and 3-level inverters are shown in Figure 23 to Figure 26.

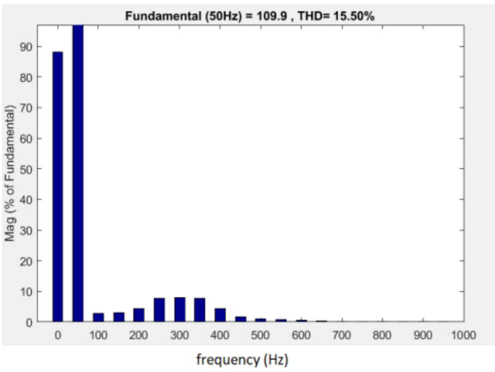

Figure 23: FFT analysis of 2-level inverter load current

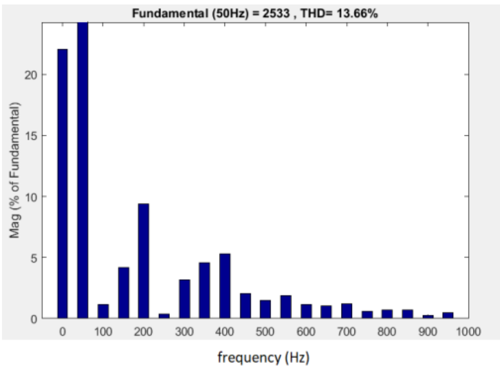

Figure 24: FFT analysis of 3-level inverter load current

The simulation parameters are:

DC voltage : 500 V

L_s : .0007 H

Fundamental frequency : 50 Hz

Switching frequency : 5 kHz

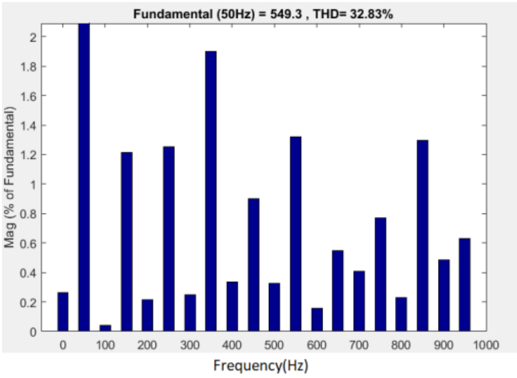

Figure 25: FFT analysis of 3-level inverter load voltage

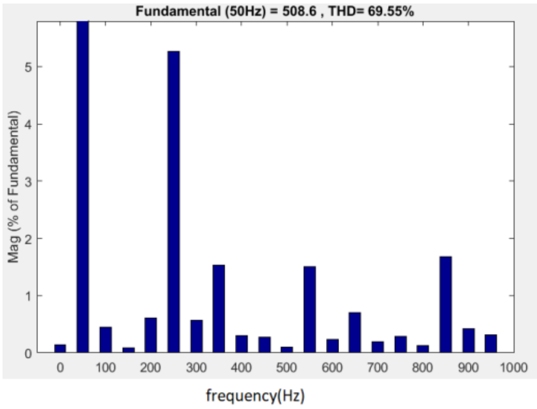

Figure 26: FFT analysis of 2-level inverter load voltage

V.CONCLUSION

This paper presents the implementation of SVPWM for three level three phase inverter. The three phase inverter is fed to BLDC motor and its position control is implemented in Simulink for different rotor angles. The FFT analysis of two level and three level inverter load voltage and current are analyzed, it shows that THD of output in three level is less compared to two level inverter. In present trend multilevel inverter fed BLDC motor is finding best application in aerospace due to its advantages over the two level inverter, which increases the robustness of the system.

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