International Journal of Electrical Engineering and Ethics- Volume 8 Issue 4, July - August - 2025

Mitigation of Torque Ripple in a Permanent Magnet Brushless DC Motor through Space Vector Pulse-Width Modulation Control.

Baridakara Deesor[1] S.L Braide[2] H.N. Amadi[3]

[1]*Electrical Department, Faculty of Engineering, Rivers State University, PortHarcourt, Nigeria.*
[2]*Electrical Department, Faculty of Engineering, Rivers State University, PortHarcourt, Nigeria.*
[3]*Electrical Department, Faculty of Engineering, Rivers State University, PortHarcourt, Nigeria.*

baridakara.deesor@ust.edu.ng

Abstract

This research explores the reduction of torque ripple in Permanent Magnet Brushless Direct Current Motors (PMBLDCM) by comparing the performance of Sinusoidal Pulse Width Modulation (SPWM) and conventional Pulse Width Modulation (PWM) techniques. The elimination of mechanical brushes and commutators in PMBLDC motors not only boosts reliability and operational lifespan but also improves efficiency and reduces maintenance needs. However, PMBLDC motors often experience excessive torque ripple, which negatively affects both performance and efficiency. This issue, marked by irregular torque output during operation, can lead to operational instability. The primary goal of this study is to implement an optimized method for torque ripple reduction in PMBLDC motors using the advanced Space Vector Pulse-Width Modulation (SVPWM) technique. Experimental results demonstrated that the torque ripple for SVPWM was significantly lower at 0.2%, compared to 1.7% for SPWM and 2.28% for PWM. Total Harmonic Distortion (THD) was also minimized with SVPWM, measuring 6%, while SPWM and PWM recorded 8% and 10%, respectively, indicating superior harmonic suppression with SVPWM. Speed regulation performance further highlighted SVPWM's advantage with only a 1.5% deviation, while SPWM and PWM showed deviations of 2.4% and 4.2%, respectively. Current ripple measurements revealed a notable reduction with SVPWM at 0.035%, SPWM at 0.08%, and PWM at 0.9%. Temperature analysis also favored SVPWM, maintaining an operational range of 50-56°C, while SPWM and PWM operated within 59-66°C and 70-86°C, respectively. Efficiency calculations reinforced SVPWM's effectiveness, achieving 88-92%, surpassing SPWM's 85-87% and PWM's 69-79%. These findings confirm that SVPWM surpasses both SPWM and PWM in key performance metrics, making it a superior choice for high-precision, energy-efficient motor control applications. The study concludes that SVPWM offers significant advantages in minimizing harmonic distortion, enhancing speed stability, reducing current ripple, and boosting overall efficiency. These insights contribute to the development of more reliable and efficient PMBLDC motor systems, aligning with industry demands for enhanced operational performance and sustainability in industrial motor applications. SVPWM's advanced control capabilities can effectively optimize BLDC motor operation while simultaneously improving overall system efficiency.

Keywords: Motor Control, Mitigation, Permanent Magnet Brushless DC Motor, Space Vector Pulse-Width Modulation, Torque Ripple.

I. INTRODUCTION

Permanent magnet-brushless DC motors work on the basis of electromagnetic induction, in which a rotating magnetic field is produced by the interaction of the rotor's permanent magnets with the stator windings. The rotor rotates as a result of interactions between the revolving magnetic field produced by the stator windings' precise sequence of energization and the rotor's permanent magnets. Electronic switches are usually used to accomplish this commutation of the stator windings, displacing the mechanical commutators used in conventional DC motors (Esmailian & Boroumand, 2022).

The broad acceptance of permanent magnet-brushless DC motors in a variety of applications is due to their distinctive design and working principles. Among other applications, these motors are widely used in robotics, computer peripherals, automotive systems, and renewable energy systems (Krishnamoorthy & Panikkar, 2024) . For permanent magnet brushless DC motors, torque ripple can have a major negative impact on performance. In applications like robots and computer peripherals that demand precise speed control, torque ripple can cause speed oscillations, which can be problematic.

These motors are a desirable option for many different applications due to their great efficiency, small size, and low maintenance needs (Deokar et al., 2021). These motors are more dependable and have a longer lifespan because they don't have mechanical commutators or brushes. They are also more efficient and require less maintenance.

Objectives

The specific objectives are to:

i. Analyze the operational characteristics of Permanent Magnet Brushless DC (PMBLDC) motors.

ii. Investigate the underlying causes of torque ripple in PMBLDC motors.

iii. Explore strategies for reducing torque ripple in PMBLDC motors.

iv. Establish the mathematical relationships and governing equations associated with torque ripple generation.

v. Implement and simulate the Space Vector Pulse-Width Modulation (SVPWM) technique in MATLAB/Simulink to model the BLDC motor settings and validate its effectiveness in minimizing torque ripple.

Permanent Magnet DC Without a Brush (PMBDC) motors are unique among other motor types because of all the benefits they provide, which make them essential in a variety of applications. One of the primary benefits mentioned by Fazdi and Hsueh (2023) is the extraordinary effectiveness of them.

Long-term energy savings and lower operating costs are also facilitated by this increased efficiency, which also improves the overall performance of systems using these motors. Similarly, DC motors that are permanent magnet-brushless have exceptional power density, as shown by Fazdi and Hsueh (2023).

Krishnamoorthy and Panikkar (2024) provide information about the varied uses of permanent magnet brushless DC motors in different sectors. Permanent magnet-brushless DC motors are preferred in computer peripherals due to their accurate speed control and small size, which makes them perfect for uses like optical and hard disk drives. Permanent magnet-brushless DC motors are also widely used in robotics applications due to their high torque-to-weight ratio, which allows for responsive and nimble motion control in robotic manipulators and unmanned aerial vehicles.

II. MATERIALS AND METHOD

Materials

The following materials are essential for the effective mitigation of torque ripple in a Permanent Magnet Brushless DC (PMBLDC) motor. Proper selection and integration of these components are important for achieving significant reduction in torque ripple. This approach combines motor design optimization, advanced control techniques, and careful material selection to ensure all components meet the required specifications for enhanced motor performance and stability.

i. Power Electronics Components

ii. Windings:

iii. Permanent Magnets

iv. Bearings

v. Control Algorithms

vi. Sensorless Controls.

Method used

The method employed in this study is the Space Vector Pulse Width Modulation (SVPWM) control method, which stands as one of the most advanced and computationally intensive pulse-width modulation (PWM) approaches for variable-frequency drive applications. SVPWM is a highly sophisticated control method that optimizes the performance of the Permanent Magnet Brushless DC (PMBLDC) motor system by enhancing torque control and reducing ripples. This intelligent technique allows for precise regulation of the motor's operational parameters, contributing to smoother and more efficient performance. Due to its superior characteristics, SVPWM is particularly effective in improving system dynamics while maintaining optimal torque minimization in the brushless DC motor.

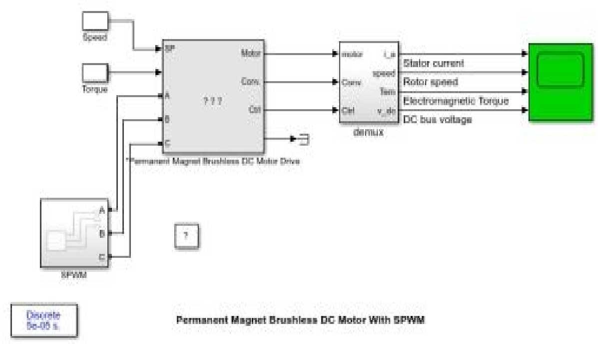

Fig 1: Model of the Permanent Magnet Brushless DC Motor Evaluating the control technique

Table 1: The PMBLDCM parameters and its comparative results in % of the Pulse Width Modulation techniques

Analysis of PMBLDC Motor Behavior

Parameter	SVPWM	SPWM	PWM
Temperature Distribution (°C)	50-56	59-66	70-86
Speed Regulation (%)	1.5	2.4	4.2
Total Harmonics Distortion (%)	6	8	10
Torque Ripples (%)	0.2	1.7	2.28
Efficiency (%)	88-92	85-87	69-79
Current (%)	0.035	0.8	0.9

To examine the behavior of a Permanent Magnet Brushless DC (PMBLDC) motor, it is essential to derive the mathematical equations that describe its electrical and mechanical dynamics. The primary equations governing the operation of the PMBLDC motor include those for back electromotive force (EMF), torque, speed, and the electrical circuit for each motor phase. The following provides a detailed explanation of these key equations:

Electrical Dynamics of SPWM

The electrical dynamics of a system describe how voltage, current, and magnetic fields interact within electrical components, influencing the overall system behavior. These dynamics are governed by fundamental principles such as Ohm's Law, Kirchhoff's Laws, and electromagnetic induction, which determine power flow, stability, and performance. Equation 3.49, 3.50 and 3.51 are equations which relate the electrical dynamics of the model presented earlier.

Where equation 3.49 looked at the voltage in phase A when current is differentiated with respect to time making the model more efficient in motoring engineering control.

$$V_a = R.i_a + L\frac{di_a}{dt} + e_a \quad (1)$$

Where equation 3.50 looked at the voltage in phase B when current is differentiated with respect to time making the dynamics more reliable in motor robotic control.

$$V_b = R.i_b + L\frac{di_b}{dt} + e_b \quad (2)$$

Where equation 3.51 looked at the voltage in phase C when current is differentiated with respect to time making the system more favorable in airspace engineering control.

$$V_c = R.i_c + L\frac{di_c}{dt} + e_c \quad (3)$$

Back EMF Equations:

The back electromotive force (EMF) equations in a Permanent Magnet Brushless DC (PMBLDC) motor describe the voltage induced in the stator windings due to the rotor's magnetic field interaction during operation. These equations are important for torque ripple analysis, as back EMF waveform shape directly affects the smoothness of torque generation and overall motor performance. Each phase's sinusoidal back EMF can be written as follows:

$$e_a = E_m \sin(\theta) \quad (4)$$

$$e_b = E_m \sin\left(\theta - \frac{2\pi}{3}\right) \quad (5)$$

$$e_c = E_m \sin\left(\theta + \frac{2\pi}{3}\right) \quad (6)$$

III. RESULTS AND DISCUSSION

Permanent Magnet Brushless DC Motor Response

The performance characteristics of a 38 kW Permanent Magnet Brushless DC (PMBLDC) motor operating at 3000 rpm with a speed ratio (S/N) of 13, as illustrated in Figure 4.1, reveal a strong correlation between phase current and motor behavior. Operating at a speed ratio of 13 S/N and a phase current of

1500A, the motor demonstrates stable torque output and efficient power delivery, both critical for achieving the desired 38 kW power output.

Table 2: Motor Parameters (Real-time data gotten from Indorama Company Port Harcourt, 2024)

V	A	HZ	KW	RPA	COSQ	n%100	% 75	% 50	Cl
Δ400	21,0	50	11,0	1470	0,83	91,4	91,7	91,0	1E3
Γ690	12,1	50	11,0	1470	0,83	91,4	91,7	91,0	1E3
Δ460	20,6	60	12,8	1765	0,84	92,4	92,6	91,2	1E3

IEC 60034 1C1:FS1 SF:1.20 1P:55 P.Date; 4/2021
S/NO:216168842 Weight: 94 kg
DS: 6309-zz NS: 6209-22

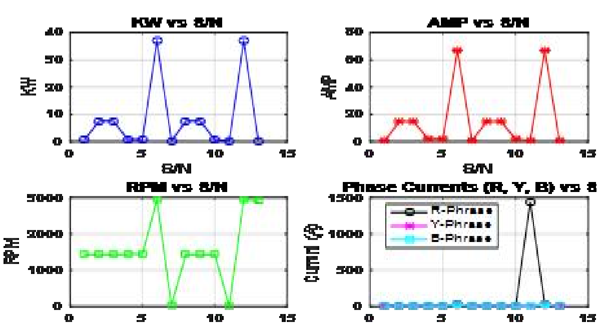

Fig 2: PMBLDC Motor Output Power Response

The graphs presented in Figure 2 illustrate the output power response of the Permanent Magnet Brushless DC Motor (PMBLDCM), showcasing its dynamic performance characteristics. The plots display variations in current, speed, amplitude, and power output, measured in kilowatts, along with their corresponding waveform behaviors.

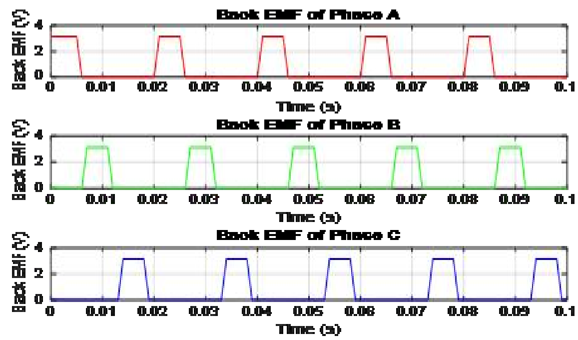

Fig 3: Back EMF Response

The back electromotive force, or back EMF, in a Permanent Magnet Brushless DC (PMBLDC) motor is depicted in Figure 3 were the effect of the back emf of each of the phases is shown. This important quantity illustrates how the motion of the rotor interacts with the magnetic field produced by the stator winding.

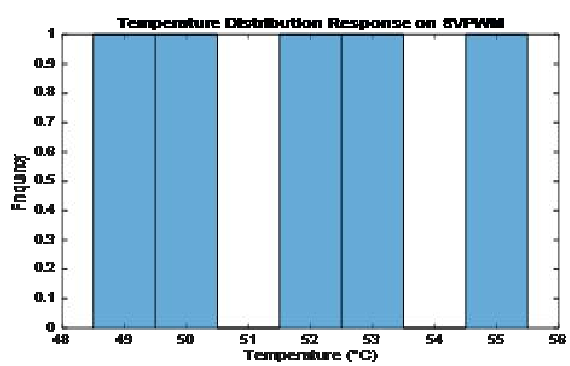

Fig 4: Temperature Distribution on SVPWM

The temperature distribution of a Permanent Magnet Brushless DC (PMBLDC) motor under Space Vector Pulse Width Modulation

(SVPWM) control is shown in Figure 4. The temperature range shown on the graph, which runs from 50 to 56 degrees Celsius, represents the motor's operating thermal performance and heat management.

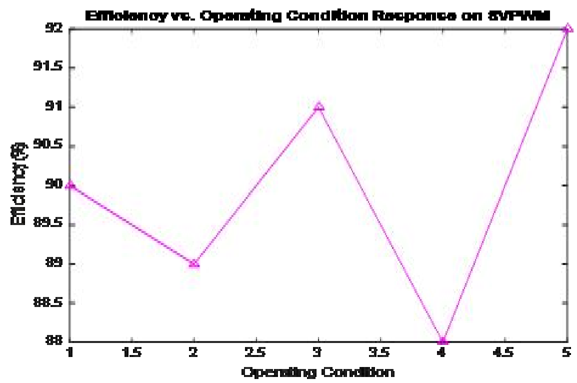

Fig 5: SVPWM Efficiency

Effectiveness of Space Vector Pulse Width Modulation (SVPWM)

Here the effectiveness of the Space Vector Pulse Width Modulation (SVPWM) technique in controlling electric motors is highlighted, particularly in improving energy efficiency, reducing power losses, and enhancing overall performance. This data evaluates how effectively SVPWM reduces power consumption and thermal losses while achieving optimal motor control outcomes.

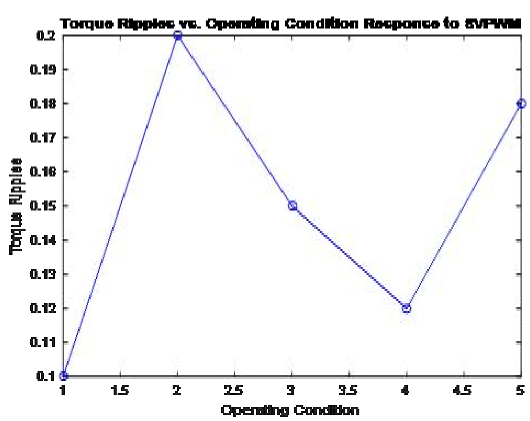

Fig 6: Torque ripples vs operating condition response to SVPWM

The torque ripples vs. operating state response to SVPWM is considered in Figure 5. When an electric motor is operated under various situations, its torque ripples can be adjusted by the use of Space Vector Pulse Width Modulation (SVPWM). This shows how torque ripples react to SVPWM management in connection to particular operating parameters like load, speed, and temperature.

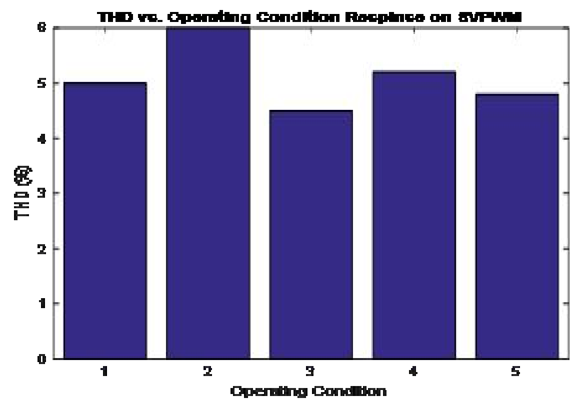

Fig 7: Total Harmonics Distortion SVPWM

This shows a bar chart of torque ripples vs. operating condition response to Space Vector Pulse Width Modulation (SVPWM) in terms of Total Harmonics Distortion (THD). This illustrates how torque ripples in an electric motor vary under various operating conditions when SVPWM is used to control them, with an emphasis on the Total Harmonics Distortion that results. This is offered to help comprehend how THD affects torque ripple while employing SVPWM across a range of operating conditions, including load, speed, and temperature.

IV. CONCLUSIONS

This study has investigated the operational performance of Permanent Magnet Brushless DC (PMBLDC) motors under various control strategies, focusing on Space Vector Pulse Width Modulation (SVPWM), Sinusoidal Pulse-Width Modulation (SPWM), and conventional Pulse Width Modulation (PWM). A thorough analysis of key performance metrics, including torque ripple suppression, total harmonic distortion (THD), speed regulation, current ripple reduction, temperature management, and overall efficiency, has provided valuable insights into the effectiveness of these modulation techniques in enhancing motor performance.

ACKNOWLEDGEMENTS

I am deeply grateful to God Almighty for the grace, strength, and insight granted to successfully complete this research titled "Mitigation of Torque Ripple in a Permanent Magnet Brushless DC Motor through Space Vector Pulse-Width Modulation Control." I sincerely appreciate the invaluable guidance, encouragement, and technical input of my supervisors, whose expertise greatly shaped the direction of this work. I also acknowledge the support of my lecturers, colleagues, and laboratory technologists who provided resources and feedback during the research process. My heartfelt thanks go to my family and friends for their continuous moral and emotional support throughout this academic journey.

REFERENCES

1. Deokar, V., Bindu, R. S., & Deokar, T. (2021). Simulation modeling and experimental validation of solar photovoltaic PMBLDC motor water pumping system. *Journal of Thermal Engineering*, *7*(6). https://doi.org/10.18186/thermal.990701

2. Esmailian, M., & Boroumand, F. (2022). Design of mechanical components for Brushless DC Motor. *Mechanic of Advanced and Smart Materials*, *2*(3). https://doi.org/10.52547/masm.2.3.347

3. Fazdi, M. F., & Hsueh, P. W. (2023). Parameters Identification of a Permanent Magnet DC Motor: A Review. In *Electronics (Switzerland)* (Vol. 12, Issue 12). https://doi.org/10.3390/electronics12122559

4. Krishnamoorthy, S., & Panikkar, P. P. K. (2024). A comprehensive review of different electric motors for electric vehicles application. *International Journal of Power Electronics and Drive Systems*, *15*(1). https://doi.org/10.11591/ijpeds.v15.i1.pp74-90