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Advanced Speed Regulation of BLDC Motors via Selective Harmonic Elimination-Based Inverter

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Abstract: *The increasing demand for efficient and precise motor control in electric vehicles and industrial applications has driven advancements in Brushless DC (BLDC) motor technology. This study proposes an advanced speed regulation strategy for BLDC motors using a Selective Harmonic Elimination (SHE)-based inverter. The primary objective is to enhance the performance of BLDC drives by minimizing lower-order harmonics in the output voltage, thereby improving torque smoothness and system efficiency. The SHE technique is employed to control the inverter's switching angles, effectively eliminating specific harmonics while maintaining the desired fundamental voltage. A detailed design of the control system, along with a simulation model, is developed to validate the effectiveness of the proposed approach. Results demonstrate significant improvements in speed stability, reduced total harmonic distortion (THD), and enhanced dynamic response. This method offers a reliable and energy-efficient solution for modern motor drive systems, particularly where high performance and reduced electromagnetic interference are critical.*

Keywords: Brushless DC (BLDC) motor, harmonic-reducing inverter, predictive speed control, pulse width modulation (PWM), selective harmonic elimination (SHE), buck converter, lithium-ion battery, battery management system (BMS), electric three-wheeler

I. INTRODUCTION

The evolution of the transportation sector has brought immense convenience and connectivity but at the cost of severe environmental consequences. Traditional vehicles fueled by petrol and diesel remain major contributors to greenhouse gas emissions, with the transportation sector accounting for approximately 37% of global CO_2 emissions as of 2021. This growing ecological concern has prompted a global shift toward electric mobility, with electric vehicles (EVs) emerging as a key solution due to their significantly lower emissions—even when indirect power generation sources are considered. Research has shown that EVs can emit nearly one-third of the carbon dioxide produced by internal combustion engine (ICE) vehicles, positioning them as a vital component in combating climate change [1].

Electric mobility represents more than just a cleaner alternative; it is a transformative force driving innovation in urban infrastructure and energy policy. Countries like India are steering toward a greener future by pledging to derive 40% of their electricity from renewable sources by 2030, aligning national ambitions with global climate targets. Furthermore, the rise of smart city frameworks emphasizes the integration of EVs into intelligent transportation systems, shared mobility platforms, and autonomous networks, paving the way for smarter and more sustainable urban environments.

Policy support and technological advancements are accelerating this transition. Both government initiatives and private sector investments are fueling the development of efficient, scalable EV technologies. Financial incentives, such as subsidies and tax reductions, are being introduced to encourage adoption among consumers and manufacturers alike. The active research and patent contributions by automotive leaders such as Toyota, Honda, and Panasonic highlight the rapid pace of innovation in electric drivetrain and energy management systems.

Among the many technical challenges in EV development, achieving precise and efficient speed control in Brushless DC (BLDC) motors remains critical. BLDC motors are widely preferred in electric vehicles due to their high efficiency, compact design, and superior torque-speed characteristics. However, managing their performance requires advanced

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control strategies to ensure reliability and responsiveness under varying load conditions. This paper explores a novel approach to speed regulation using a Selective Harmonic Elimination (SHE)-based inverter to improve motor performance while reducing harmonic distortion and power losses.

The paper is structured as follows: Section 1 presents the background and motivation for electric mobility and the need for improved motor control. Section 2 details the architecture of the proposed system, including motor specifications and the SHE control strategy. Section 3 focuses on system modeling and simulation methodology using MATLAB. Section 4 discusses the simulation results and their implications. Finally, Section 5 offers concluding remarks and outlines potential directions for future research[2].

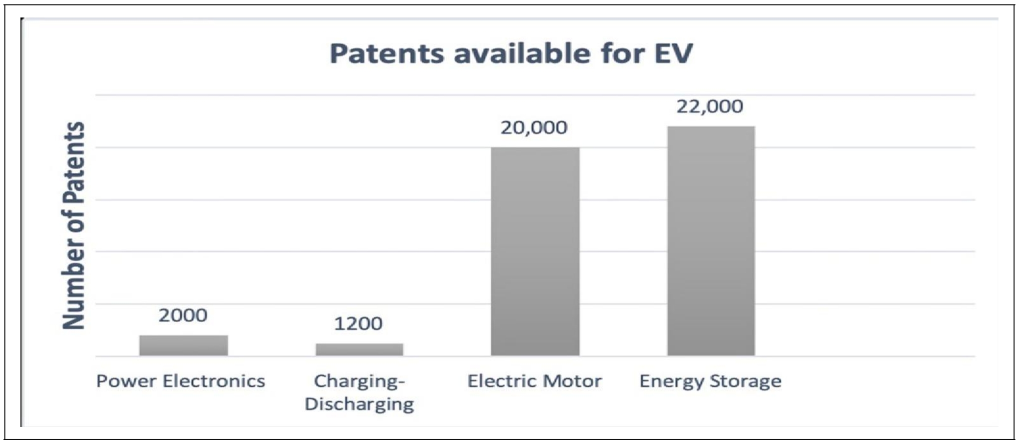

Figure 1: Intellectual property filings across major EV components reveal global R&D trends and industry focus areas for promoting the widespread adoption of electric vehicles [2].

II. DETAIL DESCRIPTION OF THE SYSTEM

The proposed system is designed to achieve precise and efficient speed control of a Brushless DC (BLDC) motor using a Selective Harmonic Elimination (SHE)-based inverter. This approach addresses the challenges associated with torque ripple, power quality, and harmonic distortion that typically affect the performance of BLDC motors, particularly in electric vehicle (EV) applications.

A. Brushless DC Motor Overview

BLDC motors are increasingly favored in automotive and industrial applications due to their high power density, excellent efficiency, and minimal maintenance requirements. The motor consists of a permanent magnet rotor and a stator with three-phase windings. Commutation is electronically controlled using position feedback from Hall sensors or sensorless estimation methods. The trapezoidal back-EMF and electronic commutation enable high-speed operation with superior dynamic response.

B. Inverter Topology and Harmonic Mitigation

The inverter used in this system is a three-phase voltage source inverter (VSI), which converts DC power from the battery or supply into controlled AC signals for the motor. The key innovation lies in the implementation of the Selective Harmonic Elimination (SHE) technique in generating the switching patterns. Instead of using conventional Pulse Width Modulation (PWM), SHE is employed to selectively eliminate lower-order harmonics that contribute to torque ripple and electromagnetic interference. By solving nonlinear transcendental equations offline, optimal switching angles are calculated and applied to control the inverter output waveform [3].

C. Control Strategy and Speed Regulation

The speed of the BLDC motor is regulated through a closed-loop control system that includes a Proportional-Integral (PI) controller. The reference speed is compared with the actual speed feedback from the motor, and the error signal is processed by the controller to adjust the inverter's switching commands accordingly. SHE-based control ensures that only the fundamental component is used for torque production while suppressing selected harmonics, improving overall motor performance and reducing power losses.

D. System Simulation and Implementation Platform

The system model is developed and simulated using MATLAB/Simulink. This environment provides flexibility to implement SHE switching logic, control algorithms, and motor dynamics within a single framework. The model incorporates electrical and mechanical characteristics of the BLDC motor, the inverter control logic, and the speed regulation loop. Simulation results validate the effectiveness of the proposed method in minimizing harmonic distortion and achieving smooth, responsive speed control.

A. Speed Control of BLDC Motor Using Selective Harmonic Elimination (SHE)

Controlling the speed of a Brushless DC (BLDC) motor with high precision and efficiency is vital in applications such as electric vehicles, robotics, and automation systems. Traditional methods like Sinusoidal or Trapezoidal Pulse Width Modulation (PWM) often result in unwanted harmonic distortion, leading to torque ripple, increased switching losses, and reduced motor lifespan. To overcome these limitations, the proposed system utilizes the **Selective Harmonic Elimination (SHE)** technique for improved speed regulation and harmonic control.

SHE is a precomputed, analytical modulation method that involves determining specific switching angles to eliminate selected lower-order harmonics from the inverter output. These harmonics, if not mitigated, can significantly degrade motor performance by introducing pulsating torques and inefficiencies. Unlike conventional PWM that switches at high frequencies across each cycle, SHE applies a finite number of optimized switching transitions per half-cycle to minimize switching losses while maintaining the desired fundamental voltage component.

In this system, SHE is used in conjunction with a closed-loop speed control strategy. A Proportional-Integral (PI) controller processes the speed error—calculated as the difference between the reference and actual motor speeds—to generate the appropriate modulation index. This index determines the magnitude of the output voltage and is used to calculate the corresponding switching angles via SHE algorithms. The inverter then applies these switching angles to generate a voltage waveform with reduced harmonic content, leading to smoother torque and improved efficiency.

By eliminating dominant low-order harmonics such as the 5th, 7th, or 11th, SHE ensures cleaner output waveforms and better electromagnetic compatibility. This is especially important in EV systems, where noise reduction, battery efficiency, and system reliability are critical.

The integration of SHE into the BLDC motor drive system results in superior speed control characteristics, including reduced total harmonic distortion (THD), lower torque ripple, and enhanced dynamic response. Moreover, the reduction in switching frequency contributes to lower thermal stress on power electronic components, thereby improving the overall durability of the motor drive system [4].

B. Detailed Designing of Buck DC/DC Converter

The **Buck DC/DC converter** plays a critical role in regulating voltage levels within electric drive systems, especially in electric vehicles (EVs) and motor control applications. In the proposed BLDC motor speed regulation system, the buck converter is employed to step down the higher DC bus voltage to a level suitable for the inverter and motor operation. Its compact design, high efficiency, and ability to deliver a stable output voltage make it an ideal choice for powering control circuits and sensitive electronic components.

1. Operating Principle

A buck converter, also known as a step-down converter, operates by switching a transistor (typically a MOSFET or IGBT) on and off at high frequencies. During the **ON** period, energy is stored in the inductor as current flows from the

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input to the output. In the **OFF** period, the inductor releases its stored energy to the load through a freewheeling diode, maintaining current flow even when the switch is open. This continuous energy transfer results in an output voltage that is lower than the input voltage.

2. Key Components and Parameters

Switching Device (MOSFET): Handles the high-frequency switching required to regulate the output. It should have low on-resistance and fast switching characteristics to reduce power losses.

Diode: Provides a current path when the switch is off. A fast-recovery diode or Schottky diode is preferred to minimize switching losses.

Inductor (L): Determines the rate of current change and stores energy. Its value is selected based on the desired ripple current and load conditions.

Capacitor (C): Smooths the output voltage and reduces ripple. A low ESR capacitor enhances filtering performance.

Controller (PWM IC or Microcontroller): Generates the switching signal based on feedback from the output voltage [5].

3. Design Equations

To achieve a desired output voltage (V_o) from an input voltage (V_{in}), the basic duty cycle D for a buck converter is:

$$D = \frac{V_o}{V_{in}}$$

The inductor value is chosen using:

$$L = \frac{(V_{in} - V_o) \cdot D}{f_s \cdot \Delta I_L}$$

Where:

- f_s is the switching frequency,
- ΔI_L is the inductor current ripple.

The output capacitor value is determined to meet a desired voltage ripple ΔV_o:

$$C = \frac{\Delta I_L}{8 \cdot f_s \cdot \Delta V_o}$$

4. Integration with BLDC Motor System

In this system, the buck converter feeds a controlled DC voltage to the three-phase inverter that drives the BLDC motor. By dynamically adjusting the output voltage of the buck converter, the system can regulate the voltage applied to the motor under various operating conditions, such as startup, acceleration, and steady-state operation. This enhances both the energy efficiency and the stability of the overall drive system.

Furthermore, the converter design is optimized to ensure minimal power loss, electromagnetic interference, and thermal stress. Careful selection of switching frequency and component ratings ensures that the converter operates reliably across the full range of motor speeds and load demands

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C. Modeling of Controller

In any electric drive system, particularly those involving BLDC motors, a well-designed controller is essential to maintain desired performance under varying load and operating conditions. In the proposed system, a **Proportional-Integral (PI) controller** is modeled to manage the motor speed by adjusting the output of the Selective Harmonic Elimination (SHE)-based inverter. The controller ensures that the motor tracks the desired speed reference with minimal steady-state error and fast dynamic response.

1. Control Objective

The main goal of the controller is to regulate the speed of the BLDC motor accurately by minimizing the error between the reference speed and the actual speed obtained from the motor's feedback. This is

2. PI Controller Structure

A PI controller is selected due to its simplicity, ease of implementation, and effectiveness in handling steady-state errors without introducing significant phase lag. The controller output u(t)u(t)u(t), which drives the modulation process These gains are tuned either manually or via optimization techniques to achieve desired performance in terms of rise time, settling time, and overshoot.

3. Implementation and Feedback Loop

The actual speed of the motor is measured either through Hall-effect sensors or sensorless estimation techniques. This real-time feedback is continuously compared to the speed command. The resulting error is processed by the PI controller, which determines the modulation index for the SHE-based inverter. This index adjusts the voltage magnitude applied to the motor, thereby controlling its speed.

A high sampling frequency is maintained to ensure precise control and fast system response. The system is modeled and simulated in MATLAB/Simulink, which provides a dynamic environment to test the controller's performance under different load and speed conditions [6].

4. Performance and Tuning

The effectiveness of the controller is evaluated based on parameters like:

Settling time

Steady-state error

Rise time

Torque ripple

Through simulation and tuning, the PI gains are adjusted to balance system stability with responsiveness. Additionally, anti-windup mechanisms may be incorporated to prevent integrator saturation during sudden changes in reference speed.

D. Inverter Topology

The inverter is a central component in the BLDC motor drive system, acting as the interface between the DC power source and the three-phase AC motor. In the proposed system, a **three-phase Voltage Source Inverter (VSI)** topology is employed, integrated with **Selective Harmonic Elimination (SHE)** for optimized switching performance. The inverter's design not only facilitates efficient energy conversion but also plays a critical role in harmonic reduction and precise speed control.

1. Structure of the Inverter

The inverter consists of **six power semiconductor switches** (typically IGBTs or MOSFETs) arranged in a bridge configuration. Each leg of the inverter corresponds to one of the three motor phases—A, B, and C—with two switches per leg (upper and lower). The operation of the switches is controlled to produce a quasi-square or modulated AC waveform from a DC input.

Upper switches (Q1, Q3, Q5): Connect motor terminals to the positive DC bus.

Lower switches (Q2, Q4, Q6): Connect motor terminals to the negative DC bus.

To prevent short-circuiting the DC bus, proper**dead-time** is introduced between the switching of the upper and lower switches in each leg.

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2. SHE-Based Switching Strategy

Unlike traditional PWM methods, the proposed inverter uses **Selective Harmonic Elimination (SHE)** to generate the gate signals. SHE determines specific switching angles within each half-cycle to eliminate selected low-order harmonics (e.g., 5th, 7th, 11th) while retaining the desired fundamental voltage. This technique significantly improves the waveform quality at the motor terminals, reducing torque ripple and electromagnetic interference.

The switching angles are precomputed by solving nonlinear transcendental equations based on the desired fundamental amplitude and harmonic elimination targets. These angles are then used to trigger the inverter switches, resulting in a stepped waveform with minimized harmonic content [7].

3. Benefits of the Selected Topology

The chosen three-phase VSI topology, when combined with the SHE technique, offers several advantages:

Improved Power Quality: Elimination of dominant harmonics leads to reduced Total Harmonic Distortion (THD).

Reduced Switching Losses: Fewer switching transitions per cycle compared to high-frequency PWM methods.

Enhanced Motor Performance: Smoother torque output, better thermal management, and improved efficiency[8].

Modularity and Scalability: Easy integration with different control algorithms and hardware platforms.

4. Protection and Reliability Considerations

To ensure safe operation, the inverter design includes:

Gate driver isolation for signal integrity,

Snubber circuits for voltage spike suppression,

Current and temperature sensing for fault detection,

Shoot-through prevention logic to avoid simultaneous conduction of switches in the same leg.

The inverter topology is simulated within MATLAB/Simulink alongside the BLDC motor and control model, enabling comprehensive analysis of dynamic behavior under varying load and speed conditions [9,10].

III. SIMULATION AND RESULT DISCUSSION

The relationship between speed and torque was analyzed, revealing an inverse correlation where torque decreases as speed rises, as illustrated in Figure 4.

This error metric confirms the model's capability to effectively replicate the dynamic behavior of the system across different operating scenarios. Notably, the proposed model reaches the maximum speed faster than the benchmark reference; while the standard driving cycle requires over 6 seconds to achieve top speed, the model accomplishes this in just 2 seconds, as presented in Figure 7. Additionally, the model effectively maintains steady speed despite fluctuations, which is clearly visible in the same figure.

From Figure 8, it is evident that the battery's charge level and voltage decline as the operation time increases, leading to a corresponding drop in battery power output. Finally, Figure 9 again confirms the observed inverse relationship between speed and torque, where torque diminishes as speed increases.

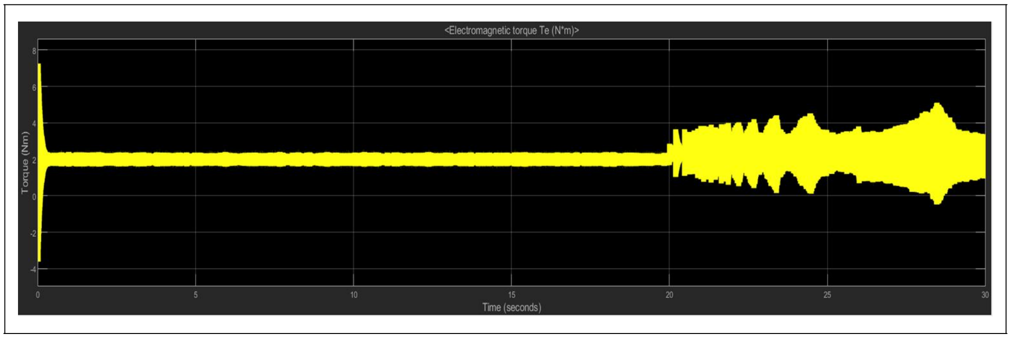

Figure4:Torque

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At motor startup, a substantial current surge is drawn from the battery, depicted in Figure 5. Once the motor attains steady-tate operation, the current stabilizes and remains relatively constant. During acceleration phases, an increase in current consumption is observed, as shown in Figure 6, which also highlights the corresponding rise in battery discharge rate with increasing speed.

A comparison between the reference speed and actual motor speed demonstrates a mean squared error of 6%, indicating a high degree of accuracy in the simulation model.

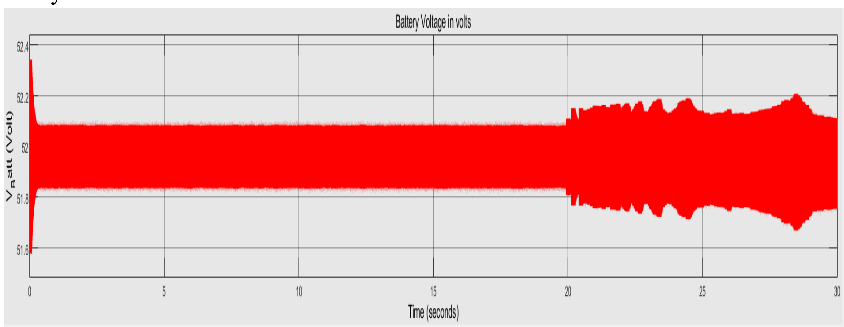

Figure 5: Voltage battery discharge

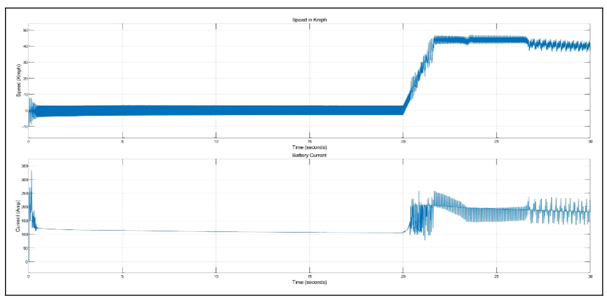

Figure 6: Comparison between Speed and Current

IV. CONCLUSION

This research presents an effective method for controlling the speed of BLDC motors using a Selective Harmonic Elimination (SHE)-based inverter. The approach significantly reduces lower-order harmonics in the inverter output, leading to smoother torque and better overall motor performance. Simulation results confirm that SHE enhances speed regulation, lowers total harmonic distortion (THD), and improves system efficiency compared to conventional control methods. The findings highlight the potential of integrating SHE techniques in advanced motor drive applications, especially where high precision and energy optimization are essential. Future work may involve real-time implementation and performance testing under varying load and temperature .

REFERENCES

[1] Statista, "Transport co2 emission share bytype," https://www.statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown/, online; [Accessed:Apr. 22, 2024].

[2] S. Feng and C. L. Magee, "Technological development of key domainsin electric vehicles: Improvement rates, technology trajectories and keyassignees,"*AppliedEnergy*,vol.260,p.114264,Feb.2020.[Online].

[3] Available: http://dx.doi.org/10.1016/j.apenergy.2019.114264

[4] S. Rout and S. K. Samal, "Optimized designed controlled driver circuitof a three-wheeled electric vehicle and implemented in hardware,"*Electrical Engineering*, vol. 106, no. 2, p. 1715–1725, Oct. 2023.[Online]. Available: http://dx.doi.org/10.1007/s00202-023-02028-6

[5] R. Kumar, P. Kumar, B. Kumar, P. Singh, R. Kumar, and A. Kumar,"Design and analysis of high performance of a bldc motor for electricvehicle," in *2022 2nd International Conference on Emerging*

Frontiersin Electrical and Electronic Technologies (ICEFEET).IEEE, Jun.2022. [Online]. Available: http://dx.doi.org/10.1109/ICEFEET51821.2022.9848307

[6] T. Mistry, S. K. Bhatta, A. K. Senapati, and A. Agarwal, "Performanceimprovement of induction motor by selective harmonic elimination(she) using newton raphson (n-r) method," in *2015 InternationalConference on Energy Systems and Applications*. IEEE, Oct. 2015.[Online]. Available: http://dx.doi.org/10.1109/ICESA.2015.7503372

[7] P.KalkalandA.V.R.Teja,"Selectiveharmoniceliminationpwm technique based on higher order sliding modes: Generalizedformulation," *IEEE Journal of Emerging and Selected Topics in PowerElectronics*, vol. 12, no. 1, p. 631–640, Feb. 2024. [Online]. Availablehttp://dx.doi.org/10.1109/JESTPE.2023.3342125

[8] S.U¨rgu¨n,H.Yigˇit,andS.Mirjalili,"Investigationofrecentmetaheuristics based selective harmonic elimination problem fordifferentlevelsofmultilevelinverters,"*Electronics*,vol.12,no.4,p. 1058, Feb. 2023. [Online]. Available: http://dx.doi.org/10.3390/electronics12041058

[9] M. Ahmed, A. Sheir, and M. Orabi, "Real-time solution andimplementation of selective harmonic elimination of seven-levelmultilevel inverter," *IEEE Journal of Emerging and Selected Topics inPowerElectronics*,vol.5,no.4,p.1700–1709,Dec.2017. [Online].Available:http://dx.doi.org/10.1109/JESTPE.2017.2746760

[10] C. Cochrane, T. Muneer, and B. Fraser, "Design of an electricallypoweredrickshaw,foruseinindia,"*Energies*,vol.12,no.17,p.3346,Aug.2019.[Online].Available:http://dx.doi.org/10.3390/en12173346

[11] A R. M. Siddique and M. S. Kaiser, "Financial and performanceanalyses of microcontroller based solar-powered autorickshaw for adeveloping country," *Journal of Engineering*, vol. 2016, p. 1–8, 2016.[Online]. Available: http://dx.doi.org/10.1155/2016/5246435