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Novel Battery Management with Fuzzy Tuned Low Voltage Chopper and Machine Learning Controlled Drive for Electric Vehicle Battery Management: A Pathway Towards SDG

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Abstract

Electric vehicles have a significant impact on the SDGs, specifically climate action, affordable and clean energy, and responsible consumption and production patterns. The present work focuses on a battery management system to effectively utilize the power from the battery to drive the brushless DC motor (BLDC) by tuning the low-voltage buck boost converter as a chopper circuit with fuzzy. The photovoltaic system acts as an additional source to charge the battery when the battery is not connected to the load, and at running conditions, fuzzy logic control enhances efficiency and provides smooth, adaptive control under varying load conditions. Also, the machine learning technique is used for drive control and automation operations. The energy in the BLDC is regulated by managing the voltage and current in a photovoltaic-powered low-voltage chopper by tuning the proportional integral derivative (PID) controller for an ideal balance between reliability and a quicker reaction. The K-Nearest Neighbour (KNN) machine learning algorithm, due to its simplicity and effectiveness in classification, ensures the enhanced reliability and efficiency of the BLDC motor system with commutation and speed control. When fuzzy and the KNN machine learning algorithm are used, the development of systems for control and automation is expedited. The work also shows the results of a study that compared the interoperability of proportionate machine learning and fuzzy controlling algorithms developed with MATLAB. In order to do a critical analysis of the data, the results are compared with the graphs. The integration of the Internet of Things (IoT) and cloud technology with the use of KNN for BLDC motor control can enhance system proficiency with monitoring and display of the observed voltage, current values of the motor, sensorless control, fault diagnosis, and predictive maintenance. The work is also connected with the SDG and impacts due to the efficient operation of electric vehicles.

Keywords: Photovoltaic System, Fuzzy Logic Controller, Internet of Things (IoT), BLDC Motor, Battery Management System

1. Introduction

Electric vehicles have a significant advantage over regular vehicles in terms of zero emissions. They emit fewer greenhouse gas emissions than gasoline-powered automobiles. They help to reduce the city's total air pollution levels. Because there would be no exhaust emissions, the carbon footprint will be reduced. An EV powered by an electric motor that gets power from the battery and can charge externally. Thus, an essential component in guaranteeing the security of electric vehicles is a battery management system (BMS), which controls the battery. By making sure that the battery works within its safe working range, it protects both the user and the battery. Mohammadreza Aghaei et al [1] proposed Photovoltaic system (PV) has the potential of producing free electricity and operating solar-powered vehicles. Due to the way they operate, portable solar panels typically generate significantly minimal energy. A.Gurung et al. and Rathore, N et.al [2], [3] proposed that photovoltaic solar power system electrically charges batteries and controls the motor via converters. The solar cells will charge the lithium-ion batteries, which are rechargeable batteries generally used for energy storage. The chopper circuit, namely called DC- DC converters, are a sort of power converter that converts a direct current source from a specific voltage form to another.

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The chopper circuits are specifically used in the electric vehicle industry because of simple in construction with the basic components of electronic switches, inductor and capacitor is shown by Mohamed, N et al [4] and M. Safayatullah et al [5]. These components perform the operation based on the load variation and decide the flow of load voltage from the source. The chopper circuits are basically used in photovoltaic connected system for their efficient utilization of the source and helps in the battery management system through effective power tracking methodologies P.Vinoth Kumar et al [6]. The need of electric vehicles with photovoltaic is gaining its importance in industrial, commercial and Agro needs for daily applications, hence research in the selection of suitable voltage converter is improved. The demerit in the chopper circuit is high switching frequency and size of the components used. At an excessive duty cycle, it draws a generous quantity of input current from the source. The problem is that in going from off to on or vice-verse there is a short time that the switcher is in transition and relatively high power is dissipated during the transition. The transition time becomes a higher percentage of the duty cycle the higher the switching frequency. Therefore, the transistor losses become higher too. The components utilized in a DC-DC converter can suffer severe issues from an excessive quantity of current. Hence, the chopper circuit offer stable DC input signal is converted to direct current signal with a decreased output value. As a result, it is intended to generate a dc signal as the output, which has a low magnitude in comparison to the dc signal input as explained in [7], [8] and [9], [10], [11] shows the efficient DC-DC converter for the EV applications.

Buck converters are used to lower the voltage, while boost converters are switch-mode converters that measure and enhance the input voltage as proposed in the work done by Mondzik, A et al [12]. The efficiency of these motors is based on the performance of these converters. Due to its minimal maintenance requirements and high-power density, BLDC motors are largely employed in the space, robotics, and pharmaceutical sectors are analyzed by Prabhu, N. et.al [13], Lee, J G et .al [14], Ramya, L.N. and K.Xia [15]. High-speed conventional control methods will not allow for adequate system switching, causing massive power losses. The EV system will encounter unnecessary power flow because of this issue. As a result, a revolutionary concept for controlling brushless DC motors was recently implemented was shown in Hussain. M.T et.al [16] and Thangavel, S. et.al [17]. The operations in this work will be carried out utilizing fuzzy logic and computational techniques, and the Node-MCU will oversee managing their data. This study describes the design of a minimized voltage Buck-Boost converter that generates efficient output by driving a brushless DC motor with photovoltaic energy employing fuzzy logic and machine learning. The precise position of the photovoltaic systems as power source and the methodology used to calculate the acceleration velocity are the two most crucial variables.

Fuzzy logic is used in this processing to offer simple responses to all kinds of complicated challenges Aishwarya, M et.al [18]. In order to achieve excellent results, this article uses machine learning techniques for fuzzy logic, which enhances the efficiency of system and lowers switch losses. The buck-boost conversion device is investigated in this context, with fuzzy and machine learning methodologies utilized to explain the findings and highlight the predicted error. To control the operation, these methods and algorithms use specified data. The K-nearest neighbour (K-NN) models are the main emphasis of the technique utilised in this work, which is used for efficiency as shown by Vinoth Kumar.P et.al [19]. The fuzzy logic implemented by the simulation, and the ML idea will control the data. Machine learning algorithms are used to construct prototypical signals, recognize combinations, and make exact changes to the output signals as proposed by Chatterjee.D et.al [20] and Nelson L. M.al [21]. After that, this to be emulated and the brushless DC motor's speed setting to be presented.

SDG 7, which aims to guarantee that everyone has access to modern, affordable, dependable, and sustainable energy, is greatly aided by EVs. Also, EVs are in line with SDG 13, which demands immediate action to mitigate the effects of climate change. Notable is also SDG 9 that emphasizes creating resilient infrastructure, encouraging equitable and sustainable industry, and supporting development. To make towns and settlements equitable, secure, adaptable, and environmentally friendly, SDG 11 is also partially achieved with the help of EVs. Controlling the quality of the air is one of the main problems in cities, since controlling the quality of the air is one of the main problems in cities. EVs present a more environmentally friendly way to consume and produce goods, particularly when combined with a circular economy strategy that recycles and reuses EV batteries and it has connectivity with the SDG 12 also. Electric vehicles also have connection with SDG3 and SDG 8 as the details referred from the refs [22], [23], [24]. The work also focuses on electric vehicles and sustainable development goals.

The work is organized as Section II. The proposed methodology explains how the proposed low voltage, buck and boost converters operate and are analyzed when connected to a voltage source. The switching modes of the converter are explained in this section. Section III follows the experimental analysis of the proposed work with the MATLAB simulation software. Section IV explains the experimental setup of the proposed converter and the connection of the IoT platform with the proposed system. Section V explains the conclusion and future scope of the work. Section V explains how the smart battery management system promotes sustainable development goals and how specific goals are achieved.

2. The Proposed Method/Algorithm

This section provides an explanation of the switching that will be used in the proposed circuit. In the proposed low voltage buck and boost converter, the modes of operation provide a description of the four steps of switching operations that are carried out by the converter.

2.1. Switching Mode 1-Boost Operation

As can be seen in figure 1(a), the chopper circuit goes through the process of activating the MOSFET (Q1 and Q2) and then switching the diodes (D1 and D2) in the opposite direction to complete this duty. It is the chopper circuit that will provide the holding current (iL), and the voltage supply (Vdc) will be controlled by the voltage in the inductor. The chopper circuit will work in boost mode.

$$di_L/dt = V_{dc}/L \quad (1)$$

The equation 1 shows the change of inductor current in the circuit when the load is connected to the circuit and voltage is applied to the circuit.

$$dV_{out}/dt = -V_{out}/RC_{out} \quad (2)$$

The equation 2 show the output of the boost converter circuit and V_out is the output voltage with the flow of current in the capacitor.

2.2. Switching Mode 2- Buck Operation

This mode describes a chopper circuit in buck operation when one switch (Q1) is ON and the other is OFF, as depicted in figure 1(b). The diode (D1) is biased in the opposite direction, and diode 2 operates in the forward direction. In a buck converter, also known as a step-down chopper, the output voltage is lower than the input voltage. The basic operation of a buck converter can be understood through its main components and their functions with the circuit.

$$di_L/dt = (V_C - V_{out} + V_{dc})/L \quad (3)$$

$$dV_C/dt = -i_L/C \quad (4)$$

$$dV_{out}/dt = i_L/C_{out} - V_{out}/RC_{out} \quad (5)$$

The equation 4 shows the change of inductor current in the buck operation of the circuit when connected to the load, 5 and 6 depicts the output voltage (V_out) with the flow of current in the capacitor.

2.3. Switching Mode 3- Boost and Buck Mode

The both boost and buck functionalities are integrated is essential in electric vehicles (EVs) for managing power flow between the high-voltage battery pack and the various subsystems that may require different voltage levels. This bidirectional DC-DC converter can operate in both directions: it can step up the voltage (boost mode) and step down the voltage (buck mode). This bidirectionality is crucial for efficiently managing energy flow, especially in systems where energy may need to be transferred in both directions, such as between the battery and the motor during driving and regenerative braking The boost chopper circuit operates when switch Q2 is operated, and the buck operation is performed when switch Q1 is switched OFF. The diode (D1) operates in forward mode, and the diode (D2) operates in reverse mode. Based on the duty cycle, the final output voltage (Vo) connected to the load exceeds the input voltage (Vi) due to the current through the inductor (iL) and capacitor connected in the circuit as shown in equation 6, 7 and 8.

$$\frac{di_L}{dt}=\frac{-V_C+V_{dc}}{L} \tag{6}$$

$$\frac{dV_C}{dt}=\frac{i_L}{C} \tag{7}$$

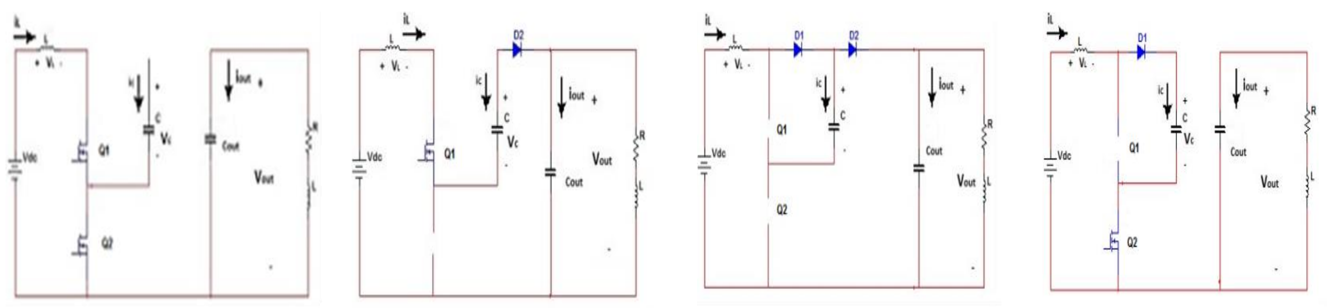
$$\frac{dV_{out}}{dt}=-\frac{V_{out}}{RC_{out}} \tag{8}$$

2.4. Switching Mode 4- Buck and Boost Mode

The buck-boost converter can function in both buck (step-down) and boost (step-up) modes, depending on the direction of current flow and the control strategy. This versatility is achieved using the inductors, capacitors, switches, and diodes which is depicted in the equations 9 and 10. The switches operate alternately when one switch (Q2) is switched ON and another (Q1) is turned OFF. This operation occurs when D1 forwards and D2 reverses the direction during diode switching. In this operation, both capacitors will conduct the inductor current (iL), which is the result of current flowing through an inductor is shown in figure 1.

$$\frac{di_L}{dt}=\frac{-V_{out}+V_{in}}{L} \tag{9}$$

$$\frac{dV_{out}}{dt}=\frac{i_L}{C_{out}}-\frac{V_{out}}{RC_{out}} \tag{10}$$



(a) (b) (c) (d)

Figure 1. Low voltage chopper circuit

These switching mode operations provide a clear insight into the flow of current through the diode and capacitor as in figure 1. The sequential switching operations at each mode provide the need for efficient control that needs to be employed with the fuzzy. The efficient fuzzy control employed in the work makes the switching operation efficient with a quick response. The experimental analysis of this low voltage DC-DC converter connected to a load is simulated with the MATLAB software. The operation of the converter connected to the photovoltaic system is explained in Section III

3. Experimental Analysis of the Proposed Work

3.1. Proposed Chopper Circuit Operation

Figure 2 displays the distinct functioning of the chopper circuit with buck and boost coupled, as well as the results of the BLDC motor's operating, which represent the effectiveness level. The charge is generated first by a photovoltaic with a 17-volt input voltage. The buck converter then lowers the voltage to a minimum level of 5 volts. In case, the boost circuit is utilized the voltage will be improved and the efficiency of the motor is increased. This work promotes effective usage with the chopper circuits as well as the discharge of voltage in the batter used in electric vehicle applications [15]. Figure 3 shows the BLDC motor operation.

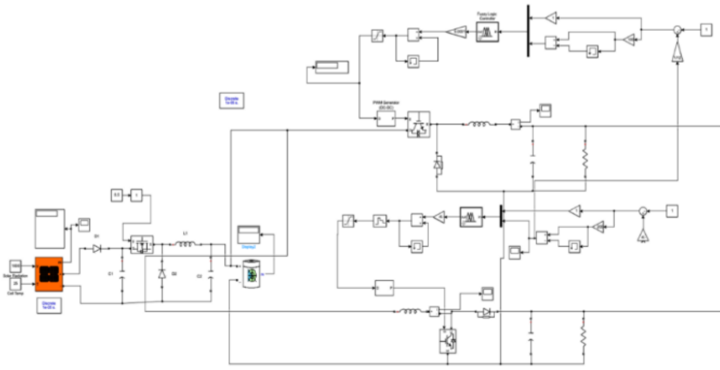
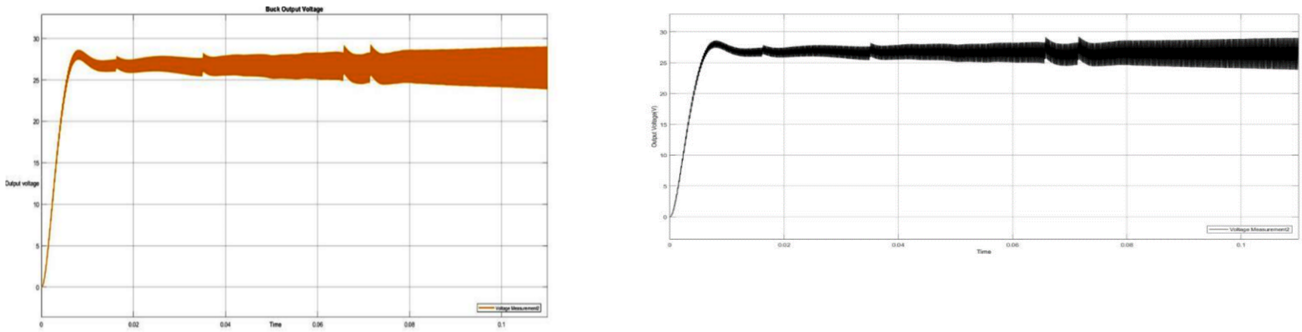


Figure 2. Simulation of the proposed chopper circuit

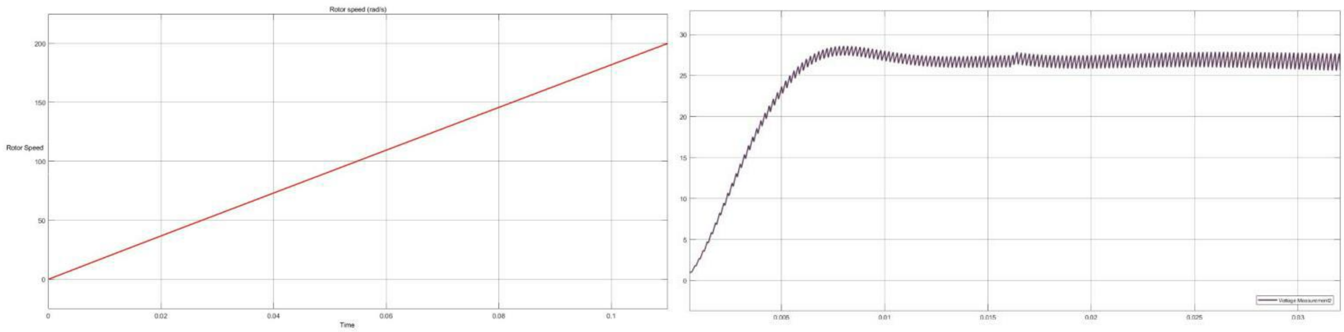


(a) (b)

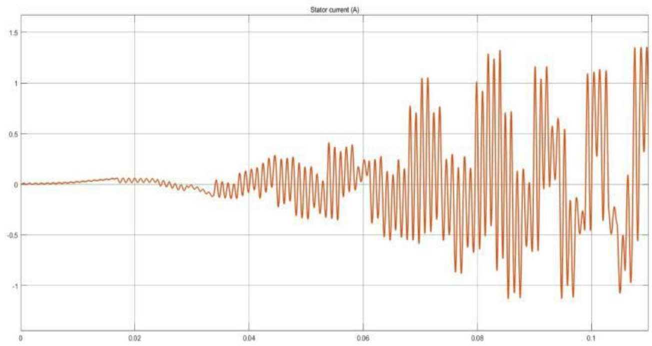
Figure 3. BLDC motor operation

Figure 3(a) and figure 3(b) exhibit the voltage at the output of the buck as a chopper and its activity with regard to time, and the buck converter function is launched from the beginning level to increase the BLDC motor's efficiency [16], [17], [18], [19], [20]. The voltage increases first, and the buck converter reduces it. Based on how the converter is running, the switching techniques allow the voltage stress in the switches to be enhanced or lessened [21], [22]. The converter that generates boost only operates when needed with this technology, increasing efficiency.

The output voltage and current of the chopper are shown in figure 4 (a), and the current and voltage acting as the output across the load are shown in figure 4 (b) and figure 4 (c).



(a) (b)



(c)

Figure 4. Output voltage and current of the chopper circuit

The simulation portion showed the fuzzy logic in action, and the machine learning idea will be used to manipulate the data. Fuzzy logic enhances the efficiency of power usage, which is critical for extending battery life. It optimizes the voltage and current supplied to the BLDC motor, ensuring that the battery is not overburdened and that energy is used efficiently. This leads to longer battery life and reduces the frequency of recharging, which is essential for applications like electric vehicles or portable devices. Fuzzy logic also provides smooth and adaptive control, which minimizes energy waste and maximizes performance, even under varying load conditions. This adaptability helps in maintaining consistent battery performance, as the system can adjust to changes without manual intervention. Additionally, the robust performance of fuzzy logic controllers ensures that the battery operates within safe parameters, protecting it from damage due to overcurrent or voltage fluctuations. This results in a more reliable and durable battery management system. The simplified design process of fuzzy logic controllers means they can be implemented more quickly and with less complexity, making it easier to integrate effective battery management into a wide range of applications. Overall, the use of fuzzy logic in BLDC motor control with a buck-boost converter significantly improves battery efficiency, lifespan, and reliability.

Using the K-Nearest Neighbors (KNN) algorithm in BLDC motor control with a buck-boost converter for battery management adapts to various operating conditions by learning from historical data, ensuring optimal performance and improved efficiency by predicting the best control actions. This adaptability helps reduce energy consumption and extend battery life. KNN also prevents overcharging and over discharging by predicting optimal rates, protecting the battery. It enhances predictive maintenance by identifying patterns and anomalies, enabling proactive interventions. Real-time decision-making capabilities ensure the system always operates efficiently. KNN's simplicity, scalability, and ease of implementation make it a practical choice for integrating machine learning into motor control. Additionally, its accuracy improves with more data, leading to better decision-making over time and enhances system adaptability, efficiency, and longevity, making the system more effective and reliable.

IoT-based monitoring in BLDC motor control with a buck-boost converter significantly improves battery management by providing real-time data, enabling remote monitoring, facilitating predictive maintenance, enhancing efficiency, and ensuring automated control adjustments. Using IoT and Thing Speak in BLDC motor control significantly enhances monitoring and management. IoT sensors collect real-time data on motor speed, voltage, current, and temperature, which is transmitted to Thing Speak, an IoT analytics platform. ThingSpeak visualizes this data, enabling operators to monitor performance remotely and in real time. It stores historical data for trend analysis and uses built-in MATLAB analytics for advanced processing, predicting maintenance needs, and optimizing efficiency. Alerts can be configured for immediate notifications of anomalies, allowing proactive intervention. Additionally, Thing Speak enables remote control adjustments to the motor, optimizing energy usage and improving overall performance. This integration leads to better efficiency, reliability, and cost savings in BLDC motor operations.

4. Experimental setup / Environment

In the prototype depicted in figure 5, the photovoltaic system is connected to a lower-voltage buck boost converter. The battery that is connected between the source and the load charges it when the load is not using it. The microcontroller integrated into the charging circuit via the fuzzy logic controller is used to control how the battery is charged. This technique takes advantage of fuzzy logic, which can offer straightforward solutions to complex issues. The machine learning technique enhanced this research on effective ways to improve power electronic devices with lower switching losses and ideal inductor values. Specifically, the DC-DC buck boost converter model is taken, along with methods of machine learning algorithms that will aid in determining and assessing the variation with respect to inaccuracy and being employed to analyse the gathered data. For the objective of efficiency,

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the algorithm used in this research mostly leverages K-nearest neighbour (K-NN) model-based approaches [23]. The voltage levels and BLDC motor performance according to the fixed value is shown in table 1.

Figure 5. Experimental prototype of the proposed system

Table 1. Voltage levels and BLDC motor performance according to the fixed value

Voltage(V1)	Voltage(V2)	Voltage(V3)	Fixed Value
4.76	4.76	4.76	0
4.75	4.75	4.75	0
4.74	4.74	4.74	0
4.76	4.76	4.76	0
4.74	4.74	4.74	0
4.77	4.77	4.77	0
4.74	4.74	4.74	0
4.77	4.77	4.77	0
4.75	4.75	4.75	0
4.75	4.75	4.75	0
5.1	5.1	5.1	1
5.1	5.1	5.1	1
5.09	5.09	5.09	1
5.11	5.11	5.11	1
5.09	5.09	5.09	1
5.08	5.08	5.08	1
5.08	5.08	5.08	1
5.09	5.09	5.09	1

The voltage values will be identified using a machine learning technique, and the functioning of the buck and boost converters will be based on those voltage levels [18], [19], [20], [21], [22], [23]. It will be tracked, along with each individual voltage, and both will be adjusted before the processes start. The voltage and current levels will be evaluated at the precise times and dates listed in table 1 and this can be viewed and will be regularly checked. The simulation of the drive with machine learning is shown in figure 6 with switches coupled to a photovoltaic voltage source.

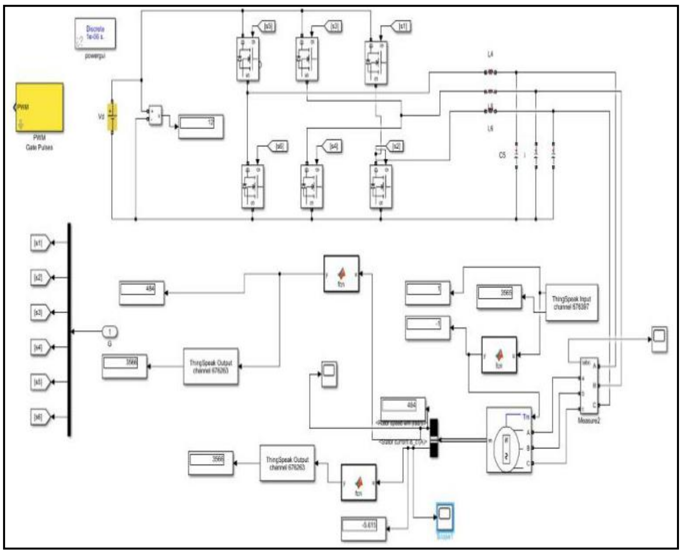

Figure 6. Simulation circuit of drive operation with the machine learning technique

Based on the values from the pre-defined data set, the system will operate. These will serve as the basis for controlling how the converters operate. The proposed low voltage converter system is simulated in figure 7(a) using a fuzzy and machine learning method. Figure 8 shows the BLDC motor performance with the IoT measuring current and voltage.

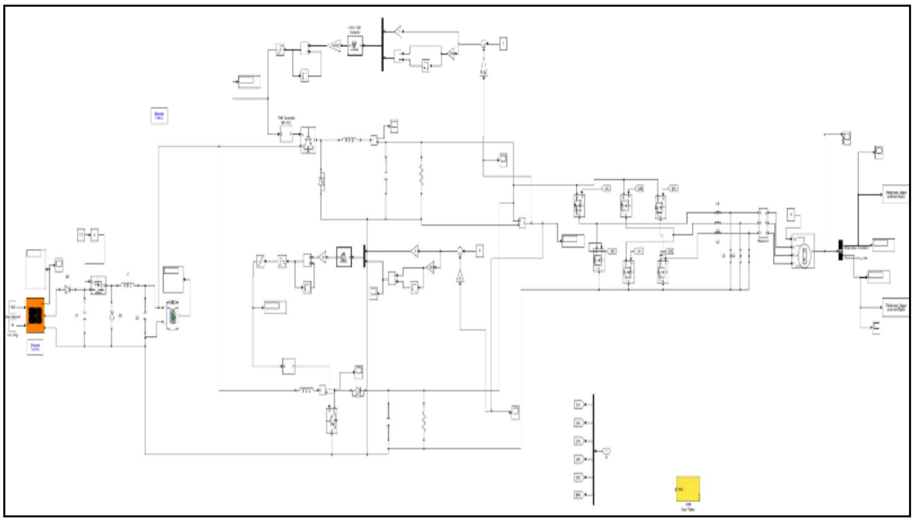

Figure 7 (a). The Simulation of proposed low voltage converter system using a fuzzy and machine learning method

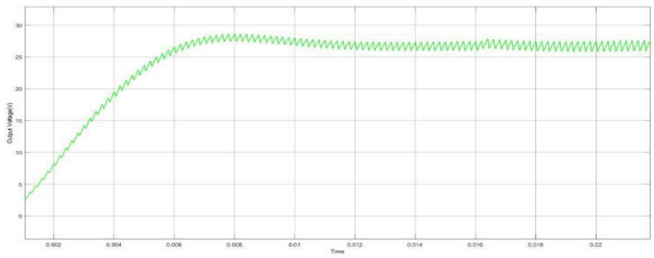

Figure 7(b). The ripples in the stator current remain in the same manner in machine learning technique

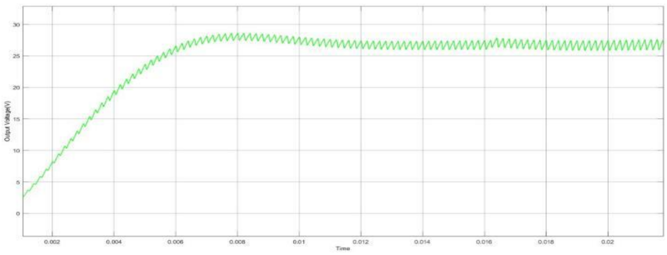

Figure 8(a). Stator Voltage

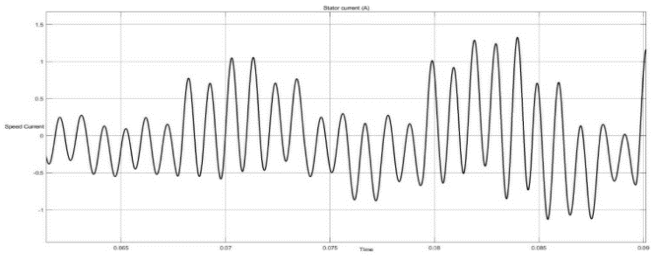

Figure 8 (b). Stator current

Figure 8. BLDC motor performance with the IoT measuring current and voltage

5. Results and Discussion

The rotor speed is depicted in figure 5(a) and figure 5(b) as increasing continually and being maintained in the fuzzy approach. However, figure 7(a) of the machine learning technique demonstrates that the maximum level indicates the first starting current created to cause the motor to take up speed. When it exceeds its highest rate of speed, the current is reduced to its normal level and continues to vary rather than continuously increasing. The stator current illustrated in figure 5(c) exhibits ripples and doesn't change frequently, as demonstrated by the fuzzy approach. In the machine learning technique, as shown in figure 7(b), ripples in the stator current remain in the same manner. The major distinction between fuzzy logic and machine learning is that the former employs feedback mechanisms for determining values, and the latter performs buck and boost operations depending on the values [19]. While the pre-set data set is used in the technique control the motor operation, figure 8 BLDC motor performance with the IoT measuring current and voltage, figure 8(a) shows stator voltage, figure 8(b) shows stator current. The simulation results also indicate the IoT components measured through it [23]. Figure 9 shows the graph of speed level monitoring with respect to date based on current and figure 10 shows the graph of speed level monitoring with respect to date based on voltage.

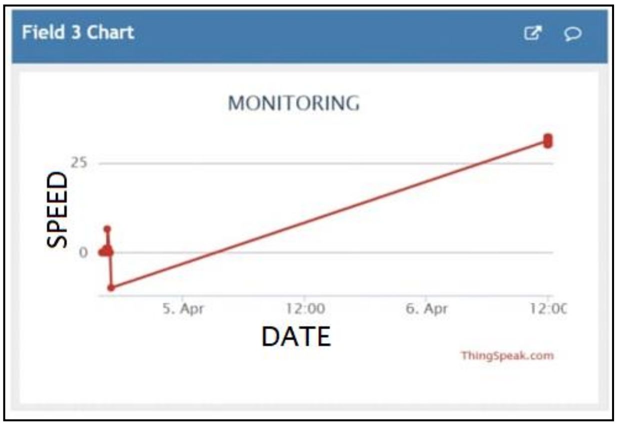

Figure 9. The graph of speed level monitoring with respect to date based on current

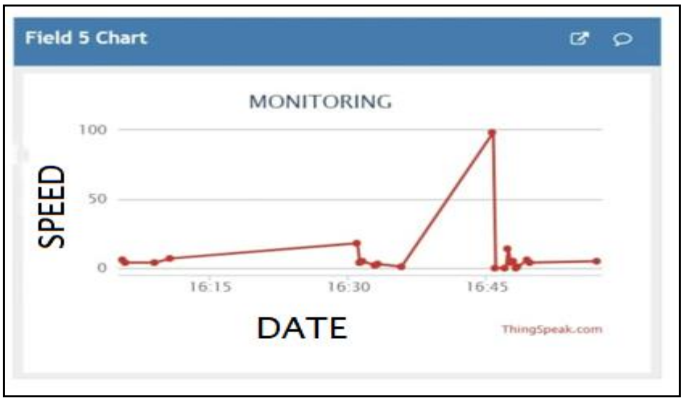

Figure 10. The graph of speed level monitoring with respect to date based on voltage

In figure 9 and figure 10, shows the outcomes of the IoT platform's continual tracking of the current and voltage with respect to time and data are displayed. Figure 11 depicts the machine learning algorithm's behaviors connected to the chopper circuit, a comparison with the voltage and the fixed value, and the correspondingly enhanced performance.

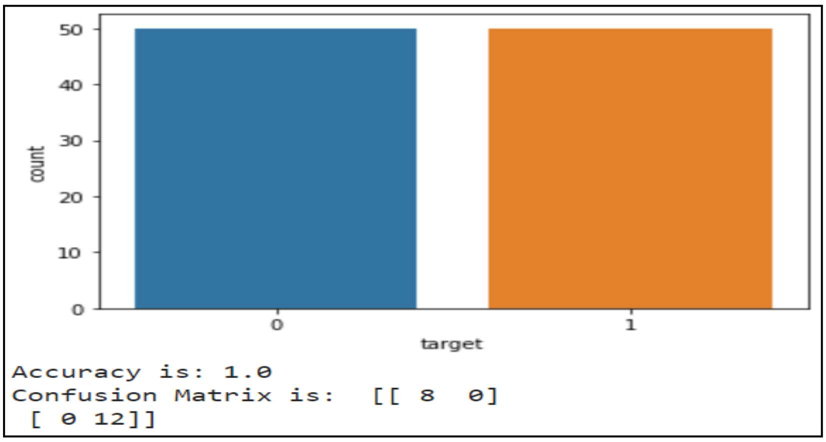

Figure 11. Investigation of the speed and the fixed level of the chopper operation

5.1. Smart Battery Management Promoting Sustainable Development Goals (SDG)

Real-time battery information is performed in this work by means of the IoT, which facilitates the continuous monitoring and cloud-based transmission of all battery-related data. By analyzing speed, acceleration, power usage, and other factors, the technology is able to forecast the remaining range of the battery and assess its overall health. Battery management systems can perform predictive maintenance with artificial intelligence, and machine learning entails understanding degradation, projecting future failures, and planning maintenance tasks appropriately. The better management system powered by solar energy helps to achieve a clean, reliable, and sustainable energy-based vehicle system meeting SDG 7. Also, SDG 13 is achieved through a reduction in emissions through carbon emissions from electric vehicles. In order to promote off-peak charging, machine learning algorithms can modify the charging rates. This encourages EV owners to charge their cars at times of lesser demand, in addition to helping to balance the load on the grid. SDG 12 is perfectly achieved by responsible consumption of energy for charging batteries and utilization. In addition to helping automakers design and construct new prototypes, it also boosts supply chain effectiveness, reinforces driver safety on the road, enhances the passenger experience, facilitates more efficient driving, and makes predictive maintenance of both factory equipment and on-road vehicles possible. Through innovative approaches used in this proposed work, improve the population's access to food, health, transportation, water, and energy services. The intelligent system used in the electric vehicle helps achieve SDG 11 advancement.

6. Conclusion

The approach described here demonstrates the fundamental operating concepts of a BLDC motor working together with a Buck converter and a Boost converter, based on a thorough investigation of current and velocity measurement. Electric vehicles play an important part in the area of electrical machines since they have significantly increased their operational efficiency. This has been achieved through the reduction of their physical dimensions and weight, while simultaneously providing exceptional torque capabilities. This is in contrast to asynchronous motors of comparable size. The use of cloud technology enables the measurement and display of current and voltage readings. The analysis of the results was conducted by examining the responses of both controllers through a graph analysis that was plotted accordingly. The BLDC motor exhibits three distinct fixed voltage levels. The input that is delivered to the system is used to adjust the speed and current values. The first goal shows current values of 0.060 amperes, while its speed value is roughly measured at 36.792 rotations per minute. Following that, the values for the next fix were recorded. The initial fixed value was adjusted, resulting in 0.025 amps of current and a considerable decrease in speed to 18.45 rpm. The following readings were taken with a raised current value of 0.060 amps and an increased speed of 34.79 rpm to restore balance to the fixed. In our operation, we have satisfactorily determined the topology of the combined chopper circuit. The optimal performance of a drive can be achieved through precise machine learning techniques, and its applications can be quantified through the use of an IoT platform.

Real-time monitoring and maintenance of the system can help to detect and address any issues that may arise. Advanced monitoring techniques, such as IoT-based sensors, can be used to provide real-time data on the performance of the system, allowing for proactive maintenance. The integration of hybrid sources along with solar systems with chopper less control using three-phase induction motors can help to improve the stability and reliability of the system. This is also an option for several applications that focus on improving efficiency [24], [25].

7. Declaration

7.1. Author Contributions

Conceptualization: V.K.P., P.S., G.D., and M.B.; Methodology: M.B.; Software: V.K.P.; Validation: V.K.P. and P.S.; Formal Analysis: V.K.P., P.S., G.D., and M.B.; Investigation: V.K.P.; Resources: M.B.; Data Curation: M.B.; Writing Original Draft Preparation: V.K.P., P.S., G.D., and M.B.; Writing Review and Editing: M.B., P.S., V.K.P., and G.D.; Visualization: V.K.P.; All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Institutional Review Board Statement

Not applicable.

7.5. Informed Consent Statement

Not applicable.

7.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] M. Aghaei, H. Ebadi, A. K. V. de Oliveira, S. Vaezi, A. Eskandari, and J. M. Castañón, "New concepts and applications of solar PV systems," *in Photovoltaic Solar Energy Conversion, Academic Press*, vol. 2020, no. 7, pp. 349-390, July 2020, doi:10.1016/B978-0-12-819610-6.00011-9.

[2] A. Gurung et al., "Highly Efficient Perovskite Solar Cell Photocharging of Lithium Ion Battery Using DC-DC Booster," *Advanced Energy Materials,* vol. 7, no. 11, pp. 1-12, Jan. 2017, doi: 10.1002/aenm.201602105.

[3] N. Rathore, N. L. Panwar, F. Yettou, and A. Gama, "A comprehensive review of different types of solar photovoltaic cells and their applications," *International Journal of Ambient Energy,* vol. 42, no. 10, pp. 1–18, Mar. 2019, doi:10.1080/01430750.2019.1592774.

[4] N. Mohamed, F. Aymen, A. Altamimi, Z. A. Khan, and S. Lassaad, "Power management and control of a hybrid electric vehicle based on photovoltaic, fuel cells, and battery energy sources," *Sustainability,* vol. 14, no. 5, p. 2551, 2022, doi:10.3390/su14052551.

[5] M. Safayatullah, M. T. Elrais, S. Ghosh, R. Rezaii, and I. Batarseh, "A comprehensive review of power converter topologies and control methods for electric vehicle fast charging applications," *IEEE Access,* vol. 10, no. 7, pp. 40753-40793, July 2022, doi:10.1109/ACCESS.2022.3166935.

[6] P. Vinoth Kumar, A. Suresh, and M. R. Rashmi, "Optimal Design of Fused Chopper based Stand alone Hybrid Wind Solar System," *Indian Journal of Science and Technology,* vol. 9, no. 21, pp. 1-6, Jun. 2016, doi: 10.17485/ijst/2016/v9i21/95154.

[7] J. Zhu et al., "A DC chopper-based fast active power output reduction scheme for DFIG wind turbine generators," *IET renewable power generation,* vol. 15, no. 11, pp. 2480–2490, Apr. 2021, doi: 10.1049/rpg2.12178.

[8] P Vinoth Kumar, A. Ramesh Kumar, and R. Tiwari, "Performance Analysis of Solar Connected Fly-Back Boost C-onverter for Electric Vehicle applications," *2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS)*, vol. 7, no. mar, pp. 1638-1643, Mar. 2021, doi:10.1109/icaccs51430.2021.9441688.

[9] BelqasemAljafari, Senthil Kumar Ramu, G. Devarajan, and IndragandhiVairavasundaram, “Integration of Photovoltaic-Based Transformerless High Step-Up Dual-Output–Dual-Input Converter with Low Power Losses for Energy Storage Applications,” *Energies*, vol. 15, no. 15, pp. 5559–5559, Jul. 2022, doi: 10.3390/en15155559.

[10] BelqasemAljafari, G. Devarajan, S. Arumugam, and IndragandhiVairavasundaram, “Design and Implementation of Hybrid PV/Battery-Based Improved Single-Ended Primary-Inductor Converter-Fed Hybrid Electric Vehicle,” *International transactions on electrical energy systems*, vol. 2022, no. 8, pp. 1–11, Aug. 2022, doi: 10.1155/2022/2934167.

[11] Andrzej Mondzik, R. Stala, S. Pirog, A. Penczek, P. Gucwa, and M. Szarek, “High Efficiency DC–DC Boost Converter With Passive Snubber and Reduced Switching Losses,” *IEEE transactions on industrial electronics*, vol. 69, no. 3, pp. 2500–2510, Mar. 2022, doi: 10.1109/tie.2021.3063874.

[12] N. Prabhu, T. Rajaram, and B. Ashok, “Critical Review on torque Ripple Sources and Mitigation Control strategies of BLDC Motors in Electric Vehicle applications,” *IEEE Access*, vol. 11, no. 1, pp. 115699–115739, Jan. 2023, doi: 10.1109/access.2023.3324419.

[13] J. Lee, Gyu Cheol Lim, and J.-I. Ha, “Pulse Width Modulation Methods for Minimizing Commutation Torque Ripples in Low Inductance Brushless DC Motor Drives,” *IEEE transactions on industrial electronics*, vol. 70, no. 5, pp. 4537–4547, May 2023, doi: 10.1109/tie.2022.3189104.

[14] K. Xia, Y. Ye, J. Ni, Y. Wang, and P. Xu, "Model Predictive Control Method of Torque Ripple Reduction for BLDC Motor," *IEEE Trans. Magn.*, vol. 56, no. 1, pp. 1-6, 2020, doi:10.1109/TMAG.2019.2950953.

[15] M. T. Hussain, Dr. N. B. Sulaiman, M. S. Hussain, and M. Jabir, “Optimal Management strategies to solve issues of grid having Electric Vehicles (EV): A review,” *Journal of Energy Storage*, vol. 33, no. 11, pp. 102114, Nov. 2021, doi: 10.1016/j.est.2020.102114.

[16] S. Thangavel, D. Mohanraj, T. Girijaprasanna, S. Raju, C. Dhanamjayulu, and S. M. Muyeen, “A Comprehensive Review on Electric Vehicle: Battery Management System, Charging Station, Traction Motors,” *IEEE Access*, vol. 11, no. 2, pp. 20994–21019, Feb. 2023, doi: 10.1109/ACCESS.2023.3250221.

[17] M. Aishwarya and R. M. Brisilla, "Design and Fault Diagnosis of Induction Motor Using ML-Based Algorithms for EV Application," *IEEE Access*, vol. 11, no. 4, pp. 34186-34197, Apr. 2023, doi:10.1109/ACCESS.2023.3263588.

[18] P. Vinoth Kumar, R. S. Athithya, R. Isai Valli, S. Abinaya and B. Hema, "Battery Management for Electric Vehicle Using Low Voltage DC-DC Converter," *2023 4th International Conference on Signal Processing and Communication (ICSPC), Coimbatore, India*, vol, 4, no. 1, pp. 62-67, doi:10.1109/ICSPC57692.2023.10125922.

[19] D. Chatterjee, Pabitra Kumar Biswas*, C. Sain, A. Roy, and F. Ahmad, “Efficient Energy Management Strategy for Fuel Cell Hybrid Electric Vehicles Using Classifier Fusion Technique,” *IEEE Access*, vol. 11, no. 1, pp. 97135–97146, Jan. 2023, doi: 10.1109/access.2023.3312618.

[20] Nelson Luis Manuel, Nihat İnanç, and Murat Lüy, “Control and performance analyses of a DC motor using optimized PIDs and fuzzy logic controller,” *Results in Control and Optimization*, vol. 13, no. 12, pp. 100306–100306, Dec. 2023, doi: 10.1016/j.rico.2023.100306.

[21] M. F. Alsharekh, S. Habib, D. A. Dewi, W. Albattah, M. Islam, and S. Albahli, “Improving the Efficiency of Multistep Short-Term Electricity Load Forecasting via R-CNN with ML-LSTM,” *Sensors*, vol. 22, no. 18, p. 6913, Sep. 2022, doi: 10.3390/s22186913.

[22] Molla et al., “Artificial Intelligence Approaches for Advanced Battery Management System in Electric Vehicle Applications: A Statistical Analysis towards Future Research Opportunities,” *Vehicles*, vol. 6, no. 1, pp. 22–70, Dec. 2023, doi: 10.3390/vehicles6010002.

[23] M. N. Akram and W. Abdul-Kader, “Sustainable Development Goals and End-of-Life Electric Vehicle Battery: Literature Review,” *Batteries*, vol. 9, no. 7, p. 353, Jul. 2023, doi: 10.3390/batteries9070353.

[24] G. Anjana, T. D. Subash, and M. Batumalay, "SCAPS-1D Simulation of CIGS-based Solar Cells with CdS as Buffer layer," *NanoWorld J.*, vol. 9, suppl. 5, pp. S186-S188, Dec.2023.

[25] W. Y. Leong, "Digital Technology for Asean Energy," *in Proc. 2023 Int. Conf. Circuit Power and Computing Technologies (ICCPCT), IEEE*, vol. 2023, no. Aug., pp. 1480-1486, 2023.