Enhanced Converter-Based Systems to Improved Hybrid Electric Vehicle Performance

Nilesh Thorat[1], Gopal Chaudhari[2], Samadhan Patil[3]

[1]Y. T. I. E.T, Department of Electrical Electronic Engineering, Bhivpuri Road, Karjat
Email: *nilesh.thorat[at]ves.ac.in*

[2, 3]Department of Electrical Electronic Engineering, Yadavrao Tasagaonkar Institute of Engineering and Technology Chandhai, Karjat
Email: *gsc88[at]rediffmail.com, samapatil111[at]gmail.com*

Abstract: ***In response to the escalating demand for sustainable transportation and heightened environmental consciousness, HEVs have emerged as a focal point of interest. This paper investigates the optimization of HEV efficiency by introducing and evaluating an innovative technology-a bidirectional converter-based system tailored specifically for HEVs. Positioned to redefine operational dynamics, this system holds the potential to make substantial strides in energy utilization and overall performance. Traditional electric vehicles often suffer from kinetic energy dissipation as heat through friction in their braking systems, leading to energy wastage. The integration of regenerative braking, facilitated by bidirectional converters, presents a transformative solution. This technology not only captures and stores dissipated energy during braking but also enables its efficient reuse, contributing to an extended driving range and heightened overall efficiency. The bidirectional converter assumes a pivotal role in this system, facilitating both the charging and discharging of the vehicle's energy storage system. Its unique ability to alter power flow direction not only enables efficient regenerative braking but also enhances energy transfer, ultimately reducing the total cost, size, and weight of the system. Amidst the challenges of rising energy consumption and the environmental impacts of conventional fuel sources, this paper aims to explore, analyze, and optimize the performance of the bidirectional converter-based system in HEVs. Through this endeavor, the paper strives to contribute to the ongoing evolution of eco-friendly transportation solutions, fostering a more sustainable and energy-efficient future. Simultaneously, addressing environmental concerns and uncertainties surrounding oil sources, the vehicle industry is increasingly embracing electricity as an alternative energy source. Regenerative braking emerges as an effective strategy to extend the driving range of battery-powered EVs. In this paper, regenerative braking for an electric vehicle is managed by a non-isolated bidirectional converter. During motoring, the converter utilizes the battery to supply energy to the motor. Conversely, during regenerative braking, the converter harnesses the available back emf to charge the battery. This process successfully captures and stores a substantial portion of the energy lost during braking, offering a sustainable means of energy recovery. The recovered energy is then stored in the battery, significantly improving battery performance and, consequently, enhancing the driving range. The simulation of this system is conducted using MATLAB/Simulink to validate the results through the creation of a real-world prototype. This paper report encompasses the simulation findings and sets the stage for potential advancements in electric vehicle technology.***

Keywords: Bidirectional Converter, H-bridge (class E-chopper), Regenerative Braking, Soft starting

1. Introduction

Revolutionising HEVs: A Comprehensive Exploration of Bidirectional Converter-Based Systems for Enhanced Energy Utilization and Efficiency. In the face of growing environmental awareness and the urgent need for sustainable transportation solutions, Hybrid Electric Vehicles (HEVs) have gained widespread adoption. This thesis delves into a ground-breaking technology – a bidirectional converter-based system meticulously designed for HEVs. Positioned to transform the operational paradigm of these vehicles, this system promises significant advancements in energy utilization and overall performance.

Conventional electric vehicles often dissipate kinetic energy as heat through friction during braking, resulting in substantial energy wastage. The integration of regenerative braking, facilitated by bidirectional converters, presents a transformative solution. This technology not only captures and stores dissipated energy during braking but also facilitates its efficient reuse, contributing to an extended driving range and heightened overall efficiency.

At the core of this transformative system lies the bidirectional converter, a pivotal component enabling both the charging and discharging of the vehicle's energy storage system. Its unique capability to alter the direction of power flow not only facilitates efficient regenerative braking but also enhances energy transfer, ultimately reducing the total cost, size, and weight of the system. In the context of escalating energy consumption and environmental concerns related to traditional fuel sources, this thesis aims to explore, analyze, and optimize the performance of bidirectional converter-based systems in HEVs. Through these efforts, we aspire to contribute to the continuous evolution of eco-friendly transportation solutions, paving the way for a more sustainable and energy-efficient future.

The literature review surrounding the optimization of HEV efficiency through bidirectional converter-based systems provides valuable insights into the challenges and advancements in this evolving field. Key aspects related to energy conservation, regenerative braking, and the role of bidirectional converters in enhancing overall efficiency are comprehensively covered.

Energy Conservation and Sustainability: The imperative of conserving energy and promoting sustainability is a recurring theme in the literature. As energy consumption continues to escalate, the environmental repercussions of conventional fuel sources have fuelled the demand for more energy-efficient transportation solutions.

Regenerative Braking in Electric Vehicles:
The focus on regenerative braking as an energy-recovery method in electric vehicles is a pivotal element in the literature. Conventional braking systems dissipate kinetic energy as heat through friction, resulting in substantial energy wastage. Regenerative braking, by converting kinetic energy into a reusable form during deceleration, stands out as an effective solution.

Bidirectional DC-DC Converters in Electric Vehicles:
The bidirectional DC-DC converter emerges as a critical component in the literature, facilitating both the charging and discharging of energy storage systems in electric vehicles. Its unique ability to alter the direction of power flow during regenerative braking is highlighted as a key feature that enhances efficiency.

Role of Bidirectional Converters in Energy Transfer:
The literature emphasizes the pivotal role of bidirectional converters in efficient energy transfer. By enabling reverse power flow during regenerative braking, bidirectional converters contribute to elevated efficiency levels. Their application in enhancing the output voltage of electrical storage systems, subsequently decreasing current output, is highlighted as a significant factor in optimizing energy utilization.

Challenges and Complexities in System Integration:
Several studies delve into the challenges and complexities associated with integrating bidirectional converter-based systems in electric vehicles.

Contributions to Sustainable Transportation:
The literature collectively emphasizes the motivation behind optimizing bidirectional converter-based systems in HEVs. Contributions to sustainable transportation, including extended driving range, reduced energy loss, and simplified system designs, are identified as key objectives.

Emphasizing regenerative braking during shorter periods, specifically less than 1 or 2 seconds, this research outlines a methodology involving a boost converter and a microcontroller to maintain a constant output voltage. However, the use of an expensive and fast microcontroller is noted, which contributes to increased costs. It is evident from the collective research that the complexity of the system and control algorithm is contingent on factors such as the type of motor selected, the inclusion of additional energy storage devices, and the chosen mode of operation. The motivation underlying these investigations is to pioneer the development of simple and cost-effective systems. This motivation is explicitly outlined in a novel methodology that utilizes regenerative braking, incorporating a model comprising a DC machine, feedback-based boost converter, and microcontroller.

The bidirectional DC-DC converter (BDC) is the subject of a detailed review, concentrating on control methodology and switching techniques. The overarching research goal is to reduce the size, weight, cost, and losses associated with these converters. The paper conducts a comparative analysis of two regenerative braking methods using bidirectional voltage-source inverters, elucidating the characteristics and implementations of each.

2. Specification & Design

Lithium-Ion battery:
Lithium-Ion batteries charge quicker, last longer, and offer a higher power density than conventional batteries, allowing for more battery life in a smaller package. Table 1 shows Battery Specification.

Table 1: Battery Specifications

Battery Parameters	Ratings
Nominal Voltage (v)	260
Rated Capacity (Ah)	50
Initial State of Charge (%)	50
Battery response time (sec)	30
Cut-off voltage (v)	195
Fully charged voltage (v)	302.63
Nominal discharge current (A)	21.73
Internal Resistance (Ohms)	0.052

The Fig.1 shows the nominal current discharge characteristics there is time in hours on x-axis and voltage in volts on y-axis.

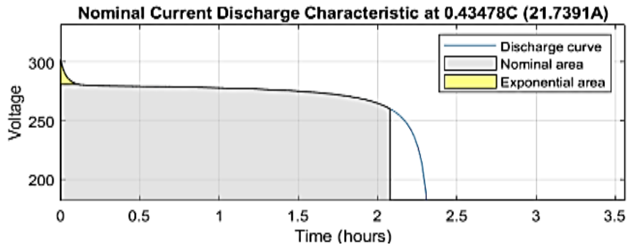

Figure 1: Nominal current discharge characteristics

If battery operating in nominal current, it will last long for 2.3 Hrs. Shaded area shows the operating hours of battery up to 2.1 hours with a voltage range of 280V to 250V and after that voltage reduces gradually.

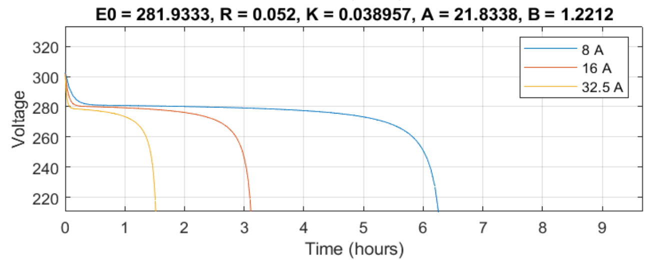

Figure 2: Discharge characteristics at different loading

The Fig. 2 shows discharge characteristics there is time in hours on x-axis and voltage in volts on y-axis at different loading conditions like 8 A, 16A, 32.5 A, so their respective discharge time is 6.3 Hrs., 3.1 Hrs., 1.5 Hrs. As the load torque is greater the battery discharge rate is faster [15].

DC-DC Converter:
These days, dependable power sources, compact design, reduced weight, and enhanced quality are necessities for the majority of electronic products. Because they rely on the principle of a voltage and current divider, energy regulators

Paper ID: SR24626145946 DOI: https://dx.doi.org/10.21275/SR24626145946

are inefficient. Switched regulators are thus employed in applications requiring a great deal of power. To toggle between a on and off state, they employ power electronics semiconductor switches, such as IGBTs or MOSFETs. When the switch is turned off, there is no current flowing through it and the voltage across it is low, thus there is almost no power loss. So, switching regulators improve the conversion efficiency of energy [16].

In DC-DC converters, electronic processors with high power frequencies are utilized. So, a direct current (DC)-to-direct current (DC-DC) converter is a circuit that takes an unregulated DC input voltage and changes it into a regulated DC output voltage of a certain level. Many modern electrical devices, such laptops, mobile phones, etc., rely heavily on these converters. It is necessary to convert the voltage of the one fixed-voltage battery that powers all of these devices. Not having to buy more power sources is an enormous expense and area saver [17].

Bidirectional DC-DC Converter

Motoring and braking are two operations that every electric machine possesses. Figure 3 illustrates the torque-speed plane, with torque shown on the x-axis and speed on the y-axis. In this plane, quadrants I and III correspond to the forward and reverse motor regions of operation, while quadrants II and IV correspond to the forward and reverse brake regions of operation, respectively. There are three modes of electrical braking: regenerative braking, reverse-voltage braking or plugging, and rheostat braking [18].

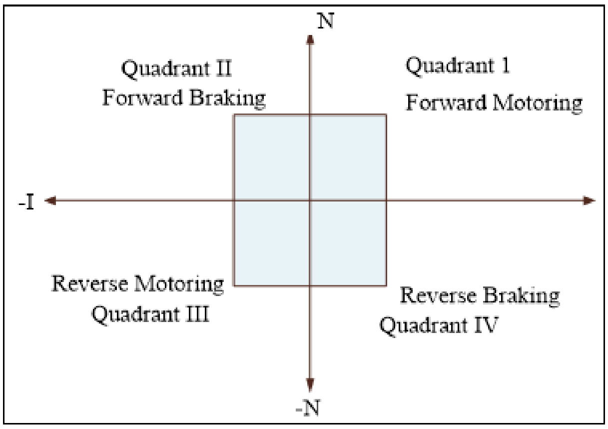

Figure 3: Interconnected smart grids

Regenerative brake technology involves the conversion of the rotor's kinetic energy into electricity, which is then returned to the power source. The power source for machines can be either a direct current (DC) power supply or an alternating current (AC) power supply. Alternatively, a direct current source can be connected to a suitable controlled power converter, such as a DC-DC or DC-AC converter. The plugging or reverse voltage braking method entails reversing the voltage that is put across the electric machine to aid the back electromotive force (EMF) in compelling the machine currents to flow in the other direction, so generating braking torque. This implies that the generation of braking torque is accomplished by harnessing energy from the power source. Rheostat braking involves connecting a bank of resistors across the electric machine, causing the kinetic energy of the rotor to be converted into heat within the resistor bank. Thus, it is evident that among the three forms of electric braking, regenerative braking stands out as the sole type that returns electricity to the power source. The objective of this study is to provide a comprehensive and precise examination of the regenerative braking capacity in converter-controlled electric machines that are powered by a DC source [19].

Four-quadrant Chopper/Type-E Chopper:

Figure 4 displays the power circuit diagram of a four-quadrant chopper. The chopper has four semiconductor switches, labeled S1 to S4, and four diodes, labeled D1 to D4, which operate in an antiparallel configuration. The operation of this chopper in all four quadrants is described.

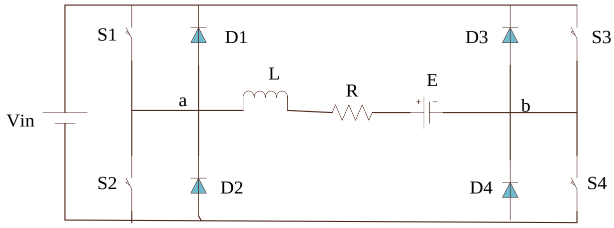

Figure 4: Type E-chopper

In order to perform operations in the first quadrant in figure 5 (a) and (b), switch S4 remains in the on position, switch S3 remains in the off position, and switch S1 is activated. When S1 and S4 are turned on, the load is directly linked to the source, causing the armature voltage (Vo = Vin) and armature current (lo) to start flowing. Both Vo and lo are positive, indicating first quadrant operation.

When S1 is deactivated, a positive electric current flow freely through S4 and D2. By controlling Vo and lo in the first quadrant, the motor rotates in the forward direction, which is referred to as Forward Motoring [20].

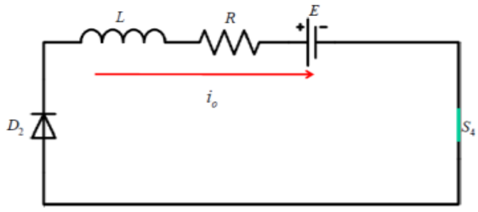

Figure 5: (a) Forward motoring

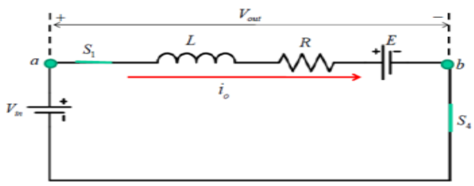

Figure 5 (b): Freewheeling operation

In Figure 6, switch S2 is activated while switches S1, S3, and S4 are deactivated. When S2 is activated, a reverse or negative current passes through L, S2, D4, and E. While S2 is active, the armature inductance 'L' accumulates energy.

Consequently, S2 is deactivated, causing the current to be redirected back to the source via diodes D1 and D4. It is important to observe that the value of (E-L(di/dt)) is greater than the source voltage Vs due to the positive Vs and negative lo. This indicates a second quadrant operation, which corresponds to the forward braking mode. The armature feeds electricity back to the source. The term used to describe this

Paper ID: SR24626145946 DOI: https://dx.doi.org/10.21275/SR24626145946

is Forward Regenerative Braking [21].

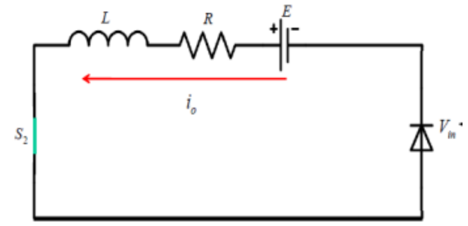

Figure 6 (a): Freewheeling action

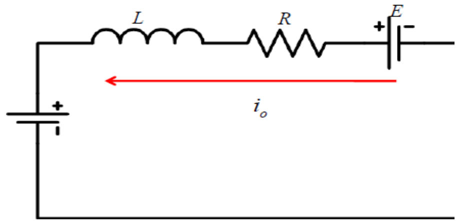

Figure 6 (b): Fed back operation

In the third quadrant operation, as shown in figure 7 (a) and (b), Switch S1 is deactivated, Switch S2 is activated, and Switch S3 is activated. In order to achieve the desired quadrant action, it is necessary to flip the polarity of the armature's back electromotive force (EMF) (E). When switch S3 is turned on, the armature is connected to the source Vs, resulting in both Vo and lo being negative. This causes the operation to occur in the third quadrant.

When S3 is off, a negative current bypasses S2 and flows through D4 without any resistance. Only V_{out} and lo may be regulated in the third quadrant using this method. Reverse Motoring refers to the phenomenon when the motor rotates in the opposite direction.

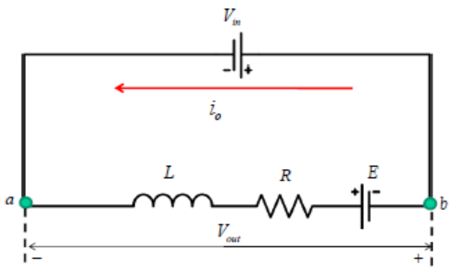

Figure 7 (a): Reverse Motoring

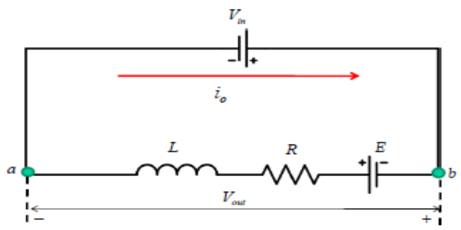

Figure 7(b): Freewheeling Action

In figure 8, switch S4 is activated while other devices remain deactivated. In this scenario, it is necessary to reverse the polarity of the back electromotive force (E), similar to the operation in the third quadrant. When S4 is turned on, an electric current with a positive charge passes via S4, D2, L, and E (the armature). The armature inductance L accumulates energy when the time S4 is active. When S4 is turned off, diodes D2 and D3 allow the current to be returned to the source. The armature voltage Va is in the negative range, while la is in the positive range, leading to the operation of the chopper drive function in the fourth quadrant. The armature also returns power to the source. The term used to describe this is Reverse Regenerative Braking [22].

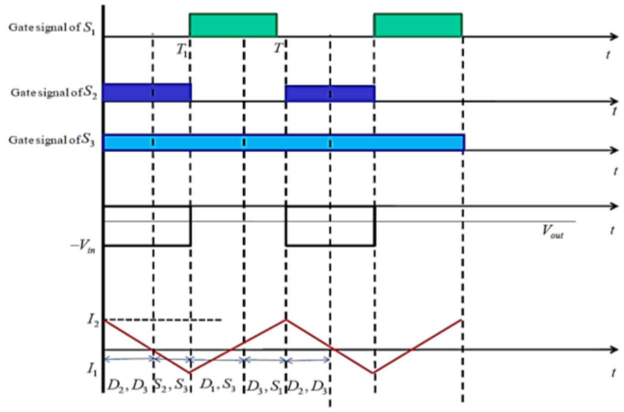

Figure 8: Output Waveform of third and fourth quadrant

As we are going to work in Forward motoring and forward braking action, first two quadrants are used in paper.

Separately Excited DC Motor

In an independently excited DC motor, the supply is provided to the field and armature windings individually. The main feature of this type of DC motor as shown in Table 2 is that the field windings are energized by a separate DC source, so the current through the armature doesn't flow through them. This can be understood in a better way from the following diagram [23].

Table 2: Specification of Motor

Motor Parameters	Ratings
Output Power (HP)	5
Armature Voltage (V)	240
Speed (RPM)	1750
Armature Resistance (ohm)	2.581
Inductance (H)	0.028
Total Inertia	0.02215
Viscous friction coefficient (N.m.)	0.002953
Coulomb friction coefficient (N.m.)	0.5161

The field coil of an independently excited DC motor is powered by an external DC source, as seen in Figure 9. The separately excited DC motor is most suitable for applications that necessitate a wide range of speed fluctuation, ranging from extremely low to very high values. These motors [23] are being utilized in various industries and others.

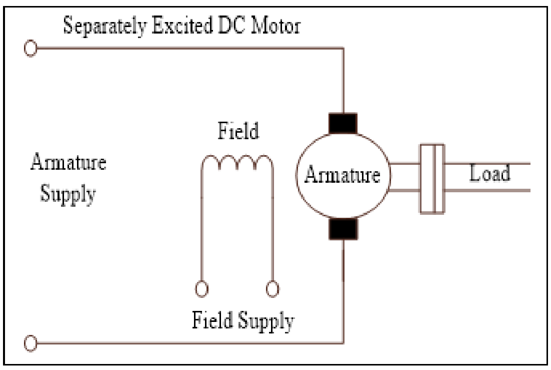

Figure 9: DC separately excited motor

Paper ID: SR24626145946 DOI: https://dx.doi.org/10.21275/SR24626145946

Concept of Back Emf

When the motor armature keeps rotating as a result of motor activity, the armature conductors intersect with the magnetic flux, causing induced electromotive forces (emfs) in them. The induced electromotive force (emf), commonly referred to as reverse emf, is oriented in a manner that opposes the applied voltage. The magnitude of the reverse electromotive force (emf) is determined by the generator activity.

$$E_b = \frac{\phi ZN}{60} \times \frac{P}{A} \tag{1}$$

I_a in terms of V, E, and Ra is given in Eq. (2)

$$I_a = \frac{V - E_b}{R_a} \tag{2}$$

The induced EMF in the armature of a motor, denoted as Eb, is influenced by various elements, including the speed of the armature. The armature current, on the other hand, is determined by the back EMF Eb, when a constant voltage is applied and the armature resistance remains constant. When the armature speed is high, the magnitude of the back EMF, Eb will be substantial, resulting in a correspondingly low armature current. When the armature speed is low, the EMF, Eb will decrease, causing the armature current I_a to increase. This leads to the generation of a significant torque [24].

The existence of back emf enables the DC motor to function as a self-regulating device. This means that the dc motor will only draw enough armature current to generate the necessary load torque.

3. Study System Implementation

In fig. 10, this circuit comprises of Battery, converter circuit with separately excited DC motor connected in H- Bridge manner. The Gate pulse is given externally from a separate control system designed to control the ON-OFF condition of Switches and monitoring the discharge rate of battery. The discharge rate at various duty cycles like 90 %, 70%, and 50% for the different load conditions is compared.

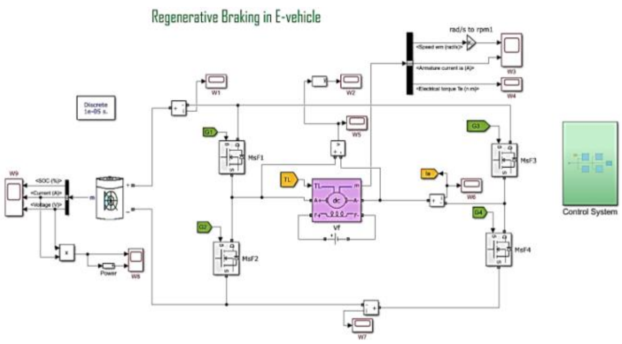

Figure 10: Study Model

At all this conditions energy delivered to the motor i.e., load from battery is analyzed and the energy required for the motoring is calculated. If motoring action performed continuously the battery will discharge to lower threshold (V_{min}) value and requires recharging [24]. If motoring is followed by regenerative braking, energy is used for charging the battery partially. This is the aim to extend the time of recharging of the battery.

Soft-starting

In DC separately excited motor at starting speed is zero, so as generated Eb is nearly zero. As the armature current given in motor is shown in Eq. (3)

$$I_a = \frac{V - E_b}{R_a} \tag{3}$$

As armature resistance is small and value of E_b near zero, the armature current at starting is very high. It is about 5-6 times of rated current. So, to limit starting current armature control method is implemented. In this system armature current sensed and fed back to duty ratio control system. By control of MOSFET 1 duty ratio at respective armature current starting current is limited at some extend. Table 3 shows the starting current of motor before soft-starting, which is nearly 72 Amps

Table 3: Armature Current with soft starting

Motor Parameters	Ratings
Output Power (HP)	5
Armature Voltage (V)	240
Speed (RPM)	1750
Armature Resistance (ohm)	2.581
Inductive Reactance (ohm)	0.028

Capacitor (UC)

The UC system is driven by a paradigm that focuses on the transfer of useable energy. The power capacity of the UC is determined based on the driving cycle need at periods of peak power, when quick discharging occurs. The basic calculations governing capacitors are represented by Eq. (3).

$$i = C\frac{dv}{dt} \;\&\; E = \frac{1}{2}CV^2 \tag{3}$$

The V decays over t is given by Eq. (4)

$$E|_k^{k+1} = \frac{1}{2}C\,(V_k^2 - V_{k+1}^2) \tag{4}$$

As demonstrated in Eq. (5), voltage discharge ratio determines usable energy.

$$V_{dr} = \frac{V_{min}}{V_{max}} * 100 \tag{5}$$

Usable energy derived as per Eq. (6),

$$E_u = \frac{1}{2}CV_{max}^2 - \frac{1}{2}CV_{min}^2 = \frac{1}{2}CV_{max}^2\left(1 - \left(\frac{V_{dr}}{100}\right)^2\right) \tag{6}$$

The equation (7) provides the total amount of useful energy derived from a specific number of UCs.

$$E_T = nE_u = \frac{1}{2}nCV_{max}^2\left(1 - \left(\frac{V_{dr}}{100}\right)^2\right) \tag{7}$$

The quantity of UCs (n) is determined using Equation (8).

$$n = \frac{2E_T}{CV_{max}^2\left(1 - \left(\frac{V_{dr}}{100}\right)^2\right)} \tag{8}$$

The battery and UC are classified according on the specific electrical load demands. Various sources are accessible, each with distinct power and energy densities. The utilization of a high-power density source and an energy-dense source significantly increases the driving range of vehicles while simultaneously reducing the weight and expense of the energy storage system.

Motor operation at repetitive cycle

Motoring Operation done for repeated cycles while motor speed is reduced and braking at less than rated speed with different load pattern to calculate recovered energy and energy required at the time of repetition of motoring Operation of motor at 0.9 duty cycle shown in Fig.11.

The Table 4 shows the results for operation of motor in repeated cycles. The first cycle is on full load and second cycle is on half load in both cycles braking is done at less than rated speed of motor. Since starting energy required for motoring for full load is 2308 J and recovered energy is 106 J so energy is recovered by 6% of starting energy with regenerative braking.

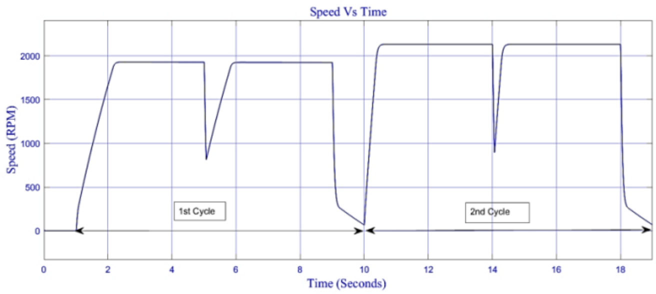

Figure 11: Repeated cycle operation of motor for full load & half load

Table 4: Result at repetitive operation of motor

Parameters	Full Load (15.7 N-m) 16.5 A	Half Load (7.8 N-m) 9 A
Speed (RPM)	1936→892→193→60	2141→ 892→2141→0
Energy in rotating mass (Joules)	455 J	556 J
Energy required for starting of motor (Joules)	2308 J	1841 J
Recovered Energy (Joules)	106 J	190 J

Starting energy required for motoring at half load is 1841 J and recovered energy is 190 J so energy is recovered by 10% of starting energy with regenerative braking. Table 5 & 6 shows conclusion at full load & half load respectively.

Table 5: Conclusion at full load

Duty Cycle	Energy Recovered by braking (Joules)	Battery Extension time (Minutes)
0.9	182.5	9.26
0.7	118	9.36
0.5	48	8.6

Table 6: Conclusion at half load

Duty Cycle	Energy Recovered by braking (Joules)	Battery Extension time (Minutes)
0.9	216	22
0.7	153.12	25
0.5	82	29

4. Conclusion

In conclusion, our comprehensive MATLAB modeling, incorporating both motoring and regenerative braking modes, has undergone rigorous execution, complemented by theoretical calculations. The analysis of diverse operational scenarios has yielded valuable insights into the system's performance. In continuous motoring mode with a 0.9 duty cycle, the battery's complete discharge time stands at 3.38 hours at full load and extends to 6.31 hours at half load. Varied duty cycles and loading conditions have been explored, introducing nuances in motoring and braking patterns.

The impact of regenerative braking on extending the time before recharging the battery is particularly pronounced, evident across both full and half loads. Notably, at a higher duty cycle (0.9), maximum speed results in increased tapped energy in the rotating mass, consequently prolonging the time before recharging due to regenerative braking. At half load and a 0.9 duty cycle, higher speed contributes to greater energy recovery during braking compared to full load operation, further extending the time before recharging.

To expedite simulation and analysis, the motor was operated for 2 and 4 seconds in motoring mode before braking, considering computational demands for longer time operations. The implementation of an armature control method has proven crucial for limiting the starting current, enhancing system stability by sensing armature current and providing feedback to the duty ratio control system.

In repeated cycle operations with braking at less than the rated speed, the starting energy required for full-load motoring is determined to be 2308 J, with a recovered energy of 106 J during regeneration. This signifies that 6% of the starting energy is fulfilled by regeneration during the first cycle. These findings collectively highlight the intricate dynamics of the system under various operating conditions, providing a comprehensive understanding of the interplay between motoring, regenerative braking, and the efficacy of the implemented control methods.

References

[1] Amit Kumar, Krupa Shah, "Practical Model of Regenerative Braking using DC Machine and Boost Converter", 2020 IEEE International Conference for Innovation in Technology (INOCON) Bengaluru, India. Nov 6-8, 2020

[2] Q. Zhao, and F. C. Lee, "High Efficiency, High Step-Up DC-DC Converters, " IEEE Trans. Power Electron., vol. 18, pp. 65-73, Jan. 2003.

[3] J. Yao, et al., "Steep-gain bidirectional converter with a regenerative snubber," IEEE Trans. Power Electron., vol/issue: 30(12), pp. 6845–6856, 2015.

[4] D. Sable, F. C. Lee, and B. H. Cho, "A zero-voltage-switching bidirectional battery charger or discharger for the NASA EOS satellite," in IEEE Appl. Power Electron. Con$ Proc., 1992

[5] C. Asok and D. M. U, "IPMSM Drive with Interleaved Bidirectional Converter for Electric Vehicle Application," 2022 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES),

THIRUVANANTHAPURAM, India, 2022, pp. 268-273, doi: 10.1109/SPICES52834.2022.9774142.

[6] A. Gupta, R. Ayyanar and S. Chakraborty, "Novel Electric Vehicle Traction Architecture With 48 V Battery and Multi-Input, High Conversion Ratio Converter for High and Variable DC-Link Voltage," in IEEE Open Journal of Vehicular Technology, vol. 2, pp. 448-470, 2021, doi: 10.1109/OJVT.2021.3132281.

[7] T. K. Haritha, S. S. Kumar, P. Jayaprakash and O. V. Asokan, "Regenerative Braking System for Fuel Cell-Battery Hybrid Sources," 2022 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), Trivandrum, India, 2022, pp. 1-6, doi: 10.1109/PESGRE52268.2022.9715858.

[8] G. Gurjar, D. K. Yadav and S. Agrawal, "Illustration and Control of Non-Isolated Multi-Input DC - DC Bidirectional Converter for Electric Vehicles Using Fuzzy Logic controller," 2020 IEEE International Conference for Innovation in Technology (INOCON), Bangluru, India, 2020, pp. 1-5, doi: 10.1109/INOCON50539.2020.9298307.

[9] Tamboli, D., Thakre, M., & Thakre, P. (2022, December). Boosting Performance with the Integration of Stochastic Energy Storage into Hybrid Electric Vehicles. In Techno-Societal 2016, International Conference on Advanced Technologies for Societal Applications (pp. 449-459). Cham: Springer International Publishing.

[10] N. K. Mydham, A. Vijayakumari and S. R. Mohanrajan, "Enhanced Regenerative Braking System for Electric Vechile with High Power Density Storage," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-7, doi: 10.1109/ICSCAN53069.2021.9526369.

[11] M. Awais, M. Anees and N. Zaffar, "Solar assisted, enhanced efficiency, induction motor EV drive with soft phase conversion," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, China, 2017, pp. 2184-2189, doi: 10.1109/IECON.2017.8216367.

[12] Kadlag, S. S., Tapre, P., Mapari, R., Thakre, M., Kadam, D., & Dahigaonkar, D. (2023). Pulse charging based intelligent battery management system for electric vehicle. Bulletin of Electrical Engineering and Informatics, 12(4), 1947-1959.

[13] A. Gupta, R. Ayyanar and S. Chakraborty, "Novel Electric Vehicle Traction Architecture With 48 V Battery and Multi-Input, High Conversion Ratio Converter for High and Variable DC-Link Voltage," in IEEE Open Journal of Vehicular Technology, vol. 2, pp. 448-470, 2021, doi: 10.1109/OJVT.2021.3132281.

[14] Y. Zhang, W. Wang, C. Yang, L. Han, Z. Zhang and J. Liu, "An effective regenerative braking strategy based on the combination algorithm of particle swarm optimization and ant colony optimization for electrical vehicle," 2019 IEEE 28th International Symposium on Industrial Electronics (ISIE), Vancouver, BC, Canada, 2019, pp. 1905-1910, doi: 10.1109/ISIE.2019.8781183.

[15] Shrivastava, R., Dhote, N., Kadlag, S. S., Thakare, M. P., Kadam, D. P., & Khule, S. S. (2023). Performance analysis and improvement of a high-efficiency DCMLI based PMSM drive for electric vehicle using AVR microcontroller. International Journal of Vehicle Noise and Vibration, 19(3/4), 133-164.

[16] Y. Shen and H. Lu, "Research on Regenerative Braking Distribution Method of Pure Electric Vehicle Based on Firefly Algorithm," 2021 4th World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM), Shanghai, China, 2021, pp. 258-263, doi: 10.1109/WCMEIM54377.2021.00060.

[17] M. Lv, Z. Chen, Y. Yang and J. Bi, "Regenerative braking control strategy for a hybrid electric vehicle with rear axle electric drive," 2017 Chinese Automation Congress (CAC), Jinan, China, 2017, pp. 521-525, doi: 10.1109/CAC.2017.8242823.

[18] A. M. and S. P. S., "Novel Regenerative Braking Controllers for Electric Vehicle Driven by BLDC Motor," 2021 Fourth International Conference on Electrical, Computer and Communication Technologies (ICECCT), Erode, India, 2021, pp. 1-6, doi: 10.1109/ICECCT52121.2021.9616660.

[19] P. Spichartz and C. Sourkounis, "Influence of the drive train topology and the center of mass on the regenerative braking in electric vehicles," 2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, Monaco, 2017, pp. 1-8, doi: 10.1109/EVER.2017.7935897.

[20] C. Li, C. He, Y. Yuan and J. Zhang, "Control, Modeling and Simulation on A Novel Regenerative Brake System of Electric Vehicle," 2018 IEEE 4th International Conference on Control Science and Systems Engineering (ICCSSE), Wuhan, China, 2018, pp. 90-94, doi: 10.1109/CCSSE.2018.8724783.

[21] Kadlag, S. S., Mapari, R., Shriwastava, R., Tapre, P. C., & Kadam, D. P. (2023). A novel pulse charger with intelligent battery management system for fast charging of electric vehicle. Bulletin of Electrical Engineering and Informatics, 12(3), 1388-1396.

[22] M. G. S. P. Paredes and J. A. Pomilio, "Control System to Regenerative and Anti-Lock Braking for Electric Vehicles," 2018 IEEE Transportation Electrification Conference and Expo (ITEC), Long Beach, CA, USA, 2018, pp. 135-139, doi: 10.1109/ITEC.2018.8449954.

[23] V. Totev and V. Gueorgiev, "A Study on Regenerative Braking of the System Battery — Power Converter - Electric Motor of Electric Vehicles," 2022 22nd International Symposium on Electrical Apparatus and Technologies (SIELA), Bourgas, Bulgaria, 2022, pp. 1-6, doi: 10.1109/SIELA54794.2022.9845753.

[24] Thakre, M. P., Shriwastava, R., Mapari, R. G., Kadam, D. P., & Kadlag, S. S. (2023). A versatile methodology for preventing a parallel transmission system using impedance-based techniques. Bulletin of Electrical Engineering and Informatics, 12(5), 2577-2585.

[25] F. Peng, B. Fang and Z. Shen, "Research on Regenerative Braking Control of Electric Vehicle Based on Multi-objective," 2021 Asia-Pacific Conference on Communications Technology and Computer Science (ACCTCS), Shenyang, China, 2021, pp. 338-343, doi: 10.1109/ACCTCS52002.2021.00074.