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Implementation of Regenerative Brake System Controller by Using Mini Controller Arduino

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***Abstract* – The key requirement for electric vehicles is efficient braking. The objective of this study is to provide a detailed description of the regenerative braking system utilizing various power flow regulators. This study utilizes a buck-boost type Boost Converter. There are two methods employed to modify the voltage derived from the fluctuating input produced during regenerative braking: one to decrease it and the other to boost it. Subsequently, a voltage sensor detects the resulting output voltage, which is then regulated using an Arduino microcontroller. The examination findings indicate that the buck-boost converter performs well, maintaining an output voltage within the range of 39-40 volts. This allows it to function well even when there are fluctuations in the input voltage. The voltage value can be utilized for the purpose of charging a battery for a 36 Volt electric motor. The findings demonstrate the efficacy of utilizing a Buck-Boost Converter regulator. Furthermore, it could charge the battery within a span of 8 seconds, making it a viable option for electric vehicles as an alternative to regenerative braking for battery recharging.**

***Keywords* – Battery, boost converter, electric vehicle, microcontroller, regenerative brake system.**

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1. Introduction

The global automobile industry is currently experiencing significant growth and technological advancements, particularly in the design and manufacturing of electric vehicles. The ideal electric car for all users is one that offers both comfort and exceptional speed and power [1]. The range of an electric vehicle is a crucial factor in determining its practicality and usefulness. Enhancing the efficiency of all components, such as the motor, power converter, and battery, can lead to an improvement in the mileage range [2]. Regenerative braking is a technique used to enhance fuel efficiency by using the energy generated during braking to recharge the battery. Typically, electric motor design relies on mechanical braking, which is known for its ability to stop quickly and its straightforward functioning. Nevertheless, the detrimental consequence of utilizing this form of mechanical braking is the emergence of mechanical inefficiencies, such as friction, which results in the generation of heat and the production of dust through friction [3].

Recently, the deployment of motors such as Brushless DC motor (BLDC), permanent magnet synchronous motor (PMSM), and switching reluctance motor has increased due to advancements in power electronic converters [4], [5]. Out of the aforementioned options, BLDC motors are frequently utilized because of their superior efficiency, significant power concentration, substantial beginning torque, noiseless activity, lightweight components, and compact dimensions [6]. Modern cars utilize hub-type BLDC motors and wheel-mounted motors to simplify power train mechanisms [7]. Within regenerative braking, the vehicle's momentum, in conjunction with the power electronic adapter, causes the motor to function as a power source, returning electricity to the battery [2], [6]. Research has demonstrated that the use of regenerative braking is capable of resulting in a distance increase of 8-25% [8], [9].

Prior studies have implemented several techniques to develop regenerative braking systems in electric vehicles. Regenerative braking in [2], [3], [4], [5], [6] are accomplished by utilizing an extra DC-DC converter to elevate the back electromotive force (back-EMF) to a suitable level for battery recharging. This approach necessitates the inclusion of an extra converter, resulting in an augmented expenditure and an amplified weight of the system. Regenerative braking in [7] is accomplished by connecting ultracapacitors in series or parallel with the battery. The ultracapacitor stores the sudden increase in regeneration energy and returns it to the battery using an extra converter. Additionally, this approach leads to an escalation in both the total expense and the mass of the system.

Regenerative braking is accomplished by the utilization of electronic gear shift technology [9]. This technique employs mechanical gears to establish sequential and parallel connections between batteries, motor windings, and ultracapacitors, depending on the vehicle's speed. The purpose of these connections is to capture and restore regenerative energy. This approach necessitates the use of a motor that has been specifically engineered to have several windings, various battery connections, and multiple switches. Furthermore, it is necessary to devise a sophisticated switching topology for practical application.

To mitigate the limitations of other regenerative approaches that were previously studied [10], an alternate approach is employed, namely employing a single-stage converter to power a BLDC motor. Single-stage converters may provide regenerative braking through utilizing switching pulses in the correct order, eliminating the requirement for extra electricity converters. This study focused on analyzing different types of braking methods, such as single-switch, two-switch, and three-switch, in a single-stage converter. The analysis depended on a variety of shifting configurations. The references for this study are [11], [12]. These experiments have determined that both single-switch and three-switch systems can generate the necessary braking torque and achieve superior energy recovery in the medium to high-speed range. Furthermore, it is advisable to utilize two switches in situations that need low speed or emergency braking, as these switches provide substantial braking torque. The study conducted in [10], [13] also examined the implementation of regenerative braking utilizing both a single switch and two switches. A recent proposal introduced electric regenerative braking as a method for achieving very efficient and accurate control over braking torque [14], [15]. Nevertheless, regenerative braking simply proves to be ineffective in low-speed situations and during emergencies [16].

This investigation aims to address the issues identified in earlier studies by developing an alternate regenerative braking system for a brushless direct current (BLDC) motor. The system is implemented using an Arduino-based electric motor. The regenerative braking system could be created by using an uncontrolled full-wave three-phase rectifier and a buck-boost converter. The rectifier serves as a battery charging electricity regulator through regenerative braking. A buck converter is employed to regulate energy flow since the voltage needs to decrease while braking, based on the battery voltage. On the reverse end of the spectrum, a boost converter is used when the voltage on the BLDC motor is lower than desired, allowing it to be increased to the appropriate level. This combination of power flow regulators enables the implementation of regenerative braking on electric motors. The objective of this project is to develop a design for a regenerative braking system on a BLDC motor using a Buck-Boost converter with micro control, which will serve as an electric car braking mechanism.

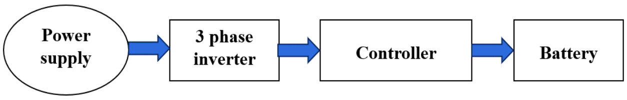


Figure 1. Regenerative brake block schematic

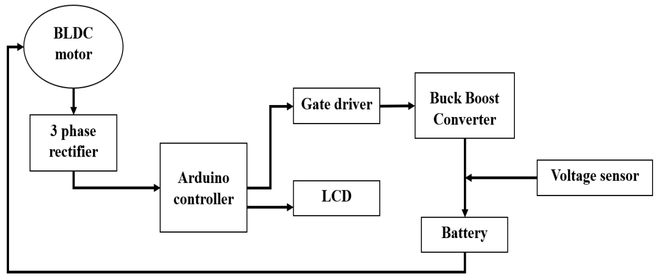


Figure 2. Regenerative brake diagram

2. Research Methodology

The objective of designing this regenerative braking circuit is to streamline the device architecture, mechanical development, and analytical process. The conceptualization process involves creating a block diagram, as depicted in Figure 1, and developing a sequence of operational structures for the device, as illustrated in Figure 2. Each block schematic serves a distinct purpose inside the operational framework of the instrument being developed. The BLDC motor serves as the electric motor drive in the aforementioned system. Once the driver applies pressure to the accelerator pedal on a bicycle, the electrical current from the battery is directed to the BLDC motor, causing the motor to increase its rotational speed. When the driver applies the brake, the switch is going to cut the power delivered coming from the battery.

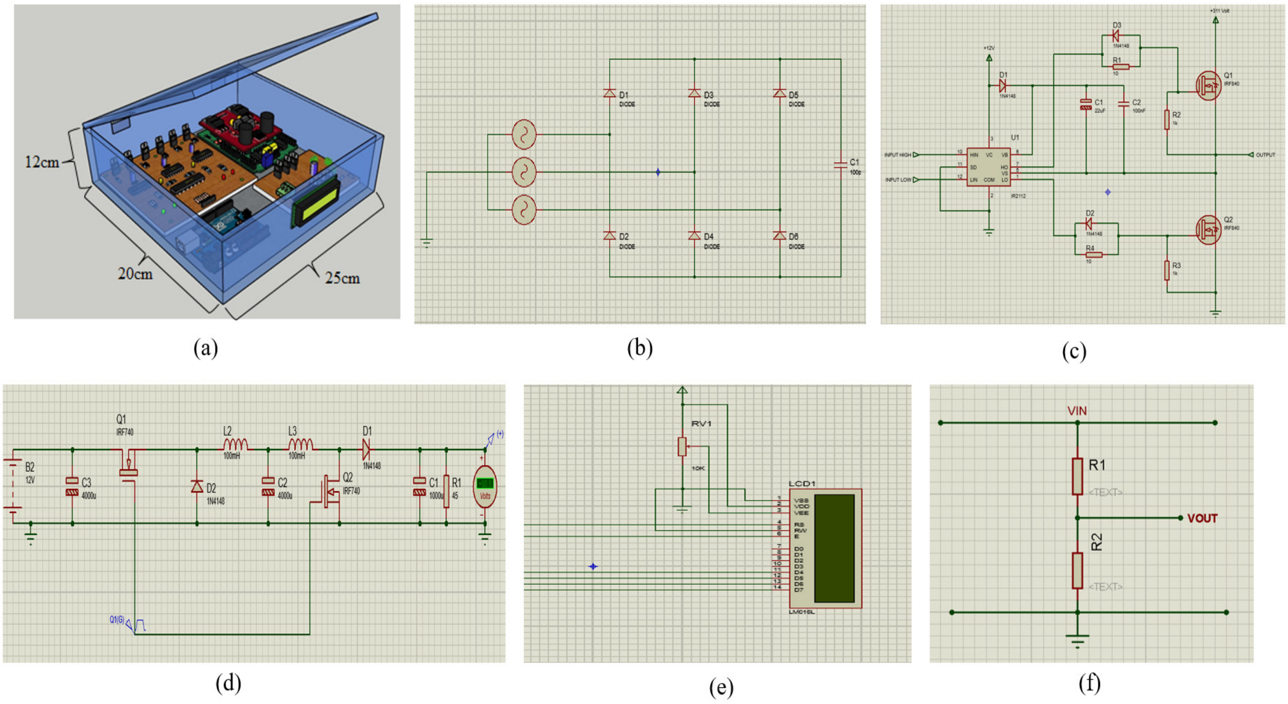


Figure 3. Implementation of buck-boost converter

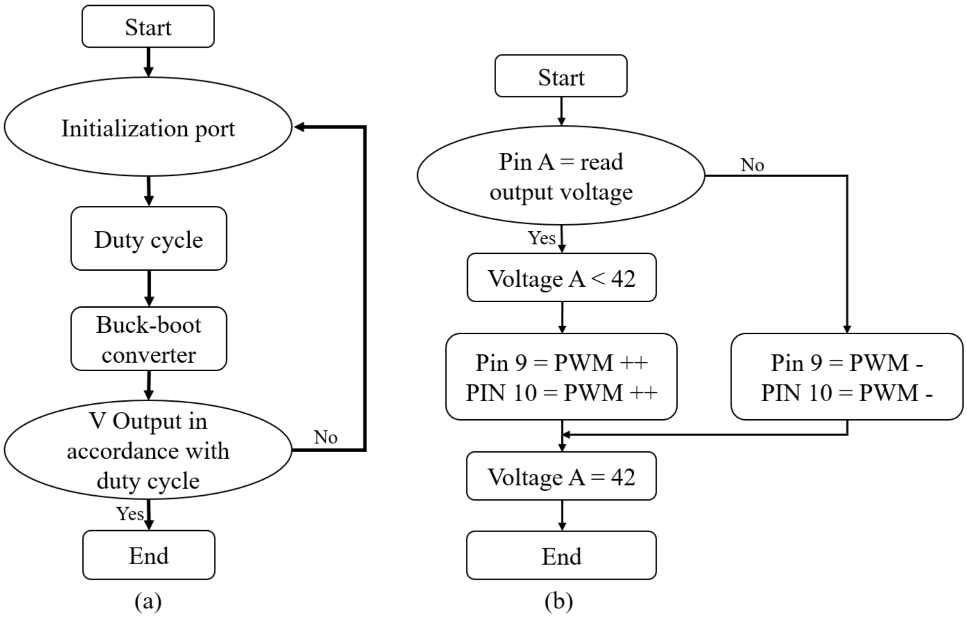


Figure 4. Controller programming process, a) voltage reading initialization, b) programming process.

The motor continues to rotate due to its load. The excess energy regarding the spinning motion of the BLDC motor then goes into the electrical flow regulator circuit, allowing it to recharge the battery until the motor comes to a stop.

As illustrated in Figure 2, the electrical power supply circuit and braking system will be partitioned by a three-phase inverter serving as a performance separator for each system. A three-phase rectifier, buck converter, microcontroller, voltage sensor, and MOSFET actuator comprise the power flow regulator circuit. At the point where the three-phase rectifier transforms the AC signal into DC. The DC voltage will serve as the input to the circuit containing the buck-boost converter. The sensor collects the DC voltage, and the resulting data could be processed by the controller. The controller intends to use the duty cycle output to control the toggling of the MOSFET in the buck-boost converter circuit. A voltage sensor could control the electrical output of the buck-boost converter in accordance with the power output of the BLDC generator, which is utilized to charge the battery. In order to visually discern the deceleration of the electric motor, with the rate of braking increasing in direct proportion to the power produced by the BLDC generator. The procedure for implementing this utility is illustrated in Figure 3.

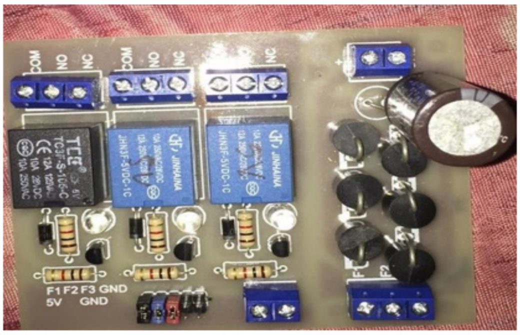
This procedure begins with the box maker (Figure 3a), followed by the 3-phase rectifier circuit (Figure 3b), gate drive circuit (Figure 3c), buck booster converter circuit (Figure 3d), LCD circuit (Figure 3e), and voltage sensor circuit (Figure 3f). In addition, the procedure for designing software commences by creating a system work flowchart (Figure 4a) that outlines the requirements for the program to be developed (Figure 4b). The flowchart provides a clear visual representation of how to manage the algorithm, specifically, how the entire structure functions as a cohesive unit. The programming language employed is C, and thereafter, the application is uploaded into the Arduino Uno. Figure 4(a) shows the process of initializing the port on an Arduino and reading the voltage from the rectifier using a voltage sensor. The rectifier output is then stabilized at 14 volts using a buck-boost converter circuit. This is achieved by adjusting the switching on the gate MOSFET leg through the Arduino, which sets the duty cycle for the buck-boost converter. The programming process is depicted in Figure 4(b).

3. Results and Discussion

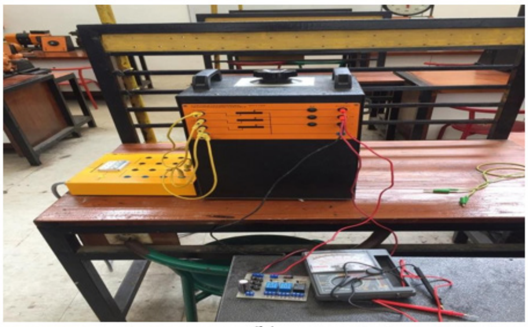
The present investigation involves four stages of testing of the braking system tool on a DC motor with the regenerative braking method. These stages include testing the circuit components, such as the 3-phase rectifier circuit, MOSFET gate drive, voltage sensor, and LCD circuit. Additionally, the overall system circuit is tested to assess the transfer of regenerative energy from the motor rotation to the battery.

3.1. 3-Phase Rectifier Examination

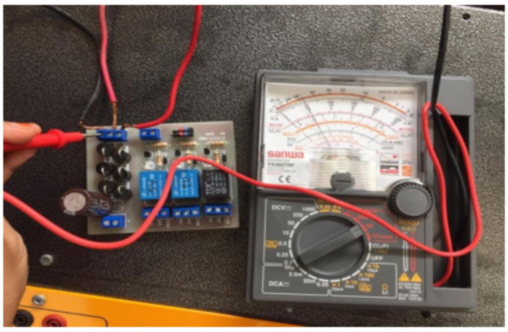
The examination involved applying a three-phase voltage to generate a direct current (DC) voltage with minimal fluctuations. The procedure is illustrated in Figure 3. The testing method commences by creating a prototype of a three-phase circuit, as illustrated in Figure 5(a). Furthermore, the user should proceed with the assembly of the components and follow the testing procedure using a power supply, as seen in Figure 5(b). Conducting a testing process by utilizing an ohm meter, as shown in Figure 5(c). The measurement results are displayed in Figure 5(d). The purpose of this test was to assess the efficacy of the three-phase rectifier circuit in functioning as a direct current (DC) power source for the buck-boost converter circuit. Testing is conducted by rectifying the three-phase voltage using a three-phase transformer.



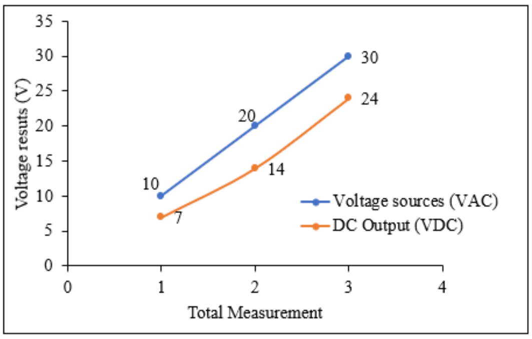
(a)



(b)



(c)



(d)

Figure 5. The circuit and examination process, a) Three-phase circuit, b) Components and analysis process, c) Measurement process with ohmmeter, d) measurement results

3.2. Arduino UNO Programming Examination

Arduino circuit testing is conducted to determine the operational functionality of the Arduino UNO. The Arduino UNO circuit is evaluated through connecting hardware to a 5-volt voltage regulator source. Voltage measurements are taken on the logic levels '0' and '1' of the Arduino UNO I/O port.

Based on the conducted tests, it has been determined that the Arduino UNO operates under two logic conditions. The first condition is the low (0) condition, where the voltage measured on the voltage measurement instrument is $0.2V_{DC}$ at the port, indicating that the system is within the ideal limits. The second condition is the high condition, where the voltage measured on the voltage measurement instrument is $4.8V_{DC}$ at the port, also indicating that the system is within the ideal limits. This is because the Arduino UNO has a working voltage range of 4.5 to 5.5 V_{DC}.

3.3. LCD Circuit examination

This LCD test is designed to determine whether the LCD in question is defective or functioning correctly. The LCD display is equipped with a total of 16 pins, which are divided into different categories. These include 8 pins for data transmission, 2 pins for power supply, 1 pin for contrast adjustment, 6 pins for control purposes, and 2 pins for grounding. The initial test involves applying a 5 V_{DC} power to the microcontroller, which then activates the LCD display. Adjusting the contrast of the LCD can be achieved by manipulating the trimpot attached to the V_{DC} terminal on the LCD. To achieve optimal character contrast, adjustments can be created within the voltage range of 4.75 to 5 V_{DC}.

3.4. Mosfet gate drive circuit examination

Gate drive testing is conducted to determine the ability of the gate drive to release voltage from the IRT 3205 Mosfet. The Arduino UNO generates the PWM signal that is utilized to fire the buck converter component. The primary purpose of the Mosfet driver circuit is to act as an isolator between the power circuit and the control circuit. It serves as a barrier between the low voltage circuit and the high voltage circuit, facilitated by the presence of an optocoupler.

3.5. Buck-Boost Converter Circuit Examination

The Arduino generates a pulse width modulation (PWM) signal with a frequency of 40 *Khz* to fire the buck-boost converter circuit. The frequency and switching characteristics of the Buck-Boost Converter have a direct impact on the output objectives, specifically in relation to the developed components. To test the converter, variable *DC* input values ranging from 20-14 V_{DC} are applied to the circuit, with a load value of 100 Ω, to achieve a consistent output of 40V. The test results are displayed in Table 1.

The measurement results of the Buck-Boost converter circuit with duty cycle are displayed in Figure 6. The test findings of the *DC*-to-DC Converter circuit indicate an output value of 39-40 Volts. Despite the changing input range of 20-14 volts, the Buck-Boost Converter could generate an output voltage within the range of 39-40 volts. By modifying the duty cycle value, the output voltage value increases proportionally as the duty cycle value increases. Moreover, as the duty cycle value decreases, the output voltage also decreases. The resulting duty cycle data value is 39.7%.

Table 1. Examination of Buck-Boost converter constant output variable input

V_{IN} (V_{DC})	V_{OUT} (V_{DC})
20	40.8
19	40.7
18	40.5
17	40.6
16	40.5
15	39.8
14	39.7

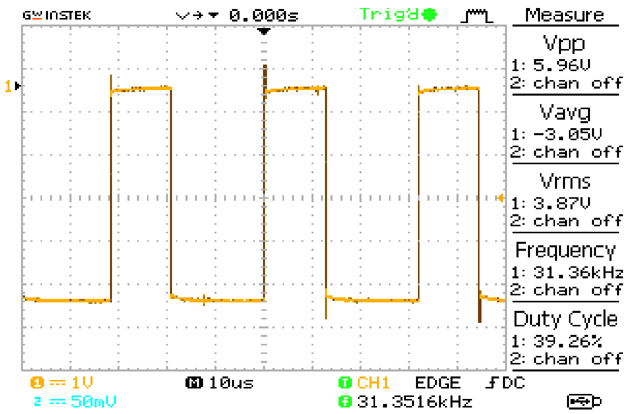


Figure 6. Buck-Boost converter circuit measurement with duty cycle

3.6. Regenerative braking circuit examination

Examination is conducted by establishing a complete circuit, wherein the BLDC motor functions as a generator as shown in Figure 7. In this instance, the motor's initial velocity is configured to operate within a range of 100-600 revolutions per minute. In order to maintain the rotation of the motor after the anchor is removed, the motor is connected to a flywheel. The flywheel serves as both a load and a means to rotate the BLDC motor. The motor is then left to rotate until it comes to a stop. This regenerative braking power regulator provides the motor power to the battery. The collected data includes measurements of charging duration and variations in braking time, both with and without the presence of a regenerative braking power flow regulator, while excluding any circuit-related factors. The test results are displayed in Table 2.

Table 2. Regenerative braking examination results

Without regenerative brake				With regenerative brake			
Speeds (rpm)	Stopping time (s)	Current (A)	Voltage (V)	Speeds (rpm)	Stopping time (s)	Voltage (V)	Charging Time (s)
600	18.7	2	20,2	600	8	40	8
500	15.0	2	18,8	500	7	39,7	7
400	13.5	2	18,6	400	5	40	5
300	10.2	2	17,8	300	4	39,6	4
200	7.3	2	18,6	200	3	39,6	3
100	3.5	2	17,8	100	2	39.5	2

Figure 7. Regenerative brake examination

The examination performed in Table 2 revealed a comparison between the regenerative braking time when releasing to stop, resulting in a time difference of 8 seconds. The regenerative braking system can halt the motor for duration of 16.2 seconds and, when disengaged, it takes 18.7 seconds to come to a complete stop. During this time, the battery is recharged for a period of 8 seconds. The results indicate that the intended regenerative brake system, which aims to enhance braking efficiency and minimize energy loss in different purposes, was successfully and effectively implemented.

Previous investigation [17], [18] has created a regenerative braking system that consists of a hydraulic brake module equipped with a motor-driven pump, inlet and outlet valves, and an accumulator for storing brake fluid. The system additionally integrates a traction control valve and a hydraulic control module to ensure accurate regulation of braking power. In addition, [19], [12] introduced a regenerative braking energy recovery system comprising a diode fairing, an energy recovery module, a detecting loop device, and a control circuit device. The system obviates the requirement for a step-up transformer, therefore diminishing expenses and enhancing energy efficiency.

In addition, Yanfeng et al., [18] introduce a regenerative braking energy saving system for an urban railway system that is coupled to the power supply system. The system comprises an energy feedback unit, an energy storage unit, a main transformer station information collection unit, and a central control unit for the coordinated regulation of regenerative braking energy allocation. [8], [20], [21] explains a regenerative brake control system for electric motorcycles that employs sensors and control units to progressively achieve the desired regenerative torque. Qiu et al., [22], and Chengqun et al., [23] introduced a method and system for controlling regenerative brakes in trains. This approach involves calculating the traction network pressure to determine the optimal timing for activating the brakes.

4. Conclusion

Considering preparation, creating a prototype, examination, and analyzing the manufacturing procedure of the BLDC motor braking structure, it is possible to infer that the three-phase full-wave rectifier and Buck-Boost Converter can function as a power transmission regulator during regenerative braking. This power regulator maintains a constant output of 39-40 Volts, which is suitable for charging the battery. Moreover, this regenerative braking system effectively reduces the time it takes for the motor to come to a stop by 16.2 seconds when power is applied to the battery during braking, as compared to not braking and allowing the battery to charge for 8 seconds. Further study could be undertaken by boosting the regenerative brake system's generation output using buck-boost converter system engineering as well as microcontroller architecture.

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