International Journal of Computer Applications Technology and Research
Volume 12–Issue 12, 80 - 86, 2023, ISSN:-2319–8656
DOI:10.7753/IJCATR1212.1012

Smart Charge Controller using Buck Converter Topology for Bicycle Power Generator in DC House Electrical Grid

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Abstract: Human energy is a renewable and abundant source. It can be effectively used in DC home electric systems. To convert human energy into electrical energy, a bicycle power generator is required, accompanied by a battery to store the converted energy. Nevertheless, the varying nature of the energy generated through pedaling may lead to swift damage to the battery. The author designed and built a charge controller to ensure a constant flow of voltage and current to the battery. Abbreviations of technical terms are explained the first time they are used. The language is clear, objective, and formal, without filler words or biased language. The writing adheres to conventional structure and uses precise word choice. Grammatical correctness and consistent formatting are employed, with common academic sections included.

The Buck Converter topology regulates the field current (I_f) entering the alternator to maintain a stable alternator output voltage. The current from the source flows into the Buck Converter circuit. The microcontroller adjusts the duty cycle to set the field current (I_f) in the Buck Converter. When the rotation of the alternator is high, the value of the field current (I_f) is decreased, and when the rotation is low, the value of the field current (I_f) is increased in order to maintain a constant output voltage despite the changes in rotation.

Keywords: chargecontroller, topology buckconverter, bicyclepower generator, optimization, charging coordination.

1. INTRODUCTION

Human power can serve as an alternative energy source due to its abundance. By converting energy from human power into electrical energy, bicycle power generators can be utilized as a power source in DC home installations. By converting energy from human power into electrical energy, bicycle power generators can be utilized as a power source in DC home installations. The tool effectively converts human energy into usable power, making it a practical and eco-friendly option. By converting energy from human power into electrical energy, bicycle power generators can be utilized as a power source in DC home installations.

In implementing the bicycle power generator, several issues arise, particularly in the form of heavy pedaling due to the field current (If) required by the alternator to generate electrical energy. This results in people's disinclination to generate energy through this bicycle power generator. Another issue with the bicycle power generator is that the voltage generated by the alternator tends to fluctuate due to changes in human power input. Directly connecting the battery to this fluctuating voltage can shorten its lifespan. This problem can be resolved by using a charge controller that regulates the field current (If) entering the alternator and produces a stable voltage to charge the battery.

This research focuses on the optimization of charge controlling for bicycle power generator in installation system of DC House. This charging control takes advantage produces a stable voltage to charge the battery using buck converter charge controller.

2. LITERATURE REVIEW

2.1 Electrical Installation of DC House

The DC House electrical installation consists of the main components: the source of electrical energy, the charge controller, the battery, the MISO (Multiple Input Single Output) DC-DC converter, and the load in the form of DC equipment. To illustrate the main system in the DC House electrical installation, refer to Figure 1.

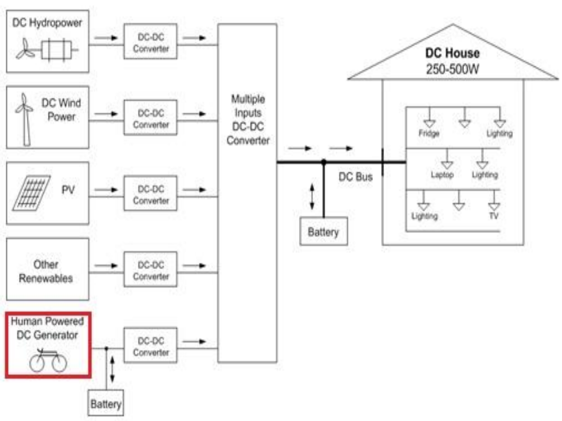

Figure 1. The main system in the DC House electrical installation.

2.2 Bicycle Power Generator

A bicycle power generator is an electricity source for DC houses that converts human pedaling power into electrical energy. The process involves pedaling a stationary bicycle connected to an alternator via a v-belt. The electrical energy produced by the alternator can be stored in a battery or used directly[1].

The main components of the bicycle power generator are bicycle, alternator, bike stand,charge controller, v-belt, battery.

2.3 Buck Converter

The buck converter operates based on two conditions: the switch is in either the ON or OFF state. In the ON state, as

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illustrated in Figure 2, the input current flows through the inductor L and capacitor C because the diode is non-conductive. During this time energy is also stored in inductor L. When VC> VOUT, capacitor C discharges and transfers energy to the output. When the switch is OFF, as depicted in Figure 3, the capacitor C transfers energy from the input to the output. The diode is conducting because of the energy previously stored in inductor L. Next, the inductor current iL flows partly to capacitor C, and the energy is then transferred to the output. The value of inductor current iL continuously decreases until the switch is turned ON again during the next cycle.

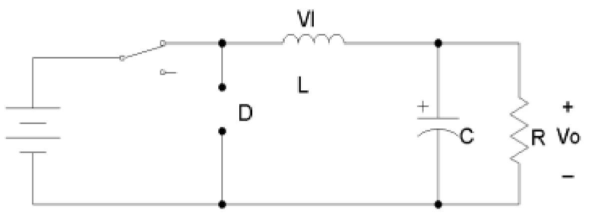

Figure 2.Buck converter circuit when switch is ON

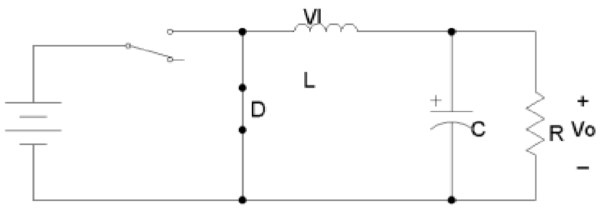

Figure 3.Buck converter circuit when switch is OFF

3. RESEARCH METHODE

This research addresses two main issues: how to create a Charge Controller utilizing the Buck converter topology to regulate the field current (If) that enters the alternator and stabilize the alternator's output voltage that enters the battery, as well as how to determine the appropriate amount of PWM duty cycle given to the Buck converter by the microcontroller control logic. Both issues have practical implications. To implement this research, it is necessary to conduct a literature study on the supporting theory, design and manufacture appropriate tools, perform tests and analysis, and draw conclusions.

3.1 Design and Development of Equipment

The design of the charge controller using a buck converter topology is segmented into various components, including the design of the MOSFET driver, the ATMega8 microcontroller acting as a pulse width modulation (PWM) regulator, a 5-Volt regulator acting as the minimum power source of the microcontroller system, and current and voltage sensors. The software design component of this project is presented in the form of a flow chart for the charge controller system.

3.2 Testing and Analysis

Testing is conducted on each circuit block, with the results observed. Technical terms are explained when first used, and clear, concise language is consistently employed throughout. After testing each block, the testing is then carried out on the entire block, resulting in one charge controller system. The testing process is divided into two stages :

1. Testing the power supply circuit
2. Testing the minimum microcontroller system circuit
3. Testing the MOSFET driver circuit
4. Testing the buck converter circuit
5. Conducting current sensor andvoltage sensor testing
6. Finally, testing the overall charge controller system for the bicycle power generator.

4. Design and Development of Equipment

4.1 Block Diagram of Charge Controller System

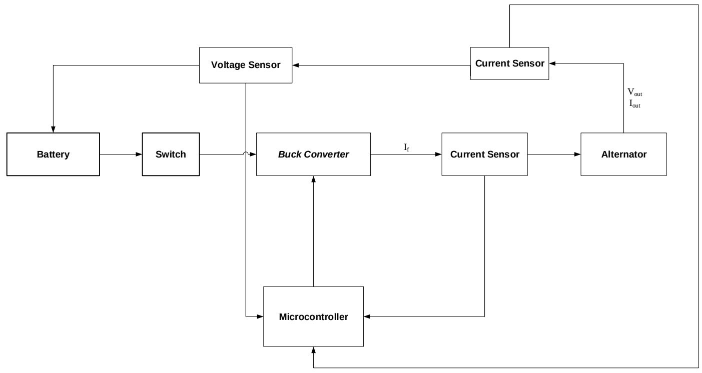

Figure 4. Block Diagram of Charge Controller System

The diagram in Figure 4 illustrates the initial step of the system, where the switch is manually closed to turn the buck converter on. A current sensor measures the output current value of the converter to determine if it meets the minimum field current required by the alternator. If it does not, the microcontroller adjusts the duty cycle value accordingly. The alternator is rotated using a static bicycle, and human pedaling energy is then used to produce electrical energy. The voltage sensor determines the battery charging voltage from the alternator. If the alternator output voltage exceeds or falls short of the battery's optimum charge voltage, the microcontroller adjusts the field current (If) by modifying the duty cycle value. The current sensor placed downstream of the alternator detects the charging current value for the battery. If the minimum current required for charging is met, current flows to the battery. To adjust the field current (If), the microcontroller adjusts the duty cycle as necessary. The MOSFET will act as a switch for the duty cycle set by the microcontroller. Technical term abbreviations will be explained upon their first use. The duty cycle is the ratio between the on time (logic 1) and the switching period and its value will impact the Buck Converter circuit's ability to increase or decrease the field current value (If).

4.2 Hardware Design of Charge Controller

The design of the charge controller hardware is divided into several parts, including:

1. Design of buck converter
2. Design of the power supply circuit
3. MOSFET driver design
4. Design of minimum microcontroller system
5. Design of voltage sensor

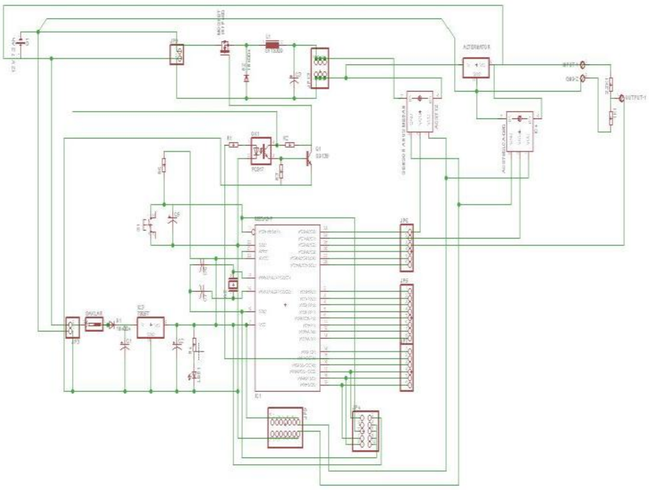

Figure 5. Overall circuit of the charge controller system

4.3 Charge Controller Software Design

The charge controller software is developed using the C language and the CodeVision AVR compiler. The algorithm supporting the operation of the device is shown in the flowchart in Figure 6.

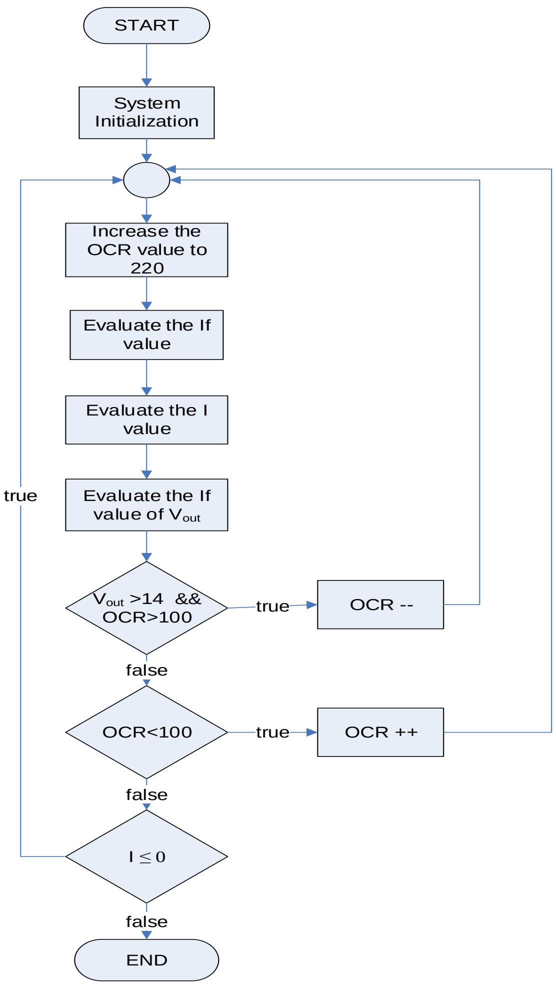

Figure 6. Flowchart of the software

5. RESULTS AND DISCUSSION

5.1 Microcontroller Power Supply Circuit Testing

This test verifies the correct operation of the microcontroller's power supply circuit, which generates a 5V voltage used to power the microcontroller.

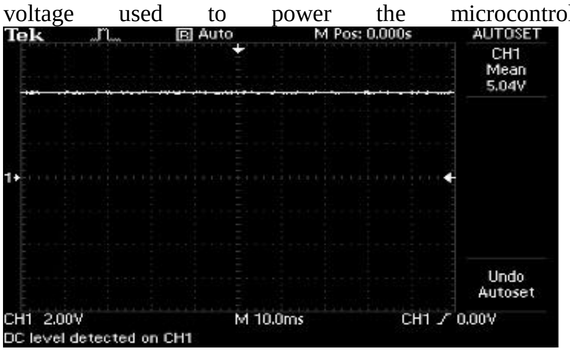

Figure 7. Example of microcontroller power supply circuit test results

The test results for the microcontroller power supply circuit are shown in Figure 7. The results demonstrate that the LM7805 regulator, with an input voltage of 12 volts for the 5 volt power supply circuit, outputs a voltage of 5.04 volts. As per the LM7805 regulator datasheet, the minimum and maximum output voltages are 4.75 volts and 5.25 volts, respectively. Therefore, it can be concluded that the LM7805 regulator operates appropriately.

5.2 PWM Testing on Microcontroller

This experiment aims to observe the PWM waveform and frequency of the Buck Converter circuit. The required frequency for the circuit is 50kHz, as determined by the design. An oscilloscope is necessary to visualize the PWM waveform and frequency.

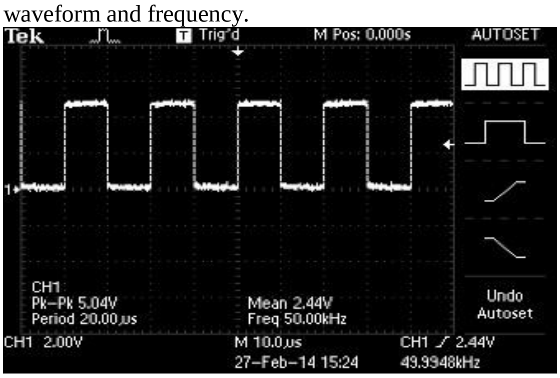

Figure 8. Example of 50% PWM waveform and 50 kHz frequency

The microcontroller is programmed with 50% duty cycle and a 50 kHz frequency. Figure 8displays a PWM waveform example generated by the microcontroller with 5 volts input voltage, the duty cycle set to 50%, and a frequency of 50 kHz.

5.3 MOSFET Driver Circuit Test

The purpose of this test is to verify that the MOSFET driver can drive the output signal from the microcontroller according to the circuit requirements using a 12V input voltage. Table 1 displays the output test results for the MOSFET driver with different duty cycle values.

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Table 1. MOSFET driver test results table

No.	Duty Cycle (%)	Calculation Voltage (volt)	Measured Voltage (volt)
1.	0	0	0
2.	25	3	3,20
3.	35	4,2	4,47
4.	50	6	5,90
5.	75	9	9,02
6.	100	12	11,80

An example of a mosfet driver output waveform result is shown in Fig. 9.

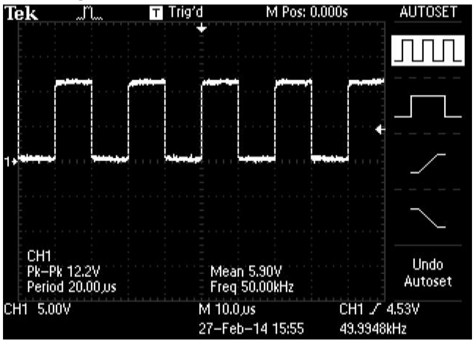

Figure 9. Example of MOSFET driver output waveform with 50% duty cycle

The waveform of the MOSFET driver circuit matches the input that comes from a PWM signal generated by the microcontroller.

5.4 Buck Converter Circuit Test

This experiment aims to observe the efficacy of the Buck Converter circuit in reducing voltage. According to the results, the Buck Converter circuit works effectively. To conduct the experiment, a source voltage of 10.98 volts is supplied from a battery to the input of the Buck Converter. Figure 10 depicts the successful operation of the Buck Converter circuit as demonstrated by the reduction of voltage from 10.98 volts to 5.87 volts. Clearly, this circuit works effectively.

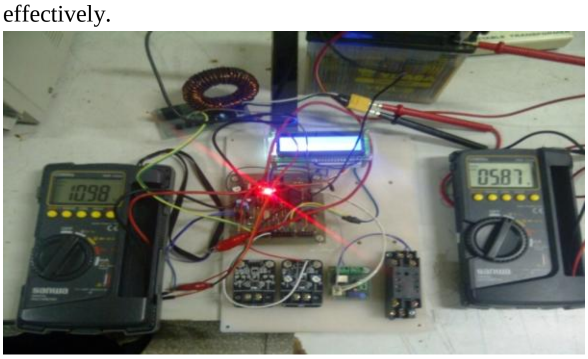

Figure 10. The test results of the Buck Converter circuit to reduce the voltage

5.5 Current Sensor Circuit Test

This is a comparison of current sensor output based on test results and ACS712 current sensor data sheet. In the first experiment, at 0 amperes current, the output voltage of the current sensor was 2.5 volts. Refer to Figure 11 for a visual demonstration of the waveform from the test results of the current sensor.

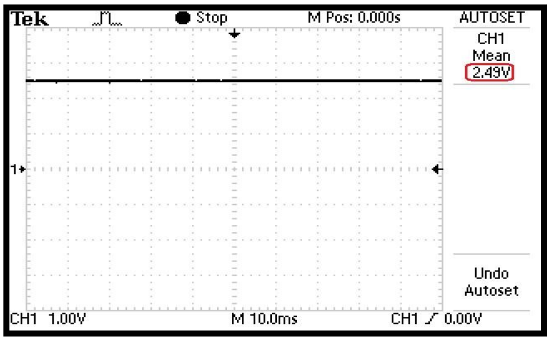

Figure 11. Example of ACS712 current sensor test results

Table 2 shows the test results of the current sensor with various current values.

Table 2. ACS712 current sensor test results table

No.	Input Current (ampere)	Output Voltage (volt)	Voltage based on Datasheet (volt)	Error (%)
1.	0	2,49	2,50	0.4
2.	0,1	2,50	2,51	0,4
3.	0,2	2,51	2,52	0,4
4.	0,3	2,52	2,53	0,4
5.	0,4	2,53	2,54	0,4
6.	0,5	2,54	2,55	0,4

Table 2 shows that the ACS712 current sensor has an average error of 0.4%. This is significantly lower than the maximum reading error of 1.5% stated in the datasheet, demonstrating that the sensor performs well.

5.6 Voltage Sensor Circuit Test

This test examines the functionality of the voltage sensor circuit in measuring voltage. The circuit is evaluated by inputting multiple voltage values to the sensor. Example results of the voltage sensor circuit when reading 11.9 volts are depicted in Figure 12.

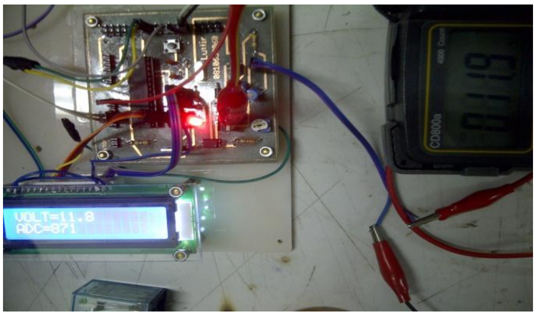

Figure 12. Test result of voltage sensor circuit

The results of the voltage sensor test are displayed in Table 3. The sensor exhibits a low average error rate of 0.13%, indicating its effective performance.

No.	Voltage sensor (volt)	Voltage multimeter (volt)	Error (%)
1.	**0**	**0**	**0**
2.	**1,2**	**1,2**	**0**
3.	**2,5**	**2,5**	**0**
4.	**3,2**	**3,2**	**0**
5.	**5**	**5**	**0**
6.	**11,8**	**11,9**	**0,8**

Table 3. Voltage sensor test result table

5.7 Overall System Test

Testing the entire circuit is crucial to determine the success of each individual circuit block that has been incorporated into a single system. The system can be deemed successful if it can showcase a consistent output voltage of the alternator between 13-13.5 volts while subjected to varying alternator rotation speed conditions. Fig. 13 depicts the testing of the complete system.

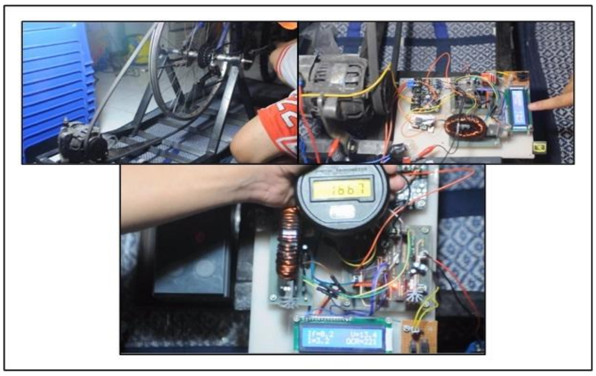

Figure 13. Overall system test

Table 4 displays the data of the comprehensive system test outcomes during alterations in rotational speed.

Table 4 Overall system test data

Rotation speed (rpm)	If (ampere)	Vout (volt)	Iout (ampere)	Torque (Nm)
826	0,3	11,3	1,7	0,207
1424	0,2	12,9	2,3	0,202
1568	0,1	13,1	2,5	0,201
1603	0,1	13,2	2,6	0,198
1668	0,2	13,4	2,8	0,218
1677	0,1	13,2	2,66	0,197
1798	0,2	13,2	3,2	0,220
1872	0,2	13,2	2,86	0,188
2006	0,1	13,3	2,82	0,172
2076	0,1	13,3	2,66	0,162
2196	0,1	13,2	2,81	0,160
2228	0,1	13,4	2,7	0,154
2360	0,1	13,2	3,1	0,166
2412	0,1	13,3	3,09	0,163
2462	0,1	13,5	3,19	0,167

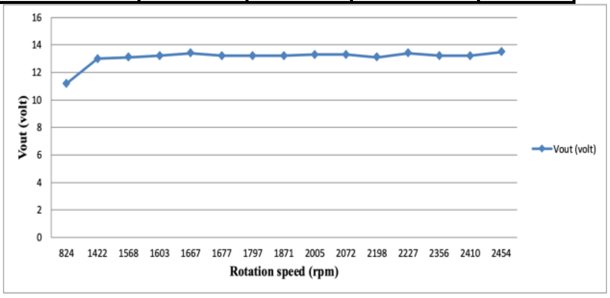

Figure 14. Graph of output voltage versus rotation speed

Figure 14 depicts a graph displaying the relationship between rotation speed and output voltage. It is observed that at high and low rotation values, there is little variation in Vout or it tends to remain constant due to a minimal difference in value. As an illustration, the Vout value remains the same at 13.2 volts for rotation values of 1677 rpm and 2356 rpm. This indicates that the device is functioning as intended - ensuring a stable output voltage with a value ranging between 13 - 13.5 volts.

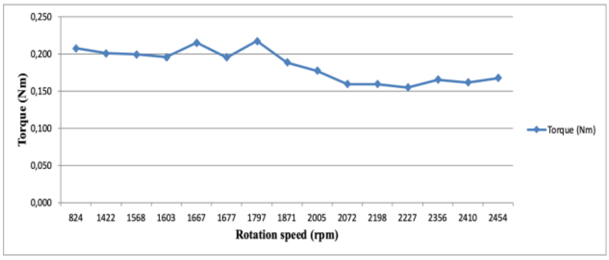

Figure 15. Graph of torque against rotation speed

Figure 15 illustrates the graph of torque generated in relation to rotation speed. Technical term abbreviations such as 'torque' should be defined when first used to improve clarity. The graph shows that the tool produces a relatively stable torque value from low to high rotation values, with only a small difference in value. Additionally, as the rotation speed increases, the torque value gradually decreases. Consistent and formal language throughout the text enhances its academic quality. This indicates that the tool functions as intended by producing an appropriate torque value without excessive increase. This allows the bicycle generator to require less initial power. This reduces the stress on the person pedaling the generator.

The following analysis aims to compare the output voltage and torque values generated with and without a charge controller in the overall system test.

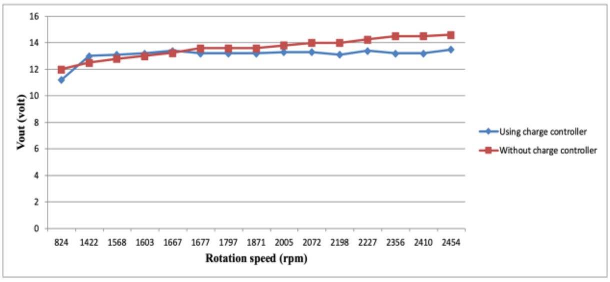

Figure 16. Comparison graph of output voltage using a charge controller and not using a charge controller

Figure 16 displays a comparative graph depicting the output voltage with and without a charge controller. The graph illustrates that as the rotation values increase, the Vout value steadily rises from 12 to 14.6 volts on the line without a charge controller. This indicates an unstable voltage and can quickly damage the battery if used for charging purposes. On the graph line utilizing a charge controller, the Vout value stabilizes between 13-13.5 volts, which guarantees safe battery charging

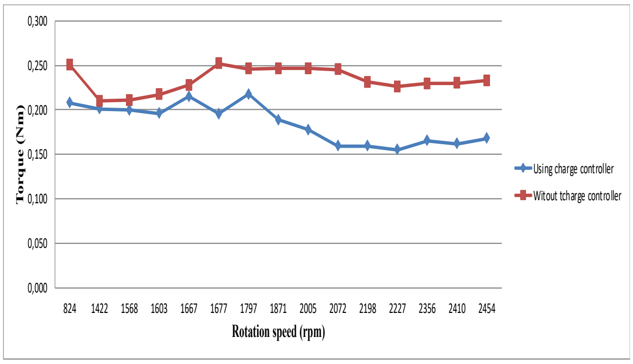

Figure 17 Comparison graph of output torque using a charge controller and not using a charge controller

Figure 17 displays a graph illustrating the correlation between torque output and rotational speed with and without a charge controller. The data reveals that torque output when using a charge controller is consistently lower compared to when one is not used, and tends to decrease. Consequently, initial pedaling of the bicycle power generator without the controller may require greater effort. The line graph shows that the torque value is consistently lower when using a charge controller compared to before its installation. In addition, the torque value generally decreases over time. Consequently, the use of a charge controller reduces the initial stroke power required for an initial bicycle power generator. This makes it easier for people who pedal the generator to experience less resistance.

6. CONCLUSION

After analyzing and testing the Charge Controller utilized in the DC House Bicycle Power Generator, we have concluded that it can effectively govern the field current entering the alternator using the Buck Converter topology. However, some circuit errors were observed in that configuration. Inappropriate component selection caused this issue. Nevertheless, the Buck Converter circuit remains functional, as evidenced by the steady output voltage and reduced torque value when compared to using the charge controller.

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