



Embedded System

Speed Bump Generator as A Power Source for Garden Lights

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ABSTRACT

In an effort to explore environmentally friendly alternative energy solutions, this study develops a Speed Bump Generator system designed to generate electrical energy as a power source for garden lighting. The system harnesses the kinetic energy of vehicles passing over speed bumps and converts it into electrical energy, which is then stored in a battery. Experimental results indicate that the system is capable of producing an average current of 1.33 mA; however, the energy generated has not yet achieved the target storage capacity of 5 Ah. To improve system functionality, a Light Dependent Resistor (LDR) sensor is integrated to enable automatic lamp activation during nighttime conditions. The findings of this research provide a basis for further development toward more efficient and sustainable energy-saving lighting systems.

INTRODUCTION

Every year, electricity consumption continues to increase in Indonesia. This situation is influenced by Indonesia's rapid economic growth and infrastructure development. Public sectors such as transportation, industry, and business require electricity in addition to household needs. Currently, electricity from PLN is still the main source of energy for public street lighting. According to the Ministry of Energy and Mineral Resources, electricity consumption in Indonesia has only reached 1,169 kilowatt hours per capita of the total target of 1,268 kilowatt hours per capita in 2022. In addition, electricity consumption in Indonesia is still below the average of other Southeast Asian countries, which is 3,672 kilowatt hours per capita [1]. In this situation, PLN, as the national military supplier of electrical energy, has a critical priority in handling national electrical energy needs. One step that can be taken to reduce dependence on electricity supply from the PLN network is to utilize other energy sources outside the conventional electrical system. Various energy potentials can be developed as sources of electricity generation, such as wind, water, steam, gas, geothermal, solar, nuclear, and mechanical energy derived from physical activity or motion.

There is previous research that serves as background for this study, which involves creating a system using speed bumps. This speed bump system uses vehicle pressure on speed bumps, which is converted into rotational energy through a rack and pinion mechanism using hydraulic pressure. As a result, this rotational energy turns a generator that produces electrical power, which is stored in a battery using a charging circuit [2]. However, this system is not yet capable of providing information on whether the power is full or not.

Park lighting is important in supporting activities around the park. Parks are places that are widely used for various outdoor activities. With adequate park lighting, activities carried out at night in the park will certainly be smoother and safer. Additionally, garden lights can enhance the aesthetic value of the garden. However, powering garden lights requires a significant amount of electricity. There are several solutions that can be implemented to address this issue. One of them is a system that utilizes alternative energy sources as an electricity supply.

There are several previous studies that serve as background. In these studies, the system uses solar energy and LDR sensors [3]. This system can adjust the lights according to needs, turning them on when no light is detected in the surrounding area. However, this system needs further development to improve its reliability so that it can be widely applied.

Another study is an automatic street lighting control system based on vehicle detection using a microcontroller. The method used is to install sensors on the road that can detect the presence of vehicles. The sensors then send signals to the microcontroller, which controls the street lighting system. When a vehicle approaches the road, the lights turn on automatically, and when the vehicle has passed the road, the lights turn off again [4]. In this study, the automatic street lighting control system based on vehicle detection using a microcontroller is an effective and efficient solution for saving energy and reducing street lighting system maintenance costs. However, sensors are installed along the road, making this system expensive, and not everyone can use it.

The use of a lighting system with light sensors to control garden lights so that they turn on at night. The use of light sensors in this system can provide additional benefits in terms of energy efficiency. By using light sensors, street lights will only turn on at night when needed, and will turn off during the day when not needed. This can reduce energy consumption and increase the lifespan of street lights. This system will also be combined with a speed bump generator as a power source that will convert previously wasted energy into electrical energy, which will help reduce daily electricity consumption.

The Objectives of the Research

This research aims to develop a system capable of converting kinetic energy into electrical energy through the use of a generator, as well as effectively storing energy using a motorcycle battery with a target of producing 5 Ah of energy storage. As part of this research, the system will be equipped with an XY-L10A (charging module) and a buzzer as a storage indicator, enabling better monitoring of the stored energy status. Focusing on energy conversion, storage, and monitoring, this research integrates several aspects to achieve the objectives set.

Speedbump

Speed bumps are road elements in the form of elevated structures installed across the road surface, generally made of asphalt or concrete, which serve as markers and a means of reducing the speed of passing vehicles. Speed bumps are generally made of materials similar to the road surface, such as asphalt, rubber, or other materials with similar functions. These speed bumps are approximately 5 cm to 9 cm high with a total width ranging from 35 cm to 39 cm, and a maximum slope of 50%. To improve visibility, speed bumps are equipped with a combination of black and white or yellow colors, with a color segment length ranging from 25 cm to 50 cm. Their function is to improve safety for road users [10].



Figure 1. *Speedbump* [11].

Generator AC

An alternating current (AC) generator is an electromechanical device used to convert mechanical energy from a motion system into electrical energy with an output in the form of alternating current. The mechanism of electricity generation in an AC generator utilizes the principle of electromagnetic induction, whereby changes in magnetic flux caused by relative movement between the magnetic field and the conductor will induce an electromotive force in the conductor, in accordance with Faraday's Law [13], which states that changes in magnetic flux through a coil will generate an electromotive force (voltage) in the coil. This voltage arises when there is a change in the magnetic field relative to the conductor, either through the movement of the conductor or the change in the magnetic field itself. With the large number of vehicles passing by, the generator will be combined with a speed bump to generate electrical energy created from the pressure of the vehicles.

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Electric Generator (AC)

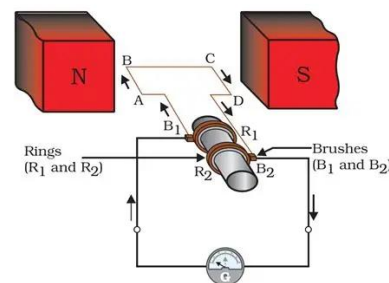


Figure 2. Generator AC[14]

LDR

LDR or Light Dependent Resistor is an electronic component that belongs to the resistor type. Its resistance value will only change when the intensity of the absorbed light changes. The working principle of LDR is very simple and not much different from other variable resistors. Light Dependent Resistor (LDR) is a component that is widely used in electronic circuits as a light sensor to control the flow of electricity. The resistance value of an LDR decreases when the intensity of light hitting it increases. With this characteristic, an LDR will more easily conduct electric current in bright conditions, while in low light or dark conditions, an LDR will provide greater resistance to the flow of electric current [19].

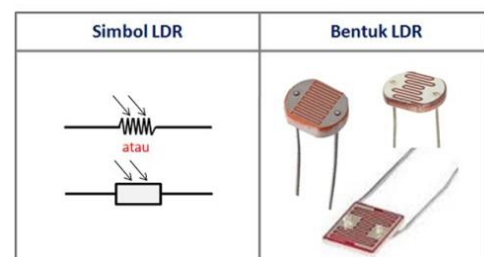


Figure 3. Sensor LDR [19]

Aki (Accumulator)

An accumulator, commonly known as a battery, is an important

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electrical component in motor vehicles that functions as a medium for storing electrical energy. This electrical energy is stored in the form of chemical energy in the battery cells and can be reused when needed. There are various types of electrical energy storage devices, including batteries and capacitors, which work on different energy storage principles[20]. When the battery capacity has decreased, it needs to be recharged so that the system can operate again as it did initially. Batteries are reversible, so they can undergo repeated energy conversion between electrical energy and chemical energy. During charging, electrical energy is converted into chemical energy, while during use, the chemical energy is converted back into electrical energy. Batteries are classified as secondary cells, which are electrochemical components in which chemical reactions can occur in both directions. The electrical energy produced during the discharge process is in the form of direct current (DC) [21].



Figure 4. Aki [22]

XY-L10A

The battery functions as a source of electrical energy for various electrical components in a system. However, the energy storage capacity of a battery is limited, so it cannot supply electrical power continuously. Therefore, the condition of the battery must be maintained so that it is always charged to ensure the availability of electrical energy when needed. The charging system plays a role in generating electrical energy to recharge the battery and distribute electrical power to electrical components when the system or engine is operating [23]. The XY-L10A has a built-in LCD component that is used as an indicator of battery power.

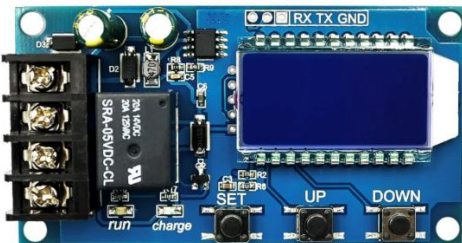


Figure 5. Modul Charging (XY-L10A) [24]

METHOD

This final project research uses an action research methodology approach, which is a research method that emphasizes continuous improvement through systematic planning, implementation, and evaluation stages. This approach aims to produce valid and reliable research data. In the designed system, electrical energy is generated through a speed bump mechanism, then stored in a battery, and subsequently used to automatically turn on lights using an LDR sensor. The system is considered successful if the lights can turn on automatically at night in accordance with the design objectives.

The general design of this system explains how all of this hardware is interconnected. The following general design of the system from this study can be seen in the figure 5.

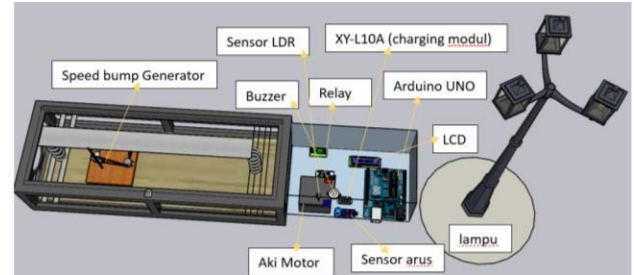


Figure 5. General System Design

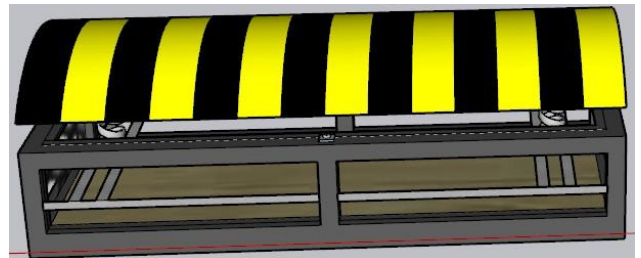


Figure 6. Speedbump Generator Design

In Figure 5, you can see how this Speedbump system model works, starting with pressure from a vehicle, which generates electricity from the generator, which is then channeled to the battery through XY-L10A (Charging Module) and to the current sensor through Arduino UNO, which calibrates the current value generated. The battery is also paired with a Buzzer, which is used as an indicator. Once the battery is charged, the electrical power from the Speedbump generator system is connected to the LDR Sensor circuit so that the lights can be turned on at night. The LDR Sensor itself sends input to the Arduino, which then sends input to the Relay connected to the lights. The current sensor circuit displays the incoming and outgoing current on the LCD connected to the Arduino and Speedbump generator. Figure 6 shows the design of the speed bump generator to be built, where the speed bump is equipped with a spring connected to the generator via a gear attached to a chain.

The process design was carried out with reference to the previously established functional requirements of the system. This stage was divided into two main parts, namely hardware design and software design, each of which described the flow of input data processing until the system produced the desired output. In its implementation, this system was divided into several stages. The speed bump generator converted the energy generated from passing vehicles into mechanical energy (DC). The energy (DC) is transferred through the XY-L10A charging module and stored in the motor battery. The battery also has a buzzer that indicates the power remaining in the battery. Next, the Arduino controls the lights using an LDR sensor. The LDR sensor is also connected to a relay, which regulates the electrical power supplied to the lights. The current value is displayed on the LCD.

The hardware design of the system is shown in the following figure 7.

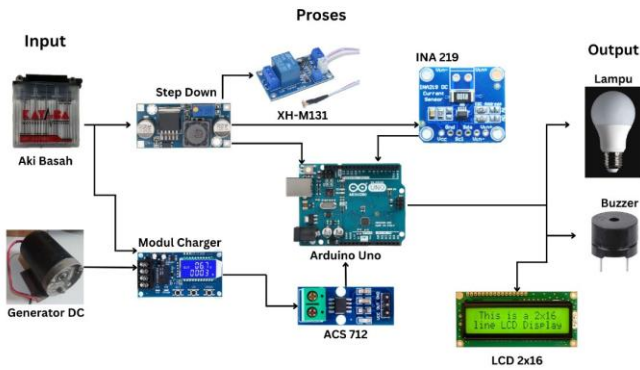


Figure 7. Process Flow Diagram.

Based on Figure 7, the system starts with an AC generator that functions to generate electrical energy when there is pressure from vehicles passing over the speed bump, making the generator the main component in energy generation. The electrical energy generated is then channeled to the XY-L10A charging module, which plays a role in charging the battery while also displaying the battery power status. The motorcycle battery then functions as a medium for storing electrical energy to supply the power needs of the entire system. Arduino Uno is used as the main controller that processes data from various sensors. The current sensor functions to measure the amount of current entering the battery and the current discharged from the battery during system operation. The LDR sensor is used to detect the intensity of ambient light so that the lights can turn on automatically when it starts to get dark. The relay acts as an electronic switch that regulates the power flow between the battery and the light. Information on the current entering and leaving the system is displayed on the LCD, while the light serves as the main output of the system. As an additional indicator, a buzzer is used to signal the battery's power condition.

Process Design

The Software Design will explain the design of the program on the system that will work, followed by data processing, to the output of the system. The general process design is shown in the form of a flowchart in the following figure.

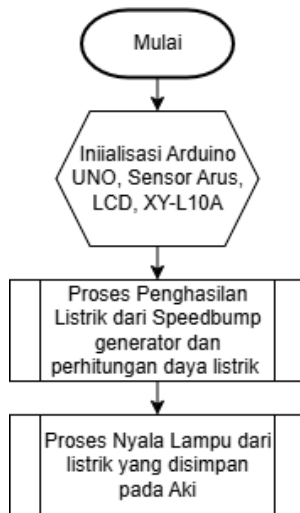


Figure 8. General Process Flowchart.

Figure 8 shows a flowchart of the general process design of the system, which begins with the initialization of the Arduino Nano, current sensor, LDR sensor, XY-L10A (Charging Module), and LCD. After that, electricity is generated by the Speedbump Generator and the energy produced is stored in the battery.

Next is the process of generating electrical energy by the speed bump generator and calculating the electric current, which is shown in the form of a flowchart and can be seen

in Figure below:

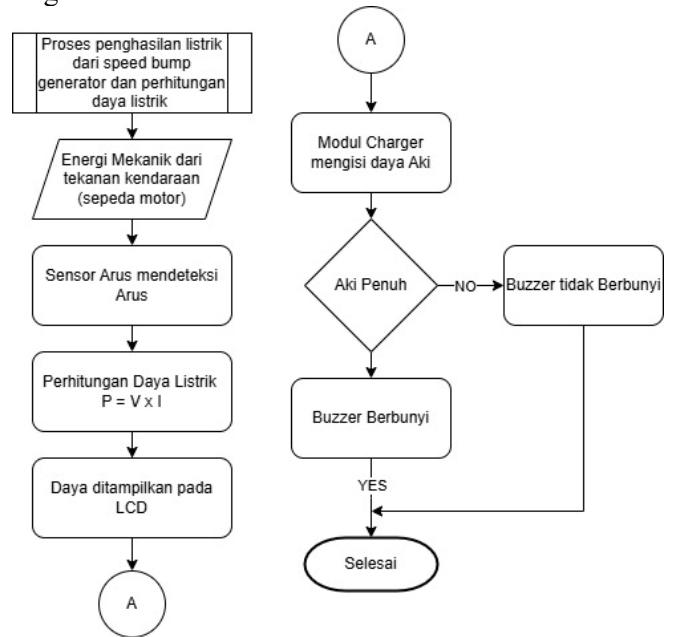


Figure 9. Process Flow Diagram.

Figure 9 shows a flowchart of the process of generating electrical energy by a speed bump generator and calculating the electric current, along with an explanation:

1. Initially, the speed bump receives pressure caused by passing vehicles.
2. The pressure on the speed bump then drives the generator underneath it to generate electricity.
3. This generates electricity with a DC current.
4. The current sensor reads the current value and then calibrates it.
5. The energy that has passed through the current sensor is stored in the motor battery.
6. The energy value that has passed through the current sensor is displayed on the LCD.
7. The buzzer sounds when the battery voltage reaches 12.5 V, and the indicator light on the charger turns green.

Furthermore, in this system, the process flow of the lamp turning on via the LDR sensor can be seen in Figure below:

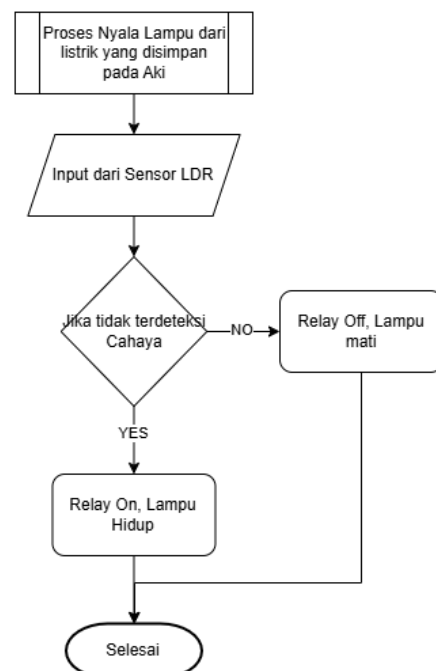


Figure 10. Energy yield flowchart and electrical current calculation. Figure 10 shows the process of energy stored in the battery and then fed into the LDR sensor, which will detect the conditions to determine whether the light will turn on or not.

RESULTS AND DISCUSSION

The system implementation stages include the deployment of hardware, software, and overall system integration. At this stage, testing is conducted on each component used, verification of the programs run, and comprehensive evaluation of system performance to ensure that the developed system has fulfilled the functions and objectives of the research.

Hardware Implementation

The hardware used in the system and supporting its operation consists of an Arduino Uno, generator, LDR sensor module, ACS712 current sensor, 1-channel relay, LCD, buzzer, battery, and XY-110A charger module. Additional components used include an INA 219 voltage sensor to calculate the power in the battery.

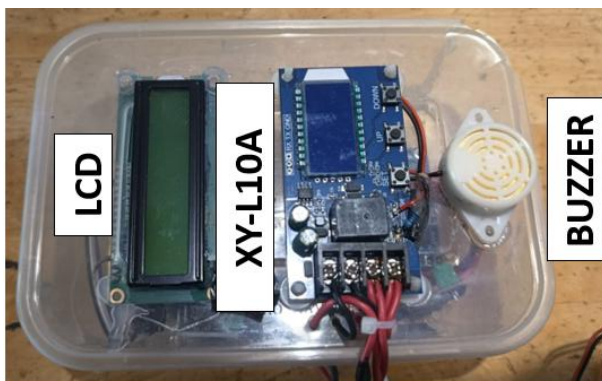


Figure 11. Implementation of the Entire System Hardware.

Figure 11 shows the generator components used in the system. The generator is connected to a mechanical circuit that converts rotational energy into electrical energy.

The use of three sets of gears in this system is based on the need to increase the rotational speed of the generator so that the electrical current produced is greater and more stable. In the initial design stage, the system only used one set of gears, but test results showed that the generator's rotational speed was still low, resulting in a relatively small and suboptimal current. This was because the mechanical energy transmitted from the vehicle's wheels to the generator did not experience an adequate increase in the rotational ratio.

By adding several sets of gears, there was an increase in the transmission ratio, causing the generator's rotational speed to be higher than the wheel's rotational speed. In terms of electromagnetic principles, the magnitude of the induced electromotive force (EMF) and the current generated by the generator are directly proportional to the rate of change of magnetic flux, which in this case is influenced by the rotational speed of the generator. Therefore, the higher the rotational speed of the generator, the greater the voltage and electric current generated.



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Figure 12 Hardware Implementation in Exterior Systems.

On the outside, there are components such as a buzzer, LCD charger module, and LDR.

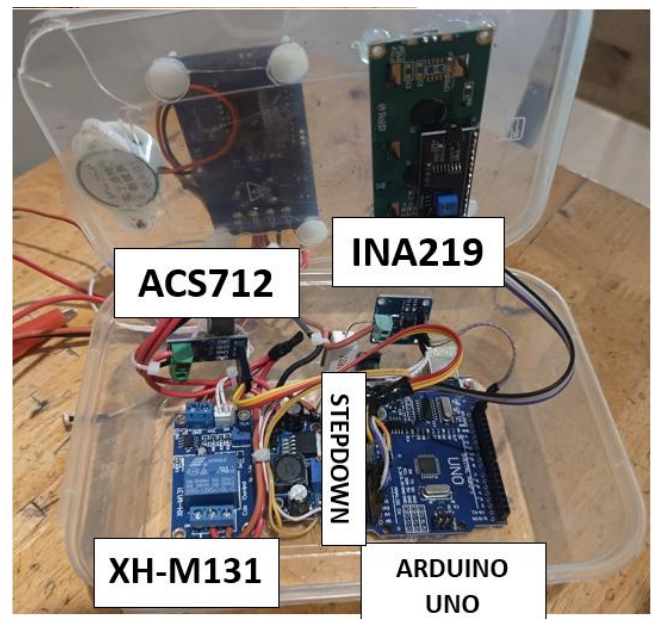


Figure 12 Hardware Implementation in Internal Display Systems.

Inside, there are stepdown components, relays, current sensors, and Arduino UNO. There are changes in the hardware components of the implemented system compared to the design process. Namely, the use of the XH-M131 module, which functions as a relay and LDR sensor combined into one. This change was made to make the circuit easier to use for users.

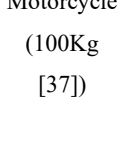
AC Generator Testing

The wet battery in this system is charged by utilizing kinetic energy that is converted into electrical energy through a generator. Kinetic energy from mechanical motion causes the generator shaft to rotate, resulting in a change in magnetic flux in the generator coil, which in turn generates electromotive force based on the principle of electromagnetic induction. The electrical current produced is then converted into direct current (DC) using a rectifier circuit to match the characteristics of wet batteries, which can only be charged with DC current. The charging current will flow to the battery when the generator output voltage is greater than the battery terminal voltage, with the current magnitude influenced by the voltage difference and the internal resistance of the battery.

The electrical energy that enters the battery is not stored directly, but is used to reverse the chemical reaction inside the battery cell. A wet battery is a lead-acid battery consisting of a positive lead dioxide (PbO₂) electrode, a negative lead (Pb) electrode, and a sulfuric acid (H₂SO₄) electrolyte. During the charging process, electric current decomposes the lead sulfate (PbSO₄) compound formed during discharge into active material on each electrode and increases the concentration of sulfuric acid in the electrolyte [31]. This process is the reverse reaction of battery discharge, in which electrical energy is converted and stored in the form of chemical energy, marked by an increase in battery voltage until it reaches a full state.

Table 1. AC Generator Testing

N	Motorcycle	Driver's	Speed	Current	Current
O	Weight	Weight		Without	With

				Rectifier Module	Rectifier Module
			Speedometer	Multimeter	Multimeter
1	2017 Beat Motorcycle (92Kg[32]) 	54 Kg	1-5 km/h	6,0 mA 	3,6 mA 
2	Beat Street Motorcycle (89Kg [33]) 	54 Kg	1-5 km/h	6,0 mA 	4,3 mA 
3	Vario 125 Motorcycle (112Kg [34]) 	54 Kg	1-5 km/h	5,5 mA 	2,7 mA 
4	2020 Beat Motorcycle (89Kg [35]) 	54 Kg	1-5 km/h	6,9 mA 	3,0 mA 
5	Scoopy Motorcycle (94Kg [36]) 	54 Kg	1-5 km/h	5,6 mA 	2,3 mA 
6	Vario 110 Motorcycle (100Kg [37]) 	54 Kg	1-5 km/h	5,9 mA 	3,1 mA 

				
Average Current			5,98 mA	3,17 mA

System testing was conducted to determine the amount of electrical energy that could be generated by the generator and to observe the effect of using a rectifier module on the generator's output current. Based on the test results at the same speed, namely 1–5 km/h, and a constant rider weight of 54 kg, the difference in motorcycle weight did not show a significant effect on the amount of current generated, as indicated by the current value without a rectifier module with an average of 5.98 mA. Meanwhile, the use of a rectifier module caused a decrease in output current with an average value of 3.17 mA, which occurred because part of the voltage and electrical energy was used to pass through the rectifier element.

Thus, it can be concluded that at low and constant speeds, the generator rotation speed is a more dominant factor in determining the output current than the weight of the motorcycle and rider, while the use of a rectifier module affects the current value due to the working characteristics of the rectifier component.

Then, tests were also conducted to determine the effect of several parameters on the performance of the energy generation system on speed bumps, particularly the effect of vehicle speed and rider weight on the amount of electric current generated by the generator.

Table 2. Beat Street Motorcycle Testing

NO	Motorcycle Weight	Driver's Weight	Speed	Current
			Speedometer	Multimeter
1	Beat Street Motorcycle (89Kg [33]) 	54 Kg	4 km/h 	6,3 mA 
			2 km/h 	3,6 mA 
2	Sepeda Motor Beat Street (89Kg [33])	70 Kg	4 km/h 	6,5 mA

				
			3 km/h	
3	Sepeda Motor Beat Street (89Kg [33]) 	78 Kg	5 km/h	
			4 km/h	
2	Sepeda Motor Genio (92Kg [38]) 	65 Kg	5 km/h	
			4 km/h	
43	Sepeda Motor Genio (92Kg [38]) 	70 Kg	5 km/h	
			4 km/h	

Table 3. Genio Motorcycle Testing

N O	Motorcycle Weight	Driver's Weight	Speed	Current
			Speedometer	Multimeter
1	Sepeda Motor Genio (92Kg [38]) 	54 Kg	5 km/h	
			3 km/h	

Based on the test results on Beat Street and Genio motorcycles, it can be concluded that vehicle speed has a more dominant effect on the amount of current generated by the generator than the rider's weight. This is demonstrated by an increase in current values as vehicle speed increases, particularly in the 2–5 km/h speed range.

Meanwhile, the effect of rider weight on generator output current is relatively small and does not show a consistent pattern. Changes in rider weight in the range of 54 kg to 78 kg only produce insignificant variations in current compared to changes caused by differences in speed. Thus, under these test conditions, it can be concluded that the rotational speed of the mechanical system that drives the generator is the main factor affecting the generation of electric current, while rider weight only has an indirect effect on the vehicle's ability to maintain speed.

To calculate how long the charging time will take, we can use the formula:

$$t = \frac{C}{I}$$

Where:

t = Battery charging time

C = Battery capacity

I = Charging current from the generator

Therefore; $t = \frac{5}{5,98+5,98mA} = 418$ hours or 17 days and 4 hours

Then, to calculate how many bumps must be passed to charge the battery, you can use the formula:

$$q = i \times t$$

Where:

q = Electric Charge

i = Charging Current

t = time

Then; $q_{Aki} = 5 \times 3600 = 18.000C$

$q_{Bump} = 6 \text{ mA} \times 1s = 0,006 C$

$$N_{Bump} = \frac{q_{aki}}{q_{bump}} = \frac{18.000}{0,006} = 3.000.000 \text{ Bump}$$

Then, to calculate the power generated, you can use the formula:

$$P = V \times I$$

Where:

P = Power

V = Voltage

I = Current

Therefore;

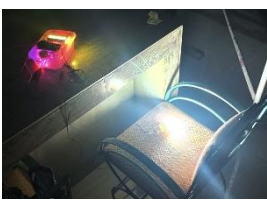
$$P = 12 \times 6 \text{ mA}$$

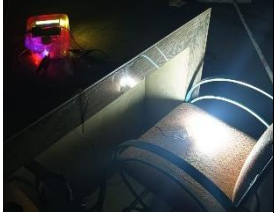
$$P = 0,072 \text{ W}$$

LDR Sensor Testing

The purpose of testing this LDR sensor is to determine the specific light intensity at which the sensor can detect light and provide a signal as input for light control. The LDR sensor works based on changes in resistance due to changes in the intensity of light that hits it, where the sensor resistance will decrease when the light intensity increases and increase when the light conditions are low. These changes in resistance are then converted into changes in voltage that can be read by the control system as an input signal. The test was conducted from 5:00 a.m. to 7:00 a.m. to observe the sensor's response to increased light intensity in the morning to determine the estimated time for turning off the lights. Furthermore, the test was conducted from 5:00 p.m. to 7:00 p.m. to observe the decrease in light intensity in the afternoon to evening as a basis for determining the time to turn on the lights.

Table 4. LDR Sensor Testing

NO	Time	Light Intensity	Lamp Condition
1	05.00	0,049 Lux 	On 
2	05.30	0,049 Lux 	On

			
3	06.00	0,049 Lux 	On 
4	06.30	17 Lux 	Off 
5	06.35	27 Lux 	Off 
6	17.30	220 Lux 	Off 
7	18.00	200 lux 	Off 
8	18.30	58 Lux 	Off 
9	19.00	0,11 Lux 	On 

In Table 4, the light will turn on when it is dark. In this study, dark conditions are defined as light intensity ranging from 0 to 150 lux. A value of 0 lux does not represent absolute darkness, but rather indicates a condition where there is still very low or dim light. In the tests conducted, even on cloudy days, there was still a lot of brightness in the sky, making it impossible for the sensor to read the existing darkness.

In addition to light intensity values in lux, the lighting conditions in this test can also be described using Exposure Value (EV). Exposure Value is a parameter that describes the overall brightness of the environment, where a smaller or negative EV value indicates dimmer lighting conditions. In dark or dim conditions, the EV value is in the low range, which is in line with the LDR sensor's reading that detects low light intensity and triggers the system to turn on the lights.

ACS712 Current Sensor Test

Testing of the ACS712 sensor module was conducted to measure the electric current generated by the generator and display the measurement results on an LCD. The current value read by the sensor was then compared with the measurement results using a multimeter as a reference measuring device to determine the accuracy of the current reading. The ACS712 sensor works based on the Hall effect principle, where the electric current flowing through the sensor's internal conductor generates a magnetic field proportional to the current. This magnetic field is detected by the Hall element and converted into an analog voltage signal proportional to the current. The sensor output voltage is then processed by the microcontroller system to calculate the current value and display it on the LCD. The test was conducted five times to determine the reading difference and error value on the ACS712 sensor module. The following are the results of the ACS712 sensor module test.

The ACS712 sensor module test aims to measure the current generated by the generator, display it on the LCD, and then compare it with the multimeter's current reading accuracy level. This test was conducted by comparing the measurement results using the ACS712 sensor module and a multimeter. This test was conducted with five trials to determine the error value in the ACS712 sensor module. The following are the results of the ACS712 sensor module test.

Table 5. ACS712 Current Sensor Testing			
NO	Sensor (Readable)	Multimeter (Measured)	ERROR
1	139mA	133mA	0,0451%
2	107mA	100mA	0,07%
3	81mA	77mA	0,051%
4	57mA	57mA	0%
5	16mA	15mA	0,066%
Average Error			0,046%

Table 5 shows that five tests were conducted by comparing each measurement result from the INA219 sensor module and the multimeter and calculating the error value. The error value in this test

was calculated using the following formula.

$$\text{error} = \frac{\text{ACS712 Sensor Module Values} - \text{Multimeter Values}}{\text{Multimeter Values}} \times 100\%$$

The average error is calculated by adding up all the error values obtained in each experiment and dividing them by the number of experiments conducted. Thus, the average error in current measurement by the ACS712 sensor module is 0.046%. However, on this sensor module, the sensor displayed was never stable. Therefore, we took the data that was frequently displayed by the ACS712 sensor, and obtained the results of the average error found in the sensor.

Overall System Testing

Comprehensive testing is conducted to ensure that the system can operate properly in accordance with the established functional design.



Figure 13. Overall System Testing.

Based on the results of testing and functional analysis of the system, all system components can work according to their designed functions. The generator is capable of producing electrical energy from mechanical energy, the sensors can read environmental conditions and electrical parameters well, and actuators such as lights can respond to system inputs automatically. This shows that the integration between components in the system is running well and is stable. In addition, the battery condition indicator, which was previously designed using a buzzer, was considered less informative because it only provided warnings in the form of sounds without showing the battery condition value quantitatively. Therefore, the use of a voltage checker module is a more effective alternative because it can display the battery voltage condition in the form of a percentage of capacity. With this information, users can find out the remaining battery energy level more clearly and accurately, so that power usage management becomes more optimal compared to using a buzzer alone.

CONCLUSIONS

Based on the results of implementation, testing, and analysis, it can be concluded that the designed system is capable of converting kinetic energy from vehicles passing over speed bumps into electrical energy with an average current output of 1.33 mA. However, this system has not been able to achieve the target storage capacity of 5 Ah due to the

limited energy output of the mechanism used. In addition, the system has successfully detected changes in light intensity using an LDR sensor so that the lights can turn on automatically at night. The voltage checker used also functions as an additional indicator to monitor the battery charging condition.

SUGGESTION

To overcome the various limitations that still exist in this system, several development efforts are needed in further research. Improvements can be made to the system circuit design to make it more flexible and universally applicable. In addition, the use of a stronger and safer mechanical frame needs to be considered so as not to endanger passing vehicles. The gear mechanism design also needs to be refined so that the generator rotation becomes more stable, thereby increasing the energy produced. The use of a more stable energy source is expected to improve the efficiency of electrical energy conversion. In addition, the addition of voltage sensors is recommended to complement the measurement system and reduce existing calculation limitations.

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