Harnessing speed breakers potentials for electricity generation: a case study of Covenant University

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ABSTRACT

The global imperative to transition towards sustainable energy sources has sparked innovative solutions for energy generation and environmental conservation challenges. As fossil fuel usage for power generation continues to raise environmental concerns, converting kinetic energy from vehicular motion via speed breakers presents a unique avenue for renewable power production. This study explores the concept of utilizing speed breakers as a means of electricity generation to power little power-consuming but critical load, with Covenant University serving as a pertinent case study. This research investigates the technical, economic, and environmental implications of implementing speed breaker-based electricity generation within Covenant University. Analyzing the university's energy consumption patterns showed that some loads do not require much power but are critical. Street lighting is one of such loads. This study discerns the potential contribution of speed breaker-generated electricity to address energy demands by simulation and constructing a prototype. Advanced engineering tools, such as simulation software Fusion 360 and Proteus 8.0, were employed to model and integrate the roller speed breaker mechanism with the electrical infrastructure. The findings offer valuable insights into the viability of speed breaker-generated electricity as an alternative energy source, paving the way for sustainable energy practices in educational institutions and beyond.

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1. INTRODUCTION

In some form or another, man uses energy throughout his lifespan. Every year, there is an increase in energy demand. Power is now, as always, a crucial component of human existence but its supply is limited. In other the bridge the energy gap, it is necessary to create alternate solutions to complement the already existing means. The least expensive the new energy source is, the better it is - energy conservation [1]. However, over 80% of the world's energy is still being supplied by fossil fuel [2]. As economies of the world strive to sustain economic growth, especially in ensuring their industrial sector's modus-operandi is optimized for healthy development, the effect of energy exploration on environment is seen as a major threat. The government of China, for example pursuing this objective proclaimed, "Green mountains and clear water are equal to mountains of gold and silver" [3]. China went on and in 2017, took a whole 40% off the global energy investment as electric cars accounted for half of the market. Wind turbines, solar panels were also adopted in order to eradicate pollution and its appalling consequences hence leading the world market in use of clean energy [4].

Nigeria has battled inadequate power supply for many years and her leaders have sought ways to improve the quality of life of their fellow citizens. Despite having an installed electricity generation capacity at about 12,500 MW, operational and transmission requirements have been deficient in supply limiting the operational capacity to a mere 32% of what is generated [4]. Private institutions therefore have resorted to providing themselves with power by installing gas and power turbines in their environs. Fossil fuels, like other mineral reserves, are not evenly distributed around the world; rather, they are concentrated on the borders of continents that historically produced a lot of biomasses. Before they can be used for energy generation, they must be found, removed, and frequently treated. At present consumption rates, it would seem that the present and forecast deposits would last only for a few thousand years.

Hence imitating the reasons behind food being stored for future uses, energy also needs to be stored and made readily available to the point in which it is to be used [5]. So, in a bid to combine energy conservation as well as optimal utilization, this study demonstrates the potential for recovering energy from the road speed breaker. This process is popularly known as energy harvesting. Humans have gone far in this quest to harvest sufficient energy from their bodies by making use of implantable medical electronics (IMEs) based on piezoelectric effect [6]. Through a number of energy conversion procedures, the lost energy can be transformed into electrical energy by a mechanism. The electrical energy used in this study is in the kW range, which is enough to power traffic signals and streetlights which are popularly referred to as “utility loads”.

There is a global concern to increase energy conversion efficiency because of the rapid depletion of fossil resources brought on by the rising energy demand [7]–[10]. However, the rate at which energy is converted for typical fossil fuel power plants is still only about 40%, and a significant portion of energy is lost as heat, contributing to problems with global warming [11]. That is why a Montreal protocol was even set up on September 16,1987 to battle substances that deplete the ozone layer [12]. Even a tiny amount of energy losses that are recycled and recovered could have a significant influence on energy savings and reduce the need for fossil fuels [11]. One model that shows how this energy can be harnessed and converted to useful form is taking advantage of the speed breaker system. Every speed breaker available in any environment is now a potential source of energy [13]. This involves a construction and analysis of relationships between speed breakers and average vehicle speeds which will determine the amount of electricity that can be generated.

Most power optimization methods deal with the total extinction of non-renewable energy sources without focusing on conservation of the numerous present sources. Power supply is poor in most developing countries as in the case of India who published a saddening report recording 85,000 villages without electricity supply [9]. The energy generated can be used to provide electrical power to be consumed by these small villages. The speed breaker system designed is used as an important, cost-effective method to harness this wasted energy converting it to another useful form to power street lights and other utility loads. Made to function as a power generation unit, the speed breakers are now used to tap energy dissipated as heat and generate power. The availability for grid-independent, sustainably produced electricity to be produced at the roadside is the goal of this project [10]. The study of the Speed Breakers helps in understanding that not only the physical significance which is to reduce speed of vehicles preventing glaring accidents but also the technical aspects. Energy harnessed then can be used to power basic critical primary roads [14]–[16].

Various researches and methods have been carried out in order to reduce or augment power shortages with energy harvesting and sensing. In Universities or tertiary institutions, the energy consumption is always high. A survey of Covenant University’s energy consumption profile shows that space cooling and lighting use the most electricity (29%) of all the university's energy needs. In the academic areas of the university, space conditioning used the most power (49%), while lighting in staff quarters used the most (39%) of the load category. Energy conservation among students have proven to be poor hence the continuous playground of inadequate power supply within the student’s village [17]. As the number of vehicles grows daily, a system can be used to convert kinetic energy form moving vehicle to electricity to compliment Covenant University's energy supply and on a larger scale, Nigerian electricity crisis. This is important as electricity has a direct relationship with social and economic activities in the university community [8], [18]. As earlier stated, there are various methods that have been used in the generation of electricity using speed breakers. A study [19] investigated a piston-based mechanism, where a dome-shaped structure acts as a speed breaker. A piston connected to a turbine and electrical generator moves as vehicles pass over the dome, creating fluid or air motion that drives the turbine and generates electricity. Another approach [20] used a Bicycle pedal mechanism. The dome that makes up the bicycle pedal mechanism-based power hump serves as a speed limiter. A pedal-wheel (sprocket) device resembling a bicycle is installed underneath the dome. The sprocket rotates when the vehicle travels over the dome (speed breaker). An electric generator's shaft is connected to the sprocket. Then, as a vehicle passes over the dome, the shaft of the electric generator and the sprocket both revolve. The rotating shaft connected to an alternator produces electricity. Hydroelectric road ramp was also explored [21]. In this system, the ramp is pressed as the vehicle move over it thereby creating a compressed air in the tank which then releases the water jet to drive the turbine, rotating the shaft converting mechanical to electrical energy. One drawback is that the tank can only be filled after being depressurized. Opening a pressurized reservoir while the system is still under pressure may cause a large local water spray or possibly an unanticipated outcome. A rack and pinion mechanism was proposed in [22]. In this system, as the vehicle moves over a speed breaker, the kinetic energy produced will be converted to electrical energy. A rack installed in the system will be depressed down and with the help of a pinion translational is converted into rotary motion which in turn is connected to a generator to produce electricity. One drawback identified is that the road needs to be dug up for installation. Require more mechanical components, increasing the mechanical losses experienced by the vehicle that travels over it at both a higher weight and velocity. Requires converting from reciprocating to rotatory motion and also requires a hefty spring assembly.

An electronic speed bump energy harvester (ESE) was introduced by [23], converting deflection caused by passing vehicles into a rotating shaft that activates an embedded generator. This approach collects energy from vehicle kinetic energy while controlling speed, though implementation costs are a drawback. Air compression using a well turbine was investigated [24]. It consists of a semi-curved dome's bottom table that moves up and down when the top table is loaded. The air in the compression chamber is compressed by this action. After that, the compressed air travels via the shaft that is attached to a generator and a Wells turbine with a profile like NACA 0015. The generator shaft experiences a significant torque because of the turbine blades' rotation. A tachometer may be used to calculate the turbine's rotations per minute (RPM). A major disadvantage of the system is the complex process of construction. [25] proposed a speed bump triboelectric nanogenerator (SB TENG). The SB- TENG system's PVC substrate is the same as a typical speed bump. The copper electrodes within the SB-TENG can begin to generate energy when a vehicle's tires travel over the PVC hump in the road. These various methods showcase the innovative ways researchers are exploring to harness energy from speed breakers. Each approach comes with its unique advantages and challenges, ranging from operational complexities to installation requirements and costs. By capturing the mechanical energy generated by vehicles passing over speed breakers, these systems offer the potential to contribute to renewable energy generation and address the energy challenges of today's world.

2. METHOD

This section sets out a comprehensive methodology followed throughout the design and development of the prototype model. Various mathematical expressions and circuit diagrams were used. The proposed design will be implemented for Covenant University. Figure 1 shows the block diagram of the entire system. The diagram shows the working of the system commencing with the vehicle pressure exerted on the speed breaker. This pressure is transmitted through the system, culminating in the activation of the roller mechanism, which in turn sets the gear system and dynamo into motion. As a result, a robust process of electricity generation is initiated, serving as a sustainable power source. The generated electrical power is then channeled directly into the charging circuit, which serves a dual purpose: it replenishes the battery for efficient storage, ensuring a steady reserve of power, and concurrently supplies energy to the designated powered appliance, in this case, the streetlight.

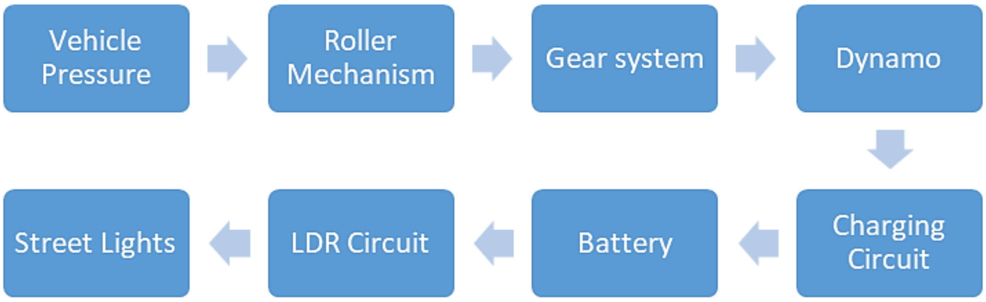


Figure 1. System block diagram

2.1. Roller mechanism

Base on the review carried out, the roller mechanism is one of the best methods. The roller mechanism is main brain behind the power generation system that capitalizes on the motion of vehicles traversing a specially designed wooden ramp. This ramp is equipped with rollers that serve as a dynamic intermediary, converting the kinetic energy generated by moving vehicles into valuable electrical energy.

As vehicles pass over the speed bump-incorporated ramp, the rollers come into action. These rollers gain rotational motion, and this mechanical movement is harnessed to drive a DC generator through a chain drive mechanism. This design ensures a smooth and efficient transfer of the vehicle's kinetic energy into the spinning motion of the rollers, which subsequently becomes a vital source of electrical power. Visualization of the roller mechanism is seen in Figure 2 which showcases the intricate workings of the Roller Mechanism within the system.

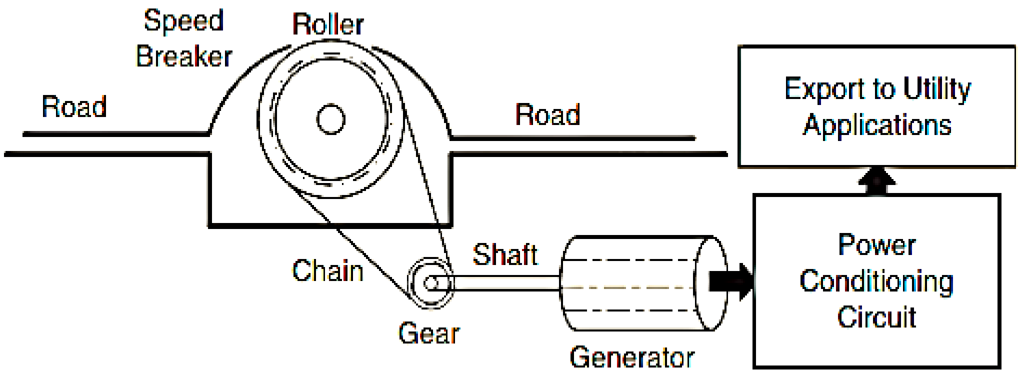


Figure 2. The roller mechanism of the system

Mathematically, the conversion of kinetic energy into electrical energy can be succinctly captured in (1). Using the principle of rotational kinetic energy. As the rollers gain rotational motion due to the passage of vehicles over the speed bump-equipped ramp, their kinetic energy is transformed into mechanical work and subsequently into electrical energy. Equation 1 shows the relationship between the energy produced, the moment of inertia of the roller, and the angular velocity of the roller.

$$E = 0.5 * I * \omega^2 \tag{1}$$

where E represents the energy produced, I denote the moment of inertia and ω represents the angular velocity of the roller.

2.2. Gear system

The rotation of the element in the roller mechanism is carried out by the gear system. This is used to transfer motion and power between rotating shafts. The constructed gear system with the roller mechanism can be visualized in Figure 3. The gears are spherical or cylindrical in shape and have outside circumferential teeth that mesh with inner gear teeth to deliver rotational torque. The gear ratio is calculated, and it is the ratio of teeth on the driving gear to those on the driven gear, as seen in (2).

The angular velocities of two mating gears, directly indicating how many times one gear rotates in relation to the other, are given in (3). Equation (2) focuses more on the relationship between the input and output of the gear system used in the system, and (3) focuses more on the speeds of the gears and how they relate to each other.

$$i = Z_e / Z_s \tag{2}$$

where Z_e is the number of teeth on the driving gear, Z_s is the number of teeth on the driven gear, and i is the gear ratio

$$rt = Nout / Nin \tag{3}$$

where rt is the rotational speed ratio, $Nout$ is the output angular velocity of the driven gear, Nin is the input angular velocity of the driving gear.

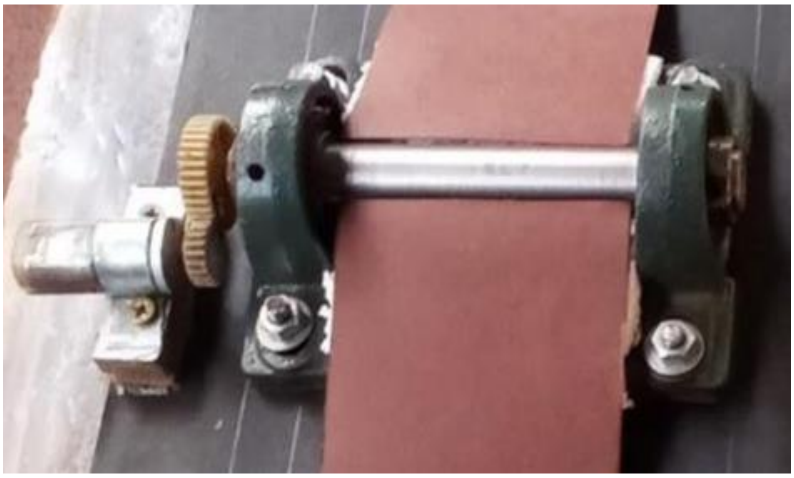


Figure 3. The mechanism

The gear ratio used here is 1:2. Therefore, a 34-tooth driving gear will rotate a 17-tooth driven gear at a speed 2 times faster. The 12-tooth gear will spin the gearbox, which will convert 100 rotations per minute (rpm) to 2400 rotations per minute (rpm), generating 12 V, which is sufficient to charge our battery.

Table 1 shows the dimensions of the bearing system used for this system. The major advantage of the bearing system is that it reduces friction between the moving elements so that rotation can happen more smoothly. Bearings aid in energy conservation and lower the amount of power required for rotation by minimizing friction. The other purpose is to keep the rotating shaft in the proper position while protecting the component that supports the rotation.

Table 1. Dimensions of the bearing

Unit No	H	L	J	N	B	S	Weight (kg)	Housing	d(mm)	Bolt size
SKP004	28	100	80	10	21	6	0.25	P004	20	M8

The final component in Figure 3 is the shaft or roller. This is a cylindrical object that was used to aid the car in moving over the speed breaker. It has a smooth surface that allows objects to roll over them with minimal friction, making it easier to move heavy or bulky objects. In this prototype, rollers can be made from different materials; however, we chose iron.

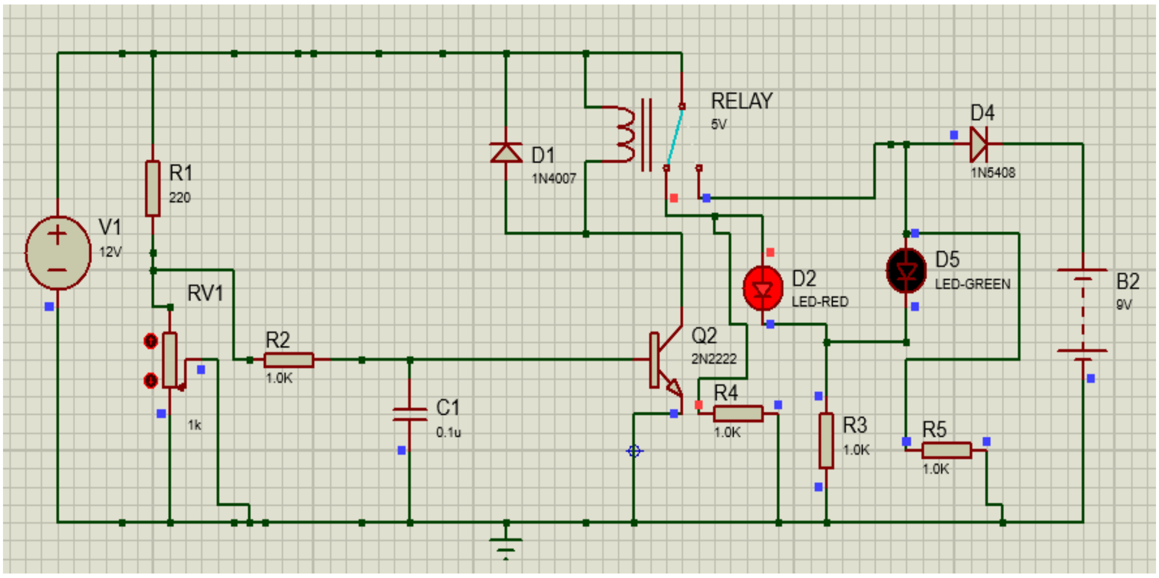
2.3. Electrical design and simulation

Protecus 8.0 Profession was used in the simulation of each of the circuit designs. The circuit of this system includes the charging circuit for the storage of the energy generated in a rechargeable battery cell and the light dependent resistor (LDR) circuit which is used to activate the load (streetlight) only at night. Figure 4 represents the charging circuit in Figure 4(a) shows the battery charging and Figure 4(b) shows the battery is full, and Figure 5 represents the LDR circuit mode where Figure 5(a) LDR OFF mode and Figure 5(b) LDR ON mode.

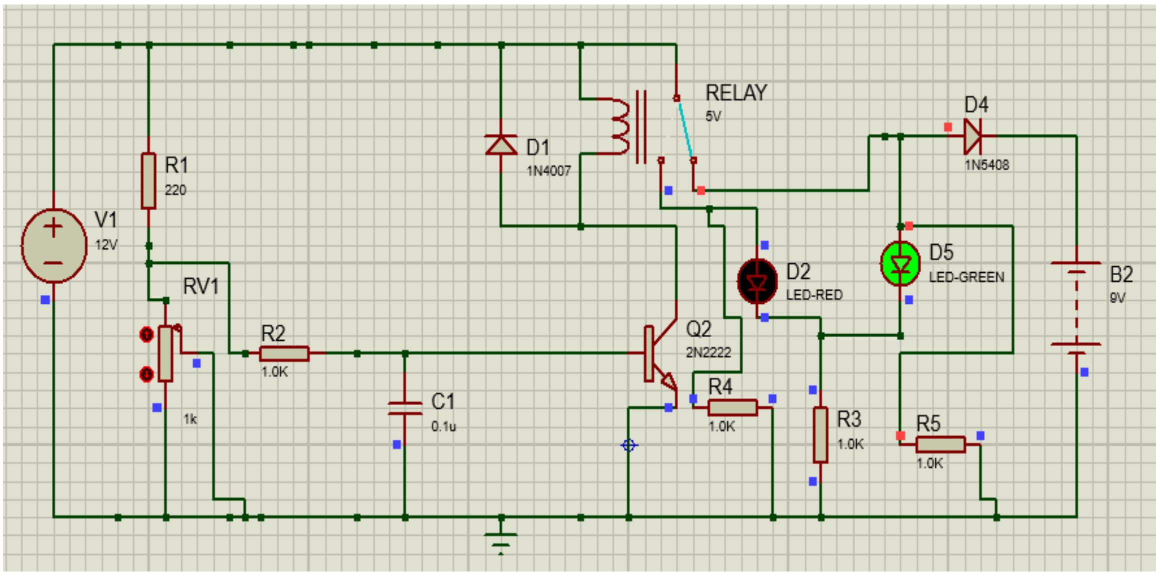
The Dynamo used in constructing this prototype system is the J3 High torque DC motor 12 V. Due to Protecus 8.0 Professional not having that component, a 12 V DC was used in place of the dynamo in the simulation. From Figure 4, current flows from the battery through the path of least resistance due to Ohn law, which is mathematically represented in (4). From the relay, current flows through the diode, charging the battery. The diode prevents feedback from the charged battery. This is necessary so the battery does not discharge into the circuit back. As shown in Figure 4, current also flows through the path that has the green LED light, switching it on. When the battery is full, current flows through the 10k resistor and as the resistance is varied in the second resistor, current flows smoothened by the capacitor and triggering the NPN transistor ON as the breakdown voltage of 0.7 V is exceeded. Current that was coming to the line with the relay before then charges the relay which is an inductor attracting the spring. This allows current flow through the red LED light indicating the battery is full.

$$V = I \times R \tag{4}$$

Figure 5 represents the LDR circuit. The relationship between the resistance of the LDR and light intensity is inversely proportional. This setup functions in two states. The first is that when there is no light from the sun, the LDR has a high resistance, and so current does not flow into the base of the NPN transistor, leaving it in its OFF state. As a result, the 12 V relay remains at its normally closed (NC) state, allowing current to flow to the LED bulb, switching it ON. The second is the reverse, and as the light intensity builds from the sun during the day, the LDR's resistance reduces, allowing current to flow through to the potentiometer, whose resistance varies until the breakdown voltage of the NPN transistor is reached. Current flows into the transistor's base, switching it ON and further into the 9V relay, creating an open circuit. In this second case, the current does not get to the LED bulb, so the lights are OFF.

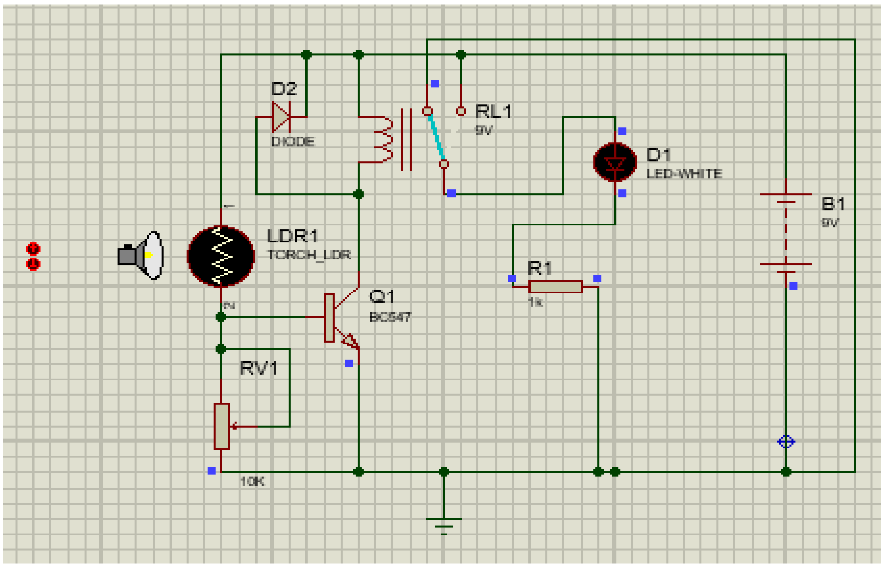


(a)

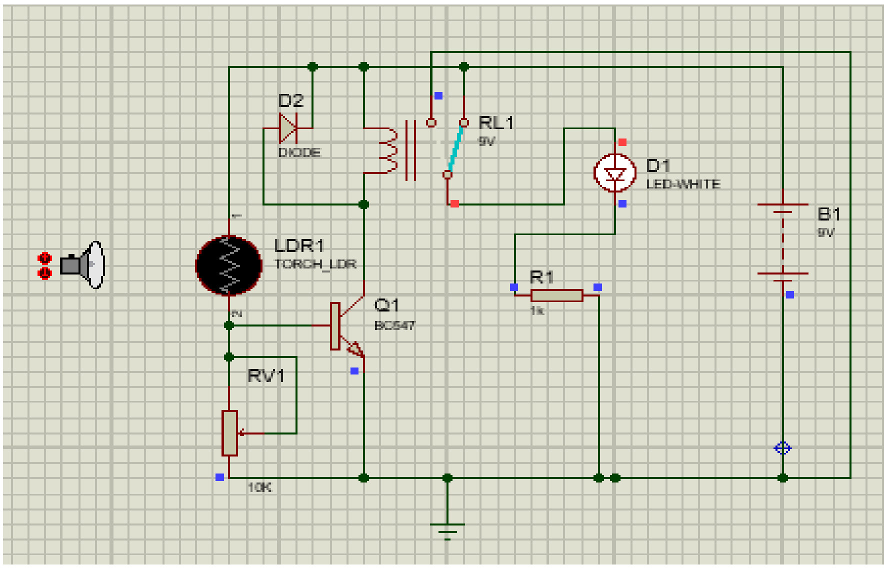


(b)

Figure 4. Charging circuit (a) battery is charging – red LED ON and (b) battery full – green LED ON



(a)



(b)

Figure 5. LDR mode (a) the LDR in OFF mode and (b) the LDR in ON mode

3. RESULTS AND DISCUSSION

During this stage, all necessary refinements and substantial modifications were undertaken. The prototype design, aligned with the electrical circuit diagrams from the previous section, utilized readily available electrical components. The construction process involved assembling mechanical components, software creation, and architectural integration to form a cohesive system. Each stage of the circuit diagram underwent construction and testing prior to advancing to subsequent design phases. The prototype adhered to the established plan, following meticulous protocols to ensure successful completion. Simulation and design were facilitated through Fusion 360's Top-down approach for system simulation, and Proteus aided in designing the electrical environment for testing the system. Physical testing steps and corresponding outcomes form the concluding part of this chapter, providing insights into the system's functional validation.

3.1. CAD model

The system is modeled after the engineering block of Covenant University using Fusion 360. Figure 6 to Figure 8 shows the modeled building and path where the speed breaker will be installed. Model of the road is visualized in Figure 6, model of the entire system including the roller mechanism of the speed breaker is visualized in Figures 7 and 8 visualizes the entire system.

Figure 6. 3D model of the engineering block

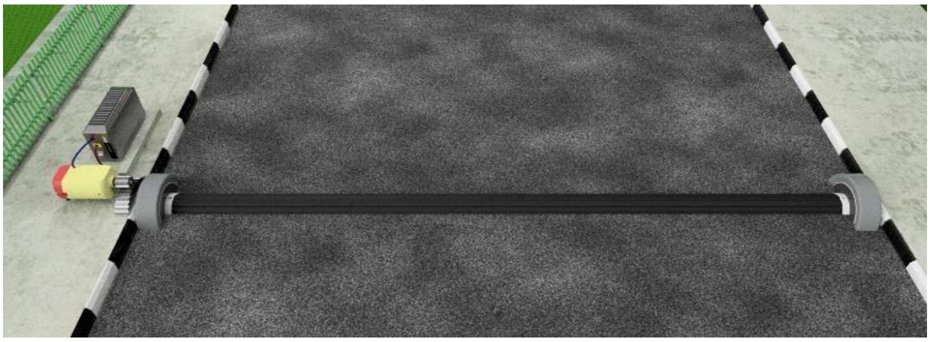


Figure 7. Top view of the roller mechanism

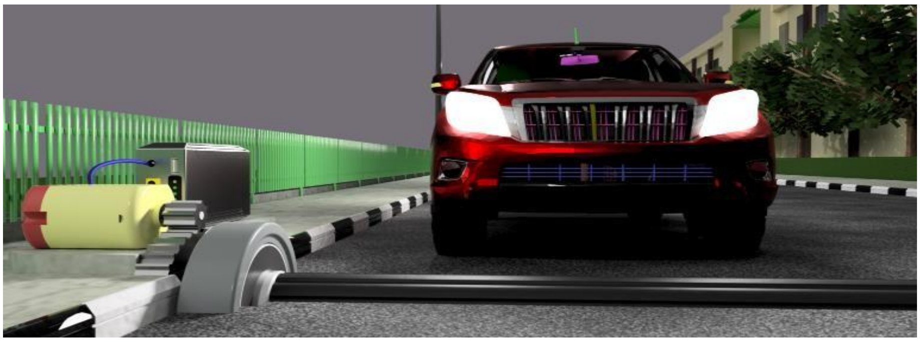


Figure 8. Detailed view of the roller mechanism and a vehicle

3.2. Hardware implementation

This entailed the building of the physical framework of the mechanical system and the architectural. The framework used was a hard strawboard measuring the standard A2 size of 420 by 597 mm. The speed bump was mounted on the strawboard and when everything was assembled together, the electrical circuit was connected according to the circuit diagram as seen in the previous chapter. The LDR circuit and charging circuit are connected along with the battery to the street lights taking power from the output of the 12 V DC battery. As soon as the whole arrangement of the system was completed, a box is created which houses the circuits so that they are not seen. Figure 9 shows the soldered circuit on the Vero board. Figure 10 shows the patching of the system together with the charging circuit and LDR circuit and Figure 11 shows the Sideview of the finished structure of the system and Figure 12 shows the top view of the system.

The roller mechanism was able to generate and supply voltage to charge the battery. The battery was able to deliver sufficient power through to the LDR in order to switch on the streetlights. The roller mechanism required 9 V DC to power from the 12 V DC dynamo as the indicator lights showed the battery level charge.

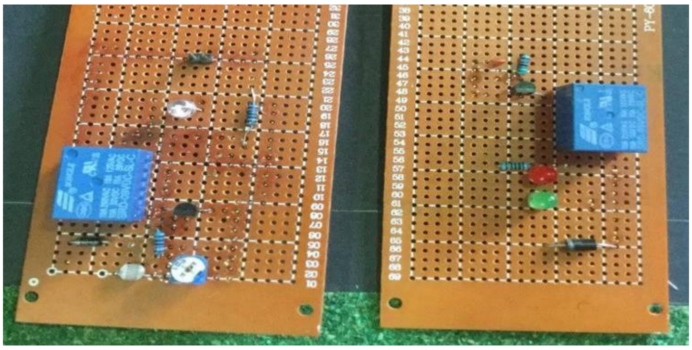


Figure 9. Soldered charging circuit on the Vero board

Figure 10. The construction

Figure 11. The side view of the structure

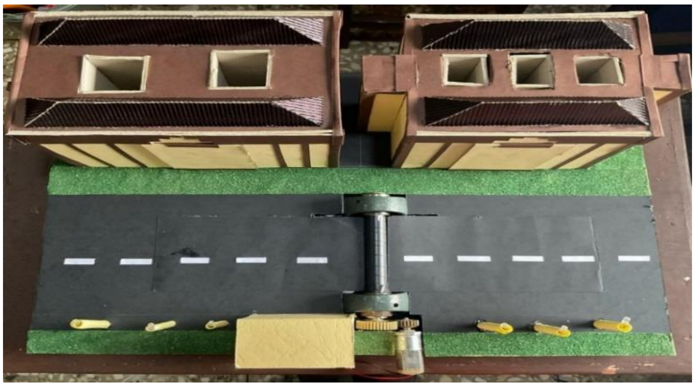


Figure 12. The top view of the structure

4. CONCLUSION

In conclusion, the speed breaker roller mechanism emerges as a highly economical and ecologically responsible approach to electricity generation. Employing a systematic methodology, this prototype has successfully crafted a solution that harnesses the kinetic energy from speed breakers, effectively converting mechanical force into electrical power. This innovative endeavor aligns with the pursuit of sustainability and environmental well-being within Covenant University. The core objective of this research was the adept development and implementation of a DC power generation system using the roller mechanism integrated into speed breakers. The output voltage, serves a dual purpose: charging batteries and illuminating streetlights. By harnessing energy from the vehicular motion, this study contributes to an alternative energy source while also functioning as a backup, decoupling reliance on the conventional electrical grid thus leading to cleaner environment and improving on the carbon footprint. This transformative approach underscores a commitment to fostering renewable energy sources while minimizing disruption to human activities. In essence, this study exemplifies a forward-looking initiative that not only taps into the power of innovation but also underscores the importance of sustainable practices in energy generation, further reinforcing Covenant University's commitment to a greener and more ecologically harmonious future.

One recommendation for further research is the optimization of roller design: Exploring different roller materials, shapes, and sizes could lead to increased efficiency and energy capture. Experimentation with materials that offer enhanced friction and wear resistance can contribute to better performance over time.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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