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Design and Development of a Hybrid Piezoelectric–Electromagnetic Seesaw Energy Harvesting System

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Abstract

This study designed and developed a hybrid piezoelectric–electromagnetic seesaw energy harvesting system that converts mechanical energy from footfall pressure and seesaw oscillation into usable electrical energy. The study was anchored on the principles of piezoelectricity and electromagnetic induction, integrating piezoelectric transducers, a DC generator, rectification, energy storage, and voltage boosting in one prototype. A developmental and experimental research design was used. The main research instrument was the hybrid seesaw prototype, which was tested under predetermined load conditions of 40 kg, 50 kg, 60 kg, and 70 kg to represent varying user weights. Data were gathered by measuring voltage and current outputs from the piezoelectric footfall system and DC generator during one-minute trials. Results showed that piezoelectric voltage generally increased as applied load increased, with average outputs ranging from 6.65 V at 40 kg to 15.59 V at 70 kg, while current remained relatively stable. The DC generator also produced usable output from seesaw motion, and the overall prototype achieved an average voltage of 14.4 V and a maximum current of 16.65 mA. The study concluded that the hybrid seesaw system is feasible as a micro-scale energy harvesting device for low-power applications, although its output remains limited and dependent on user weight and frequency of use. The study supports SDG 7, SDG 9, SDG 11, SDG 12, and SDG 4 by promoting clean energy, innovation, sustainable communities, responsible energy use, and applied renewable energy learning. Its sustainability impact lies in technological, environmental, educational, and community-based energy innovation.

Keywords: Electromagnetic Induction, Energy Harvesting, Piezoelectric Transducers, Renewable Energy, Seesaw Energy Harvester, Sustainable Energy, Voltage Output

1. Introduction

This study focuses on the design and development of a hybrid piezoelectric–electromagnetic seesaw energy harvesting system that converts mechanical motion from human activity into usable electrical energy. The proposed system responds to the continuing need for alternative, decentralized, and sustainable energy sources by integrating piezoelectric transducers with a DC generator in a seesaw structure. By harvesting footfall pressure and oscillating motion, the system aims to generate power for low-energy applications such as mobile charging and lighting loads, particularly in schools, parks, and community spaces.

Electricity is essential to modern life because it powers household appliances, business operations, industrial equipment, and public lighting systems in parks, retail centers, highways, and other public spaces. It also supports technological development, particularly in industrial automation and production systems, which have improved human convenience, productivity, and efficiency. In the Philippines, economic development has contributed to a transition from agriculture to industry, increasing the importance of a reliable energy supply. However, the country remains dependent on conventional fossil fuels, while renewable energy sources continue to play an important but still developing role in the national energy mix. Although solar energy is among the most widely used renewable energy sources, it still has environmental implications, including greenhouse gas emissions associated with manufacturing processes. At the same time, small amounts of wasted ambient energy remain underutilized. If captured effectively, these small energy quantities may contribute to environmental and economic benefits. Energy harvesting, also called energy scavenging, addresses this opportunity by collecting small amounts of heat, light, sound, vibration, or movement that would otherwise be wasted and converting them into usable energy.

Vibration energy is a common ambient energy source because it is produced by ordinary activities such as motor rotation and human motion. Although often treated as noise, vibration can be harvested and used for beneficial purposes. Electromagnetic induction is also a promising energy harvesting method because it requires only coils and magnets, making it relatively low-cost; however, its effectiveness depends on design architecture, magnet lifespan, and sustained mechanical force. Hybrid renewable energy systems are increasingly considered practical because they combine two or more energy sources to produce a more reliable and effective output. In this study, piezoelectric and electromagnetic technologies are integrated into a seesaw-based hybrid system to harvest mechanical energy from repeated human movement. The piezoelectric component converts pressure and vibration into electrical energy, while the electromagnetic component uses oscillating motion to drive a DC generator. Since a single piezoelectric transducer produces only a few millivolts depending on applied pressure, several transducers are connected to increase the voltage output. The alternating current produced by the transducers is converted to direct current through a full-wave bridge rectifier, while a capacitor reduces ripple and stores charge before energy is boosted and transferred to a rechargeable battery.

Globally, rising electricity demand and dependence on fossil fuels have intensified interest in alternative energy sources. Many renewable technologies are weather-dependent, making mechanical energy harvesting a practical complementary approach because mechanical movement is a constant byproduct of daily life. Nationally, the Philippine energy context reflects the need for renewable and localized energy alternatives, especially as industrialization increases energy demand. Locally, the proposed system is intended for community spaces such as schools and playgrounds, where children and passers-by can generate energy through seesaw use while simultaneously supporting mobile charging and lighting loads.

The study is conceptually grounded in the conversion of mechanical input into electrical output through two processes: piezoelectricity and electromagnetic induction. The mechanical input comes from footfall pressure and seesaw oscillation. The piezoelectric footfall system generates electrical energy when piezoelectric materials are subjected to stress, while the seesaw's oscillating motion drives the DC generator. The electrical output passes through a full-wave bridge rectifier, capacitor, DC-DC booster, charger controller, battery, and inverter before being used for mobile charging and lighting loads. The project therefore combines mechanical design, circuit conditioning, and renewable energy conversion into one integrated system.

The study addresses the need for a low-cost, community-based, and mechanically driven energy harvesting system that can operate independently of weather-dependent renewable sources. It specifically examines how the system will generate electrical energy, whether the materials can be obtained at a reasonable cost, how long the seesaw can be used, and who will benefit from the project. The project aims to design and construct an energy harvesting seesaw using piezoelectric materials and a DC generator. Because playground equipment is attractive to young children, the seesaw can capture their movement as a clean energy source while also allowing them to exercise. The study also provides an applied electrical engineering opportunity by using available technologies to benefit a community.

This study aligns with SDG 7 – Affordable and Clean Energy because it explores a renewable energy harvesting system that converts wasted mechanical motion into usable electricity. It also supports SDG 9 – Industry, Innovation and Infrastructure by developing a hybrid piezoelectric–electromagnetic prototype that combines mechanical, electrical, and energy conversion technologies. The study relates to SDG 11 – Sustainable Cities and Communities because the proposed system may be installed in public spaces such as schools, parks, and playgrounds to support localized energy generation. It also contributes to SDG 12 – Responsible Consumption and Production by recovering small quantities of otherwise wasted energy and using them for practical low-power applications. Where deployed in schools and playgrounds, the system may also support SDG 4 – Quality Education by demonstrating renewable energy concepts through an applied engineering project.

The study contributes to technological sustainability by integrating piezoelectric transducers, electromagnetic induction, rectification, energy storage, and voltage boosting into a single hybrid system. It contributes to environmental sustainability by promoting energy harvesting from existing mechanical motion rather than relying exclusively on fossil-fuel-based electricity. It also supports community sustainability because the system is designed for public and educational spaces where children and passers-by can generate small amounts of usable energy through ordinary activity. In addition, the study has value for educational sustainability because it demonstrates how engineering knowledge can be applied to renewable energy systems and community-oriented innovation. Overall, the project positions the seesaw as both a recreational structure and a small-scale sustainable power-generating device.

2. Material and methods

2.1 Research Design

The study used a developmental and experimental research design. The developmental component focused on designing and constructing a seesaw-based energy harvesting prototype using piezoelectric transducers and a DC generator. The experimental component involved testing the prototype under predetermined loads to evaluate the electrical output generated by the piezoelectric footfall system and the electromagnetic generator. Mechanical energy from footfall and oscillating motion was converted into electrical energy, processed through rectification and power-conditioning components, stored in a battery, and intended for use in mobile charging and lighting loads.

2.2 Locale of the Study

The study identifies Quezon City University in Quezon City, Philippines, as the institutional setting connected to the development of the project. The proposed application of the system was intended for public and educational spaces such as schools and playgrounds, where seesaw use could provide repeated mechanical motion for energy harvesting. However, the manuscript does not specify a separate field-testing site.

2.3 Respondents of the Study

The study considered elementary students as the intended primary users of the seesaw energy harvesting system because children are likely to use playground equipment frequently. The testing parameters were based on children's average age, average weight, time availability, and duration of use. It considered elementary students aged approximately 6 to 13 years old, with average body weights increasing by grade level.

2.4 Sample and Sampling Procedure

The study does not describe a formal sampling method. Instead, the prototype was tested using predetermined load conditions that represented different user weights. The piezoelectric footfall system and DC generator were tested under load levels of 40 kg, 50 kg, 60 kg, and 70 kg. These loads were used to examine how weight and repeated motion affected voltage and current generation.

2.5 Research Instrument

The main research instrument was the hybrid seesaw energy harvesting prototype. The system consisted of mechanical components and electrical components. The mechanical structure included the seesaw beam, fulcrum, base, springs, plates, handles, gear mechanism, bicycle chain, sprocket, bicycle wheel, and belt-connected generator shaft. The seesaw beam measured 7 ft long, while the fulcrum height was 2.5 ft. The operating swing arc length was 2.7 ft, and the maximum swing apex height was 5 ft. The base was designed to house and protect sensitive electrical components. The electrical system included piezoelectric transducers, a full-wave bridge rectifier, capacitors, a charge controller, a DC generator, a DC-DC boost converter, a rechargeable battery, an inverter, and the intended output loads. The piezoelectric footfall system was placed at both ends of the seesaw to receive footfall pressure. It measured 30 inches by 20 inches and used plywood boards, piezoelectric transducers, compression springs, and bolts. The springs were included to absorb impact and increase vibration detection by the sensors. The piezoelectric module generated unstable AC voltage from stress or vibration, which was then rectified into DC and smoothed for more usable output.

2.6 Data Gathering Procedure

The project began with planning and consultation, followed by feasibility assessment, material canvassing, design, construction, and prototype testing. The researchers selected piezoelectric transducers and related hardware before integrating the mechanical and electrical components. The prototype underwent testing under varying loads to determine whether the piezoelectric sensors and DC generator could produce sufficient voltage for a USB charging station and lighting load while also withstanding the force applied by users. For the piezoelectric footfall system, tests were conducted according to user weight, and each trial lasted one minute. Voltage and current outputs were recorded after the voltage had passed through the boost converter but before storage in the rechargeable battery. For the DC generator, tests were conducted according to the speed produced by the seesaw's up-and-down motion. The output voltage and current were likewise recorded for each one-minute trial.

2.7 Data Analysis Techniques

The data were analyzed by comparing the voltage and current generated under different load conditions. The researchers examined how applied weight affected piezoelectric output and how seesaw motion influenced the DC generator output. Average voltage and current values were computed for each load condition. The study also used electrical formulas to estimate charge, capacitor charging time, battery discharge rate, and charging rate. Charge was calculated using the relationship between capacitance and voltage, while charging time was determined using charge and current. These computations supported the evaluation of whether the harvested energy could be stored and used for low-power applications.

3. Results and Discussion

3.1 Energy Harvesting Performance of the Prototype

3.1.1 Testing Conditions and User Load Parameters

The prototype was tested using load conditions based on elementary school users, since children were identified as the likely primary users of a seesaw installed in schools or playgrounds. The considered age range was approximately 6 to 13 years old, with average weights increasing across grade levels. The testing also considered user availability and duration of seesaw use, while individual testing parameters were based on assumed loads and actual student schedules. These parameters were used because the system's output depends on repeated mechanical input from body weight, footfall pressure, and seesaw movement. Since children are expected to use playground equipment frequently, their repeated motion can provide a practical source of mechanical energy for harvesting.

3.1.2 Piezoelectric Footfall Output Under Varying Loads

The piezoelectric footfall system produced different voltage outputs as the applied load increased. At 40 kg, the average voltage was 6.65 V with an average current of 10.79 mA. At 50 kg, the average voltage increased to 12.63 V with an average current of 10.89 mA. At 60 kg, the system generated an average voltage of 14.49 V and an average current of 10.04 mA. At 70 kg, the average voltage further increased to 15.59 V, while the average current was 10.70 mA. The results show that higher applied weight generally produced higher voltage output in the piezoelectric system. However, the current remained relatively close across different loads because the piezoelectric transducers were connected in parallel. This indicates that while greater force can increase potential difference, the circuit configuration helped maintain a more stable current output despite variations in user weight.

3.1.3 Effect of Impact Frequency on Piezoelectric Generation

The early assumption of the study was that piezoelectric transducers could harvest energy mainly through prolonged pressure or heavier applied loads. However, the testing showed that the effectiveness of the piezoelectric sensors also depended on the frequency of impact. The addition of springs improved vibration response because the sensors were sensitive to repeated mechanical impacts rather than static pressure alone. This finding suggests that piezoelectric harvesting in the seesaw system is influenced not only by weight but also by how frequently the user applies force. The springs helped intensify vibration and impact detection, making the footfall system more responsive to repeated motion during seesaw use.

3.1.4 Capacitor Charging and Battery Storage

The system used capacitors to reduce ripple effects and temporarily store charge before energy was transferred to a rechargeable battery. Using a 16 V, 22 µF capacitor, the theoretical charge was computed as 352 µC. Based on the current value used in the study, the estimated capacitor charging time was 2.65 ms. The system was designed so that stored energy would be discharged to a 3.7 V Li-Ion battery before being boosted. The battery discharge estimate was 40 minutes, while a 40 Ah battery charged at 1 A would require an estimated 40 hours. These computations indicate that the harvested energy required conditioning and storage before it could be used for practical loads. Since the piezoelectric output alone was not sufficient for direct battery charging, the capacitor, boost converter, and battery were necessary to stabilize and improve the usability of the generated power.

3.1.5 DC Generator Output from Seesaw Motion

The DC generator was tested using the up-and-down motion of the seesaw. At 40 kg, the generator produced an average voltage of 11.38 V and an average current of 8.33 mA. Other recorded generator results showed higher average values, including an average voltage of 14.82 V and an average current of 10.90 mA. Across the prototype testing, the system achieved an average voltage of 14.4 V, while the maximum recorded current was 16.65 mA. The DC generator output was affected by the oscillating motion of the seesaw, particularly the speed transferred to the gear, wheel, belt, and generator shaft. Higher and more frequent seesaw movement increased the rotational speed of the system, which influenced both voltage and current generation. However, the output also fluctuated, showing that mechanical consistency is important for stable electromagnetic energy harvesting.

3.2 Relationship Between Applied Load and Electrical Output

The results showed that applied load affected the voltage generated by the piezoelectric footfall system and influenced the motion-driven output of the DC generator. In the piezoelectric system, heavier loads generally increased voltage. In the DC generator system, output depended not only on weight but also on the speed and frequency of the seesaw's motion. This relationship confirms that the hybrid system relies on both pressure-based and motion-based energy conversion. The piezoelectric component benefits from repeated impact and applied force, while the electromagnetic component depends on continuous oscillation and sufficient rotational motion. Combining both systems improve the potential for harvesting energy from irregular human movement.

3.3 Overall Feasibility of the Hybrid Seesaw Energy Harvester

The prototype testing showed that it is feasible to design a seesaw as an energy harvesting device using piezoelectricity and electromagnetic induction. The recorded output was sufficient to serve as an initial basis for developing small-scale power-generating devices dependent on user weight and frequency of seesaw use. The system remained limited to micro-scale energy harvesting, but the results demonstrated that the concept can generate and store electrical energy. The findings suggest that the system is more suitable for low-power applications and locations with frequent users, especially schools and playgrounds. Although the output was modest, regular use by many children could increase stored energy over time. With further improvement in structural design, energy storage, and circuit optimization, the hybrid seesaw system may support future applications in alternative energy generation and storage.

4. Conclusion & Recommendations

Based on the prototype testing, the study concluded that a seesaw can be feasibly designed as an energy harvesting unit using piezoelectricity and electromagnetic induction. The system generated an average voltage of 14.4 volts and recorded a maximum current of 16.65 mA, showing that its output can serve as an initial basis for developing power-generating devices dependent on user weight and frequency of seesaw use. Although energy harvesting through piezoelectricity and DC generation remains at a micro-scale level, the study found that further improvements may enable the system to produce sufficient and sustainable energy in the future.

Future researchers are encouraged to continue studying power generation through piezoelectricity and electromagnetic induction, since the prototype demonstrated feasibility within its specified load and output conditions. Careful planning is recommended, particularly in constructing the seesaw structure. Although the system produced low output, it may generate and store more energy if installed in areas where many users, especially children, regularly use the seesaw. Future researchers may also explore other applications of piezoelectric and DC generator systems, as the project may serve as a basis for power-generating technology and alternative energy storage.

The study was limited to a specific load range, output capacity, and prototype design. Its energy generation remained low and was dependent on the applied weight and frequency of seesaw use. The system was therefore more suitable as a starting point for small-scale energy harvesting rather than as a complete high-output power source.

Compliance with ethical standards

The study was conducted in accordance with institutional ethical standards, with all prototype testing carried out responsibly and only with voluntary participation, appropriate consent, and due consideration for user safety, particularly because the proposed system is intended for school and playground settings. Information gathered during testing was treated with confidentiality and used solely for research purposes. The authors declare that there was no conflict of interest in the conduct of the study, acknowledge the support and contributions of Quezon City University and all individuals who assisted in the project, and affirm that they are responsible for the originality, accuracy, and copyright ownership of the research work.

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