ECO – GYM: A PUBLIC POWER HARVESTER

Aravinda Shilpa Konathala Assistant Professor, Department of Electrical Engineering, Andhra University College of Engineering for Women, Visakhapatnam – 530017, Andhra Pradesh, India : aravindashilpacf@andhrauniversity.edu.in
Dr. K. Soumya Assistant Professor, Department of CS&SE, Andhra University College of Engineering for Women, Visakhapatnam – 530017, Andhra Pradesh : soumyacf@andhrauniversity.edu.in
Dharani Ketireddi Student, Department of Electrical Engineering, Andhra University College of Engineering for Women, Visakhapatnam – 530017, Andhra Pradesh: dharani63040@gmail.com
Tejaswitha Badireddi Student, Department of Electrical Engineering, Andhra University College of Engineering for Women, Visakhapatnam – 530017, Andhra Pradesh: btejaswitha@gmail.com

Abstract
As the need for sustainable energy solutions continues to grow, alternative energy harvesting technologies are being explored. This paper presents the design and implementation of an Eco Gym: A Public Power Harvester, a hybrid renewable energy microgrid that combines human kinetic energy with solar photovoltaic energy. The system features a four-limb power generation setup, where both upper-body and lower-body exercises generate electrical energy through DC gear motors acting as generators.

The generated electrical output is rectified, boosted and stored in a 12V, 12Ah battery. The results indicate that approximately 70Wh of electricity can be produced through a combination of human effort and solar input. This energy is sufficient to power two 10W DC lights for nearly seven hours. The system demonstrates a sustainable approach to integrating renewable energy generation with public fitness infrastructure while promoting awareness of energy consumption.

Keywords: Human Energy Harvesting, Pedal Generation, Renewable Energy, Hybrid System, Energy Storage, Sustainable Power.

Introduction
Over the years, various studies have examined the concept of human-powered energy generation systems, especially through exercise equipment like stationary bikes and treadmills connected to electrical generators. While these systems prove the potential of converting human mechanical movement into electricity, many rely on a single energy source and do not combine other renewable sources for better reliability and efficiency. The proposed Eco Gym: A Public Power Harvester tackles this issue by developing a hybrid renewable energy system that merges human kinetic energy from both upper and lower body exercises with solar photovoltaic energy. The system includes a pedal-based lower-body generator and a shoulder wheel upper-body generator, both connected to DC gear motors functioning as electrical generators. The power generated is processed using rectifiers and boost converters and stored in a 12V battery system. Additionally, a solar photovoltaic panel provides extra energy input, ensuring continuous power production.

Problem Statement
The growing demand for electricity in public spaces such as parks and recreational areas has increased dependence on conventional energy sources, leading to higher costs and environmental concerns. At the same time, a considerable amount of mechanical energy produced during physical activities in outdoor gym equipment remains unused and is lost without any practical benefit. Despite the adoption of renewable sources like solar energy, the potential of human energy harvesting is still not effectively utilized. Therefore, there is a need for an efficient and economical system that can capture this wasted mechanical energy and convert it into useful electrical energy. Integrating human-powered generation with solar energy can improve reliability and provide a continuous power supply for applications such as lighting and mobile charging, while also promoting awareness about energy

conservation and encouraging public participation in sustainable practices.

Objectives of the Study

- To design a system capable of transforming mechanical energy produced during physical activities into electrical energy.
- To combine human-generated energy with solar power to form a dependable hybrid energy system.
- To store the produced energy effectively and utilize it for applications such as lighting and device charging.
- To increase awareness about energy efficiency while motivating people to engage in fitness-based energy generation.

Review of Literature

Linqiang et al. (2010) designed a manually operated mobile charging system that converts human effort into electrical energy, proving that small-scale power generation is possible through mechanical input. Studies by Priyan et al. (2015) and Rajesh et al. (2014) examined bicycle-driven power generation systems and reported that pedal-based mechanisms can effectively generate electricity for basic needs. Simon and Rahman (2020) introduced an improved stationary bicycle system using magnetic integration, which enhanced the efficiency of standalone power generation. These works highlight the practical use of human-powered systems for localized energy production.

Zhang et al. (2022) reviewed different energy harvesting technologies and emphasized their role in sustainable energy development. The study pointed out that combining multiple energy sources can significantly improve system performance and reliability. Khan et al. (2016) focused on solar photovoltaic systems and discussed the importance of efficient battery charging techniques for stable energy storage. Additionally, research published in Applied Sciences (2022) explored innovative design approaches that improve energy generation through better system configuration and integration.

Sasaki et al. (2013) and Williams et al. (2018) investigated the energy output generated during physical exercise, showing that activities such as cycling can produce a measurable amount of energy depending on intensity and duration. Their findings indicate that human activity can be considered a supplementary energy source for low-power applications. Overall, the reviewed studies suggest that integrating human-powered energy systems with renewable sources can lead to a reliable and sustainable solution for decentralized energy generation.

Methodology

The methodology adopted in this study follows a systematic and design-oriented approach for developing a hybrid energy generation system using human mechanical effort and solar energy. Initially, the problem of energy wastage in public spaces and the need for sustainable power generation are identified. Based on this, a hybrid model is proposed that combines pedal and hand-crank mechanisms with a solar energy source to ensure continuous power generation.

In the next stage, suitable hardware components such as DC generators, solar panels, diodes, rectifiers, boost converters, charge controllers, and batteries are selected based on system requirements. The system design involves integrating mechanical energy conversion units with electrical circuits to ensure efficient power generation and transfer. The generated mechanical energy is converted into electrical energy and processed through appropriate power conditioning components to maintain proper current flow and voltage levels.

Finally, the developed system is assembled and tested under different operating conditions to evaluate its performance. Parameters such as output voltage, energy generation, and load utilization are observed to assess the efficiency and reliability of the system. The obtained results are analyzed to verify the feasibility of the proposed system for practical applications in public environments.

System Implementation and Working Model

The developed prototype of the Hybrid Eco-Gym Public Power Generation System, as shown in Fig 1, represents the practical realization of the proposed concept by integrating essential components for energy generation, control, storage, and utilization. The system consists of a pedal-driven mechanism and a manually operated hand-crank, both coupled with DC generators that convert mechanical motion into electrical energy during operation. These mechanisms enable power generation using both lower and upper body effort, thereby increasing the overall energy output. To ensure continuous power availability, a solar panel is also incorporated into the system, which generates electricity during daylight and supports the system when human input is not available.

Fig 1 Working Model

The electrical energy generated from different sources is combined and passed through protective components such as diodes and fuses to maintain proper current flow and to protect the system from overcurrent conditions. This enhances the safety and reliability of the system under varying operating conditions. A charge controller is used to regulate the voltage and to ensure safe charging of the battery. Additionally, a DC-DC boost converter is employed to increase the generated voltage to a suitable level for efficient storage and utilization.

The regulated energy is stored in a 12V rechargeable battery, which acts as an energy backup for later use. The stored power is supplied to various loads such as LED lighting systems for public illumination and USB charging ports for small electronic devices. Overall, the system demonstrates an effective approach for utilizing human effort along with solar energy for practical applications. The developed model confirms the successful integration of mechanical and electrical subsystems and validates the feasibility of the proposed hybrid energy generation system for real-time applications.

Sources of Power Generation

The proposed system utilizes multiple energy sources to generate electrical power in an efficient and reliable manner. It integrates human-powered mechanisms such as pedaling and hand-crank operation along with a solar panel to ensure continuous energy generation. This hybrid approach improves the overall power output and reduces dependency on a single source, thereby enhancing system performance under varying operating conditions.

❖ **Pedal Power Generation**

Fig 2 illustrates the pedal power generation circuit, where mechanical energy produced through cycling is converted into electrical energy.

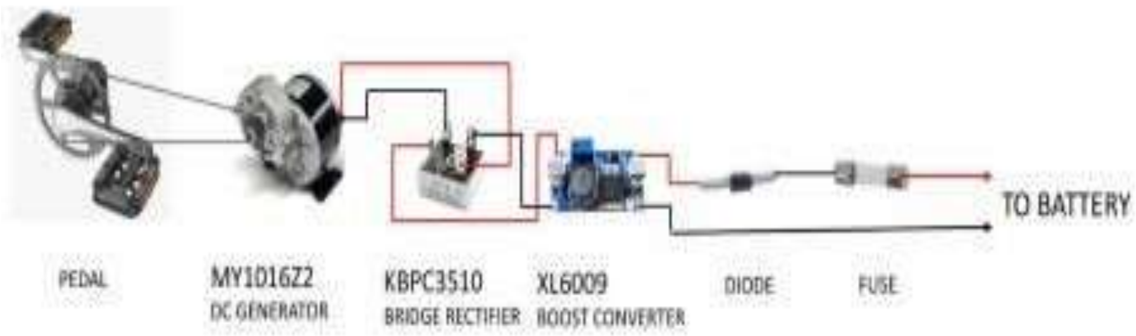


Fig 2 Pedal Power Circuit

In this mechanism, the rotational motion generated by pedaling drives a DC generator to produce electrical power. The generated output is passed through a rectifier, diodes, and a boost converter to maintain proper current flow and to increase the voltage to the required level. The regulated energy is then stored in the battery for later use. This method is effective as continuous leg movement enables higher energy generation, making it a major contributor to the total system output.

❖ **Hand Crank Power Generation**

Fig. 3 illustrates the hand crank power generation circuit, where electrical energy is generated through manual rotation.

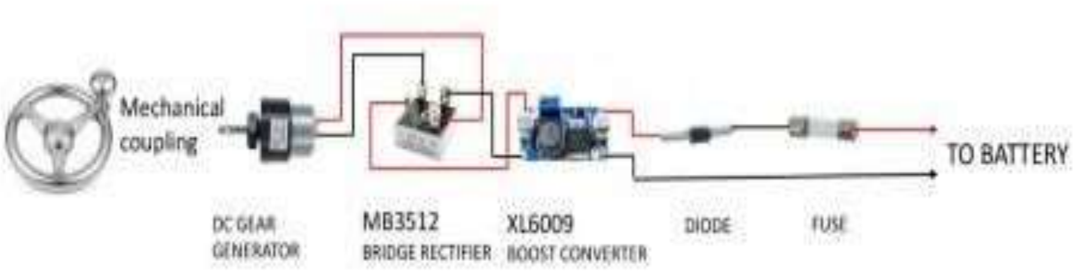


Fig 3 Hand Crank Power Circuit

When the crank is rotated, mechanical energy is converted into electrical energy using a DC generator. The generated output is processed through rectifier circuits, diodes, and a boost converter to ensure proper current direction and voltage enhancement. The processed energy is then stored in the battery for future use. Although the output is lower compared to pedal generation, this mechanism provides an additional energy source and improves system flexibility.

❖ **Solar Power Generation**

Fig. 4 illustrates the solar power generation circuit, where solar energy is converted into electrical energy using a photovoltaic panel.

Fig 4 Solar Power Circuit

The electrical output from the solar panel is passed through diodes and a charge controller to regulate the voltage and ensure safe battery charging. This source provides continuous energy during daytime and supports the system when human input is not available. As a result, it enhances the overall efficiency and reliability of the hybrid energy generation system.

Electrical Design

Fig. 5 illustrates the mechanical design and power flow circuit of the proposed hybrid energy generation system, showing the integration of multiple energy sources into a single framework.

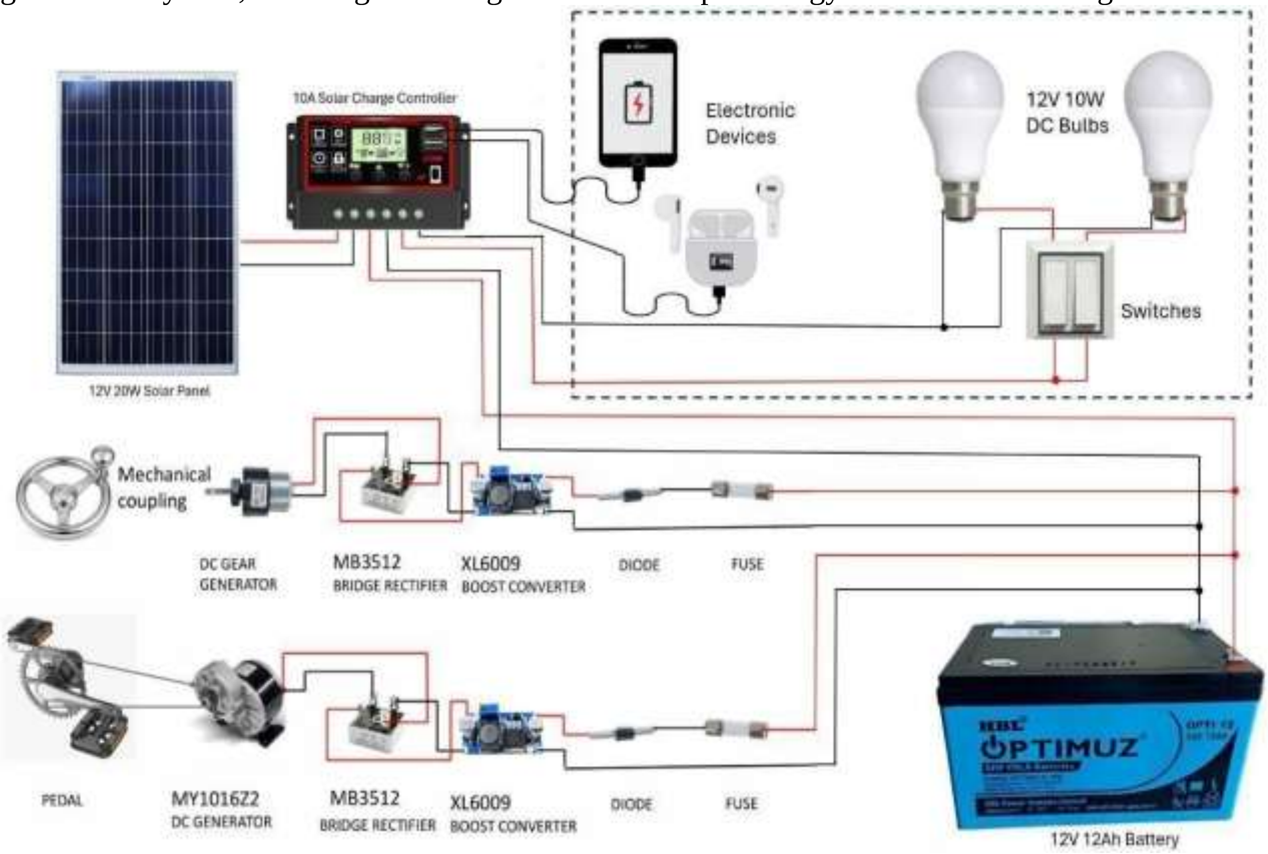


Fig 5 Mechanical Design and Power Flow Circuit

The system combines three energy sources, namely the pedal generator, hand-crank generator, and solar panel, to generate electrical power under different operating conditions. The electrical output from the pedal and hand-crank generators is initially in variable form and is processed through rectifier circuits where required. Diodes are incorporated for each source to ensure unidirectional current flow and to prevent reverse current between sources. In addition, fuses are used to protect the circuit from overcurrent and short-circuit conditions, thereby improving overall system safety.

The combined electrical output from all sources is then supplied to a DC-DC boost converter, which increases the voltage to a suitable level for efficient battery charging. The boosted voltage is regulated using a charge controller that maintains stable voltage levels, prevents overcharging, and ensures proper energy management. The regulated energy is stored in a 12V battery, which serves as an energy storage unit. The stored power is delivered to various loads such as LED lighting systems for illumination and USB ports for charging small electronic devices. This integrated design ensures smooth power flow, efficient energy conversion, and reliable operation of the hybrid system.

Tables and Graphs

Table 1: Power Generation Data

The power generated from different energy sources is presented in Table 1. The system uses pedal mechanism, hand-crank and solar panel to generate electrical energy. The values are based on observations from the developed model under specific operating conditions.

Source	Time Duration	Energy Generated (Wh)	Efficiency
Pedal	30 min	50 Wh	High
Hand Crank	30 min	12 Wh	Medium
Solar Panel	30 min	10 Wh	Medium - High

From Table 1, it is observed that the pedal mechanism generates the highest energy compared to the other sources.

Table 2: Load Estimation

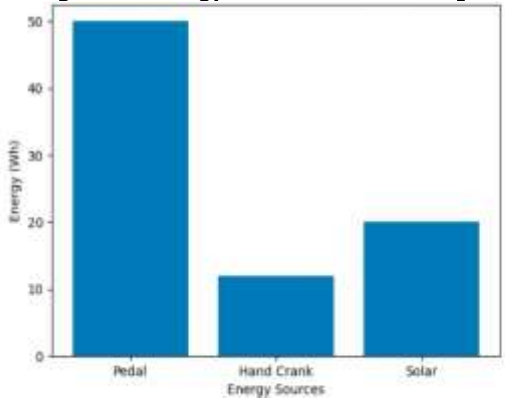
The load requirements of the system are shown in Table 2.

Load Type	Power Ratings	Time Used	Energy Required
LED Light	10W	5 hrs	50 Wh
USB Charging	5W	3 hrs	15 Wh

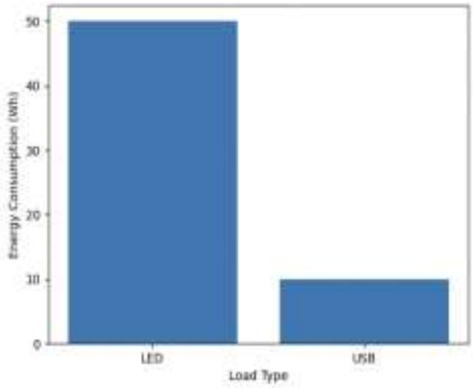
Table 2 indicates that the generated energy is sufficient to operate LED lighting and support small loads such as USB charging.

Graphs

Graph1: Energy Generation comparison



Graph2: Load vs Energy Usage



Graph 1 and Graph 2 show the energy generation from different sources and the load requirements of the system. It is observed that the pedal mechanism generates the highest energy compared to the hand-crank and solar sources, making it the main contributor to the total power output.

Graph 1 represents the energy generated from each source, while Graph 2 shows the energy consumption of the loads. From the comparison, it is clear that the total generated energy is sufficient to meet the load requirements, proving the effectiveness of the proposed hybrid energy system.

Results and Discussion

Load estimation is essential to evaluate the practical usability of the proposed system. It helps in determining how effectively the generated energy can be utilized for real-time applications such as lighting and charging. In the proposed system, energy is generated using three sources: pedal mechanism, hand-crank system and solar panel. Based on experimental observations, the pedal mechanism generates approximately 50Wh in 30 minutes, while the hand-crank system produces around 12Wh in the same duration. The solar panel contributes additional energy during daytime. The generated energy is stored in a 12V battery and is used to power loads such as a 10W LED light and USB charging devices. By analyzing the generated energy and load requirements, the system can support lighting for several hours, making it suitable for small-scale applications.

The electrical power generated by the system is calculated using the fundamental power equation P = V*I

From the experimental setup, the average observed values are:

- Voltage (V) ≈ 10V
- Current (I) ≈ 2A (during normal pedaling)

Therefore,

Power (P) = 10 × 2 = 20 Watts

This indicates that the system is capable of generating approximately 20W of electrical power under standard operating conditions. It is important to note that this value may vary depending on user effort, speed, and system efficiency.

Energy Generation over Time

Electrical energy is calculated using the relation:

Energy (Wh) = Power (W) × Time (hours)

For a duration of 30 minutes (0.5 hours), the energy generated from different sources is:

- Cycle pedaling generator ≈ 50 Wh
- Hand crank generator ≈ 12 Wh
- Solar panel ≈ 10 Wh

Total Energy Generated = 72 Wh

This hybrid combination of energy sources improves the overall efficiency and ensures continuous energy availability. Research also indicates that combining human-powered systems with renewable sources like solar significantly enhances total energy output.

Calculation of LED Wattage

The electrical power consumed by the LED light can be calculated using the basic power equation:

$$P = V * I$$

The Eco Gym system operates using a 12V DC battery supply. If the LED light draws a current of approximately 0.83 A, then:

Power (P) = 12 × 0.83 ≈ 10W

This confirms that the selected LED light operates at a power rating of 10 Watts. Load Requirement for Multiple Lights

In practical applications, multiple LED lights may be required to illuminate a park area. The total load can be calculated as:

- 1 LED light → 10W
- 2 LED lights → 20W

This shows that the total power demand increases linearly with the number of lights connected to the system. From the above mathematical analysis, it is proven that the Eco Gym system can successfully power LED lights for a significant duration at night. This confirms the practical feasibility and real-world applicability of the project in public parks and smart city environments.

Conclusion

The Eco Gym Public Power Harvester successfully demonstrates a hybrid renewable energy system that combines human kinetic energy and Solar's energy. The system efficiently converts physical activity into electrical energy using pedal and shoulder wheel generators. With integrated solar support and battery storage, the system can power park lighting and small electrical loads. Additionally, the gamified monitoring system encourages user participation and raises awareness about energy generation. This concept can be implemented in public parks, smart cities, and fitness centers to promote sustainable energy practices.

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