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Harnessing Human Kinetic Energy: Household-Based Electricity Generation Using Stationary Exercise Bike

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Abstract. This study examines the sustainability of harnessing human kinetic energy through a stationary exercise bicycle modified to include electricity-generating capabilities for household applications. The apparatus utilized in this research was designed to produce 500 watts of power at a cadence of 42 revolutions per minute, equipped with a 300-watt power inverter and a 12V-65Ah battery. Employing a human-centered technology development approach, the exercise device was tested by ten participants with minimal or no athletic experience under controlled conditions. The results indicated that 70% of the participants generated significant electrical output, highlighting the device's potential for sustainable energy production. Furthermore, qualitative feedback underscored the opportunity to integrate touchscreen controls, monitoring panels, and virtual reality technologies to enhance user engagement. The study also explores alternative methods for energy integration, such as net metering and hybrid power systems, to optimize the incorporation of generated electricity into residential grids. Overall, the empirical findings provide a solid framework for advancing human-powered energy solutions, thereby supporting the mainstream adoption of this technology as a viable renewable energy source.

Keywords: Electricity Generation; Household-based Electricity Generation; Human Kinetic Energy; Stationary Exercise Bikes

1. Introduction

Many feasibility studies have explored the use of human kinetic energy for electricity generation, including studies conducted by Jafek & Salmon (2017) and Karthik et al. (2018). Technological and engineering solutions have been presented to demonstrate that it is possible to harness the energy produced by humans through cycling to generate electricity (Pham et al., 2022). However, one question remains unanswered: can an average person with minimal or no athletic

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https://neust.journalintellect.com/quest

background sustain enough cycling activity for the substantial duration needed to produce sufficient electricity for practical use?

This study explores whether an average person with little to no athletic background can generate enough electricity using stationary bikes for practical household use. It examines the sustainability of generating electricity from human kinetic energy and considers applications like battery charging, net metering, or integrating hybrid power sources. It includes participant feedback on improving the technology and explores potential applications for reducing electricity costs.

Human kinetic energy presents a viable and environmentally friendly source of energy (Dai & Liu, 2012; Khalifa et al., 2018). This energy could be harnessed for electricity generation by implementing appropriate technology. According to Riemer & Shapiro (2011) and Geisler et al. (2017), activities such as walking, running, and cycling can be utilized to generate electrical power. Integrating electricity-generating devices into fitness routines could enhance their effectiveness, allowing individuals to produce electricity while exercising (Yang et al., 2013).

Stationary bicycle-powered generators offer potential for electricity generation while promoting physical fitness. Regular cycling combats inactivity and helps prevent chronic conditions such as heart disease, diabetes, and obesity. (Thompson et al., 2020). It's beneficial for knee osteoarthritis, easing pain and improving function, but may have little effect on stiffness or overall quality of life, serving as a partial solution for symptom management. (Luan et al., 2021). Additionally, cycling is assumed to be a sustainable and eco-friendly mode of electricity generation (Arellano-Sánchez et al., 2020). Using these devices for electricity generation is both pragmatic and eco-friendly, providing a convenient way for individuals to stay fit while also contributing to a sustainable future (Carbajales-Dale & Douglass, 2018; P R et al., 2023).

Despite the benefits of exercise and the potential for stationary bicycles to generate electricity, challenges remain. Balancing power generation with user comfort is difficult, as sustained effort can cause muscular fatigue and increased stress during intense activity.(Amann & Dempsey, 2008).

Studies on cycling performance have shown that prolonged exertion can precipitate both peripheral and central fatigue, reducing exercise efficiency and

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Received: 03-04/ Revised: 05-06/ Accepted:06-30-2025
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compromising biomechanical performance (Laursen et al., 2002). Repurposing stationary bicycles for electricity generation may increase fatigue compared to traditional training due to added resistance. Additionally, cycling biomechanics research shows that poor force distribution and ergonomics can amplify musculoskeletal strain. (Jobson et al., 2014).

To address these issues, it is essential to design effective interventions. An appropriate gear ratio can reduce torque demands, lowering muscular load and delaying fatigue. Ergonomic adjustments, like adjustable seat height, help maintain optimal posture and comfort during extended use. Additionally, adaptive resistance mechanisms that respond to the user's physiological state can alleviate fatigue and support long-term performance, as suggested by Eckard et al. (2018). Research in ergonomics and biomechanics highlights the need for optimal design in devices aimed at human energy harvesting. Considerations include user comfort and sustainability, as inadequate design can lead to fatigue and strain.

These strategies emphasize a multidisciplinary approach to device design, integrating exercise physiology, biomechanics, and ergonomics to achieve energy generation and physical fitness while ensuring user safety. Optimizing human kinetic energy as a renewable source is feasible but depends on sustainable performance. Research on energy harvesting from motion shows potential for powering low-power devices, but natural fatigue limits the maximum extractable energy based on human biomechanical capabilities.

2. Methodology

This study employs a human-centered technology development research design. It purposively targeted participants who had no underlying health issues or comorbidities and possessed minimal or no sporting background. An additional element of this research design is to thoroughly capture the experiences of end-users with the technology and to gather their recommendations for enhancing its acceptability, based on their genuine preferences (Taylor, 2024). This approach as a research design ensures the technology is functional and meets user expectations effectively, as suggested by Odom et al. (2016) and Fischer et al. (2020).

2.1. Participants of the Study

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A total of ten participants (6 males, 4 females) aged 19 to 22 years were invited to use a stationary exercise bike for electricity generation. Informed consent was obtained, and data privacy was prioritized. Participants could withdraw at any time without penalties. Most had minimal or no sports experience, and all were deemed physically capable of using the equipment.

2.2. Data Gathering Procedures

To evaluate the functionality and durability of the electricity-generating stationary exercise bike, tests were conducted using various cycling methods. Key metrics, such as generator RPM, electrical current, and voltage at different speeds, were measured. Battery charging times and discharge rates were also assessed for overall performance. Cycling cadence was tracked in one-minute intervals for thirty minutes using an observation sheet monitored by three observers. After cycling, participants were interviewed about their experiences, ease of use, comfort compared to conventional bikes, and applications in homes, gyms, or schools. They provided feedback on impressive features, suggested improvements, and shared additional thoughts.

2.3. Data Analysis

The device's performance was assessed by measuring power, voltage output, and battery capacity using tools like digital multimeters and electric meters. Calculations followed Watt's law, factoring in battery capacity, charging rates, magnetic torque, and force required for electricity generation. A line graph illustrated the cadences achieved by participants over 30 minutes, helping identify the common range and optimization opportunities. Additionally, feedback from participants was thematically analyzed to highlight perceived benefits and areas for improving the stationary exercise bike's functionality and acceptability for electricity generation.

3. Results and Discussion

3.1. Cadence to Generator RPM Ratio

The installation of the gear combination in the stationary exercise bike has established a 1:19 ratio between cadence and the rotation of the three-phase permanent magnet generator. The generator at 800 RPM can produce 500 watts based on its rated power. The required cadence to reach 500 watts at 800 RPM is detailed in the computation below.

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https://neust.journalintellect.com/quest

$$N = \frac{800RPM}{n_{generator}}$$

Where:

N is the number of cadences required for the Generator to achieve 800RPM. $n_{generator}$ is the number of rotations in the generator per cadence (1:19, based on the output of the installed gear combination).

$$N = \frac{800RPM}{19} = 42.11 \ or \ 42$$

An individual must pedal at 42 to 43 revolutions per minute on the stationary bike to generate 500 watts of power. A charge controller rectifies the generator's output to direct current and limits the voltage to 14.5 volts, enhancing safety and reducing fire risks. At this pedalling rate, the system registers an output voltage of 14.4 volts.

3.2. Amperage Output

Following Watt's Law, the amount of electrical current produced using the apparatus at 42 cadences per minute was calculated:

$$P = VI$$

where:

P is the power in watts (W), I is the voltage in volts (V), and I is the current in amperes (A).

$$500 \ watts = 14.4 \ volts \ (I)$$

$$I = \frac{500 \ watts}{14.4 \ volts} = 34.72 \ amperes$$

At 42 cadences per minute, the device was able to produce a current of 34.72 amperes.

3.3. Battery Charging and Operation Time

To determine the time required to charge a 12V-65Ah battery using the stationary exercise bike with electricity-generating capabilities, the formula below was utilized to calculate the charging time:

$$Q = I \ x \ t$$

In this equation, Q represents battery capacity in ampere-hours (Ah), I denotes the current in amperes, which is calculated as 34.72 A at 42 cadences

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per minute, and t signifies the time required for charging the battery. This computation allows for determining the battery's charging requirements.

$$65Ah = 34.72A\ (t)$$

$$\frac{65Ah}{34.72A} = 1.87\ hours$$

Charging a 12V-65 Ah battery at 42 cadences per minute takes 1.87 hours. Batteries need to operate within specific voltage ranges; for instance, lead-acid batteries function between 12.0 to 12.9 volts. Lower charge levels are not suitable for household use. A 300-watt power inverter allows operation of devices up to 300 watts, but it’s best to use appliances under 100 watts for longevity. The usage duration of the 12V 65 Ah battery can be calculated using the formula below.

$$Batter\ Capacity\ (Ah) = \frac{DC\ Power\ x\ Time\ (hr)}{Battery\ Voltage\ (V)}$$

Where:

$DC\ Power$ (W) is the load power in watts, Time (hr) denotes the duration the battery needs to supply power, the battery voltage is rated at 12V DC, and the inverter efficiency is typically 95%.

To use this formula, first convert the AC Load to its DC Equivalent. The load runs on 220V AC, while the battery provides 12V DC. It's important to account for inverter losses, which usually have an efficiency of 95% to 98% (Park et al., 2020). For this analysis, a 95% inverter efficiency was used.

$$DC\ Power = \frac{AC\ loadPower\ (W)}{Inverter\ Efficiency}$$

The load power is 100 watts, and the inverter operates at an efficiency of 95%.

$$DC\ Power = \frac{100\ W}{.95} = 105.26\ W$$

To calculate the operational time for a 12V 65Ah battery using a power of 105.26 watts, the formula below was applied:

$$Batter\ Capacity\ (Ah) = \frac{DC\ power\ x\ Time\ (hr)}{Battery\ Voltage\ (V)}$$

$$65\ Ah = \frac{105.26\ Watts\ x\ Time\ (hr)}{12\ V}$$

$$12\ V\ (65\ Ah) = 105.26\ W\ x\ Time\ (hr)$$

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$$780\ W - h = 105.26\ W\ x\ Time\ (hr)$$

$$\frac{780\ W - h}{105.26W} = Time\ (hr)$$

$$7.41\ hr = Time$$

This calculation indicates that a fully charged 12V 65A battery, under a 105.26 DC power load, can provide power for approximately 7.41 hours.

Table 1. Estimated Operation Time of Selected Appliances Using a 12V 65Ah Battery with a 300W Inverter (95% Efficiency)

Appliances	Rated Power Watts	Inverter Efficiency	DC power (Watts)	Operation Time (hr.)
Electric Fan	100	0.95	105.26	7.41
Laptop Charger	100	0.95	105.26	7.41
LED Light Bulb	10	0.95	10.53	74.10
Television (42" LED)	150	0.95	157.89	4.94
Humidifier	40	0.95	42.11	18.53

The table presents estimated operating times for household appliances under 300 watts, using a 12V 65Ah battery with a 300-watt inverter at 95% efficiency. To prolong lead-acid battery life, avoid discharging below 50%. Doubling the amp-hour capacity via parallel connections is recommended for longevity. Lower-wattage devices like LED bulbs and humidifiers run longer than higher-wattage appliances like televisions and laptop chargers, aiding power management in off-grid or backup situations.

3.4. Torque Requirements to Maintain 42 Cadences Per Minute

Since mechanical power (P) in rotational systems is given by:

$$P = \tau \cdot \omega$$

where:

τ = Torque (Nm) and ω= Angular velocity in rad/s.

Converting 800 rpm to rad/s:

$$\omega = \frac{2\pi \times 800}{60} = \frac{1600\pi}{60} = 83.73 rad/s$$

Now, solving for the torque requirements of the generator at 800 rpm:

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https://neust.journalintellect.com/quest

$$\tau = \frac{P}{\omega} = \frac{500}{83.73} = 5.97\ Nm$$

Torque Requirement at the Pedals

$$T_{pedal} = T_{generator} \times Gear\ Ratio$$

Where:

T_{pedal} = Required pedal torque (Nm),

$T_{generator}$ = Torque needed by the generator (5.97 Nm), and

$Gear\ Ratio = \frac{Generator\ RPM}{Pedal\ RPM} = \frac{19}{1} = 19$.

Additional considerations were taken into account for computing the required total torque, factoring in mechanical losses. An efficiency (η) of 85% will be used in this computation.

$$T_{pedal} = \frac{T_{generator} \times Gear\ Ratio}{\eta} = \frac{5.97 \times 19}{0.85} = 96.42\ Nm$$

Determining the required pedal torque (T_{pedal}) enables us to compute the force needed to generate 500 watts of power using a stationary exercise bike. By applying the formula below, the force that needs to be sustained was calculated.

$$F = \frac{T}{r}$$

where:

$F = Force\ (N)$, $T = Torque\ (96.42\ Nm)$ at 85% efficiency, and $r = Distance\ from\ the\ axis\ of\ rotation\ (.20\ m)$.

$$F = \frac{96.42\ Nm}{.2\ m} = 482.1\ N$$

To maintain a speed of 800 RPM, a person must apply over 482.1 Newtons of force to effectively generate electricity for a 12V 65Ah battery, producing 500 watts of power. Douglas et al. (2021) note that individuals with normal physical capabilities, especially trained cyclists, can sustain this force for over 300 seconds without significant fatigue.

3.5. Sustainability of Using Human Kinetics for Electricity Generation Using a Stationary Bike

To determine the sustainability of using human kinetic energy for electricity generation, the number of cadences per minute recorded over 30 minutes for each participant was analyzed.

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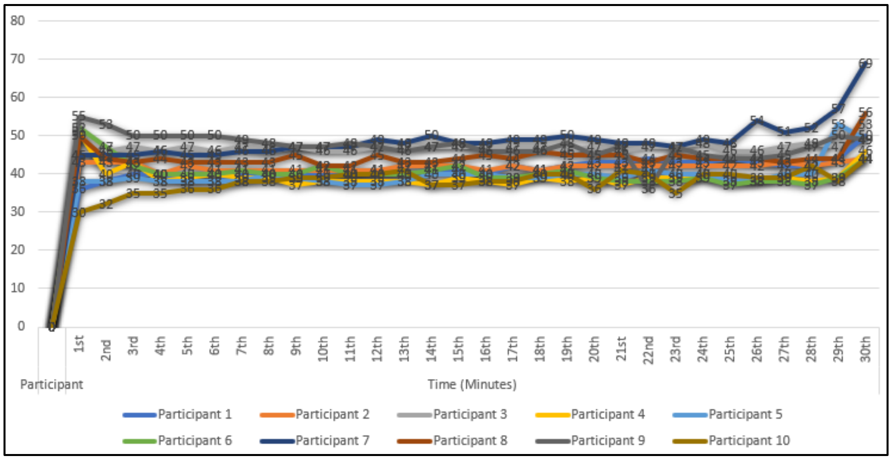

Figure 1 Cadence Achieved by Each Participant Every Minute While Using the Stationary Exercise Bike for Electricity Generation

The figure shows a line graph of participants' cadences on a stationary exercise bike for electricity generation, fluctuating between approximately 30 and 69 RPM over 30 minutes. In the first minute, 7 participants achieved 43-55 RPM. Throughout most of the session, the average cadence ranged from about 40 to 47 RPM. In the last minutes, some participants peaked at 69 RPM.

With a cadence of 42 generating 800 RPM, most participants consistently operated above this threshold, indicating stable power generation and endurance without rapid fatigue. The final increase in cadence may reflect a competitive spirit or bursts of energy, suggesting potential for short-term power surges when needed (Périard et al., 2015).

Table 2. Power at Different Cadences

Cadence (RPM)	Generator RPM (Cadence x 19)	Estimated Power Output
30	570	~360W
35	665	~420W
40	760	~475W
42	800	500W (Baseline)
45	855	~535W
50	950	~590W
55	1045	~650W
60	1140	~710W
65	1235	~770W

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https://neust.journalintellect.com/quest

69	1311	~820W

Table 2 shows the cadence (RPM), generator RPM, and power output, indicating that generator speed increases by a factor of 19 with cadence. Higher cadences result in greater power output; for example, at a cadence of 30 RPM, the generator runs at 570 RPM and produces 360W. Incremental cadence increases lead to non-linear power boosts, such as a 115W increase from 30 to 35 cadence compared to a 50W increase from 65 to 69. Optimal power generation occurs at higher cadences, with 60 RPM yielding 710W and 69 RPM achieving 820W. Further research is needed to explore efficiency and resistance effects.

3.6. Other Potential Applications of the Stationary Exercise Equipment with Electricity-Generating Features

Net-metering allows users to offset electricity costs by feeding excess energy back into the grid (Revesz & Unel, 2016). For the stationary bike to be integrated into such a system, it would need a grid-compatible inverter. While individual cyclists may not generate significant power, collective outputs from multiple bikes, like those in fitness centers, could provide a meaningful contribution to the grid.

Combining the bike's output with other renewables (e.g., solar or wind) can optimize power generation. When solar or wind production is low, the bike can help charge batteries, ensuring a steady power supply. This hybrid approach diversifies energy sources, reduces reliance on traditional grids, and may lower electricity costs. Additionally, the exercise component supports health goals (Raggatt et al., 2018), appealing to households and community initiatives.

While energy production from a stationary bike is limited, its integration into renewable energy systems offers practical, eco-friendly solutions for small-scale power needs.

3.7. Insights and Recommendations from the Participants of the Study

Participants suggested using virtual reality to make the electricity-generating apparatus more engaging. They recommended replacing physical switches with touchscreen panels that monitor cycling speed, cadence, battery status, charging time, and generated power. To improve comfort, they advised adding more padding to the seat and integrating water bottle holders.

Participants reported the stationary bike to be effective for cardiovascular health and body conditioning, reporting minimal fatigue during use. This indicates that even those with little athletic background could generate electricity for extended periods. They highlighted that if this technology gained popularity, it could transform how exercise and energy generation are integrated, proving especially useful during power outages.

4. Conclusions

In this study, seven out of ten participants maintained the minimum cadence of 42 per minute to drive a 500-watt generator at 800 rpm, demonstrating that individuals without extensive athletic backgrounds can produce enough energy for small household applications. During 30 minutes of cycling, participants reported minimal fatigue, suggesting they could sustain the activity longer. The device shows promise in transforming exercise into a renewable energy source, enhancing health while supporting sustainability efforts.

5. Recommendations

The stationary exercise bike can be used for electricity generation, with a recommended cadence of 42 to 45 revolutions per minute to meet the generator's minimum operational threshold. Additionally, researching the integration of virtual reality technology could enhance the functionality of these bikes. It's also important to explore the use of multiple stationary exercise bikes in net-metering and hybrid power systems to assess their economic feasibility and practical implementation.

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Vol. 4 No. 1 (2025)
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