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(Research Article)

Pedaling and cranking operated power generator for small home appliances

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Abstract

Electrical energy has and will continue to be of concern because of availability, cost and environmental issues. There will always be the need to source and tap energy from numerous sources to supplement these gaps. This research was built on the premise to tap energy from pedal operated bicycle for small appliances at homes especially for rural areas. The design was made such that energy can be tapped while the bicycle was ridden or in a stationary position. The conversion process involved riding or cranking from the pedal to the alternator, which is transmitted to the battery and from the battery to the inverter, where direct current was obtained and served for the loads. The voltage obtained depended on speed, varies from 9.8V to 20 V and was able to power four mobile phones, two laptops for about 4.2 hours from 114 watts. This is a significant saving for those living in rural areas as well as low income earners.

Keywords: Pedaling; Cranking; Bicycle; Cycling; Electric energy; Small home; Appliances

1. Introduction

Throughout human history, energy has generally been applied through the use of arms, hands and back .With minor exceptions, it was only with the invention of sliding-seat rowing shell and particularly of the bicycle, that legs also began to be considered as normal means of developing power from human muscles [1]. Over the centuries, the treadle has been the most common method of using the legs to produce power. Treaties are still common in the low-power range, especially for sewing machines. Historically, two treadles were used for some tasks, but even then the maximum output would have been quite small, perhaps only 0-15 percent of what an individual using pedal operated cranks can produce under optimum conditions. However, the combination of pedals and cranks, which today seems an obvious way to produce power, was not used for that purpose until quite recently. It was almost 50 years after Karl and Krais invented the steerable foot-propelled bicycle in 1817 that Pierre Michaud added pedals and cranks, and started the enormous wave of enthusiasm for bicycling that has lasted to the present. Ever since the arrival of the fossil fuels and electricity, human powered tools and machines have been viewed as an obsolete technology. This makes it easy to forget that there has been a great deal of progress in their design, largely improving their productivity. The most efficient mechanism to harvest human energy appeared in the late 19th century, but the arrival of cheap electricity and fossil fuel abruptly stopped all further development [2]. Otto Von Guericke is credited with building the first electrical machine in 1660. This form of electricity precedes electromagnetic energy which dominates today. The landscape for today's electricity usage practice bloomed from 1831 t0 1846 with theoretical and experimental work from Faraday, Weber and Gauss in the relationship of current, magnetic fields and force. These theories enabled the design of modern motors and generators. From 1880 to 1900, there was a period of rapid development in electrical machines.

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Studies in power generation shows that bicycling is one of the most efficient form of power generation known, in terms of energy expended per person. [3] gives us an insight into the test conducted by Stuart Wilson using a 24 V (at 1800 rpm), 20 A generator to charge a 12V car battery. A belt-drive was used to connect a 15.5' (39.37 cm) diameter bike flywheel to a 2.5' (6.35cm) diameter pulley that turned the generator. During this test, an average cyclist produced 75W of sustainable electrical power 12V (9000 rpm) for a period of hour. In 1980, Carl Nowiszewski, a mechanical engineering student at Massachusetts Institute of Technology worked with Professor David Gordon Wilson on a design of a human powered generator which built will serve as an auxiliary control function in a sail boat in an Atlantic; he built a light weight foldable apparatus. The energy storage was primarily for automatic steering while the pilot sleep and the pedaling was a way of keeping warm and avoid boredom. The overwhelming problem in the design was the cramped quarters which Nowiszewski eventually solved. And then in 1988, George Alexander Holt III designed human powered generator using recumbent bicycle technology for use in a sail boat using 6061-T6 aluminium; he built a light weight foldable apparatus. The human power requirement was 120 Watt at 75 rpm [4].

[5]Mohd and others (2013) discussed charkha device in India, stating that spinning wheel horizontally could be rotated by a cord encircling a large, hand –driven wheel where the fire is held in the left hand and the wheel slowly turned with the right. Holding the fire at a slight angle to the spindle produced the necessary twist. Jansen and Slob (2003) improved the power generation system known as ''Better Water Maker''(BMW) water disinfection system. The BMW was designed for use where water is unsafe for drinking and electricity was scarce. The BMW utilizes a manual hand crank to provide power to its pump. They also studied one hand cranking and found that 50W of power could be sustained for up to 30 minutes, which is more than double the 17W required by BMW . As early as 2007, fitness facilities around the world begun researching application for converting human power to electricity. The California fitness in Hong Kong was one of the first gym establishments to incorporate human powered machines. Started by French inventor Lucien Gambarota an entrepreneur Doug Woodring, the gym began a programme called ''Powered by You'' in which the excess energy generated by members on 13-step cycling and cross training machines is diverted and converted to power lighting fixtures in the gym [6], **[7**], in the proceeding of ASME 2010, 4th International Conference on Energy Sustainability made us to understand that other gyms in the United States began the harness human power as well. The Dixon recreation centre at Oregon State University (OSU) is one of the many facilities retrofitted between the years 2008 and 2009 by the Clearwater Florida based company known as ReRev. The company retrofitted 22 elliptical machines at OSU so that the excess energy generated by patrons was diverted to the electric grid. According to the company's website, ''An elliptical machine in regular use at a gym using ReRev technology will generate one kilowatt-hour of electricity every two days. [8] revealed that human legs are up to four times more powerful than human arms. One average, a human can sustain about 100W of power through pedaling for an hour but only hand crank about 30W of power in an hour [9] demonstrated that a person's oxygen consumption, and consequently their potential power output, decrease with age, with the peak of potential power output being 29 to 40 years of age [10], [11].Convergence Tech and Magnificent Revolution have manufactured stationary pedal powered generators. Typical design include a back-wheel stand that elevates the bicycle and causes the back wheel to come in contact with a smaller wheel that is hooked up to a ''bicycle dynamo'' and large battery.

Alan Cote wrote in bicycling magazine in 2005, that most of the forces acting again a rider are due to off bike force such as wind, gravity and rolling resistance. He explains- Together, these three off bike forces make up about 95% of the force against the rider, which means the bike itself is about 955 efficient. The bicycle is one of the most efficient uses of the human body's existing muscular and the ergonomic position allows for nearly everyone to utilize. As published in the International Journal of Industrial Ergonomics, pedaling is the most efficient way of utilizing power from human muscles. Pedal power enables a person to drive devices at the most or higher rate as that achieved by hand cranking, but with far less effort and fatigue. The human muscular is concentrated in our legs and the bicycle set-up allows for harnessing the maximum output. The article also explains that stationary power generation on bicycle has been skipped over in past research but with the rising cost of other power generation, reliance on human power generation will become more important; furthermore, the bicycle is a universal symbol of transportation in all types of countries especially developing ones. We can find bicycles everywhere and the robustness of the simple mechanical system makes the learning curve essentially zero.

The rotational nature of the bicycle drive train or more specifically the pedals is a steady style of movement. The constant driving of the pedals become more constant when reaching the drive train since there is rotational inertia to smooth out any subtle changes in the speed. The rear wheel therefore becomes the ideal prime mover for electrical generation; we would need to connect alternator and rear wheel through either direct contact or belt system. Modern bikes have gears that can adjust the range of rpms and make initial pedaling easier. The user is able to start softly and increase the resistance as momentum is gained. The user can also adjust the speed and perceive resistance to their comfort levels. When the bicycle stabilizes and gains more speed, the user - shift thereby increasing perceived resistance and outputs more power.

In developing countries, people use bicycles more often than motor vehicles. The idea of electricity generation through bicycling has been introduced in selected area, but more as recreation focus in the United States. An elementary school in New Jersey uses a pedal –a-Watt system that requires children in gym class to pedal for at least five minutes. These Stationary bicycles generate electricity to power the gym's sound system as well as charge batteries in the school's laptop computers.

Electricity generation activities started in Nigeria in 1896 when the first power plant was built in Lagos. However, it was not until 1929 when the Nigeria Electricity Supply Company was established as an electricity utility company that the phenomenon spread as the public works Department (PWD) was empowered to build plants in different parts of the country. This resulted in the construction of a hydroelectric power station at Kuru near Jos, among others. Electricity supply at that time was mainly for government offices and quarters as well as for the very influential. A power generation plant is designed to produce electricity from a source of energy such as heat- thermal energy generated from fossil fuels(coal, petroleum, natural gas), solar thermal energy, geothermal energy and nuclear energy; potential energy from failing water in a hydroelectricity facility, wind energy, solar electric from solar (photovoltaic) cells; chemical energy from fuel cells or batteries. There are many different types of electric power generating plants which include hydroelectric power plant, solar thermal plant, nuclear plant, wind power towers, geothermal plant and fossil fuel plant. However, the use of fossil fuels and other non-re-useable sources of energy must be reduced in order to keep emissions low and alleviate the use of diminishing resources. The idea of human powered generation has been implemented in many different situations. Some examples include hand-crank radios, shaking flashlights. And receiving power from gym equipment [12]. The use of exercise equipment for a clean source of energy would turn out to be an even more fun experience for participants .It would provide them a means to exercise while generating power indirectly. Bicycles are a popular means of maintaining physical wellness and health. They are also useful a form of transportation for commute distances (short trips ranging from approximately 0-5 mile) and recreation (short and long trips ranging from 0-100 miles). The bicycle -0perated generator utilizes human energy to produce electricity quickly and efficiently. Less commonly, bicycle power is used to power agricultural and hand tools and even to generate electricity. Some applications include pedal powered laptops, pedal powered grinders and pedal powered water wells. This design related to very compact and easily portable power generating unit, which besides being used as a power generator can also be used as cycle exerciser. It serves the dual purpose of power generation and helping the person to maintain physical fitness through exercising the leg muscles. It can be pedaled or cranked by hand and foot to charge 12 volt batteries and run small appliances.

2. Material and methods

The general design criteria was to design a pedal-operated generator that can provide an optimum of 12V direct current and 220V alternating current. The basic design consideration were economic, safety and ergonomics.

2.1. Design Analysis

The force input for pedaling is given in Equation 1:

$$F = \frac{mv}{t}$$ ……………..Equation 1

where, m is the mass(kg), v is the velocity(m/s), and t is time in seconds.

The input torque T(Nm) is given in Equation 2:

$$T = FxR$$ …………….Equation 2

where F is the input force (N), R is the radius N

The power developed P(Watts) is expressed in Equation 3:

$$P = \frac{2\Pi NT}{60}$$ ……………Equation 3

where Π is a constant, N is the number of turns and T is the time in seconds.

The work output on a bike exerciser (Joules) is expressed in Equation 4,

$$W = Fxd$$ ………………….Equation 4

where d is the distance and F the applied force.

The force is a friction resistance provided by the teeth of the gear around the alternator (which is the smaller gear) around the tire. One revolution of the tire is equal to a distance computed d, and is the circumference.

Thus from Equation 4, the work done is expressed in Equation 5 as,

$$W = Fx2\Pi r$$ ………………Equation 5

where r is the radius (m).

From the above, the power is expressed in Equation 6:

$$P = Fx2\Pi rN$$ ………………Equation 6

where N is the number of turns.

The Mechanical efficiency is expressed in Equation 7, thus,

$$P_{OUT} = Tx2\Pi xN$$ ………………Equation 7

This power is equivalent to $2.1Kcal/\min$.

Pedal power input is given in Equation 8

$$P_{(in)} = V_{0xy/\min} x5kcal/V_{oxy}$$ ……………..Equation 8

where $P_{(in)}$ the input is power and V_{0xy} is the volume of oxygen.

The expended power (P_P) in the pedal system is the difference of power out and power input and is given in Equation 9.

$$P_P = P_{(OUT)} - P_{(in)}$$ ……………… Equation 9.

The voltage induced across the terminals of the wire loop E(V), when the magnetic flux passing through the loop varies and can be computed using the expression in Equation 10

$$E = \frac{N\Delta\phi}{\Delta t}$$ …………….. Equation 10

N is the number of turns of wire in the loop, $\Delta\phi$ is the variation in intensity of the magnetic flux passing through the wire loop, expressed in Webbers (Wb) and Δt is the time interval during which the magnetic flux variation occurs, expressed in seconds and given in Equation 11.

$$\frac{w_A}{w_B} = \frac{R_A}{R_B} = \frac{N_B}{N_A} = \frac{D_B}{D_A}$$ ……………..Equation 11

where w_A, w_b are the angular speeds of sprocket A and B respectively.

$R_A.R_B$ are the radii of sprockets A and B respectively.

$N_{A,} N_B$ being the number of teeth on sprocket A and B and $D_{A,} D_B$ are the diameters of sprocket A and B respectively.

2.2. Battery Selection

The battery selection is based on the time expected to operate the full load (r 4 mobile phones, 2 laptops) which was about 3-4 hours. This selection was also based on the size and weight of the battery. Generally, the relationship between the energy stored in the battery and the time of discharge is important. Fulfilling the 12V DC battery requirements, a battery with 40 Ah was selected. If the battery is discharged at 40% at most, this battery leaves 16Ah for operation. A load of 4 phones and 2 laptops which use about 114 Watts. With a 12V DC battery and 114 W load, the design has about 9.5 A of current, which gives 4.2 hours of use at full load.

2.3. Inverter Selection

The power of the inverter was selected according to the way it would be used. The sum of the power of the entire load should not exceed the rated power of the inverter. The maximum power of the inverter should be able to cover the starting current of the loads. Generally, pure sine wave inverters are preferred to the square wave inverter or trapezoidal inverters as it produces a real controlled sine wave (red sine wave) at its output, it offers no significant noise and no loud background noise is heard on a connected radio.

2.4. Generator Selection

The choice of generator to use is critical, as emphasis was placed to low speed considering the pedaling speed of an average human and in order not to exceed maximum gear ratio. [13] provided an insight into the use of a permanent magnet (DC) as the generator which is brushless-type DC; a diode is use to block the flow of current back to the generator. Since 12V controllers, chargers and appliance are common, a generator that produces 100 to 200 Watts at 240 Volts DC was found to be good choice and also one designed to deliver optimum output at speeds under 1000 rpm. DC permanent magnet generator for its simple, pre-assembled and required low rpm when compared with a car alternator was the best option chosen because it produces direct current (DC) and batteries need DC for charging, that is with the charge produced from the generator, the battery can be charged without any special modification. Considering the amount of voltage required to charge a 12V battery, a generator of 24 V permanent magnet DC at 800 rpm would have sufficed. A car alternator was used.

2.5. Measurement of Energy Expenditure

Different methods of energy measurement are available; Direct calorimetry based on the heat production, Indirect calorimetry based on the volume of oxygen consumed, open circuit spirometry based on the measurement of ventilator volumes, open-flow system, etc. For this research, the indirect calorimetry method is used. This method includes: Measurement of oxygen consumption: one litre of oxygen, equals 21kJ used (varies slightly with metabolic fuel consumption-carbos/fats; and oxygen consumption is measured by difference method.

2.6. Maximum Oxygen Consumption

According to Stephen (2009), VO_2 max is the maximum of oxygen that the body can consume during intense whole body exercise, while breathing air at sea level. This volume is expressed as a rate, either litres per minute (l/min) or milliliters per kg body weight per minute (ml/kg/min). Because oxygen consumption is linearly related to energy expenditure, when oxygen consumption is measured, one is indirectly measuring an individual's maximal capacity to do work aerobically.

The typical young untrained male will have an absolute VO_2 maximum of 3.5 liters/min, while the typical same age female will be about 2 liters/min. This is a 43% difference. Much of the difference is due to the fact that males are bigger, on average than females, Humans are all sort of geometrically similar. So heart size sizes in proportion to lean body size. If we divide V02 by body weight, the difference is diminished (45 ml/min/kg vs.38ml/min/kg) to 15 to 20%, but not eliminated. Young untrained women average about 25% body fat compared to 15% in young men. So, if we factor out body consumption differences by dividing VO_2 by lean body mass (Body weight minus estimated fat weight), the difference is maximal o_2 consumption decreases to perhaps 7-10%. By measuring oxygen consumption (VO_2) during the exercise on a bicycle ergometer, the energy expended as well as the mechanical efficiency can be determined. VO_2 can be converted to energy unit to give power input, so long as the exercise does not require oxygen a rate greater than the highest rate at which a person can consume oxygen (ie VO_2 max).

As a rule of thumb, 1 liter of oxygen consumed is equivalent to 5kcal of energy 'turned over' I aerobic metabolism. Therefore, if we assume the person's VO_2 consumption as 2.5 l/min, we know that this person is turning over energy at a rate of 10.5kcal/min, and this equals

$$\frac{10.5kcal}{1hr}[\frac{4.19J}{1calorie}][\frac{1hr}{26000\sec}] = 12Watts$$ ....Equation 12

Table 1 shows the materials used for the research.

Table 1 Bill of Engineering Measurement and Evaluation

Item	Description	Quantity
1	Bicycle	1
2	Alternator	1
3	Wood	2
4	Chain	1
5	Bicycle sprocket	2
6	12 V battery	1
7	Inverter	1
8	Wires	Lump sum
9	Switch	1
10	Nails	Lump sum

3. Results

The results of the bicycle ridden around the University of Uyo main campus a distance of 2180m and presented in Table 2.

Table 2 Measured Voltages and Speed While Cycling

Item	Mass(kg)	Weight (N)	Voltage(V)	Time (Sec)	Speed(m/s)
1	50	490.5	13.4	325	6.2
2	55	539.55	10.5	400	5.5
3	60	588.6	11.0	396	5,5
4	62	608.22	14,2	290	7.5
5	65	637.65	9.8	620	3.5
6	65	637.65	13.0	340	6.4

Table 3 Shows the results when the bicycle is stationary and ran at various speeds

Table 3 Voltage Produced with Speed in a Stationary Position

Item	Mass (kg)	Weight (N)	Speed (Rpm)	Voltage (V)
1	50	490.5	0	0
2	55	539.55	180	4
3	60	588.6	400	8
4	62	698.22	560	12
5	65	637.65	640	16
6	65	637.65	820	20

4. Discussion

The results obtained in Table 2 show that the magnitude of the voltage produced is dependent on the speed and distance covered. The faster the cycler, the more the voltage produced. When the speed was 6,2m/s the voltage was 13.4 V and 9.8 V when the speed was 3.5m/s. It became 13.83V. It shows that the most important parameter is the speed and not necessarily the mass or weight, though a higher mass has the potential to produce higher speed. In Table 3 similar results are obtained with the bicycle stationary and cranking done by hand. The results from both Tables show the voltage produced solely depends on the speed and not the method. One can see that cranked stationary bike produced more voltage that the former purely on the fact that it was able to develop higher speed. With the global high cost of energy in recent times, there is the need to develop secondary or auxiliary methods of energy production for low energy consuming equipment. The bicycle cycling system in one of these sorts

5. Conclusion

The bicycle while being used for transportation or leisure can be used to produce electric energy sufficient to power household items such as phones, torches, gadgets, laptops, fans etc. The voltage produced is dependent on the speed of the alternator. It is independent of the mode in which the speed is produced. Power can be produced from bicycle by mere cranking and without taking a ride. Cycling is added as another form of green energy as no fuel is needed or carbon dioxide produced during the operation. Further steps should be made to tap energy from human and animals trekking to useful electrical energy.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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