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Research Article

POWER GENERATION BY EHEE

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ABSTRACT
In any gymnasium there are treadmills, stationary bikes, elliptical bikes or rowing machines producing power in order to burn calories for normalising Body Mass Index (BMI). The power being produced is dissipated primarily as heat. The machine for capturing, converting and storing this energy from exercise equipment is known as Energy Harvesting Exercise Equipment (EHEE). The aim of paper is to create a portable EHEE, thus making it affordable and easy to use. A prototype of EHEE was designed using CATIA V5 R16. A typical pedalling arrangement was acquired. After the set-up was complete the EHEE was pedalled; voltage, current and power output recorded, the findings showed that while energy was harvested the quantity was sufficient to energize various house hold (domestic) devices up to 10 W; however with further research and in conjunction with other forms of energy it could be used to operate high capacity devices. This paper was successful in creating a system of EHEE from a stationary pedalling arrangement, Speed Increaser, D.C. generator, Battery and Inverter. Results obtained by mathematical modelling and Experimental are approximately same. EHEE address 4E's Energy saving, Exercise, Environmental protection and Emergency.

Key Words: Mathematical Model, Experimentation, Power Generation and Environment Protection

INTRODUCTION
This research work is on development of dual purpose EHEE for electricity generation exercising for fitness (Arinola & Frank, 2013). The main purpose of EHEE is improving electricity generated during pedalling exercise and reducing the dependence on fossil fuels and its attendant emissions of green house gases especially carbon dioxide, this can eventually lead to reduction in the risk of global warming. In recent times, attempts have been made to harvest energy generated from human powered fitness bicycles and convert it to electricity. The existing EHEE designs were unable to generate feasible electricity that can compensate for the considered financial investment. Therefore, the existing fitness bicycle designs were analyzed and improvements needed in the area of energy conversion were noted and carried out.

MATERIALS AND METHODS
The schematic of the leg, the EHEE with crank arm, the V belt drive and the generator is shown in figure1. The leg-crank arm-pedalling frame is modelled as a five-bar planar linkage system with four numbers of active links and one inactive link. The system is assumed to be revolute rigid bodies in planar motion with frictionless pinned joints. This is a two degree of freedom problem. The configuration of the model will depend on two coordinates θ_3, and θ_4. From figure1 below, we can write the position vector (r_p) of the pedal represented by its spindle in two ways, (1) using the leg segments, and (2) using the EHEE with the crank arm of the pedal. This gives rise to equation 1a and equation 1b.

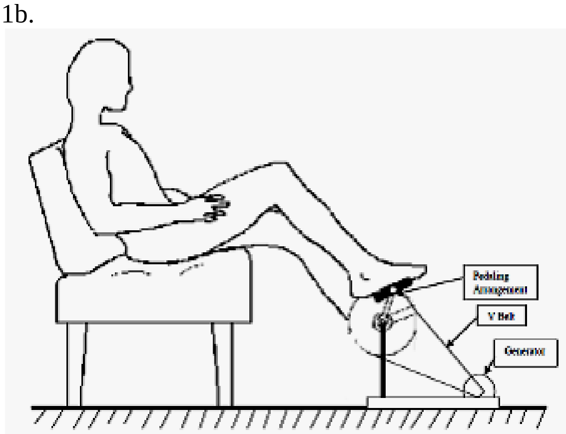

Figure1a: Schematic diagram of EHEE

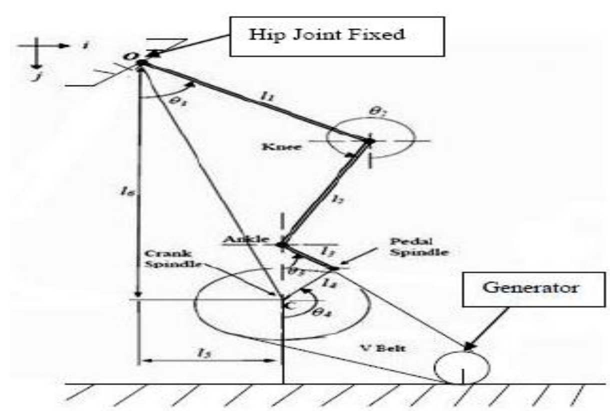

Figure1b: Mathematical Modelling of EHEE

$$r_p = (l_1 \sin\theta_1 + l_2 \sin\theta_2 + l_3 \sin\theta_3)i - (l_1 \cos\theta_1 + l_2 \cos\theta_{2+} l_3 \cos\theta_3)\, j \qquad \leftarrow (1a)$$

$$r_p = (l_6 \sin\pi + l_5 \sin\frac{\pi}{2} + l_4 \sin\theta_4)i - (l_6 \cos\pi + l_5 \cos\frac{\pi}{2} - l_4 \cos\theta_4)\, j \qquad \leftarrow (1b)$$

Differentiating Eq. 1a and Eq. 1b above twice and simplifying will give the expression for the acceleration of the leg segments, and given as Eq. 2a, Eq. 2b, and Eq. 2c

$$\ddot{\theta}_1 = \frac{\begin{Bmatrix}\left\{l_2\dot{\theta}_2^2 \cos\theta_2 + l_1(\dot{\theta}_1^1 \cos\theta_1) + l_3\ddot{\theta}_3 \sin\theta_3 + l_3\dot{\theta}_3^2 \cos\theta_3 - l_4\ddot{\theta}_4 \sin\theta_4 - l_4\dot{\theta}_4^2 \cos\theta_4\right\} l_2(\cos\theta_2) \\ \left\{l_1\dot{\theta}_1^2 \sin\theta_1 - l_2\dot{\theta}_2^2 \sin\theta_2 + l_3\dot{\theta}_3^2 \sin\theta_3 - l_3\ddot{\theta}_3 \cos\theta_3 - l_4\,\dot{\theta}_4^2 \sin\theta_4 + l_4\ddot{\theta}_4 \cos\theta_4\right\} l_2(\sin\theta_2)\end{Bmatrix}}{(-l_1 \sin\theta_1)(-l_2 \cos\theta_2) - l_1(\cos\theta_1) l_2(-\sin\theta_2)} \qquad \leftarrow (2a)$$

$$\ddot{\theta}_2 = \frac{\begin{Bmatrix} l_1(-\sin\theta_1)\left\{l_1\dot{\theta}_1^2 \sin\theta_1 - l_2\dot{\theta}_2^2 \sin\theta_2 + l_3\dot{\theta}_3^2 \sin\theta_3 - l_3\ddot{\theta}_3 \cos\theta_3 - l_4\,\dot{\theta}_4^2 \sin\theta_4 + l_4\ddot{\theta}_4 \cos\theta_4\right\} \\ -l_1(\cos\theta_1)\left\{l_2\dot{\theta}_2^2 \cos\theta_2 + l_1(\dot{\theta}_1^2 \cos\theta_1) + l_3\ddot{\theta}_3 \sin\theta_3 + l_3\dot{\theta}_3^2 \cos\theta_3 - l_4\ddot{\theta}_4 \sin\theta_4 - l_4\dot{\theta}_4^2 \cos\theta_4\right\}\end{Bmatrix}}{(-l_1 \sin\theta_1)(-l_2 \cos\theta_2) - l_1(\cos\theta_1) l_2(-\sin\theta_2)} \qquad \leftarrow (2b)$$

$$\ddot{\theta}_3 = \frac{\begin{Bmatrix} l_3\sqrt{\left(1-\left(\frac{l_4}{l_3}\sin\theta_4\right)^2\right)}\left(l_4\left[\dot{\theta}_4 \sin\theta_4\right]\right) \\ \left(\left(l_4\dot{\theta}_4 \cos\theta_4\right)^2\left[1-\left(\frac{l_4}{l_3}\sin\theta_4\right)^2\right]^{-\frac{1}{2}}\right)\end{Bmatrix}}{l_3^2\left(1-\left(\frac{l_4}{l_3}\sin\theta_4\right)^2\right)} \qquad \leftarrow (2c)$$

The force developed by the lower limb segments is given in equation. 3 below

$$F = m_t a_t + m_s a_s + m_f a_{f=} \sum_{i=1}^{i=3} m_i\, a_i \qquad \leftarrow (3)$$

$$F = m_t\ddot{\theta}_1 + m_s\ddot{\theta}_2 + m_f\ddot{\theta}_3$$

The mechanical torque T_m, developed at the pedal spindle

$$T_m = F(l_4 \sin\theta_4)$$

$$T_m = l_4 \sin\theta_4\,(m_t\ddot{\theta}_1 + m_s\ddot{\theta}_2 + m_f\ddot{\theta}_3)$$

Mechanical Power P_m developed at the crank spindle is,

$$P_m = T_m\dot{\theta}_4$$

Electrical Power P_E generated by the alternator is given by:

$$P_E = EI_a$$

Energy harvesting exercise equipment

Figure 2: Actual Model of EHEE

Development of EHEE

The dual-purpose EHEE can be constructed with the help of the bicycle pedal, pedestal bearing, belt drive and DC generator with specially designed stand to fit into the frame constructed for the purpose. The crank wheel of the bike is connected to the DC Generator through a V belt drive system. The V belt system is an increasing system that has one velocity ratio of 5. The whole assembly is placed on a frame constructed by strip having elongated hole on it of rigid base. The DC generator is connected to the load through inverter/charger system which connects to the battery for the storage of electrical power. Electricity Generated during pedalling Mechanical power generated by the EHEE is transferred to the DC Generator to generate electricity through the V belt drive as shown in figure 3.

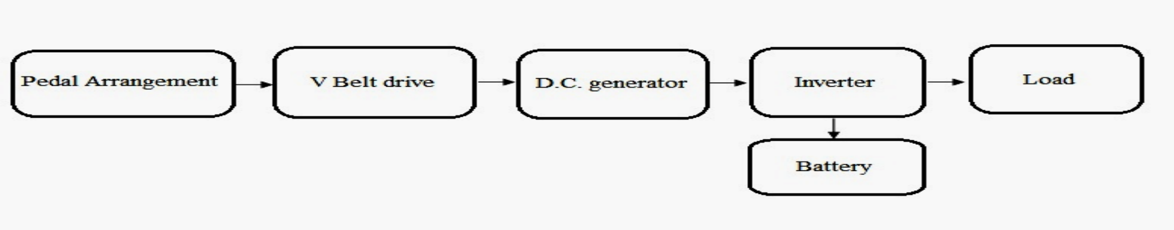

Figure 3: Block diagram of EHEE for electricity generation

From the above Mathematical Modelling equations data for various crank positions is prepared. The graph obtained by mathematical results is plotted for Crank Angle (θ) Vs Torque is as shown in figure 4 it shows that near about 150^0 crank angle position Torque is maximum and minimum near about crank angle 100^0.

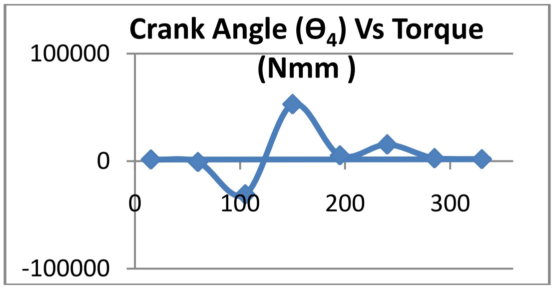

Figure 4: Mathematical Calculated Crank Angle Vs Torque

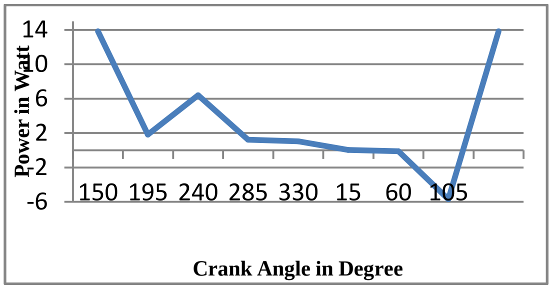

Figure 5: Mathematical Calculated Crank Angle Vs Power

The Power generated at various positions is shown in figure5 which is obtained by entering the required data in the Mathematical Modelling equations. It shows that the power is maximum at crank angle near about 150^0 and it is minimum at 105^0.

Carbon Emission

Energy Consumption of Home Monthly electricity bill for the year 2014-2015 is displayed in figure 6.

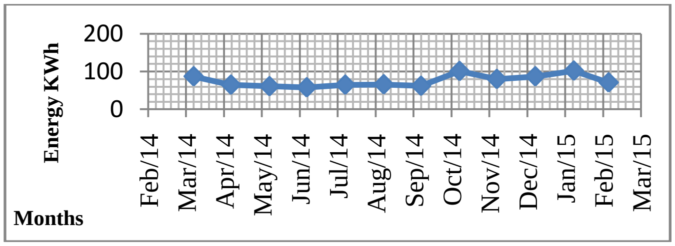

Figure 6: Monthly Electricity Consumption

It shows that the average energy consumption of the facility is about 75.41 kWh per Month of these years, the peak was approximately 102 kWh in the Month Nov 2014, followed closely by a 84 kWh usage in month October 2014 due water heating in Winter season; the minimum was about 58 kWh in the month July 2014 in Monsoon due minimum use of Fan and Heater.

Cost-benefit analysis

Given that the EHEE machines at home can result in harnessing approximately 36 kWh per year, based on the 2014-2015 energy consumption of the home of 905 kWh, the energy harnessed amounts to 3.9 % of the energy consumed by home. When analyzing the cost benefits of EHEE machines, it was assumed that the home will continue to use EHEE machines regardless of the electricity generation and exercising for maintaining health. Considering that the facility pays a relatively low cost for electricity, from 5 to 10 rupees per kWh, the energy harnessed would amount to about 300 rupees in yearly savings. Approximating the cost of the EHEE to be 5,000 rupees, the installation would pay itself off financially in about 17 years. However, the average cardiovascular machine at the gymnasium is replaced every 5-7 years, which would mean the EHEE machines would be retired before the money saved from their harnessed energy could pay off the cost of EHEE. Thus, from a strictly economic standpoint, EHEE exercise machines do not seem economically sustainable unless the EHEE could be reapplied to the new EHEE. Furthermore, assuming a discounted rate of 10%, the true financial payback time would be well over 20 years. However, this analysis did not take into account the inflation rate of energy, which, when considered, would lower the payback time of the EHEE. Economic analysis of the EHEE further details that, assuming a discount rate of 10%, the present value of the total savings from the EHEE after 5 years would be approximately Rs 1,500/-. Therefore, the actual cost of EHEE machines (present value cost minus the present value of total savings after 5 years) would be about Rs 3,500/- (Table 1).

Table 1: Present Value Economic Analysis of EHEE

Sr. No.	Description	Cost
1	Total Cost of EHEE	Rs 5,000/-
2	Annual Savings	Rs 300/-
3	Present Value of Savings after 5 Years	Rs 1,500/-
4	True Cost of EHEE	Rs 3,500/-

Life cycle assessment

In conducting a Life Cycle Assessment (LCA) on the proposed EHEE machine, it was assumed that operation and maintenance of EHEE machines after use would be identical to that before use. Additionally, a one to one ratio between the amount of energy generated and the amount of energy produced by the power plant. For example, it was assumed that producing 36 kWh annually at the EHEE amounts to reducing the amount of power produced by the power plant by 36 kWh annually. According to PG&E's 2008 Corporate Responsibilities Report, on average 0.00037 metric tons (MT) of carbon dioxide are emitted per kWh of electricity produced. Given that the EHEE generating 36 kWh at the Home; Suppose 100 homes use EHEE which generate 3600 KWh would result in reducing the average yearly CO_2 emissions by approximate 1.332 metric tons (MT). Over the minimum lifetime of a machine (5 years), this would equate to a savings of 6.66 MT of CO_2.

Table 2: Assessment of Life Cycle for EHEE

Sr. No.	Parameter	Description
1	Potential Energy Generated	3600 KWh
2	CO_2 Emitted from Purchased Energy	0.00037 MT per KWh
3	CO_2 Saved Annually by Installation	1.3327 MT
4	Minimum CO_2 Saved over Lifetime of Machine (5 Years)	6.66 MT
5	CO_2 Emitted to manufacture additional parts required for EHEE	3.33 MT
6	Time to Reclaim CO_2 Emissions	2.9 years

The parts used in the EHEE consist mainly of AC/DC micro-inverters, electrical wiring and components, and DC-DC converters. If we use 100 EHEE is estimated to cost Rs 5000 each and total cost for 100 units is Rs 500000. Thus, using Economic Input-Output Life Cycle Assessment (EIO-LCA) method, Rs. 500000 of economic activity in the "Miscellaneous electrical equipment manufacturing sector" amounts to approximately 3.33 metric tons of CO_2 emissions. Therefore, by this measure, the CO_2 emissions from EHEE at the home could be reclaimed in less than 3 years by the energy generated from the installation (Table 2).

Experimentation on EHEE

Over an 8 hours day for a 54 hours week, a useful norm for a 35-year-old labourer for total power expenditure, including basal metabolism energy, is 0.49 hp (366 W). Of this total expenditure, approximately 0.1 hp (75 W) is available for useful work. A 20-year-old man can generate about 15 percent more power than this norm, and a 60-year-old man about 20 percent less. The total energy or power expenditure is needed for determining nutritional requirements for classes of labour. A rule of thumb for power developed by Indian males can be expressed as a function of age and duration of effort in minutes for work lasting from 4 to about 480 min, assuming that 20 percent of the total output is useful power.

Table 3: Age and power generating capacity formulae

Sr. No.	Age in Years	Useful Horse power (t in min)
1	20	hp = 0.40 – 0.10 log t
2	35	hp = 0.35 – 0.09 log t
3	60	hp = 0.30 – 0.08 log t

For a well- trained man, useful power production by pedalling, hand cranking, or a combination of the two for working duration of 20 to 120 s may be summarized as follows (t is in seconds): (Table 3)

Arms and Legs hp = 4.4t– 0.4
Legs Only hp = 2.8t– 0.4
Arms only hp = 1.5t–0.4

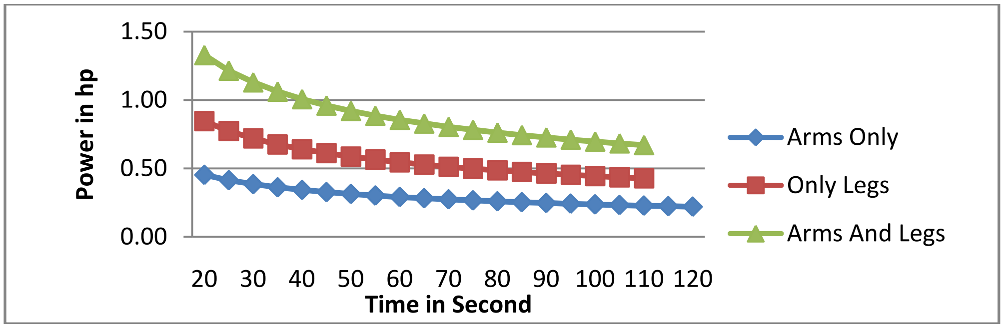

Figure 7: Time Vs Power in Hp graph

There are examples of well-trained athletes generating between 1.5 and 2 hp for efforts of 5 to 20 s, using both arms and legs to generate power. For pedalling efforts of from 1 to about 100 min, the useful power generated may be expressed as hp Vs t (t is in minutes). Work scheduling, either as rhythmic work activity or with rest stops for recuperation, the temperature and humidity of the environment and the detailed nature of the labourer's diet are factors which influence ability to generate and maintain the above nominal power values. These considerations should be factored in for specific work situations.

Experimental Analysis

In the present section, we initially discuss the performance of the plugged-in DC generator to end up commenting the different loads that can be addressed with our EHEE.

RESULTS AND DISCUSSION

EHEE Performance

The EHEE is designed to accommodate from 8- 15 Watts in the cadence range from 50 to 70 rpm, while using the speed ratio available in the EHEE is 5.9 the experimental readings is taking on EHEE by three different ways and the output power obtained by these three way is shown by graphical way. The graph is drawn by taking the mean of all reading. The reading is taken for single hand cranking, double hand cranking and double leg cranking. Graph contains time in minute on horizontal axis and Power in watt on Vertical axis.

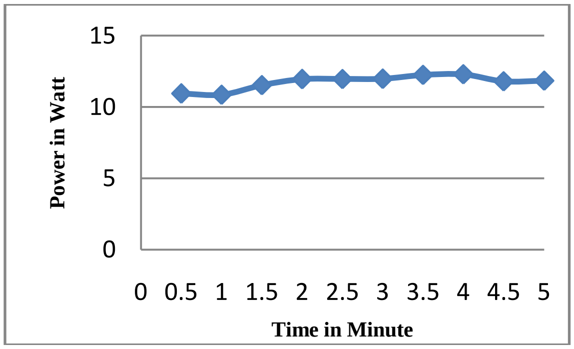

Figure 8: Single Hand Cranking Time Vs Power graph for Male

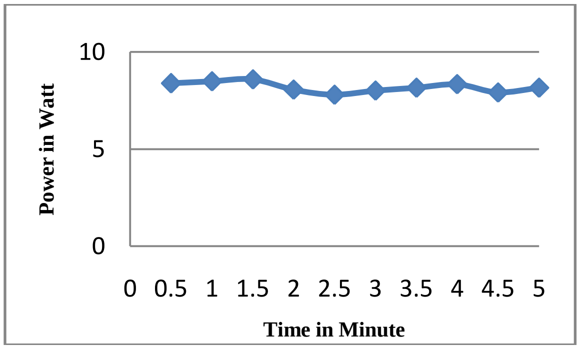

Figure9: Single Hand Cranking Time Vs Power graph for Female

From the above graph it has been seen that the power obtain by the single hand cranking is between 10 to 12 watt for male and it is about 7 to 9 watt for Female. The reading is taken for Voltage in Voltmeter and Current in the Multimeter.

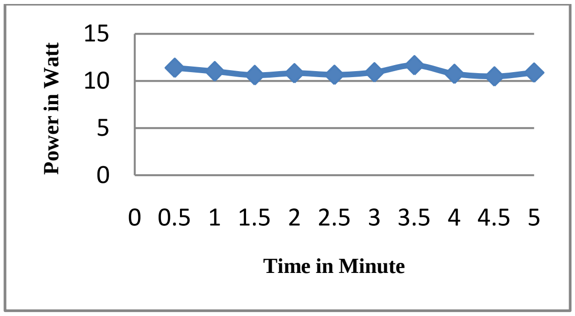

Figure10: Double Hand Cranking Vs Power for Male

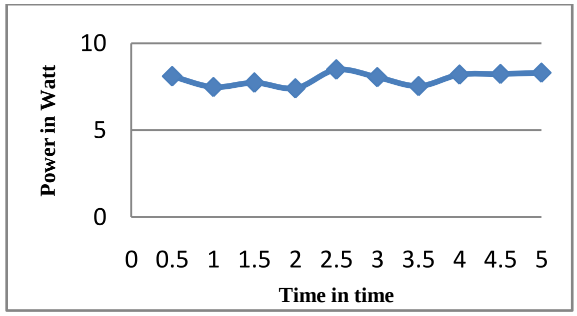

Figure 11: Double hand Cranking Time Vs Power for Female

The figure 10 and 11 shows the graph for Time in minute Vs Power in watt for the Double hands cranking. From the graph we get the information about the power. The power generated by the double hand cranking having the range of 8-11 watt for male and 7-9 watt for female.

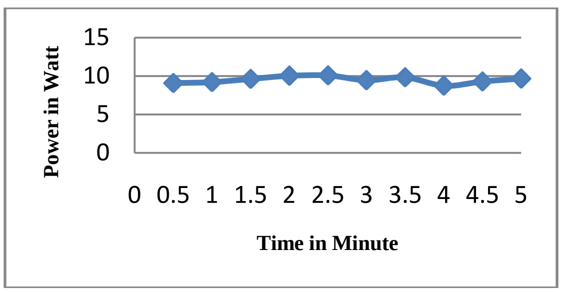

Figure 12: Double Leg Cranking time Vs Power for Male

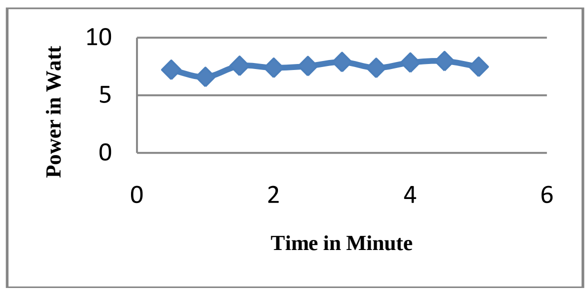

Figure 13: Double Leg Cranking time Vs Power for Female

The power generated by the double leg is about 8-10 watt from the male and 6-8 watt from the female. The figure 12 and figure13 shows the graph for Time in minute Vs Power in watt for the Double leg cranking.

CONCLUSION

After discussing the electric capabilities of our plugged-in generator, we assume 95 Watts-hour of electric energy as a sensible value to be harvested by regular adult people during one hour. Secondly, with the creation of the portable power supply unit, we deliver to the customer an energy system that enables them to supply electricity for their electrical demand like charging mobile phones, electric lighting. If we set up a limit of half an hour per person per day of pedalling, and considered that every person harvest half of the 96Wh already discussed, 28Wh are available for consumption with our EHEE. Number of people pedalling 30 minutes each.
The Information of EHEE when full charged is as given in Table 4

Table 4: Load capabilities of our EHEE

Electric Products	**About Using Time**	**Electric Products**	**About Using Time**
5 Pcs Led Light	85 Hours	9 PCS Led Light	40 Hours
2 W Night Light	30 Hours	15w CD Player	4 Hours
18w Desk Lamp	3 Hours	40w 14`` TV (B/W)	90 Min
55w Fan	75 Min	70w Notebook	55 Min
75w 21’’tv[Colour]	35 Min	100w Lamp	20 Min
Mobile Phone	Battery Specification Dc -4.2V ; 1000mah		15 Times
Digital Camera	Battery Specification Dc -3 .7V; 1100mah		15 Times

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