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Research Article

Rack and Pinion Based Electricity Generation through a Speed Breaker: A Feasibility Study

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Keywords

Electricity,
speed breaker,
rack and pinion,
total power,
capital recovery factor.

Abstract

Electricity is an essential power source for the economic performance of a developing country like Bangladesh. Due to significant system losses, delays in the installation of new plants, low plant efficiency, and lack of incentives for power plant maintenance, the country's energy-producing facilities have been unable to fulfill the present demand. To meet up this enormous demand, a very simple electricity generation technology was designed. The objectives of the study were to design and fabricate a considerable electricity generation system from a speed breaker and finally determine the technical performance of the system. The production plant was set up using a rack and pinion system. The Damper system comprised of a spring that pushed the speed breaker upwards when it was pushed upon by the weight of the vehicle downwards during trafficking of any vehicles over the speed breakers. As a result, the Rack moved downward, transmitting power to the pinion as motion. The production unit was able to produce 4.2 watts, 6.72 watts, and 0.84 watts, respectively, using a motorcycle, a car, and an easy bike. Our fabricated plant has a total power output of 2683 kW. The unit's entire annual cost, including starting costs and total running costs, is projected to be around $269.65. The capital recovery factor and capital consumption were 0.395 and $44.87 respectively. The proposed design will be helpful to reduce the energy crisis problem in Bangladesh because nowadays in our country the number of vehicles is in increasing trend.

1. Introduction

Nowadays, power has become a basic requirement for human living. In the fiscal year 2022-23, electricity was generated in Bangladesh from natural gas at about 44%, furnace oil at about 24%, diesel at about 5%, coal at about 7%, captive at about 11%, from renewable energy sources of about 5% and imported at about 4% [1]. At present 16,000 MW power produced by the Government of Bangladesh, then in 2031 this power will expand to 40,000 MW and after that in 2041 it will be 60,000 MW [2].

As we all know that the nature's basic part is electricity and this form of energy is long-established in the whole world [3]. But the widespread use of electricity has created a crisis. Presently Bangladesh is facing notable energy insufficiency in production system, transmission system and distribution system [4]. So, it is necessary to establish optimal usage strategies that would end the crisis and protect the environment from the detrimental effects of global climate change. The government and electricity-generating firms, particularly in power plants, endure large losses in electrical power generation because of ineffective methods and a variety of additional responsibilities. Bangladesh's government is targeting more than 15-20% of electricity will have come from renewable energy sources by 2030 [5]. Based on this target, investigated some approximate, alternative, and new sources for the production of electricity that will not be depleted in the very few years.

The present speed breakers are rigid in construction and huge amount of potential energy losses occur when any vehicle passes over the speed breakers [6]. There is an average of about 2 to 3 highways in every district in Bangladesh. The number of vehicles running on the roads shows an increase in trends. Using an electricity-generating speed breaker can be a fascinating technology for optimal use of available sources. Lots of energy is misused at the speed breaker because of heat dissipation and also for friction [7]. This technology will show the chances of tapping the misused energy in the road speed breaker. By just simply placing a unit for electricity production, so much energy can be tapped. By rack and pinion mechanism moving vehicle's kinetic energy can be converted into shaft's mechanical energy. Then, it is possible to convert this mechanical energy to other forms of energy and later on a battery will be used to save that energy [8]. Also, this energy can be converted into electricity and then it can be used for many purposes such as lighting on either side of the roads, road signals, digital advertise boards on roads, highways check post, at the toll plaza etc. Therefore, an effort was made for this study by considering the energy sources, cost of operation, space and environmental pollution. The specific objectives of the study were to design and fabricate a considerable electricity generation system from a speed breaker and finally determine the technical performance of the system.

This research can be helpful to reduce the energy crisis problem in Bangladesh because nowadays in our country the number of vehicles is in increasing trend [9]. The aim of the work is to generate free electricity with no fuel cost, no pollution, and with the minimum space requirement. Also, the production of electricity can be huge if it will install on a large scale.

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2. Materials and Methods

2.1. Basic components

2.1.1. Rack and Pinion

The pinion is the gear, while the rack is the flat-toothed component. It converts linear motion to rotary motion and rotary motion to linear motion. Rack and pinion were made by mild steel plate. The length of the rack was 420 mm and a total of 21 teeth, while the primary shaft of 30 mm diameter and a total of 10 teeth, served as the pinion. Figure 1 displays the rack and pinion.

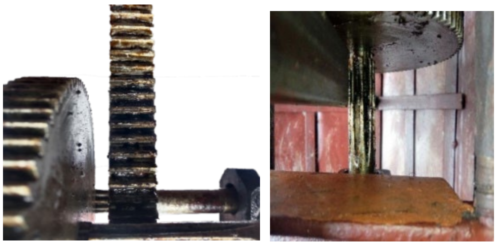

Figure 1. Rack and Pinion

2.1.2. Ball Bearings

Pillow block unique 6205 C3 bearings as shown in Figure 2 were used to carry the load. The inside dimension, outside dimension and width of the single row deep groove ball bearing were 25 mm, 52 mm and 15 mm respectively with C3 clearance.

Figure 2. Pillow Block C3 Ball Bearings

2.1.3. Spur Gear

In the electricity generation unit, two gears were used. Gears as shown in Figure 3 were made by mild steel plate. The diameter of the larger gear was 140 mm and a number of teeth was 90, while the diameter of the smaller gear was 100 mm and a number of teeth was 70.

Figure 3. Large and Small Spur Gear

2.1.4. Spring

The springs utilized as it is shown in Figure 4 had 22 coils, 15.24 mm outside diameter, 2.34 mm wire size, 65.12 mm compressed length, and 88.9 mm free length, according to ASTM A313 spring temper standards.

Figure 4. Spring

2.1.5. Shaft

Figure 5 shows two shafts which were utilized in the generation unit: one was the primary shaft (which served as a pinion) and the other was the secondary shaft, which was connected to the dc motor. The pinion was made up of a primary shaft of 30 mm diameter and total number of teeth was 10. The secondary shaft, which was similarly 30 mm in diameter and featured 10 teeth attached to the gears, was connected to the dc motor via a dc motor.

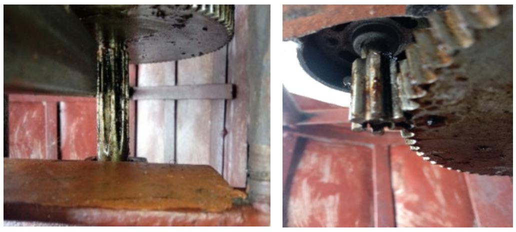

Figure 5. Shaft act as a pinion

2.1.6. DC Motor

A 12-volt DC motor, with 25 mm diameter, a length of 55 mm, and a shaft diameter of roughly 5 mm as shown in Figure 6 was used. With the use of a DC regulated power supply with 12 volts and 2A adapter adjustment, the measuring no-load current was 0.28 A. The DC motor produced 2.5 kg.cm of torque and rotated at 400 rpm.

Figure 6. DC Motor

2.1.7. Battery

A 12-volt battery with six single cells connected in series produces a fully charged output voltage of 12.6 volts was used.

2.2. Fabrication of the unit

To support the speed breakers, a damper system was necessary. The system was constructed from an M.S. sheet with an M. S. rod casing beneath it. When the vehicle's weight pushed the speed breaker downwards, a spring was used in the damper system to bring back the speed breaker. They also had to withstand the shocks caused by the automobiles passing through the speed bumps. The speed breaker rack moved downward as the vehicle passed over it, transmitting power to the pinion as motion. The reciprocating motion was translated to rotary motion using this rack and pinion system. The main shaft serves as a pinion in this case. Figure 7 illustrates the work-flow diagram of electricity production from the system.

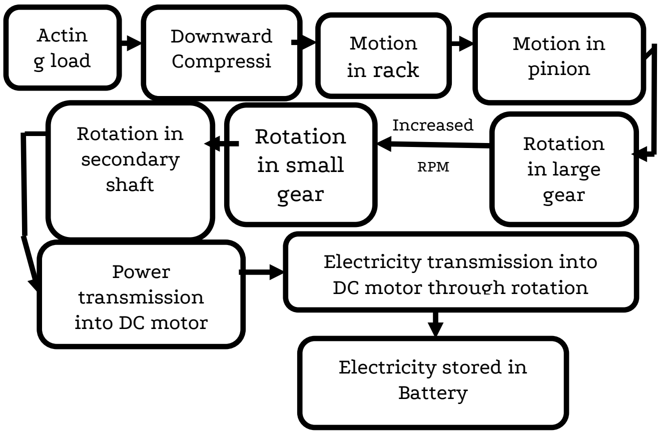

Figure 7. Work-flow diagram of electricity production from the system

The larger gear was attached and rotated in the same motion as the primary shaft. The smaller gear's speed increased as the larger gear turned. The speed available at the larger gear was multiplied at the rotation of the smaller gear as the power was transmitted from the larger gear to the smaller gear. The power was transferred from the main shaft to another shaft, where the dc motor was installed, using this gear arrangement. Though the speed achieved at the larger gear was lower due to rotational motion, the final speed achieved was great since the power was transferred to another shaft. This other shaft's rotation was sufficient to cut the flux into the rotor and operate as an armature The battery was used to store this energy, which was then used for a variety of purposes. Figure 8 shows the electricity production system.

Figure 8. A photographic view of the electricity production system

2.3. Technical Performance

Two methodologies were used to determine the performance of the electricity production unit. Firstly, an ammeter was used to measure the output electricity or current. The electricity from the production unit was obtained from equation (1).

Power(watt)=voltage(volt)× measured current(amp)(1)

Secondly, to determine the system's effectiveness, it was installed in a nearby field and operated simultaneously with a motorcycle, car, and easy bike for loading purposes, and each parameter of electricity production was measured periodically and profiled to compare with predicted values and tolerances throughout the life cycle of the project. Calculation of per-hour electricity generation was done by equation (2)

Power(watt-hr) = power(watt)× no of vehicles passing over the unit (2)

2.4. Operating Cost

2.4.1. Fixed Cost

In this study, equation (3) was used to determine the depreciation by straight-line method [10].

D = P-S/L (3)

where, D = Depreciation [$/yr], P = Purchase or Make cost of the machine[$], S = Salvage value[$], L = Life years of the machine[Yr]

The interest on the investment of considerable electricity production from the system is included in fixed cost estimation. The equation (4) was used for the calculation of interest on investment such as-

I = (P+S/2)×i (4)

where, i = Interest rate (decimal)

2.4.2. Variable Costs

The variable cost depends on labor and repair & maintenance costs for each field operation. The cost of repair and maintenance (0.025% of purchase price) was calculated in $/hr with the sum of labor cost also in $/hr.

2.4.3. Total Cost Calculations

Total cost was calculated by using equation (5).

TC = FC+ VC (5)

where, TC = Total cost in [$], FC = Fixed cost in [$], VC = Variable cost in [$]

2.4.4. Annual Operating Cost

Annual operating cost was calculated by the equation (6):

AC = FC + (VC×U) (6)

where, U = Annual use in Hours

2.4.5. Capital Recovery Factor

Capital recovery factor and capital consumption were calculated by using equation (7 & 8).

CC = (P-S)× CRF + (S×i) (7)

where, S = Salvage value [$], P = Purchase or Make cost of the machine [$], i = Interest rate (decimal)

$CRF = i(1+i)^L/(1+i)^L-1$ (8)

where, i = Interest rate (decimal),
L = Life years of the machine [Yr]

3. Results and discussion

3.1. Constructional view of the unit

Figure 9(a, b, c, d), the pictorial views of the unit showed a brief description of the design consideration of electricity production from a speed breaker using a rack and pinion ((All dimensions are in mm).

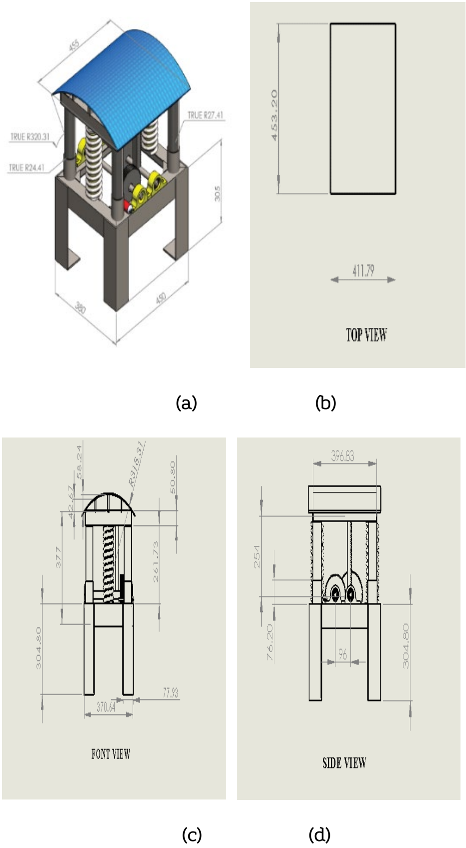

Figure 9. Constructional (a)full view (b)Top view (c) Front view (d)Side view of the unit

3.2. Fabrication cost of the unit

To complete the system design, the following materials were purchased from a local market in Dinajpur and produced to the appropriate sizes and shapes in a nearby workshop. From table 1, we can see the total cost to complete the prototype design as an electricity-producing unit is around $123.10.

Table 1. Fabrication cost of the unit

Name of the materials	Cost in $
Gear sheet	19.79
DC motor	0.64
Spring	3.28
M.S. rod Bearings plain sheet Nuts and Bolts Rack Welding	91.18
labor cost	2.74
Colors	3.65
Others	1.82
Total cost	123.10

3.3. Technical Performance

The ammeter was used to measure the amount of electricity produced by the speed breaker, with the load being provided once at a time by a motorcycle, a car, and a simple bike with a voltage of 12 volts. The current and power gained from the production unit by providing one load at a time from the speed breaker have shown in Figure 13 (a,b) represent a graphical illustration with the standard deviation of the power calculations.

A nearby highway road was chosen and counted the vehicles passing over the speed breaker, such as motorcycles, cars, and easy bikes, to determine the power or electricity gained in an hour from the production unit, and the following data value was obtained. The number of vehicles passing through the speed breaker in one hour and the subsequent power gained using equation (2) from the electricity production unit were shown in a graphical representation with the standard deviation of the power calculations in the watt-hour.

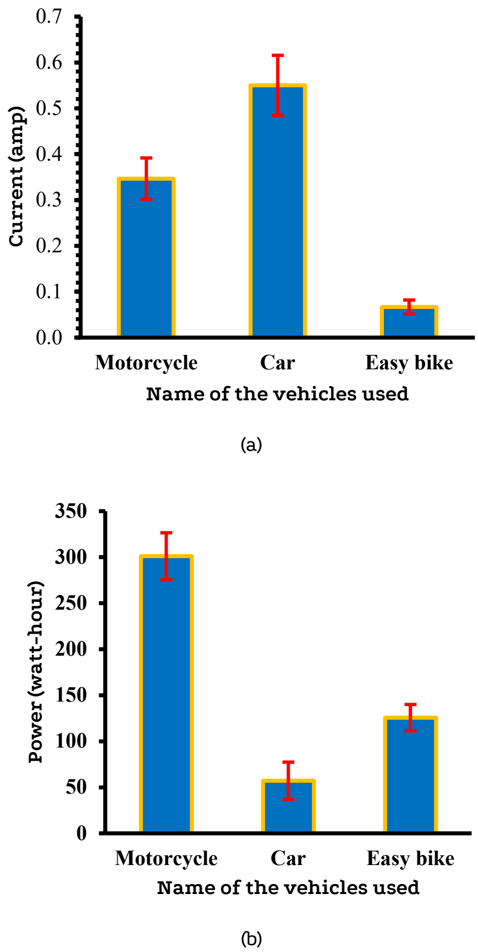

Figure 13. Obtained (a) current and (b) Power during several trial of vehicles

3.4. Cost Benefit Analysis

The overall significant output of electricity from the unit was measured at 490 watt-hours, which was calculated using three vehicles: a motorcycle, a car, and an easy bike. The proposed design unit will produce around 7350 watts if the whole running time is considered 15 hours per day. As a result, capturing the unused energy in the road speed breaker will have a massive impact on the scale of electricity production. A solar panel may provide 250 to 400 watts per day, according to a literature assessment of solar power systems, and the cost of installing a solar panel to produce 1 kW of power is around $911.83. When considering another renewable energy source, hydropower, it will cost $410.32 to $501.51 per kW of power generated. Wind power can produce per kW power for roughly $2325.16 to $2735.48 in installation costs. As a result, it is evident that the proposed design will be able to offer a lot of power at a low cost of installation. In comparison to other renewable energy sources, the cost of repair and maintenance will be cheap. The plant's expected lifetime is three years, and our planned plant will theoretically generate 2683 kW per year. Throughout the year, this amount of power can be used for lighting more than 11, 60-watt lights.

3.5. Economic performance analysis

According to the table 2, the annual fixed cost of significant electricity production from a speed breaker using rack and pinion was 0.12 $/hr. The variable cost per hour, including labor, was 0.49$. The overall running cost per hour is around 0.61$. The capital recovery factor was 0.395, and capital consumption was 44.87$. The unit produces approximately 2683 kW, which is worth 295.13$ at the current power rate of 0.11$ per kW. The unit's entire annual cost, including original costs and total operating costs, is projected to be 269.65$.

Table 2. Operating Cost of the unit

Cost Item		Amount
Fixed Cost	Depreciation	36.93 $/yr 0.10 $/hr
	Interest	6.10 $/yr 0.018 $/hr
Variable Cost	Repair and Maintenance	0.036 $/hr
	Labor Cost	0.46 $/hr
Total Cost		0.61 $/hr
Capital Recovery Factor		0.395
Capital Consumption		44.87 $
Annual Cost		269.65 $

4. Conclusion

The purpose of the research was to design and construct a new power generation system out of a speed breaker, as well as analyze the system's technical performance. The available achievable power for a motorcycle, a car and an easy bike were 4.2 watts, 6.72 watts and 0.84 watts respectively for one pass over the speed breaker. The total power output of our fabricated plant was 2683 kW. Capital consumption was 44.87$, and the capital recovery factor was 0.395. The overall yearly cost of the unit, including initial and running costs, is expected to be roughly 269.65$. The factory can be built bigger, and the bearings and plain sheets can be replaced with more durable materials, lowering the danger of failure. Traffic signals can be controlled using this technology, also different types of works such as lighting on either side of the roads, road signals, digital advertise boards on roads, highways check post, at the toll plaza this technology can be used.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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