Torque Sensor Based Electrically Assisted Hybrid Rickshaw-Van with PV Assistance and Solar Battery Charging Station

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***Abstract*— A significant percentage of population in Bangladesh is directly or indirectly dependent upon the traditional tri-wheeler rickshaw. In order to advance the lifestyle and modernize the traditional tri-wheeler, battery powered rickshaws were introduced and thus it gained enormous popularity. However, after a few months, the Bangladesh government decided to ban import and assembly of electric vehicles, as it consumed energy from the already overloaded grid. Aiming to modernize the traditional tri-wheeler and make efficient use of renewable energy, Control &Applications Research Centre (CARC), BRAC University has proposed a field tested solution with the use of PV panel, torque sensor pedal and solar battery charging station to make the whole system independent of national grid. The paper describes the design and implementation of the PV array and torque sensor into the system and findings from the field tests along with the implementation of the solar battery charging station. It was found that 73% energy is saved when both PV array and torque sensor were integrated into the system. The distance travelled by the rickshaw-van was around 2.8 times greater than normal battery operated rickshaws.**

Keywords*— *Electrically assisted; PV array; rickshaw-van; torque sensor; solar battery charging station

I. Introduction

Rickshaw , being the most popular and comparatively faster mode of transportation in Bangladesh, the modernization in this sector and electrification of rickshaws caused more energy consumption from the national grid, resulting in more load shedding and thus the government decided to ban the battery-run electric rickshaw [1]. Work on reducing this energy consumption from the national grid by installing PV array on rickshaw[2] and replacing the throttle input with a torque sensor pedal and a solar battery charging station has already been done [3] individually. To modernize the rickshaw-van, Control and Application Research Centre (CARC), BRAC university has designed motorized rickshaw-van with PV assistance and torque sensor pedal with solar battery charging station to charge the batteries [4,5] This paper represents the design and performance analysis of the rickshaw-van with PV array and torque sensor pedal installed as shown in Fig.1 to determine the percentage of energy saved. A solar battery charging station is also implemented to charge the batteries and thus making the whole system independent of national grid [4].

II. Project Overview

Initially, the tri-wheeler was a full throttle controlled electric vehicle, manufactured by Beevatech Limited. The motorized rickshaw-van is made with light weighed modern steel body and a different architecture compared to the traditional rickshaw or vans. Usually a traditional rickshaw-van as shown in Fig.1 [6] is capable of carrying 4 or 5 passengers, whereas the motorized rickshaw-van is capable of carrying 6 to 8 passengers. The modernized tri-wheeler with PV array and torque sensor pedal installed is shown in Fig. 1. The motorized rickshaw-van has a 750W, 48V brushless DC gear motor, 48V (4 X 12V, 25Ah connected in series) lead acid battery, a controller unit, a throttle, main power key, emergency motor stopper, traditional front wheel brake and an extra rear wheel break, charge controller, charge indicator, headlights and direction indicators. A 400Wp (4 X 100Wp connected in series) panel is installed on the roof of the rickshaw-van that provides a share of the required electrical load alongside the battery bank to reduce the energy consumption from the battery bank and thus increase the battery cycle duration. Another purpose of this array is to charge the batteries when the tri-wheeler is at rest, thus reducing the need to charge the batteries in the middle of the day when the grid is already supplying power at peak condition. A torque sensor pedal is introduced in the system to reduce the over-use of the battery bank. The rickshaw-puller will get assistance from the motor while paddling. A torque-

Fig. 1. Traditional rickshaw-van and rickshaw-van with PV array and torque sensor pedal installed

transducer pedal will output the corresponding voltage of torque applied upon pedal by the puller, which will be compared to a predetermined value (the minimum torque). If the applied torque is more than the predetermined value, the motor will be allowed to assist the puller. After crossing this threshold, the more the torque (voltage) is excess to the threshold, the more assistive power will be provided to the puller, proportionately. Certainly, there will be a cut-off; which means that there will also be a maximum value of torque. After that torque, the motor will either not be allowed to assist the puller, or be assisting with its maximum level preset by the designer. These will be done for the safety of the motor and also the driver [7]. The operation of the vehicle with both PV array and torque sensor is shown in Fig. 2. A solar battery charging station is implemented on the rooftop of BRAC University Campus to charge the batteries shown in fig 11. This avoids consuming power from the already overloaded grid during peak hours and allows efficient use of renewable energy. The whole project is independent of national grid.

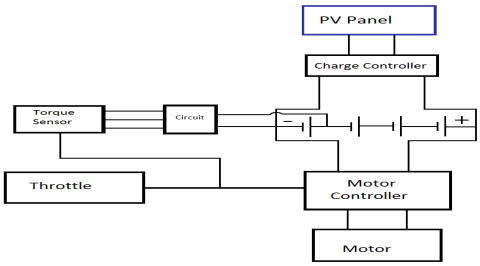

Fig. 2. Block diagram of the whole system

III. Torque Sensor Design

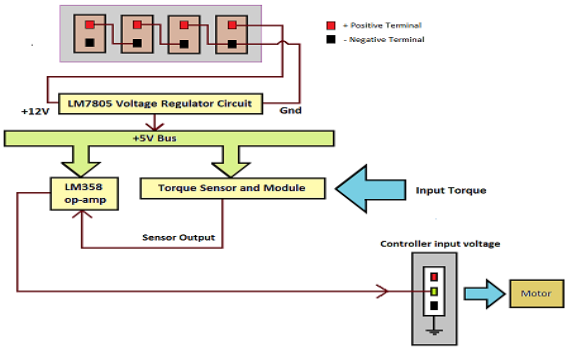

Fig. 3. Block diagram of the torque adjuster

The specification of the torque sensor is available at [8]. The torque adjuster diagram of the system is illustrated in Fig. 3. The key devices used here are LM7805 and LM358. LM7805 is a voltage regulator which gives an output of +5 V when the voltage more than 7.5 V is provided as input. The output is always fixed and it is +5 V. The amplifier's maximum output is 3.6V when a voltage of +5V is supplied. This characteristic will help the system to maintain a maximum tolerable voltage input to the CU without interrupting the whole system by motor switching or sudden-stop-runs. For instance, if gain is set to 2, an input of 1.5V will give 3V as output, but an input of 2.5V will give a fixed 3.6V instead of giving 5V as output. This advantage is utilized in the circuit diagram. While practically running the vehicle, it was seen that when puller uses torque sensor pedal, the voltage generated is much higher around 3-4 V. So to minimize this voltage, a voltage divider is used in such a way that output voltage from torque sensor pedal to the circuit is 0.6 times.

IV. Control Algorithm

The torque sensor or throttle signal controls the speed of the BLDC motor. When there is no signal from the torque sensor or throttle, the rickshaw is at stationary. The PV array is generating power but rickshaw is at stationary, the total generating power will be used to charge the battery only. Fig 4 shows the flowchart of the whole system. The conditions that may occur depending upon the power required by the motor by using throttle or torque sensor pedal are listed below.

1. The PV array cannot generate any power due to solar irradiation, in this case battery supply the load motor solely.

2. The PV array generates more power than required by the load, in such situation, excess power is used to charge the battery.

3. The PV array is generating power but not adequate enough to run the load, in this situation load power is shared by the PV array and the battery bank.

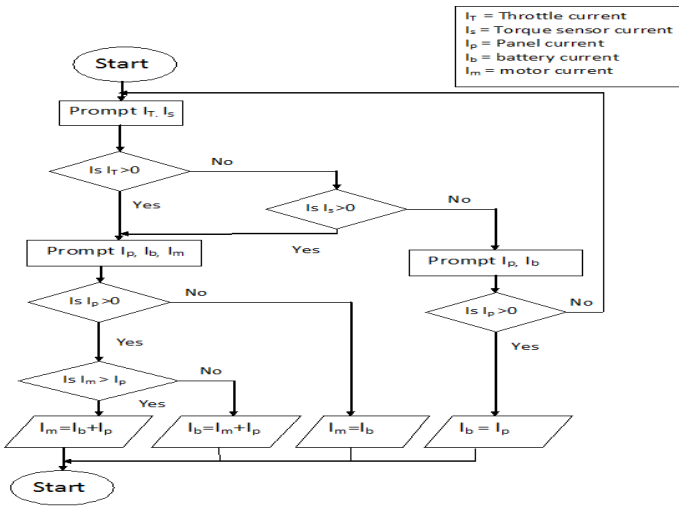

Fig. 4. Flowchart of the whole system

V. Field Test

The objective of the field test was to find out the percentage of energy saved by using both PV array and torque sensor pedal. The data was obtained during the peak sun hours from 12pm to 3pm. The test was conducted in an area which had free road for running the rickshaw-van and sufficient amount of solar irradiation to determine the impact of the PV array on the performance of the rickshaw-van. The voltage and current readings for the PV array, the battery and the load were recorded. A GPS tracking system was used to estimate the average speed of the rickshaw-van and the distance travelled. The test was carried out until the battery was

discharged down to 50% SOC and all the tests were carried out at full load condition. The field test was carried out in four steps:

- Without any PV array assistance and torque sensor pedal
- With PV array assistance only
- With torque sensor pedal and no PV array assistance
- With torque sensor pedal and PV array assistance.

VI. Analysis Of Field Test Results

A. Without PV array assistance and Torque Sensor Pedal.

Initially field test was carried out to determine the energy consumed by the battery without PV support and Torque Sensor pedal. The battery voltage and current drawn by the load from the battery were recorded. Fig 5 shows the power supplied by the battery to the load. It was seen that the rickshaw-van travelled 12.455km in 1.24 hrs with the battery discharged down to 50% SOC. At maximum torque, maximum current and power drawn by the load was 33A and 1700W respectively. The energy consumed by the load is calculated from the area under the curve of battery power vs. time graph shown in Fig 5. It can be seen that the average power supplied by the battery is 483W and the energy supplied by the battery to load is 2.184MJ.

B. With PV array assistance only

The test was carried out during the peak sun hours from 12pm to 2pm. Panel voltage, battery voltage, current drawn by the load from battery and current supplied by the panel were record. Fig 6 shows the panel, battery and load power curves. It was found that the rickshaw can travel 17.2 km in 1.69hrs with the battery discharged down to 50% SOC. From the area

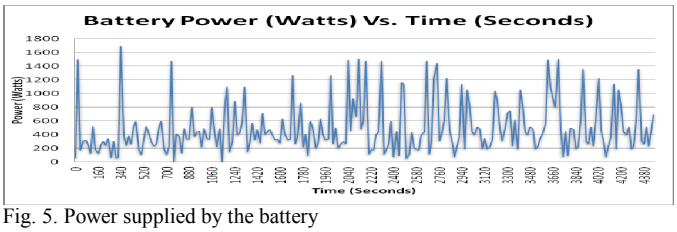

Fig. 5. Power supplied by the battery

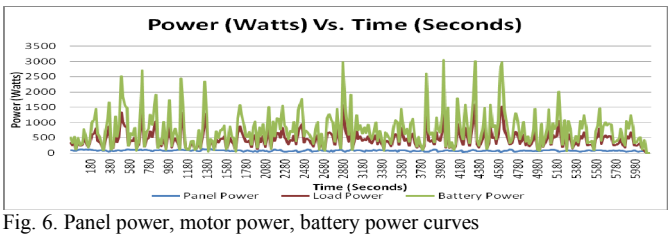

Fig. 6. Panel power, motor power, battery power curves

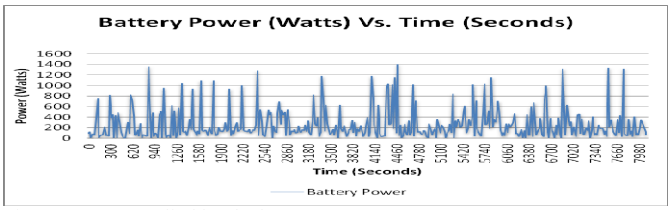

Fig. 7. Power supplied by the battery

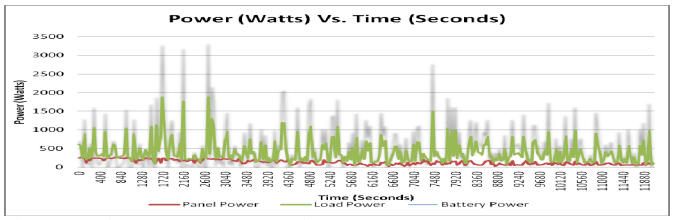

Fig. 8. Panel power, motor power, battery power curves

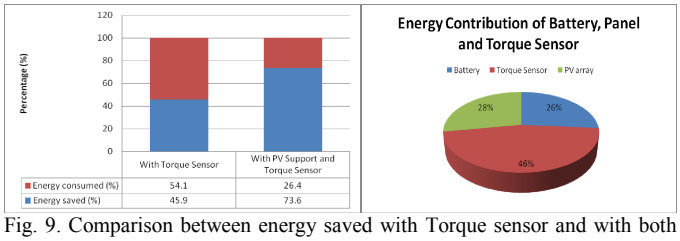

Fig. 9. Comparison between energy saved with Torque sensor and with both Torque Sensor and PV array and energy contribution

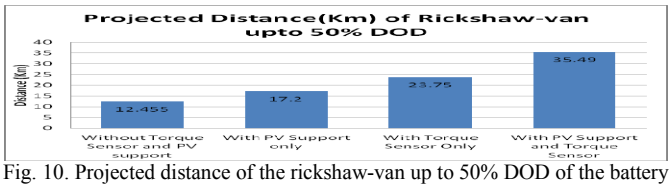

Fig. 10. Projected distance of the rickshaw-van up to 50% DOD of the battery

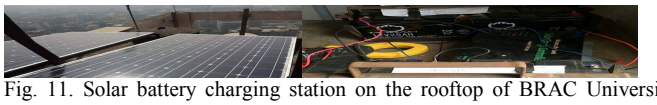
Fig. 11. Solar battery charging station on the rooftop of BRAC University Campus

under the power curves in Fig 6, it can be seen that the energy supplied by the panel is 0.49MJ at an average power supply of 80W, energy supplied by the battery is 1.94MJ at an average power supply of 310W and energy consumed by the load is 2.42MJ at an average load power of 390W.

C. With Torque Sensor Pedal and no PV array assistance

The field test was carried out by eliminating the use of throttle from the system and by using torque sensor pedal. Battery voltage and current drawn from the battery were recorded. The torque sensor input voltage to the controller unit and output voltage from the torque sensor pedal to the torque adjuster were recorded as well. Fig 7 shows the power supplied by the battery at this condition. It was found that the rickshaw-van travelled 23.75km in 2.25hr with the battery discharged down to 50% SOC. The energy consumed by the load is calculated from the area under the battery power curve in Fig 7. It is seen that the energy consumed by the load during test without torque sensor and PV support is 2.183MJ in 1.24hrs whereas the energy consumed by the rickshaw –van with torque sensor is only 1.18MJ in 1.24hrs. The system consumed 54.05% of the throttle controlled design and it saved 45.95% energy.

D. With PV array assistance and Torque Sensor Pedal.

Field test was carried out during the peak sun hours from 12pm to 4pm. Panel voltage, battery voltage, current supplied by the PV panel and current drawn by the load were recorded.

The torque sensor input voltage to the controller unit and output voltage from the torque sensor pedal to the torque adjuster were recorded. Fig 8 shows the battery, panel and load power curves. It was found that the distance travelled by the rickshaw-van was 35.49km in 3.36hrs with the battery discharged down to 50% SOC. The energy consumed by the load is calculated from the area under the load power curve. Energy supplied by the PV array is calculated from the area under the panel power curve and battery energy consumption is calculated from battery power curve. It is calculated that the PV array supplied 1.563MJ energy, battery supplied 1.963MJ energy and the load consumed 3.51MJ energy. The energy consumed by the load during the test without torque sensor and PV support is 2.183MJ in 1.24hrs whereas the energy consumed by the rickshaw –van up to that time interval is only 575.67KJ. From this we can say that with torque sensor and PV support, the system consumes 26.3% energy of the throttle controlled design and saves 73.6%.

VII. Impact of Pv Array and Torque Sensor-Comparitive Study

A. Energy Saved

From the field test data, it was determined that the rickshaw-van can travel 23.03km extra with the both PV support and torque sensor pedal. With torque sensor and PV support, the system consumes 26.3% energy of the throttle controlled design and saves 73.6% energy. With torque sensor individually, 45.9% energy is saved. Thus, we can say that the PV panel provides 27.7% energy. Fig 9 shows the energy contribution of battery, panel and torque sensor.

B. Projection of distance coverage for the rickshaw van

For the batteries used in the rickshaw-van, 50% DOD has been considered for the longevity of the battery-bank. Fully discharging the batteries causes the battery life to decrease and thus adding up extra cost for replacing batteries. It was found that the rickshaw-can travel 12.455km without PV support and torque sensor pedal, 16.18km with PV support only, 23.75km with torque sensor pedal only and 35.49km with both PV support and torque sensor pedal. The projected distance coverage at each field tests are represented in Fig 10.

VIII. Future Work

The basic goal of the whole project was to transform the existing traditional rickshaw-van to the motorized modern tri-wheeler and analyze its performance. There are also scopes of future research to develop more power assisted tri-wheeler in the form of ambulance and cargo hauler. To make it commercially feasible it is important to add extra features. The system is sometimes unstable on uneven road surfaces. To avoid this, suspension can be added. Special features such as special compartment for keeping spare wheels, toolbox, windshield for driver's safety, lock system, casing for charge controllers can be added to make it much more user friendly. An automatic reverse gear system should be added in future. Easy battery swapping techniques should be found for the ease of the driver for swapping batteries from solar battery charging station to the van and vice versa.

IX. Conclusion

A large number of people will be benefited with the commercialization of such vehicle nationwide. This will improve the lifestyle and income of the rickshaw pullers. The slow speed non-motorized traditional rickshaw-van which is often blamed to be the reason for physical exhaustion and stress on the rickshaw-van pullers can be replaced by this modernized tri-wheeler [9]. The cost of the overall system is comparatively higher but faster payback overcomes this problem. Through the implementation of these technologies, lifestyles of the millions of people those who are directly or indirectly dependent upon rickshaws or rickshaw-vans can be improved tremendously. The designed tri-wheeler with PV support, torque sensor pedal causes zero pollution to the environment and thus it is a green project. It does not consume power from national grid for charging batteries. Instead, it uses renewable energy that is inexhaustible and thus the whole system is a complete off grid solution that can be sustainable.

Acknowledment

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