Power Conversion for Environment Friendly Electrically Assisted Rickshaw Using Photovoltaic Technology in Bangladesh

[1] S.J. Chowdhury, [2]R. Rahman and [3]A. Azad
[1, 2, 3]Control & Applications Research Centre, Department of EEE, BRAC University
Dhaka, Bangladesh
[1]sherijahan91@gmail.com, [2]rafiur@bracu.ac.bd and [3]a.azad@bracu.ac.bd

***Abstract*-Addressing the problem of high energy consumption from national grid of electrically assisted rickshaw the Control and Applications Research Centre (CARC), BRAC University has proposed a field tested green solution: provide a share of the required energy of these rickshaws using solar energy. A 360Wp PV array was installed on a rickshaw and the performance was evaluated to determine its impact on the rickshaw and the energy saved from the national grid. The paper presents the findings from the field tests. It is seen that 50% of the required load energy can be provided by the PV array, consequently saving that energy from the national grid. It is further seen that for the same amount of energy consumed from the battery, the distance coverage of these rickshaws can nearly be doubled.**

I. INTRODUCTION

As reported by The Daily Star [1], over 50,000 electrically assisted rickshaws are running in Dhaka city currently. The number of reported electrically assisted rickshaws in towns nearby Dhaka city is 15,458 [2]. It has been further reported that in a town where these electrically assisted rickshaws are available, 88.02% of the town's population prefer the use of these rickshaws over the manually pulled rickshaws, out of which 86.09% users use them as their primary mode of transport [2]. Furthermore, due to these rickshaws higher transport speed and thus greater distance coverage, per day income of the pullers of these electric rickshaws are much higher than the pullers of manual rickshaws. Due to the electrical assistance, stress induced on the health of the pullers is reduced. The electrification of the rickshaws means that there is zero pollution emission from these vehicles, unlike any combustion engine. The popularity of these rickshaws has outgrown Bangladesh's ability to supply power for utility let alone for charging these battery banks. Each of these rickshaws requires charging its battery bank twice a day which accumulates to over 1.92KWh of energy. It has been reported that in the year 2013 Bangladesh had a deficit in generation of electricity of 1,915MW in spite of a massive 8,537MW of generation capacity [4]. The total maximum generated power and energy during this period was 6,434MW and 38,229GWh respectively [4]. In the current design of these rickshaws, the power supply to the load is controlled by a throttle system like motorcycles which has led to complete elimination of the human effort and higher energy consumption from the battery bank and consequently from the national grid as the battery energy is depleted more frequently. Work on reducing this energy consumption from the national grid by replacing the throttle input with a torque sensor paddle and a solar battery charging station has already been done [3][5]. Similar work on providing solar energy support to a tri-wheeler vehicle in India has been carried out in [6,7,8] along with its economical, commercial and social aspects. This paper represents the acquired data and its analysis of a 360Wp PV array supported rickshaw from field tests to determine the impact of the PV array on the rickshaw system and the energy consumption from the national grid.

II. PV ARRAY AND DESIGN

A PV array system of 360Wp was chosen for providing the support to the rickshaw. Our rickshaw is suitable to carry the puller and two passengers with some baggage as load. The electric rickshaw also has a steel structure. For this weight 500W motor is appropriate. To provide this power to the 48V battery already installed in this rickshaw, we have chosen two 180W solar panel as this gives maximum suitable accommodation to the rickshaw rooftop. Since our main target is to go commercial, we have tried to improvise with the rickshaw model already in the market. Our experiment has been done on an existing model of electrically assisted rickshaw that use 48V battery bank and 3 phase brushless motor. Four 12V, 20Ah rechargeable batteries are used in series to provide 48 Volts to the BLDC motor [3]. Here the rotor has permanent magnets and stator has electronically controlled rotating field that use sensors (back EMF) to detect rotor position. It is more efficient and powerful than commuted motors. The complicated electronics for the brushless motor is integrated all in a black box by the manufacturer. The identification controller cables is shown in the Fig 1.

The specifications of the PV modules are available at [9]. The array has been installed at 0° tilt angle on top of the rickshaw for optimal harnessing of solar irradiation and power supply. The global horizontal irradiation incident on Dhaka city is presented in the SWERA report Bangladesh [10]. Table I shows the available peak solar hour (PSH) in Bangladesh for different months. The rickshaw and the data acquisition method are shown in Fig. 2. The schematic with the connections are shown in Fig. 3. The rickshaw with the implemented test setup is shown in Fig. 4. We are using

PWM charge controller as it can operate the motor using the power supplied by both the solar panel and the battery. This type of charge controller forces the solar panels to operate at the same voltage as battery bank while charging. With MPPT controller the power is higher but it is also very costly and suitable for higher power systems. [11]

III. THE ALGORITHM OF THE OPERATION

There are four conditions of operation:

1. The array generating more power than the required load and the excess generated power is used to charge the battery bank.
2. The array generating less power than the required load and the excess required power is supplied by the battery bank.
3. The array generating insignificant or no power compared to the load due to heavily clouded weather and the whole load is supplied by the battery bank
4. The array generating power but no load power is required (e.g. when the rickshaw is still), so all the generated power is used to charge the battery bank.

The algorithm of the operation of the whole system in different operating conditions is shown in Fig. 5.

IV. THE FIELD TEST

A location with unobstructed solar insolation and minimum intrusion of any kind (e.g. traffic, road with too many potholes etc.) was selected as the test site. Major focus was put on the solar insolation that is available in a significant amount for at least 5-6 hours each day as a site selection criterion.

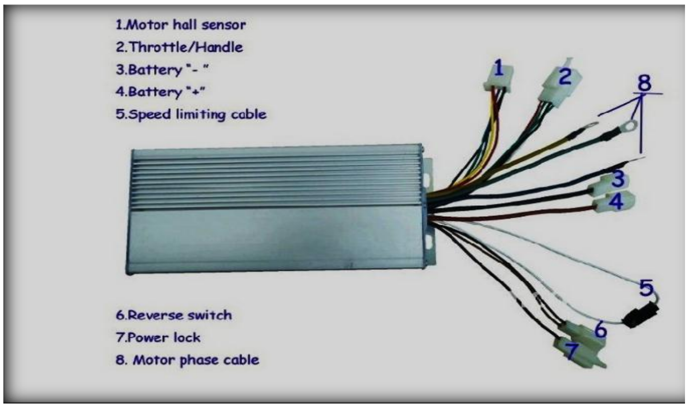

Fig. 1. Identification of controller cables

TABLE I
Average monthly peak solar hour in Dhaka city, Bangladesh

Month	PSH	Month	PSH	Month	PSH
Jan	3.16	May	5.46	Sep	3.74
Feb	4.46	Jun	4.22	Oct	3.53
Mar	4.88	Jul	4.42	Nov	3.92

Fig 2: The steel structured electrically assisted rickshaw available in market and data acquisition method

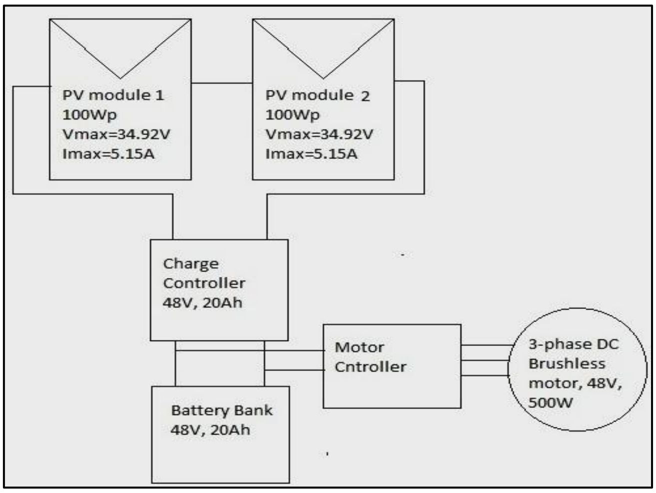

Fig. 3. Schematic diagram of the system

Fig. 4. The rickshaw with the PV array installed

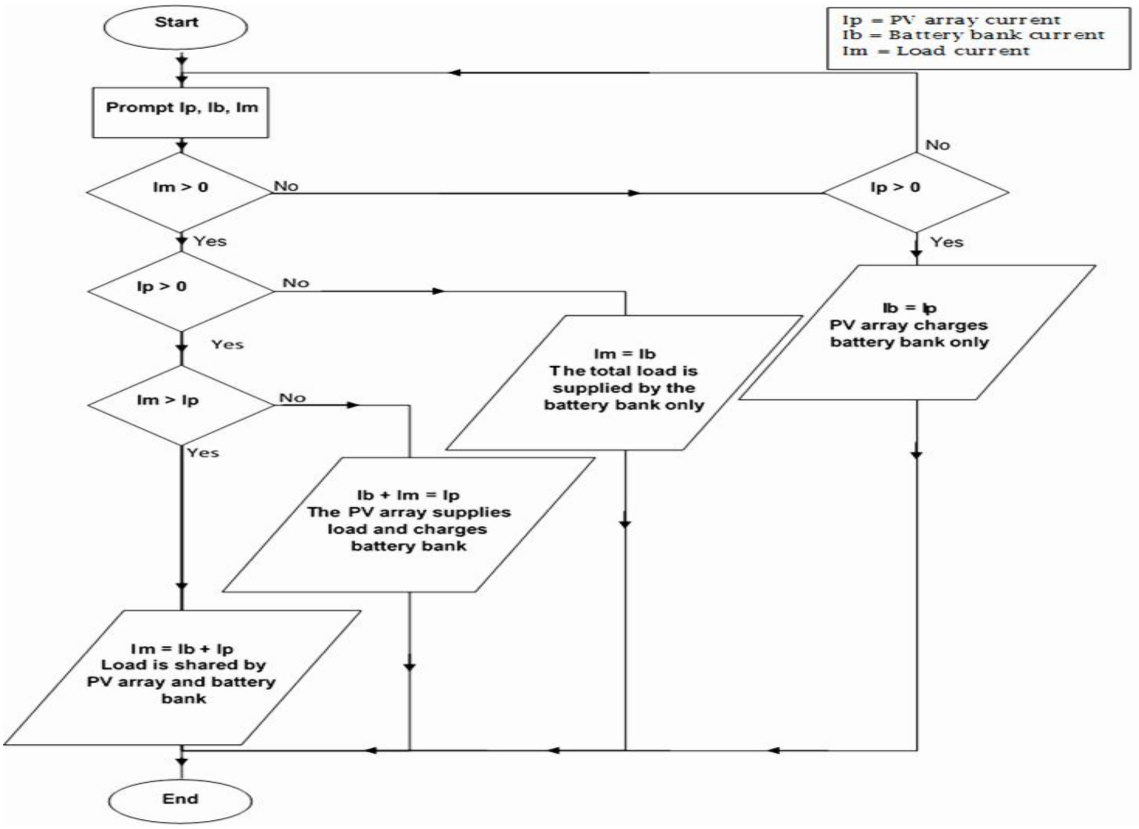

Fig. 5: The algorithm of the operation

The test was conducted from 10am to 4pm as the irradiation beyond this time can be fairly negligible. The rickshaw was run at the site with a passenger riding the rickshaw.

The field test was carried out in two steps:

1. With PV array support – to determine performance enhancement due to PV array support, i.e. due to load sharing between the array and the battery.
2. Without any PV array support – to determine the typical system behavior of the rickshaw, i.e. the battery supply profile.

V. Analysis Of The Field Tests

A. With PV array support

The following parameters were measured during the field test: (1) array voltage and current (2) battery voltage and current, and (3) the distance travelled by the rickshaw using GPS. The array setup can be seen from Fig. 2 as mentioned before. The collected data for the field test with PV array support are presented in the Fig. 6-8. During this test the rickshaw covered a distance of total 22.3km. The array supply, battery supply and the load profile were determined from the data shown in Fig. 6, 7 and 8 respectively. It can be seen from these figures that the average panel supply current is approximately 2.25A and the average battery supply current is 2.7A. The average motor current is 5A which is shared by the panel and the battery nearly equally. The results were used to determine the share of load power and energy between the PV array and the battery. The supply and load energy has been calculated from the area under the curve in Fig. 9, as 849.58kJ at an average power draw of 137.26W from battery bank and 718.87kJ at an average power supply of 116.14W from the PV array totalling 1568.45kJ at a load power of 253.40W for the load motor.

B. Without PV array support

The following parameters were measured during the field test: (1) battery voltage and current (2) the distance travelled by the rickshaw using GPS. The collected data for the field test without PV array support are presented in the Fig. 10. As the load motor is connected directly across the battery, the battery voltage and current also represents the voltage and current for the load motor. The average load current in this case is approximately 5A (similar in both cases, i.e. with and without PV support). During this field test the rickshaw covered at distance of total 18.8km. The instantaneous load power, shown in Fig. 11, has been calculated from the data shown in Fig 10. The energy consumed by the rickshaw or the energy supplied by the battery 1.115MJ, has been calculated from the area under the graph in Fig. 11.

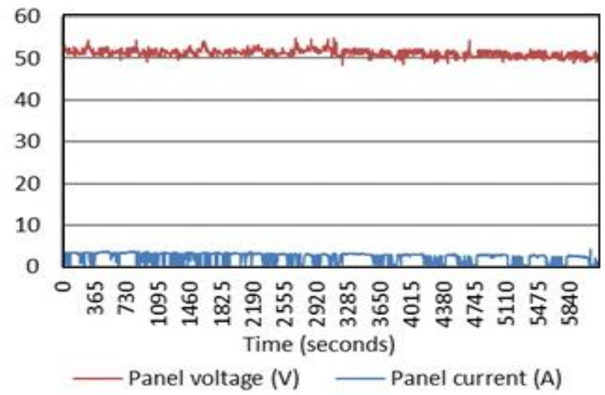

Fig. 6. The PV array supply profile

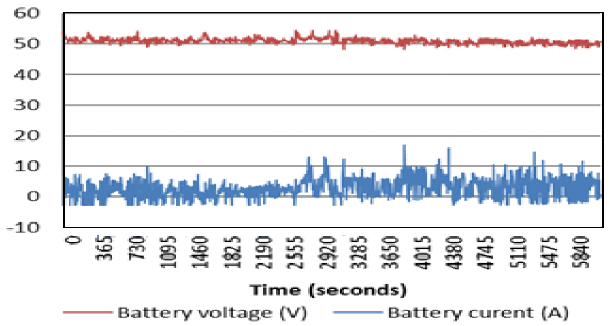

Fig. 7. The battery supply profile with PV support

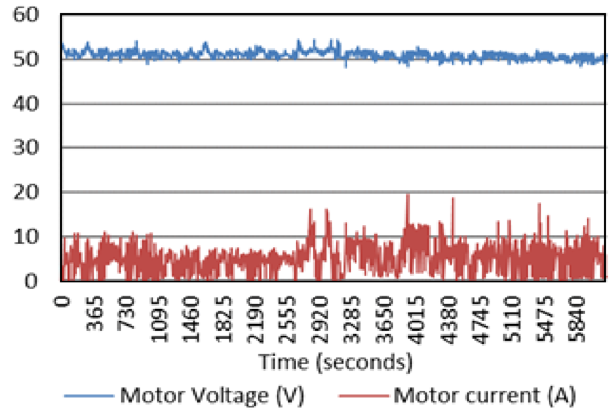

Fig. 8. The load profile of the rickshaw with PV array support

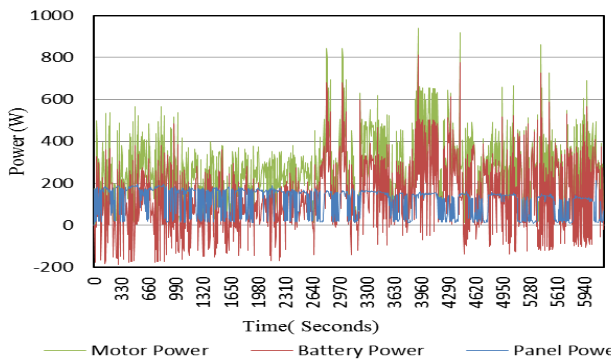

Fig. 9. The sharing of the motor load power between the PV array and the battery during the field test

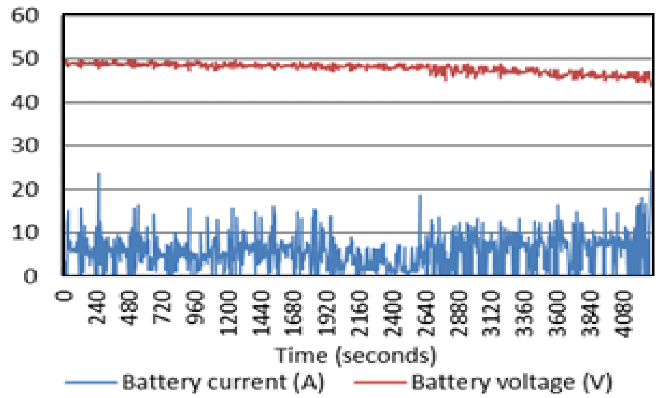

Fig. 10. The battery supply (also the motor load) profile without PV support

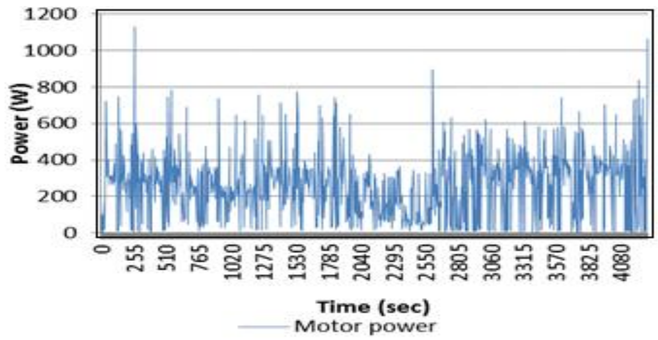

Fig. 11. The load profile of the motor of the rickshaw during field test without PV array support

VI. The Impact Of Pv Array On The Rickshaw And The National Grid – The Comparative Study

A. *Sharing of the load power between the array and the battery bank*

The rickshaw travelled 3.5km extra with the PV array support. For comparison of the performance of the rickshaw data for 18.8km has been taken from Fig. 11 and the power and energy consumption calculated. It is seen that the rickshaw consumes 1.094MJ of energy, where the PV array supplied 548.00kJ, 50.07%, and the battery bank supplied 546.49kJ, 49.93% as shown in Fig. 12.

B. *Energy saved from the national grid*

The battery bank of the rickshaw holds 3.456MJ of energy

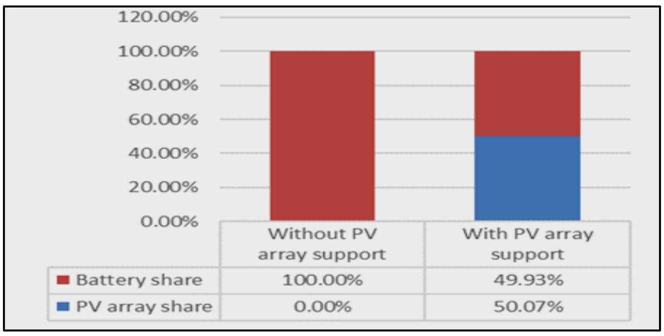

Fig. 12. Comparison between sharing of load energy between the PV array and the battery bank

when fully charged. The energy consumption of the rickshaw during the two tests is used to determine the state of charge (SOC) of the batteries at the end of the two tests. The result is shown in Fig. 13. It is seen that only 15.86% of the available battery energy was used with the PV array support while 32.28% of the energy was consumed without any PV support for running 18.8km by the rickshaw. The energy saved from the battery, that is the energy supplied by the PV array, is the energy that is saved from the national grid. Fig. 14 shows the comparison between the energy consumption from the battery for the two systems. It is seen that 49.12%, 567.64kJ, less energy is consumed from the battery and consequently from the national grid with the PV array sharing the load power each day. Due to this lesser energy consumption or lesser depth of discharge (DOD) attained per day, the battery life is expected to be higher than the current practice. The maximum DOD attained is expected to be 50%; in contrast to 100% in the current practice, thus it is expected that battery can last about twice as long of its current life.

C. *Projection of distance coverage for the rickshaw*

A projection of the distance that the rickshaw can cover up to 50% discharge of the battery is done considering linear relationship between the distance covered by the rickshaw and the energy consumed from the battery. Currently, these batteries are regularly fully discharged by the rickshaw pullers, which damage the battery and significantly reduce battery life. For longevity of the battery bank, a 50% DOD has been considered. It is seen that the rickshaw can run 59.28km with PV array support while 29.12km without PV support as shown in Fig. 15.

D. *Cost comparison*

Currently these rickshaws are bought for a price around BDT 52,000 (USD 670, USD 1 = 77.60BDT) and then the factory default 20Ah battery, which costs BDT 16,000 (USD 206), is replaced with a higher capacity battery bank e.g. 40Ah, 60Ah, 80Ah for increased distance coverage. These higher capacity batteries can run the rickshaws for approximately 10 hours or more each day upon 80% discharge and the lowest of them can cost over BDT 30,000 minimum (USD 386) and have to be replaced almost once every year. The rickshaw cost becomes BDT 82,000/- (USD 1,056) with a recurring cost of BDT 30,000 each year. If considered for the guaranteed period of the PV modules (20 years) the replacement cost is less by a minimum of BDT 266,000 (USD 3,428), BDT 14,000 (USD 180) per year. The PV array support enables these rickshaws to cover this high distance while using the factory default battery bank. Adding the PV support on these rickshaws added about BDT 25,400 (USD 327) which sums up to BDT 77,400 (USD 997). BDT 4,600 (USD 59) is saved when the rickshaw is purchased, but more importantly BDT 14,000 (USD 180) is saved each year for replacing the battery. Conclusively, it can be saved that a PV supported rickshaw can be more feasible and affordable than rickshaws in their current practice.

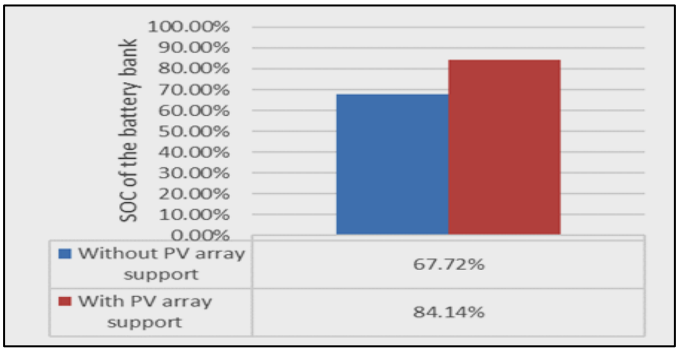

Fig. 13. SOC of the battery bank

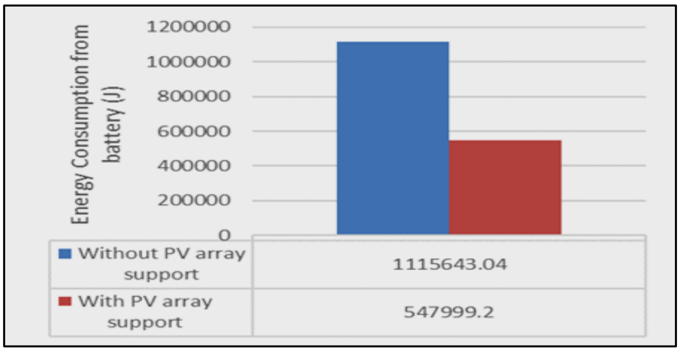

Fig. 14. Comparison between the energy consumption from the battery bank with and without PV array support

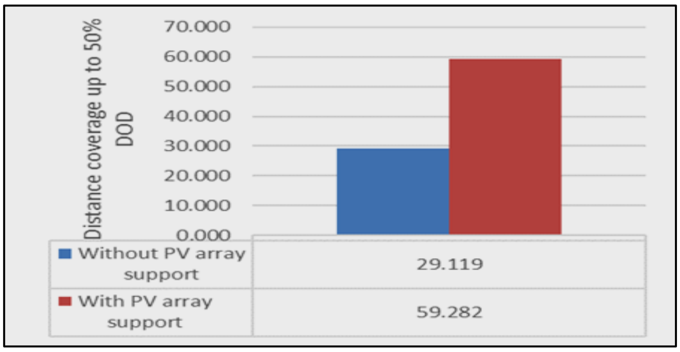

Fig. 15. Projected distance for the rickshaw up to 50% DOD of the battery

VII. Future Works

Further research is being planned, with the support of the IEEE SIGHT USA, to determine the impact of the integration of a smart charge controller, the torque sensor paddle system, the solar battery charging station and the PV array support system on the performance of the rickshaw and the energy consumption from the national grid throughout the whole year. Our analysis has led to the development of this rickshaw model into rickshaw vans using PV array, torque sensor and charge station the concept of which is shown in the Fig. 16 and 17. This model is also tested in terms of energy saving and cost effectiveness. We have PV panels with a warranty of twenty five years to minimize the drawbacks of using battery and the solar system. Study reveals that the individual implementation of the torque sensor paddle and the PV array support save over 50% energy consumption from the national grid, increase battery life time due to lesser battery discharge each day and result in higher distance coverage. The solar battery charging station can then be used to charge the batteries fully thus converting the electrically assisted rickshaws completely independent of the national grid. PV array we have used is a customized one from Electro Solar company. We are also planning to commercialize by IDCOL who has a scheme of battery recycling through Solar Home System. Our future work now revolves in developing successful prototypes of human hauler, cargo hauler and ambulance in the rural areas of the country where only vans are used as ambulance.

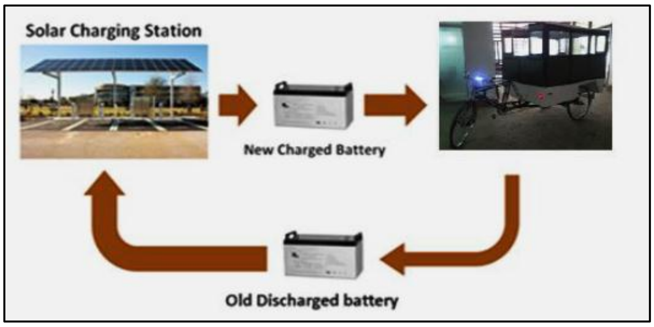

Fig. 16: Concept for the solar battery charging station (alternative to fast charging problem)

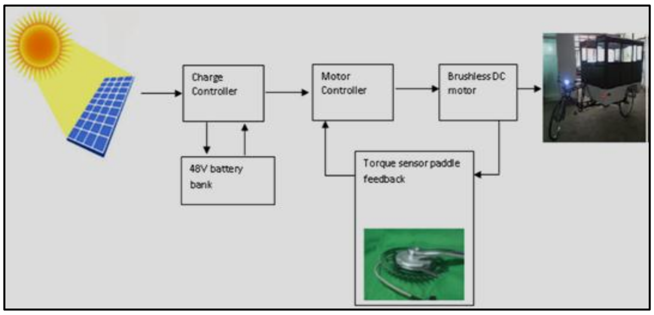

Fig. 17: Concept for the PV and torque sensor assisted rickshaw van

VIII. CONCLUSION

The 360Wp PV array has a significant impact on the performance of the electrically assisted rickshaw and the energy consumed from the national grid. The process involves a very environment friendly method as carbon-dioxide and other harmful chemical emission is eliminated due to the use of electricity. Use of long life PV panels is also advantageous. The array can share half the load power and energy required by the rickshaw which cuts down energy consumption of these rickshaws from the national grid by half. Based on the report from The Daily Star [1], it can be assumed that the overall energy saving from the national grid can be approximately 28.38GJ. The battery consumption for the distance covered is significantly lower for the rickshaw with PV array support. It is also seen that, with PV array support, the rickshaw can run almost twice the distance of without PV support for the same amount of energy consumed from the battery. Availing solar energy on these rickshaws can ultimately lead to their complete independence from the national grid, which can facilitate their commercialization in rural areas where faster transport can bring about a boost in the economy of the locality, higher income for the pullers themselves and reduced stress on health. Furthermore, availing these rickshaws in those areas means availing employment and thus a step towards poverty elimination. Availing solar energy in rural parts of Bangladesh means expansion of the already rapidly growing market of solar energy. Both government and NGOs like BRAC can step forward and lend their hand through providing subsidies and incentives and help develop this technology even further.

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