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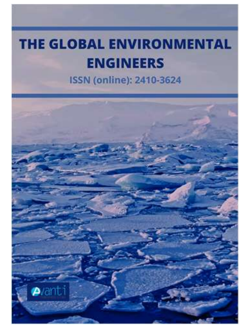

Energy and Environmental Benefit of Solar Charging System for Charging Auto-Rickshaw in Developing Countries

Md. Uddin*, A.Z.M. Rahman and Sumon Mondol

Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh

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ABSTRACT

The energy crisis and environmental impact are the major concern mf the present world. Three-wheeler auto-rickshaw becoming an important passenger transport vehicle in a developing country which are indirectly powered by the grid electricity through the batteries. Such vehicle consumes significant grid energy during charging which increases the load in the national grid and put extra stress on the electrification in line with the environmental impact. This paper investigated the existing facilities for charging auto-rickshaw in Bangladesh and designed a proposed solar charging model as a replacement based on the existing model. Then the energy and environmental benefit were estimated to reflect the significance of the proposed model and contribution in the context of the global energy crisis and environmental impact. The investigation found that the daily energy consumption is 290 kWh for a charging station capacity of 30 auto-rickshaws which is significant. The proposed solar model is designed to meet this demand offset. The environmental analysis showed that the proposed model can offset CO_2, CH_4, and NOx emissions by 54 tCO_2eq, 40 $kgCO_2eq$, and 60 $kgCO_2eq$ per year respectively of which the contribution of CO_2 is significant. Further research could be focused on the economic and financial analysis in-depth to promote the proposed model.

*Corresponding Author
Email: shazib0397@gmail.com
Tel: +61470 251 883

1. Introduction

Three-wheeler auto-rickshaws became very popular in developing countries in short-distance travel. They are low transportation cost, comfortable, and do not create any environmental pollution directly as the other types of conventional vehicles which consume fossil fuels. In the last few years, the amount of three-wheeler auto-rickshaws has increased rapidly, around 60% in Bangladesh and neighboring countries [1]. Those auto-rickshaws need electrical energy to drive. The lead-acid batteries are usually placed in these auto-rickshaws and are usually charged by grid electricity. Such grid electricity is produced by burning mostly fossil sources and emitting serious pollutants into the environment. So in the broad sense of view although these vehicles do not affect the environment directly they cause environmental pollution indirectly. The daily electricity consumption by the auto-rickshaw is significant which reflects such vehicles are a consumer of significant electricity of the generation [2].

The developing countries achieved a significant level of technological advancement over the last 15 years [3]. The technological advancement in low and middle-income nations has increased rapidly compared to the high-income countries. The adaption of technology by developing countries reflected the insightful effect on the country's economies through reducing the production cost, establishing the standards of quality, and establishing communication between individuals from a distance. The countries are moving towards renewables as part of the industrialization process. Because the renewables are clean, enhance energy security and respond to the essential of economic [4].

Solar photovoltaic is a renewable energy technology getting high priority in developing countries due to their favorable location for solar utilization. The photovoltaic panel can be utilized for charging the auto-rickshaw batteries which could be one of the ways to mitigate the use of countries' grid electricity is the focus of this paper. In this regard, a solar charging station utilizing the solar photovoltaic panel is proposed.

There are limited numbers of research papers based on three-wheeler auto-rickshaw found online. Mankar and Ghute, 2015 [5] investigated a simulation study on the charging and discharging performance of a battery using a PV panel and electric motor to drive the electric vehicle. They found that the battery is successfully charged and to drive the vehicle. The electric vehicle is more cost-effective than a conventional fuel vehicle. Ahmed et al., 2015 [6] constructed and investigated the performance of PV-operated cycle rickshaws. They found that the maximum speed of the rickshaw found to 15-25 km/h with a load of 250 kg. Full charging time is 3.5-4 hours and the miles run by full charge is 35-45 km. Rian and Rahman, 2014 [7] investigated the feasibility study of battery-operated auto-rickshaw and the effect on the socio and environmental aspects. They found that the energy consumption by auto-rickshaw is 8-11 kWh per day. Operating cost is lower than that of fuel-operated conventional auto rickshaw. The operating cost and CO_2 emission for battery-operated auto-rickshaw are lower than the fuel-operated auto rickshaw. Rana et al., 2013 [8] investigated the effect of charging on local towns and its contribution to reduce transport emissions. Around 5.9% of the daily electricity demand of the town is consumed for auto rickshaw battery charging where the recharge demand is 17%. A total of 11,208 battery-operated auto-rickshaws consume 82.90 MWh of electricity per day to be recharged. Significant direct emissions could be reduced by these vehicles. Shaha and Uddin, 2013 [9] studied the feasibility of hybrid charging of battery-operated auto-rickshaw using battery charger, rooftop installed a solar panel and regenerative technique. Advanced vehicle simulator software is used for the analysis. Energy consumption can be saved by 20% using a regenerative way for low-speed conditions. The vehicle mileage increased by 1.5 hours and driving range of 35 to 40 km using the solar panel. A hybrid energy storage system increases vehicle performance and efficiency. Rahim et al., 2013 [10] investigated the positive socio-economic impact, drawbacks, energy consumption, comparison with fuel-operated vehicles, trends of the maintenance cost, charging time, and vehicle performance with the age. They found that per km running cost is lower with passenger comfort. The high initial investment, maintenance cost, replacement cost are the barrier to promoting such vehicles. The charging time is increased and performance is decreased with lifetime. Nunes et al., 2016 [11] reviewed a comprehensive overview and framework of the solar parking lot, review of the state of the art, challenges, and opportunities to develop and implement the concept is studied. Solar electricity generated parking space is enough to the electric car by 75-100% depending on the availability of solar radiation. Smart chargers using optimization can adjust to deliver the energy to cars and the grid. Financial, economic, and revenue analysis is required to implement such a system.

The studies reported above are reflected for the moving solar panel installed on the rooftop of the auto-rickshaw. The availability of continuous sunlight is the barrier of such a system studied which could be overcome by installing a stationary renewable charging station. In addition, environmental pollution analysis for such a system seems missing in the previous studies. This paper fulfilled those research gaps. This study aims to design a proposed solar charging station for the auto-rickshaws and investigate the potential energy and environmental benefit.

2. Existing Charging Facility

This section presented the status of the existing charging system (base case). Based on the existing analysis the proposed charging facility is presented in the following section. In the existing system, the grid electricity is connected to the charging station and the auto-rickshaw recharges from the station. The typical schematic of the existing charging system is shown in Figure **1**. The details of the existing charging station have been collected inside one of the divisional cities of Bangladesh. The data are collected through measures and questionnaires wherever applicable for the same capacity station. The details of the charging station are given in Table **1**.

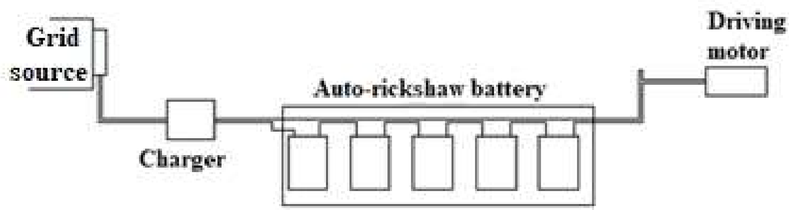

Figure 1: Existing charging system layout.

The lead-acid type 12V, 140-160 amp battery is usually installed in the autorickshaw. The time required to fully charge is 8-10 hours, the distance traveled per full charge is 150 km and the energy consumed per full charge is 10 kWh measured from the charging station. The charger input is 220V, 4.95 A and the output is 60V, 14 A measured from the station.

Table 1: Details of the existing charging station.

No of Station	Name of Charging Station	No. of Autorickshaw Capacity at a Time	Time Required to Full Charge Per Autorickshaw (hr)		Avg. Time to Full Charge (hr)	Cost Per full Charge (BDT)	Monthly Electricity Bill Paid by the Station (BDT)
			At New Condition	At Old Condition			
1	NM	30	8-9	10	9	160	85000-90000
2	MM	30	8-8.5	10		160	
3	SM	30	8	10		160	
4	TM	28-30	8-9	10		160	
5	KL	30	8	10		160	

Source: Measured and field survey.

The voltage and current are measured during the charging to quantify the energy consumption by the battery for both new conditions and old conditions. The currents are measured at the inlet and the exit of the charger to find out the actual energy consumption by the battery. The details of the measured data are given in Table **2**.

3. Prospective Charging Facility

The proposed charging facility emphasized the replacement of conventional grid power by solar power in the charging station for the number of autorickshaws accommodated is 30. To design a solar-powered charging station the components required are a solar panel, controller, inverter, battery, wiring, and support frame. The layout of the proposed charging system is shown in Figure **2**.

Table 2: The current and voltage details for the battery.

Battery Condition	Obs. No.	Wall to Charger Inlet Current (A)	Average (A)	Charger Exit to Battery Current (A)	Average (A)
New	01	5.1	5.79 (220 V)	15	16.68 (60 V)
	02	6.5		18	
	03	6		18.4	
	04	6.5		18.4	
	05	5.2		15.6	
	06	6.2		17.3	
	07	7.2		18.7	
	08	5		15.1	
	09	6.5		17.5	
	10	6.5		17.6	
	11	4.8		15.6	
	12	5.5		17.5	
	13	5.5		15.5	
	14	4.5		13.3	
Old	01	2.5	3 (220 V)	7	8 (60 V)
	02	3.2		8.6	
	03	1.7		5.7	
	04	2.1		6.2	
	05	4.3		10.5	
	06	4.2		10	

Source: Measured in the station.

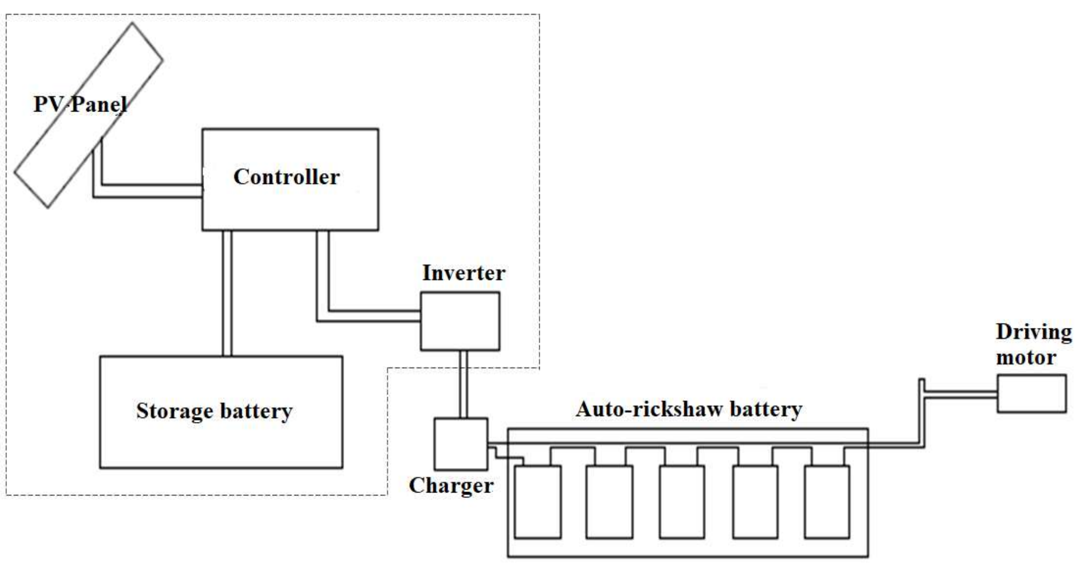

Figure 2: Proposed charging system design layout.

In this layout, the existing grid power source is replaced by four main components. The solar PV panel generates electricity using solar radiation which is rooftop installation. The controller monitors the battery condition and charging update and regulates the input to avoid overcharging. The storage battery is a backup source that stored the solar energy in the daytime and delivers it at night-time or the day having low solar radiation. The inverter converts the direct current (DC) from the battery to alternating current (AC) suitable for the load.

The design calculation showed that the area required by the panel for such a capacity station is more than the area required for parking 30 auto-rickshaws and charging setup. The rest of the space is proposed for the retail shops. The floor layout is shown in Figure **3**.

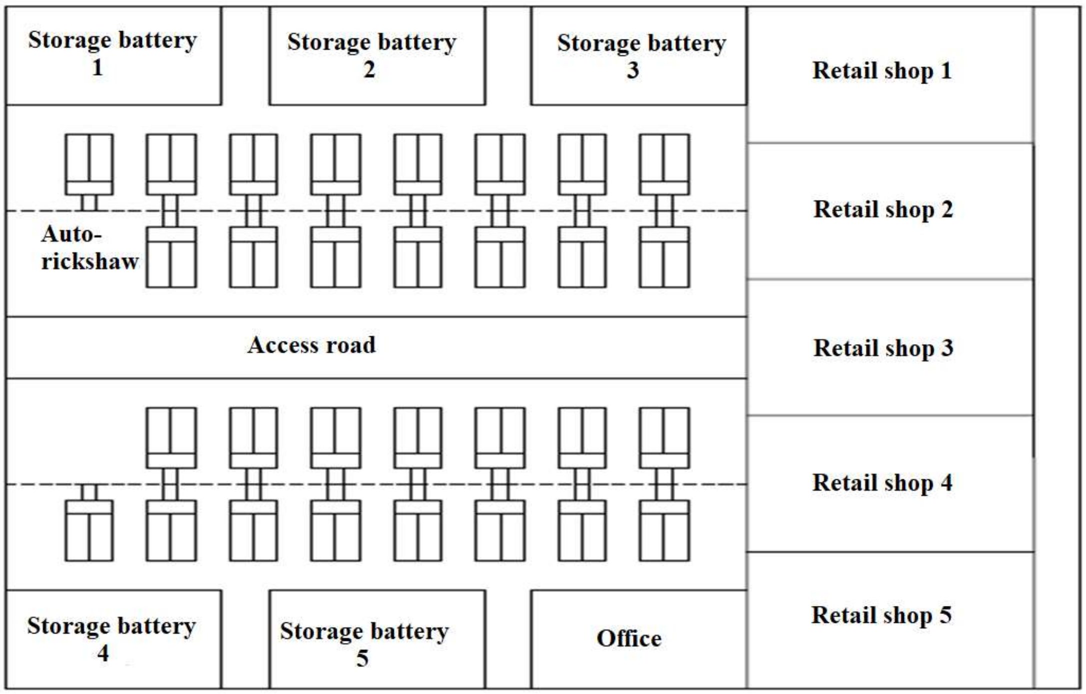

Figure 3: The floor layout of the solar charging station.

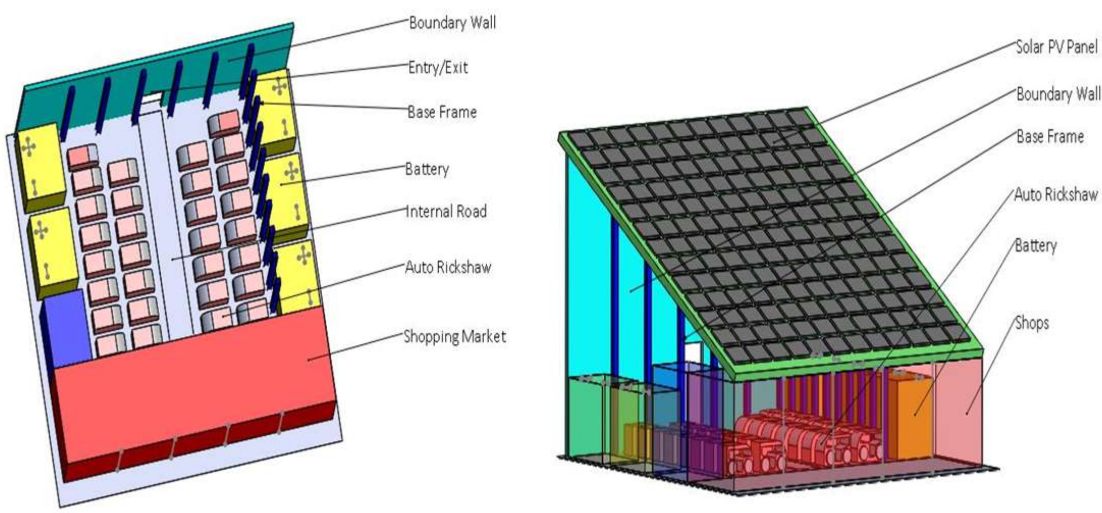

Figure 4: The 3D view of the charging station.

4. Design Calculations

This section describes the calculation behind the design of a solar charging station for charging auto-rickshaw.

Daily Energy Required for Charging

The daily energy required for the charging can be computed as follows.

The voltage at the charger exit V = 60 V

Current at the charger exit I = 16.68 A

The battery input energy for 30 auto rickshaws per day= VI×No of hours to full charge/day×no. of autorickshaw/day

=60×16.68×8×30 (Wh)

=240.19 kWh/day

The system loss measured in the charger is 21%

The daily energy required including system loss=290 kWh/day required to deliver by the solar panel to meet the charging demand for the station.

PV Panel Required

Assuming the panel generation factor for Bangladesh is 4.5 sunshine hour

The total watt peak (Wp) of the panel required=290 kWh/4.5 hr=64.44 kW

The PV panel available in the local market medium size rating is 250 W_p.

The number of PV panels =64.44*1000/250=258 each of 250 W_p rating.

Land Required for PV Installation

The land required for parking 30 auto-rickshaws is 1,100 m^2.

The field survey shows that one 250 W_p PV panel dimension=1.956 m×0.992 m=1.94 m^2.

The land required to install the PV panel=258×1.94=500 m^2=22.35 m×22.35 m which is around 50% of the parking land consumption.

Storage Required

The daily energy required= 290 kWh/day

Nominal battery voltage = 12 V

Days of autonomy = 1 days

The battery capacity can be computed by the following expression [12].

$$\text{Battery capacity} = \frac{\text{Wh/day}\times\text{days of autonomy}}{\text{efficiency}\times\text{depth of discharge}\times\text{nominal battery voltage}}$$

$$= \frac{290\times1000\times1}{0.85\times0.6\times12} = 47,385\ Ah$$

Where battery efficiency is 0.85, the depth of charge is 0.6.

So the battery should be rated as 12 V, 47,385 Ah for 1-day autonomy.

The battery capacity is available in the market = 130Ah

So with this rating, the number of batteries required $= \frac{\text{Required battery capacity (Ah)}}{\text{Each battery capacity (Ah)}}$

$$= \frac{47,385}{130} = 364 \text{ each of } 12V$$

5. Energy and Environmental Analysis

5.1. Energy in Terms of the Primary Form

The charging station with a capacity of 30 auto-rickshaws requires daily energy demand is 290 kWh. This amount is supposed to meet from the grid as per existing facilities. If the transmission loss from the power plant to the supply feeder is 15% then the energy demand at the power plant raised to 333.5 kWh.

In Bangladesh, more than 90% of the country's generation comes from fossil sources of which 62% are from natural gas plants and 30% are from oil-based plants [13]. In this regard, the breakdown of the energy demand is 207 kWh from the natural gas-based plants and 100 kWh from the oil-based plants. The contribution of the coal power plant is insignificant. If the average efficiency of the power plant is 38% then the energy demand in terms of primary form can be estimated as follows.

Primary energy for the gas power plant $= \frac{207\, kWh}{0.38}$ =544.73 kWh=1961 MJ

Similarly, the primary energy for the oil-based power plant is 947 MJ. In terms of quantities of fuel, the requirement can be estimated as 42.63 kg natural gas and 22.0 kg oil per day.

5.2. Emission and Environmental Impact

The CO_2, CH_4, and N_2O are the major components of the greenhouse gas emission which is released during the combustion of fossil fuels. The emission factor of these gases for stationary combustion is shown in Table **3**.

Table 3: Emission factors for the stationary combustion [14].

Fuel	CO_2 (kg/MJ)	CH_4 (gm/MJ)	NO_x (gm/MJ)
Natural gas	0.056	0.001	0.0001
Oil	0.074	0.003	0.0006
Coal	0.094	0.001	0.0015

The quantities of the emissions can be estimated using Table **3** for the primary energy use demanded in the solar charging station given in Table **4**. The quantities of the emissions are computed using the following expression.

Quantities emission (kg) =Amount of estimated fuel (kg/day) ×Energy content (MJ/kg) ×Emission factor (kg/MJ)

Table 4: Quantities emission per day.

Fuel	CO_2 (kg)	CH_4 (gm)	NO_x (gm)
Natural gas	109.8	1.96	0.196
Oil	70.07	2.84	0.568
Total	179.87	4.8	0.764

If the station is energized from the grid supply then the daily CO_2, CH_4, and NOx emissions estimated are 179.87 kg, 4.8 gm, and 0.764 gm respectively of which the contribution of CO_2 is significant. If the 100 year GWP for the CO_2, CH_4, and NO_x are 1, 28, and 265 [15] then the daily environmental impact can be estimated as 179.87 kg CO_2eq, 134.4 gm CO_2eq, and 202 gm CO_2eq for the CO_2, CH_4, and NO_x respectively. Such an amount of daily environmental impact will be offset when the charging station will be energized by the solar system. If the number of days of solar utilization per year is 300 then the annual environmental impact can be estimated as 54 tCO_2eq, 40 kgCO_2eq, and 60 kgCO_2eq for the CO_2, CH_4, and NO_x respectively.

6. Conclusions

This paper emphasized the solar charging system for charging three-wheelers auto-rickshaw in the context of a developing country. The energy consumption of the existing charging facilities is measured and analyzed to discover the basis of proposed charging facilities. The proposed charging facilities design layout and necessary design calculations are presented. The energy and environmental emission offset by the proposed design facilities are studied. The result showed that the existing grid-connected charging station capacity of 30 auto-rickshaws consumes 290 kWh energy per day which is significant. The proposed solar model is designed to meet this daily demand. The environmental analysis showed that the proposed model can reduce CO_2, CH_4, and NOx emissions per year by 54 tCO_2eq, 40 kgCO_2eq, and 60 kgCO_2eq respectively of which the contribution of CO_2 is significant.

The information discovered in this study will be useful for the national energy and environmental regulatory team of a developing country to develop the energy and environmental planning in target to reduce national energy consumption and environmental emission.

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