Performance Evaluation of a Microcontroller-based Solar Powered Auto-rickshaw

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***Abstract*—This paper represents the performance evaluation of a microcontroller based solar-powered auto-rickshaw which can be used extensively in Bangladesh for transportation. The battery operated traditional auto-rickshaw is charged by national grid whereas the battery bank of the proposed microcontroller based solar-powered auto-rickshaw is charged by solar power. A PIC microcontroller is programmed to control the duty cycle of the dc motor and thereby reduce the battery discharge time of the battery bank. The life cycle cost (LCC) analysis has been done and compared with the traditional battery operated auto-rickshaw. It has been found that LCC/kWh of the proposed rickshaw is minimum. The practical measured results reveal that the performance of the proposed rickshaw outperforms the conventional battery operated auto-rickshaw.**

***Index Terms*—Solar energy, Performance analysis, Drag force, Breaking force, Driving energy.**

I. Introduction

In Bangladesh, there are many modes of transport. Especially in the city areas, the varieties are seen frequently. Rickshaw is one of the most popular vehicles in the capital city Dhaka as well as in the rural areas. But in recent times, the number of rickshaws has increased and the passengers find as a very comfortable mode of transport both economically and also environmentally. It has gained more popularity among the poor people as a source of income. Most of the riders of these rickshaws belong to the middle class and lower middle class society. Dhaka is one of the most populous cities in the world. 38.3% of the whole population in Dhaka choose rickshaw as their first priority for transportation [1]. Day by day this number is increasing.

A rickshaw is generally a three wheeled mode of transportation that is driven by paddling of a person. It is commonly known as cycle rickshaw. But the scenario of the previous rickshaws were not the same what we see today. In the early years of the $18th$ century, the rickshaw was supposed to be a two wheeled vehicle that is pulled by a person. The puller used to hold the two wooden bars attached to the body and ran along the roads. But with time the rickshaws are changed to a new look with an extra wheel and a paddle and also brakes. Nowadays, a new type of rickshaws is seen in the streets which get power from battery. In those rickshaws, the battery produces electrical energy which converts into translational motion.

In the past, the human pulled rickshaws were very common in the streets of India. Even now in Kolkata, there are few streets where this type of rickshaw can be seen. The main problem with these rickshaws was the necessity of human efforts in a large scale. So it lost interest and introduces cycle rickshaws. But these rickshaws also create health problems to the puller significantly. Physical strength of the puller is decreasing day by day. They are affected by air pollution and cardiac problems. A rickshaw puller works relentlessly throughout the day for more than 7 to 9 hours a day. In the cycle rickshaws, the expenditure of energies varied from 23.5±2.66 to 25.35±1.51 kj/min. For that the cardiac strain and the cost makes the job 'heavy to very heavy' [2]. With this kind of pollution the DNA can be damaged potentially [3].

The recent introduction of battery powered auto rickshaws gained popularity because of its reduced physical labor necessity, less time for traveling. The modifications are made by adding dc motor to the wheel that is powered by battery. But the main concern is that the batteries are charged by the national grid supply lines causing much problem to the power distribution. It also creates more loads to the generators. So the millions of money spending as subsidy is not holding good. Almost $50,000$ battery operated rickshaws are moving in Dhaka city. These rickshaws are using around $200-250$MW electricity everyday just to recharge the battery [4].

To eliminate the additional power demand and to save our power our work is done by using solar panel. Solar energy is renewable and environment friendly. Bangladesh is situated in a very suitable geographical position for the solar radiation. Everyday we get bright sunshine 4 to 10 hours and solar radiation in our country is 4 and $6.55KJ/m^2$ [5] [6]. In that case solar power is very helpful. Our proposed model is thus suitable for those countries that have shortage of electrical power. It is also beneficial to the growing economic activities and the development. The micro-controller based solar powered battery operated rickshaws are more financially feasible and more effective than the others. Such rickshaws are the best alternative of the present auto rickshaws which is charged by the national grid supply.

In this paper, section II depicts the perspective of solar energy in Bangladesh as well as in the third world country, section III discusses system description and it's special features, section IV describes life cycle cost analysis of the system, section V includes energy calculation, section VI includes the data and performance analysis, and finally the work is concluded in section VII.

II. Perspective of Solar Energy

As a developing country like Bangladesh, there is always a shortage in the demand of electrical energy. By giving subsidy our country is trying hard to continue all development works. In that case, renewable energy has become one of the most significant subjects of research nowadays. It is the energy that can be regenerated. It is produced from natural resources such as sunlight, wind, tides, rain, geometrical heat and so on. There are different types of renewable energy such as solar power, wind power, biomass, bio-fuels and hydroelectricity. So these sources can be used to minimize the pressure on the other non renewable sources. Solar energy is the most widely used source of energy. It is generated from sunlight. The importance of solar energy is more than the other renewable energy. The reason behind it is the availability of the sunlight in all countries of the world. Another reason is the cost of this energy is much less than the other renewable energy.

In most of the countries power sector plays the most vital role in the development .In the last 30 years , the expenditure of solar power system has decreased at a good rate. It's because of the increasing demand of the system among the common people. In different countries nowadays it is used widely. It is very much popular in those countries where the climate is more suitable for this. Countries like Bangladesh, India, Pakistan, Sub Saharan Africa etc have more demand of this technology than the others.

Different countries in the world are using the solar power as an alternative to the other power. Countries that installed highest number of solar power are: Germany 9,785MW, Spain 3,386MW, Japan 2,633MW, United States 1,650MW, Italy 1,167MW, Czech Republic 465MW, Belgium 363MW, China 305MW, France 272MW, India 120MW [7]. So, it has become very clear that the solar power is growing more eagerness among the people to use solar power as their alternative power system.

As Bangladesh is a third world country, power sector needs a lot of development. It mostly depends on natural gas and hydro power stations to produce electricity. Necessary infrastructure is not at all getable to use the natural gas for producing the power though there is a high amount of natural gas. As the population is growing at a rapid rate, the demand of electricity is increasing day by day at a great speed. So it is high time we had the opportunity to use the solar technologies. The annual demand of energy of the country is 13% as per government's estimation of 7% [8]. In Bangladesh the average demand of electricity was 5660MW and generation 5500MW and average load shedding 160MW on January01, 2014 [9] [10]. Around 60% people can have access to the electricity. The geographical placement of Bangladesh is very important for solar radiation. According to NASA Surface meteorology and Solar Energy RET Screen Data, Bangladesh has got a great future in the field of solar energy generation. Figure 1 unfolds the data of daily solar radiation of Dhaka city [11].

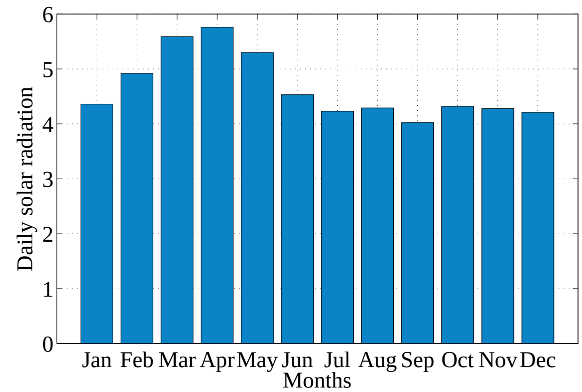


Fig. 1: Bar plot of daily solar radiation data

III. Proposed Model Description and Features

Figure 2 shows the overall block diagram of our proposed auto-rickshaw model. They are photovoltaic (PV) panel, Maximum Power Point Tracking (MPPT), solar charge controller, voltage controller, DC-DC converters, battery bank, emergency power supply, DC motors, microcontroller based Pulse Width Modulation (PWM) for regulation of speed.

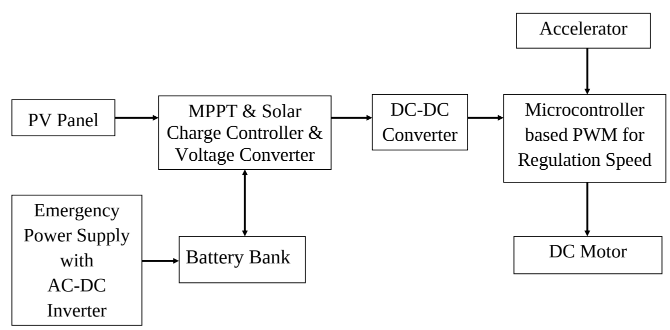


Fig. 2: Block diagram of proposed solar powered microcontroller based auto-rickshaw

The PV module converts solar radiation to the electrical energy. The energy comes from the sunlight stored in the lead acid battery bank that is controlled by microcontroller based charge controller. This type of battery is used for its low cost, high current, low initial impedance, tolerance to overcharge capabilities. The charge controller protects the battery from being over charged. Microcontroller based PWM is used for regulation in speed, it controls the duty cycle of the dc motors situated at the bottom of the structure. There is also an emergency power system to charge the battery from the supply lines. So the battery can be charged in both ways . In place of dc motors we could have used stepper motors. But those motors are more costly and large in size.

In our proposed solar based auto-rickshaw model there are four batteries each having 12Volt and the total power it needs is 120watt.The solar PV panel is situated at the roof-top which is connected to the Maximum Power Point Tracker (MPPT) and the battery charge controller. The controller is connected with the battery bank. The other side is connected to the DC-DC converter which is connected to the micro-controller based PWM. This is an important part for the auto-rickshaw. Finally the micro-controller based PWM drives the DC motor according to the program. The battery and other things are situated under the seats and the motor is located at the bottom.

The main feature of our proposed model is the battery charging from the solar panel situated at the roof-top. Micro-controller based MPPT has been designed to control the charge. The DC motor driving circuit is also micro-controller based. The another vital feature is its hydraulic disk braking system. To make it comfortable there is suspension system and some constructional changes. Figure **??** shows front view of the proposed auto-rickshaw model.

IV. System Cost Assumption And LCC Analysis

The following assumptions have been made on the basis of present market prices to determine the life cycle cost (LCC) and cost of unit energy of the proposed solar powered rickshaw:

- The operation and maintenance cost is considered 10% and for solar system it is 5% of the total capital cost [10].
- The installation cost is considered on the basis of an average labor cost of Bangladeshi taka (Tk) $250/day$.
- Unit cost of the solar panel is Tk 60 (found in local market survey).
- The inflation rate of conventional electricity is considered 5%.
- The LCC nonrecurring General Escalation (GE) of 3% (typically the value is $3-8\%$), discount rate of 7% (typically the annual value is $7-15\%$), LCC nonrecurring cost factor of 0.565 are considered [10].
- The interest rate is 3% [10].
- The period of analysis is 20 years which is equal to the assumed physical and economic of the PV system [10].

For the life cycle cost (LCC) analysis, we consider the following four different cases:

- Case A: Existing battery operated rickshaw charged by the national grid.
- Case B: Solar power battery operated rickshaw.
- Case C: Existing battery operated rickshaw charged by the national grid. But government is not giving subsidy.
- Case D: Microcontroller based proposed rickshaw.

Table I presents the estimated costs for different cases of driving rickshaw in (Tk) [1 USD=78 Tk].

where LCC_c is the Life cycle capital cost, LCC_{NC} is the Life cycle non-curring cost and it includes battery replacement cost, $LCC_{O\&M}$ is the Life cycle operation and maintenance cost.

TABLE I: LCC/kWh for the Different Cases

Cost Item	Case A	Case B	Case C	Case D
Rickshaw Structure	25000	25000	25000	25000
120W PV Array	–	7200	–	7200
Solar Charge Controller	–	900	–	900
Battery Bank	18500	18500	18500	18500
DC to DC converter	3500	3500	3500	3500
Installation Cost	2000	2500	2000	2500
LCC_c	56400	65000	56400	66000
License cost for 20 yrs	24000	24000	24000	24000
O & M Cost in 20 yrs	112800	65000	112800	66000
$LCC_{O\&M}$	136800	89000	136800	90000
LCC_{NC}	63382.5	63382.5	63382.5	63382.5
Cost of Electricity	226008	–	628905	–
Total 20 yrs LCC	482590.5	217382.5	882484.5	219382.5
Total Energy (kWh)	43800	43800	43800	52560
LCC/kWh (Tk/kWh)	11.02	4.96	20.12	4.17

V. Net Energy of Solar Rickshaw

There are some factors which have to be considered for evaluating the performance for our proposed model. If solar efficiency is η_{pv}, area of solar is A_{pv}, driving hour is H_d, parking hour is H_p, the average sun hour is H_{pv} and ϵ is constant, then total energy E is

$$E = \eta_{pv} A_{pv} [(\epsilon \times H_p) + H_d \times (1 - \epsilon)] \tag{1}$$

where

$$\epsilon = \frac{H_p}{H_{pv}} \tag{2}$$

The total ampere-hour required by motor, denoted by Γ_{req} can be written as

$$\Gamma_{req} = \frac{L_{daily}}{0.8} \tag{3}$$

where L_{daily} is the ampere-hour daily load demand and total system loss is 20% [10].

The total number of required PV array sizing can be calculated by

$$\text{No of solar module in series} = \frac{V_s}{V_{pv}} \tag{4}$$

and

$$\text{No of solar module in parallel} = \frac{\Gamma_{req}}{\Gamma_{pv}} \tag{5}$$

where V_s and V_{pv} are nominal system voltage and output voltage of PV respectively, Γ_{pv} is the Ah from the PV array. The capacity of the battery can be written as

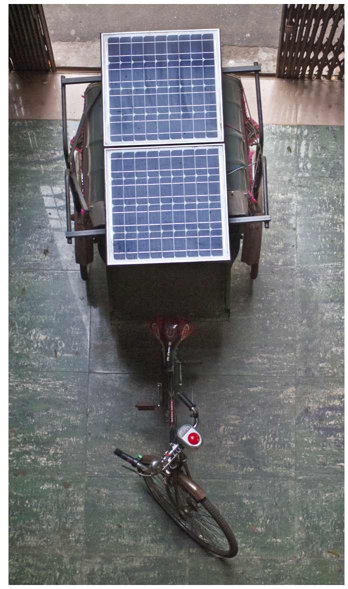
$$\text{Battery Capacity} = \frac{D_r \times L_{daily}}{u_{max}} \tag{6}$$

where D_r is the reserve day(s), u_{max} is the maximum usable in percentage.

The expression for number of required batteries in series and parallel can be calculated as

$$\text{No of Battery in series} = \frac{V_L}{V_B} \tag{7}$$

(a) Front view



(b) Top view

Fig. 3: Photograph of the proposed solar power rickshaw

V_L is nominal load voltage and V_B is the nominal battery bank voltage.

$$\text{No of modules in parallel} = \frac{L_{daily}}{V_{pv} \times \varrho \times \eta_{charge}} \quad (8)$$

Where V_{pv} is the Module Output, ϱ is the Derating factor, η_{charge} is the charging efficiency. There are mainly two resistive forces which act on the auto-rickshaw. These are: drag force and frictional force.

Drag force is one kind of mechanical force which opposes an incoming object through the air. It is generated by the body of the object when the object interacts with any other substance like air or fluid. It means that if there is no obstacle (air or fluid) there is drag. For this project work, we considered drag force is caused by the body of the rickshaw.

Air resistance is approximated by the following formula

$$F_{drag} = \frac{1}{2} \times C_d \times A \times \rho \times v^2 \quad (9)$$

where C_d is coefficient of friction (0.3), A is frontal area of rickshaw, ρ is the density of air ($1.29 kg/m^3$), v is speed of the rickshaw in meter/sec.

The frictional force, denoted by Frr, can be approximated by

$$F_{rr} = W \times C_{rr} \times 9.8 \quad (10)$$

where C_{rr} is the rolling resistance and W is the weight of the rickshaw. The weight distribution dramatically affects the maximum traction force per wheel. While braking, the traction force is replaced by a braking force, which is oriented in the opposite direction to the driving force. The total longitudinal force is then the vector sum of these three forces.

$$F_{total} \quad = \quad F_{drag} + F_{rr} \quad (11)$$

TABLE II: Different Drag Forces with the variation of speed

Speed(km/h)	F_{drag}(Newton)	F_{Total}(Newton)	P_r(Watt)
3	0.137	441.59	367.99
5	0.381	441.83	613.65
8	0.975	442.42	983.17
10	1.523	442.97	1230.48
12	2.193	443.64	1478.81
15	3.426	444.88	1853.65
20	6.091	447.54	2486.34
25	9.517	450.98	3131.72
30	13.705	455.15	3792.96

0

The required power to oppose all the resistive forces acting on the rickshaw will be-

$$P_r = F_{total} \times v \quad (12)$$

VI. Performance Analysis

During our practical work, we did several experiments about determining the relation between motor current with respect to speed for different loading condition for our proposed solar powered rickshaw model (without friction, rickshaw puller with one passenger and rickshaw puller with two passengers). Figure 4 shows variation of motor current with different loads for different speed.

For the proposed model, C_d = 0.3, A = 1.01m/s, ρ = $1.29 kg/m^3$. Substituting these values in Equation (10), we get different values of required power for various speed which can be calculated using equation (11). Table II refers different F_{drag} for different speed obtained.

Again, the weight of our model is around 150 kg and C_{rr} = 0.3 (assumption). Table II gives total resistive forces and the required power P_r.

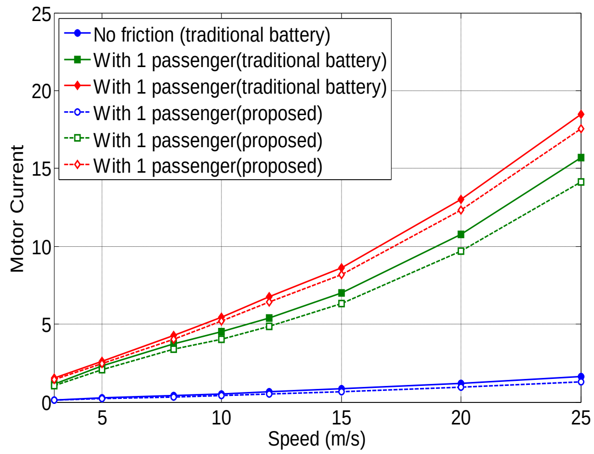


Fig. 4: Current variation with different speed for different numbers of passengers

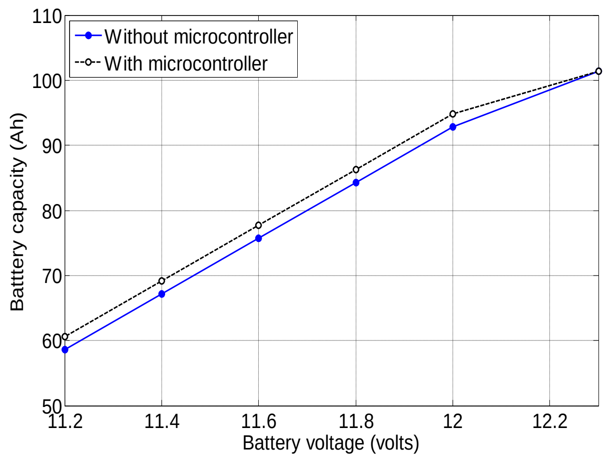


Fig. 5: Relationship between battery capacity and battery voltage

Figure 5 shows the relationship between battery capacity and battery voltage. The figure depicted that battery discharging time has raised due to the use of microcontroller to drive dc motor of the proposed rickshaw.

In the proposed auto-rickshaw a 300 Watt dc motor is used. The voltage rating is 48V and current rating is 3.25 A. If the average time of running this motor is about 6 hours (hr), then the average energy required to drive the motor, denoted by E_m, is

$$E_m = 3.25A \times 6hr \times 48V = 780J \tag{13}$$

Due to the space constraint on the roof-top and to have good balance in case of speed more than 15 km/hour, we have installed two solar panel. The electrical specification of the solar panel is 100×2 i.e., 200 watt. If they are connected in series, then the nominal system voltage is 24 volts and measured current is found to be 8.33 A. Then ampere-hour(Ah) produced by solar panel E_{pv} is

$$E_{pv} = 8.33A \times 6hr \times 12V \times 2 = 1199.52J \tag{14}$$

Using Equation (6), number of battery in series is

$$\text{No of Battery in series} = \frac{48V}{12V} = 4 \tag{15}$$

$$\text{Battery capacity} = \frac{1 \times 3.25 \times 5}{0.5 \times 0.75 \times 1.56} = 27.78 \tag{16}$$

The battery capacity is 48 V, 4.5 A, then energy supply by the battery E_b is

$$E_b = 40 \times 12 \times 4 = 1296 \tag{17}$$

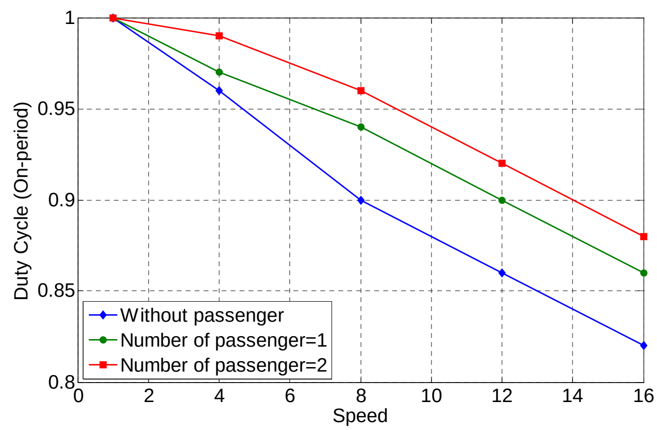


Fig. 6: Effect of speed on the on-period of the duty cycle

Figure 6 shows the effect of motor speed on the on-period (i.e., duty cycle) generated by PIC microcontroller. It has been found from the practical measurement that the duty cycle depends on the frictional force. The increase of the speed of the motor reduces the on-period of the dc motor. When the number of passenger increases the more energy is required to overcome the frictional force, thus the duty cycle is increasing.

VII. Conclusion

This work presents the LCC analysis and performance evaluation of proposed micro-controller based solar powered auto-rickshaw. The results showed that LCC unit price is minimum for our proposed micro-controller based solar powered auto-rickshaw. It has also been found that micro-controller based dc motor control circuit reduced battery discharge rate compared to the traditional battery operated auto-rickshaw. Approximately 200W PV-array is enough to drive a 300 W motor and the system will operate more than 5.5 hours a day.

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