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Design and Development of Low-Cost Solar Powered Automobile System for Eco-friendly Transportation

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ABSTRACT

Solar car can be categorized as a 'green vehicle' with zero carbon emission. With an aim to develop low-cost eco-friendly commuting system, a prototype of solar car has been designed and developed. Engine and transmission system of an old petrol car were completely removed to refurbish it by Variable Drive Brushless Direct Current Motor, battery bank, control mechanism, sensors and solar modules. 48 V, 105 Ah Valve Regulated Lead Acid tubular thin plate battery bank was designed to operate a VBLDC motor of 1248 W capacity. 300 Wp polycrystalline solar array has been installed on the car rooftop to deliver synchronized power through charge controller. Results revealed that in the course of insolation array of 5.0-6.00 kWh/m^2, the solar modules were found to deliver consistent Voltage in between 71 V to 83 V, sufficient to charge battery bank reliably through the protection of Maximum Power Point Tracker charge controller. Maximum instantaneous power values found were 224.84 W and 222.98 at corresponding voltage and current measurement of 49.2 V, 4.57 A and 48.9 V, 4.56A respectively. The battery bank took complete two days to achieve full charging status of 52.1 V when charged by solar array. Lab test showed that the car kept working for 2 hours and 57 minutes till the battery bank gets exhausted to 40.4 V. During field test the solar car performed for 1 hour and 50 minutes at an average speed of 30 km/h. Life Cycle Cost of solar car was found about five times less as compared to traditional petrol car. When compared with petrol car, average payback period and CO_2 emission reduction were found to be about 02.32 years and 1679 kg/year.

KEYWORDS
Solar Car, Photovoltaic, Insolation, VBLDC, battery

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INTRODUCTION

Solar car is a battery-operated vehicle powered by solar photovoltaic (PV) array. A solar array is a packaged, connected assembly of solar modules that can convert solar energy directly into electrical power. The electricity produced would act as fuel for the battery which would eventually power the car's motors (Mohan *et al*, 2019). Amid the rising price of fossil fuels and, pollutions, the world over the concept of electric cars is emerging very fast. Control mechanisms and sensors are crucial components to regulate power and ensure compatibility among the active devices of the electric vehicle. The project was undertaken with objectives to develop solar-powered electric cars and to carry out the techno-economic evaluation.

MATERIALS AND METHODS

The solar car was developed by roof-mounting of a solar array comprising of four PV modules, each of 75 Wp capacity to recharge battery bank of 5040 Wh (48V × 105Ah). Variable Drive Brushless DC Motor (VBLDC) motor was the main electro-mechanical component to propel the solar car (Dwivedi and Tiwari, 2013 and Alphonse *et al* 2012). The electric motor receives power from the rechargeable batteries. An intermediate device called a charge controller was connected in series to protect the battery and regulate power, transmitted to the electric motor and auxiliary components.

Calculation of Rolling Resistance Force

$$F_{ROLLING} = \mu R \times W$$

Where,
W=mg is the weight of the car,
μR= the coefficient of rolling resistance and is a constant that depends on the type of tires of the vehicle and the surface on which it will roll.

$$\begin{aligned} F_{ROLLING} &= \mu R \times W \\ &= 0.010 \times 660 \times 9.81 \\ &= 64.68\ N \end{aligned}$$

Calculation of aerodynamic drag force

The aerodynamic drag force is simply the force exerted by the air to prevent the vehicle from moving through it. The aerodynamic drag force can be expressed as,

$$F_{DRAG} = \frac{1}{2} \times C_D \times Across \times \rho \times V^2$$

Where,

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C_D = The coefficient of drag of the vehicle,
Across = Frontal area in square feet,
ρ = A constant that accounts for the air mass density and
V = the vehicle's speed.

$$F_{DRAG} = \frac{1}{2} \times C_D \times Across \times \rho \times V^2$$
$$= \frac{1}{2} \times 0.32 \times 1.0 \times 1.2 \times 8.33^2$$
$$= 13.32\ N$$

Calculation of force of acceleration

The force of acceleration should be only accounted for when the car is accelerating and is given by newton's 2nd law of motion

$$F_{ACCELERATION} = m \times a$$

Where,
m = the mass of the car and
a = the acceleration.
The car was to design to achieve maximum speed of 30 km/h in 90 seconds, so
Acceleration = (30000-0/3600)/90
= 0.09 m/s^2
Therefore,

$$F_{ACCELERATION} = m \times a$$
$$= 660 \times 0.09$$
$$= 59.40\ N$$

The total driving force thus required to overcome the sum of these opposing forces to move the car is,

$$F_D = F_{ROLLING} + F_{DRAG} + F_{ACCELERATION}$$
$$= \mu R \times W + \frac{1}{2} \times C_D \times Across \times \rho \times V^2 + m \times a$$
$$= 64.68 + 13.32 + 59.40$$
$$= 137.40$$

The power needed to be supplied by the motor in order to provide the current speed and acceleration will therefore be,

$$P_T = F_D \times V$$
$$= 137.40 \times 8.33$$
$$= 1144.5\ W$$

Where,
P_T= maximum power of BLDC motor,
F_D = drive force and
V = maximum allowable speed of the car.
Considering the values derived from the calculations and market availability, a permanent magnet, VBLDC motor of 1248 W has been selected to power solar car.

Battery Capacity

Battery capacity is the measurement of how much energy the battery can contain (in Ampere-hours). In perspective of the project, the maximum operating hours decided were 3 h. In the design battery capacity to drive VBLDC motor was determined based on following formula

$$Battery\ Capacity\ (Ah) = \frac{WR \times OH}{VN \times DM}$$
$$= \frac{1248 \times 2.5}{48 \times 0.80}$$
$$= 81.25\ Ah$$

Where,
WR = Rated Wattage of BLDC Motor
OH = Operating Hours
VN = Nominal Voltage
DM = Maximum Allowable Discharge
Considering above value and market availability four lead acid solar batteries, each of 12 V, 105 Ah have been selected and arranged in series configuration to make 48 V, 105 Ah battery banks to deliver required power to the VBLDC motor.

Selection of solar module and array

However, considering the area on the car top and load bearing capacity four 75 Wp solar modules were selected, and arranged in series configuration to make 300 Wp solar array, which would constantly charge battery bank at the rate of 49 0.9 V and 3.14 0.75 Ah during day time (Taha *et al*, 2010).

$$Array\ \ Load = \frac{Battery\ charging\ requirement \times Depth\ of\ Discharge}{Battery\ efficiency \times Charge\ Regulator\ Efficiency}$$
$$= \frac{4800 \times 0.80}{0.80 \times 0.90}$$
$$= 5333.33\ Wh/day$$

$$Array\ size = \frac{Array\ Load}{Annual\ Avg\ insolation \times Mismatch\ factor}$$
$$= \frac{5333.33}{5.8 \times 0.85}$$
$$= 1081.81\ W_P$$

Basic statistics of Solar Powered Electric Car

The solar car was developed (Figure 1)and its different design parameters are presented in Table 1.

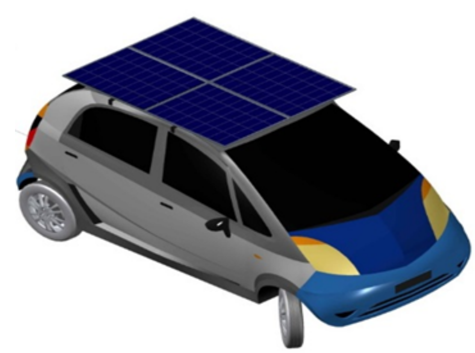

Fig. 1: Three dimensional view ofsolar power electric car

RESULTS AND DISCUSSION

The chapter includes details of available solar resources in the region, design of working components of solar car and its performance evaluation.

Performance evaluation of solar array

Figure 2 shows value of voltage, current and power at output of charge controller corresponding to solar insolation similar result obtained that solar irradiation conditions and other factors on the outdoor performance of photovoltaic modules (Elminir *et al*, 2001). Results revealed that voltage varied in line with solar insolation. Maximum and minimum values of solar array Voltage found to be 83 V and 71 V, which were at insolation of 778 W/m^2 and 353 W/m^2, respectively.

The charge controller however was calibrated to deliver constant voltage of about 49 V for synchronous charging of battery bank.

Instantaneous peak power value of 224.84 W was obtained at solar insolation of 778 W/m2. Results depict that current, voltage and power vary in accordance with the solar insolation.

Performance of solar battery bank

Figure 3 illustrates behaviour of battery charging in context to time and solar insolation. It was revealed that the battery bank took two full days to achieve full charging status of 52.1 V under solar charging system during winter days on November, 22 and 23.

Performance evaluation of battery bank under ideal operation of solar car

To study discharge rate of the battery bank, an experiment was carried out under ideal speed of solar car under rated speed of VBLDC motor. The test was carried out on fully charged battery bank till the battery got exhausted. Similar result obtained by car testing in 2018 ((Premkumar *et al*, 2018).

Table 1: Basic Statistics of Solar Powered Electric Car

Dimensions:		3100 × 1660 × 1500 mm
Wheel Size	**Front**	90/90-12
	Rear	90/90-12
Body Size (L×B×H)		3.10×1.66×1.50 m
Gross Weight		690 kg
Passenger Capacity		300 kg (1+3)
Speed and Mileage	Maximum speed :	35 km/h
	Maximum mileage :	35 km or about 2.25 hours per one charge of battery
Motor Power		1248 W
Battery Type		Sealed Lead-Acid, Maintenance Free
Battery Capacity		48V, 105Ah (12 V, 105 Ah x 4 Batteries in series configuration)
Charging Time		6-7 Hrs
Climbing Slope Capacity		30^0
Charger		AC 220V 50Hz
Front Brake		Oil Brake
Rear Brake		Wire Brake

Figure 4 shows that, at initial voltage of 50.2 V, speed of the car was 30 km/h. with the use of battery both the voltage and speed gradually going down. The battery delivered power continuously for 2 hours and 57 minutes till the voltage of 40.4, when speed was recorded as 20 km/h, the cut-off speed of the car.

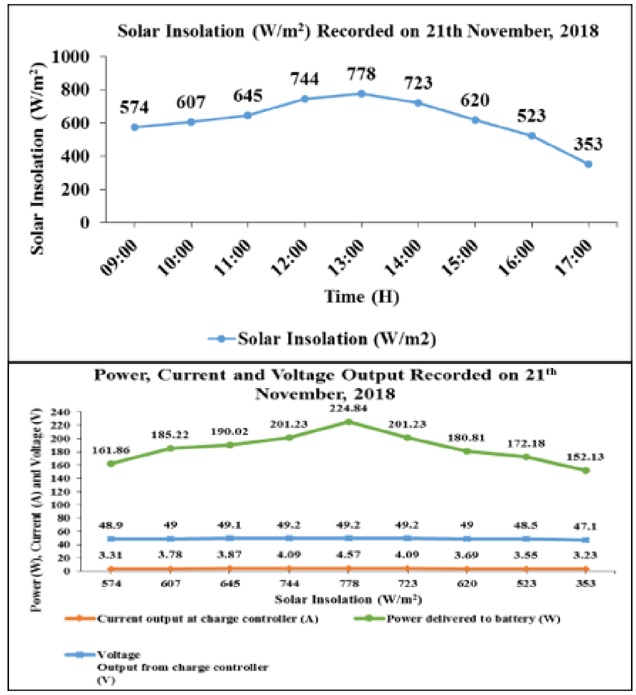

Fig. 2: Influence of solar insolation on current, voltage and power yield.

Performance evaluation of fully charged battery was carried out on university road of by boarding four passengers. Results in fig. 8 shows that initial stable speed of the car was recorded as 28 km/h at corresponding voltage value of 46.5 V. Both the voltage and speed have been decreasing gradually with time. The battery lasted for 1 hour and 50 minutes. Final voltage and speed were found to be 41.2 V and 20 km/h, respectively.

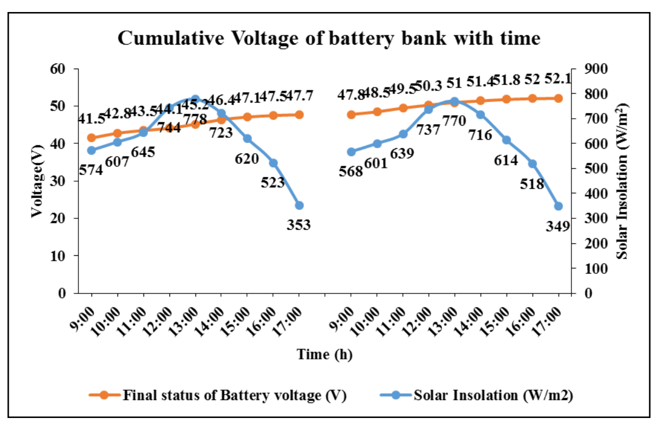

Fig. 3: Battery bank charging level corresponding to solar insolation and time.

Life Cycle Cost Analysis

tABLE 2 depicts comparison of life cycle cost (LCC) analysis between solar and petrol car. Significant difference was found in LCC as it stood less than 3 times for solar car when compared to petrol car.CO_2 emission reduction was found to be

17325 kg/year @ 2.31 kg per liter of petrol fuel saved.

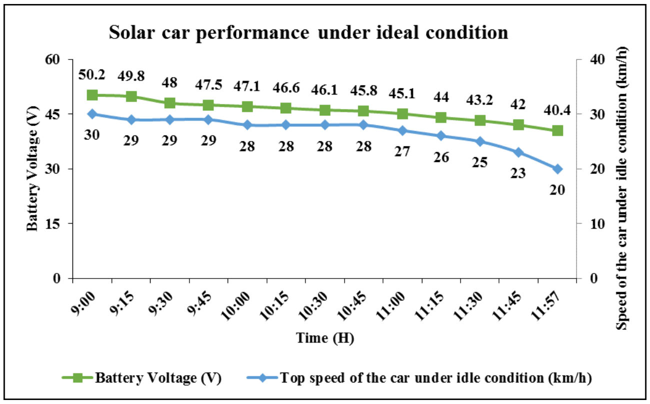

Fig. 4: Performance of battery bank under ideal condition of Solar Car

CONCLUSION

The solar photovoltaic module powered electrical vehicle would present a sustainable and eco-friendly transportation solution. The developed vehicle witnessed substantial reductions in fuel consumption andCO_2emissions. The 300 Wp solar array feeds battery to reduce battery charging time considerably and keeps vehicle going during daytime, which ensures extended hours of operation. The key challenge is life and cost of battery bank which needs to be addressed. Future work is required to improve power performance of solar array by rooftop shaped solar mounting, it would help in optimizing weight of the vehicle and offer attractive look. However, power and pickup are not comparable with commercial vehicle. Its cost is quite attractive. It provides ideal alternative for campus visit and leisure travelling.

Table 2: System Cost Comparison by Life Cycle Cost Analysis

Sr. No.	Costs (₹)	Solar Car	Petrol Car
1	Capital Cost (CC)	1,19,000	2,50,000
2	Maintenance Cost (MC)	10,000	20,000
3	Fuel/Energy Cost (EC) for 10 years and 15000 km per year @ 70 Rs./l	None	5,25,000
4	Replacement Cost (RC)	1,50,000	75,000
5	Total Cost	2,79000	8,70,000
6	Salvage Cost	10,000	25,000
7	Life Cycle Cost (LCC)	2,69,000	8,45,000

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