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Innovative Design and Performance Analysis of Solar-Powered Electric Vehicles for a Promising Approach for Green Transportation

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ABSTRACT

The objective of this paper is to explore the potential of using solar power to drive an electric vehicle for use in Public Gardens and golf fields. The motivation for this study is the need to reduce greenhouse gas emissions and find sustainable alternatives to fossil fuels. Electric vehicles have several advantages over traditional gasoline-powered cars, including quiet operation, zero emissions, and lower maintenance costs. Using solar energy to drive electric vehicles would reduce need to recharge the vehicle battery or eliminate it altogether. The paper provides a summary of solar power technology and its application in automotive systems. The key components of a solar-powered electric car are also introduced, including the engine controller and the mechanical structure of the chassis. The electrical and mechanical systems are described in detail, and the connection between the two is also explained. The experimental and theoretical work to design a solar-powered electric vehicle is presented, and an analysis of vehicle performance at different conditions is included. The paper concludes by highlighting the potential benefits of using solar power to power electric vehicles and the need for further research in this area.

1. INTRODUCTION

Solar powered cars are a new and innovative approach to reduce reliance on fossil fuels and addressing environmental concerns related to transportation sector. These vehicles use solar panels to capture energy from the sun and convert it into electricity, which can be used to power the car's motor or recharge its battery (Figs. 1 and 2). Solar powered cars have been a subject of research and development in recent years, as they have the potential to reduce greenhouse gas emissions and help mitigate the effects of climate change. Three-wheelers are a type of vehicle with three wheels, which have several advantages over four-wheelers. They have a smaller turning radius and reduced rolling resistance, resulting in better mileage for the same weight. Additionally, they have less aerodynamic drag, making them more efficient, Fig. 3. However, there are still many technical and practical challenges to be addressed before solar powered cars can become a practical and feasible option for widespread use. The literature review will examine some of the key studies and research conducted on solar powered cars for better understanding their potential and limitations.

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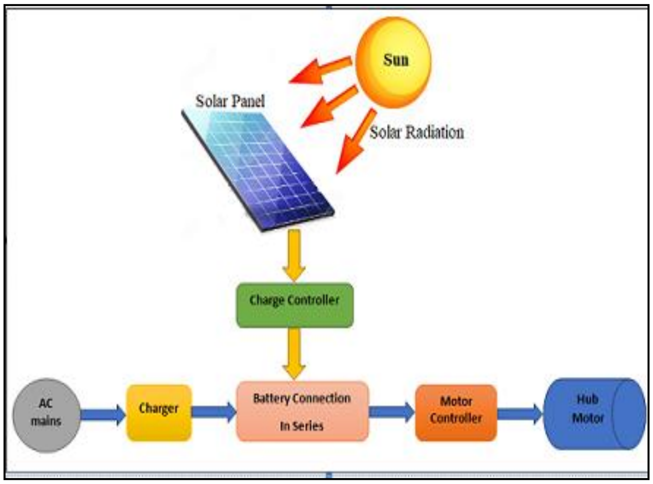


Fig. 1: An elementary block schematic of a solar-powered vehicle's powertrain

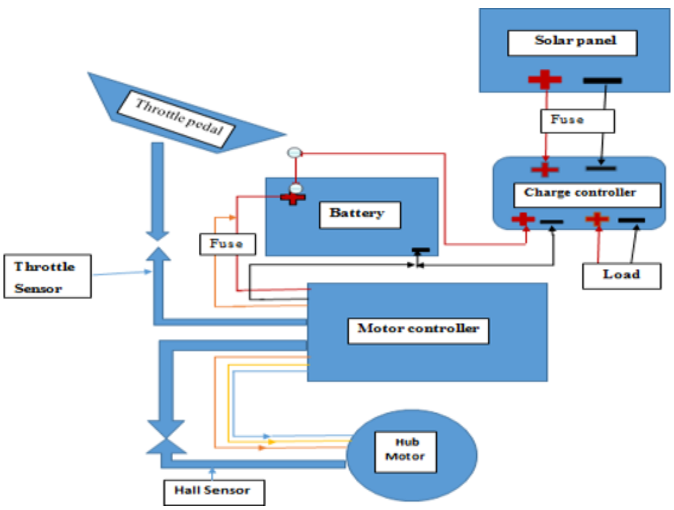


Fig. 2: Working principle of solar assistive wheeler [1]

Fig. 3 Design of three wheel solar electric vehicle

2. MOTIVATION AND JUSTIFICATION

In order to lessen pollution and reliance on fossil fuels, the goal of this endeavor is to develop and build a solar-powered clean automobile for urban commuters in October area. The cost of fuel is rising alarmingly on the global market, and soon it will be too expensive for the average person to afford. In addition to growing fuel expenses, October city pollution poses a serious health risk, particularly during work hours when automobiles are snarled in traffic and hazardous emissions from modern private cars are emitted in large quantities, necessitating prompt action. The outcomes also demonstrate that the car's solely harvested solar power will be adequate for daily city commuting. Both the environment and the general public, who are currently exposed to numerous health issues because of poisonous exhaust gases from fuel-powered cars, will benefit from the clean solar car. The following list highlights some of the main advantages and disadvantages of the solar car [2]:

- Environment-Friendly, pollution-free, clean energy.
- Renewable source of energy.
- Reduce pollution related lung and other life-threatening diseases and improve pub health.
- Small and Lightweight
- They don`t produce any noise.
- Appropriate for remote locations.
- They require little maintenance.
- Prevent scarce resources like fossil fuels from depletion.
- Will not consume rather facilitates energy collection while waiting in traffic signal.

The disadvantages of using solar power are:

- Relatively high initial cost to buy and install.
- Do not generate power at night.
- Currently, relatively low efficiency.

3. LITERATURE REVIEW

Both industrial and household fuel consumers contribute to air pollution **[3].** There doesn't seem to be any research on using PV as one of the energy sources for EV charging, though. Given the growing interest in the topic, this review updates and summarizes some of the essential aspects of PV-EV charging **[4]**. The authors provided background information on the principles of EVs, batteries, and both the PV-grid and PV-standalone PV-EV charging approaches are thoroughly covered. In addition, a case study comparing grid-only charging was carried out using Matlab simulation to assess the technical and economical sustainability of both strategies.

To enhance the total all-electric mileage while keeping in mind that the energy infrastructure severely limits the overall charging capability of each workplace. (Distance travelled using only the traction batteries in each PHEV). A number of input variables, such as state-of-charge, battery size, travel distance, and parking length, were taken into account in order to distribute this power as effectively as feasible.

A unique agent-based model, that represents the spatiotemporal movement of individual PHEVs, was employed to produce the necessary vehicle mobility [5]. The results suggest that clever control strategies could increase Helsinki's all-electric mileage

A research examined the possibility of solar-powered vehicles becoming widely used and dominating other types of electric vehicles in the future [6]. This indicates that mounting solar panels on the hoods and roofs of vehicles is a growing trend. Resulting in significant sum of money that can be saved. The price-performance ratio of solar cell technology will also result in lower solar car costs.

Charging electric vehicles (EVs) have the potential to overload transformers, create voltage imbalances, and interfere with the quality of the power. However, pricing signals during coordinated charging help control energy and lessen the drawbacks of EV charging. Therefore, this might encourage EVs to charge during a time when less energy is being used [7]. The article examined the influence of electric vehicle charging on distribution transformer loading using actual data from smart meters. The authors developed scenarios that take into account the real-time pricing (RTP) and time-of-use (TOU) electric charging tariffs, as well as the uncoordinated and coordinated vehicle charge control techniques.

A brand-new, completely decentralized method for coordinating the functioning of electric vehicle charging was Zhang et al. suggested a technique; based on stochastic switching control of on-board chargers, that guarantees high-efficiency charging, minimizes load fluctuations during charging times, and achieves charge completion with a high probability. To determine the fundamental characteristics of the techniques and quantitatively demonstrate performance enhancements, stochastic analysis is carried out **[8]**.

Transportation Medias are a large consumer of petroleum fuels since transportation uses a significant portion of fuel. Rattankumar and Gopinath provided a plan for creating a solar-powered alternative vehicle **[9]**. The purpose of their study was to create a solar-powered automobile prototype for a specific type of motor; Brushless Permanent Magnet D.C. Motor (BLDC) driving the car, which is managed by a microprocessor.

Electric cars (EVs) are becoming more and more popular due to a number of factors, including dropping prices and more environmental and climate consciousness **[10].** The article presented an assessment of the improvements of EVs in terms of battery technology trends, charging methods, fresh research challenges, and unexplored opportunities. Additionally, several EV charging protocols that are available as well as the concepts for power management and battery energy management were investigated.

Abdelhamid et al. presented a study to offer a thorough analysis of the possibilities and uses for solar panel technology in electrified cars **[11]**. In plug-in hybrid electric cars (PHEVs), full hybrid electric vehicles (FHEVs), and battery electric vehicles (BEVs), photovoltaic (PV) panels are used as an auxiliary energy source of on-board fuel. The advantages of many potential applications, including active car interior ventilation, low-voltage battery charging and high-voltage (HV) traction battery charge for longer driving distances were discussed.

According to the current trend, ICE vehicles may soon be replaced by this means of transportation. Each of the main EV components currently uses, or has the ability to use, a range of technologies. The electrical infrastructure, the environment, and other connected areas could be significantly impacted by EVs. The current electricity system could become very unstable with enough EV penetration, but with the correct management and coordination, EVs can play a vital role in the successful implementation of the smart grid concept **[12]**.

Using modeling, simulation, and validation on a real-world vehicle system, a study described a method for building and developing an electric vehicle power train and provides a detailed analysis of the results. Although modeling EV power trains in software simulation settings is critical for the design and development of EVs, testing these models on actual car systems is as important for boosting the overall performance, safety, and dependability of the vehicle **[13]**. This modeling method was performed using Mat lab / Simulink software to model and simulate an EV power train. It is further enhanced by validating the modeling outcomes using an actual car that is put through performance testing on a chassis dynamometer.

In order to quickly develop and validate high-performance EV power trains at a low cost, these modeling methodologies must be combined with real-world validation. This methodology fills the gaps in the literature regarding how these modeling methodologies can be used in a research framework.

4. PRACTICAL 3D MODEL FOR BASIC OPERATION

Figure 4 shows a practical 3D model designed for a solar-powered vehicle, where the primary energy source for the car is the sun. Solar panels receive the sun's energy and convert it into electrical energy, which is then fed into the batteries to be charged. The electrical energy is used to power a high torque 12V DC chain motor connected to the vehicle's rear wheel through the sprocket in the chain. The batteries are initially fully charged, and then charged with boards to complete the battery charge and discharge cycle, which is critical for proper operation and preservation of the life of the batteries.

4.1 SYSTEM ARCHITECTURE

Figure 5 is a block diagram that depicts the intricate system design of the entire system. The solar panels, which will be positioned on the car's top, will absorb solar radiation and transform it into useful electrical energy. The electrical energy will then be stored in a lead-acid battery and provided to the engine through that battery. Depending on the battery's present status, instructions from a microcontroller will determine whether it is necessary to charge the motor directly rather than recharge the battery. The charge controller will help prolong the battery's life by limiting excessive charging and discharge.

Fig.4 Practical 3Dmodel applied to the Solar Car

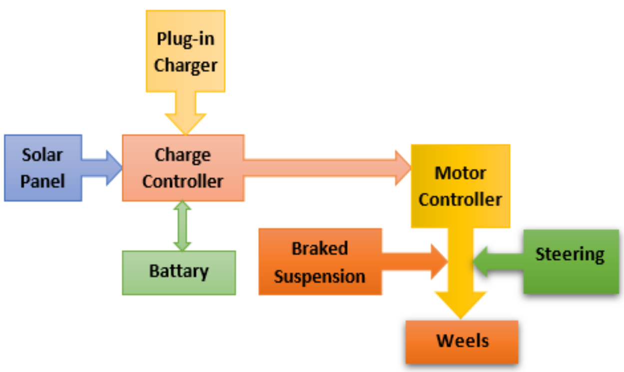


Fig. 5: System architecture of solar powered EV

4.2 Solar Electric Vehicle Rating Calculations

There are numerous calculations and procedures that must be followed while developing a powered prototype in order to create one that is powerful enough, reliable, and secure. Acceleration, rolling, and aerodynamic resistances are a few examples of resistances for moving vehicles that must be considered when modeling vehicle energy consumption. These are the key factors that determine the size of a motor that can produce enough torque to drive the vehicle. The road power demand equation displays the amount of energy required by a car whose power is lost while it travels down a road. The formula is as follows:

Total Power = (Acceleration + Climbing + Aerodynamic +Rolling) resistance

$$F_{TT} = F_{AC} + F_{CR} + F_{AE} + F_{RR} \quad (1)$$

The motor is the essential component of our prototype. Our electric automobile can accomplish and give more work and performance the more powerful the motor is. The first thing that needs to be determined is how many watts the motor is capable of producing. Here are some fundamental methods, key formulas, and mathematical specifics for calculating a DC motor's mechanical power requirements, torque, etc. The chassis frame should be made to suit the necessary requirements, which are shown in Table 1 below. The total amount of force required to overcome all resistances must be known in order to determine a motor's required rating power. For each form of resistance, the definitions are given in Equations (2) to (7).

Acceleration resistance, $F_{AC} = \lambda\, m\, a \quad (2)$

Climbing resistance, $F_{CR} = m\, g \sin \alpha \quad (3)$

Aerodynamic resistance, $F_{AE} = 0.5 \rho C_w A_C v^2 \quad (4)$

Rolling resistance, $F_{RR} = m\, g\, f_R \cos\alpha \quad (5)$

$$F_{TT} = \lambda\, m\, a + m\, g \sin \alpha + 0.5 \rho C_w A_C v^2 + m\, g\, f_R \cos\alpha \quad (6)$$

$$q_{TP} = F_{TT}\, v \quad (7)$$

Table 1 Technical Specifications of the Solar Vehicle

Properties	Value
Mass of the vehicle	100 Kg
Battery weight	20Kg
Solar panel weight	11Kg
Driver Seat weight	10 Kg
Dc motor weight	19Kg
Average speed	35 km/hr
Max Speed	50Km/hr
Max travel distance	10 km
Max time to reach max speed	30 sec
Wheel diameter	0.52 m
Slope	0.1
Linear velocity speed	50km/hr
Frontal area of the vehicle	1.85m

The system's overall efficiency, the amount of electricity generated by solar panels, and their efficiency were all determined using equations 8, 9, 10, and 11. From the PV panel to the vehicle wheel Equation 10 illustrates that a PV panel's efficiency is roughly equal to the electrical energy produced by the panels divided by the solar energy received on the panel's total surface. Each symbol used in equations is described by the nomenclature.

$$q_{SR} = I_R\, A_{PV} \quad (8)$$

$$q_{pv} = V\, C \quad (9)$$

$$\eta_{PV} = q_{pv} / q_{SR} \quad (10)$$

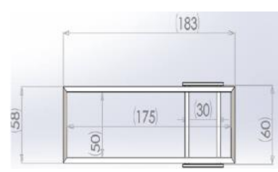
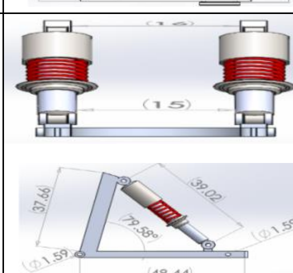
$$\eta_{SY} = \eta_{TR} + \eta_{BA} + \eta_{PV} + \eta_{DC} + \eta_{MPPT} \quad (11)$$

$\eta_{TR} = 0.96$ $\eta_{BA} = 0.8{:}0.9$ $\eta_{PV} = 0.17$ $\eta_{DC} = 0.85$ $\eta_{MPPT} = 0.95$

4.3 System Components

The goal of this study is to propel the solar car at a speed of 40-50 km/h on various road surfaces (**see Fig. 6 below**). To achieve this, we performed calculations using equations to help select the appropriate system components **(see Table 2).**

Table 2: List of Various Components Used

S/No.	Components used	Specifications		Q
1	**Solar Cell Controller**	Voltage 12-24 V Current 4.48A:80A		**1**
2	**Battery**	Voltage 12 V Capacity 65 AH Type Lead-Acid		**1**
3	**Solar Cell Frame**	Power 160 Watt Voltage 12-24V Current 8.7A		**1**
4	**Switch Pedal**	Throttle pedal box assembly 12/24V		**1**
5	**Series Dc-Motor**	Torque 9 NM @ 1600RPM Current 80 A		**1**
6	**Chassis**	The chassis made from 1023 carbon steel sheet with thickness 0.25 mm to support mechanical parts.		**1**
7	**Suspension System**	Consist of two springs and made of the same material of the chassis 1023 carbon steel sheet.		**2**
8	**Tire**	Consist of two parts the solid ram and the rubber tire.		**3**

9	**Shock Absorber**	Oil filled		**2**

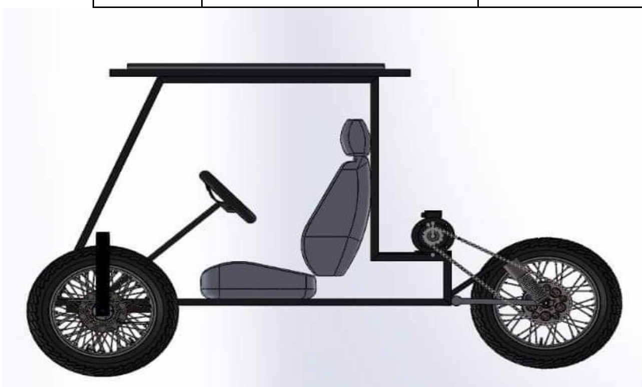


Fig.6: Practical Model Applied to the Solar Car Chassis

Fig.7 Final Model Design To Solar Powered EV

5. RESULTS AND DATA ANALYSIS

The whole reason of the paper is to study the performance EV for effect of solar cells in the discharge time of the battery during working due to several conditions of working such as road type, at day light, at night, different loads and different speeds. We conducted multiple tests on the final model of the Solar Car (**see Fig. 7**) in different times and under varied conditions, documenting our work with curves, and arguing whether it is worth to add solar charging to electric vehicles today or not.

Over the course of three months (June, July, and August 2022), the Solar Car model was tested on two different road types: an asphalt-paved road with a roughly 0% gradient and a grass road with a gradient ranging from 0% to 20%. The practical PV panels used in the tests were estimated to have an average efficiency of around 11%. Using Equation 11, it was calculated that the overall system efficiency of the solar vehicle (measured from the PV panel to the wheel) was approximately 9%.

Furthermore, the study found that the average solar radiation and daily sunshine hours in October City, Egypt, were 618.08 W/m^2 and 12 hours per day, respectively, as illustrated **in Figure 8.**

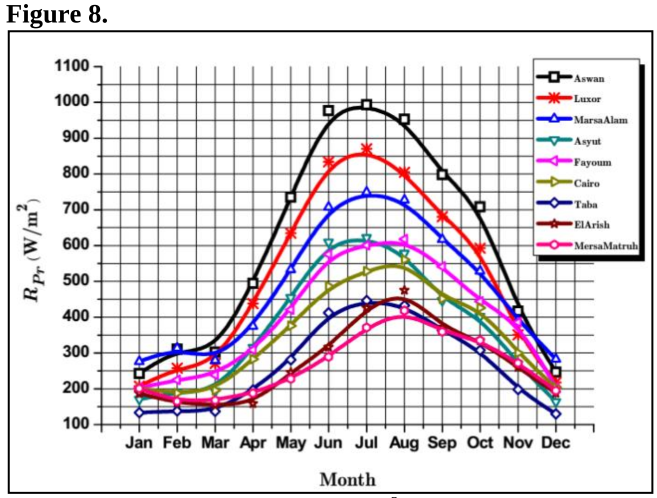


Fig. 8 Monthly Averages of R_{pr} (W/M^2) of the Selected Regions in Egypt during 2022 [**14**]

5.1 Discussion between Voltage Discharges Due to Time at Several Conditions:

5.1.1 Effect The Speed And Timing On Voltage Discharge:-

The experiment compared voltage readings under constant road type (asphalt) and normal load (210 kg) at different times of the day and night to examine the impact of speed on battery discharge. The results revealed that at any given time during the day, the power drain at low speed (20 km/hr) was lower than that at high speed (50 km/hr). Additionally, the power drain during daylight hours was significantly lower than at night, indicating that solar energy is effective in reducing battery discharge time. These findings are illustrated in **Figures 9 and 10.**

The results suggest that EVs equipped with solar panels can potentially benefit from reduced battery discharge during the daytime, especially at lower speeds. Additionally, it highlights the importance of utilizing solar energy to improve the performance and efficiency of EVs.

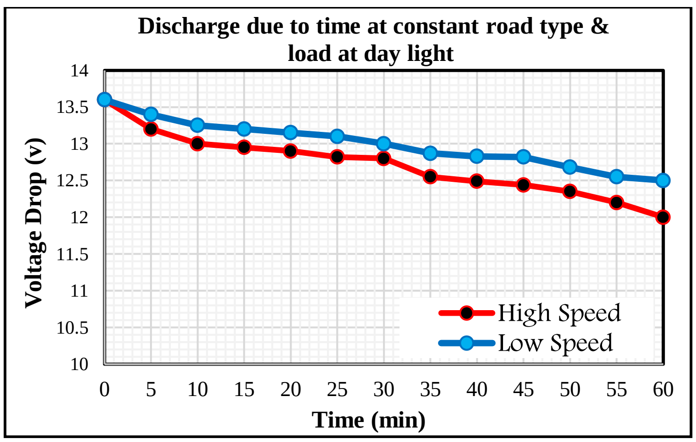


Fig. 9 Discharge due to time at constant road type and load at day light

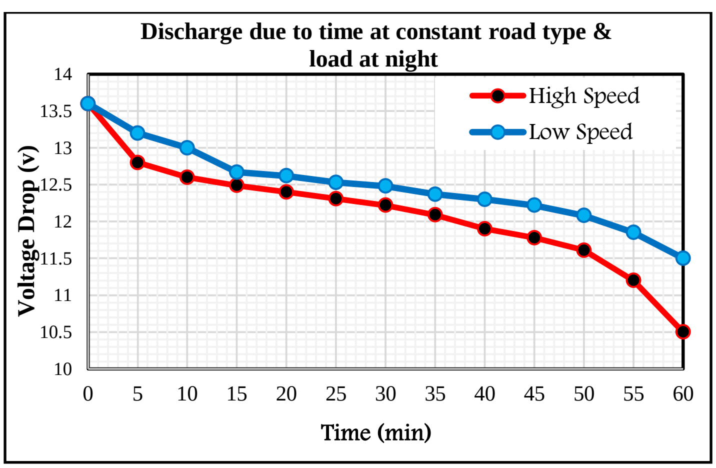


Fig.10 Discharge due to time at constant road type and load at night

5.1.2 Effect The Load And Timing On Voltage Discharge:-

Through conducting experimental comparisons of constant conditions (Asphalt Road type and speed 20km/hr), with varying loads during both daytime and nighttime, the effect of load on battery discharge was investigated, as presented in **Figures 11 and 12**. Based on the results shown in Figure 11, it is evident that the load has a significant impact on battery discharge. With a load of 210 kg during daylight, the final voltage reading after 5 minutes was 11.26 V, whereas with an additional 10 kg load, the voltage reading was 10.8V at the same time. A 40 kg load resulted in a voltage reading of 10.1 V. Notably, the voltage decreases more rapidly during nighttime, as illustrated in Figure 12. Thus, the load is a critical factor in determining the extension of battery life.

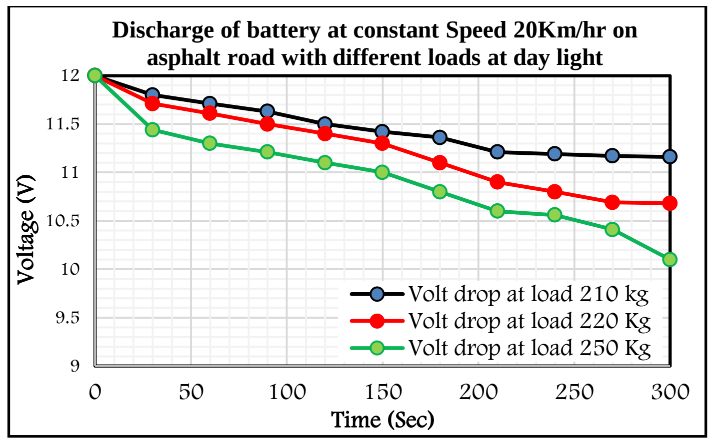


Fig. 11 Discharge of battery on asphalt at speed 20km/hr with difference load at day light

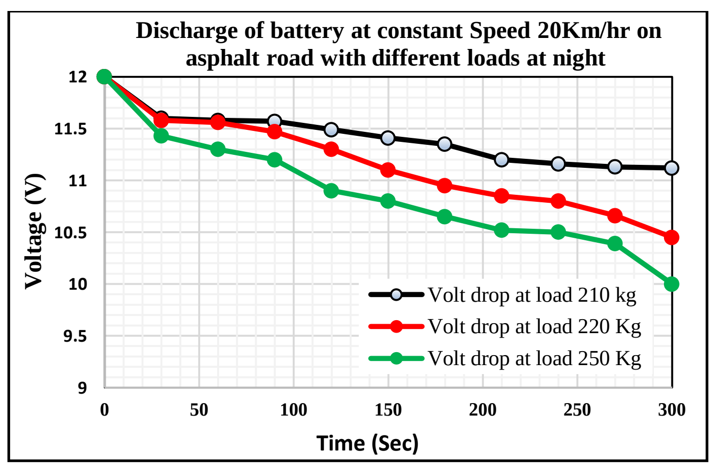


Fig. 12 Discharge battery on Asphalt at speed 20km/hr at night

5.1.3 Effect the timing on voltage discharge:-

In Figure 13, the voltage drop was measured at varying speeds until the maximum speed was reached. The findings reveal that the car's performance is more efficient during the daytime compared to nighttime. **Figure 14** presents the results of testing different weights (210 kg, 220 kg, and 250 kg) on two different road types, asphalt and grass. The voltage drop during startup increased, and it was observed that the car operated more efficiently on asphalt roads compared to grass roads.

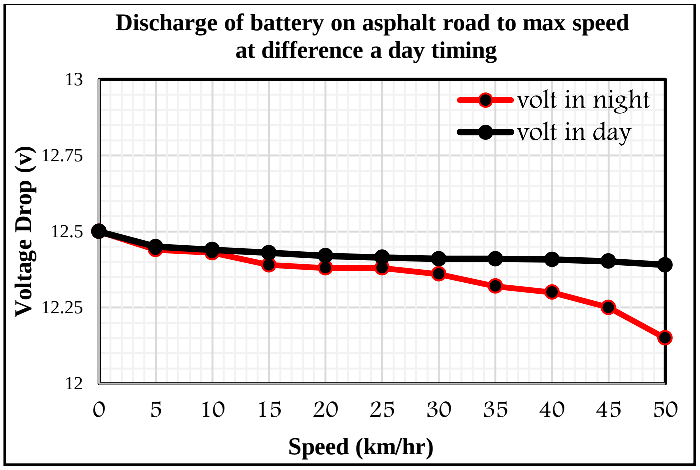


Fig.13 Discharge of battery on asphalt road at difference a day timing

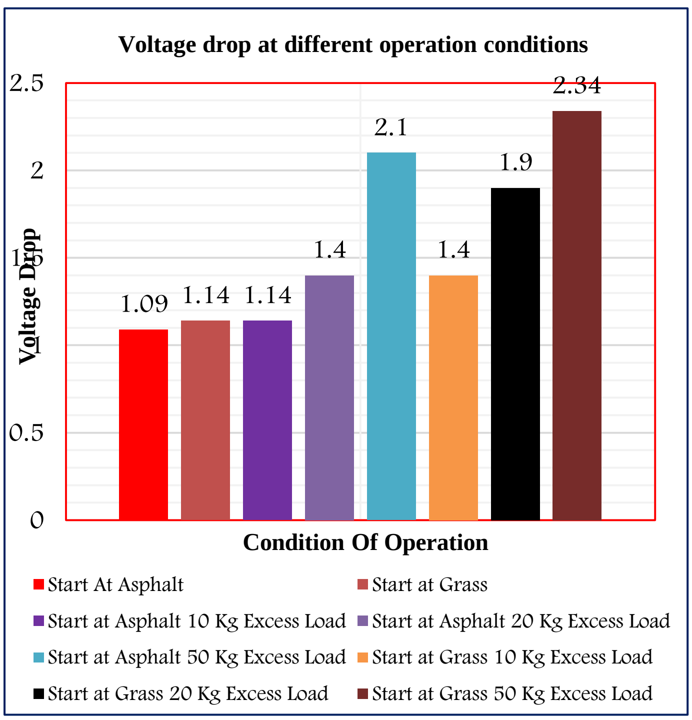


Fig. 14 Voltage drops due to different operation conditions

5.1.4 Effect the Road Type on Speed:-

Figure 15 compares the time required to cover a distance of 600 meters, accelerating from zero, on different road types (grass and asphalt). The results indicate that the type of road significantly affects the time needed to cover the distance. Specifically, when the vehicle starts on grass, it takes approximately 120 seconds to reach the endpoint, while on asphalt it takes approximately 100 seconds. This suggests that the road type can have a significant impact on the performance of the EV, potentially affecting its efficiency and battery life.

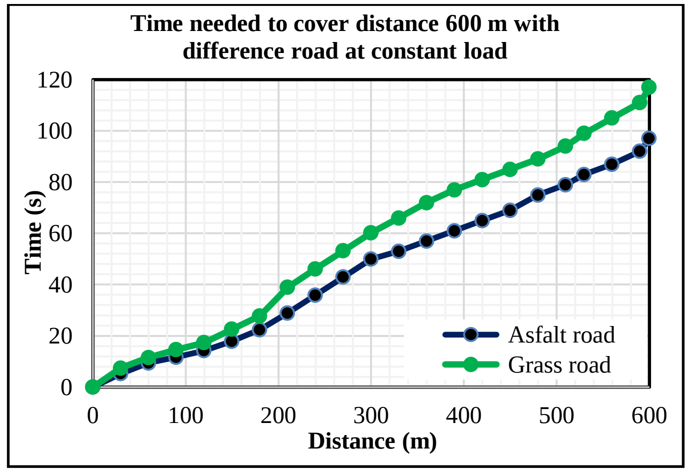


Fig.15 Time to cut 600 m

5.1.5 Effect Throttle Angle on Velocity and Power:-

The gathered data and graph demonstrate a linear relationship between the speed and power drawn and the throttle angle. At a greater throttle angle, all values become saturated. When there is no load, just 184 W of forward power and 64.24 W of reverse power are drawn from the battery at full throttle. The motor's current consumption and RPM are lower in reverse than in forward motion.

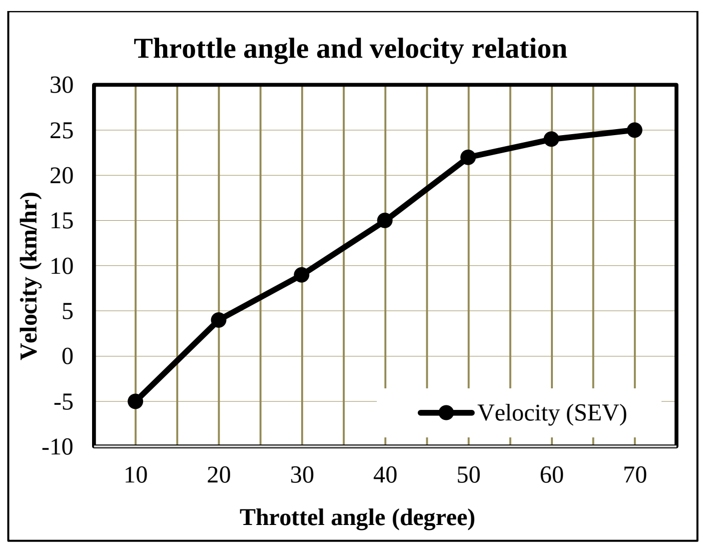


Fig. 16 Throttle angle and velocity relation

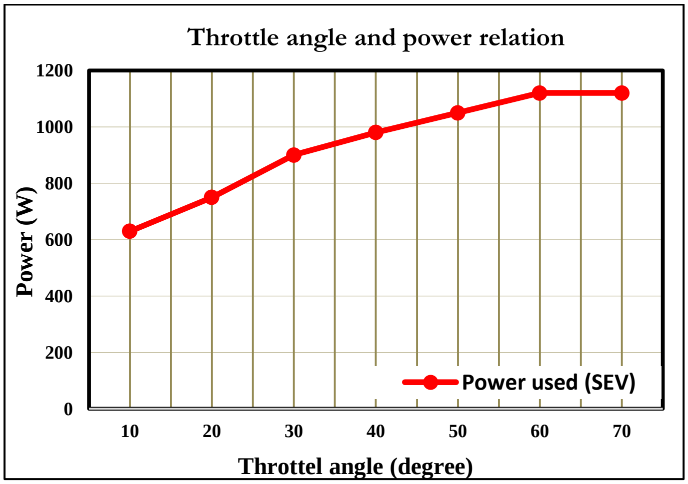


Fig.17 Throttle angle and power relation

6. CONCLUSION

In conclusion, this investigation has provided valuable insights into the practical efficiency and performance of semi-flexible monocrystalline silicon PV panels and solar vehicles. The results suggest that the practical efficiency of these panels is lower than what is claimed under standard test circumstances, and that the efficiency of the entire solar vehicle system is also lower than expected.

Four variables (Road type, Vehicle speed, Load, and Time of experiment) are being altered simultaneously in this investigation. Upon completion of the experimental work, the findings are as follows:

The results showed that, despite the manufacturer company's claim of 17% under standard test circumstances of 1000 W/m2 and 25 °C, the average practical efficiency of semi-flexible monocrystalline silicon PV panels is roughly 11%. The efficiency of the solar vehicle's entire system, from the PV panel to the wheel, was similarly observed to be around 9%. Therefore, the practical losses of the PV panels and vehicle power supply system should be taken into account in order to design any solar car with the least amount of error. If not, theoretical approximation should fall short of what is actually required. Additionally, the solar car's performance tests revealed a top speed of 50 km/h and a range of 19.29 km.
The objective is to apply this conclusion to regularly used electric vehicles, even if the main paper of this study focuses mostly on helping electric automobiles. Therefore, the solar car offers the finest pollution-free solution and addresses numerous environmental issues. In order to lessen our reliance on fossil fuels, we must utilize them. Solar cars do have several drawbacks, such as a limited speed range and a high starting cost. Additionally, the rate of energy conversion (only 13%) is unsatisfactory. But if further study is done in this area, these drawbacks can be readily overcome. For example, the issue with solar cells can be resolved by employing extremely efficient solar cells that provide roughly 30–35% efficiency. Overall, this investigation highlights the potential of solar cars as a sustainable transportation solution, and underscores the need for continued research and development in this field. Some of the recommendations for better improvement of results are stated as:

- **i.** Using lithium-ion batteries to lighten things up.
- **ii.** Solar panels that are flexible can be used as a superstructure.
- **iii.** Utilize an effective solar charge controller to monitor the sun's maximum power.
- **iv.** Using a motor with high power for excellent performance.
- **v.** Battery performance can be improved by using the BMS system.
- **vi.** High performance solar panels made on monocrystalline material are available.

7. RECOMMENDATIONS

Based on the findings of this study, several recommendations can be made for the development and improvement of solar-powered cars:

1. Optimize the solar panel efficiency: The overall system efficiency of the solar car was found to be around 9%. Improving the efficiency of the solar panels can significantly enhance the performance and range of the vehicle.

2. Utilize solar energy during the day: The results indicate that solar energy is more effective in reducing battery discharge during daylight hours. Therefore, EVs equipped with solar panels should be designed to optimize the use of solar energy during the day.

3. Consider road type and speed: The type of road and speed can have a significant impact on the performance and efficiency of the EV. Therefore, designers should take into account the road conditions and speeds likely to be encountered by the vehicle.

4. Further testing and development: More extensive testing and development of solar-powered cars is needed to improve their efficiency, range, and practicality. This can include advancements in battery technology, solar panel efficiency, and vehicle design.

5. Raise public awareness: Educating the public about the benefits of solar-powered cars can increase demand for these vehicles and accelerate their development and adoption.

Yes, implementing these recommendations can indeed help in resolving many issues faced by the vehicle industry. Solar cars can play a crucial role in reducing carbon emissions and promoting sustainable transportation. By improving the efficiency, range, and practicality of solar-powered cars, they can become a viable option for daily use, reducing the dependency on fossil fuels and promoting a cleaner environment. Moreover, the market for solar cars is expected to grow in the coming years, as more and more people become aware of the benefits of renewable energy and sustainable transportation. By investing in the development of solar-powered cars, the industry can tap into this growing market and offer customers a more environmentally-friendly and cost-effective transportation option.
Overall, the implementation of these recommendations can pave the way for a more sustainable and energy-efficient future for transportation, benefiting not only the environment but also the economy and society as a whole.

REFERENCE

1. Neupane, S., Joshi, P., Badu, S., Kalauni, R. K., and Rajak, B. P. (2021). Design Modification and Performance Testing of Solar Assistive Electric Vehicle. Journal of Innovations in Engineering Education, 4 (1).

2. Li, Z., Li, Y., and Li, Y. (2021). A review of solar-powered electric vehicles. Renewable and Sustainable Energy Reviews, 139, 110678. https://doi.org/10.1016/j.rser.2020.110678.

3. Abouel-Seoud, S. A., Shiba, M. S., and Abdallah, A. S. (2022). Real world evaluation and control of vehicle engine exhaust air pollution using adaptive neural fuzzy inference system. International Journal of Engine Research, 1468-0874. https://doi.org/10.1177/14680874221133213

4. Bhatti, A. R., Salam, Z., Abdul Aziz, M. J. B., and Yee, K. P. (2016). A critical review of electric vehicle charging using solar photovoltaic. International Journal of Energy Research, 40(4), 439-461.

5. Lindgren, J., Niemi, R., and Lund, P. D. (2014). Effectiveness of smart charging of electric vehicles under power limitations. International Journal of Energy Research, 38, 404–414. doi: 10.1002/er.3130.

6. An, T. (2021). Study of a new type of electric car: Solar-powered car. In Earth and Environmental Science, 2021 3rd International Conference on Air Pollution and Environmental Engineering. doi: 10.1088/1755-1315/631/1/012118.

7. Bitencourt, L., Borba, B. S., Dias, B. H., and Maciel, R. S. (2019). Electric vehicles charging optimization to improve the insertion considering the Brazilian regulatory framework. Energy Storage, 1, e76. doi: 10.1002/est2.76.

8. Zhang, W., Zhang, D., Mu, B., Wang, L. Y., Bao, Y., Jiang, J., and Morais, H. (2017). Decentralized electric vehicle charging strategies for reduced load variation and guaranteed charge completion in regional distribution grids. Energies, 10 (2), 147. doi: 10.3390/en10020147.

9. Rattankumar, V., and Gopinath, N. P. (2012). Solar powered car using brushless DC hub motor with advanced PIC microcontroller. 2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM), December, 13-15, doi:10.1109/ICETEEEM.2012.6494483.

10. Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., and Marquez-Barja, J. M. (2021). A Review on Electric Vehicles: Technologies and Challenges. Smart Cities, 4(1), 372-404. doi:10.3390/smartcities4010022.

11. Abdelhamid, M., Rhodes, K., Christen, E., and Kok, D. (2018). Solar Panels on Electrified Vehicles: Applications and Off-Cycle CO2 Credit. SAE International Journal of Alternative Powertrains, 7(3), 311-322. doi:10.4271/2018-01-0426.

12. Un-Noor, F., Padmanaban, S., Lucian Mihet-Popa, L., Mollah, M. N., and Hossain, E. (2017). A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development. Energies, 10, 1217. doi:10.3390/en10081217.

13. Adegbohun, F., Jouanne, A., Phillips, B., Agamloh, E., and Yokochi, A. (2021). High Performance Electric Vehicle Powertrain Modeling, Simulation and Validation. Energies, 14, 1493. doi:10.3390/en14051493.

14. Abdelmonem, M., and Said, G. (2021). Study of the Best Regions of Solar Radiation in Egypt. GSJ: Volume 9, Issue 10, October.

APPENDIX

The third table, which has been provided by the manufacturer, shows the evaluation of the solar panel used in this research.

Table 3: Rating of Solar Panel

Module160 Watt Monocrystalline Bendable	**Photovoltaic Module**
Max Power (Pmax)	160W
Max Power Voltage (Vmp)	18.8V
Max Power Current (Imp)	8.7A
Open Circuit Voltage (VOC)	23.3V
Short Circuit Current (ISC)	9.7A
Maximum System Voltage	600V
Series Fuse Rating	10A
Temperature Co-efficient Power	-0.38% / ^oC
Temperature Co-efficient Voltage	-60.8mV / ^oC
Temperature Co-efficient Current	2.2mA / ^oC
Cell Efficiency	17%
Number of Cells in Series	32
Max Power Tolerance	±5%
Weight	11 kg
Dimension	1480*680*36

Nomenclature	
a	*Acceleration, m/s^2 (0.3:0.5)*
g	*Gravitational acceleration, m/s^2*
m	*Vehicle mass, kg*
v	*Speed of the vehicle, m/s*
Ac	*Frontal area of the vehicle, m^2 (1.85)*
A_{PV}	*Photovoltaic PV area, m^2*
q_{PV}	*Photovoltaic PV power, W*
C_w	*Coefficient of drag (0.3)*
C	*Average current, A*
V	*Average voltage, V*
F_{AC}	*Needed force for acceleration, N*
F_{AE}	*Needed force for aerodynamic resistances, N*
F_{CR}	*Needed force for grade (Climbing) resistance, N*
F_{RR}	*Needed force for rolling resistance, N*
q_{TP}	*Needed total power of the vehicle, W*
f_R	*Coefficient of rolling friction (0.01:0.02)*
F_{TT}	*Needed total force to overcome all resistances, N*
I_R	*Incident solar radiation, W/m^2*
q_{SR}	*Incident solar power, W*