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Solar-Powered Electric Vehicles: Enhancing Endurance and Sustainability through Photovoltaic Integration

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Abstract. The potential of solar photovoltaic (PV) technology as a transformative and sustainable energy solution in the context of global energy challenges is explored in this work. The advancements in solar PV technology, including innovative cell architectures like heterojunction and Passivated Emitter Rear Contact (PERC) cells, the emergence of perovskite solar cells, and the influence of roll-to-roll manufacturing processes are discussed in this paper. The paper also highlights the diversification of energy portfolios, enhanced energy system reliability, resilient energy infrastructure, energy security, and the profound environmental benefits associated with solar PV technology. The results of a performance study involving a prototype electric vehicle, both with and without integrating a solar panel as an alternative energy source are noted. The findings reveal a substantial increase in the vehicle's endurance when the solar panel is incorporated, emphasizing the transformative potential of solar PV in reshaping energy systems, mitigating environmental hazards, and promoting responsible land use. The work underscores the ongoing journey towards a cleaner and more resilient energy future, empowered by the harnessing of solar energy.

Keywords: Solar PV Technology; Energy Sustainability; Electric Vehicle Integration; Solar Power Endurance; Renewable Energy Solutions.

1. Introduction

The depletion of non-renewable energy resources and the challenges posed by climate change are key factors fuelling the transformation of the energy industry worldwide [1]. Fossil fuels (oil, gas and coal) have been the major source of energy for decades and their continued use pose a significant threat to the planet. This threat has sparked the need for the exploration of cleaner and renewable options [2], [3]. A very viable option, which has proven to hold much promise as a result of abundant energy from the sun, is solar photovoltaic technology. This study explores the power of this technology when used alongside other energy sources.

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Much popularity has been gained by solar photovoltaic technology as a result of its ability to directly transform light into electrical energy. This presents an environment-friendly and unlimited source of energy [4]. This technology holds promise not only in the context of reducing carbon emissions but also in diversifying the energy mix and enhancing energy security [5]. In recent times, the breakthroughs in PV technology have significantly increased the efficiency making it more viable for grid integration [6]. In addition, the integration of solar PV technology exceeds the aim of generating electricity [7]. Architectural designs have explored the aesthetic appeal and functional purpose of including solar panels in buildings. Windows and rooftops have been designed and constructed to also serve as solar panels for power generation.

One of the major drawbacks of solar energy is its intermittent nature which has been tackled by the availability of energy storage technologies (heat [8], [9], chemical, etc) , making it a more reliable source. Environmental impacts of the PV technology from production to disposal stages have been studied and evaluated [10]. Regardless of the advantages identified, issues like cost-effectiveness, energy storage capacity, and grid integration still require attention [11]. Grid integration challenges of high-penetration solar PV systems have been studied extensively, highlighting the need for innovative solutions. Researchers have also investigated the impact of solar PV adoption on residential electricity consumption patterns [12].

Solar PV technology has emerged as a promising and transformative solution in the quest for cleaner and more sustainable energy sources. Its technical capabilities, coupled with its potential to mitigate environmental concerns, make it a pivotal player in reshaping the global energy landscape. As research and innovation continue to drive improvements in efficiency, storage, and integration, solar PV technology is poised to play an increasingly vital role in meeting the world's energy needs while safeguarding the planet [13].

1.1 Solar PV as a Complementary Energy Source

Advancements in Solar PV Technology The current state of maturity of solar PV technology is attributed to dedicated and continuous research and development efforts aimed at improving the efficiency, cost-effectiveness, stability and feasibility of solar energy conversion. So far, researchers have made significant progress in improving the overall performance of photovoltaic cells, leading to increased energy output from solar panels [14]. This advancement has been achieved through various innovative approaches, including the development of novel cell architectures and the exploration of new materials.

Innovative Cell Architectures: Heterojunction and PERC Cells Two vivid examples of significant advancements in this technology are the Heterojunction and Passivated Emitter Rear Contact (PERC) cell architectures. Heterojunction cells combine different materials with varying energy bandgaps to create efficient electron-hole separation and collection mechanisms. This reduces losses due to recombination and enhances overall efficiency. PERC cells, on the other hand, involve a rear surface passivation layer that minimizes electron recombination, allowing for improved collection of charge carriers. These architectures significantly contribute to higher energy conversion efficiency in solar panels [15].

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Breakthroughs in Materials Science: Perovskite Solar Cells Perovskite solar cells have garnered considerable attention due to their exceptional light-absorbing properties and potential for cost-effective fabrication. Perovskites are a class of materials with a specific crystal structure that allows them to efficiently convert sunlight into electricity. They can be manufactured using simpler processes compared to traditional silicon-based solar cells, making them attractive for large-scale production. Although challenges such as stability and scalability remain, perovskite solar cells have demonstrated impressive efficiency improvements over a short period, highlighting their potential as a disruptive technology in the solar industry [16].

Innovations in Manufacturing Techniques: Roll-to-Roll Processing Manufacturing techniques play a significant role in determining the cost and accessibility of solar panels. Roll-to-roll processing is an innovative manufacturing approach that involves the continuous fabrication of solar cells on flexible substrates. This technique streamlines production, reduces material waste, and lowers manufacturing costs. As a result, solar panels become more affordable and accessible to a broader range of consumers. This advancement is essential for driving the widespread adoption of solar technology as a viable energy source [17].

Advancements in solar PV technology have been driven by research into improving the efficiency of photovoltaic cells, development of innovative cell architectures like heterojunction and PERC cells, exploration of new light-absorbing materials like perovskites, and innovations in manufacturing techniques such as roll-to-roll processing. These innovations collectively contribute to higher energy conversion efficiency, making solar energy a more attractive and practical option for a variety of applications, from large-scale power generation to residential installations.

1.2 Diversification of Energy Portfolios
The diversification of energy portfolios through solar PV integration provides a hedge against a range of risks. Economically, it reduces vulnerability to price volatility in fossil fuel markets. Geopolitically, it lessens dependence on energy resources from politically unstable regions. Environmental risks, such as regulatory changes aimed at reducing carbon emissions, are also mitigated by incorporating a cleaner energy source.

In regions heavily reliant on a single energy source, such as coal or oil, the transition to solar PV can lead to a more resilient and adaptable energy mix. This diversification not only enhances energy security but also creates opportunities for economic growth and job creation in the renewable energy sector.

Enhancing Energy System Reliability Solar PV's contribution to energy system reliability lies in its distributed generation model. During peak demand periods, centralized power plants can struggle to meet the heightened energy requirements, leading to strain on the grid and potential blackouts [18]. Solar PV installations, scattered across rooftops, solar farms, and other locations, alleviate this strain by providing localized power generation.

Furthermore, the modularity of solar PV installations allows for incremental expansion. As energy demands grow, additional solar panels can be easily integrated into the system. This

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flexibility ensures that the energy supply can adapt to changing needs without requiring large-scale infrastructure overhauls.

Resilient Energy Infrastructure The resilience of energy infrastructure is crucial for maintaining essential services during crises. Natural disasters, cyberattacks, and other disruptions can cripple centralized energy systems. Solar PV's distributed nature offers a solution: even if some installations are affected, others remain operational. This redundancy prevents complete system failures and ensures that critical facilities can continue to function.

Solar installations can also be combined with microgrid systems, allowing local communities to operate independently from the main grid if needed [19]. This capability enhances community resilience during emergencies, providing vital services and communication channels when central power systems might be compromised.

Energy Security and Independence Energy security becomes increasingly critical as global energy markets face geopolitical uncertainties [20]. Relying on energy imports can expose countries to risks ranging from supply disruptions due to conflicts to trade-related challenges. By integrating solar PV, nations can reduce their reliance on external sources, bolstering their energy security.

1.3 Environmental Benefits

The environmental advantages of solar PV are profound. Unlike fossil fuels, solar energy production releases no greenhouse gases [21], sulfur dioxide, or particulate matter. This translates to improved air quality, reduced health risks, and a lower carbon footprint. The integration of solar PV aligns with international climate agreements and environmental goals, making it a critical tool in the fight against climate change. Moreover, the adoption of solar PV contributes to sustainable land use. Solar installations can be deployed on a variety of surfaces, from rooftops to unused land. This minimizes the need for large-scale land clearance associated with some traditional energy sources, preserving ecosystems and biodiversity.

The continuous evolution of solar PV technology carries profound implications across various dimensions of energy and society. From advanced materials to resilience in emergencies, solar PV emerges as a versatile and transformative energy solution with the potential to reshape how we generate, distribute, and think about energy. In addition, Solar PV's technological advancements, from pioneering cell architectures to the discovery of innovative materials like perovskites, have propelled efficiency levels to unprecedented heights [22]. This enhanced efficiency translates into more compact installations and broader accessibility, vital for optimizing energy generation in constrained spaces.

The resilience of energy infrastructure is underscored by solar PV's decentralized nature. The ability to operate independently during emergencies through microgrid systems enhances community resilience, ensuring critical services persist even when faced with disruptions. Furthermore, solar PV's stabilizing effect on the grid, combined with energy storage solutions, nurtures grid stability and flexibility, minimizing voltage fluctuations and ensuring a consistent power supply.

Perhaps most significantly, the environmental advantages of solar PV cast a long shadow over traditional energy sources. Its ability to generate clean, emissions-free energy aligns with global climate goals and curbs the detrimental impacts of conventional energy production on air quality and public health. Solar PV's adaptable deployment options promote responsible land use, protecting ecosystems and biodiversity.

In essence, solar PV has transcended its role as a mere energy source to become a cornerstone of sustainable progress. From reshaping energy systems to mitigating environmental hazards, its influence resonates through economic, social, and ecological dimensions. The journey to integrate solar PV into our energy fabric is ongoing, fuelled by innovation, collaboration, and a shared commitment to a cleaner and more resilient energy future. The aim of this work is to demonstrate the advantage of solar powered electric vehicles over those designed without immediate access to solar power.

2. Methodology

Two vehicles were constructed. One with and the other without a solar panel for comparison (Figures 1 and 2). The components used were electric motors, three-way switch, battery packs, batteries, solar panel, led lights, voltage-current sensor (MAX471), Arduino Uno, and RTC module (DS3231) to record time. The voltage, current, time and power index readings were analyzed and calculated for 2 hours 30 mins at an interval of 10 mins for 3 days for the batteries of the electric vehicle with and without the solar panel. The data obtained were processed and analysed to acquire the graphs that will be discussed in the next section. Data showing the variation of voltage and current with time as well as the variation of power and voltage with time is presented in plots in the next section.

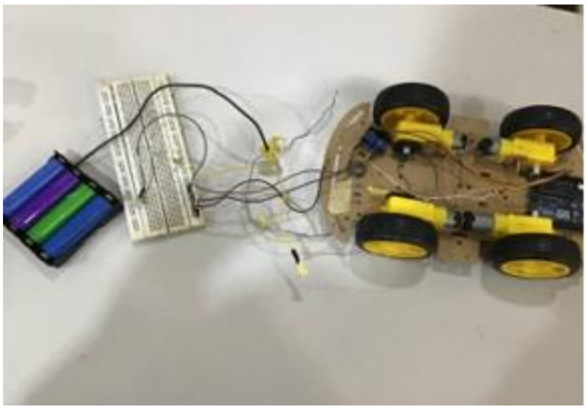

Figure 1: Electric vehicle and battery cell

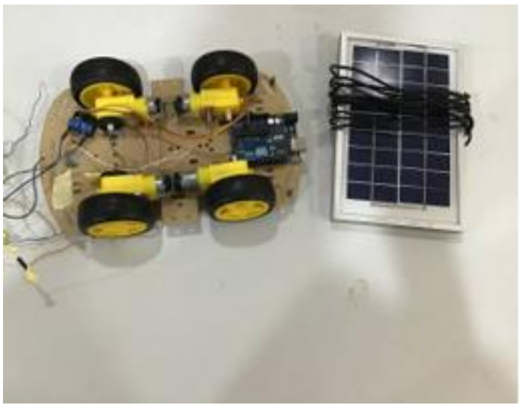

Figure 2: Electric vehicle and solar cell

3. Results and Discussion

This section shows the results obtained from the performance study of the power duration of the prototype electric vehicle with and without an alternative energy source (Solar radiation). A steady decline in the voltage and current values can be clearly observed from Figures 7 – 8. This level of decline is as a result of no enhancement from the solar panel.

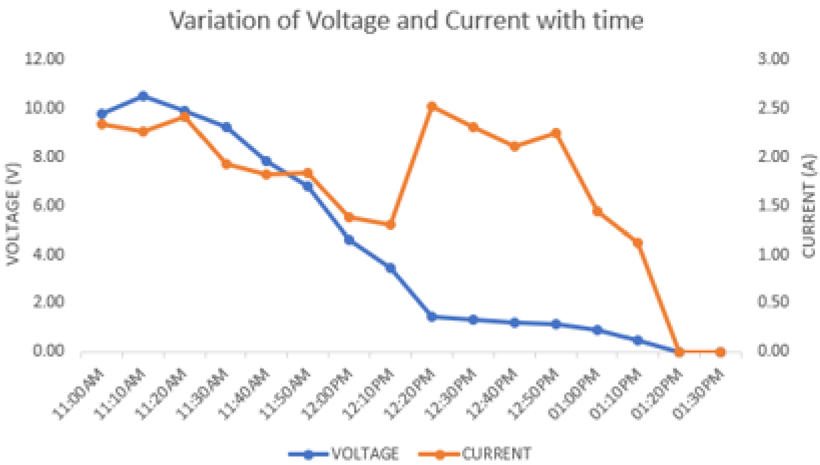

Figure 3: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without the solar panel.

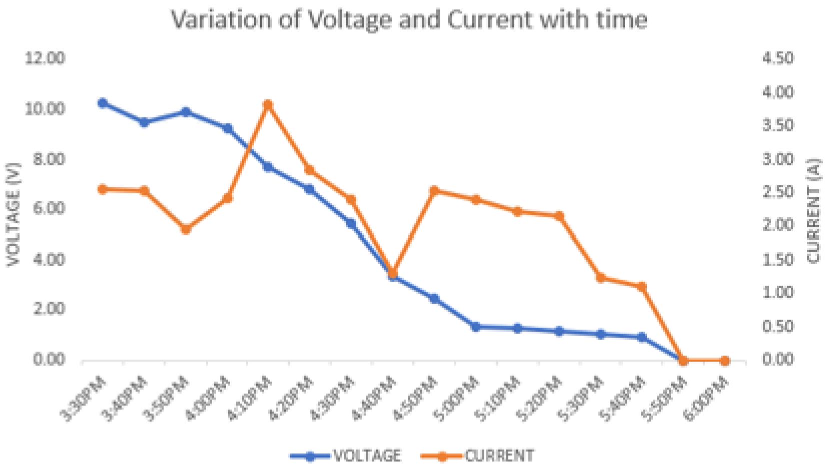

Figure 4: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without solar panel. This reading was taken after 2hours of recharge of batteries.

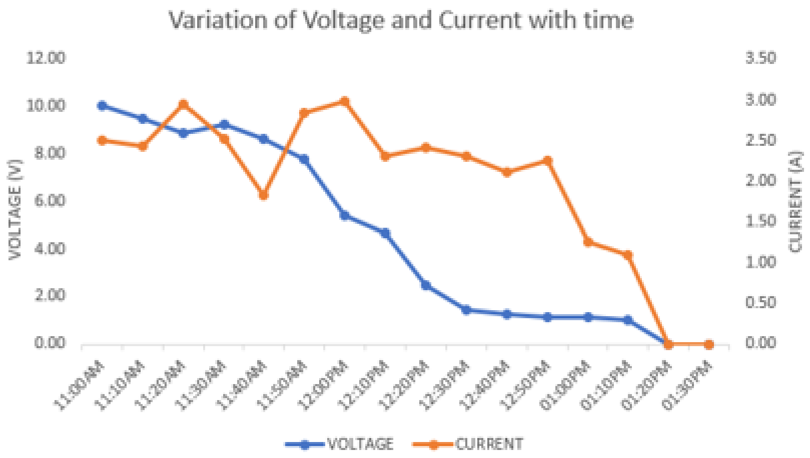

Figure 5: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without solar panel.

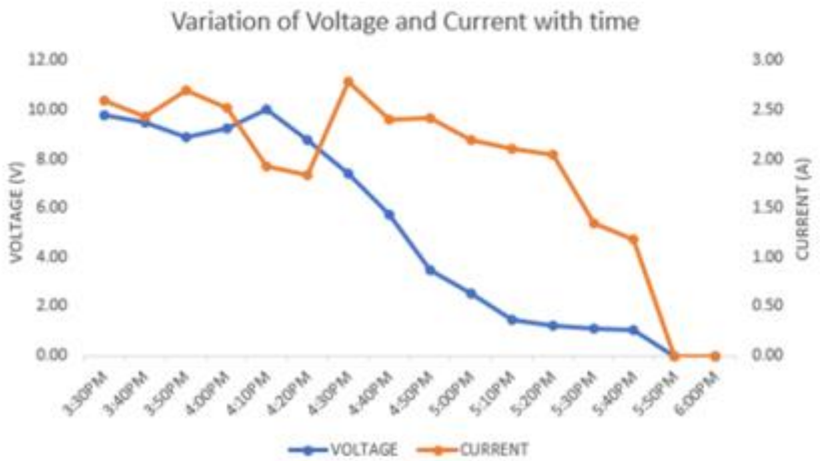

Figure 6: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without solar panel. This reading was taken after 2 hours of recharge of batteries.

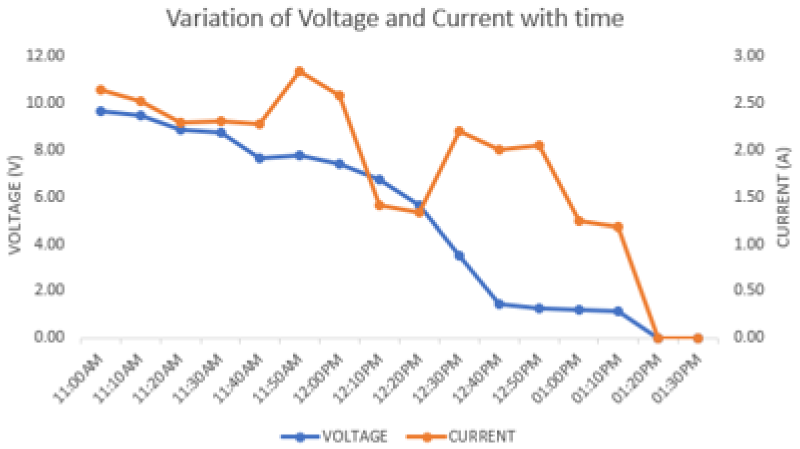

Figure 7: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without the solar panel.

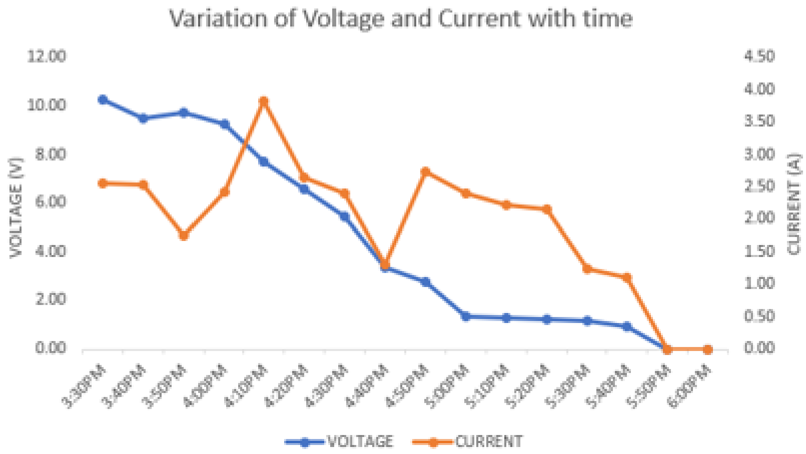

Figure 8: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle without solar panel. This reading was taken after 2 hours of recharge of batteries.

After 3 days of taking readings of current of the electric motor and battery voltage as a function of time for the built prototype, the solar panel was connected to the battery pack and further readings of current and voltage were taken. Figure 9 – 1 shows a steady voltage and current reading compared to those in Figures 3 – 8. This indicates the effect of having an alternative power source (solar panel in this case).

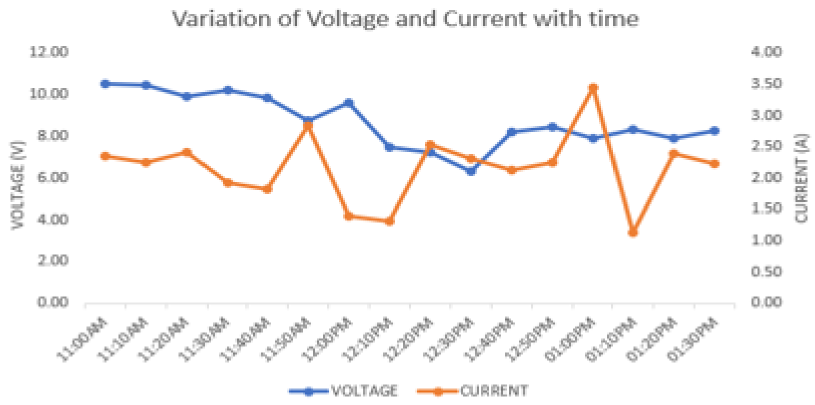

Figure 9: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle with solar panel.

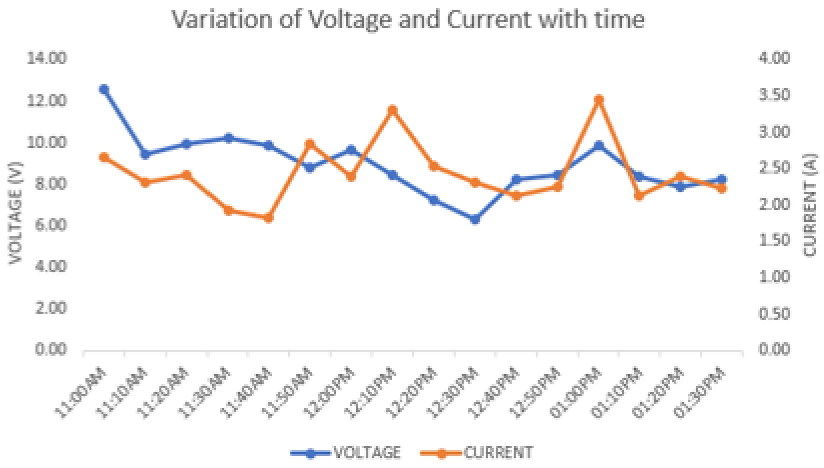

Figure 10: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle with solar panel.

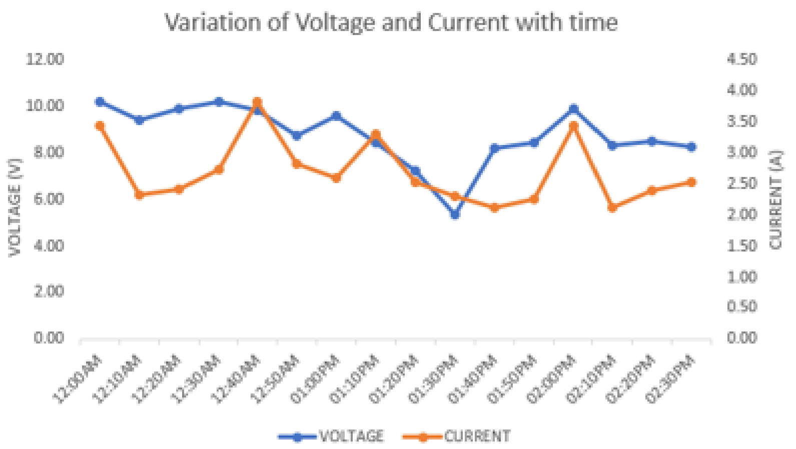

Figure 11: The current of the electric motor and battery voltage as a function of time for the built prototype solar vehicle with solar panel.

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From the results presented in Figures 3 – 8, it could be observed that the prototype electric vehicle could only last 2 hours 30 mins before the batteries went to zero. However, from Figures 9 - 11, it can be observed that with the help of the sun acting as an alternative charging supply using the solar panel, 2 hours 30 minutes after, the prototype was still sustained and test running on. This is because the sun kept generating power to the electric vehicle while the test running was going on.

4. Conclusion and Recommendation

The study presented in this paper investigated the performance of a prototype electric vehicle with and without the integration of a solar panel as an alternative energy source. The results revealed a significant difference in the vehicle's endurance. Without the solar panel, the prototype could only last for 2 hours and 30 minutes before the batteries were depleted. However, when the solar panel was incorporated, the electric vehicle continued to operate after the same duration of testing, benefiting from the continuous generation of solar power.

This outcome underscores the potential of solar power in enhancing the sustainability and resilience of electric vehicles. Solar PV technology, as demonstrated in this study, offers an effective means to prolong the operational duration of electric vehicles, reduce dependence on grid electricity, and contribute to the reduction of greenhouse gas emissions. As the world grapples with the challenges of climate change and the need for cleaner energy solutions, the integration of solar PV in various applications, including transportation, emerges as a pivotal strategy to meet energy needs while safeguarding the environment. The journey towards a more sustainable energy future continues to be illuminated by the transformative capabilities of solar PV technology.

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REFERENCES

[1] N. K. Dubash and A. Florini, “Mapping Global Energy Governance,” *Global Policy,* vol. 2, no. s1, pp. 6–18, 2011, doi: 10.1111/j.1758-5899.2011.00119.x.

[2] E. A. Diagi, M. L. Akinyemi, M. E. Emetere, I. E. Ogunrinola, and A. O. Ndubuisi, “Comparative analysis of biogas produced from cow dung and poultry droppings,” in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2019, p. 012064. Accessed: Nov. 09, 2023. [Online]. Available: https://iopscience.iop.org/article/10.1088/1755-1315/331/1/012064/meta

[3] R. Nepal, H. Phoumin, and A. Khatri, “Green Technological Development and Deployment in the Association of Southeast Asian Economies (ASEAN)—At Crossroads or Roundabout?,” *Sustainability*, vol. 13, no. 2, Art. no. 2, Jan. 2021, doi: 10.3390/su13020758.

[4] A. T. Hoang, V. V. Pham, and X. P. Nguyen, “Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process,” *Journal of Cleaner Production,* vol. 305, p. 127161, Jul. 2021, doi: 10.1016/j.jclepro.2021.127161.

[5] D. Zhu, S. M. Mortazavi, A. Maleki, A. Aslani, and H. Yousefi, “Analysis of the robustness of energy supply in Japan: Role of renewable energy,” *Energy Reports*, vol. 6, pp. 378–391, Nov. 2020, doi: 10.1016/j.egyr.2020.01.011.

[6] S. Shahzad, M. A. Abbasi, H. Ali, M. Iqbal, R. Munir, and H. Kilic, “Possibilities, Challenges, and Future Opportunities of Microgrids: A Review,” *Sustainability*, vol. 15, no. 8, Art. no. 8, Jan. 2023, doi: 10.3390/su15086366.

[7] M, Freitag, J. Teuscher, Y. Saygili, X. Zhang, F. Giordano, P. Liska, J. Hua, S.M. Zakeeruddin, J. E. Moser, M. Grätzel and A. Hagfeldt, “Dye-sensitized solar cells for efficient power generation under ambient lighting,” *Nature Photon*, vol. 11, no. 6, Art. no. 6, Jun. 2017, doi: 10.1038/nphoton.2017.60.

[8] I. E. Ogunrinola, M. L. Akinyemi, H. O. Boyo, O. Maxwell, A. Akinpelu, and T. E. Arijaje, “Evolvement of thermal energy storage systems,” in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2018, p. 012042. Accessed: Nov. 09, 2023. [Online]. Available: https://iopscience.iop.org/article/10.1088/1755-1315/173/1/012042/meta

[9] I. Ogunrinola, M. Akinyemi , A. Aizebeokhai, R. Sule, S. Sanni, H. Boyo, M. Omeje and P. Babalola., “Silica and kaolin reinforced aluminum matrix composite for heat storage,” *REVIEWS ON ADVANCED MATERIALS SCIENCE*, vol. 62, no. 1, p. 20220305, May 2023, doi: 10.1515/rams-2022-0305.

[10] M. P. Tsang, G. W. Sonnemann, and D. M. Bassani, “Life-cycle assessment of cradle-to-grave opportunities and environmental impacts of organic photovoltaic solar panels compared to conventional technologies,” *Solar Energy Materials and Solar Cells*, vol. 156, pp. 37–48, Nov. 2016, doi: 10.1016/j.solmat.2016.04.024.

[11] O. J. Guerra, J. Zhang, J. Eichman, P. Denholm, J. Kurtz, and B.-M. Hodge, “The value of seasonal energy storage technologies for the integration of wind and solar power,” *Energy Environ. Sci.*, vol. 13, no. 7, pp. 1909–1922, Jul. 2020, doi: 10.1039/D0EE00771D.

[12] X. Shen, Y. L. Qiu, X. Bo, A. Patwardhan, N. Hultman, and B. Dong, “The impact of co-adopting electric vehicles, solar photovoltaics, and battery storage on electricity consumption patterns: Empirical evidence from Arizona,” *Resources, Conservation and Recycling*, vol. 192, p. 106914, May 2023, doi: 10.1016/j.resconrec.2023.106914.

[13] A. Kumar, K. Kumar, N. Kaushik, S. Sharma, and S. Mishra, “Renewable energy in India: Current status and future potentials,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 8, pp. 2434–2442, Oct. 2010, doi: 10.1016/j.rser.2010.04.003.

[14] Z. Zhang, Z. Chen, J. Zhang, W. Chen, J. Yang, X. Wen, B. Wang, N. Kobamoto, L. Yuan, J. A. Stride, G. J. Conibeer, R. J. Patterson, S. Huang, “Significant improvement in the performance of PbSe quantum dot solar cell by introducing a CsPbBr3 perovskite colloidal nanocrystal back layer,” *Advanced Energy Materials*, vol. 7, no. 5, p. 1601773, 2017.

[15] Z. C. Holman, A. Descoeudres, S. De Wolf, and C. Ballif, “Record infrared internal quantum efficiency in silicon heterojunction solar cells with dielectric/metal rear reflectors,” *IEEE Journal of Photovoltaics*, vol. 3, no. 4, pp. 1243–1249, 2013.

[16] N.-G. Park, “Perovskite solar cells: an emerging photovoltaic technology,” *Materials today*, vol. 18, no. 2, pp. 65–72, 2015.

[17] M. L. Chabinyc; W. S. Wong; A. C. Arias; S. Ready; R. A. Lujan; J. H. Daniel; B. Krusor; R. B. Apte; A. Salleo and R. A. Street, “Printing methods and materials for

large-area electronic devices," *Proceedings of the IEEE*, vol. 93, no. 8, pp. 1491–1499, 2005.
[18] S. Matthewman and H. Byrd, "Blackouts: A Sociology of Electrical Power Failure," Jan. 2014, Accessed: Aug. 27, 2023. [Online]. Available: https://researchspace.auckland.ac.nz/handle/2292/22764
[19] A. Hirsch, Y. Parag, and J. Guerrero, "Microgrids: A review of technologies, key drivers, and outstanding issues," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 402–411, Jul. 2018, doi: 10.1016/j.rser.2018.03.040.
[20] E. Hache, "Do renewable energies improve energy security in the long run?," *International Economics*, vol. 156, pp. 127–135, Dec. 2018, doi: 10.1016/j.inteco.2018.01.005.
[21] A. K. Karmaker, Md. M. Rahman, Md. A. Hossain, and Md. R. Ahmed, "Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh," *Journal of Cleaner Production*, vol. 244, p. 118645, Jan. 2020, doi: 10.1016/j.jclepro.2019.118645.
[22] "High-Efficiency Perovskite Solar Cells | Chemical Reviews." Accessed: Oct. 18, 2023. [Online]. Available: https://pubs.acs.org/doi/abs/10.1021/acs.chemrev.0c00107