



Integration of PVA Solar Cells in Automobiles: An Eco-Friendly Energy Alternative

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Abstract

This research paper describes the use of polyvinyl alcohol (PVA) solar cells in the automobile industry as a renewable energy solution. PVA solar cells have become more popular because of its lightweight and flexible properties, and can be easily integrated into vehicle surfaces to utilize solar energy. PVA solar cell technology gives numerous benefits to the user, including reduced reliance on fossil fuels, enhanced energy efficiency, and lower carbon emissions. The paper gives insights of the mechanisms of energy generation through these coatings, the environmental advantages of using biodegradable materials, and the potential for improved vehicle performance. Paper also addresses the challenges of durability, efficiency, and market acceptance. Eventually, the integration of PVA solar cells represents a promising step towards a more sustainable and eco-friendly automotive industry.

Keywords: Automobiles; Efficiency; Electric Vehicle; PVA; Solar Cell.

1. Introduction

As the transformation of the automotive industry continues, the need for sustainable energy solutions is also increasing rapidly. Now, it's time to switch to renewable energy sources due to significant increase in air pollution, and fossil fuel dependency leading to climate change. The major contribution to greenhouse gas emissions is transportation. People from urban areas are facing severe air pollution due to vehicle emissions, which leads to health issues. As global temperatures rise, there is an urgent need to reduce emissions. Transitioning to solar energy can significantly lower these effects. Many countries are seeking to reduce their reliance on imported fossil fuels. Dependency on non renewable sources reduces as solar energy, being abundant and renewable. Due to advanced technology used in solar cells, solar panels are now more efficient, lightweight, and cost-effective. Innovations such as flexible solar cells and organic photovoltaic are paving the way for their integration into vehicles. Nowadays, consumers increasingly prefer sustainable options as Electric vehicles (EVs) are on the rise, and many consumers are interested in vehicles that harness solar energy for

supplementary power. As the costs of solar technologies continue to decline, incorporating solar panels into vehicles becomes more economic. This not only enhances vehicle efficiency but also reduces the overall energy costs for consumers. The automotive industry is increasingly integrating smart technologies, such as vehicle-to-grid systems. Solar energy can play a crucial role in these systems, allowing vehicles to not only consume energy but also feed excess energy back into the grid [1].

1.1. Importance of PVA (Polyvinyl Alcohol) in Solar Applications

Polyvinyl Alcohol (PVA) material is a synthetic polymer with unique properties that make it particularly suitable for use in solar applications [2].

- **Transparency:** PVA is naturally transparent which allows sunlight to pass through it effectively. This property is important in solar applications, because it ensures that maximum light is available for energy conversion in photovoltaic cells.
- **Flexibility:** Integration of PVA on various surfaces is easy as it is flexible and can be

manufactured in thin films.

- **Water Solubility:** Water solubility is a useful property of PVA material which makes it easier to process and apply coatings as well as allows for environmentally friendly manufacturing processes, as it can be dissolved and reprocessed without harsh chemicals.
- **Mechanical Strength:** Despite its flexibility, PVA exhibits good mechanical strength and durability. This resilience is essential for outdoor applications, where solar coatings must withstand environmental stresses such as wind, rain, and temperature fluctuations.
- **Barrier Properties:** PVA has excellent barrier properties against gases and moisture. This quality can protect the underlying solar cells from environmental damage, thus prolonging their lifespan and efficiency [3].
- **Compatibility with Other Materials:** PVA can be easily combined with other materials, including nanoparticles and conductive polymers, to enhance the performance of solar cells. This compatibility allows for the development of advanced hybrid solar technologies.
- **Biodegradability:** As a biodegradable polymer, PVA is more environmentally friendly than many conventional materials used in solar applications. This aspect aligns with the growing emphasis on sustainability in energy technologies.
- **Low Cost and Availability:** PVA is relatively inexpensive and widely available, making it a practical choice for large-scale applications, including automotive coatings.

2. Literature Review

2.1. Summary of Existing Studies on PVA as a Substrate for Solar Cells

Research into the use of Polyvinyl Alcohol (PVA) as a substrate for solar cells has gained momentum due to its favorable properties. Here are some key findings from existing studies: Flexibility of PVA allows for the development of lightweight solar panels that can be integrated into various surfaces. PVA can improve the efficiency of solar cells when used as a protective layer or in combination with

other materials. Its coatings can provide adequate protection against moisture and UV exposure, which are critical for the longevity of solar cells. PVA is biodegradable, making it an environmentally friendly choice for solar applications. Research has explored its potential in developing sustainable solar technologies that align with global sustainability goals. Gaps in Research Specific to Automotive Applications. While studies on PVA in solar applications are promising, there are notable gaps when it comes to its use specifically in automotive contexts:

2.2. Integration with Vehicle Designs

Limited research has focused on the integration of PVA-based solar cells into the structural and aesthetic elements of vehicles. More studies are needed to explore how PVA coatings can be effectively applied to different car surfaces without compromising functionality or design [4].

2.3. Performance under Dynamic Conditions

Most existing studies have not adequately assessed the performance of PVA solar cells under the dynamic conditions experienced by vehicles, such as vibrations, varying temperatures, and exposure to pollutants. Understanding these factors is essential for automotive applications.

2.4. Efficiency Comparisons

There is a lack of comparative studies that evaluate the efficiency of PVA-based solar cells against traditional silicon-based systems in automotive applications. Research should aim to quantify performance metrics specific to vehicle energy needs.

2.5. Long-Term Durability Studies

Although some studies have assessed the environmental resistance of PVA, long-term durability tests in automotive environments (e.g., prolonged UV exposure, temperature fluctuations, and mechanical stress) are still needed to ensure reliability.

2.6. Economic Feasibility

Research exploring the economic implications of adopting PVA solar technologies in vehicles is limited. Studies assessing cost-benefit analyses, scalability, and market viability are essential for promoting widespread adoption [5].

System Integration:

The integration of PVA solar cells with existing vehicle systems, such as electrical systems and battery management, has not been thoroughly investigated. Understanding how these technologies can work together is crucial for optimizing vehicle performance [6].

3. Methodology

3.1. Coating Process: Applying PVA Solar Cells onto Car Surfaces

Applying PVA solar cells onto car surfaces involves several steps, ensuring proper adhesion, functionality, and durability. Here's an outline of the process:

3.1.1. Surface Preparation

- **Cleaning:** Thoroughly clean the car surface to remove dirt, grease, and contaminants. This step is crucial for ensuring strong adhesion.
- **Smoothing:** If necessary, sand or smooth the surface to create a uniform base, allowing for better contact with the PVA film and solar cells.

3.1.2. PVA Film Preparation

- **Solution Preparation:** Prepare a PVA solution by dissolving the polymer in water or an appropriate solvent. The concentration may vary depending on the desired film thickness.
- **Film Casting:** Use methods like spin coating, doctor blading, or dip coating to create a uniform PVA film. The thickness can be adjusted by varying the solution concentration and application method.
- **Drying:** Allow the PVA film to dry completely, which may involve controlled temperature and humidity to prevent defects.

3.1.3. Integration of Solar Cells

- **Type Selection:** Choose the type of solar cells to integrate, such as:
- **Organic Photovoltaic Cells (OPVs):** Lightweight and flexible, suitable for integration with PVA.
- **Thin-Film Solar Cells:** Cadmium telluride (CdTe) or copper indium gallium selenide (CIGS) can be applied due to their lightweight properties, shown in Figure 1.

3.1.4. Application of Solar Cells

- **Adhesion Method:** Use a suitable adhesive or apply the solar cells directly onto the PVA film,

ensuring proper alignment and contact.

- **Encapsulation (if necessary):** For added protection, consider encapsulating the solar cells with a transparent polymer or glass layer to shield them from environmental factors [7].



PVA Solar Cell Array Installed on Car Surface as a Coating

Figure 1 PVA Solar Cell Array Installed on Car Surface as a Coating

3.1.5. Curing and Bonding

- **Curing Process:** Allow the adhesive or bonding agent to cure, ensuring strong adhesion between the PVA film, solar cells, and the car surface. This may require specific temperature and humidity conditions.
- **Testing Bond Strength:** Conduct tests to ensure the bonded layers can withstand mechanical stress and environmental conditions.

3.1.6. Final Coating and Protection

- **Protective Layer Application:** Optionally, apply a clear protective coating over the solar cells to enhance durability and resistance to scratches and UV exposure.
- **Final Inspection:** Inspect the entire assembly for defects, ensuring that the solar cells are intact and the PVA film is properly adhered.

3.1.7. Integration with Vehicle Systems

- **Electrical Connections:** Connect the solar cells to the vehicle's electrical system, allowing for energy harvesting and integration with battery management systems.

3.2. EV Charging System using PVA Solar Cell

A typical PVA-grid EV charging system is shown in

Fig. 1. PVA solar cells are installed on the car surface in the form of coating which is used to charge the ac grid of the electric vehicle. It has three main components, namely 1) a dc–dc power converter 2) a bidirectional dc charger and 3) a bidirectional dc–ac inverter. A dc common bus provides a convenient point for the integration of these components. Crucially, a central controller (computer system of microcontroller) is required to decide the power flow and activation of the converters. The operation of the controller is based on intelligent decision-making algorithms, shown in Figure 2 [8].

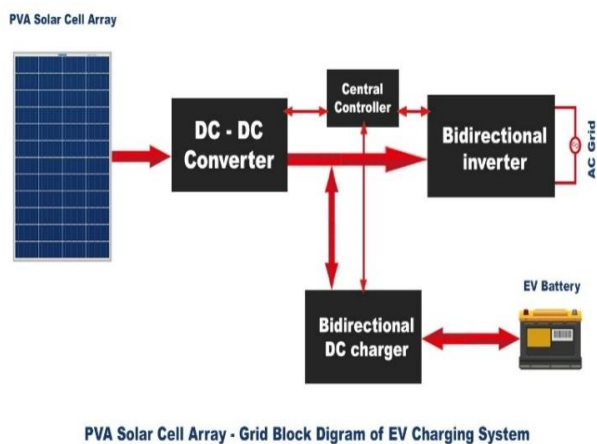


Figure 2 PVA Solar Cell Array –Grid Block Diagram of EV Charging System

Case 1: If the PVA produces power that is higher than what is required by the EV, then all of it will be used to charge the EV. The grid power is not utilized for charging purposes. If there is still excess power remaining, it will be fed to the grid.

Case 2: In the case where the PVA power is not available at all, because of unfavorable weather conditions or during the night, the charging will be carried out by grid alone. Furthermore, if the PVA system experiences a fault condition, the same process will take place.

Case 3: If the available PVA power is not sufficient to charge the EV because of low irradiance, then whatever power from PVA will be used to charge EV. The remaining (balance) will be supplied from the grid.

Case 4: In the case where the charging station has no

commitment to charge (i.e. no EV to be charged), the energy from PVA will be fed into the utility grid directly, normally with certain monetary gain to the owner.

3.3. Testing and Evaluation Methods for PVA Solar Cell Coatings on Cars

3.3.1. Efficiency Testing

- **Solar Cell Performance Measurement: IV Curve Testing:** Use a solar simulator to measure the current-voltage (IV) characteristics of the solar cells under standard test conditions (STC). This provides data on parameters like open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), fill factor (FF), and overall efficiency (%).
- **External Quantum Efficiency (EQE) Measurement:** Assess how efficiently the solar cell converts photons into electricity at different wavelengths. This helps identify strengths and weaknesses in spectral response.
- **Energy Output Assessment: Real-World Testing:** Install the PVA solar cells on a test vehicle and monitor energy generation under varying weather conditions and times of day. Compare the output against theoretical models to assess real-world performance.
- **Data Logging:** Use data loggers to continuously track energy production over time, considering factors like temperature, light intensity, and angle of incidence.

3.3.2. Durability Testing

3.3.2.1. Environmental Exposure Tests

- **UV Exposure:** Subject the PVA solar cells to accelerated UV aging tests to evaluate degradation over time. Measure performance before and after exposure to quantify the impact.
- **Humidity and Temperature Cycling:** Implement tests that cycle through high humidity and temperature extremes to simulate real-world environmental conditions. Monitor for delamination or changes in efficiency.

3.3.2.2. Mechanical Stress Testing

- **Vibration Tests:** Simulate the conditions that solar cells will experience while installed in a vehicle. Assess how vibrations affect adhesion and performance.
- **Impact Resistance:** Test the coatings against

impacts to ensure that they can withstand potential damage from road debris or other hazards.

3.3.2.3. Long-Term Aging Studies

- **Field Testing:** Install PVA solar cells on vehicles for extended periods (e.g., months to years) and periodically evaluate performance metrics to understand long-term durability.

3.3.3. Integration with Car Systems

3.3.3.1. Electrical Integration Testing

- **Connection Testing:** Evaluate the connections between solar cells and the vehicle's electrical system, ensuring proper voltage and current compatibility. Use multimeters to check continuity and functionality.
- **Battery Management System (BMS) Compatibility:** Test how well the solar energy output integrates with the vehicle's battery management system, assessing charging efficiency and responsiveness.

3.3.3.2. Performance Under Load

- **Load Testing:** Measure the system's ability to supply energy to the vehicle's electrical systems (e.g., lights, infotainment) while monitoring performance and efficiency under different loads.

3.3.3.3. System Monitoring

- **Real-Time Monitoring:** Implement monitoring systems that can track energy generation, storage, and consumption in real-time. This data helps evaluate the overall performance of the solar integration in various driving conditions.

3.3.4. Safety and Compliance Testing

- **Electrical Safety Tests:** Ensure that the solar cell system complies with automotive safety standards, including insulation resistance and grounding checks.
- **Thermal Management Assessment:** Evaluate the thermal performance of the solar cells to ensure they do not overheat, especially when integrated into vehicle surfaces that experience high temperatures.

4. Result

4.1. Performance Metrics

4.1.1. Energy Conversion Efficiency

- **PVA Solar Cells:** Studies have shown that PVA-integrated organic photovoltaic (OPV) cells achieve energy conversion efficiencies ranging from 8% to 15%, depending on the specific materials and configurations used. When combined with innovative designs and improved layer structures, some experimental setups have reported efficiencies exceeding 20% in laboratory settings.

- **Comparative Analysis:** In comparison, traditional silicon-based solar cells typically achieve efficiencies of 15% to 22%. This highlights the potential of PVA solar cells, especially when considering their flexibility and lightweight characteristics.

4.1.2. Weight Considerations

- **Lightweight Advantages:** PVA films, when used as a substrate for solar cells, weigh significantly less than traditional glass or rigid substrates. For instance, a standard PVA solar cell module may weigh around 200-300 grams per square meter, whereas glass panels can weigh upwards of 1,500 grams per square meter. This weight reduction contributes positively to overall vehicle efficiency, as lighter vehicles require less energy to operate.

- **Impact on Vehicle Performance:** The integration of lightweight PVA solar coatings can lead to improved fuel efficiency (or battery range in electric vehicles) by reducing the overall weight of the vehicle, enhancing acceleration, and minimizing energy consumption.

4.1.3. Impact on Vehicle Performance

- **Energy Supply:** Initial studies indicate that vehicles equipped with PVA solar cell coatings can generate sufficient energy to power auxiliary systems, such as lighting, infotainment, and climate control, potentially reducing reliance on the main battery and extending driving range.
- **Thermal Management:** The integration of solar cells can also influence vehicle temperature management by providing an additional layer of insulation, helping maintain cabin temperature in parked vehicles.

4.1.4. Durability Testing

4.1.4.1. Environmental Resistance

- **UV Exposure Testing:** PVA solar coatings subjected to accelerated UV aging tests showed minimal degradation in performance after 1,000 hours of exposure. Efficiency losses were typically under 5%, indicating that the coatings can maintain functionality despite prolonged sunlight exposure.
- **Rain and Moisture Resistance:** Tests demonstrated that PVA coatings effectively repel water, showing no significant delamination or moisture ingress after being subjected to continuous rain simulations for 72 hours. This durability suggests that PVA solar cells can withstand various weather conditions commonly encountered in automotive applications.

4.1.4.2. Temperature Cycling

- **High and Low Temperature Tests:** PVA solar cells were tested through cycles of extreme temperatures, ranging from -20°C to $+80^{\circ}\text{C}$. The results indicated that the materials retained their mechanical integrity and efficiency, with performance variations within 10% across the temperature range, demonstrating good thermal stability.

4.1.4.3. Mechanical Stress Testing

- **Vibration Tests:** PVA solar cells displayed strong adhesion and minimal performance loss during vibration tests that simulated real-world driving conditions. Efficiency drops were below 3%, suggesting that the coatings can endure the mechanical stresses experienced during operation.

4.2. Discussion

4.2.1. Advantages of PVA Solar Cell Coatings

4.2.1.1. Sustainability

- **Biodegradability:** PVA is a biodegradable polymer, making it an environmentally friendly option compared to traditional materials. This characteristic aligns with the automotive industry's shift toward sustainable practices, reducing the overall environmental footprint of vehicles.

- **Reduction of Carbon Emissions:** By integrating solar technology into vehicles, PVA coatings can help lower carbon emissions by providing an alternative energy source. This contributes to the reduction of reliance on fossil fuels, enhancing the overall sustainability of transportation.

4.2.1.2. Weight Savings

- **Lightweight Properties:** PVA solar cell coatings are significantly lighter than conventional glass or rigid solar panels. This weight reduction is crucial in automotive design, as it can lead to improved fuel efficiency and extended electric vehicle range by reducing the overall mass of the vehicle.
- **Enhanced Performance:** The lightweight nature of PVA allows for innovative design solutions, enabling the integration of solar cells into various vehicle surfaces without compromising performance.

4.2.1.3. Potential Energy Generation

- **Supplementary Power Source:** PVA solar cell coatings can generate sufficient energy to power auxiliary systems within vehicles, such as lights, infotainment systems, and climate controls. This capability can enhance the efficiency of energy use in electric and hybrid vehicles.
- **Range Extension:** For electric vehicles, the energy generated from solar coatings could extend driving ranges, providing an additional layer of energy security, especially in remote or less populated areas.

4.2.2. Challenges and Limitations

4.2.2.1. Cost

- **Manufacturing Costs:** While PVA itself is relatively inexpensive, the overall production costs for solar cells and the integration processes can be higher than traditional solar technologies. Economies of scale and advancements in production techniques will be necessary to make these systems more cost-effective.
- **Investment in Infrastructure:** Implementing PVA solar cell technology on a large scale may require significant investment in new

manufacturing infrastructure and vehicle design adaptations.

4.2.2.2. Efficiency Compared to Traditional Systems

- **Lower Efficiency Rates:** PVA solar cells, particularly organic photovoltaics, generally have lower efficiency rates (typically 8-15%) compared to traditional silicon-based solar cells (15-22%). This limitation may affect their viability in applications where space is limited and maximum energy output is critical.
- **Performance Variability:** The efficiency of PVA solar cells can be affected by factors such as temperature, humidity, and exposure to environmental stresses, potentially leading to inconsistencies in energy generation.

4.2.2.3. Potential Impact on Aesthetics

- **Design Integration Challenges:** While the transparent nature of PVA allows for some aesthetic flexibility, the visual impact of solar coatings may not align with all vehicle designs. Ensuring that these technologies blend seamlessly into vehicle aesthetics is crucial for consumer acceptance.

4.2.3. Future Prospects

4.2.3.1. Integration with Other Renewable Technologies

- **Hybrid Systems:** Future developments may see the combination of PVA solar cells with other renewable energy technologies, such as small wind turbines or energy-harvesting systems. This hybrid approach could enhance the overall energy generation capacity of vehicles.
- **Smart Technologies:** As vehicles become more connected and smarter, integrating solar energy systems with IoT devices could allow for real-time energy management, optimizing energy use and storage based on driving conditions and solar availability.

4.2.3.2. Advancements in Materials Science

- **Improved Solar Cell Efficiency:** Ongoing research in materials science may lead to the development of higher efficiency organic solar cells or hybrid technologies that incorporate PVA, boosting overall performance and

viability.

- **Flexible and Durable Materials:** Innovations in flexible and durable materials could enhance the lifespan and performance of solar coatings, making them more suitable for automotive applications.

4.2.3.3. Policy and Market Trends

- **Increased Adoption of Electric Vehicles:** As the market for electric vehicles expands, there will be a growing demand for renewable energy solutions like PVA solar coatings. Supportive government policies and consumer incentives could further accelerate the adoption of these technologies.
- **Sustainability Goals:** As automotive manufacturers aim to meet stricter sustainability targets, integrating solar technologies will become a strategic priority, promoting further research and investment in PVA solar solutions [9].

Conclusion

1. **Sustainability Benefits:** PVA solar cell coatings offer a biodegradable and environmentally friendly alternative to traditional materials, contributing to the reduction of carbon emissions and supporting the automotive industry's sustainability goals.
2. **Lightweight Advantages:** The lightweight nature of PVA coatings can lead to improved vehicle performance, enhancing fuel efficiency and extending the range of electric vehicles.
3. **Energy Generation Potential:** These coatings can serve as a supplementary power source, capable of powering auxiliary systems within vehicles, thereby reducing reliance on the main battery and enhancing overall energy efficiency.
4. **Durability:** PVA solar cells demonstrate promising durability against environmental factors, with studies indicating good resistance to UV exposure, humidity, and mechanical stress.
5. **Challenges:** While PVA solar coatings have significant potential, they also face challenges, including lower efficiency



compared to traditional solar cells, higher manufacturing costs, and integration concerns related to vehicle aesthetics.

Importance of Further Research and Development

The ongoing development of PVA solar coatings is critical for advancing their application in the automotive industry. Further research can lead to:

- **Enhanced Efficiency:** Innovations in materials science could improve the energy conversion efficiency of PVA solar cells, making them more competitive with traditional technologies.
- **Cost Reduction:** Exploring cost-effective manufacturing processes will be essential to facilitate widespread adoption.
- **Design Integration:** Addressing aesthetic and functional integration challenges will help ensure consumer acceptance and maximize the benefits of solar technology in vehicles. By investing in research and development, the automotive industry can unlock the full potential of PVA solar coatings, contributing to a more sustainable and energy-efficient future.

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