IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 10, May 2025 Impact Factor: 7.67

SolarPanelCleanerRobot

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Abstract:*Dust accumulation presents a significant challenge to solar panel efficiency in Southeast Asia,aregioncharacterizedbyhighhumidity,industrialpollution,andseasonalhaze.Thisresearch investigatestheimpactofdustonphotovoltaicperformance,highlightingenergylossesrangingfrom 17% to 50% depending on environmental and particulate factors. High humidity enhances dust adhesion, complicating removal and intensifying performance degradation. Conventional water-basedcleaningmethodsareshowntobeinefficientandenvironmentallyunsustainableduetoresidue formation, frequent maintenance needs, and regional water scarcity. The study explores alternative solutions,includingroboticdrycleaning,anti-dustcoatings,andhydrophobictreatments,alongside the need for policy-driven pollution control. Sustainable solar energy production in Southeast Asia demandsanintegratedapproachcombiningtechnologicalinnovationwithenvironmentalregulation to mitigate the detrimental effects of dust on solar infrastructure.*

Keywords: Solarcells;Dustaccumulation;Efficiency;Transmittance

I. INTRODUCTION

The increasing global demand for renewable energy has positioned solar photovoltaic (PV) panels as a vital electricity generation source. However, the accumulation of dust and other particulates significantly impedes PV panel efficiency, leading to substantial energy losses. This degradation, particularly pronounced in arid regions, necessitates effective cleaning strategies. This paper reviews and analyzes various PV panel cleaning methodologies, including natural, manual, and automated techniques, with a focus on robotic and waterless solutions. We further present the development and testing of a portable, microcontroller-controlled robotic cleaning device, addressing the challenges of efficient and automated PV panel maintenance. This research aims to provide a comprehensive overview of current cleaning solutions and contribute to the advancement of sustainable solar energy technologies by optimizing PV panel performance and minimizing maintenance costs

II. LITERATURE SURVEY

Solar photovoltaic (PV) technology plays a crucial role in the transition toward sustainable energy. As an efficient and scalable renewable source, solar power has gained widespread adoption worldwide. However, the efficiency of PV systems is significantly affected by environmental factors, particularly the accumulation of dust and debris on panel surfaces. Studies indicate that soiling can reduce energy output by up to 20%, leading to lower productivity and financial losses. This challenge is especially pronounced in arid and semi-arid regions, where high dust deposition rates and infrequent rainfall exacerbate the problem. To maintain optimal efficiency, periodic cleaning is necessary, but traditional cleaning methods often pose logistical and environmental challenges.

Conventional cleaning techniques such as manual washing, water spraying, and wind-assisted cleaning are commonly employed to remove dust accumulation from solar panels. While effective, these methods come with drawbacks, including high labour costs, water dependency, and potential long-term damage to panel surfaces. In regions where water resources are scarce, excessive water use for cleaning solar panels is unsustainable and can lead to unintended consequences such as light refraction and corrosion. Furthermore, relying on rain and wind for natural cleaning is inconsistent, making it difficult to ensure continuous high performance in solar energy production. To address these

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concerns, researchers and industry experts have explored advanced cleaning technologies that optimize efficiency while minimizing maintenance costs and environmental impact.

One of the most promising advancements in solar panel maintenance is the development of automated cleaning systems. These systems range from electrostatic dust removal to robotic cleaning solutions that eliminate the need for manual intervention. Electrostatic technologies use charged surfaces to repel dust particles, preventing accumulation without requiring physical contact. Hydrophobic and hydrophilic coatings are also being investigated to reduce the adherence of dust and dirt, improving efficiency while reducing the frequency of cleaning cycles. Among automated solutions, robotic cleaning systems are gaining attention for their ability to clean solar panels efficiently and autonomously. These systems operate on pre-programmed schedules or in response to real-time soiling levels, ensuring consistent maintenance with minimal resource consumption.

This paper reviews existing solar panel cleaning methods and introduces an advanced, self-powered robotic cleaning system designed to optimize maintenance processes. The proposed system incorporates real-time monitoring, automated cleaning mechanisms, and wireless control capabilities to maximize efficiency while reducing water dependency and operational costs. By implementing such a system, solar PV installations can achieve higher energy output, extended system longevity, and enhanced sustainability. As solar energy continues to be a cornerstone of global renewable energy strategies, investing in efficient cleaning technologies will be critical to ensuring reliable and cost-effective power generation.

Fig 1: Before cleaning

Fig 2: After cleaning

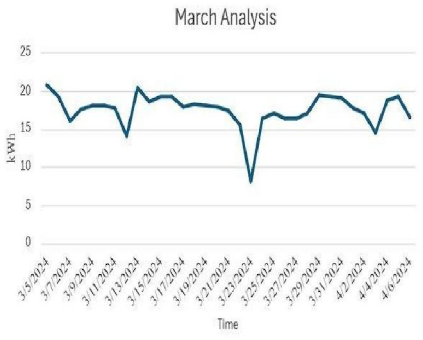

Fig 3: Graphical Analysis Month of March 2024

Fig 4: Data Logger

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III. DESIGNING SOLAR PANEL CLEANING BOT WITHOUT WATER

Dust accumulation significantly reduces the efficiency of solar panels, with losses ranging from 15% to over 50% depending on the density, composition, and geographical location of the dust. Traditional water-based cleaning methods are inefficient and can worsen dust accumulation due to stickiness caused by water residues. An automated cleaning bot powered by solar energy offers a sustainable solution to this challenge. Below is a conceptual design based on research findings.

• Key Challenges with Dust Accumulation

1. Efficiency Loss: Dust can reduce solar panel efficiency by up to 40-50%, with variations based on climate, particle size, and humidity.
2. Geographical Impact: Desert areas and regions with low rainfall experience higher dust deposition rates, requiring frequent cleaning cycles.
3. Water Use Issues: Water-based cleaning methods are inefficient, environmentally unsustainable, and can leave residues that attract more dust.

• Proposed Solution: Automatic Cleaning Bot

The bot is designed to clean solar panels without water while powered by its solar panel.

Core Features

1. Solar-Powered Operation: The bot integrates a small solar panel to charge its battery, ensuring sustainable energy use.

It operates autonomously during low-light hours (e.g., early morning or evening) when panels are not actively generating power.

2. Dry Cleaning Mechanism: Utilizes soft brushes or microfiber rollers to remove dust without scratching the panel surface.

Incorporates electrostatic or vibration-based systems to dislodge stubborn particles.

3. Mobility: Designed as a lightweight robot capable of traversing panel surfaces using tracks or wheels.

Includes anti-slip mechanisms for inclined or horizontal panels.

4. Durability: Built with weather-resistant materials to withstand harsh climates like deserts or coastal areas prone to high humidity and salt deposition.

Advantages Over Traditional Methods

1. Water-Free Cleaning: Eliminates the environmental impact of water usage while avoiding sticky residues that attract more dust.
2. Energy Efficiency: Operates independently using renewable energy from its built-in solar panel.
3. Cost-Effective Maintenance: Reduces labour costs and frequency of manual interventions compared to traditional methods.

• Research Insights Supporting Design

o Dust accumulation rates vary geographically, with desert regions experiencing higher deposition due to low rainfall and frequent storms.

o Smaller dust particles block more light and increase efficiency losses; hence, regular cleaning is crucial.

o Studies suggest that dry cleaning methods such as vibration-based systems or electrostatic techniques can effectively mitigate dust without damaging panels.

This cleaning bot addresses the inefficiencies of traditional methods while leveraging renewable energy for sustainable operation in diverse climatic conditions.

IV. CONCLUSION

Solar photovoltaic (PV) technology is critical for sustainable energy production, yet its efficiency is significantly undermined by the accumulation of dust and debris, which can reduce energy output by up to twenty percent,

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particularly in arid and semi-arid regions. Conventional cleaning methods such as manual washing, water spraying, and reliance on natural weather conditions demand high labour and water consumption, potentially leading to panel degradation through corrosion and abrasion. To overcome these limitations, this project introduces an innovative, self-powered robotic cleaning system designed to autonomously monitor and maintain solar panels at optimal performance levels. Integrated with real-time sensors and wireless control, the system dynamically adjusts cleaning protocols based on soiling conditions, ensuring maximum energy capture while preserving panel integrity. Field tests and experimental data demonstrate that this automated solution significantly enhances energy yield and prolongs the lifespan of PV installations. By minimizing water usage and reducing operational costs, the robotic system offers a sustainable alternative to traditional cleaning approaches. This project validates the feasibility of implementing advanced technology for solar panel maintenance and underscores the importance of continued research in sensor integration and control algorithms, paving the way for more efficient, cost-effective, and environmentally responsible renewable energy solutions for tomorrow.

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