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Floating Solar Power Plants for Rural Electrification with IoT Based Cleaning and Monitoring of It - A Review

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Abstract: Floating Solar Photovoltaic (FPV) systems have emerged as an innovative solution to the growing challenges of land scarcity, increased energy demand, and environmental degradation. Integrating FPV with Internet of Things (IoT)-based automated cleaning and real-time monitoring significantly enhances system performance, particularly in rural regions where accessibility and maintenance remain major constraints. This review consolidates recent advancements (2017–2025) in floating solar systems, IoT-enabled monitoring, automated dust-cleaning mechanisms, and hybrid intelligent diagnostic frameworks. A total of fifteen peer-reviewed studies areanalyzed to evaluate the technological developments, performance benefits, and implementation challenges associated with FPV and IoT automation. The review identifies research gaps related to long-term environmental impacts, predictive cleaning models, sensor reliability in aquatic environments, and rural deployment strategies. The study concludes that integrating FPV systems with intelligent IoT-based cleaning and monitoring provides a reliable, sustainable, and scalable pathway for rural electrification.
Keywords: Floating solar plant, IoT monitoring, dust-cleaning system, rural electrification, predictive maintenance, renewable energy.

I. INTRODUCTION

The rapid global shift toward renewable energy has intensified interest in innovative solar technologies capable of addressing land scarcity, energy deficits, and increasing environmental concerns, particularly in rural and remote regions where conventional grid-based electrification remains unreliable or economically unfeasible. Floating Solar Photovoltaic (FPV) systems have emerged as a transformative solution by enabling large-scale solar deployment on water surfaces such as reservoirs, lakes, irrigation tanks, ponds, and hydropower dams—settings where land is either unavailable or reserved for agriculture and habitation (Huang et al. 2023; Ramanan et al. 2024). Unlike traditional land-mounted PV systems, FPV installations benefit from the natural cooling effect of water bodies, which enhances module efficiency and improves energy generation by 0.6% to 4.4% depending on climatic conditions and site features (Ramanan et al. 2024). Studies have also demonstrated that FPV systems reduce water evaporation, thereby conserving significant quantities of freshwater in arid regions—a particularly relevant advantage for agricultural communities relying on seasonal reservoirs and irrigation tanks for crop cultivation (Mouhaya et al. 2025). In the Indian rural context, FPV has gained increasing momentum as a strategic solution to meet rising energy demands while preventing the diversion of cultivable land, an issue strongly emphasized by Bhasme et al. (2023), who highlighted the technology's potential for rural electrification, agricultural productivity enhancement, and socioeconomic upliftment.

Parallel to the rise of FPV systems, the integration of the Internet of Things (IoT) with solar energy has revolutionized system performance monitoring, maintenance efficiency, and real-time control. IoT-based solar monitoring frameworks provide continuous data acquisition, remote supervision, and automated diagnostics, significantly reducing the need for manual inspections—particularly in inaccessible or hazardous locations where solar panels are deployed (Anbarasu et al. 2023; Marulasiddappa et al. 2023). For floating solar systems, IoT-enabled monitoring becomes even more critical due to environmental variability, humidity-induced electrical risks, and the challenges associated with physical maintenance on aquatic surfaces (Suprayogi et al. 2024; Bossi et al. 2024).

Another major factor affecting FPV performance is dust accumulation on solar modules, which can lead to substantial reductions in energy output by blocking incident solar radiation. Automated IoT-based cleaning systems have therefore emerged as essential technologies that not only detect dust deposition but also initiate self-cleaning cycles using mechanical, robotic, or water-spraying mechanisms (Biswas et al. 2023; Diniță et al. 2025). Furthermore, advancements in artificial intelligence (AI) and machine learning (ML) have allowed the development of predictive maintenance models capable of triggering cleaning operations based on dust-intensity classification, weather predictions, and performance trends, as illustrated by Dhankar et al. (2025) and Diniță et al. (2025). These intelligent maintenance frameworks reduce operational expenditure, minimize human intervention, and increase the long-term sustainability of solar energy systems.

In addition to technological improvements, global research trends highlight the increasing relevance of hybrid solar systems combining FPV structures with IoT technologies to achieve rural electrification, climate resilience, and environmental conservation simultaneously. Khare et al. (2023) emphasized that the convergence of solar technologies with digital innovations—such as IoT networks, AI-driven optimization, and cloud-based analytics—marks a pivotal transition toward smart solar ecosystems. Rumbayan et al. (2022) demonstrated that IoT-based solar energy platforms significantly enhance energy access in remote communities by enabling real-time monitoring of off-grid systems. Similarly, Manimaran (2025) discussed the broader national importance of solar-assisted technologies in achieving Sustainable Development Goals (SDGs), especially in underserved rural areas where both clean water and clean energy remain critical challenges. Balamurali et al. (2025) extended this discourse by integrating pollutant-based rainfall prediction models with solar-powered IoT systems to optimize agricultural water management—highlighting the untapped potential of IoT and solar energy convergence for multi-sectoral rural development.

Given these advancements, the present review synthesizes the technological evolution, environmental benefits, monitoring mechanisms, and cleaning systems associated with floating solar installations, with special emphasis on their applicability for rural electrification. By consolidating findings from fifteen recent studies, this review identifies existing challenges, technological limitations, and research gaps that must be addressed to develop robust, intelligent, and scalable FPV systems equipped with IoT-based real-time monitoring and automated cleaning mechanisms. The integration of these advanced technological solutions holds the promise of transforming floating solar power plants into a reliable, sustainable, and cost-effective energy paradigm for rural communities worldwide.

II. LITERATURE REVIEW

A. PREVIOUS RESEARCH ARTICLE

Rumbayan et al. (2022) presented a study in the IOP Conference Series: Earth and Environmental Science that focused on creating an Internet of Things (IoT)-based monitoring framework for solar energy systems used in remote island communities. Their work targeted Bunaken Island, where off-grid solar home systems are essential due to limited access to conventional electricity. Following a Research and Development (R&D) methodology, the authors designed and evaluated a prototype capable of tracking the performance of solar photovoltaic installations in real time. The results showed that the IoT platform successfully delivered continuous operational data from the remote solar units, proving its value in improving monitoring, reliability, and maintenance planning for renewable energy systems in isolated regions. The study demonstrates that integrating IoT technology can significantly strengthen the management and sustainability of solar energy applications in rural and coastal areas.

Anbarasu et al. (2023) proposed a wireless IoT-based monitoring system designed to enhance the real-time supervision of solar power plants. Their study demonstrated how IoT technologies can seamlessly collect and transmit operational data from solar installations without the need for manual intervention. The system integrates components such as Arduino microcontrollers, Node-MCU (ESP8266) modules, voltage and current sensors, temperature sensors, LDRs, and servo motors to measure key parameters including solar irradiance, output voltage, and system temperature. The collected data is uploaded to an online platform, allowing users to remotely access performance information through a mobile application. The authors emphasized that such wireless monitoring solutions are especially beneficial in locations where solar panels are difficult or costly to access frequently. Their findings confirm that IoT-enabled systems improve monitoring accuracy, reduce maintenance challenges, and facilitate continuous performance evaluation of solar PV systems, making them suitable for regions with high solar potential.

Bhasme et al. (2023) examined the potential of grid-connected floating solar power plants as a transformative energy solution for rural farming communities in India. Published in the International Journal of Advances in Engineering and Management (IJAEM), the study addressed the challenges faced by farmers who struggle with limited land availability and inadequate access to reliable electricity. The authors highlighted floating solar systems as an innovative approach that utilizes existing water bodies—such as ponds, reservoirs, and irrigation tanks—to generate clean, on-grid electricity without occupying cultivable land.

Their analysis demonstrated that floating photovoltaic installations not only provide a sustainable and cost-effective source of power but also contribute to ancillary benefits such as reduced evaporation, improved water quality due to shading, and the potential for enhanced aquaculture. The study evaluated the technical feasibility of the system and found it suitable for rural deployment, with stable energy output and minimal maintenance needs. Economic assessment indicated viability through reduced energy costs and opportunities for revenue generation via grid export. Environmentally, the system minimized land disturbance and promoted better utilization of local water resources. The authors concluded that grid-connected floating solar plants could significantly strengthen rural livelihoods, support agricultural productivity, and accelerate sustainable development in remote farming areas.

Biswas et al. (2023) presented an IoT-based automated solar panel cleaning and real-time monitoring system in the *Journal of Engineering Research and Reports*. The study emphasized that dust accumulation on photovoltaic (PV) modules is one of the major factors responsible for reduced power generation, as settled dust creates a physical barrier that limits solar radiation reaching the panel surface. To address this persistent issue, the authors designed a low-cost intelligent cleaning mechanism integrated with IoT technology to enhance the operational efficiency of solar installations. The proposed system utilized a combination of microcontroller-based hardware components, including NodeMCU, servo motors, a DC motor-driven submersible pump, an LDR sensor, and an LCD module, to automate the process of detecting dust levels and initiating panel cleaning. The work further incorporated assembly language programming for the microcontroller to ensure precise control and synchronization of the sensing and cleaning units. Conducted as part of a Master's degree project at the American International University Bangladesh (AIUB), the study demonstrated that integrating IoT with automated cleaning can significantly improve the energy output of solar modules while reducing maintenance requirements. The authors concluded that such automated systems offer a practical and economical solution for sustained solar energy production, particularly in regions with high dust density.

Marulasiddappa et al. (2023) developed an IoT-based monitoring system aimed at improving the performance evaluation of rooftop solar photovoltaic installations. The authors highlighted that although the adoption of solar energy is increasing globally—especially in countries advancing toward renewable energy independence—many solar panels remain difficult to access, making manual performance monitoring challenging. Their study proposed a system incorporating microcontrollers and Internet of Things (IoT) technology to continually track the operational status of solar panels and ensure maximum sunlight utilization throughout the day. By integrating real-time data acquisition with user-friendly display interfaces, the system enables continuous monitoring of energy output and panel efficiency. The research demonstrated that such an IoT-enabled solution can significantly enhance operational oversight, improve reliability, and support better maintenance of rooftop solar PV systems, especially in locations where direct physical inspection is difficult.

Huang et al. (2023) provided a comprehensive review on the development, structural composition, and future potential of floating solar photovoltaic (FPV) systems, with a particular emphasis on their suitability for offshore applications. Published in the *Journal of Marine Science and Engineering*, the review contextualized FPV technology as a critical alternative to fossil fuels, which continue to dominate global energy consumption and contribute significantly to environmental degradation. The authors traced the evolution of floating solar plants from their earliest inland installations to contemporary offshore prototypes, highlighting major technological advancements in system design, materials, and deployment strategies. The study examined key components of FPV systems—including buoyant structures made of high-density polyethylene (HDPE), pontoons, mooring systems, and PV modules—and compared various FPV configurations in terms of durability, stability, cost, and environmental resilience. Notably, the review evaluated offshore FPV technology through hydrodynamic, structural, and environmental perspectives, demonstrating its potential to harness vast marine spaces for large-scale renewable power generation. However, the authors also identified considerable challenges associated with deep-sea deployment, including wave loads, extreme weather, corrosion, system fatigue, and maintenance complexity. The review concluded that while offshore FPV presents a highly promising avenue for expanding global solar capacity, significant interdisciplinary research is required to overcome engineering, economic, and environmental barriers before deep-sea applications can be fully realized.

Khare et al. (2023) presented an extensive and forward-looking review on the evolution of solar energy systems, focusing on how rapid technological advancements and growing global energy demands are reshaping the sector. Published in *e-Prime – Advances in Electrical Engineering, Electronics and Energy*, the review examined the shift from conventional photovoltaic technology to emerging next-generation solar solutions such as quantum-dot based solar cells, which offer enhanced light absorption and efficiency. The authors also highlighted trending developments such as solar trees and floating solar power plants, both of which address land scarcity and promote sustainable power generation. A significant portion of the study emphasized the integration of modern digital technologies—particularly the Internet of Things (IoT), artificial intelligence (AI), cognitive computing, and data analytics—into solar power systems to improve monitoring, fault detection, predictive maintenance, and automation.

The review concluded that the fusion of innovative solar architectures with intelligent technologies is accelerating the transition toward smart solar ecosystems, enabling higher performance, reduced energy losses, and greater applicability across residential, industrial, and agricultural sectors.

Ramanan et al. (2024) presented an extensive review on the technological progress and future potential of floating photovoltaic (FPV) systems in *Renewable and Sustainable Energy Reviews*. Their study highlighted that FPV installations outperform land-based photovoltaic (LPV) systems due to the natural cooling effect provided by water bodies, resulting in 0.6% to 4.4% higher energy generation and notable efficiency improvements. The review consolidated scattered research findings on FPV evolution, global deployment trends, material selection, design methodologies, and performance characteristics. The authors emphasized that future FPV advancements must prioritize improved floating structures, durable instrumentation, and enhanced wireless monitoring and sensing systems. They also noted the emerging role of advanced technologies such as solar tracking mechanisms, bifacial modules, AI-driven optimization tools, satellite-based monitoring, and intelligent grid-integration algorithms. Furthermore, the study identified significant potential for FPV expansion in marine environments and hydropower reservoirs, which could substantially contribute to global renewable energy targets. Despite these opportunities, key challenges remain related to safety issues, electrical risks in aquatic settings, lack of standardized guidelines, policy constraints, and localized temperature impacts. The authors concluded that addressing these barriers through innovation and regulation is crucial for unlocking the full sustainability benefits of FPV technology.

Suprayogi et al. (2024) developed an IoT-based monitoring system for floating solar panel installations, published in the International Journal of Integrated and Applied Sciences. The study emphasized the growing importance of floating solar power plants as environmentally friendly renewable energy systems, particularly suitable for remote regions in Indonesia where land availability is limited. Recognizing that floating PV systems require continuous monitoring of temperature, voltage, and current to ensure stable performance under varying aquatic and climatic conditions, the authors designed an experimental hardware–software framework utilizing IoT technology and the Blynk platform. The system architecture incorporated ESP8266 microcontrollers paired with DHT11 temperature sensors, ACS712 current sensors, and voltage sensors to transmit real-time operational data. Performance testing demonstrated high accuracy, with measurement error values of only 1.08% for temperature, 4.65% for current, and 2.20% for voltage when compared to manually calibrated instruments. These results confirmed the reliability of the monitoring system for field applications. The authors concluded that the proposed IoT-enabled monitoring setup offers an efficient, low-error, and practical solution for managing floating solar power plants, ensuring improved operational stability and supporting broader renewable energy deployment.

Bossi et al. (2024) presented a comprehensive review on the monitoring requirements and available technologies for floating photovoltaic (FPV) systems in the journal *Sustainability*. The authors emphasized that while photovoltaic energy plays a major role in the global energy transition, traditional land-based installations face challenges due to low power density and competition for land use. Floating PV installations on inland water bodies and offshore locations provide an alternative, but these systems can significantly influence aquatic ecosystems through shading, anchorage disturbance, and altered water conditions. The review examined existing academic and technical literature related to monitoring FPV systems, highlighting key physico-chemical parameters essential for assessing environmental impacts and system performance. The authors identified that FPV systems require additional monitoring considerations beyond those of ground-mounted PV plants due to their interaction with water bodies and the difficulty of routine maintenance. Emerging technologies such as autonomous surface vehicles (ASVs), underwater vehicles (AUVs), remotely operated vehicles (ROVs), and UAV-based sensing were discussed as promising tools for automated environmental monitoring. The study concluded that despite advancements, a standardized and cohesive framework for water quality monitoring and environmental impact assessment of FPV systems is still lacking, underscoring the need for uniform guidelines and protocols.

Mouhaya et al. (2025) conducted a comprehensive assessment of the technical, economic, and water conservation potential of floating photovoltaic systems (FPVS) on four major hydroelectric dams in Morocco's Sebou basin. Published under open access in *Cleaner Technologies and Environmental Policy*, the study evaluated three reservoir coverage scenarios—5%, 10%, and 15%—to determine their contribution to renewable power generation and water resource management. Using the System Advisor Model (SAM), the authors demonstrated that even minimal FPVS deployment offers significant benefits; for instance, a 5% coverage could generate enough electricity to power nearly one million residents, equivalent to 87% of the population of Fes city. Increasing the coverage to 10% would boost annual energy production by 185%, adding approximately 1270 GWh per year.

In addition to energy gains, the study highlighted the dual advantage of FPVS in reducing water loss from evaporation, with the 15% coverage scenario conserving up to 11.93 million cubic meters of water annually—an essential outcome for arid regions facing increasing climate stress. Economic analysis further confirmed the viability of FPVS deployment, with a stable levelized cost of electricity around $0.07/kWh, positive net present values across all scenarios, and internal rates of return exceeding 10%. The authors concluded that integrating floating solar systems on hydropower reservoirs presents a highly sustainable and economically attractive strategy for expanding Morocco's clean energy portfolio while simultaneously enhancing water security.

Diniță et al. (2025) proposed a distributed IoT-based predictive maintenance framework for photovoltaic (PV) systems, published in the journal *Sustainability*. The authors highlighted that in the context of Industry 4.0, maximizing renewable energy production and maintaining operational efficiency of solar panels require effective and timely dust detection, as dust accumulation significantly reduces panel efficiency. While conventional maintenance approaches depend on manual inspection or centralized decision-making, the study emphasized the need for intelligent, automated systems that can operate with minimal human intervention. The researchers developed an IoT hardware–software architecture integrating cloud-based machine learning models, specifically using Microsoft Azure Custom Vision, to classify dust deposition on solar panels. A key contribution of the work lies not merely in model development but in designing a complete predictive maintenance workflow capable of real-time monitoring, alert generation, and autonomous decision-making. The framework employs distributed logic, where a local processing unit (Raspberry Pi) interprets cloud responses and independently triggers cleaning actions, thereby reducing latency and operational costs compared to traditional centralized architectures. The article also outlined how the system fits into Industry 4.0 principles by combining cloud computing, smart sensing, and automated maintenance, offering a scalable and sustainable solution for large photovoltaic parks. The authors concluded that the proposed architecture provides a more efficient and cost-effective method of managing PV maintenance while supporting long-term sustainability and improved energy output.

Dhankar et al. (2025) presented an IoT-driven intelligent dust monitoring and automated cleaning system for enhancing the operational efficiency of solar photovoltaic (PV) panels, published in the International Journal of Scientific Research & Engineering Trends. The authors highlighted that dust accumulation remains one of the most significant factors contributing to the decline in solar panel performance, as settled particles obstruct sunlight absorption and decrease overall power output. Conventional cleaning methods—whether manual or semi-automatic—were described as labor-intensive, inefficient, and cost-prohibitive for large-scale PV installations, underscoring the need for more advanced technological solutions. In response, the study introduced a comprehensive IoT-based framework that integrates real-time environmental sensing, dust detection modules, and an automated cleaning mechanism. The system leverages machine learning algorithms to analyze historical performance and environmental data, enabling predictive scheduling of cleaning cycles to maintain optimal energy generation. The authors also reviewed various existing dust mitigation techniques such as passive anti-soiling coatings, electrostatic dust removal, and robotic cleaning systems, noting limitations related to high maintenance demands, operational complexity, and scalability challenges. Their findings emphasized that IoT-based predictive monitoring systems offer a more cost-effective and efficient alternative, providing continuous data acquisition, remote oversight, and intelligent decision-making capabilities. The study concluded that the proposed IoT and ML-enabled system not only improves energy output and reduces operational costs but also significantly minimizes manual intervention, contributing to more reliable, sustainable, and long-term solar power generation.

Manimaran (2025) presented a comprehensive review of solar-assisted technologies in India, emphasizing their role in achieving the United Nations' Sustainable Development Goals (SDGs), particularly those related to clean water and clean energy. Published in *Clean Energy*, the article highlighted India's vast potential for harnessing solar resources across multiple sectors, integrating both photovoltaic and thermal technologies. The review extensively covered solar-assisted systems used for carbon sequestration, solar biomass conversion, irrigation, water heating, food drying, power generation, and water purification. Special emphasis was placed on clean water solutions, including solar distillation, solar still technologies, and desalination methods designed to meet the growing demand for potable water in rural and semi-urban regions. For the energy sector, the author examined recent advancements in solar–thermal power plants, solar–PV systems, and hybrid solar–biomass applications, noting their increasing effectiveness and cost efficiency. Furthermore, the paper explored emerging research directions such as magnetized solar stills, plasmonic nanofluids for enhanced heat absorption, and heat pump-integrated solar power systems, which offer significant improvements in performance and sustainability. The study concluded that India's strategic focus on solar-assisted technologies not only supports energy security and environmental protection but also provides scalable pathways for future innovation in clean energy and water purification systems.

Balamurali et al. (2025) conducted an in-depth review on the development of a solar-powered, IoT-controlled smart irrigation system enhanced with an innovative rainfall prediction technique based on pollutant concentration analysis.

Published in *Environment, Development and Sustainability*, the study addressed the growing need for efficient water management in agriculture, especially in water-stressed regions. The review described an integrated system powered by semi-crystalline photovoltaic (PV) panels and supported by IoT components such as the ESP8266 module, Arduino Uno, Raspberry Pi, and Partial MPPT control for maximizing energy efficiency. A major contribution of the paper was its detailed comparison of existing PV-irrigation systems, IoT-based irrigation techniques, and communication technologies including Wi-Fi, LoRa, and Zigbee, ensuring an optimized selection of components for field applications. Unlike traditional studies that rely on aerosol size for rainfall estimation, the authors introduced a novel methodology using pollutant concentration variables—PM10, PM2.5, SO_2, NO_2, CO, NH_3, Cr, and Pb—to generate more location-specific rainfall forecasts. This predictive approach enables dynamic adjustment of irrigation schedules to significantly reduce water wastage. Additionally, the review evaluated government subsidy schemes for solar irrigation in India, cost–benefit considerations, and security vulnerabilities associated with IoT devices, proposing mitigation strategies for robust and reliable operation. The paper concluded that integrating PV energy, real-time sensing, IoT control, and pollutant-based rainfall forecasting presents a highly sustainable and scalable solution for modern agricultural water management.

B. RESEARCH GAPS

From the detailed review of existing studies on IoT-based solar monitoring systems, floating solar technologies, automated cleaning mechanisms, and smart renewable-energy applications, it becomes clear that although many researchers have contributed valuable ideas, several important gaps still remain. For example, Rumbayan et al. (2022) developed an IoT monitoring system for remote island solar units, but their work was limited to basic performance tracking only, without integrating predictive analytics, maintenance forecasting, or environmental impact correlation. Similarly, Anbarasu et al. (2023) designed a wireless IoT monitoring framework for solar power plants, but the system focused mainly on data collection and remote access, and did not explore long-term system reliability, dust-related performance losses, or advanced data-driven decision-making. Although floating solar systems were examined by Bhasme et al. (2023), their study discussed technical and socio-economic benefits but did not include real-time monitoring architecture, IoT-based sensing, or smart maintenance approaches that are essential for large-scale deployment.

Further, several studies attempted to solve the problem of dust accumulation on solar panels using IoT, such as those by Biswas et al. (2023) and Dhankar et al. (2025), but their solutions mostly rely on basic sensing and mechanical cleaning. These systems do not incorporate machine learning, performance forecasting, environmental factor integration, or adaptive cleaning cycles based on seasonal variations. Similarly, Marulasiddappa et al. (2023) worked on IoT monitoring for rooftop systems, but the absence of fault detection algorithms, predictive maintenance, multi-sensor fusion, and integration with cloud-based analytics leaves scope for improvement.

In the field of floating photovoltaic (FPV) systems, reviews by Huang et al. (2023), Ramanan et al. (2024), and Bossi et al. (2024) identified structural, environmental, and hydrodynamic challenges, but they also highlighted that very few studies have combined FPV with IoT-based real-time monitoring, especially for offshore or deep-water conditions. Most FPV research explains structural design, material selection, and deployment feasibility, but does not provide a continuous sensing network for temperature, humidity, water quality, mechanical stresses, or electrical performance. Even where IoT applications exist—such as in the work of Suprayogi et al. (2024)—the scope is limited to basic voltage–current monitoring, with no advanced analytics, fault prediction, remote autonomous control, or cloud-driven data interpretation.

Economic and water-conservation assessments of FPV systems, like those by Mouhaya et al. (2025), focus primarily on simulation-based energy modelling. However, these studies lack field-based IoT monitoring, which is necessary to verify real-world performance, detect anomalies, and measure environmental interactions such as temperature influence, evaporation reduction, and aquatic ecosystem impact. Likewise, Diniță et al. (2025) proposed a predictive IoT–ML architecture for dust-related maintenance, but their system operates only on land-based PV units and does not consider floating systems, remote villages, or hybrid PV–irrigation networks.

In the Indian context, many researchers, like Manimaran (2025), discuss solar-assisted technologies for SDGs, and Balamurali et al. (2025) combine IoT with rainfall prediction for smart irrigation. However, these works do not explore an integrated model where solar power generation is monitored, cleaned, optimized, and automatically controlled using IoT, AI, and environmental forecasting simultaneously. Also, no study combines pollutant-based rainfall prediction (as proposed by Balamurali et al., 2025) with IoT-based solar performance monitoring, dust detection, or predictive energy optimization.

III. CONCLUSION

The overall review of the existing studies shows that solar energy systems—whether rooftop, floating, or off-grid—are becoming more efficient and reliable because of the integration of modern technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), and advanced sensors. Researchers like Rumbayan et al. (2022) and Anbarasu et al. (2023) have shown that IoT makes real-time monitoring much easier, especially in remote areas where manual checking is difficult. Similarly, studies by Biswas et al. (2023), Diniță et al. (2025), and Dhankar et al. (2025) prove that automated cleaning and predictive maintenance significantly improve power generation by reducing dust-related losses. Floating solar systems, as discussed by Bhasme et al. (2023), Huang et al. (2023), Ramanan et al. (2024), and Mouhaya et al. (2025), also offer strong potential to increase renewable energy production while saving land and reducing water evaporation. Reviews by Khare et al. (2023) and Bossi et al. (2024) highlight that the future of solar power lies in combining innovative solar designs with intelligent monitoring, data analytics, and environment-responsive technologies.Although all these studies show great progress, the literature also makes it clear that more work is needed to develop standardized monitoring methods, low-cost intelligent systems, advanced rainfall-based irrigation controls, and strong environmental assessment frameworks. Many researchers have successfully demonstrated prototypes and experimental systems, but large-scale field deployment, long-term performance testing, hardware durability, and integration with power grids still need further improvement. Overall, the combined findings indicate that IoT-based solar monitoring, floating PV systems, automated cleaning mechanisms, and smart irrigation systems are highly promising technologies that can support sustainable development, especially in rural, coastal, agricultural, and water-stressed areas. With continued research, collaboration, and innovation, these technologies can help achieve higher energy efficiency, improved reliability, reduced maintenance efforts, and stronger adoption of renewable energy across different sectors.

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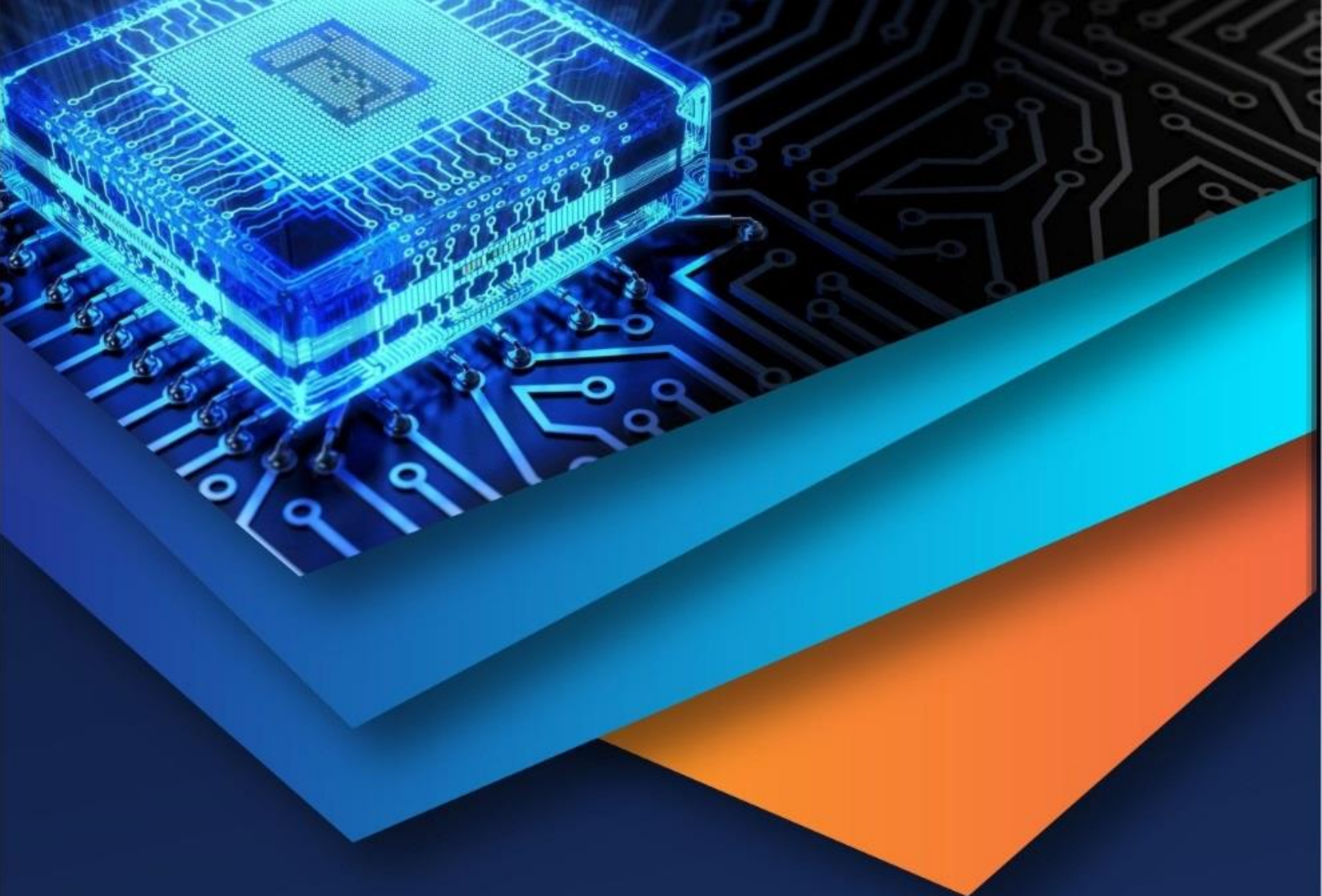

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