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Intelligent Monitoring Of Solar Panel Degradation Using Iot And Ai

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The performance of solar photovoltaic (PV) systems, one of the most promising renewable energy sources, deteriorates with time as a result of dust collection, temperature changes, environmental stress, and material ageing. Conventional monitoring methods are frequently reactive, which reduces productivity and raises maintenance expenses. In order to allow real-time detection and prediction analysis of solar panel deterioration, this research proposes an intelligent monitoring system that combines artificial intelligence (AI) with the Internet of Things (IoT).

Keywords: Solar Panel Degradation, IoT, Artificial Intelligence, Predictive Maintenance, Smart Monitoring, Photovoltaic Systems.

I. INTRODUCTION

Globally, solar photovoltaic (PV) systems are becoming more and more popular as a sustainable and clean energy source. However, degradation variables such dust deposition, temperature stress, microcracks, and material ageing have a major impact on solar panels' long-term performance. These problems raise operating expenses and lower energy production. Conventional maintenance techniques, such as reactive procedures or regular inspections, can lead to efficiency losses and ineffective issue diagnosis.

II Degrdation of solar panel

The effectiveness of the PV system and its different degradation patterns are the primary factors that determine its reliability and longevity. Since the early 1970s, data on PV module failures has been accessible. The most frequent degradation modes in modules over the past ten years, according to data published by the National Renewable Energy Laboratory (NREL) in 2017 and displayed in Figure 1, were hot spots (33%) followed by ribbon discolouration

(20%), glass breakage (12%), encapsulant discolouration (10%), cell breakage (9%), and potential-induced degradation (PID, 8%).

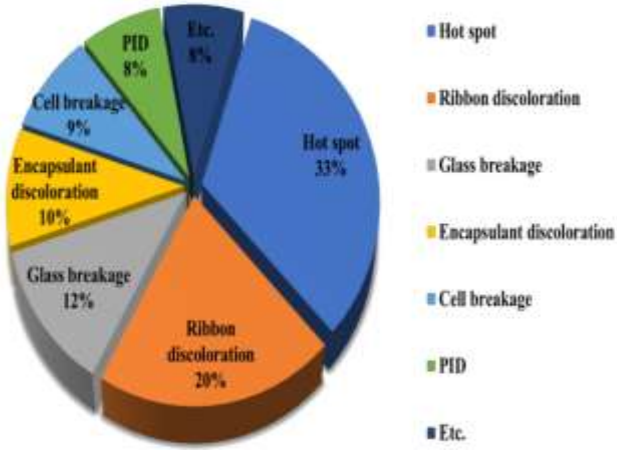

Figure 1. Representative degradation modes of silicon PV modules for the last 10 years.

Table 1 lists a number of types and rates of deterioration that have been documented in different nations. Environmental factors such excessive humidity, extremely high temperatures, and exposure periods longer than ten years are mostly responsible for the degradation.

Table 1. Degradation rates reported from various countries.

Country	Module Type	Degradation Rate	Cause of Degradation
Spain [7]	Multi-Si Solar Cell	−0.8% to −1.1%/year	Wind speed
Italy [8]	Multi-Si Solar Cell	−0.8% to −1.1%/year	PV cell shading
Cyprus [9]	Multi-Si Solar Cell	−0.8% to −1.1%/year	Solar irradiance and cell temp
Greece [10]	Multi-Si Solar Cell	−0.9% to −1.13%/year	Ambient temp, solar irradiation and wind speed
Poland [11]	Multi-Si Solar Cell	>−0.9%/year	Elevated air temp
India [12]	Mono-Si Solar Cells	−1.4%/year	High cell temp and humidity
Southern India [13]	Multi-Si Solar Cell	−1.3%/year	Air temp and high irradiance
Thailand [14]	Multi-Si Solar Cell	−1.5% to −4.9%/year	Humidity and moisture
Northern Thailand [15]	Multi-Si Solar Cell	−1.5%/year	Delamination of EVA [1] sheet
Japan [16]	Multi-Si Solar Cell	−1.15%/year	Ambient environmental factors
Singapore [17]	Multi-Si Solar Cell	−2.0%/year	Ambient temp
Republic of Korea [18]	Multi-Si Solar Cell	−1.3%/year	Corrosion and discoloration
Scotland, UK [19]	Multi-Si Solar Cell	−1.05% to −1.16%/year	Extreme low temp and humidity
Australia [19]	Multi-Si Solar Cell	−1.35% to −1.46%/year	Extreme high temp and moisture

Figure 2 shows the conceptual representation of the AT program on the modules.

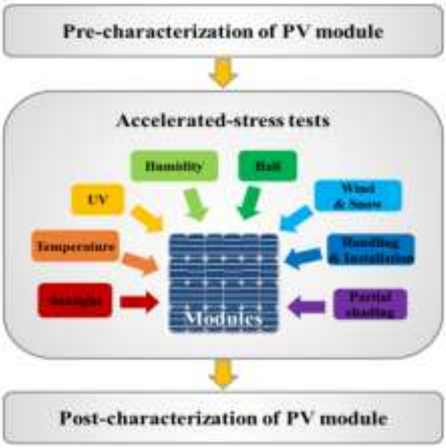

Figure 2. Conceptual representation of the AT of PV modules.

In addition to being designed for comparison and lifespan test programs, the generated PV modules need go through the standard qualification test programs set by the International Electrotechnical Commission (IEC) standards (IEC 61215 for terrestrial photovoltaic modules).

III BLOCK DIGRAM OF ARDUINO UNO

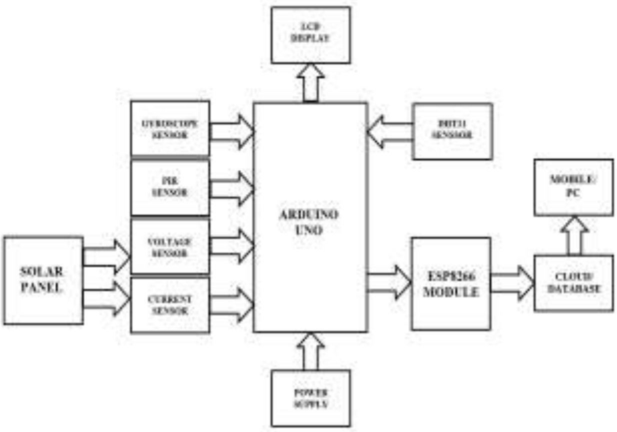

Figure 3.Block digram of Arduino uno

A. (IOT AND AI TECHNOLOGY)

In recent years, there has been a significant surge in research and development efforts to integrate IoT and AI technologies into solar panel monitoring systems. IoT-enabled sensors have the ability to collect real-time data on vital parameters like as temperature, voltage, current, and sun irradiance, allowing for comprehensive environmental and system performance monitoring. Meanwhile, AI technologies like machine learning and deep learning techniques enable automated fault detection, predictive maintenance, and anomaly identification based on collected data. By leveraging the synergy between IoT and AI, solar panel monitoring systems may become more efficient, reliable, and autonomous. In the end, this will lead to higher energy output, cheaper maintenance, and more resilient systems.

This paper aims to provide a comprehensive overview of recent advancements in solar panel monitoring, with a focus on the integration of IoT and AI techniques. Through a thorough analysis of the literature, the research will examine the newest methods, technologies, and applications in solar panel monitoring, highlighting their benefits, limitations, and opportunities for future development. By reviewing significant findings and highlighting emerging trends, challenges, and opportunities, this article seeks to contribute to the ongoing conversation on how IoT and AI could improve solar energy systems.

The integrity and authenticity of this review research will be upheld by taking strict measures to prevent plagiarism. All sources will be properly referenced and cited in compliance with academic standards, and original concepts and analyses will be presented based on the synthesis of the corpus of recent literature. The item will also undergo a thorough review and validation process by subject-matter experts to ensure accuracy, clarity, and relevance.

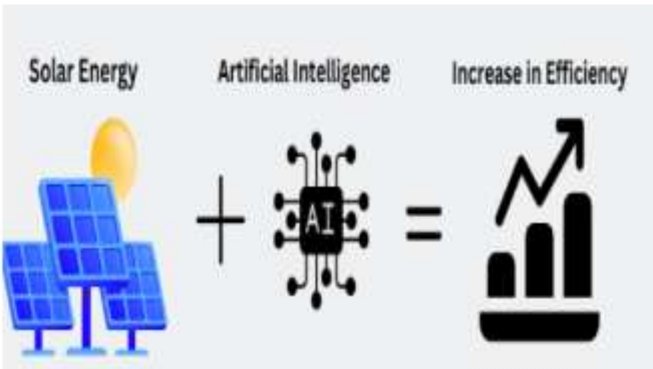

Figure 4. Solar Panel & AI

B. AI Technologies in Renewable Energy Maintenance

Wind turbines, solar panels, and hydroelectric power plants are examples of renewable energy sources that are essential to the worldwide effort to battle climate change and decrease carbon emissions. However, because of the complexity of their operations and their exposure to severe climatic conditions, sustaining these systems presents substantial hurdles. Renewable energy systems are increasingly being maintained with the use of artificial intelligence (AI) technology, which provide solutions that increase longevity, efficiency, and dependability while lowering operating costs.

Predictive maintenance is one of the most important uses of AI in renewable energy maintenance. Conventional maintenance techniques, such reactive or scheduled maintenance, frequently turn out to be expensive and ineffective, either resulting in unplanned equipment breakdowns or needless downtime. By using machine learning algorithms to evaluate real-time data from sensors integrated into renewable energy equipment, AI-driven predictive maintenance provides a solution. AI algorithms, for example, can interpret data from sensors that track temperature, vibrations, and other turbine component operating characteristics in wind energy systems.

These algorithms identify minute variations that might indicate possible problems like gearbox defects, bearing wear, or blade fractures. Predicting these problems in advance allows for proactive maintenance scheduling, which lowers the chance of unplanned downtime and lowers repair expenses. Similar to this, AI tracks the performance of photovoltaic (PV) panels in solar energy systems, spotting deterioration tendencies that can result in failure or decreased efficiency and allowing for prompt solutions.

For instance, AI-driven optimisation in wind turbines may modify the nacelle's yaw and the blades' pitch to optimise energy extraction and minimise mechanical stress, hence increasing the turbines' lifespan. AI may be used in solar PV systems to adjust the panels' tilt and orientation during the day to maximise solar absorption and boost total energy output. These optimisation strategies help renewable energy systems become more reliable over the long run and require less maintenance, in addition to increasing their immediate efficiency.

Sensors and microcontrollers, which enable real-time tracking and performance optimisation, are essential parts of solar energy monitoring. Long-term monitoring and control systems are essential for dynamically modifying panel operations in response to real-time data, enhancing responsiveness and efficiency. Maintaining system performance and increasing operational longevity are two more important functions of fault detection. Intelligent and automated techniques for locating PV system issues have been developed by recent developments. These technologies provide real-time problem identification through the use of IoT-enabled monitoring devices, improving the overall dependability and efficiency of solar energy systems. AI adds sophisticated data analytics to IoT capabilities to enhance energy forecasts, optimise panel orientation, and save operating costs.
In order to predict weather trends, identify issues, and plan maintenance in advance, artificial intelligence systems examine both historical and real-time data. These features increase the lifespan of PV systems and help prevent system breakdowns. Furthermore, by precisely forecasting energy demand, AI helps integrate smart grids and enhances the scalability and reliability of solar power networks.

To optimise the performance of solar energy systems, AI and IoT—collectively, AIoT—represent a cohesive strategy that blends intelligent data processing with networked equipment.

IoT-enabled technologies for real-time monitoring, energy optimisation through tracking and cleaning systems, and AI-driven applications for defect detection, predictive maintenance, and energy forecasting are the primary topics of this survey, which looks at the integration of IoT in solar energy systems.

IV SURVEY METHODLOGY

1.1. Survey Methodology

We used a structured process to choose, examine, and contrast pertinent research on AIoT in solar energy in order to guarantee a thorough and methodical assessment. Search Methods: To find pertinent publications, we used Google Scholar in a methodical manner. IEEE, MDPI, and Elsevier journals provided the majority of the results. Peer-reviewed journal articles, conference proceedings, and review studies about AI, IoT, and how they are integrated into solar energy management were the main emphasis of the search.

"A IoT in solar energy," "IoT-based solar monitoring," "AI in photovoltaic systems," and "fault detection in PV systems" were among the keywords. Inclusion Criteria: We made sure to include research that particularly addressed AIoT applications in solar energy monitoring, optimisation, defect detection, and predictive maintenance by using precise selection criteria. To create a solid theoretical basis for our assessment, we also included publications that offered basic definitions of AI and IoT.

We included several earlier publications that are still highly referenced and have influenced the development of AI and IoT applications in solar energy, even though our primary focus was on recent research. Understanding the historical development of AIoT technologies and their influence on recent developments required knowledge of these earlier research. Exclusion: non-peer-reviewed publications, out-of-date studies with little bearing on contemporary AIoT applications, and generic AI or IoT research without a distinct focus on solar energy were not included.

Bibliometric Analysis: A comprehensive assessment of 199 academic publications, 127 of which particularly address the use of AI and IoT in PV systems, served as the foundation for our study. Figure 5 displays the distribution of these 127 publications throughout time. Foundational definitions are one of the many topics covered in the remaining investigations.

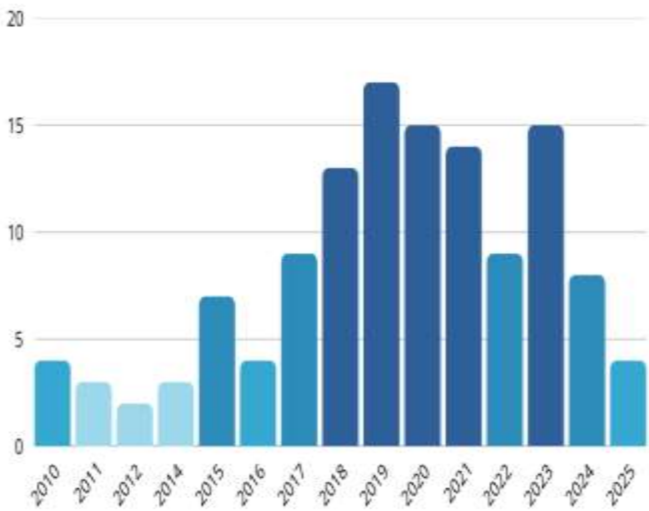

Figure 5. shows the distribution over time of the examined articles on AI and IoT applications in PV systems. To make sure we included the most current developments and new trends in the area, the main focus was on research that were published between 2015 and 2025.

1.2. Survey Organization

This work is structured as follows to guarantee a thorough and organised review: An introduction of AI and IoT is given in Section 2, along with an explanation of their basic ideas and functions in solar energy applications.

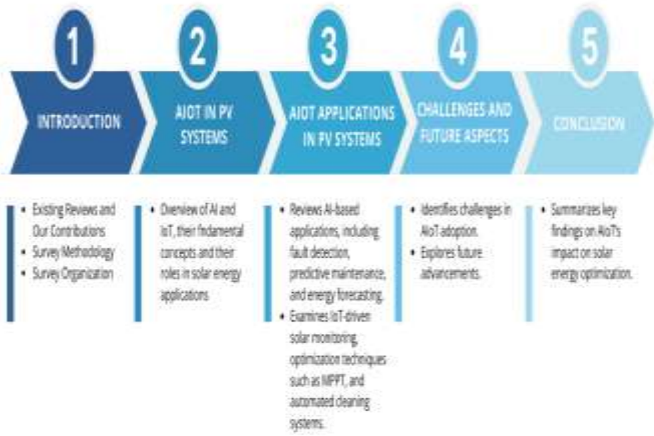

Figure 6. Survey roadmap: key topics and structure.

Additionally, it emphasises important AIoT supporting technologies such as cloud computing, IoT sensors, communication protocols, deep learning models, and machine learning algorithms. In order to improve energy efficiency, Section 3 classifies and examines IoT applications in solar energy, such as monitoring systems, PV system fault detection and diagnosis, predictive maintenance, energy forecasting, and optimisation strategies like MPPT, solar tracking, and automated cleaning systems.

V. CHALLENGES

CHALLENGES AND SOLUTIONS IN IOT-BASED

smart energy management system for photovoltaic power Generation Although IOT-based SEMS have significantly increased PV power generation efficiency, a number of obstacles prevent their widespread use. Risks to cyber security, high infrastructure expenses, complex data management, interoperability problems, and reliance on reliable internet connectivity are some of these difficulties. To guarantee a safe, scalable, and effective smart solar energy ecosystem, these problems must be resolved.

These research initiatives, technical developments, and encouraging regulations all work together to make solar systems more successful and affordable, increasing their viability and appeal as a renewable energy source.

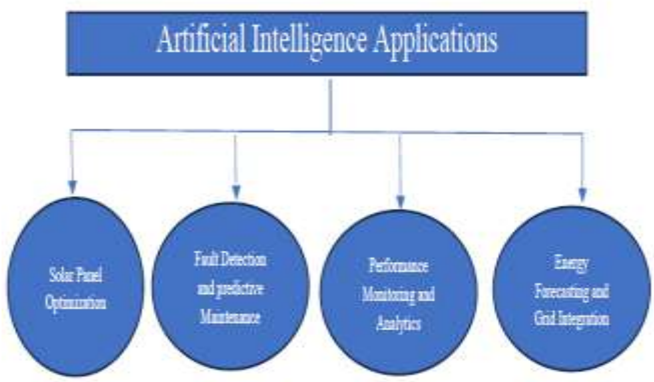

Figure 7: Keys of Artificial Intelligence in Solar Panel Technologies

The performance of PV systems has been shown to be significantly impacted by artificial intelligence (AI) algorithms.

AI algorithms may be used for modelling, sizing, control, problem diagnosis, and affair estimation in solar systems. For every kind of operation, it contrasts conventional and artificial intelligence algorithms. Figure 7 illustrates the main AI applications in solar panel technology.

VI RELATED WORK

I. LITERATURE REVIEW:

The literature review provides an in-depth analysis of current research on IoT, AI, and solar panel monitoring technologies, highlighting the drawbacks of traditional monitoring techniques as well as the possible benefits of combining IoT and AI for better solar panel system monitoring and control. To find gaps in the literature and support the need for the suggested strategy, prior research in similar fields is examined.

The inefficiencies of conventional approaches, which are frequently typified by time-consuming inspections and irregular data collecting, have drawn more attention from research in solar panel monitoring. Current research highlights how IoT technologies can monitor factors including temperature, irradiance, and output efficiency while enabling real-time data collection from vast sensor networks (Smith, 2021). Predictive maintenance and problem detection skills are greatly improved by using these systems as the basis for data processing using AI approaches (Johnson et al., 2019).

For instance, by examining patterns and irregularities in data gathered by IoT devices, the incorporation of machine learning algorithms has proven to be capable of anticipating system breakdowns and optimising energy output (Lee et al., 2020). In order to optimise energy capture, decision-making systems may also automate reactions to shifting environmental circumstances by dynamically modifying panel angles (Al-Ali et al., 2018).

However, there are still issues with these technologies' smooth integration into completely automated and dependable monitoring systems. Current implementations frequently ignore a comprehensive approach to system management in favour of concentrating on discrete elements of the monitoring process (Kumar & Patel, 2021). Furthermore, there is a significant need for more research and development since the scalability and cost-effectiveness of implementing such integrated systems in various situations have not been thoroughly examined.

This analysis highlights how IoT and AI may revolutionise solar panel system monitoring and operating efficiency, opening the door to more intelligent renewable energy solutions.

II. SYSTEM ARCHITECTURE:

The suggested system architecture is painstakingly created to smoothly combine AI and IoT technologies, improving solar panel systems' monitoring and management capabilities. The architecture, which consists of a number of essential parts, each plays a crucial part in guaranteeing the system's overall efficacy and usefulness.

1. Arduino-based Sensor Nodes:

The main data gathering devices at the centre of the system are sensor nodes based on Arduino. Numerous sensors, such as those for temperature, humidity, voltage, current, tilt angle, and light intensity, are included with these nodes. Their main job is to collect environmental data from the solar panel installation in real time. The sensor data is processed effectively by the Arduino microcontroller, guaranteeing that it is prepared for transfer to the Internet of Things platform.

2. Wi-Fi Modules:

Wireless connectivity between the Arduino-based sensor nodes and the Internet of Things platform is made possible in large part by the Wi-Fi modules. They facilitate smooth connectivity and remote solar panel system monitoring by acting as the backbone for sensor data transmission over Wi-Fi networks.

The Wi-Fi modules' strong performance is one of its primary features; it guarantees dependable data transfer, which is necessary for real-time monitoring and management. A constant flow of information on the performance and condition of the solar panel system depends on their capacity to send data reliably and uninterruptedly.

Additionally, these modules are made to blend in well with current Wi-Fi networks, guaranteeing interoperability in a variety of settings and infrastructures. This interoperability makes it easier to integrate and deploy the monitoring system in a variety of contexts, ranging from large-scale solar farms to residential installations.

The Wi-Fi modules' low power consumption is another outstanding characteristic. These modules' low energy consumption, in spite of their potent capabilities, prolongs the battery-powered sensor nodes' operational lifetime and lowers the system's overall energy expenses.

Additionally, the modules' integrated security measures offer strong defence against data breaches and illegal access. The confidentiality and integrity of sensor data transferred across a network are guaranteed by secure data transmission protocols, encryption techniques, and authentication procedures.

The monitoring system's scalability and adaptability are further improved by the Wi-Fi modules' modular architecture. As needed, it enables smooth growth to add more sensor nodes or sophisticated features, guaranteeing that the system can expand and adjust to changing needs.

Administrators may also monitor and configure sensor nodes from any location with internet connection thanks to the modules' remote management features. In the end, this remote accessibility lowers downtime and improves overall system dependability by making system management, troubleshooting, and maintenance simpler.

In conclusion, the solar panel monitoring system's Wi-Fi modules are essential parts that enhance its scalability, dependability, and effectiveness. They are crucial for guaranteeing the smooth functioning and efficient administration of solar panel installations because of their strong performance, interoperability, low power consumption, security features, and remote management capabilities.

3. Thing Speak IoT Platform:

The ThingSpeak IoT platform is essential to the operation of the system as it acts as the primary location for data storage, visualisation, and analysis. Without the need for complex procedures or interfaces, its user-friendly interface simplifies data administration responsibilities and provides insightful information about the operation of the solar panel system.

System operators can easily explore and obtain vital information because to ThingSpeak's user-friendly interface, which makes data administration more efficient. This interface design's simplicity improves operational efficiency by facilitating quick decisions based on data that is updated in real time.

Additionally, ThingSpeak offers a comprehensive array of data analytics tools that enable customers to extract useful information from sensor data. By enabling thorough analysis, these technologies reveal trends, patterns, and anomalies that are essential for enhancing system performance and putting proactive maintenance plans into place. Operators may minimise downtime and maximise energy generation by utilising sophisticated analytics skills to detect possible problems early on. Sensor data is securely stored in a centralised repository thanks to ThingSpeak's powerful data storage features. In addition to ensuring

data integrity, this centralised storage makes it simple to retrieve and analyse previous data for the purpose of identifying long-term trends.
Interoperability and scalability are further improved by the platform's support for smooth interaction with various IoT platforms and devices. The system's capabilities and features may be expanded as needed thanks to this interoperability, which makes it possible to integrate extra sensors or third-party applications.

All things considered, the Thing Speak IoT platform is essential to our system design as it offers a centralised platform for effective data administration, analysis, and visualisation. Its comprehensive data storage capabilities, interoperability, sophisticated analytics tools, and user-friendly interface make it an essential tool for maximising the dependability and performance of solar panel systems.

4. AI-Based Analysis:
An AI-based module thoroughly analyses the gathered sensor data, allowing for processing and decision-making in real time. In order to analyse the data and find trends, abnormalities, and possible problems affecting the functioning of the solar panel system, machine learning algorithms are carefully trained. By maximising energy generation and improving system dependability, this clever analysis enables the system to implement proactive maintenance and optimisation measures.

5. System Expansion and Scalability:
Furthermore, the suggested system design may easily be expanded to include more sensor nodes or sophisticated AI modules due to its inherent scalability. This scalability makes it easier to integrate the system into a variety of situations and guarantees that it can adapt to changing requirements. Furthermore, the architecture's modular form encourages adaptability, making it possible to add new features and technologies to further expand its possibilities.

VII. WORKING METHOD

In order to satisfy the established system needs and objectives, our integrated IoT and AI-based solar panel monitoring system is being implemented using a methodical manner. The following stages cover the essential procedures for setting up and deploying the monitoring system:

1. Requirement Analysis:
To determine the goals and needs of the system, a comprehensive analysis must be carried out as the first stage. This entails establishing the parameters to be monitored, identifying the intended results, defining the scope of the monitoring system, and comprehending the operating environment of the solar panel installation. Alignment with the goals of enhancing energy generation and system dependability is ensured via stakeholder discussions and subject knowledge. Setting up the hardware components for data collecting comes next, after the system requirements have been determined. Temperature, humidity, light intensity, tilt, current, and voltage sensors are among the sensors that are constructed and fitted into Arduino-based sensor nodes. To guarantee precise data collection, great consideration is

given to sensor location, calibration, and selection. The hardware configuration is made to resist environmental factors and easily connect to the Internet of Things platform in order to transmit data.

3. Software Development:
To make data collecting, preprocessing, and transmission from Arduino-based sensor nodes to the Thing Speak IoT platform easier, custom software is created. The software is customised to meet the needs of the monitoring system and uses the Arduino programming language (C/C++) for data manipulation and sensor interface. For stable and dependable functioning in real-world settings, a focus is focused on maximising code efficiency, reducing resource usage, and putting error handling systems in place.

4. Data Transmission:
Sensor nodes start gathering environmental data from the solar panel installation as soon as hardware configuration and software development are finished.

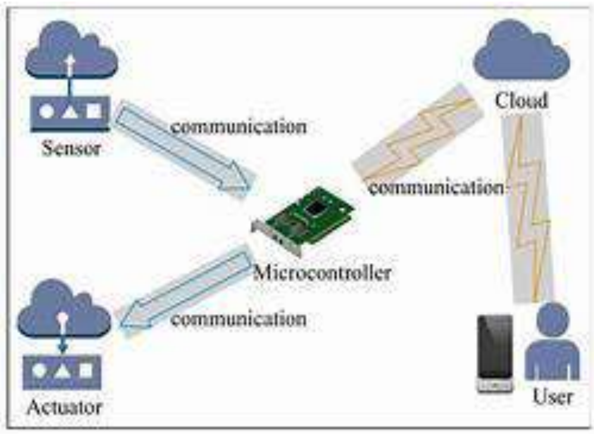

Fig 7: Data Transmission
Wi-Fi modules are used to wirelessly transfer collected sensor data to the ThingSpeak IoT platform. ThingSpeak ensures interaction with the monitoring system by providing an intuitive user interface and APIs for smooth data feeding. To guarantee data confidentiality, integrity, and adherence to IoT standards, data transfer protocols are put into place.

5. AI-Based Analysis:
Real-time AI-based analysis is performed on sensor data to uncover possible problems influencing solar panel performance and to provide actionable insights. Both current and historical data are analysed using machine learning techniques including regression analysis, anomaly identification, and predictive modelling. By identifying patterns, trends, and departures from typical operating circumstances, these algorithms make it easier to proactively identify maintenance requirements, optimisation possibilities, and performance improvements.

ALGORITHEM

I. Setup:

- Import necessary libraries (NumPy, pandas, Matplotlib, scikit-learn, etc.).
- Define helper functions (if any).

II. Data Collection:

- Fetch sensor data from the Thingspeak channel.
- Extract voltage, current, tilt, vibration, temperature, and humidity readings.

1.Data Preprocessing:

- Prepare the data for prediction (e.g., convert strings to numeric values, scale the data if necessary).

2.Model Training:

- Load the labeled dataset (salar.csv).
- Split the dataset into training and testing sets.
- Train a KNN classifier on the training data.

3.Model Evaluation:

- Evaluate the classifier's accuracy using the test set.

4.Real-time Prediction:

- Continuously collect sensor data.
- Convert the data into the required format.
- Use the trained classifier to predict the system state ("Normal" or "Action Required").
- □Based on the prediction, trigger alerts or take appropriate actions.

5.Visualization (Optional):

- Plot sensor data over time.
- Visualize model performance (e.g., accuracy, confusion matrix).

6.Continuous Monitoring:

- Run the monitoring script continuously to keep track of system state in real-time.

7.Improvement and Optimization (Optional):

- Fine-tune the model parameters.
- Explore other machine learning algorithms for classification.
- Optimize the code for efficiency and scalability.

VIII Output Generation:

The monitoring system provides system operators and stakeholders with actionable insights, warnings, and suggestions based on the findings of AI analysis. These outputs are presented in an intuitive manner through dashboards, visualisations, and notifications, which aid in proactive maintenance plans and well-informed decision-making. Furthermore, to resolve detected problems or instantly optimise system settings, automatic reactions or control actions could be initiated.

1.AI-Driven Anomaly Detection:
The AI technology skilfully detects irregularities and departures from defined operating rules by analysing data in real-time. The system identifies anomalies like temperature spikes, humidity changes, or voltage swings by comparing incoming sensor data to preset criteria. These notifications reduce the possibility of operating disruptions and enable prompt corrective action to address problems.

2. Fault Detection:
By utilising AI-powered insights, the system generates defect detection alerts and offers practical maintenance recommendations to maintain the solar panel installation's peak performance. Significant deviations, such abrupt voltage reductions, trigger alarms and call for specialised actions, like panel cleaning or recalibration, to maximise system performance.

Operators may optimise the performance of the solar panel system with the use of insights obtained from AI analysis and recommendations given by the system. Operators seek to maximise energy generation efficiency and strengthen system dependability by modifying parameters like panel orientation, tilt angles, or maintenance schedules based on data patterns. This reduces operational downtime.

The conclusions drawn from the solar panel monitoring system encourage a culture of flexibility and iterative development. Operators are able to identify areas for improvement and proactively adopt remedial actions through long-term system performance monitoring and historical data analysis. Furthermore, continuous improvement of AI algorithms in response to stakeholder input and updated data guarantees that the system will continue to be flexible and adaptable to changing environmental factors and operational requirements.

IX CONCLUSION & SUMMERY

Combining IoT and AI technology offers a compelling way to increase solar panel systems' efficiency and reliability. Our integrated approach enables stakeholders to take proactive actions, maximising energy generation and strengthening maintenance procedures, by facilitating real-time monitoring and insightful analysis. In order to advance the field of renewable energy management, future efforts will concentrate on improving AI algorithms and making sure the monitoring infrastructure is scalable to handle large deployments.

The performance and robustness of solar panel systems might be revolutionised by the combination of IoT and AI. Our technique enables stakeholders to traverse complex energy environments with accuracy and foresight by seamlessly combining intelligent analysis and real-time monitoring. As we move forward, further research will refine AI algorithms for even higher efficiency and strengthen our monitoring framework's scalability to meet the demands of the future's renewable energy frontiers.

REFERENCES

1. Da Fonseca, J.E.F.; de Oliveira, F.S.; Prieb, C.W.M.; Krenzinger, A. Degradation analysis of a photovoltaic generator after operating for 15 years in southern Brazil. Sol. Energy 2020, 196, 196–206.

2. Ishii, T.; Masuda, A. Annual degradation rates of recent crystalline silicon photovoltaic modules. Prog. Photovolt. Res. Appl. 2017, 25, 953–967.

[3] S. K. Srivastava, "Application of Artificial Intelligence in Renewable Energy," in In 2020 International Conference on Computational Performance Evaluation (ComPE), pp. 327– 331, Shillong, India, July 2020.

[4] S. Rao, S. Katoch, V. Narayanaswamy et al., "Machine learning for solar array monitoring, optimization, and control," Synthesis Lectures on Power Electronics, vol. 7, no. 1, pp. 1–91, 2020.

5. Sahu, D.K.; Brahmin, A. A review on solar monitoring system. Int. Res. J. Eng. Technol. 2021, 8, 111–113.

6. Merza, B.N.;Wadday, A.G.; Abdullah, A.K. Study and analysis of fault detection in solar array system based on internet of things.
AIP Conf. Proc. 2024, 3092, 050010.

7.Martín-Martínez, S.; Cañas-Carretón, M.; Honrubia-Escribano, A.; Gómez-Lázaro, E.J.E.C. Performance evaluation of large solar photovoltaic power plants in Spain. Energy Convers. Manag. 2019, 183, 515–528.

8.Lovati, M.; Salvalai, G.; Fratus, G.; Maturi, L.; Albatici, R.; Moser, D. New method for the early design of BIPV with electric storage: A case study in northern Italy. Sustain. Cities Soc. 2019, 48, 101400

9. Singh, R.; Sharma, M.; Rawat, R.; Banerjee, C. Field Analysis of three different silicon-based Technologies in Composite Climate Condition–Part II–Seasonal assessment and performance degradation rates using statistical tools. Renew. Energy 2020, 147, 2102–2117.

10.Gaglia, A.G.; Lykoudis, S.; Argiriou, A.A.; Balaras, C.A.; Dialynas, E. Energy efficiency of PV panels under real outdoor conditions–An experimental assessment in Athens, Greece. Renew. Energy 2017, 101, 236–243.

11.Jurasz, J.K.; Dąbek, P.B.; Campana, P.E. Can a city reach energy self-sufficiency by means of rooftop photovoltaics Case study from Poland. J. Clean. Prod. 2020, 245, 118813.

12.Chandel, S.S.; Naik, M.N.; Sharma, V.; Chandel, R. Degradation analysis of 28 year field exposed mono-c-Si photovoltaic modules of a direct coupled solar water pumping system in western Himalayan region of India. Renew. Energy 2015, 78, 193–202.

13.Thotakura, S.; Kondamudi, S.C.; Xavier, J.F.; Quanjin, M.; Reddy, G.R.; Gangwar, P.; Davuluri, S.L. Operational performance of megawatt-scale grid integrated rooftop solar PV system in tropical wet and dry climates of India. Case Stud. Therm. Eng. 2020, 18, 100602.

14.Tongsopit, S.; Junlakarn, S.; Wibulpolprasert, W.; Chaianong, A.; Kokchang, P.; Hoang, N.V. The economics of solar PV self-consumption in Thailand. Renew. Energy 2019, 138, 395–408.

15.Dechthummarong, C.; Wiengmoon, B.; Chenvidhya, D.; Jivacate, C.; Kirtikara, K. Physical deterioration of encapsulation and electrical insulation properties of PV modules after long-term operation in Thailand. Sol. Energy Mater. Sol. Cells 2010, 94, 1437–1440.

16.Park, J.H.; Lee, H.D.; Tae, D.H.; Ferreira, M.; Rho, D.S. A Study on Disposal Diagnosis Algorithm of PV Modules Considering Performance Degradation Rate. J. Korea Acad. Ind. Coop. Soc. 2019, 20, 493–502.

17.Teah, H.S.; Yang, Q.; Onuki, M.; Teah, H.Y. Incorporating External Effects into Project Sustainability Assessments: The Case of a Green Campus Initiative Based on a Solar PV System. Sustainability 2019, 11, 5786.

18.Jordan, D.C.; Deline, C.; Deceglie, M.; Silverman, T.J.; Luo, W. PV Degradation–Mounting & Temperature. In Proceedings of the 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), Chicago, IL, USA, 16–21 June 2019; pp. 673–679.

19.Dhimish, M.; Alrashidi, A. Photovoltaic Degradation Rate Affected by Different Weather Conditions: A Case Study Based on PV Systems in the UK and Australia. Electronics 2020, 9, 650.

[20] Kusiak A, Verma A. A data-driven approach for monitoring and fault detection of wind turbines. IEEE Trans Sustain Energy. 2012;3(4):956-66.

[21] Ahmed R, Sankar A. Critical analysis of data-driven solar photovoltaic fault detection techniques and their feasibility for large-scale integration. Renew Sustain Energy Rev. 2020;135:110239.

[22] Yildiz B, Bilbao JI, Sproul AB, Dincer I. Recent advancements in optimization of hybrid renewable energy systems. Int J Energy Res. 2021;45(4):4899-932.
[23] Ranaweera K, Jayawickrama D, Wijekoon L. AI-based optimization of solar PV system in smart grid environment. Renew Energy. 2020;153:1116-28.

[24] Mellit, A.; Kalogirou, S.A.; Hontoria, L.; Shaari, S. Artificial intelligence techniques for sizing photovoltaic systems: A review. Renew. Sustain. Energy Rev. 2009, 13, 406–419.

[25]. Zhao, H.x.; Magoules, F. A review on the prediction of building energy consumption. Renew. Sustain. Energy Rev. 2012,16, 3586–3592.

[26]. Dounis, A.I. Caraiscos, C. Advanced control systems engineering for energy and comfort management in a building environment—A review. Renew. Sustain. Energy Rev. 2009, 13, 1246–1261.

[27]. Kalogirou, S.A. Artificial neural networks in renewable energy systems applications: A review. Renew. Sustain. Energy Rev. 2001,5, 373–401.

[28]. Mellit, A.; Kalogirou, S.A. Artificial intelligence techniques for photovoltaic applications: A review. Prog. Energy Combust. Sci.2008, 34, 574–632.

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