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Review of the Internet of Things Based Photovoltaics.

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ABSTRACT:

Solar panels necessitate effective monitoring and management to optimize their performance. Leveraging the Internet of Things (IoT) offers a viable solution to this challenge. This paper presents an IoT-based control system designed to oversee, regulate, and optimize the energy harvested from solar panels. The architectural framework emphasizes the tracking of panel performance, their periodic cleaning, and the early detection of faults. The primary system is categorized into three components: data acquisition, data gateway, and software architecture. Additionally, we delve into the advantages of this system, its socioeconomic and environmental impact, and an array of technical challenges. Furthermore, we propose a series of solutions to address these technical hurdles.

INTRODUCTION

Clean energy, particularly solar energy, has gained increasing popularity and significance due to its substantial benefits across various domains [1]. Solar energy stands as a crucial player in the realm of renewable energy sources globally. In 2015, solar power generation experienced remarkable growth, with a staggering 35% increase. Although its overall contribution to global power generation remains modest at 1.7%, this share has more than doubled in just three years. Solar power is now making a noticeable impact in terms of powering growth, contributing to nearly 20% of the global power growth in 2017 [2].

Several nations have made substantial investments in solar generation. For instance, Germany boasts an impressive installed capacity of 39,700 MW [3], which is almost equivalent to the installed and inspected thermoelectric power plants in Brazil [4]. Moreover, the installed solar generation capacity in countries like China, Japan, and the United States saw substantial increases of 15,150 MW, 11,000 MW, and 7,300 MW, respectively, in just 2015 [3].

Nevertheless, power generation from solar photovoltaic (PV) plants is inherently variable due to factors such as fluctuations in solar irradiance, temperature variations, and other environmental influences. These PV power plants are often situated in harsh outdoor environments, including deserts and rooftops. Consequently, they are susceptible to failures under such demanding conditions [5-7]. Hence, it becomes imperative to establish remote monitoring systems for PV systems to ensure efficient power delivery.

In general, remote monitoring systems are tasked with the retrieval, analysis, transmission, management, and feedback of remote information [8]. The advent of the Internet of Things (IoT) has led to a proliferation of applications, such as smart homes, intelligent cities, and smart campuses [9]. The IoT streamlines human efforts by enabling machine-to-machine interactions, which proves invaluable in effectively facilitating material production integration. Therefore, integrating IoT with PV systems becomes an essential step forward in harnessing the full potential of solar energy.

I. Benefits of deploying IOT in PV systems: [10]

1) The integration of IoT with cloud computing will facilitate end-to-end service provisioning and provide on-demand access to information.

2) IoT enhances sensing capabilities, leading to improved power flow, information flow, and service quality.

3) IoT renders PV systems scalable and interoperable, enhancing their adaptability.

4) IoT technologies can mitigate damages to PV systems caused by natural disasters through real-time monitoring and alerting.

5) IoT enables real-time data-based energy distribution, replacing reliance on historical data.

6) Real-time data availability through IoT enhances transparency in PV systems.

7) Predictive analytics in IoT can proactively alert operators to component issues, maintenance needs, and inspection schedules.

8) Predictive analytics can optimize output and service affordability for providers.

9) Adaptive analytics in IoT automatically balance energy loads, prevent equipment overheating, and reduce stress on components.

10) Real-time system output forecasts enable providers to offer data to resellers for selling power on the open market.

11) IoT functions on both macro and micro levels, managing national smart grids and aiding consumers with rooftop PV installations.

12) Data from IoT-enabled smart meters can enable providers to offer value-added services to consumers.

13) IoT improves the efficient management of energy storage systems.

14) IoT enables real-time communication of operational data from solar panels, whether on rooftops or remote locations.

15) IoT, in conjunction with Big Data, handles a wealth of information from PV systems, including temperature, voltage, and efficiency, aiding decision-making.

16) IoT-connected computers monitor data from various PV system sensors, providing insights into cell performance and fault detection.

17) IoT significantly reduces monitoring time and eliminates the need for numerous on-site visits.

18) The primary financial advantage of IoT lies in its potential to replace human monitoring and maintenance efforts, leading to cost savings for providers.

Transformation of Solar O&M Trade with IoT: -[11]

O&M (Operations and Maintenance) services play a critical role in optimizing the performance of solar power plants. IoT (Internet of Things) technology offers several valuable benefits to solar O&M, including:

1) Networked Connectivity: IoT enables seamless connectivity across the solar power plant, allowing for efficient data exchange and communication between various components and systems.

2) Real-time Performance Monitoring: IoT allows for continuous real-time monitoring of the plant's performance, helping operators quickly identify any deviations or issues.

3) Preventive Maintenance: IoT facilitates proactive maintenance by providing early warnings and alerts, enabling operators to address potential problems before they escalate.

4) In-depth Data Analysis: IoT systems collect and analyze vast amounts of data, providing valuable insights into plant performance, which can be used to make informed decisions.

Plant operators have significant responsibilities, including:

1) Managing Geographically Dispersed Megawatts: They are tasked with overseeing large-scale solar installations, often spread across different locations, while ensuring precise control and supervision of critical parameters at the grid connection points.

2) Managing Power Feed-in: Operators are responsible for managing the feed-in of both active and reactive power, which are interconnected with national and regional grids.

IoT can assist plant operators by collecting, displaying, and analyzing the necessary data to facilitate real-time decision-making and action.

Relying on technology and data-driven decision-making offers several advantages, such as:

1) Enhancing Professional O&M Services: The use of IoT technology improves the quality and effectiveness of O&M services, leading to better plant performance and reliability.

2) Lowering Operating Costs: IoT-driven automation and predictive maintenance can reduce operational expenses by optimizing resource allocation and reducing downtime.

3) Improving Efficiency: Real-time monitoring and data analysis enable operators to fine-tune plant operations for maximum efficiency and energy production.

4) Transparent Data Access: Authorized stakeholders, including asset owners, grid operators, and regulators, gain transparent access to plant performance data, promoting transparency and accountability.

5) Real-time Asset Health Monitoring: IoT allows operators to continuously assess the health of assets, enabling timely intervention and maintenance when needed, thus ensuring the longevity of the equipment and sustained performance.

In summary, the integration of IoT technology into solar power plant operations and maintenance brings numerous advantages, from real-time monitoring and preventive maintenance to improved efficiency and cost savings. It also facilitates transparent data access for various stakeholders, contributing to the overall success of solar energy systems.

IoT Architecture

In Internet of Things any object can generate data through sensors and can also be assigned an IP address to transfer data over a network. The architecture of IOT is shown in figure 1.

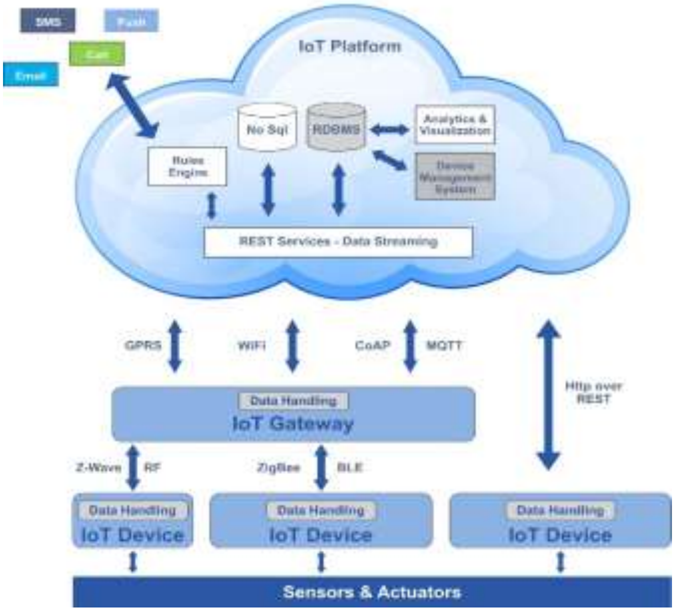


Figure 1: IOT architecture[12]

Sensors: -

A sensor, in the context of the Internet of Things (IoT), serves as a transducer whose primary function is to extract a wide array of information. IoT sensors, often referred to as nodes, play a pivotal role in collecting data and transmitting it to the external world via various communication protocols. These nodes serve as the data sources, and they typically relay the collected data to a central device known as a Gateway.

Pyranometer (Irradiance sensor): -

One specific type of sensor commonly used in solar energy applications is the pyranometer, which is employed to measure irradiance. Irradiance represents the amount of radiant energy (electromagnetic radiation from the sun) received by a flat surface. It is crucial to measure irradiance because it provides insights into how much power a solar project could potentially harness from the sun. Irradiance is typically measured in watts per square meter (W/m2).

A pyranometer is specifically designed to measure irradiance from all directions, making it suitable for assessing solar energy potential. It is instrumental in determining the optimal placement of solar panels, as it helps in gauging the solar energy available at a specific location. Additionally, irradiance data, such as the ratio between direct and diffuse radiation on-site, plays a pivotal role in the selection of solar generating technologies (e.g., PV, CPV, or CSP) and racking technologies (e.g., fixed or tracking panels).

While a pyranometer measures the solar energy input into the system, a power meter measures the electrical power generated by the solar panels. By continuously monitoring these two values, it becomes possible to calculate a performance ratio (PR) for a solar plant. The performance ratio is a critical parameter that provides insights into the efficiency and health of the solar plant. It can indicate whether the solar plant is operating optimally or if there are issues such as soiling, shading, short-circuits, or module degradation that need attention.

For precise and reliable measurements, the choice of pyranometer is essential. Secondary-class thermopile pyranometers are often preferred due to their thermal sensitivity, precision, long-term stability, and low error rates. These attributes make them well-suited for accurately assessing solar irradiance and ensuring the effective performance of solar energy systems [13].

Hall effect sensors: -

Hall Effect Sensors are devices that respond to external magnetic fields. These sensors rely on two key properties of a magnetic field: flux density (B) and polarity (North and South Poles). The output signal generated by a Hall effect sensor is determined by the magnetic field density in its vicinity.

Hall effect sensors are commonly utilized to measure various parameters, including voltage and current. They possess several advantageous characteristics that make them well-suited for applications like monitoring the voltage and current produced by solar panels:

1. High Sensitivity: Hall effect sensors exhibit a high level of sensitivity to changes in magnetic fields. This sensitivity enables them to detect even subtle variations in the magnetic field strength, making them effective in accurately measuring voltage and current.

2. Excellent Anti-Interference: These sensors are known for their resistance to electromagnetic interference (EMI) and other external disturbances. This capability ensures that the measurements obtained from the sensor remain reliable and unaffected by external factors.

3. Low Power Consumption: Hall effect sensors typically have low power requirements. This characteristic is advantageous, particularly in energy-sensitive applications like solar panel systems, where minimizing power consumption is essential for efficiency.

In the context of solar energy systems, Hall effect sensors can be employed to measure the voltage and current generated by solar panels accurately. By providing reliable data on these parameters, Hall effect sensors contribute to the efficient operation and monitoring of solar energy systems, allowing for effective management and optimization of power generation [14].

Temperature sensor: -

Temperature sensors play a crucial role in solar energy systems, as they directly impact the performance of solar panels. Here's why temperature sensors are essential:

1. Effect on Power Output: The temperature of a solar panel has a direct and significant effect on its power output. As the temperature of a solar panel increases, its output current rises exponentially, while the voltage output decreases linearly. Since power is the product of voltage and current, this relationship means that warmer solar panels produce less power.

2. Efficiency Optimization: To maximize the efficiency and power generation of a solar panel system, it's essential to monitor and control the panel's temperature. Temperature sensors provide real-time data on panel temperature, enabling the implementation of efficient cooling systems or strategies to mitigate temperature-related power losses.

3. DS18B20 Sensor: The DS18B20 sensor is a suitable choice for monitoring solar panel temperature. It offers several advantages, including its ability to measure temperature accurately, even when the sensor is located at a distance from the target area. Additionally, DS18B20 sensors are known for their durability and suitability for use in challenging environmental conditions, including wet or outdoor settings.

By integrating temperature sensors like the DS18B20 into solar panel systems, operators can monitor and manage panel temperatures effectively. This data empowers them to make informed decisions about cooling strategies, shading, or other measures to ensure that the panels operate within their optimal temperature range, thereby maximizing power generation and system efficiency [15].

IoT gateway

An IoT gateway serves as a critical component on the Internet of Things (IoT) ecosystem, playing the role of a bridge between IoT devices and the internet. Here are some key functions and attributes of IoT gateways:

1. Communication Bridge: IoT gateways are designed to connect and communicate with IoT devices that use various communication protocols and technologies. These devices may employ different wireless or wired protocols such as Wi-Fi, Bluetooth, Zigbee, LoRa, or MQTT. The gateway acts as an intermediary that abstracts the underlying communication methods, making it possible to interface with diverse IoT objects.

2. Data Collection and Parsing: IoT gateways are equipped to collect data from connected IoT devices. They gather information from sensors, actuators, and other IoT endpoints. Once collected, the data is parsed and organized for further processing and analysis.

3. Data Transmission to Cloud Servers: After collecting and processing the data, IoT gateways are responsible for transmitting this information to cloud servers. The cloud servers can then perform advanced analytics, storage, and visualization of the data. This cloud-based processing is crucial for generating insights and making data-driven decisions.

4. Security: IoT gateways play a crucial role in ensuring the security of data transmission. They provide a secure channel for the transfer of data from IoT devices to cloud servers. This includes encryption and other security measures to protect the data from unauthorized access or tampering during transmission.

5. Operating Systems: IoT gateways typically run on real-time operating systems (RTOS) or Linux-based operating systems. These operating systems provide the necessary functionality to manage data, network connections, and communication with IoT devices and cloud servers.

6. Hardware and Software Encryption: To enhance security, IoT gateways often incorporate hardware and software-level encryption mechanisms. These encryption methods safeguard the data as it travels through the gateway, ensuring that it remains confidential and secure.

In summary, IoT gateways are crucial components in IoT architectures, enabling the seamless and secure communication of data between IoT devices and cloud-based systems. They play a pivotal role in abstracting communication protocols, collecting and processing data, and ensuring the integrity and confidentiality of data during transmission [16].

Cloud platform and Big data analytics: -

Cloud platforms and big data analytics play a pivotal role in harnessing the full potential of the Internet of Things (IoT). Here's how they work together:

Cloud Platform Support Protocols: Cloud platforms for IoT are designed to support a variety of communication protocols, including GPRS, Wi-Fi, CoAP, MQTT, WebSocket, and RESTful, among others. These protocols facilitate the seamless exchange of data between IoT devices and the cloud.

Scalability and Elasticity: Cloud computing provides IoT with the essential features of scalability and elasticity. This means that IoT systems can leverage cloud resources to adapt to the massive and often unpredictable influx of data. Cloud offers elastic computing power, storage, and networking capabilities, allowing IoT applications to efficiently handle the vast amount of data generated by connected devices.

Big Data Analytics: The substantial amount of data generated by IoT devices can be overwhelming. Cloud platforms integrate with big data solutions to analyze this data and extract valuable insights. By applying big data analytics, patterns of usage and behavior of both machines and humans can be identified. This business intelligence is instrumental in predicting future data demands and deploying additional resources as needed.

Real-time Monitoring and Control: Cloud-based IoT applications offer real-time monitoring and control capabilities. Patterns identified through data analysis can trigger automatic actions. For instance, if an anomaly is detected, relevant information is sent to the user's hand-held devices. Users can control and monitor their devices remotely, ranging from simple room thermostats to complex systems like jet engines and assembly lines.

Bidirectional Communication: IoT systems support bidirectional communication flows, allowing users and manufacturers to interact with IoT devices and systems:

1. User/Manufacturer Input: Users or manufacturers can send input in various forms such as SMS, push notifications, emails, or calls. This input is forwarded to the internet, specifically the cloud.

2. Cloud Processing: The cloud processes the input, identifies the target object or system through its IP address, and selects the appropriate communication protocol.

3. Communication to the Gateway: The cloud sends the processed information through the chosen communication protocol to the IoT gateway.

4. Actuation: The IoT gateway, upon receiving the information, triggers the relevant actuator responsible for controlling and manipulating the system or object in question.

In summary, cloud platforms and big data analytics are integral to the IoT ecosystem. They enable the efficient handling of data, provide valuable insights, support real-time monitoring, and control, and facilitate bidirectional communication, allowing users and manufacturers to interact with IoT devices and systems effectively [17].

IoT architecture designed for PV.

The proposed conceptual system described in this work aims to monitor and control the state of a photovoltaic (PV) system using an IoT-based network. Here's an overview of the system architecture and its components:

System Architecture:

The system architecture is depicted in Figure 2 and consists of three layers:

1. Sensing Layer: This bottom layer includes various sensors, such as current sensors, voltage sensors, and a pyranometer for irradiance measurement. These sensors collect essential data related to the PV system's performance. Additionally, microcontrollers are used for data processing, where data acquired from the sensors is processed and prepared for transmission.

2. Network Layer: In the second layer, which is the network layer, data from the PV system is logged in real time. This layer involves data processing and storage, including the use of a database for storing the collected data.

3. Application Layer: The top layer is the application layer, where sophisticated web-based services are designed based on the data collected, processed, and stored in the network layer. This layer includes graphical user interfaces (GUIs) that facilitate monitoring of the PV system's performance. Furthermore, there is a console that provides valuable insights and recommendations to administrators based on historical data, which can significantly reduce decision-making time.

Data Transmission and Communication:

- Data from the sensors and microcontrollers are transmitted via a mobile radio network.

- A GPRS module is employed to send this data to a remote server.

- The remote server handles data processing and storage in the network layer.

- Sophisticated web-based services are built on top of this stored data in the application layer.

Benefits of the IoT-Based System:

- The system allows for remote monitoring and control of the PV system.

- Real-time data processing and storage enable timely decision-making.

- Historical data analysis provides insights for improving system performance.

- Graphical user interfaces make it easy to monitor and visualize the PV system's status.

- The IoT-based approach streamlines supervision, making it more efficient and accessible via the web.

In summary, this IoT-based remote monitoring system offers a comprehensive solution for overseeing the performance of a solar power plant. It integrates sensors, data processing, real-time monitoring, and historical data analysis, all accessible through user-friendly web interfaces, making it a valuable tool for optimizing the operation of PV systems.

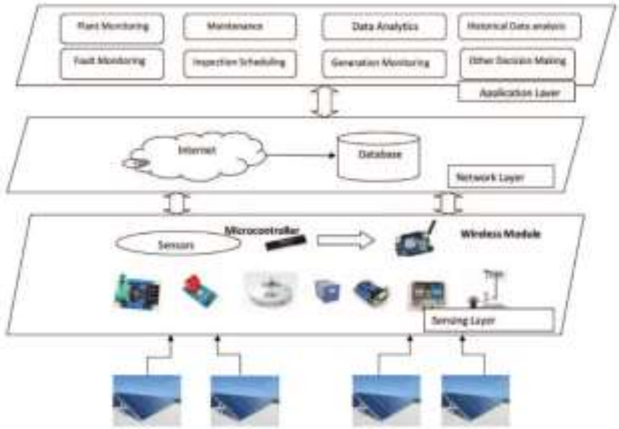


Figure 2: Proposed IoT Application for Solar Power Plant

Important areas in the IoT architecture

Shading prediction: -

There is a huge amount of power loss due to shading. MATLAB simulations show that for large panels even 20%-30% of shading results in a power loss of 30%-40% [18]. Weather and cloud motion prediction is very useful for forecasting the power output [19-23] of the solar array. Several methods have been used for shading prediction [24] including Kalman methods [25,26], machine learning and neural networks [27-29], and Autoregressive (AR) models [30, 31]. The research in [23] shows that efficiency improvements of up to 4% were documented using circuit simulation models. Their estimates show that efficiency improvements up to 10% are possible using shading prediction, customized sensor fusion and machine learning algorithms for fault detection. Machine learning and fusion enables them to implement robust shading prediction.

Cleaning: -

Output power gets reduced due to accumulation of dirt and dust on the panels. This effect is higher in areas where dust storms or dusty environments are present. Dust accumulation has a considerable effect on power production, reducing power output down to 50% or even less [32]. For the PV plants to remain operational at nominal installed power, periodical cleaning of the solar panels is required. For larger PV plants human manual cleaning of the panels is not feasible, especially in harsh and torrid environments or in cold weather conditions. For efficient cleaning in harsh environments cleaning robots can be installed. The solution provided in paper [33] shows an increase of 70% to 130% of electric power after the cleaning process.

The authors have proposed a fully automated cleaning system based on using a robot. The described system consists of the cleaning robot and a rail platform carrier that allows the transfer of the robot from one panel to the next as shown in Fig. 1. Robot cleaning steps are shown in the following figure:

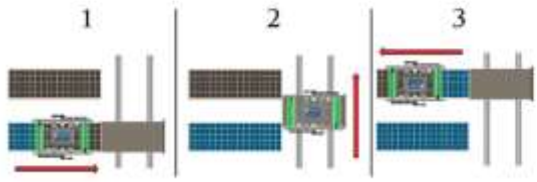
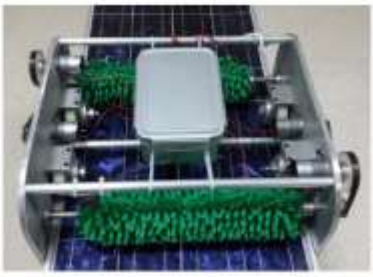


Fig 1. Robot cleaning steps [34]

The design based on a symmetrical mechanism allows easier adaptation for larger solar panels as seen in Fig. 2. It shows a robot with a microcontroller to control the motors which in turn controls the brushes.



There is another system proposed in paper [35] which is based on current dry-cleaning systems and is designed to work at a preset timing and to be simple, user friendly, robust, lightweight precise and fully autonomous. the design which is shown in Fig 3. consists of three cleaning mechanisms: air compressor, polyurethane foam roller and polywool synthetic duster (electrically charged). The system starts working when the constraints regarding humidity are satisfied. The panels are brushed, cleaned with the polyurethane foam roller, and after that by the polywool duster. The mechanical design is based on a triangular shape on which the main components are placed. The structure is attached on two rails with both mechanical functionality and electricity distribution for the cleaning robot.

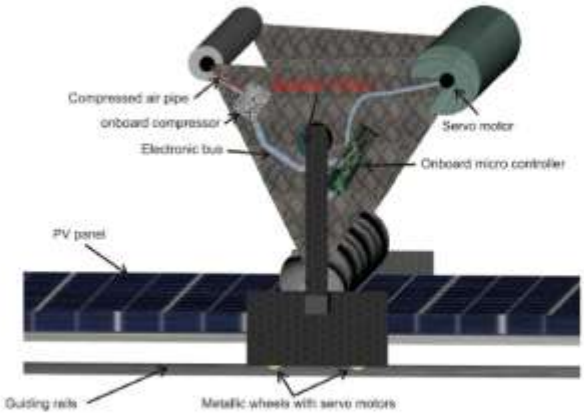


Fig 3. Cleaning system design

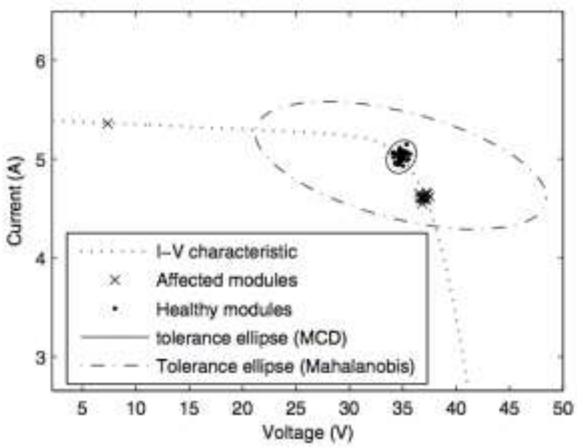
Fault detection: -

Reliability in solar arrays is crucial for power generation efficiency. Faults need to be detected.

The I-V data of the solar panel is quite useful and can be monitored in an inexpensive manner. An optimal operating point for a panel is the one that yields maximum power. We can use statistical analysis can be used to detect outliers in I-V data. Faults are typically identified by human operators using inverter data. In general PV array performance model is used to derive the expected array I-V curve. The expected I-V curve is usually compared with the measured one. Another approach involves taking measurements and detecting outliers. In [2] the Euclidean and Mahalanobis distance were used for detecting outliers. These are given below for data vectors **x**1 and **x**2:

$$d_{\mathrm{MA}}(\mathbf{x}_1, \mathbf{x}_2) = \sqrt{(\mathbf{x}_2 - \mathbf{x}_1)^T \mathbf{C}^{-1} (\mathbf{x}_2 - \mathbf{x}_1)}.$$

The simulation from [2] in Figure below shows the I-V curve and the tolerance ellipses for a ground fault simulation. It is shown that a minimum covariance determinant (MCD) estimator [2,35] forms a useful cluster to detect outliers while the Mahalanobis distance has an unacceptable tolerance.



IV. SYSTEM ARCHITECTURE

The system includes a data acquisition part and data gateway, and PVMC website for the entire PV array. The system acquires the temperature, irradiance, voltage and current of PV sub-array, and transmits to the data gateway via Zigbee. Then, the gateway stores the data, and uploads them to the PVMC website. In addition, the monitoring video for PV sub-array is sent to the PVMC website via the RTMP. PVMC website achieves data storage, user management, video surveillance and fault diagnosis. There are statistics displayed on the PVMC website, which make it conveniently for users keep a track of the situation of indicators of the PV array, such as daily power generation and the total historical power generation, temperature of the system, cooling properties, voltage, current etc. [36]. The system architecture is shown in the figure below.

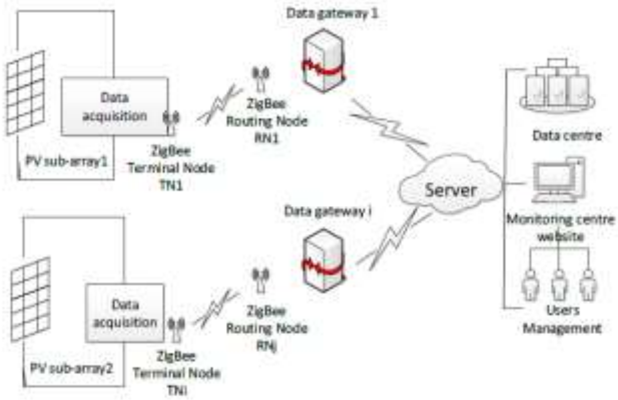


Figure 3. The architecture of the monitoring system.[36]

V. DATA ACQUISITION

As a well-known embedded processor, DSP-TMS320F28335 has plentiful hardware resources, such as 12-bits resolution analog-to-digital converters (ADC), serial communication interface (SCI) and abundant I/O ports [18], which make it ideal to be the microprocessor in the proposed monitoring system. The block diagram of data acquisition is shown in the figure below.

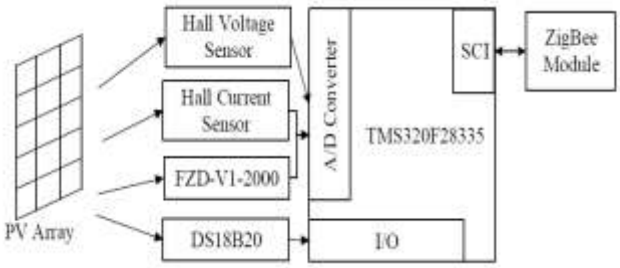


Figure 1. The block diagram of data acquisition.[3]

The Hall sensor is used to collect voltage and current due to its high sensitivity, excellent anti-interference, and low power consumption. Temperature sensor DS18B20 is applied to sensing the temperature in PV array via single bus protocol. ZigBee module is utilized to transmit the PV data to the data gateway. Irradiance sensor FZD-V1-2000 with fast response and high sensitivity is carried out to measure the irradiance. To ensure data transmission reliability, Md5 cryptographic algorithm with a 16-bit hash function is applied to the proposed system. It generates the public key for each node in the sensor network for authentication. [37]

VI. THE DESIGN OF DATA GATEWAY: -

The block diagram of data gateway is shown in the figure below. It includes Raspberry Pi 3, GPS module, ZigBee serial transmission module and USB camera. The Raspberry Pi 3 has advantages such as cost effectiveness, excellent interconnection, small size, powerful and low power consumption. In addition, wireless network card and Bluetooth module are embedded into Raspberry Pi 3. Hence, the data gateway applies to the Raspberry Pi 3 installed with Ubuntu Mate16.04 LTS operating system as the processor. The data gateway receives the PV data via the ZigBee network and employs the GPS module to obtain the geographical location of the PV array. The camera is applied to capture live video in the PV array. Then, the gateway connects to the Internet via wireless network card and uploads the PV data, GPS data and video to the PVMC website. [38]

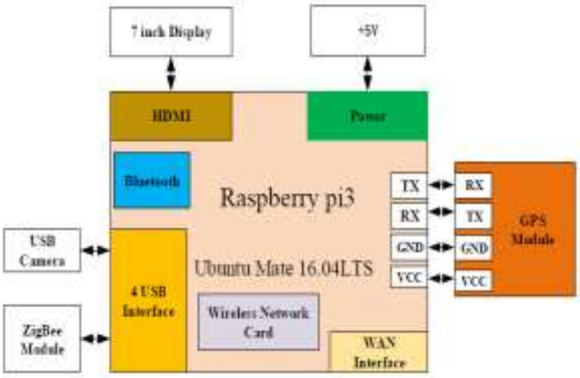
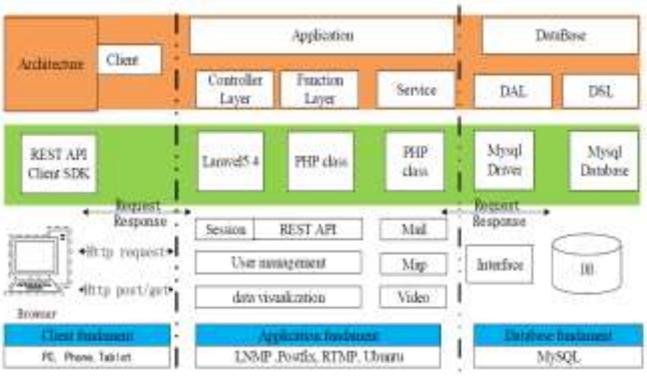


Figure 1. The block diagram of data gateway.[38]

VII. PV ARRAY MONITORING CENTRE WEBSITE

To make it convenient for users to view monitoring information via web browsers, the B/S architecture is selected to design the PVMC. A monitoring center website is designed on the base of the PHP Laravel framework that is running in the LNMP (Linux + Nginx + MySQL + PHP) installed on a server. Meanwhile, the Postfix mail server is installed to provide E-mail service for informing users of the fault warning. The framework of the monitoring center website is shown in figure 4, the PVMC website consists of client layer, application layer and data layer. In the client layer, users can visit websites via the web browser. The Laravel 5.4 is applied as the framework in the application layer, and e-mail, maps and video surveillance services are integrated in this layer to achieve data visualization, user management, and message management. The data layer selects MySQL as the database management platform to store PV data. The gateway communicates with the PVMC by representational state transfer (REST) API design patterns in website design. Moreover, the gateway integrates software development kit (SDK) coded by Python. As shown in figure 6\below, the database contains data access layer (DAL) and data service level (DSL).[39]



VIII. ECONOMIC IMPACT OF IOT

1) McKinsey Global Institute estimated the economic impact of IoT in electricity provision to be in the range of $200 billion to $500 billion per year by 2025

2) Cisco analysts estimated the net profit of IoT in intelligent power network technologies to be $757 billion between 2013 and 2022

3) IoT for PV systems presents an exciting era of growth, development, and opportunities

IX. SOCIETAL IMPACT OF IOT

1) IoT promises higher business productivity with increased energy efficiency and greater control and auditing capabilities

2) Data collected from the smart meters can help users to be more energy conscious and the utilities to better manage demand response

3) IoT can also be a threat to one's security and privacy

4) Data collected keeps track of user movements and activities. From this data, one can ascertain information, such as if the user is home or not or if a child is left home alone.

5) The IoT devices are networked through the internet and hence impose a security risk as they can be hacked

6) IoT deployment cannot be pushed onto the society and expected to be readily accepted

7) People's choices must be respected, and they should not be

forced down a path that makes them uncomfortable.

X. ENVIRONMENTAL IMPACT OF IOT

The biggest impact on the environment with IoT enabled smart PV will be the reduction in carbon dioxide (CO2) emissions. With IoT, almost 2 Gigatons of CO2 emissions in the power sector are estimated to be reduced annually by 2020. This CO2 emission reduction will be brought about by IoT devices by minimizing the amount of wasted energy and optimizing the control systems to absorb maximum solar and wind power.

XI. DIRECTIONS FOR FUTURE RESEACH

1. **Compatibility**: As of now, there is no standard for tagging and monitoring with sensors. A uniform concept like the USB or Bluetooth is required which should not be that difficult to do.

2. **Complexity**: There are several opportunities for failure with complex systems.

3. **Privacy/Security**: Privacy is a big issue with IoT. All the data must be encrypted so that no one other than the company will have any access to the data and location of the PV systems.

4. **Safety**: There is a chance that the software can be hacked, and your personal information will be misused. The possibilities are endless. Your prescription being changed, or your account details being hacked could put you at risk. Hence, all the safety risks become the consumer's responsibility.

XIII. CHALLENGES

• Need to ensure that cellular modules, gateways, and web platforms are all integrated properly, without breaks in connectivity

• Need equipment and software to show in real-time whether the solar station is delivering sufficient energy levels and maintaining load balance on the grid

• Need to cater for fluctuating energy generation in response to changes in the weather and other environmental factors

• Solar plants tend to be clustered and widely distributed increasing the complexity of an energy system

• More the number of panels, higher is the potential for vulnerabilities in the energy system

XIV. TECHNICAL CHALLENGES AND PROPOSED SOLUTIONS

* Sensing: -

a) Challenges:

Current IoT sensors lack the following critical features:

1) Situational intelligence

2) Efficient power management

3) Enhanced cyber security

b) Solutions:

1) Integrating historical IoT sensor data with real time data

2) Using arrays of low accuracy sensor modules with subsequent data fusion to generate high accuracy. information

3) Embedding hardware security features and adding more security layers.

*Connectivity: -

a) Challenges:

1) Lack of interoperability between different IoT standards

2) Coexistence challenge Solutions:

1) Comprehensive connectivity standards (e.g., 5G)

2)Wireless convergence modules, fair channel assignments, and dynamic licensed spectrum sharing.

*Power management: -

a) Challenges:

Difficult to incorporate power management in IoT devices due to variations in power collection methods.

b) Solutions: -

1) Energy harvesting systems deployed in randomly distributed multi-hop topology and uniformly distributed ring topology

2) Energy-efficient wireless, wired, optical, and optical-wireless communication networks

*Big Data: -

a) Challenges:

Difficult to store, track, analyze, capture, cure, search, share, transfer, secure, visualize, and interpret the generated data.

b) Solutions:

1) Apache Hadoop – an open-source software framework

2) New IoT cloud ecosystem

*Computation: -

a) Challenges:

Centralized computation and storage solution is not ideal for real-time heterogeneous IoT data:

1) Inefficient service-provisioning

2) Increased latency

• IoT ecosystems are constrained:

1) Low power communications

2) Scarce energy

3) Lossy communications

b) Solutions:

Localized computation and storage solutions for processing, analyzing, and storing IoT data.

1) Fog computing

• IoT data footprint reduction methods:

2) Dimensionality reduction

3) Data filtering

*Complexity: -

a) Challenges:

1) Increased network size from wide penetration of IoT devices

2) Increased heterogeneity from different vendors providing services, equipment, and applications

b) Solutions:

1)Simplification of IoT device design and development

2)Encapsulation of wireless capabilities

3)Providing easier to understand reference designs, modules, and on-chip connectivity stack and development environment

4)Software-defined networking

*Security: -

a) Challenges:

1)The system can be hacked, and confidential data can be stolen

2)Adding security features in IoT devices increases costs and there are no incentives for adding these features

3)Market pressure results in the IoT devices being inadequately secured

b) Solutions:

1)Layered approach: Greater the number of security layers, the more time it will take the attacker to steal confidential data, thereby giving businesses more time to protect it

2)Security solutions should be integrated into each IoT component

XV. CONCLUSION

Use of IoT for monitoring of a solar power plant is an important step as day-by-day renewable energy sources are getting integrated into utility grid. Thus, automation and intellectualization of solar power plant monitoring will enhance future decision-making process for large scale solar power plants and grid integration of such plants. In this paper we proposed an IoT based remote monitoring system for solar power plants. The approach is studied, implemented, and successfully achieved the remote transmission of data to a server for supervision. IoT based remote monitoring will improve energy efficiency [16] of the system by making use of low power consuming advanced wireless modules thereby reducing the carbon footprint. Web Console based interface will significantly reduce time of manual supervision and aid in the process of scheduling task of plant management. A provision of advance remotely manages the Solar PV plants of various operations like remote shutdown, remote management is to be incorporate with this system later.

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