IoT-based smart solar PV monitoring system; A Cost Effective and reliable solution

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Abstract:
The current world demands sustainable and eco-friendly energy sources as conventional energy sources (mainly fossil fuels) are depleting day by day. Therefore, there has been a great focus on Renewable Energy Sources (RES) in recent years of which solar photovoltaic, PV energy is one of the potential candidates. Since solar energy is sporadic in nature and its output depends on various meteorological parameters such as the intensity of sunlight on solar panels and soiling on PV panels. Any defect or damage to the PV panel can affect the PV panel's efficiency and desired yield. Therefore, the parameters of the PV systems have to be supervised remotely offering the stockholders increased yield and efficiency at reduced cost with minimum human interventions. The Internet of Things (IoT) is the best candidate for such systems offering improved supervision, data acquisition, and preventive maintenance at low cost.

Keywords: *Cloud-based architecture, IoT, IoT architecture, smart monitoring, solar plant monitoring, WSN*

1. Introduction

The photovoltaic effect (PV effect) is the conversion of sunlight into electrical energy. It was first discovered by Edmund Becquerel in 1839. Solar PV cells are made of different layers of semiconducting materials like Silicon that produce a direct current (DC) upon exposure to the sun. It is estimated the world will be consuming 30 TW of energy by the year 2050 [1] and the world is already in search of alternate sources of energy like RES. According to a report from the International Energy Agency (IEA), the contribution of RES will be around 28% of the world's total electricity generation by the end of 2022 [2]. Solar being the most prevalent and universally available can provide us with surplus energy to encounter the energy requirements of the modern world. Also, it is an eco-friendly and reliable source of alternative energy. The interest in solar has increased over the recent decades and it is believed that the annual solar installations will exceed 100GW at the end of the year 2022 [3] with annual growth of 60 %.

Also, the production cost has been reduced by 60% in recent years [4]. Figure 1 shows the production and cost of PV modules over the past couple of years.

The output of solar PV plants is subjected to various environmental parameters and climate conditions. The output parameters need to be monitored and supervised to get the desired output, increased efficiency, and locate faults promptly. However, the plants are mostly installed in far-off areas and physical monitoring and supervision may not be possible. Therefore, there is a need for a

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system that can monitor and supervise the system remotely in real-time. This purpose can be achieved by the use of IoT and cloud which offers tools for improved supervision, detailed monitoring and reporting [15]. This work presents a unique architecture for solar PV systems using IoT and Cloud. The system provides proficient monitoring of solar PV panels at the module level at reduced cost and reduced power consumption. The system offers detailed monitoring along with the capability to notify and alarm the user in case of undesired situations.

Fig. 1. Shows the drop in the prices of PV modules versus the production in the recent era. [5].

2. Literature Review

There are various techniques proposed in the literature for the monitoring of solar PV systems which can be classified into three main groups [6]:

- Systems with proprietary desktop applications for data processing.

- Systems that send the data to a web server/database via a local gateway.

- Industry standard SCADA systems.

The huge data produced by different sensors is processed by computer boards which may be either microcontroller boards or a single computer board [8]. The proposed solutions in the literature can be broadly categorized into two main categories based on the architecture; Centralized and De-centralized systems. M. Fuentes et al. [9] have proposed a unique IEC-based datalogger. The system makes use of open-source technologies and claims to offer improved performance as compared to other conventional systems. A remote monitoring system with the capability of system prediction and alarming the end user in case of any undesired situation is proposed by Gagliarducci et al. [7]. Andò in [10] has presented an IEEE 802.15.4-based Wireless Sensor Network system that detects losses in efficiency and monitors the performance of the system at the module level. The system is reliable and has better power consumption. A cloud-based system is proposed by Patel et al. [2] in which the data is sent to the cloud through a web page hosted on Raspberrypi.

Tejwani et al. [12] have proposed a system in which real-time data from different sensors is integrated into Atmega 2560 Arduino. The Blynk app is used to send data to a smartphone via Wi-Fi. Rashidi et al. [11] have presented a monitoring system based on LabVIEW. The sensed data is sent to a computer using a USB dongle. An electronic system using Bluetooth and Wi-Fi is proposed by Sohail et al. [13] in which the sensed data is sent to a control machine. A ZigBee and ThingSpeak-based system for monitoring hybrid energy sources is proposed by Dhongade et al. [14]. A cost-efficient system open source is designed by Papageorga et al. [15] using Arduino using ZigBee for wireless connectivity.

Mostly, the solar plants are located in far-flung and out-reach regions and manual monitoring/supervision may be hectic as it may require a lot of resources and manpower. Also, the PV output depends on various varying meteorological parameters. It is believed that the system may encounter an error/fault within the first year of its operation [12]. A single faulty module and undetected faults can greatly influence the desired output

and may eventually cause the entire system to fail. A lot of work has been done to increase the productivity and lifespan of solar PV systems but there are certain limitations in the current practices. Some researchers have used a proprietary tool, some have proposed systems that are harder to implement and have certain limitations. Some systems are designed for small-scale systems and may not apply to larger plants. A real-time remote monitoring system is required to supervise, maintain and troubleshoot the system at reduced cost and reduced human intervention with the benefits of detailed monitoring along with avoidance of unwanted power disruptions.

3. Generalized Design of Solar Monitoring Systems

The architecture design of an IoT-based solar PV monitoring system comprises the following layers:

- Data Acquisition layer

The sensors sense the physical world and acquire the data in analog form. A Microcontroller (computer board) is responsible for changing the analog data into the digital form [15]. The sensors and the processing unit make up the data acquisition layer.

- Data Transmission Layer (Network Layer)

The data from the various sensors is collected and processed by a computer board and sent through the network via communication technology (wired or wireless communication). The data is stored in either a centralized or a decentralized location. Ethernet, Bluetooth, ZigBee, Wi-Fi, RF and GSM, Sigfox and LoRA are the various communication technologies reported in the literature for solar plant monitoring systems [4].

- Support Layer

Before sending the data to the next layer (application layer), the data is temporarily stored/buffered at the terminal.

- Application Layer / Managing Node

This layer allows the end user to interact with the system using GUI (graphical user interface) and other data analytic tools. This can be a host computer, laptop, or web server.

Fig. 2 gives an overview of the generalized architecture of IoT-based solar PV monitoring systems.
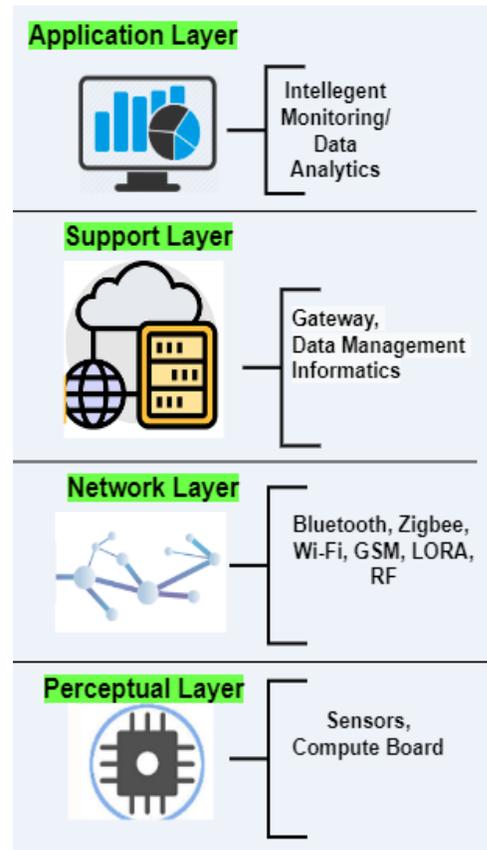

Fig. 2. Generalized architecture of Solar PV monitoring systems.

4. Performance Parameters

For accurate performance evaluation of installed solar plants, it is imperative to monitor meteorological and electrical parameters at both the panel and system levels. To have a brief insight into the performance of the system, voltage, current, temperature and

irradiance has to be measured and analyzed at the module level. According to the IEC 61724 standard, the monitoring systems can be classified into three classes based on the accuracy requirements [8]. Class A demands higher accuracy while Class B and C systems have average accuracy which is mainly used in smaller commercial and residential installations [8].

The factors affecting the installed solar plant's efficiency can be broadly characterized into:

4.1   Meteorological Parameters

Solar arrays are installed facing south at a certain angle for optimum capturing of solar radiations. Depending upon the solar installation configuration varying meteorological parameters (such as ambient temperature, humidity, clouds, wind, rain, dust, soiling, irradiance, and panel temperature) can affect the overall output of a solar plant.

4.2   Electrical Parameters

The main components of PV systems are solar panels which produce a direct current (DC), inverters which transforms the DC into alternating current (AC), and batteries which store the electrical energy [8].

5. PV systems hardware

The hardware platform mainly comprises:

- PV panels.
- Sensors
- Compute Board
- Storage (batteries)
- Inverters

The following section reports some of the commonly used sensors in the literature for solar PV monitoring systems.

A. ACS712 Sensor (Current Sensor)

The ACS712 from Allegro Microsystems is a Hall Effect-based linear Current sensor used for sensing both AC and DC currents. It has voltage isolation of 2.1 kV RMS and 66 to 185 mV/A output sensitivity. It has almost zero magnetic hysteresis and low noise with extremely stable output offset voltage.

B. LM35 sensor

LM35 by Texas Instruments (TI) is a low-priced temperature sensor. It can sense temperatures in the range of -40°C - 150 °C with a current drain of less than 60-μA. The measurements are on a Centigrade scale and do not need a calibration circuit.

C. INA219 sensor

TI's INA219 measures both current shunt and power. It has an I2C interface with 16 programmable addresses. It consumes 1 mA of the supply current and can measure current shunt on buses ranging from 0 to 26 V.

D. PT100 sensor

PT100 is a platinum-based temperature sensor from the group of temperature detectors (RTD) that can sense temperatures from -70 to +500°C.

E. DHT-11

DHT11 is a basic, low-cost digital sensor used for sensing temperature and humidity. The sensor can be easily integrated with any microcontroller. It has 3-5 V power and a sensing range of 0°-50°C with a precision of 2 degrees. It senses humidity ranging from 20 to 80% with an accuracy of 5%

F. Yocto Amp ammeter

It is a digital ammeter that can sense both alternating and direct currents up to 2mA. It consists of a built-in datalogger and has support for communication technology (wireless, GSM, or Ethernet).

G. CMP21 Payranometer

CMP21 manufactured by Kipp and Zonen is an ISO 9060 standard pyranometer that measures solar radiation, and radiation flux (Watt/m²).

H. **Voltage Divider**

A Voltage Divider is used in the literature for measuring voltage but it requires an ADC, Analog to Digital Converter to be fed into a microcontroller. Figure 3 shows some of the sensors mentioned above. The hardware boards responsible for managing the huge data from the sensors are of 2 types: divided into two main categories:
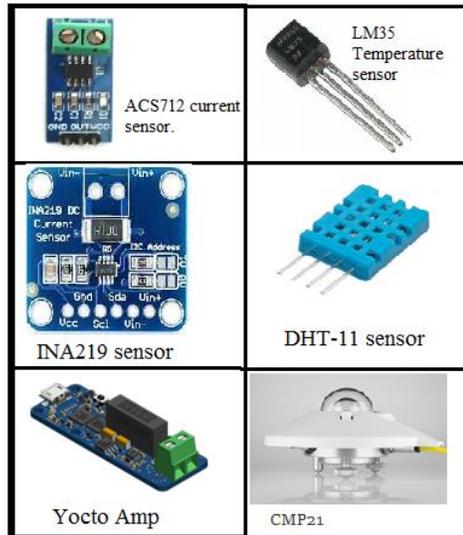

Fig. 3. Sensors used in the monitoring of Solar PV systems.

5.1 **Microcontroller board**

A microcontroller is designed to process the data received. It is a printed circuit board known as the PCB with some computation power and memory design. Microcontrollers are integrated with processors, memory, chipset, and onboard peripherals (LCD, Keypad, USB, serial ports, ADC, SD card slot, and Ethernet). The data from the sensors is communicated to the microcontroller board using a communication protocol. Examples of the commonly used boards in the literature are Arduino UNO, Arduino Mega 2560 Microcontroller, MSP430 Launchpad, ESP8266 and ESP32.

5.2 **Single computer board**

A single computer board may be termed as a complete computer built on a single chip having the features of a functional computer like microprocessor, memory and input/output. Single-board computers either synchronize sensor networks or acts as gateways to transfer the sensed data. It has the capability to run an operating system and can use communication protocols as well.

There are several compute boards reported in the literature on solar PV monitoring systems but the following points should be taken into consideration while selecting an electronic board for the system:

- Affordable price

- RAM of at least 512 MB in the CPU.

- The board should have built-in communication protocol or should have support for communication technology.

- Community support (this may include rich documentation and an online developers community)

The electronic board/compute board should have support for an operating system (usually Linux or Windows).

6. Proposed System

According to the standards of the International Electro-technical Commission, IEC-61724. The IoT architecture for solar PV systems should take care of the following parameters:

- Cost

- Reliability/Trustworthiness

- Scalability

- Security

Based on the IEC standards, the proposed architecture is described in the following section:

6.1 Data Acquisition Layer

Parameters like current, voltage, and temperature are sensed at the module level. ACS712 sensor is used for current sensing and LM35 for temperature sensing. The voltage can be sensed through a low-cost voltage sensor or a voltage divider. The choices of the sensors are made based on their price, availability, and low power consumption. Arduino Nano BLE (32-bit 64 MHz ARM processor) as an edge device receives data from the sensors and converts the analog data into digital form. The data is transmitted to the Fog layer via Bluetooth.
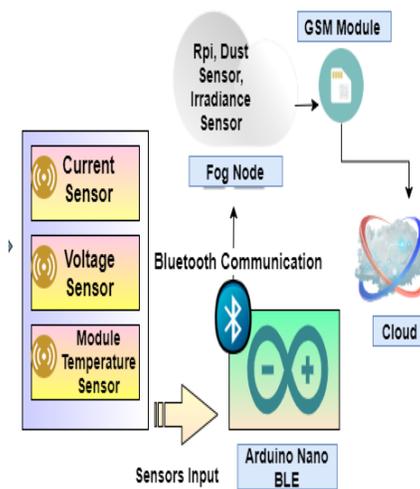
Fig. 4. Proposed IoT/Cloud-based System for Solar PV monitoring.

6.2 Fog Layer

Several Arduino Nano BLE devices operating at the edge transmit the data to the fog layer. The Fog layer is a compute board with irradiance and dust sensor. Having minimum sensors at the Gateway (Fog Layer), will reduce the computation and computation power at the module level. LDR and DSM501 sensors are used for sensing irradiance and dust at the Fog Layer. Rpi is used as a gateway device forwarding information to the cloud via GSM (2G or 3G) for further processing.

6.3 Presentation/Application Layer

Detailed and in-depth analysis is done at the application layer (cloud layer). This work proposes a platform based on Amazon Web Services (AWS). AWS offers extensive tools and services and has massive support for IoT systems. Along with the support of massive data, we can make use of the Amazon notification services to notify the end user in case of any abrupt/undesired behavior of the system. The system offers detailed monitoring and reporting which can help locate faults and predict system behavior. Figure.4 gives a brief overview of the proposed system.

7. Cost

As mentioned above, the basic parameters like current, voltage and temperature are sensed at the module level. The estimated cost of the single module is given in Table 1.

TABLE I.   ESTIMATED COST AT THE MODULE LEVEL

Components	Cost ($)
Arduino Nano BLE	20
ACS712 sensor	1
Voltage sensor	1
LM35 Sensor	3
Total	25

8. Conclusion

This work presents a brief overview of the solar PV plant monitoring architectures. A detailed analysis of the various hardware platforms like sensors and microcontroller boards is presented. We have proposed a system based on the IEC standard which is not only cost-efficient, reliable, and scalable but offers extensive detailed and secure monitoring via the cloud.

The concept of the work can be applied to other cyber-physical systems like smart homes/cities, smart health monitoring systems, smart agriculture and various other IoT-based smart systems.

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