REVIEW OF MONITORING TECHNOLOGIES USED IN HYBRID PHOTOVOLTAIC SYSTEMS

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Abstract: In the present context, due to the increase in global energy demand and the need to reduce greenhouse gases, hybrid systems that produce electricity and heat from renewable sources have been proposed, designed and implemented. Most of the available solar energy is captured using photovoltaic systems and converted into electricity. Today's modern systems refer to combinations of photovoltaic and thermal panels (PV/T) to obtain electricity and domestic hot water, and systems consisting of photovoltaic panels with wind turbines which provides only electricity. With an optimal design, PV/T systems can provide buildings with 100% renewable electricity and heat. This is done in a more cost-effective and efficient way compared to using photovoltaic and solar thermal systems separately. The areas required to install photovoltaic systems can be reduced by using hybrid energy production systems. The introduction of a hybrid photovoltaic-wind system reduces the land area from 1.5 ha/MW to 0.4 ha/MW. Due to the influence of environmental factors affecting the functionality of hybrid systems and the need to achieve optimal performance, the development and implementation of advanced monitoring methods has become a mandatory requirement. The paper presents different methods of monitoring hybrid systems, their progress and performance.

Keywords: internet of things, monitoring, photovoltaic, hybrid systems, solar, wind, IoT.

1. INTRODUCTION

The performance of a PV, PV/T and PV/wind photovoltaic system depends on climatic conditions, the equipment used and the configuration of the system. These performances can be measured as the ratio between the actual output of the photovoltaic solar system and the expected values. Measurement by means of sensors is essential for the proper operation and maintenance of the solar photovoltaic installation. Performances values are determined with PV monitoring systems consisting of a data recorder and, most often, a weather measuring device [1].

The systems for monitoring these performances serve the following purposes [1]:

- trend tracking in a single PV photovoltaic system.
- identification of malfunctions or damages to solar panels and inverters.
- comparing the performance of a system with the design specifications.
- to compare photovoltaic systems in different locations.

These applications require various sensors and monitoring systems adapted to the intended purpose, requiring both electronic and meteorological sensors (irradiation, temperature, etc.). Sensors and monitoring equipment are

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standardized in IEC 61724-1 and classified into three levels of accuracy, denoted by the letter's "A", "B" or "C", or by labels that says, "High accuracy", "Mean precision" or "Basic accuracy" [1].

Researchers have had a particular interest, in recent years, in improving the performance of solar monitoring systems of hybrid PV and PV/T systems using different technologies. An upward trend of these researches is noted by the large number of articles between 2019-2021, which indicates that these researches highlight the importance of implementing different communication modules and protocols in the applications of solar photovoltaic and hybrid systems [2].

Figure 1 reveals the trends and evolution of the research of these PV monitoring systems with an increase in the number of articles published between 2019-2021, compared to 2016-2018. The result of the examination process can be divided into three sections: the first is a review of data processing modules monitoring systems with limitations, comments, implementation, and design characteristics; the second section studies different data transmission protocols used in PV solar monitoring systems; third section is about the environmental impact of monitoring technology for solar PV systems [2].

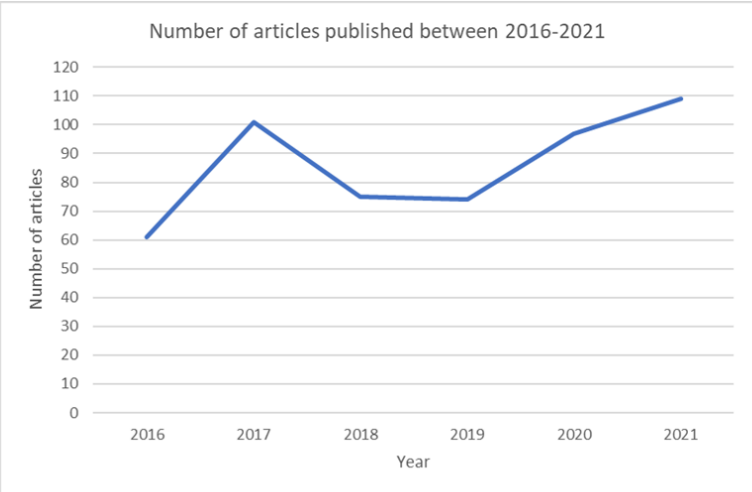


Fig. 1. Number of articles published between 2016-2021.

In Figure 2 we can analyze the annual percentages of all articles published over the entire chosen period. As can be seen in 2016, the percentage was 12 %, reaching 21 % in 2021. Even if in these years there were also periods with fewer published articles (2017-2019), overall, for the entire chosen period, a sharp increase can be observed from 2019 to 2021, from 14 % to 21 % [2].

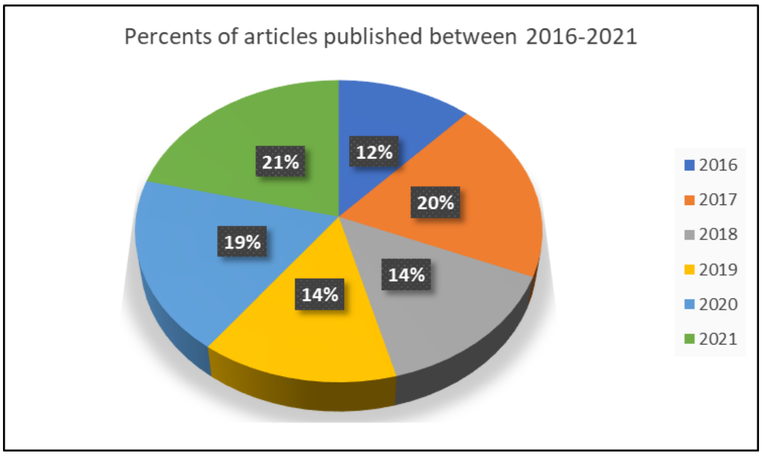


Fig. 2. Total of articles published between 2016-2021 in percent.

The data monitoring system used with photovoltaic equipment has an architecture that can be divided into three levels as can be seen in Figure 3 [3]:

- the level of data acquisition.
- the level of data processing.
- the level of display and storage of data.

At the first level data are registered from a series of sensors like: humidity, temperature, current, voltage, solar irradiation, etc. The acquired data is then sent by means of wired or wireless systems to the next stage. At the following level the data is temporarily stored in data recorders, processed and sent to the next level. Next step is represented by last stage where these received data are displayed in the form of results [3].

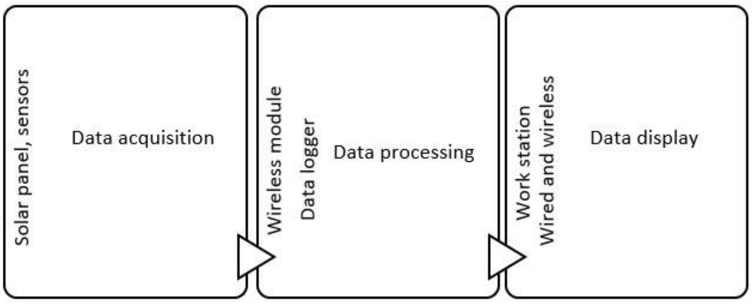


Fig. 3. Solar PV monitoring system basic architecture.

2. PROCESSING TECHNOLOGIES AND DATA TRANSMISSION PROTOCOLS

The solar monitoring system constituted of a structure with four layers that contains sensors (environmental and electrical) for collecting data like panel humidity (on a small scale), temperature, current, voltage, etc., a network layer for transmitting data using different transmission protocols, like: LoRa, Bluetooth, Wi-Fi, ZigBee [2].

This article is based on the search for the keywords “PV monitoring system” in the database "Web of Science" for the period 2016-2021. The classification was carried out following the individual analysis of a number of 517 articles. The review based on two distinct classes of monitoring technologies (data processing modules, transmission protocol) is shown in Figure 4 [2]:

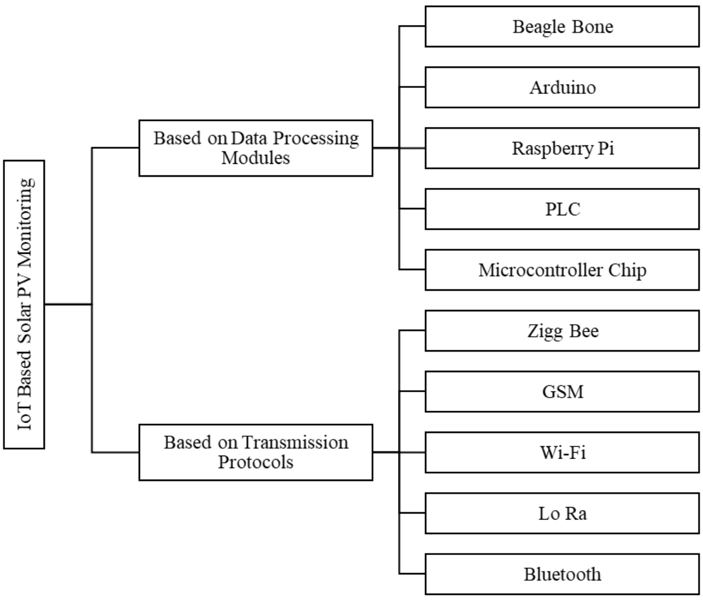


Fig. 4. PV monitoring system data transmission protocols and data processing technology.

2.1. BeagleBone-based module

Okhorzina A. and Bikbulatov A. together with the research team proposed a monitoring and control system using the beagle bone module with reduced radius. In order to reduce the heating of solar panels, the work proposes and designs a tracking and cooling system consisting of the Beagle Bone module, that controls the temperature sensors and the general system operation. Using a liquid cooling mechanism used an algorithm for controlling and monitoring the heat of the photovoltaic system. It has been noted that the proposed algorithm by the author requires more carefulness to control the cooling of the photovoltaic equipment but also its functionality that could improve the performance of the system [4].

Beagle Bone modules have a number of advantages: open-source platform, high processing power, low power consumption (up to 2W), compact size. Their disadvantage is given by the limit of factors like: color limited in HDMI resolutions, limited connectivity to Bluetooth and Wi-Fi, lack of extensive support, high costs, low number of USB ports for connecting external devices [5].

2.2. Arduino-based module

Arduino IDE is used due to the easy availability with which one can work, the hardware design and the software programming codes. It is used for programming an Arduino card that is a simplified variant for C++, this board is able to read the inputs from multiple sources and show the outputs in different forms: starting/stopping the engine, writing text online, controlling the light [6].

Allafi and its collaborators have designed for photovoltaic systems a monitoring system with Arduino board, using surveillance control and data acquisition (SCADA), which has low costs. With the help of a voltage sensor and an ACS712 current sensor data were extracted then transmitted to the Arduino Uno microcontroller and then sent via a USB cable to the computer. On Arduino, the Modbus library was installed to be able to realize the communication between SCADA and Arduino. The proposed system was aimed at determining the efficiency of the MPPT of the system with the help of sensor data extracted [7].

Lopez Vargas, Fuentes M. and Garcia M. have developed a data recording system to monitor remote PV systems, with the help of Arduino Uno plate having low costs and able to operate in remote locations that have less coverage to the network. Improvements have been suggested to bit down the boundaries of Arduino Uno such as: a visual interface and a power consumption module to make this system compatible according to IEC standards, SD flash memory, two external ADC's, a real-time clock (RTC), the integration of the 12C bus with the PCB. The algorithm was written in C/C++ for the Arduino operation with the Arduino IDE. With more data manipulation capabilities and for a large coverage area this type of model could be more developed [8].

Newly Jamil N. and Jumaat S. presented for floating solar PV systems an Arduino-based efficiency monitoring system. Arduino Nano was considered the main controller in this approach and a number of electrical parameters like output power, current and voltage of photovoltaic 10W modules were guarded. In addition, the research prototype of floating solar PV system is tested under two conditions: on the surface of the water and on a land surface [9]. Based on the results, the production power and PV efficiency is higher at the surface of the water in analogy with the terrestrial system. This type of system is easier to implement and can be developed with a higher monitoring capacity [9].

Gonzalen I. and Calderón A. set out a hybrid manner consisting of Arduino Mega and PLC S7-300 to monitor the temperature of photovoltaic panels in applications like Micro and Smart Grids. The information acquisition and display were carried out combining SCADA and PLC. The Arduino MEGA 2560 R3 platform completed their extraction and transmission. The results achieved iterates and demonstrates the feasibility and effectiveness of data exchange [10].

2.3. Raspberry Pi-based module

The scale of the Raspberry Pi module is as reduced as that of a credit card having a capacity to perform the tasks of a computer. The model has a Linux operating system, a built-in ARM-based CPU with lower power consumption, can activate wireless technology. All these advantages leading to its use in real-time monitoring schemes [11, 12].

Pereira R. and her collaborators have developed a remote renewable energy monitoring system (REMS) that is based on Raspberry Pi and IoT (internet of things). REMS is able to detect and modify the management of the monitoring process through remote firmware update through the developed integrated analog/digital conversion system (ADCES), but also to communicate with a cloud server profile developed personally through the Raspberry Pi Embedded Linux (ELS) system, thus not requiring a dedicated PC [13]. The experiment was conducted at the load of 50 W and had the following specifications: short circuit current (Isc) of 5.59A, open circuit voltage 22.5V, efficiency of 14.3 %, maximum power of 95Wp and model YL95P-17b 2/3. When using the multi-user cloud service, the architecture did not have to open firewall or ports. The suggested model could be changed not only to record data from other types of digital or analog sensors, but also for applications that use renewable sources [13].

Paredes Parra and Mateo Aroca introduced a Raspberry Pi-based PV system for solar monitoring using IEC 61724 standard, monitoring carried out at the level of the module that provided a series of detailed information about the performance of the photovoltaic plant. The system monitors electrical and environmental data and evaluates the performance of the module identifying any functional abnormality. Variable PV parameters were monitored using LabVIEW. The results came up to have less than 2 % error rate. The introduced design of Raspberry Pi-based PV solar monitoring system is able to be modified to store the information on the cloud/internet for future studies so that it can be easily reached [14].

Jain R. and Gupta A. propose a solar metering system, which can be accessed from anywhere, for monitoring and analyzing solar settings, through which any interruption can be monitored immediately. The IoT (Internet of Things) based system is best suited for remote areas where solar systems are installed due to the wide availability of solar energy. Sometimes access to areas is difficult and then it is not cost-effective. The energy deficit can be overcome with the help of solar energy. Problems caused by the depletion of conventional energy sources (coal, gas, etc.) can be overcome if small solar systems (solar grids), solar water heating systems, solar air heating collectors and solar street lights are configured [15]. The composition of the system includes Raspberry Pi (a computer based on microcontroller), MCP3008 (analog-to-digital converter), DC voltage transducer and current shunt. This system was developed in the LabVIEW programming language and aims to monitor and analyze any solar configuration, starting from the smallest photovoltaic matrices installed, to the largest solar farms in the world, with the help of the Internet, through the IoT platform [15].

2.4. PLC-based module

A PLC (programmable logic controller) is used in commercial and industrial applications with a robust structure and construction. It has the following operational features: reliable control, easy-to-use hardware, easy to program, sequential control, meters and timers, features that are vital in most monitoring and automatization applications. The leading operation of the programmable controller is to monitor, and carry-on decisions based on how the output is controlled and how the system is programmed to work [16, 17].

Goto Akira and his collaborators proposed a model in the area of photovoltaic solar power plant to monitor the strings with the help of PLC, the monitoring of each string was introduced due to factors like the initial failure and the aging of the solar panels that degrades the output power of the solar plant. The team monitored a total of 30 power plants with supply power between 1-15 MW and conducted research at a single 1 MW power plant that had for 13 months a total of 314 strings. The research and monitoring methodology was focused on strings and gives the opportunity to improve by monitoring at module and matrix level of low-energy applications [18].

Zhang X. and Mao W. together with a team of researchers have introduced an intelligent monitoring scheme of photovoltaic modules, established on a parallel resonant coupling unit that uses DC bus as a communication channel and modulates the monitoring data in a high frequency form, in order to achieve the carrier's connection. The scheme presented provided high transmission efficiency and a strong low-cost anti-interference capability [19].

Kabalci Y. and Kabalci E. introduced a PV solar monitoring method PLC-based to evolve a micro-network model on the environment of MATLAB/Simulink. When designing the system, they used a transmission line of 25km using real line parameters and a PLC modem, a multilevel inverter for three-phase AC line voltage, three solar power plants with maximum power point tracking (MPPT) system and a DC-AC converter. The use of the proposed energy monitoring technique eliminates additional monitoring costs, due to the fact that power lines are not only operated to carry the generated voltage, but also used to transmit the extracted power rate of the loads to the rear of the micronet. By simplifying at distribution as well as sub-distribution level the use of technology of their proposed monitoring system the methodology could be further improved [20].

PLC has a number of advantages and a number of strengths because it offers superior performance compared to other output control monitoring methods; lifespan of between five and ten years; low cooling costs. PLCs have their own limitations, but the recent findings indicate that PLCs modules have more advantages than disadvantages. Also, PLC microprocessors development and production poses characteristics that can represent risks for the manufacture personal [21].

2.5. Microcontroller-based module

The PV monitoring system proposed by Suryavanshi S. with Tiwari S. and the research team is based on an AVR ATMEGA16 microcontroller in which the battery and charge were connected via a relay to the solar panel. The microcontroller detects the load power requirement and therefore manages the two photovoltaic cells to joint them to the load. To manage the direction of power from the solar panel was used the relay system to either the load or the battery. At any time one relay (either the first or the second) will be connected to the load (according to the load requirements). The relay that does not provide power to the load will provide power to the battery to charge it. One photovoltaic cell is used to supply the energy of the load, and another is used to supply battery energy. Further improvements in the support of solar panels through the monitoring of environmental indexes could be assessed in order to cultivate a more reliable wireless PV solar PV monitoring system [22].

Ayesh S. and its collaborators designed a network of photovoltaic monitoring sensors based on a PIC181F4620 microcontroller using the Microchi MiWi protocol. The monitored parameters are: open circuit voltage (Voc), open circuit current (Ioc), short circuit voltage (Vsc), short-circuit current (Isc) related to panels connected to a string, without affecting their operation. The reliability and efficiency of photovoltaic panels are effectively monitored by WSN (wireless sensor networks). The location of the detection of faults is possible in the event of a failure in the panels of a photovoltaic string [23].

Harmini H. and Nurhayati T. developed a monitoring system for an autonomous photovoltaic installation utilizing the ATMEGA8 microcontroller via ethernet. The accuracy of reading of the monitored parameters of the photovoltaic panel was determined by the accuracy of the reading of the current sensors and voltage sensors used in the monitoring system. The accuracy of the current sensors was 95 % and the voltage sensors 99.3 %. The reading difference of the voltage and current sensors between the measurement of the monitoring system and the measurement of the multimeter was 0.08 volts and 0.02 amps. To use and implement a basic visual system for real-time monitoring, it is essential to compile a cloud-based monitoring technique, this way, it will be possible to effectively use the data for future reference [24].

2.6. ZigBee-based module

A solar PV system based on the technology of ZigBee was developed Liu Y. to monitor the efficiency of PV modules and achieve an automatic detection and control system. They also proposed in the paper a method of reducing total harmonic distortion (THD) in the current bound to the network through a simulation study. The algorithm realized gives the ability to improve by developing and imply a cloud-based system for real-time monitorization [25].

Vipul Dhongade and Shaligram A. D. have developed a parameter monitoring system such as voltage, temperature, etc., based on cloud services for renewable energy systems (HRES) using the IoT platform with ZigBee low power protocol. The developed wireless monitoring system collects information about the power generated from hybrid energy sources in different locations, analyzes and visualizes sensor data, being a new framework that provides a more efficient service for users using the storage, service and computing capacity of the cloud platform [26].

2.7. WiFi-based module

Allafi and Iqbal proposed a method of monitoring the electrical indexes of the battery and solar panel using an ESP32 module. This realized system used an SD card reader, an ESP32 Wi-Fi module and low-cost sensors. A maximum of 12PV modules with a power of 130W each were tested [27]. ESP32 microcontroller collects data from the sensors and they are saved in a text file on the SD card for a period of one week, after which the system deletes them and begins to save new data. Esp32 is programmed to access the web page using Wi-Fi through a laptop, mobile phone, or tablet. The web page has a link that allows users to download the data text file with a simple click remotely. The study can be improved for high-power applications even though consists of low-power applications [27].

Gusa R. and his collaborators introduced a monitoring PV system that is found on the use of a Wi-Fi module with which to monitor a series of indexes of the solar panel like temperature, current and voltage in real time. The Arduino AT Mega 2560 also connects to the Wi-Fi module with smartphone connection, to display the measurements of the current, voltage and power of the solar panel and ambient temperature through the Blynk app. The designed system has a good degree of accuracy, average voltage errors of 0.96 % and current of 5.6 %, with an average error rate of the output results from the panel of less than 10 %. The method could be improved for applications such as: fault detection, panel status and efficiency measurement [28].

Rouibah and the research team designed a low-cost monitoring system based on an ESP8266 Wi-Fi module to track the maximum power point (MPPT) in a photovoltaic solar installation, consisting of two electronic plates: the first board used to detect data acquisition and the second one a DC-DC boost amplification converter. The designed monitoring plate consists of a built-in board (Arduino Mega 2560 based on ATmega2560), current and voltage sensors, Mini BEC voltage regulator, LCD display and an ESP8266 Wi-Fi module to send the monitored information over the internet. To store and display the monitored data in real time a website was also designed. Users can easily check whether the system is working well or not, based on the monitored data by comparing the output power measured with the expected results from the model [29].

Aghenta L. and Iqbal M. proposed an open-source SCADA architecture using the Thinger IoT platform that incorporates web services with traditional SCADA to control, monitor and surveille PV systems. The components of the developed system are a series of sensors, local Wi-Fi, ESP32 Thing as RTU (Micro-Controller), Thinger IoT platform, Raspberry Pi and IO for local server. To verify the introduced SCADA system solution, the engineered hardware was configured to remotely monitor voltage, current and photovoltaic power (PV), as well as the voltage of a photovoltaic solar system of 260W, 12V storage battery [30].

2.8. Bluetooth-based module

Sarabia S. with Figueroua C. and their research team designed a portable PV system with which they could measure data on the generated photovoltaic energy, using a series of protocols with Bluetooth communication. For the study was used an INA219 sensor with the purpose of monitoring parameters such as voltage, current and power, but also to execute the 12C protocol which consists of a serial clock (SCA) and two serial data communication cables (SDA) which allows the connection of up to 12 devices. Development of this application was focused on educational and technical purposes. A built-in Arduino-based platform handles data acquisition, which is transmitted wirelessly via a Bluetooth communication protocol, then a LabVIEW-based interface displays currents, voltages and power generated per device in real-time monitoring. This is useful for analyzing the ability to generate electricity with solar irradiation at a very low cost [31].

Tsai Huan with Le Phuong and collaborators have proposed a photovoltaic system for monitoring, assessing and detecting wireless failures, based on the STM32F4DISCOVERY board with Bluetooth data transmission in the MATLAB/Simulink platform. Through the microcontroller-based DAQ plate, data on irradiation, temperature, voltage and current of photovoltaic devices are acquired. This data is transferred to a host computer via both the Bluetooth slave module and the Bluetooth master module integrated into a laptop, then displayed visually as a dashboard in the MATLAB/Simulink environment and introduced into the PV model of theoretical modeling. The acquired data was displayed on the platform of MATLAB/Simulink software. The experimental study was realized on a solar panel of 1kWp with a one-minute sampling time. This system has proven sufficient accuracy, confidence in the functions of visualization, monitoring, evaluation and detection of failures and compared to other more developed systems comes with the advantage to reduce the configuration of the cable, hardware, integrates the monitoring, evaluation and detection of failures exclusively in the MATLAB/Simulink environment [32].

Mohapatra S. and its collaborators using the HC-05 Bluetooth module to transmit data, introduced a solar PV monitoring system. The system contains several networks of solar panels in which each network is connected to various sensors to measure parameters for monitoring the system. The data was monitored by the user remotely using a smartphone through the Bluetooth Terminal App. The work is also aimed at distributing the power that was previously monitored using a relay which was turned on/off with the help of Arduino Uno control signal to distribute correctly the power. Realized paper aims to make existing systems more efficient and cost-effective. The complexity of the system could be simplified if advanced microcontrollers with AVR and ARM architectures and Wi-Fi transmission protocols that could offer a wider transmission palette were used [33].

2.9. GSM-based module

Ahmad and his collaborators have developed a GSM-based online monitoring and solar energy control system for areas located rural. The data is sent using the service of SMS messaging through a GSM interface to the targeted mobile station. Once an error occurs, a user alert can be sent via email. Experimental information indicates that the presented system model can monitor with effectiveness the photovoltaic matrix in real time, and the failure diagnosis approach reaches a high accuracy of 97.5 %. Future work focuses on the security of data sent through the SMS (short message service) [34].

Georgescu Maria and Leluțiu Laura presented a system to monitor solar PV based on GSM to control throughout a one-year period the orientation of solar panels. The studied system consisted of 24V/6A panels and a bipolar stepper motor with a torque of 0.23 Nm of 12V, two 6V batteries, a controller for Steca-Solsum 6.6F/12, an ATMEGA328 board and a solar panel. The system has been able to monitor through the GSM network the solar tracker and generate renewable energy for small farms and homes achieving a maximum gain of 40 % in energy. The presented research could be improved by gaining the electrical and environmental parameters in order to observe the state of the panel together with the control of its orientation [35].

Xia K. and his collaborators have developed a communication platform based on 4G system to monitor electrical parameters like current and voltage. The 4G modules have been integrated with a server type cloud services to monitor and display the acquired information. At the same time, this study designed an analysis of the inverter operating status. Based on neural network (NNP) was designed a probabilistic model with the 660 defective datasets for model training from the photovoltaic inverter achieved online at 2-8kW. The final experimental results show that the proposed system has a better communication performance and a higher diagnostic accuracy in real-time monitoring. The user can interrogate and store the operating information of photovoltaic systems via the internet on his personal computer or via his mobile phone [36].

2.10. LoRa-based module

Based on LoRa modules a solar PV monitoring system has been proposed by Shuda J. and his collaborators. A network of wireless sensors (WSN) is proposed, with sensors placed at strategic points of a photovoltaic installation at a utility scale. The proposed sensors measure performance parameters at the module level like: ambient temperature, rear temperature, current, module voltage and irradiation. Test and measurements were performed and recorded accordingly, on a 250Wp monocrystalline PV module. Due to its low power consumption and long range LoRa modules have been chosen as a wireless technology. The results showed that a distance of 9.27km was reached considering a spread factor (SF-specific setting of data transfer rate) of 12 and a bandwidth of 125KHz. Range tests were conducted to ensure that the chosen wireless technology meets the range requirements found on a typical photovoltaic installation. The system was analyzed and evaluated against a number of factors to be sure that the sensors provide accurate data so a more accurate forecast model of the PV installation could be created [37].

Choi C. with Jeong J. and the research team realized a system for monitoring renewable energies (solar and wind) utilizing LoRa technologies with a frequency of less than 1 GHz for remote data transmission. The amount of information received from the LoRa module was stored using MongoDB database, a web server was also designed using CSS (code files), PHP (Hypertext Preprocessor), Apache and JavaScript. The data gathered concerns the state of energy of these solar and wind installations, and with the help of web-based protocols, various analysis services are provided. The indicated system could be assessed considering the basis of the solar PV plant efficiencies. Also, higher optimization ought to be achieved [38].

2.11. AI monitoring

Kallol Roy and his collaborators proposed a hybrid method for intelligent energy management (EM) in the network-connected micro-grid (MG) system. The micro network system consists of PV, wind turbine (WT), microturbine (MT) and battery. The proposed method is the combined execution of the radial base-based neural network (RBFNN) and the search algorithm (SSA), which bears the name of RBFNN-SSA. The load demand required for the micro network system is constantly monitored by the AI. The average square error (RMSE), the absolute average percentage error (MAPE) and the average bias error (MBE) of the proposed methods are analyzed. The proposed method is activated on the MATLAB/Simulink work site. With the proposed technique, the RMSE of 9.3 is achieved; MAPE of 4.2; MBE of 2 for a number of 50 routes and for a number of 100 routes is obtained a RMSE of 13.5; MAPE of 3.9 and MBE of 5.7. The elapsed time of the RBFNN-SSA method reaches 30,15 s [39].

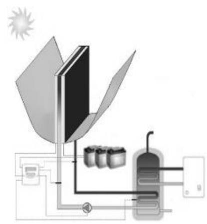
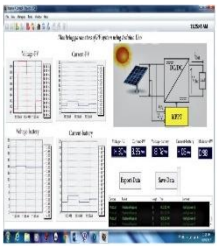
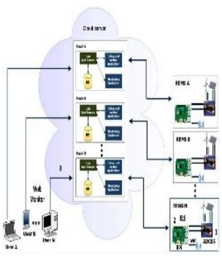
2.12. ANN monitoring

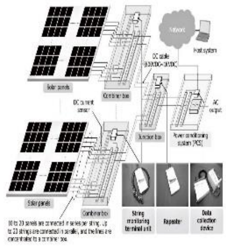
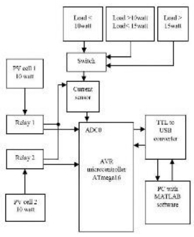
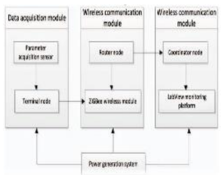
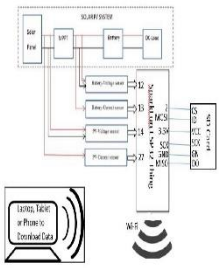
Kamal, Kallol Roy and Atis Chandra proposed an energy management system (EMS) of the micro networks (MG) connected to the grid, aiming to reduce the cost of electricity and improve the flow of energy between source and load. The proposed method is a combination of artificial neural network (ANN) and the Hybrid Whale Optimization (HWO) approach, a method known as ANN-HWO. This proposed a technique that uses MATLAB/Simulink to evaluate the power generation from different sources based on ANN-HWO. The total cost of the system, accuracy, RMSE, MAPE, MBE and the consumption time of ANN-HWO are studied [39].

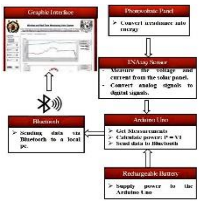
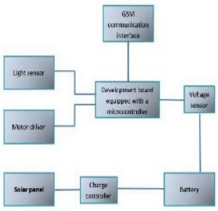
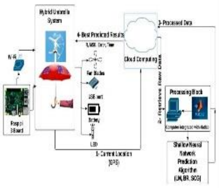
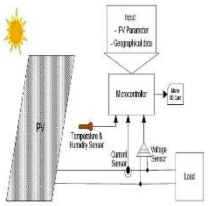
2.13. IoT smart wearable devices monitoring

The study done by Zakria Qadir together with the team of researchers proposes an intelligent energy management mechanism for portable devices using predictions, monitoring and analysis of performance indicators that generally focus on hybrid PV-wind systems (Table 1). The model uses a dynamic closed-loop recurring neural network (NARX) that predicts the active power and energy of a hybrid system based on the experimental data collected. Weather data retrieved and stored in the cloud through the Smart Umbrella System (SUS) uses a Raspberry Pi module and is processed using prediction algorithms via the SNN model. The work provides an error rate of 0.004 with a calculated efficiency in 20 s [40].

Table 1. Details of monitoring systems used in hybrid PV equipment's.

No.	Title	Image	Technology	Monitored parameters	Remarks
1.	Beagle Bone control system and cooling of PV/T solar system [4]		Processor Sitara AM3359AZCZ100; Graphics accelerator SGX530; Processing core Cortex-A8.	Temperature of the PV; computer controls the pump; orientate station towards the sun.	Algorithm controls the hybrid solar system; the functioning of an experimental station was proved.
2.	Photovoltaic system stand-alone using Arduino and low-cost SCADA [7]		Arduino Uno Microcontroller; Current sensor ACS 712; Voltage sensor 25V; Arduino IDE; Sun-tracker system; MODBUS RTU protocol.	The PV current, voltage and battery; Monitor real-time electrical data of solar module and batteries.	SCADA works in real time and the developed system cost less 100$; Can be modified for a different PV system.
3.	Remote monitoring of Arduino based standalone PV systems [8]		Arduino Uno; Microcontroller AT Mega 328; Sensor DHT22; Sensor DS18B20; Voltage sensors; Current sensors.	Irradiance; Ambient Temperature; Humidity; Current; Voltage.	The good accuracy of the datalogger has proven its robustness and reliability.
4.	Monitoring of a decentralized photovoltaic plant based on Raspberry Pi [13]		RPi 2 Model B; Wi-Fi Dongle USB; Current sensor ACS712; Temperature sensor LM35; Pyranometer LP02; Sensor DHT11.	Relative humidity; Irradiance; Ambient temperature; Temperature, current and voltage of PV module.	Data collected and sent to the database can be accessed by users as charts and logs through the developed Web.

5.	String monitoring unit for solar power plants [18]		Ethernet (100BASE-TX); Modbus protocol; Current sensor.	String voltage, current; power consumption; Frequency range used; Communication speed.	A decrease in the power generation amount discussed above is likely to be overlooked, resulting in a loss of electricity sales.
6.	Online monitoring of PV solar power through AVR microcontroller ATmega 16 [22]		AVR AT Mega 16 Microcontroller; MATLAB R2012b; Current sensor module; Personal computer.	Current; Temperature; Solar radiation; Panel efficiency.	More number of loads and panels can be used and analyzed for the practical implementation for high voltage regions.
7.	Monitoring and control strategy of photovoltaic power based on ZigBee [25]		Temperature sensor; Radiant intensity sensor; Current and voltage acquisition module.	PV module monitoring; Temperature; Current; Solar radiation.	The schema feasibility was verified through MATLAB simulation.
8.	Monitoring hybrid systems using internet of thing platform [26]		Zig Bee protocol; HTTP protocol; Microcontroller AT Mega 328P Sensors to monitor physical or environmental conditions; Temperature sensor LM35.	Monitoring PV systems; Latitude, longitude and elevation; Temperature; Voltage; Current.	This paper provides more efficient service for the user with make full use of cloud platform.
9.	Real-time monitoring of PV system trough a web server over Wi-FI [27]		Microcontroller module ESP 32; Voltage sensors; Current sensors ACS 712; Resistors.	Current and voltage of PV; Current and voltage of battery.	This is the lowest cost possible system that could be used for logging small PV system data and monitoring.
10.	A low-cost monitoring system of a PV using IoT, Wi-Fi [29]		Sensor current ACS712 ; Sensor voltage LM24; Microcontroller AT Mega 2650; Wi-Fi module ESP8862-01; Voltage regulator BEC.	Current; Voltage; Regulate the supply voltage; Monitored parameters in real time.	In the future, it is planned to detect faults and monitor with remote sensing technology.

11.	Real-time monitoring of photovoltaic power through wireless [31]		Arduino Uno; INA 219 sensor; Bluetooth module; Lab VIEW.	Acquisition from the sensor; Calculate power; Send data to the Bluetooth module; Voltage and current.	One important characteristic is its low cost and capacity of exporting data for further analysis.
12.	Remotely control and monitoring of PV through the GSM [35]		Arduino Uno ATmega328; Big Easy driver A4988; GSM network; Controller Steca Solsum.	Monitoring; Voltage control; Voltage of battery; Smooth charging in multiple steps; controls the stepping motor.	This system is able through the GSM network to monitor the sun tracker.
13.	LoRa wireless solar PV plants monitoring [37]		Sensor; Wireless sensor network (WSN); MySQL database.	Isolated DC voltage, current; Ambient temperature; Irradiance; Humidity; Orientation.	WSN is capable of measuring module-level performance parameters on a utility scale PV plant.
14.	Smart Portable Accessories Powered Up by Prediction Algorithms [40]		Smart Umbrella System (SUS); MATLAB software.	Irradiation; Wind speed; Humidity; Atmospheric pressure; Wind direction.	New hybrid neural network models can be explored to improve the performance, efficacy and efficiency.
15.	Reduction due to dust accumulation and weather conditions of photovoltaic output power [41]		Microcontroller STM32F407; Voltage, current, temperature, humidity sensors; PV output power sensors.	Voltage; Current; Temperature; Humidity; Power.	Further research is required in relation to issues of PV generated power losses due to dust deposition and weather conditions.

3. ENVIRONMENTAL IMPACT

Several environmental factors such as temperature, dust, humidity, irradiation, can affect the performance of data processing and transmission modules, requiring attention when install in the open environment [2].

Ramli Makbul and his collaborators conducted experimental research to analyze the effect of dust layer on solar PV output utilizing an ARM Cortex-M4 STM32F407 microcontroller used as an autonomous digital controller. The study observed a decrease in energy production by 10.8 % over four weeks. The suggestion would be that before installing the devices in a certain area, an assessment of the environmental factors should be made. The suggestion referred that Raspberry Pi could be used within a range that is predefined [41].

A number of important suggestions to realize an effective monitoring PV solar system for future studies are listed in the following [2]:

- Data must be protected from theft or authentication of other third parties when transmission modules are used, and there is a need to implement NB-IoT (Narrow-Band-IoT) technology to broaden the coverage spectrum, which results in better security, quality and scalability, compared to LPWA (Low Power Wide Area) networks that are not licensed. As examples we could account LoRa and Sigfox [2].

- Linked to the increase in the size of solar systems, several aspects need to be studied, such as: security, data manipulation, range of data transmission, the efficiency and the need to develop a state-of-the-art, reliable, wireless monitoring system. The emergence of low energy Bluetooth and 5G state-of-the-art technology recommends them to be used in PV monitoring systems with several benefits: high transmission speed, low power consumption, high number of attached devices and high remote execution capacity [2]. In order, to be able to verify the data received through the monitoring system, a number of simulation platforms have been developed. The accuracy that validates data varies depending on the variety of these platforms. It would be necessary, even essential, to develop a common simulation platform with data transmission modules, in order for all this to be evaluated and received as a result of the simulation [2].
- An important issue data transmission, related to the energy performance of sensor nodes. At the occurrence of faults of the battery nodes, real-time communication is disrupted and a low network life results. It is necessary to design in the future modules that have a high service life and can ensure the data sending without interruptions [2].
- Studies are also needed to be able to develop new intelligent real-time PV monitoring systems that have low costs and can identify their degradation. In order, to obtain a monitoring system for the photovoltaic environment that is efficient, precise, robust, it is necessary to implement wireless technologies, which are IoT-based, with high-performance sensors, data processing boards and communication protocols [2].

4. CONCLUSIONS

The main purpose of monitoring systems for photovoltaic power plants is to communicate information in a safe, reliable, efficient and constant way. This paper highlighted a review of the different technologies used to monitor photovoltaic systems that was based on a series of data processing modules and a series of protocols for their transmission. A general picture was provided about the monitoring systems, a classification of them, descriptions, structure, specifications, advantages, deficiencies. Discussions about the data transmission modules, their transmission rate, energy consumption, their type, sampling rate and power have been taken into consideration. Also, several limitations on their operation, problems and challenges of existing technology, data security, handling, energy efficiency, signal interference, transmission radius, environmental impact, as well as suggestions for improved monitoring systems that have a sustainable management were presented [2].

In future studies, more complex prediction systems should be investigated using extensive artificial intelligence (AI) techniques and new hybrid neural network methods that lead to an improvement in the performance of the efficiency and effectiveness of monitoring systems [41].

All analyses, problems, recommendations, can be advantageous, profitable, for a sustainable development, which leads to obtaining clean energy, a reduction in gas emissions and economic prosperity. Research is needed on monitoring systems for large-scale IoT-based solar applications that can encourage solar PV industries and the development of advanced systems that can achieve the global decarbonization goals by 2050 [2].

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