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IoT Monitoring systems applied to photovoltaic generation: The relevance for increasing decentralized plants

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Abstract. The increasing of photovoltaic plant installations at different scales promotes the development of monitoring systems that facilitate the communication, control and automation of the generating units, allowing to guarantee the predicted energy generation performance. Monitoring systems are composed of different interfaces that involve sensing and capturing data; conversion, treatment, pre-storage and transmission of data; and publishing and final storage through graphic interface. This article focuses on describing the growth of decentralized plants, as well as the increasing demand for monitoring and data acquisition system, commenting the limitations of current commercial models and presenting alternative developed monitoring systems with different platforms.

Keywords

PV plants, Decentralized generation, Monitoring systems, Data Acquisition

1. Introduction

According to the 2018 REN21 report [1], about 73.5% of the electricity produced in 2016 was based on fossil fuels and other non-renewable sources. Although reduced, renewable sources have shown a continuous growth over the last decade, more than doubling its installed capacity and reaching 2,195 TW [2], [3]. Solar photovoltaic source, despite its great potential for power generation, still represents a reduced share of the total electric energy produced. However, like other renewable sources, it also has an exponential growth curve, recording a five-fold increase in installed capacity in the period 2007-2017, reaching an installed capacity of 402 GW. Once concentrated in Europe, the solar photovoltaic power plants have in China its fastest growing market with 131 GW of installed power, followed by the United States, 51 GW; Japan, 49 GW and Germany, 42 GW [1]-[3]. In addition to the availability of the solar resource, a key factor for this expansion is the reduction of the Levelized Cost of Energy (LCOE) in all generation scales, caused by the confluence of acquisition cost reduction and equipment efficiency increase. Fu *et al.* [4] comment that the photovoltaic module as the equipment responsible for the largest reduction in acquisition costs, calculating a 15% decrease in its value in the American market between 2010 and 2017. Fraunhoffer Institute [5] tracks the efficiency of solar cells over the last 25 years, pointing to an average efficiency between 16 and 18% of commercial modules, however some manufacturers like SunPower, Panasonic and LG already market models that exceed the efficiency mark of 20%.

The liberalization of the electric market enabled the greater penetrability of low power self-generated solar energy systems, installed in a decentralized manner [6], initially aiming to meet local energy demands and, in a second moment, to commercialize the excess of energy generation with the utility [6], [7]. The International Renewable Energy Agency (IRENA) reports the case of the United States and Germany, as the main exponents of solar photovoltaic generation in residential scale [8]. According to the study, in the US, the residential sector accounted for 20% of solar installed capacity, totaling about 7,9 GW in 2016, of which 41% are in California [9]. Germany, on the other hand, presents a less expressive participation of the residential class with around 6.1 GW, 14% of the installed capacity, nevertheless a greater participation in the volume of new facilities, representing 18% of new power installed in 2016, compared to 9% in 2010. [7], [8].

The penetration of decentralized systems of energy self-generation through renewable sources, especially in the residential scale, is aligned with house automation and energy efficiency, forming an essential toolkit in the management of energy resources. Demand-side Management emerges from these concepts, which Palensky & Dietrich [10] affirm tends to move further from the distributors to the consumers or prosumers themselves, offering them the ability to act actively in reducing energy costs through the monitoring and control of energy consumption, generation and storage according to different tariff, contractual or emergency stimuli [11], [12]. Palensky & Dietrich [10] also point out the trends in the development of intelligent systems, based on the Internet of Things (IoT), which not only allow a quick response, but also a safe and effective one.

Within this context of confluence between sources of renewable energies, decentralized generation and management of energy resources, this work aims to investigate, compare and synthesize the application of monitoring systems based on IoT for decentralized small-scale PV plants. For this purpose, Section 2 describes the current scenario of the residential generation model in Brazil, presenting the main updated market data. Section 3 presents the basic architecture of a monitoring system. Section 4 specifies the monitored parameters as well as the data transference mechanisms. Section 5 details the commercial monitoring systems in Power Control Units (PCUs) and its limitations. Section 6 points the main IoT platforms applicable for PV monitoring. Section 7 discusses relevant developing monitoring systems based on IoT technologies. And Section 8 summarizes this paper indicating some future demands and works.

2. Decentralized Small-Scale Solar PV Generation in Brazil

Brazil has its territory mostly in the intertropical region, allowing an average global solar irradiation in the range of 1.500 – 2.500 kWh/m²/year [13]-[15], a figure higher than that observed in countries with higher penetration of solar photovoltaic technology, as the case of Germany with a irradiation range of 900 – 1.250 kWh/m²/year [16].

Despite the availability of the solar resource, the high LCOE of solar photovoltaic source and the historical predominance of hydroelectricity in the energy matrix of Brazil acted to block any incentive of economic or ecological matter that would justify the investment in solar energy, especially in the small prosumers scale. The worsening of water scarcity problems observed since 2010, however, led to a historical and prolonged drought period with reduction of reservoirs levels and, consequently, less participation of hydroelectric plants in the energy matrix, causing a national average increase of energy tariffs of 8% per year (not including taxes) between 2010-2017, according to the National Electric Energy Agency (ANEEL) [17]. The increase of energy costs is a key factor for the growth in new adoption of photovoltaic solar source in a decentralized small-scale modality.

The legislation of Brazil presents the distributed generation terminology to any decentralized generation sources connected directly to the distribution utility, except for hydroelectric plants with installed capacity above 30 MW and thermoelectric plants with efficiency less than 75% [18]. Within the plants framed by this definition, the ANEEL Normative Resolution 482/2012 highlights renewable sources with installed capacity of less than 75 kW as a distributed microgeneration and between 75 kW and 5 MW as distributed minigeration [19]. The photovoltaic solar resource has shown a large predominance over other renewable energy sources, accounting for more than three-quarters of the installed capacity of mini- and microgeneration [20]. Table 1 describes the growth between 2012 and 2018 of the distributed generation in Brazil, highlighting the participation of the solar photovoltaic source.

Table 1 – Total mini- and microgeneration and solar photovoltaic share of installed capacity [20]

YEAR	TOTAL INSTALLED CAPACITY	SOLAR PV SHARE
2012	0,4 MW	0,4 MW
2013	1,8 MW	1,8 MW
2014	5,2 MW	4,2 MW
2015	16,9 MW	13,8 MW
2016	83,0 MW	62,2 MW
2017	244,3 MW	183,1 MW
2018	590,4 MW	487,6 MW

According to the Brazilian Solar Energy Association (ABSOLAR) [21] and National Electric System Operator (ONS) [22], the solar photovoltaic source accounts for an installed capacity by 2017 of 1.678 MW, corresponding to only 1,07% of the national energy matrix. The decentralized generation model, in the categories of mini- and microgeneration, in turn, represents 29% of the installed capacity of the solar photovoltaic source, of which more than 12% are generated in consumer units within the residential class [20]-[23], as observed in Fig. 1.

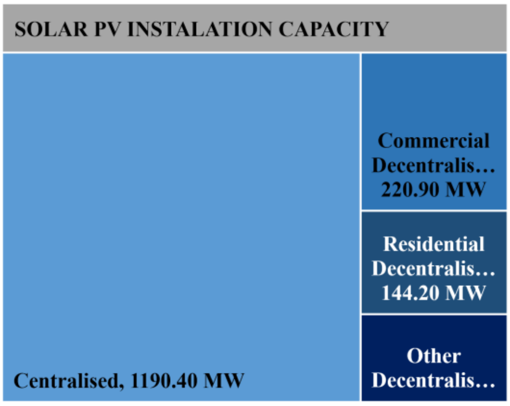

Fig. 1. Installed capacity of solar photovoltaic plants and the participation of decentralized plants by class [20]-[23].

The development of projects that combines residential automation or smart grits with distributed generation in Brazil faces a lack of information from governmental bodies. Despite that, some of those are under implementation mainly by utilities and private companies of the electrical sector.

Di Santo *et al.* [24] analyze eight pilot projects developed in Brazil until 2014, seven of which contain distributed generation from renewable sources and are developed in the following cities: Búzios (RJ), Barueri (SP), Várzea Grande Paulista (SP), Sete Lagoas (MG), Parintins (AM), Fernando de Noronha (PE) and Curitiba (PR). According to the authors, all projects made use of photovoltaic solar generator systems, featuring intelligent metering systems as well as network automation for fault detection. Gallo *et al.* [25] also comment briefly on the programs developed in Búzios (RJ), Sete Lagoas (MG) and Parintins (AM), elaborating an assessment methodology for the implementation of strategies to the development of smart grids. Fadaeenejad *et al.* [26] points out the potentialities of the development of smart grids in Brazil, not mentioning decentralized generation directly, but addressing the difficulties in terms of viable smart metering technologies and the effectiveness of demand response programs.

It is observed that the confluence between smart grid, IoT and decentralized photovoltaic solar generation is still in development stage in Brazil and depends on the success of the pilot projects implemented, as well as their adaptability to different locations and a stronger national demand.

3. PV Plants Basic Monitoring System Architecture

The monitoring of any plant aims to capture and process pre-established parameter data, providing this information through a graphical user interface (GUI) to oversee its operation and assess its energy performance both by the end user as installation, distribution, manufacture or audition companies. Thus, the monitoring systems base any decision making within the good practices of operation and maintenance (O&M) of the plant.

The monitoring systems differ from one another according to the monitored parameters, the mechanism of data transfer, the control levels, the sampling interval and the developed user platform [27]. Thus, the IEC61724 standard [28] defines three levels of monitoring systems according to the accuracy and the desired application, ranging from Class A (higher accuracy and more applications) to Class C (basic accuracy and less applications). According to the standard, Class B and C would be most appropriated for small scale PV plants. Table 2 describes each class according to the aforementioned characteristics.

Table 2 – PV plants monitoring system classification according to IEC61724 standard [28]

APPLICATION	CLASS A	CLASS B	CLASS C
Basic system performance assessment	x	x	x
Documentation of a performance guarantee	x	x	
System losses analysis	x	x	
Electricity network interaction assessment	x		
Fault localization	x		
PV technology assessment	x		
Precise PV system degradation measurement	x		

Rahman *et al.* [29] describe the architecture of current monitoring systems composed of three different process layers in which there is a flow of data and information from its raw state to the end user. The layers are schematized in Fig. 2 and detailed hereafter.

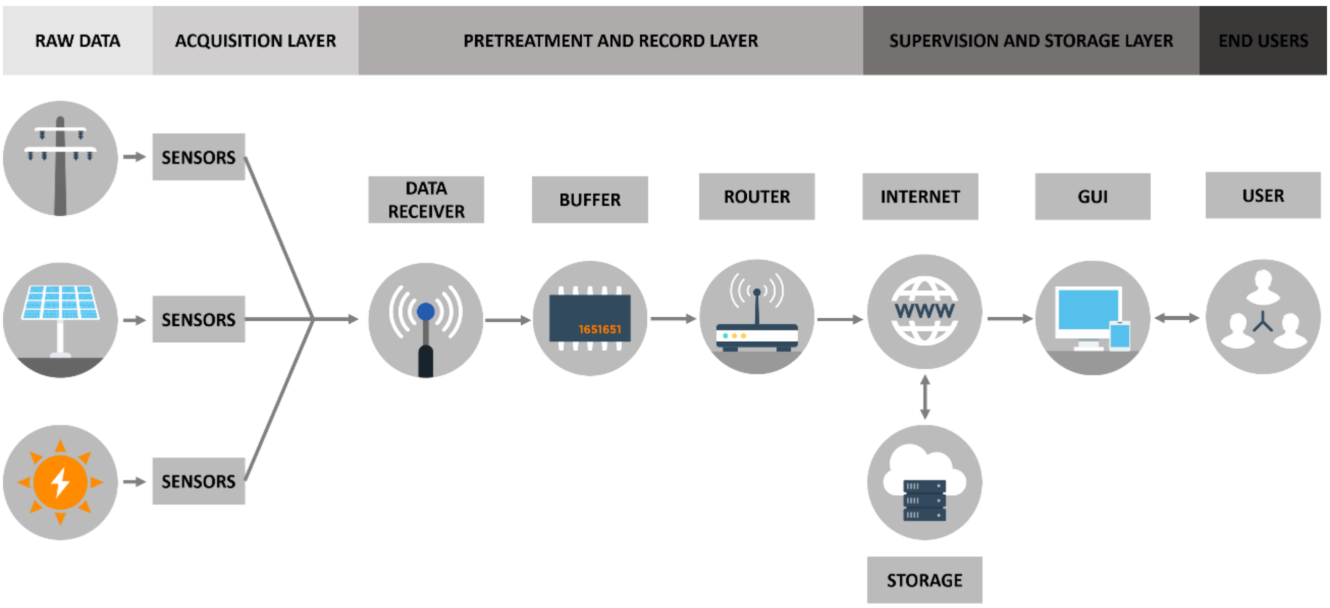

Fig. 2. General monitoring system layers and information workflow.

The first layer is the **Acquisition Layer,** which is composed mainly by two devices: a set of sensors responsible for collecting locally the data of required parameters and a communication connection which forms a network allowing data transmission using wireless or wired communication.

The **Pre-Treatment and Record Layer** represents the second layer. This intermediary level in the monitoring architecture receives the data from the sensors network, storing it temporarily and transmitting it in a regular period to the end server. Therefore, this layer works as an information hub as well as a gateway linkage between first and third layer, avoiding information losses during short periods due communication loss.

Finally, the third layer, **Supervision and Storage Layer**, is responsible for the permanent and final storage of the data in local or cloud-based server, allowing its access remotely through a software, website or smartphone application using a Graphic User Interface (GUI). This layer also enables some control and automation tools, which may vary its complexity from a simple turn on/turn off to a fine management of the delivered power.

4. Data Acquisition Parameters

A. Monitored Parameters

The IEC61724 standard sets the parameters for PV plants measurements and monitoring [28]. Monitored parameters are classified under two groups: environmental and meteorological parameters; and electrical parameters. The general parameters for the monitoring and electrical performance analysis of photovoltaic plants (stand-alone and grid connected) are presented in Table 3.

Table 3 – General Parameters for Monitoring Systems according to IEC61724 [28]

CLASS OF PARAMETER	REQUIRED PARAMETER	
Meteorology	Plane of Array Irradiance	G_I
	Ambient Temperature	T_{AM}
	Wind Speed *(optional)*	-
	Humidity *(optional)*	-
Photovoltaic Array	Module Temperature	T_{MO}
	Array Output Voltage	V_A
	Array Output Current	I_A
	Array Output Power	P_A
Utility Grid	Utility Voltage	V_U
	Current from Utility	I_{FU}
	Current to Utility	I_{TU}
	Power from Utility	P_{FU}
	Power to Utility	P_{TU}
Energy Storage	Operating Voltage	V_S
	Current from Storage	I_{FS}
	Current to Storage	I_{TS}
	Power from Storage	P_{FS}
	Power to Storage	P_{TS}
Load	Load Voltage	V_L
	Load Current	I_L
	Load Power	P_L
Back-up sources	Output Voltage	V_{BS}
	Output Current	I_{BS}
	Output Power	P_{BS}

B. Data transmission mechanisms

There are two main mechanisms for data transmission: wired and wireless. Wireless communication mechanism has different applicable technologies, highlighting four of them: GSM, ZigBee, Bluetooth and Wi-Fi.

Coaxial cables represent the main mechanisms of wired communication. Its usage for data transmission represents a solution of low resistance and error rate in addition to a data transmission rate reaching up to 10Gbps. However, its main limitation in the residential sector is the installation process, especially in houses without a previously planned logical and electrical infrastructure [30].

Direct transmission to mobile network via GSM module is a reliable solution with large data transmission capacity and applicable to remote installations [27], however its maintenance costs (including the mobile network service) limits its applicability, especially in highly urbanized locations with a great Internet accessibility.

ZigBee protocol is characterized by a smaller transmission rate and low energy consumption, its extendibility properties allow to cover long distances. Bluetooth, instead, supports a greater transmission rate, however has limited distance range. For that reasons, ZigBee tends to have more application in sensors networks [27].

At last, the high penetration of Wi-Fi communication technology in the residential sector to Internet connection favors the usage of this communication protocol, despite its higher costs and energy consumption [31]. Therefore, the Wi-Fi network may be used for the transmission in parallel of the monitored data, which can be transmitted either directly by the Acquisition Layer devices, or by the Pretreatment and Record Layer platform.

5. PCUs Monitoring Systems

PCUs are the equipment responsible for the array direct current conversion and electrical parametrization according to the utility grid technical specifications. For decentralized small-scale PV plants, two PCU technologies are dominant: string inverter and microinverter.

String inverters are PCUs capable of receiving a large number of PV modules array, ranging in a scale from 1-100 kilowatts (kW) of nominal power. String inverters besides its main function also monitor electrical parameters from the photovoltaic array such as output voltage and current, as well as the electrical parameters from the inverter itself, providing the instantaneous power of the plant, as well as the integration of its generation curve and the history of those data. The meteorological and environmental parameters provided are from on-line database. In addition to those data, string inverters may also inform on monetary savings and carbon dioxide reduction, however both variable dependent on input data by the end user or the installer. As one may conclude, these systems only provide global system data, not allowing for more granularity of information. In terms of control and automation, some systems allow the remotely shut down of the PV plant by deactivating the inverter [32]-[36].

In contrast to string inverters, microinverters are only capable of supporting a range from one to four PV modules. Therefore, larger plants demand a great number of microinverters, leading to a cost escalation. Despite that, microinverters comprise one of the Module Level Power Electronics (MLPE) technologies, a growing trend for decentralized small-scale generation. As a MLPE technology, microinverter allows to monitor the current and voltage from each PV module, leading to a faster failure identification [37].

Commercial monitoring systems, however, presents restrictions, mainly in regard to the flexibility for addition and customization of new functionalities, given the closed nature of the platform. The end user may not modify the monitoring platform to suit a set of loads or generators not predicted initially, or even export automatically the generation data into a pre-existent energy management or automation system [29], [38].

6. Applicable IoT Platforms

The IoT integrates different technologies with communication solutions, allowing the transit of information between a set of equipment. Within the technological context of monitoring, IoT is applied directly in the real-time acquisition and transmission stages of large data volumes [29]-[30]. The use of cloud computing, in this case, combines the demands for a flexible and cost-effective platform for processing and storing such data [39]. The integration of IoT to cloud computing is called CloudIoT [30].

The main platforms used by IoT developers for initial prototyping in the development of products and projects are presented below:

- Arduino: A widely used platform with one of the largest developer's community, Arduino presents a broad range of boards from simple 8-b microcontroller boards to products for wearables, IoT items, three-dimensional (3-D) printing, and others applications [40].

- Raspberry Pi: A single board computer, its onboard wireless LAN and Bluetooth capability are fundamental tools for IoT applications. Raspberry Pi can run many operating systems, including Raspbian Linux, Ubuntu Mate, and Windows 10 IoT Core [41].

- Beagle Bone Black: This platform is also a single board computer. It offers two 46-pin headers, an Ethernet port, and many more connectivity options. It supports the Debian, Android, and Ubuntu operating systems and claims to be able to boot Linux in under 10s [42].

- ESP boards comes with an integrated transmission-control protocol/Internet protocol stack and a self-calibrated radio-frequency antenna, supporting Wi-Fi Direct (P2P) and allowing it to operate under several conditions [43]. Due to its connection capacity and low energy consumption, this platform has been applied largely for projects of home automation and solar-powered file server [44].

Table 4 presents a comparison between the properties of the described platforms.

Table 4 – General comparison of IoT platforms [40]-[44]

	ARDUINO UNO	**RPI 3**	**ESP-32**	**BEAGLEBONE BLACK**
Processor/ Microcontroller	ATmega328P	Broadcom BCM2837 and ARM Cortex-A53 64-b Quad Core	Tensilica Xtensa LX6	AM335x ARM Cortex-A8
Clock Speed	16 MHz	1.2 GHz	160 MHz	1.0 GHz
Size	69x53 mm	85x56 mm	26x48 mm	86x56mm
Memory	32 KB	Micro-SD	4 MB	4 GB, micro-SD
RAM	2 KB	1 GB LPDDR2	520 KB	512 MB DDR3
Supply Voltage	5V	5V	3,3 V	5V
USB Ports	No	4 x USB 2.0	No	1 x USB
GPIO	14	26	12	69
ADC/DAC	10b	No	No	12b
Ethernet	IEEE 802.3 10/100 Mb/s	IEEE 802.3 10/100 Mb/s	No	IEEE 802.3 10/100 Mb/s
Wi-Fi	No	IEE 802.3 10/100 Mb/s	IEE 802.3 10/100 Mb/s	IEE 802.3 10/100 Mb/s
Bluetooth	No	Bluetooth 4.1 LE	Bluetooth 4.1 LE	No
Communication	4x SPI, 2x I2C, PCM/I2S, 2x UART	1x SPI, 2x I2C, PCM/I2S, 1x UART	4x SPI, 2x I2C, PCM/I2S, 3 x UART	4x UART, 2x SPI, 2x I2C, 2x CAN BUS
Listed Price	$ 22.00	$ 35.00	$ 10.00	$ 49.00

7. Monitoring Systems based on IoT Platforms

The IoT platforms present a range of functionalities within the decentralized small-scale generation universe, especially for the residential class, combining monitoring, control and automation in a single platform with greater flexibility to the specific demands of each project. This topic will discuss different projects of relevance developed between the period 2016-2019. These projects focus on the use of IoT technologies for different applications in power plants restricted to PV solar resource and decentralized small scale generators.

Manzano *et al.* [31] presented a review describing the development of IoT technological applications in monitoring projects of renewable energy sources between 1994 to 2014. Manzano *et al.* [31] showed the evolution and gradual abandonment of wired data transmission, especially after 2000. with application of satellite technologies, followed by GSM and finally Zigbee.

Regarding IoT platforms, Manzano *et al.* [31] pointed its usage rise after 2010 with boards Arduino and Waspmote, in addition to PIC microcontrollers. The use of cloud storage, in turn, is emphasized by the author as a necessity for the technological evolution of these platforms within this context. The projects described below mostly use this storage model, but there is no confluence of the IoT platform used, because each project focuses on a certain constructive aspect of the monitoring and its architecture of data acquisition, transmission and storage. In this way, these projects were divided into subsections according to the used equipment. Table 5 summarizes a comparison between the described papers in this topic.

A. Arduino

Touati [45] uses a customized monitoring system to assess the impacts of extreme weather conditions in Doha, Qatar on photovoltaic systems. To do so, the authors elaborate a monitoring system with sensors for measuring the following parameters: photovoltaic modules and ambient temperature, solar irradiation, relative humidity, dust level, wind speed, as well as the main electrical ones for plotting the P-V and I-V curves. The sensors were connected to an Arduino with an Atmega 32A microcontroller, whose communication with the remote monitoring station was done through XBee Pro modules. The data were compiled and stored in the monitoring station itself and accessed through the user interface programmed within a customized LABView platform. A distinctive aspect of this work is that the author himself points out the high cost of his system, calculating an investment of circa US$ 1.000,00 and referring to previous works in which this econometric data is missing.

Lopéz-Vargas *et al.* [46], [47] presentes two papers with the use of Arduino UNO as a receiving and transmiting data. The final storage is a cloud server, using 3G modem as main transmitting channel. The ThingSpeak platform works as a user interface and allows graphical visualization of the information collected in real time. In both papers it is observed that the objective is the development of a complete monitoring system focused on the processing and transmission of data, as well as its access through smartphone and site applications.

Kekre and Gawre [48] also developed a monitoring tool focusing on electrical parameters, applying the system in a small installation of 1 kWp in a remote area. The paper briefly described the network architecture for communication through the GSM module, which allowed the data transmission to a workstation, responsible for the final storage. The authors disregard the limit of processing limit of the adopted platform.

At last, Shrihariprasath & Rathinasabapathy [49] utilized an Arduino UNO R3 board coupled with an Atmega328 microcontroller to export electrical parameters from the PCU. The authors proposed an alternative and cheaper system, allowing the establishment of a free and customized platform, adaptable for different usages. In their paper, however, the connection between PCU and the microcontroller is not fully clarified. The communication equipment utilized a GPRS modem responsible for the transmission of the data from the Arduino board to the cloud-server. The data could be accessed by a web-site also developed by the authors.

As seen, the use of Arduino focuses mainly on the development of monitoring tools, limiting the means of transmission and the temporary storage capacity due to the intrinsic characteristics of this platform.

B. Raspberry Pi

Raspberry Pi was also applied as a monitoring tool. The main advantages of the RPi over microcontrollers are the cost/benefit ratio, the standard programming language and communication, the many input/output pins and graphic interface.

The usage of Wi-Fi with RPi is applied by Othman *et al.* [50], Patil *et al.* [51] and Prasanna *et al.* [52]. All three of them used a RPi 3, which allows Wi-Fi connection without peripherical devices. Pereira *et al.* [53] used a RPi 2 Model B. The sensors communicate with the RPi board via wire, sending the following data: electric current and voltage, module temperature, ambient temperature, solar irradiance and relative humidity. The RPi processes the data and send via Wi-Fi connection to a cloud server, allowing its access through a website developed by the authors. The authors also point out as one of the main advantages and innovations the possibility of using Wi-Fi connection to update the embedded systems firmware remotely. It is also highlighted that open source platforms for online generation monitoring systems allow a greater user interaction and accessibility.

All four works [50]-[53] demonstrated a well-suited usage of RPi in the gathering and transmission of data, constructing a personalised website for remote data access.

Table 5 – Comparative summary of the main characteristics of each revised paper

REF.	YEAR	CLASS OF PARAMETERS	COMMUNICATION MECHANISM	PROCESSING PLATFORM	DATA TRANSMISSION	STORAGE	SCADA SOFTWARE	MONITORING PLATFORM
[45]	2016	Meteorological, Photovoltaic Array	Wire	Arduino UNO	Zigbee	In House Server	LabVIEW	Web-site
[46]	2019	Meteorological, Photovoltaic Array, Storage, Load	Wire	Arduino UNO	Ethernet 3G Modem	In House Server and Cloud Server	ThingSpeak	Web-site and Smartphone Application
[47]	2018	Meteorological, Photovoltaic Array, Storage, Load	Wire	Arduino UNO	Ethernet 3G Modem	Cloud Server	ThingSpeak	Web-site and Smartphone Application
[48]	2017	Photovoltaic Array	Wire	Arduino UNO	GSM Module	In House Server	-	Web-site
[49]	2016	Photovoltaic Array, Utility	PCU	Arduino UNO	GSM Module	Cloud Server	-	Web-site
[50]	2018	Photovoltaic Array, Storage, Load	Wire	RPi 3	Wi-Fi	Cloud Server	Node-RED	Web-site
[51]	2018	Meteorological, Photovoltaic Array	Wire	RPi 3	Wi-Fi	Cloud Server	-	Web-site
[52]	2018	Photovoltaic Array	Wire	RPi 3	Wi-Fi	Cloud Server	LabVIEW	Web-site
[53]	2018	Meteorological, Photovoltaic Array	Wire	RPi 2 Model B	Ethernet	Cloud Server	-	Web-site
[54]	2018	Photovoltaic Array	Wire	ESP8266	Wi-Fi	-	-	Web-site
[55]	2018	Photovoltaic Array, Load	Wire	ESP8266 Arduino UNO	Wi-Fi	Cloud Server	ThingSpeak	Web-site and Smartphone Application
[56]	2016	Photovoltaic Array, Load, Utility	Wire	Beaglebone Black	GSM Module	Cloud Server	-	Web-site and Smartphone Application
[57]	2016	Meteorological, Photovoltaic Array	Radio Frequency	PIC18F46K22	GSM Module	Cloud Server	-	Web-Site
[58]	2017	Photovoltaic Array, Storage, Load	Wire	Wi-LEM Solar-LOG50	Wi-Fi	In House Server	-	Software

C. ESP8266

Srivastava *et al.* [54] and Pramono *et al.* [55] applied an ESP8266 not for monitoring purposes but for control and automation ones. The author evaluates the control of a hybrid system between wind energy and photovoltaic solar energy with a focus on residential automation. Its work is based on the ESP8266 microcontroller, responsible for monitoring residential loads as well as whether the generators are in ON or OFF mode, enabling the activation of a wind and / or a solar power generator remotely through a simple command via smartphone application.

Pramono *et al.* [55] monitors the load of a residence and the generation of solar photovoltaic small-scale plant, using the ESP8266 as an automation tool to close a relay, allowing the supply of the loads with power from the renewable source.

D. Others

Adhya *et al.* [56] developed a remote monitoring system for a stand-alone plant, using wireless communication between the different layers, justifying that wire limited usage leads to a reduced risk factor. In their paper, the monitored parameters are ambient temperature, module temperature, direct solar irradiation, wind speed, besides the voltage and current of the photovoltaic modules and inverter output. The information together is transmitted via radio frequency to a PIC18F46K22 microcontroller, coupled to a data logger with 2GB of storage space, as well as a SIM900A GPRS module for the wireless communication. Then, the processed data is sent via Wi-Fi to a cloud-server, responsible for the final storage and the availability of the information. The authors also stated the perspective of using GPS for tracking the localization of photovoltaic modules, especially for operation and maintenance purposes, highlighting the case of fault faster identification through a GPS coupled monitoring.

Ngo *et al.* [57] develops a monitoring system of generation and loads using a BeagleBone Black as data processing equipment, exporting them to a cloud server. The author develops both an application and a web interface. The web interface allows not only the monitoring of loads and generation, but a cost forecast for electric power bill, as well as meteorological data from an online database. In the Android application, in turn, the data are detailed from graphs with real-time construction.

Fabrizio *et al.* [58], in turn, goes beyond monitoring and presents a micro-smart grid project applied to an agro-industrial plant. Thus, his work comprises a complete modelling of all loads, consumption and generation units that compose the plant, in order to monitor and control different processes. For the scope of this paper, however, the architecture presented in [58] is more relevant from his evaluation of the synchronicity of different generators (small wind turbines, photovoltaic modules and biomass combustion generators). In the case of solar, the energy produced by the photovoltaic modules is measured by a commercial datalogger Solar-LOG50. This equipment has its own wi-fi module, allowing its communication with the network. In the case of the whole micro-smart grid complex, the datalogger communicates with Bee-Units, responsible for local data collection and for sending them to a storage centre called the Merging Unit. Access to all data of the plant is done through a customized portal.

8. Conclusion

The installed capacity growth of renewables in the residential scale has been expressive, with the increase of the penetrability of the solar photovoltaic source in this consumption class. Decentralized residential photovoltaic systems have significant participation in countries with the highest solar installed capacity: 20% in the U.S., 14% in Germany, and representing 29% of solar generation in Brazil. Within the current paradigms of smart grits, successive automation and remote control of equipment and processes, solar photovoltaic systems are demanded the improvement of its monitoring and control systems. Main commercial monitoring systems, despite providing practical solutions, have restrictions, not allowing the exchange of data between systems from different manufacturer or even allowing a small level of customization of the initial system.

Thus, this work presented a set of papers focused in developing IoT tools aiming to meet specific demands of monitoring system performance, as well as fault detection and, finally, automation and integration with smart grids. As seen, different devices can be used separately or together for IoT monitoring applications: Arduino, RPi, ESP, BeagleBone, PIC and other dataloggers. The definition of the equipment should observe the restrictions of costs, energy consumption, processed data and method of transmission of the information. The majority of the described papers used a cloud server, proving the dissemination of CloudIoT as an important tool for the improvement of monitoring, control and automation tools.

At last, is important to acknowledge that community size impact on the research as Arduino and RPi representing more than half of the gathered papers. It is arguable that the growing popularity of ESP may lead to an increase in the number of projects aiming to align monitoring and automation in residential class.

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