This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2876635, IEEE Sensors Journal

IoT application for real-time monitoring of Solar Home Systems based on Arduino™ with 3G connectivity

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***Abstract*—A novel datalogger based on free software and hardware has been designed, built, programmed and installed as an experimental prototype in multiple sites. Remote monitoring extends the effectiveness of the datalogger in areas deprived of electrical grid and traditional wired telecommunication networks. The integration of Internet of Things (IoT) in solar measurement systems allows the remote monitoring of small stand-alone photovoltaic (PV) systems, enhancing the performance and the maintenance of the system. The datalogger measured electric and climatic parameters (up to 14 parameters, expandable) with the required accuracy established by the IEC61724 standard; to include 3G technology in it allowed the stand-alone PV systems system monitoring remotely via web or via mobile application, all at low cost. An outdoor campaign of over 12 months under the harsh environmental conditions at multiple locations was performed to test the new datalogger under real and different conditions demonstrating the robustness and the reliability of the system.**

***Index Terms*—3G mobile communication, Internet of Things, photovoltaic systems, remote monitoring**

I. Introduction

AN estimated 1.1 billion people currently lack electricity access [1], mainly residing in rural areas of sub-Saharan Africa and Southeast Asia, and, to a lesser extend in the Middle East, Central Asia and Latin America [2]. Due to the emergence of rural electrification programmes, thousands of Solar Home Systems (SHSs) [3] are installed in remote regions, commonly in locations with no electrical grid, no traditional wired telecommunication networks and often with difficult accessibility by common transport. SHSs are stand-alone PV (SAPV) systems. Typically, these installations use crystalline-silicon PV modules. Regarding the battery backup unit, the most commonly battery type installed is lead-acid and most small SHS employs charge controllers using PWM to regulate the charge current to the battery [4].

The absence of adequate monitoring of SHS and, therefore, the impossibility of detecting operation and maintenance problems, can lead to a dramatic shortening of the useful life of the PV systems or even to the withdrawal of their use. [5].In the case of grid-connected PV systems generally have high budgets, and the associated data acquisition systems allow to monitor the main parameters to conduct the necessary maintenance actions without impacting significantly in the total installation cost. However, it is very difficult to supervise the operation of SHSs due mainly to the fact that the required commercial dataloggers available in the market are very expensive compared to the total system cost, they require special software and they also generally demand an external power supply or a PC to be connected all of the time.

As a result, it is necessary to further develop data acquisition systems very accurate and independent of external sources, all at low cost. In recent years, analytical monitoring has been progressively applied to small PV systems.

II. Related works on dataloggers for PV monitoring

The literature includes numerous reports of PV monitoring systems during the last two decades. Mukaro et al. [6] in 1998 developed one of the first low-cost systems designed for solar radiation monitoring. With 4 analogue inputs, this monitoring system was based on an 8-bit microcontroller. This datalogger was suitable for monitoring of meteorological parameters at remote stations, especially in developing countries. The main disadvantage of this work was the connection of the datalogger to PC. Koutroulis and Kalaitzakis [7] in 2003 reported another monitoring system for renewable energy sources. With 16 single ended (eight differential analog) input channels, the datalogger used a DAQ card installed in a PC and a 12-bit accuracy ADC converter. As a disadvantage, the dependence on a PC and the use of commercial software increased the final cost of the system. Forero et al. [8] in 2006 proposed a system for monitoring a stand-alone PV plant. The system was designed for measuring environmental variables, as well as for monitoring the performance of a stand-alone PV solar plant. The datalogger was based on precision electronic modular field point I/O devices and a high speed data acquisition card. The main inconveniences were the use of a graphical environment based on the Labview™ program and the requirement of a PC connection. Tina and Grasso [9] in 2014 proposed a dedicated data acquisition system for remote monitoring the operation of a stand-alone PV appliance. With

Manuscript received August 20, 2018.
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20 analog inputs, the monitoring system measured electrical and climatic parameters using low-cost commercial sensors. However, measurements were not compared with another calibrated datalogger and the errors were not weighted. After reviewing the published literature, it was identified that it is difficult to track the functioning of these SAPV systems with conventional dataloggers mainly due to various limitations:: external source dependency [10-13], requirement of commercial software [14, 15] and in numerous designs the measurement of errors were not bounded following international standards of accuracy [16, 17].

To solve the former technical and economic issues, a low-cost prototype based on open source and free hardware technologies (Arduino™) for monitoring PV systems was proposed by M. Fuentes et al. [18] in 2014. With 8 analogue inputs for measuring up to 8 electrical/meteorological parameters and 3 inputs for low-cost analogue temperature sensors, the resolution of the datalogger was 18-bits. Virtually unlimited inputs for digital temperature sensors were available. The datalogger was especially designed for installing in remote areas or regions in developing countries. The datalogger was tested under the harsh environmental conditions of the summer and winter in Southern Spain and it accomplished the accuracy requirements of the IEC standards for PV systems. Later on, López-Vargas et al. [19] in 2018 developed an improved version of this low-cost datalogger in order to overcome several of the shortcomings of the solar Arduino™ datalogger, and so the power consumption was minimized, the number of meteorological parameters measured was increased, the electrical measurements were improved and a user-friendly interface was integrated. The new prototype was specifically designed for SAPV systems located in remote areas. The new datalogger was empirically tested measuring a real stand-alone system. The results indicated that the datalogger provided high accuracy, and it was autonomous, low-cost and robust in harsh environments. Data was stored in SD card, allowing the installation of the system in isolated areas, requiring minimal maintenance. But this minimal maintenance of the novel datalogger was based on a manual procedure requiring human operator intervention for collecting data, which can be an inconvenient at locations that are difficult to access as well as it increases the maintenance costs and operation.

The objective of this new work has been to develop a novel and improved version of this solar Arduino™ low-cost datalogger based on the application of IoT (Internet of the Things), adding internet connectivity and allowing the SAPV system to be monitored remotely via web or via mobile application, which means that not only data of the long-term system performance is retrieved but also that instantaneous information is received and so the problems related to the operation and maintenance of the stand-alone PV system can be rapidly detected and solved. Additionally, another novelty of this work lies in designing, manufacturing and testing the prototype under real (electrical and environmental) working conditions.

III. Requirements for the SAPV Electrical Performance Monitoring System

The IEC61724 standard [20] entitled "Photovoltaic system performance" describes the general guidelines for the monitoring and analysis of the electrical performance of photovoltaic systems (stand-alone and grid connected). In Table I, a summary of parameters to be monitored in real time PV systems is presented.

TABLE I
Parameters to be Monitored in Real Time PV Systems

General parameters	Specific parameters	Symbol
Meteorology	Total irradiance, in the plane of the array	G_i
	Ambient temperature in a radiation shield	T_{amb}
	Wind speed (optional)	-
	Rainfall (optional)	-
	Humidity (optional)	-
PVarray	Output voltage	V_A
	Output current	I_A
	Output power	P_A
	PV module temperature	T_{mod}
Energy storage	Operating voltage	V_S
	Current to storage[a]	I_{TS}
	Current from storage[a]	I_{FS}
	Power to storage[a]	P_{TS}
	Power from storage[a]	P_{FS}
Load	Load voltage	V_L
	Load current	I_L
	Load power	P_L
Utility grid	Utility voltage	V_U
	Current to utility grid[a]	I_{TU}
	Current from utility grid[a]	I_{FU}
	Power to utility grid[a]	P_{TU}
	Power from utility grid[a]	P_{FU}
Back-up sources	Output voltage	V_{BU}
	Output current	I_{BU}
	Output power	P_{BU}

[a]A single current or power sensor can be used for the measurement of current or power for directions or both input and output.

The standard defines three classes of monitoring systems, corresponding to different levels of accuracy and different intended applications: Class A (high accuracy), Class B (medium accuracy) and Class C (basic accuracy). The accuracy classification and the suggested applications are presented in Table II.

TABLE II
Monitoring System Classification and Suggested Applications

Typical applications	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
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		

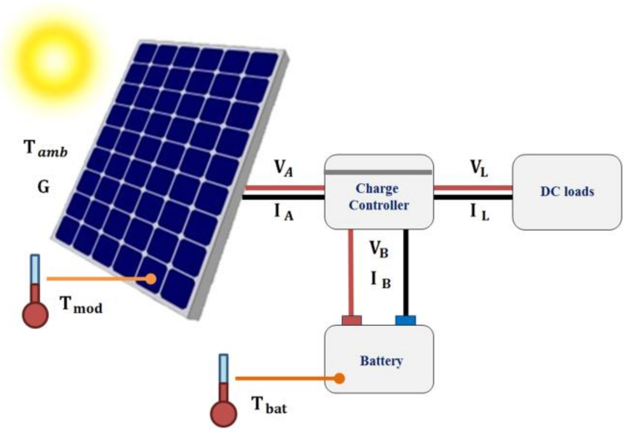

Fig. 1. Example of application of the IEC61724 standard: SAPV system.

According to IEC61724 standard, Class B or Class C would be most appropriate for small systems, such as smaller commercial and residential installations. An example of the IEC61724 standard appliance for SAPV systems is shown in Fig.1.

A. Electrical and climatic parameters

The measurements of electrical parameters provide information on the consumption and the efficiency of SAPV systems. According to IEC61724 standard, the accuracy (the most restrictive case, high accuracy class) of the voltage, current and power measurements, including signal conditioning, must be better than 2% of the reading. IEC61724 standard indicates that climatic parameters must be measured at a location that is representative of the SAPV system conditions. The accuracy of temperature measures must be better than ±1 ºC and the accuracy of irradiance measures must be better than 8% of the reading from 100 $W{\cdot}m^{-2}$ to 1,500 $W{\cdot}m^{-2}$ (including signal conditioning). The measurement of optional parameters such as wind speed, also must comply the standard requirements of accuracy: $\leq$ 0. 5 $m{\cdot}s^{-1}$ for wind speeds $\leq$ 5 $m{\cdot}s^{-1}$, and $\leq$ 10 % of the reading for wind speeds greater than 5 m·s-1. According to the results obtained by López-Vargas et al. in 2018 [19], the previous version of the datalogger [19] met all the precision requirements established by the IEC61724 standard mentioned above.

B. Monitoring requirements

According to IEC61724 standard, for medium and basic accuracy systems (Class B and Class C, as indicated earlier), the maximum sampling interval should be 1 min and maximum recording interval should be 15 min (medium accuracy) and 60 min (basic accuracy). The recording interval should be an integer multiple of the sampling interval, and an integer number of recording intervals should fit within 1 h. Each record shall include a timestamp, and the time should refer either to local time (not daylight saving time) or universal time, to avoid winter/summer time changes. When multiple data acquisition units are involved that each independently apply timestamps, the clocks of the units must be synchronized, preferably by an automated mechanism such as global positioning system (GPS) or network time protocol (NTP).

To be able to apply the automated synchronization mechanisms advised by the IEC61724 standard, the connection to the Internet is required. To access the Internet, the standard does not set any requirements concerning the type of communication method. However, in the case of decentralized systems, wireless technologies are most appropriate: commonly SAPV systems are located in remote and inaccessible regions, in locations without access to traditional wired telecommunication networks. The datalogger should be able to transmit the measured data anywhere; the location of the SAPV system should not act to the detriment of the correct functioning of the monitoring system. The communication technology should be capable of operating autonomously, without requiring additional wired communications networks. To obtain real-time monitoring, the delivery speed of the data transmission system should allow compliance with the sampling intervals established by the IEC61724 standard.

IV. SAPV MONITORING SYSTEM CONNECTIVITY

Among all the different standards deployed in the market [21], usually distributed in different frequency bands and using multiple communication protocols, selecting the most suitable connectivity technology for an IoT application can be a challenge. Wireless technologies have been widely used in the case of decentralized systems, although Ethernet cable is also an alternative for centralized systems [22]. As there are different options to add wireless connectivity to the Arduino™ solar datalogger, previous PV monitoring wireless systems according to their data transmission techniques have been reviewed. The connectivity requirements of different types of IoT networks vary widely, depending on their purpose and resource constraints. Relevant wireless communications techniques have been studied: Table III [23] shows a wireless connectivity technologies (non-exhaustive) comparison focused on range, bandwidth and cost.

A remote PV-system monitored via satellite was developed by Krauter and Depping [24] in 2004, where irradiance and electrical parameters were collected and sent to the ARGOS-SCD satellite. The satellite data was transferred from the receiving ground station to the Internet, providing worldwide access via WWW. Data transmission via satellite is very useful in regions without access to telephone communications. But this data transmission was reported to be slow, taking around 8 to 12 min, and the initial cost for the transmitter was very high.

Papageorgas et al. [25] in 2013 reported a solar panel monitoring system based on Zigbee. The system measured data for each solar panel of a solar park installation and allowed the optimization of electric power production through a web-based application. The client-server-web-publishing software was based on an open-source platform. The integrated Zigbee communication technology was based on a Zigbee RF modem available from ATMEL. However, the

TABLE III
CHARACTERISTIC OF WIRELESS CONNECTIVITY TECHNOLOGIES (DATA SOURCE ITU [23])

Type	Technology	Maximum range	Maximum bandwidth	Module cost
WPAN	ANT+	30 m	1 Mbps	\$1 - \$15
	Bluetooth 4.0 LE	50 m	24 Mbps	\$1 - \$15
	RFID	10 m (passive) 100 m (active)	100 kbps	<\$1 - \$15 (passive) \$5 - \$25 (passive)
	NFC	10 cm	424 kbps	<\$1
	802.15.4g	200 m	200 kbps	\$1 - \$15
	ZigBee	10 m -100 m	250 kbps	\$1 - \$15
WLAN	Wi-Fi	300 m	250 Mbps (802.11n) 54 Mbps (802.11a/g) 11 Mbps (802.11b) 1 Gbps (802.11ac)	\$10+
WWAN	LoRa	2 – 10 km	200 kbps	\$1 - \$15
	Weighless	2 – 10 km	200 kbps	\$1 - \$15
	Dash 7	2 km	200 kbps	\$1 - \$15
	WiMax	40 km	34 Mbps – 1Gbps	\$1 - \$15
	2G (GSM, GPRS, EDGE)	35 km	9,6 kbps – 384kbps	\$1 - \$15
	3G (UMTS, HSPA)	up to 100 km	384 kbps– 10 Mbps	\$35 - \$50
	Cellular 4G/LTE	up to 100 km	3 Mbps – 100 Mbps	\$80 - \$120

system required a wired network due to this technology only covers short distances. The same applies to the Bluetooth technologies that support simple wireless networking but only cover short distances (100 m is the maximum range without repeaters [26]) as reported by Hua et al. [27] in 2009: typically up to 10 m for Bluetooth class 2 and 100 m for Bluetooth class 1. A series of novel wireless portable systems including calibration, monitoring and ISP systems were implemented for fuel cell city buses, using Bluetooth for transmitting data.

Rosiek and Batlles [28] in 2008 developed a system for the data acquisition from remote meteorological stations located in the north side of the Natural Park of Sierra Nevada (Granada, Spain). The system was based on an ATmega16 microcontroller and they compared this system against two other commercial acquisition systems obtaining an error in the order of 1 %. They used mobile communications due to the considerable advantages in transmitting the information at big distances in isolated areas. The experimental data was received from the remote stations network, located about 100 km of distance.

Due to the location of PV systems in isolated regions, the study of communication techniques focused on technologies that provide greater ranges (WWAN). The use of mobile communications (2G, 3G) ensures an affordable and stable long-distance data transfer, but the effectiveness of this technique is subject to the signal strength in the location of the stand-alone PV system. The International Telecommunication Union (ITU) [29] in 2016 estimated that approximately seven billion people, the 95 % of the global population, live in an area that is covered by a mobile network. Regarding the mobile-broadband networks (3G or above) they reach 84 % of the global population, 67 % of the rural population [29].

On the other hand, a clear signal of the global mobile penetration rate is that in developing countries, there are more households that own a mobile phone that have access to electricity or drinking water: roughly 70 % of the bottom fifth of the population in developing countries own a cell phone, as reported by the World Bank's World Development Report for 2016 [30]. According to a Groupe Speciale Mobile Association (GSMA) report [31], in 2014, more than a half of all global mobile money deployments were carried out in sub-Saharan Africa. The 63 % of Africans had access to improved water supply and 32 % to electricity, compared to 82 % who had access to GSM coverage. A United Nations research in India [32], in 2008, showed nearly 366 million people (31 % of the population) had access to improved sanitation, meanwhile, 545 million mobile phones were connected to service.

After studying the available wireless techniques, the use of mobile communications was selected for adding wireless connectivity to the Arduino™ datalogger, since this technology presents more advantages than the other communication techniques studied and both, industrialized countries and developing countries, are covered by mobile communications networks, even reaching areas where the electric grid and the water supply network do not. In addition, other studies endorse the use of mobile communications for this specific application. In 2014, R. Tejwani et al. [33] presented the advantages and disadvantages of several monitoring systems for rural application based on different techniques of communication. After discussing, they proposed remote monitoring using mobile communications. In 2017, V. Villagrán et al. [34] presented the design and implementation of monitoring system to study down-slope winds in the Laja River Valley, southern-central Chile. They used mobile communications because of the continued growth of the mobile telecommunication industry, its coverage has also expanded in Chile, even in remote areas inhabited by small communities.

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V. Design of the 3G Datalogger for Solar Photovoltaic Monitoring

A. General description

Fig.2 shows the diagram of the new wireless monitoring system as well as the basic distribution of environmental and electrical sensors for monitoring the SAPV system. The new datalogger measures meteorological and electrical parameters; data is sent via 3G and information is stored in two different servers: a dedicated server (located in the University of Jaén) and a cloud server (free storage platform). The connection to the internet allows to monitor the SAPV system from any device or computer.

B. Hardware

The previous datalogger was designed around the Arduino™ UNO board as it stands out in comparison with the other open-source platforms due to its robustness, cost and developer community [18]. However, it did not cover all the functionalities for PV monitoring itself, so hardware enhancement was integrated by López-Vargas et al. [19] integrated in an ad-hoc PCB (Printed Circuit Board): (a) a bi-directional I2C™ bus, (b) sensors signal conditioning including the integration of electronic elements for filtering

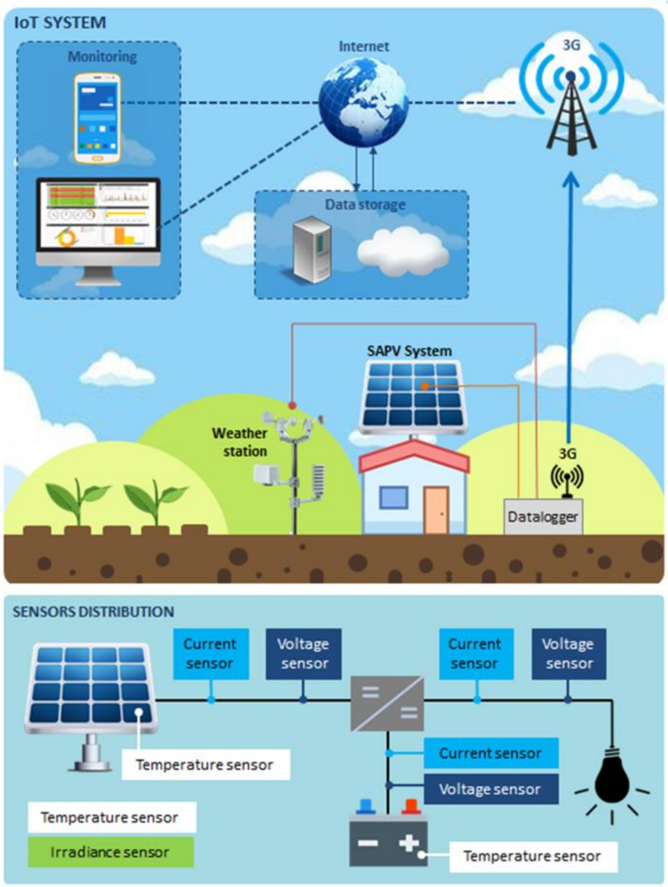

Fig.2. Final remote datalogger diagram.

undesirable signals, (c) a RTC for tracking time and ensuring the precise synchronization of the measurements, (d) two external ADCs of 18-bits resolution for accomplishing the IEC61724 accuracy requirements and (e) a specific module to reduce the energy consumption.

When designing the new datalogger with connectivity features, it was found that Arduino™ UNO would not allow to connect directly the board to the internet (it would require an extra shield board). The 3G shields compatible with Arduino™ found in the market that met the requirements of transmission were extremely expensive so the use of these shields was discarded. As a low-cost alternative, an Ethernet board with a nanorouter could perform the same connectivity functions.

TABLE IV
Arduino™ UNO and Arduino™ Ethernet comparison

Component	UNO	Ethernet
Processor	ATmega328P	ATmega328P
Operating/Input Voltage	5 V / 7-12 V	5 V / 7-12 V
CPU Speed	16 MHz	16 MHz
Analog In/Out	6/0	6/0
Digital IO/PWM	14/6	14/4
EEPROM [kB]	1	1
SRAM [kB]	2	2
Flash [kB]	32	32
USB	Regular	Regular
UART	1	-

Therefore, Arduino™ Ethernet (Rev 3) was selected as it has connectivity functions and similar characteristics integrated all in a single board. Table IV shows the comparison between Arduino™ Ethernet and Arduino™ UNO boards. The use of an Arduino™ UNO with an Ethernet shield stacked on top could be also considered as an alternative option as the price is comparable to that of the Arduino™ Ethernet board.

Regarding connectivity itself, studies based on PV system monitoring were reviewed (see Section IV) to select a suitable data transmission technique. The use of mobile communications, concretely 3G, offers the most significant advantages. Main advantages of the 3G prototype are flexibility and unlimited reach, although the latter is restricted by the 3G mobile penetration rate. The system based on 3G does not require the installation of additional networks and this flexibility makes the 3G system more suitable for the monitoring of SAPV systems located in remote areas, especially in developing countries. Among the numerous options to connect Arduino™ to the internet using 3G, the TL-MR3020 router from TP-LINK (Fig.3a) stands out over the rest because it offers the potential to configure Wi-Fi and 3G

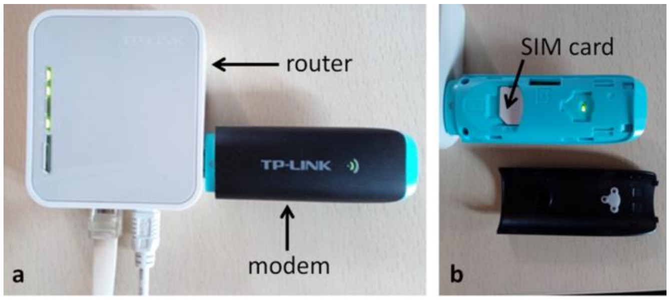

Fig.3. Connectivity system: router and modem (a) and SIM card into the modem adapter (b).

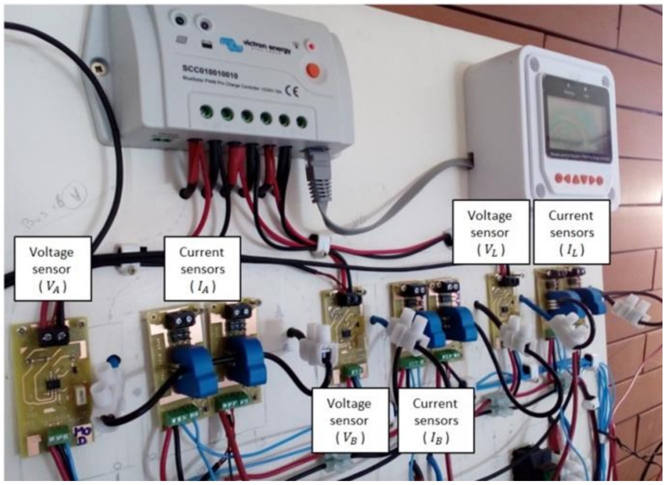

Fig.4. Development of PV output generation, battery and load current and voltage sensors.

transmission systems at a low price. This device requires an external 5VDC/1A power supply and it operates over a temperature range from 10 ºC to 60 ºC and relative humidity conditions in the humidity range of 10 % RH to 90 % RH (non-condensing).

As the router has an on-board interface USB 2.0 port, the 3G operating mode can be configured providing internet connection through a 3G USB stick modem (Fig. 3b). For this purpose, MA260 modem from TP-LINK was selected. This modem allows to acquire 3G mobile broadband access by inserting a SIM card into the adapter. It supports 3G HSPA+ technology, which provides improved data transfer rates. The USB modem operating temperature range is 0 °C to 40 °C. Thus, the operating temperature of the entire system (router and modem) is limited by the most restricted values: 10 ºC - 40 ºC. This is particularly important since, depending on the location of the system, temperature evacuation systems (fans, heat sinks…) may be required.

The novel datalogger was developed ad-hoc for the monitoring of SAPV systems that in most cases are isolated systems, so an individual data transmission system was the most appropriate option. However, in the case of finding several SAPV systems installed close enough, the monitoring system was designed to provide scalability. The novel monitoring system stands out due to its stackable hardware design. By adding boards with the hardware improvements, the number of analog or digital inputs can be expanded, and various SAPV systems can be monitoring using a single datalogger. To do this, only it would be necessary to extend the number of parameters transmitted in each cycle by SW, achieving scalability at a reduced cost.

C. Meteorological and SAPV sensors

Sensor characteristics for measuring both electrical and meteorological system parameters were previously detailed by López-Vargas et al. [19] in their work on the Arduino™ basic datalogger. Employing exclusively low-cost sensors, the prototype for measuring SAPV systems includes a wide range of climatic measures: irradiance (G_i), ambient temperature (T_{amb}), humidity (H), wind velocity (W) and rainfall (R). DS18B20 temperature sensors from Maxim Integrated™ were used to acquire PV module temperature (T_{mod}) and PV battery temperature (T_{bat}). The electrical parameters measured by the low-cost datalogger include the PV generator output voltage (V_A), battery voltage (V_S), load voltage (V_L), PV generator output current (I_A), battery current (I_S) and load current (I_L). Based on voltage divider circuits, low-cost voltage sensors that increase the ADC input range were developed and three common-mode voltage amplifiers were also used to allow measuring differential signals in presence of high common-mode voltage range accurately. Hall Effect sensors, LTS 15-NP from LEM™, were used for current measurements. These sensors presented a level of accuracy from ± 0.2 % to ± 0.7% (operating with internal measuring resistance at 25 ºC). Fig. 4 shows both voltage and current sensors developed.

D. Software

Fig. 5 shows the flow diagram of the process followed by the microprocessor. At start, the internet connection is established and the RTC is synchronized: these processes run every time the routine is initialized or the reset button is pressed. In addition, once per day, at 00 AM, the RTC is synchronized to avoid drifts. Every minute, in second 0 and second 30, parameters are measured; data transmission and data storage processes are carried out. Software improvements have been developed and new processes have been included:

a) The internet access provides the possibility of synchronizing the RTC using a NTP server. The clock is

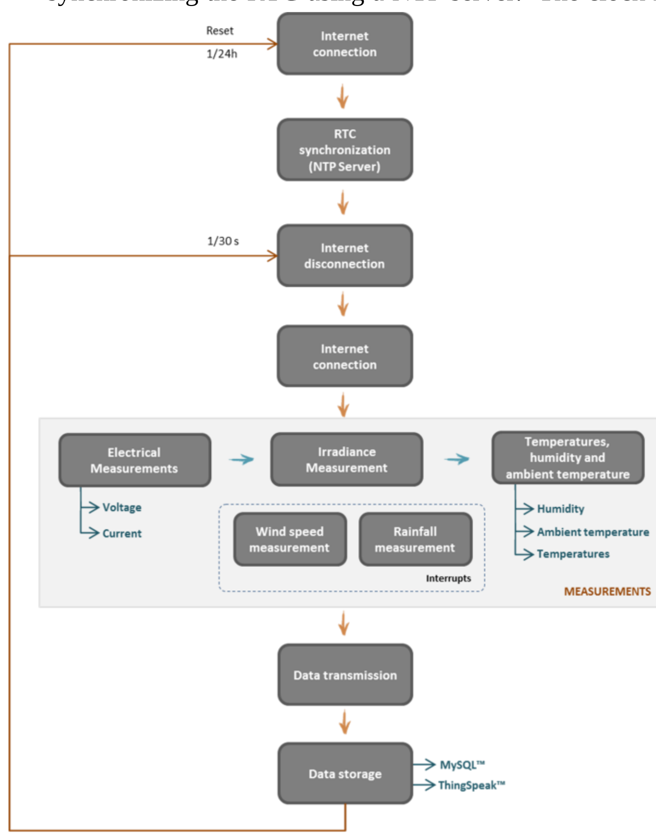

Fig.5. Diagram for the routine executed by each iteration: sequence of processes and communications.

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synchronized at the start of the program or in case of reset. As the drift of the RTC is a few seconds per week, to synchronize once a day (at 00 AM) is enough.

b) The connection between the microcontroller and the server is established by a Hypertext Transfer Protocol (HTTP) petition. After establishing the connection between datalogger and server, the process of data transferring starts.

c) The information is stored in a MySQL™ database hosted in a server, located in the University of Jaén, with a specific order and format.

d) Additionally, data is sent to ThingSpeak™, an open source Internet of Thing analytics platform service that allows inserting, visualizing and analyzing live data streams in the cloud.

Two types of data storage were implemented: a dedicated server (conventional method) and a cloud service platform (novel application of IoT). Both alternatives of storage allow to monitor the system in a remote way. The use of free cloud service platforms allows to obtain a highly accessibility and cost-effective monitoring system based entirely on free SW and HW.

In the first option (conventional), the measured data is stored in the main base PC (located in the University of Jaén) which serves as the server for the website, such that users can retrieve data from any previous date within the monitoring period. The web-based monitoring feature was included for adding value to the global monitoring system. The website allows users to observe the monitored parameters and statistical data, as well as other information: daily production, charge of battery or consumptions. The website was developed in HTML language while the table and graph were created by integrating PHP code and library from Highcharts. The parameters monitored are processed and analyzed to produce information that can be understood easily by users; data is protected by password and the information is represented in graphs. The website is accessible using the following link: http://energiaagua.ujaen.es/FVMonitor/.

On the other hand, a second option was also developed, as the advantages of open cloud systems are really interesting for this type of applications: they provide large data storage, high reliability and low-cost. Cloud systems reduce the cost of data storage facilities and extra maintenance to keep or maintain the data. Open cloud-based IoT platforms and services were reviewed [35]. ThingSpeak™, an open IoT data platform based on public cloud technology was selected mainly due to its variety of third party platforms that include Arduino and Twitter amongst others. ThingSpeak™ platform stores and retrieves data from things using HTTP over internet. ThingSpeak™ allows to analyze data using MATLAB without requiring the purchase of a license from Mathworks™. Each monitoring system sends data to an individual channel. These channels can be configured as a public or a private channel (protected by password). In addition, mobile applications allow to monitor ThingSpeak™ channels using a smartphone. Free users are limited to 10 million messages (3+ years at minimum update interval, 15s) and 8 fields per channel.

Irradiance (G_i), ambient temperature (T_{amb}), PV module temperature (T_{mod}), PV generator output voltage (V_A), battery voltage (V_S), PV generator output current (I_A), battery current (I_S) and load current (I_L) parameters were selected for monitoring.

Fig.6. SAPV system installed at IMDEA Water Institute facilities: PV mono-crystalline module (a), charge controller (b) and lead-acid battery (c).

VI. Experimental Set-up

Studies on rural electrification in developing countries and renewable-based initiatives energy programs were previously reviewed by López-Vargas et al. [19]. Two real SAPV systems, similar to those typically employed in developing

Fig.7. SAPV system installed at University of Linares facilities: PV mono-crystalline module (a), charge controller (b) and lead-acid battery (c).

countries, were installed in different locations to verify the proper functioning of the monitoring system under real conditions:

a) Alcalá SAPV system: The SAPV system (Fig. 6) was located at the test facilities in IMDEA Water Institute (Alcalá de Henares, Madrid, Spain, latitude 40.513° N, longitude 3.339° E). The PV system included an 80W mono-crystalline module, a 12 V lead-acid battery (90Ah-C100) and a PWM serial charge controller.

b) Linares SAPV system: The SAPV system was composed by a 100W mono-crystalline module, a 12 V lead-acid battery (90Ah-C100) and a PWM serial charge controller. The real SAPV system (Fig.7) was installed at the test facilities in the University of Jaén, in the Linares School of Engineering (Linares, Jaén, Spain, latitude 38,085ºN, longitude 3,646ºW).

Another version of the Arduino^{TM} solar datalogger was installed in the School of Science of the University Benito Juarez of Oaxaca (Oaxaca, Mexico, latitude 17.047° N, longitude 96.712° W). This datalogger was connected directly to the Internet via cable, using the Ethernet input of the board. In this case, the datalogger measures meteorological parameters; data is sent to the Linares server.

Typical domestic energy consumption of a household in developing countries will usually have several lamps for lighting and it might also have a small household appliance. A real load profile was designed by López-Vargas et al. [19] identifying all the commonly used appliances in terms of power and hours of usage per day for estimating the daily energy consumption used in this work. The load system was composed by two 12 V luminaries of 3 W and 50 W, respectively. The total daily energy consumption of the designed load profile was 79 Wh.

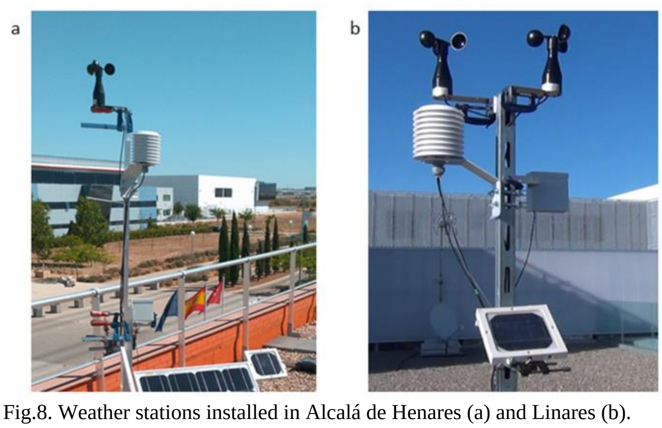

Fig.8. Weather stations installed in Alcalá de Henares (a) and Linares (b).

Each SAPV system had also their own low-cost modular weather station (Fig. 8), including a calibrated solar cell from Nousol^{TM} to measure solar global irradiance in the same plane of the PV mono-crystalline module (G_i), a DHT22 digital sensor with shield protector to monitor ambient temperature (T_{amb}) and relativity humidity (H), a Small Wind Transmitter sensor from Thies Clima to measure horizontal wind speed (W) and a rain gauge sensor from Pronamic^{TM} to measure rainfall (R).

VII. Experimental Results

Fig. 9 shows the final prototype of the new low-cost datalogger installed in Alcalá de Henares (Fig.9a) and Linares (Fig. 9b). At both sites, the results from the testing period indicated how the new 3G datalogger monitored and sent the data correctly for the complete period of time.

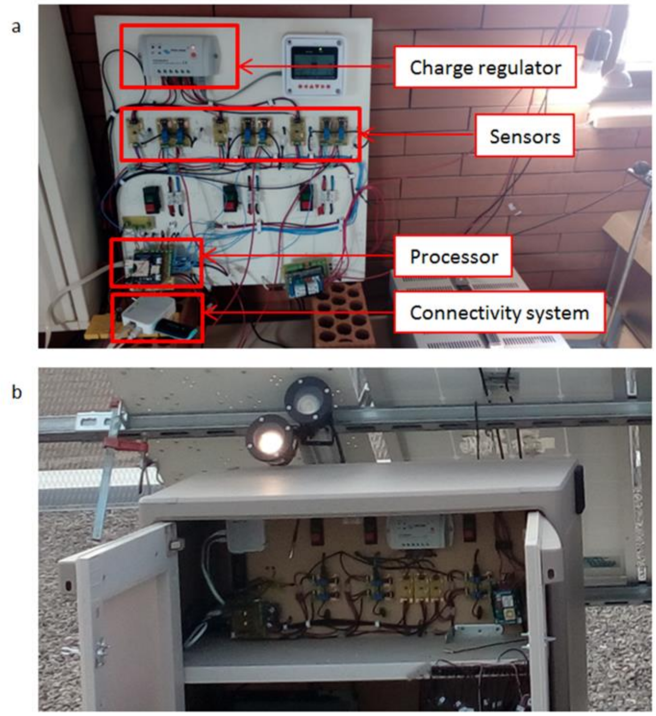

Fig.9. Final prototype assembly. Datalogger installed in Alcalá de Henares (a) and datalogger installed in Linares (b). The datalogger uses 9 small PCBs for electrical sensing (current and voltage measurements). The load control system includes an Arduino^{TM} UNO board and a relay system.

The measurements were compared with a commercial monitoring system that acted as a pattern. This pattern commercial monitoring system was an Agilent^{TM} 34972 datalogger of 22 bits with a voltage accuracy resolution of 0.004% that uses Labview^{TM}. Every 30 s, this datalogger measured and recorded the same parameters as the Arduino^{TM} datalogger.

A. Electrical and meteorological parameters monitoring: comparison with commercial datalogger

Lopez-Vargas et al. demonstrated in 2018 that the Arduino^{TM} datalogger works well under adverse climatic conditions [19]. As expected, the new datalogger continued to measure correctly both the meteorological and electrical parameters, always complying with the IEC standard. Fig.10 shows an example of the daily variations of the solar irradiance and the ambient temperature monitored by the low-cost Arduino^{TM} datalogger and the commercial Agilent^{TM} datalogger in Alcalá de Henares (Fig.10a) and Linares (Fig. 10b), revealing the correct functioning of the Arduino^{TM} datalogger: the uncertainly of irradiance measures was below the 8 % required by the standard and the mean absolute errors of measured ambient temperatures were better than the ±1 °C required.

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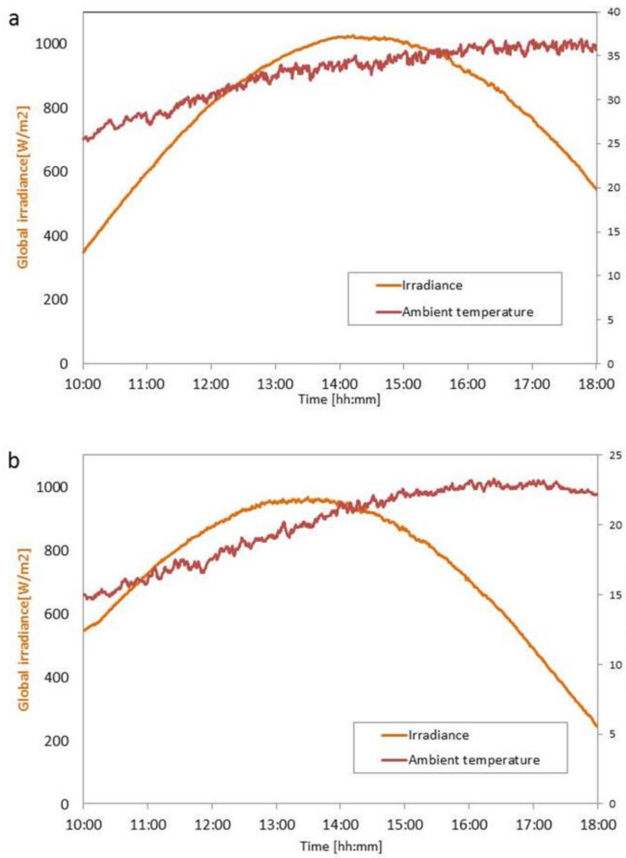

Fig.10. Irradiance and ambient temperatures measured in Alcalá de Henares (27/07/2017) and Linares (20/03/2017) sites under clean sky conditions.

Regarding electrical parameters, Fig. 11 shows an example of the daily variations of the PV generator output voltage, the battery voltage and the load voltage monitored by the low-cost Arduino™ datalogger in Alcalá de Henares (Fig. 11a) and Linares (Fig. 11b) sites. Battery voltage line and load voltage line overlap. The voltages measured by the Arduino™ datalogger using low-cost sensors under clear sky conditions shown in the Fig. 11 demonstrate the correct functioning of the Arduino™ datalogger. The uncertainly of electrical measures was below the 2% required by the standard.

B. *System reliability*

During the experimental period, it has been verified that all the installed dataloggers send data correctly and that the quality of the data is excellent (meteorological and electrical) as indicated previously. All the dataloggers have been intensively tested over a period of 12 months, identifying the performance of the datalogger when a failure occurred. The dataloggers only failed in 4 occasions over the year, due to different reasons. One of these errors was an access failure (to the server installed in Linares). The datalogger located in Oaxaca registered 1 error as a result of a network outage. The datalogger installed in Alcalá de Henares failed in 1 occasion due to a power shortage. An equipment failure was detected in the datalogger installed in Linares. The experimental results showed that after 12 months under operation, taking into account the low number of failures and that the most of the failures are due to external factors, the datalogger is **highly reliable**. Details on the errors of different origin were registered:

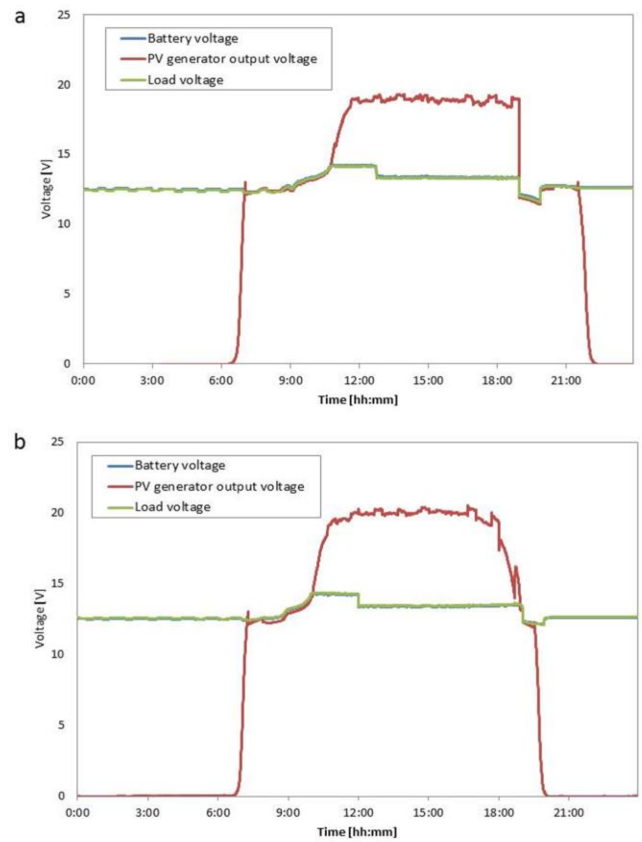

Fig.11. Voltages measured in Alcalá de Henares (27/07/2017) and Linares (20/03/2017) sites under clean sky conditions.

1) Access failure

On 16/11/2017, it was detected an **access failure** to the server installed in Linares. This failure affected all three systems (dataloggers sent data to the same server). In the experimental phase, one of the problems encountered was the loss of data sent for brief periods of time. As previously stated, each datalogger sends the collected data to a dedicated server, located in the Superior School of Linares. Eventually, because of performing the maintenance activities by the university, the server installed in Linares was disconnected for short periods of

TABLE V
EXAMPLE OF EXTREME CONDITIONS RECORDED IN THE DAYS BEFORE THE FAILURE. DATA RECORDED ON 24/06/2017.

Parameter	Minimum value	Average value	Maximum value
Ambient Temperature [ºC]	21.4	31.61	40.7
Humidity [%]	14.3	21.46	36.3
Module Temperature [ºC]	19.5	38.29	67.5
Battery Temperature [ºC]	25.31	33.57	41.19
Electrical Cabinet Temperature [ºC]	22.44	35.25	47.63
Horizontal Wind Speed [m/s]	0	3.77	17.37
Irradiance [W/m^2]	0	259.29	903.37

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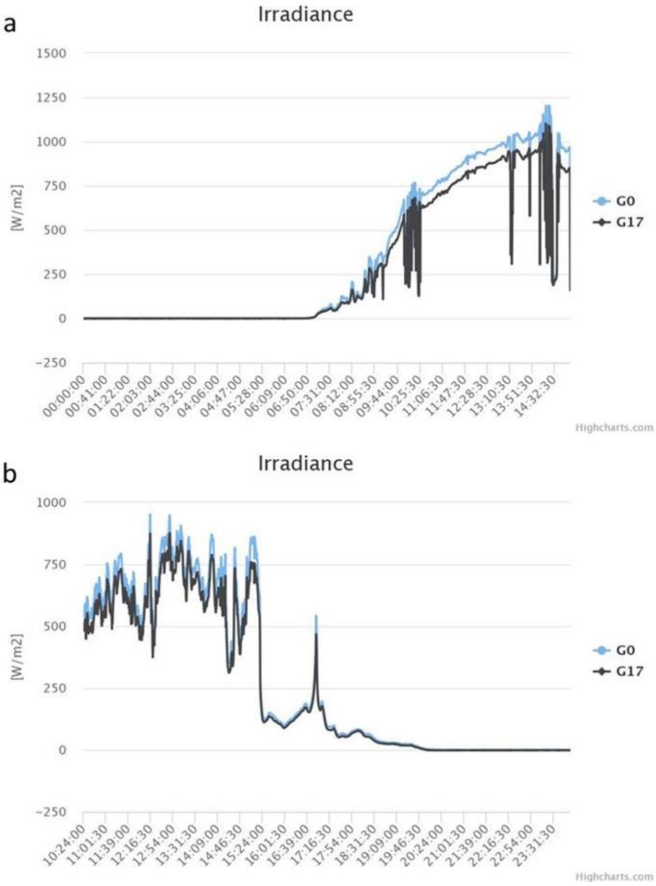

Fig.12. Global horizontal irradiance (G_0) and in-plane irradiance (G_{17}) data registered in the network failure period in Oaxaca. Data recorded on 17/6/2017 (a) and 19/6/2017 (b).

time (it was beyond our scope of work: these maintenance works were carried out by the general university technical unit). In these periods, the datalogger could not establish the connection to the server and data was not received or stored. The server downtimes lead to observe the behavior of the datalogger under this condition: it was verified that as soon as the server functioned again, the monitoring system was reconnected and the data was sent again and stored as normal.

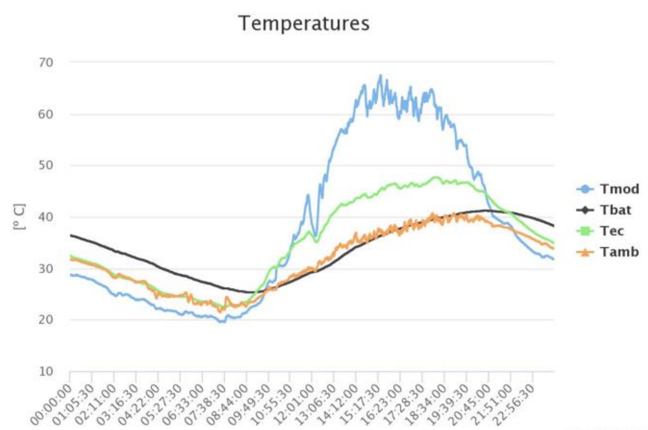

Fig.13. Temperatures recorded by the datalogger in Linares, a previous day before the failure (24/06/2017).

2) Power failure

Another data: in Alcalá de Henares, on 21/05/2017 a power failure was detected in the Alcalá de Henares site. Problems with Agilent^{TM} pattern datalogger occurred due to power shortages that forced to initialize the software and perform maintenance. The Arduino^{TM} datalogger was designed to start-up without external help after power shortages and it did not require any external initialization. This result is of special interest since the SAPV systems studied in this work are usually installed in isolated and inaccessible regions. The datalogger does not require external help to recover from a power failure; the datalogger does not need an external operator. In addition to providing the reliability to the system, it was empirically proved the proper functioning of the system without the need for maintenance, reducing the operational costs of the monitoring system to a minimum.

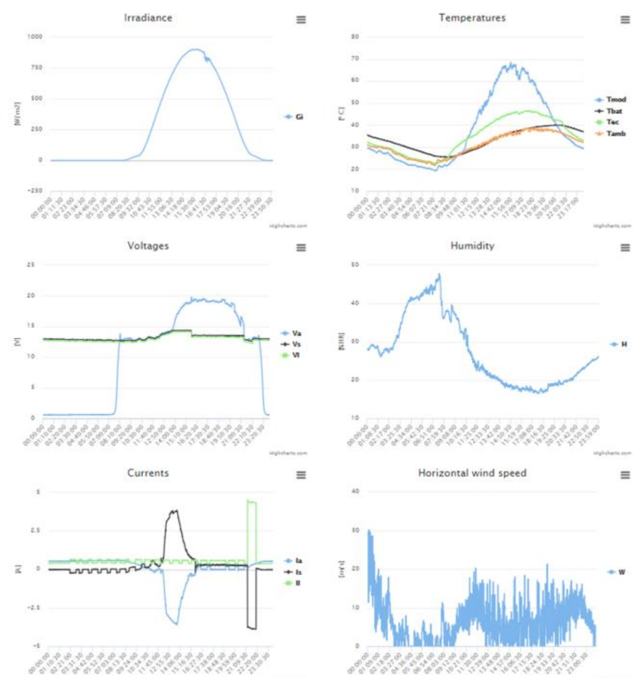

Fig.14. Online web-page view of data measured in the Linares site: graphs on 13/06/2017.

3) Network failure

The solar Arduino^{TM} datalogger installed in Oaxaca provided information on how the new monitoring system responds to a network failure. Jointly with the Ardino datalogger, another commercial dataloggerr (LabJack^{TM} U12 series) was installed. This commercial datalogger stored the data in a folder shared over the Internet. On 17/06/2017, the datalogger stopped sending data to the server as shown in Fig 12.a. It was observed that, the commercial datalogger, stopped sending data too. On 19/06/2017, the solar datalogger (Fig 12b) and the commercial datalogger started sending data again. As the commercial datalogger has to be initialized manually in case of power failure, the bug was registered as a network failure.

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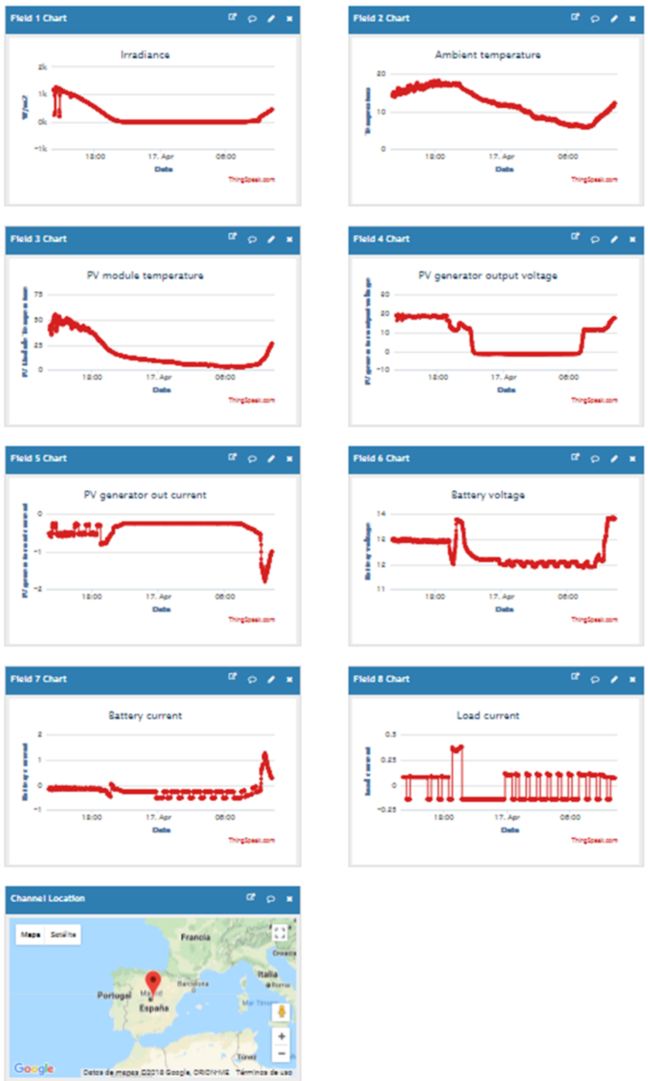

Fig.15. ThingSpeak™ visualization of parameters measured by the monitoring system located in Alcalá de Henares.

The Arduino™ datalogger stopped sending data to the server due to a (WAN) network error. This failure served to verify empirically that after a network failure, the datalogger can re-hook and resend the data, as designed by the software. Subsequently, other networks failures were registered with a certain frequency in the Oaxaca site, and these failures have led to the loss of data in the fault period. It was found that, often in developing countries, due to the quality of the wired networks it is common to suffer successive Internet drops; it was empirically proved that the monitoring system based on transmission via mobile communications is more reliable than a data acquisition system that is wired network dependent.

4) Equipment failure

The datalogger installed in Linares recorded a fall on 29/06/2017. The system was completely inoperative; it stopped sending data to the server and the cloud. In Linares, the summer period usually contains some of the harshest environmental conditions for PV systems and electronic equipment, including temperatures up to 45º, dust storms (from winds from the Sahara Desert), and occasional electrical storms with high speeds and heavy rain. In the days before the failure, ambient temperatures (T_{amb}) were recorded above 40 degrees Celsius as shown in Fig. 13. Table V includes a summary of the daily environmental parameters recorded on 24/06/2017 by the datalogger, including temperatures, irradiance, humidity and horizontal wind speed.

Although a cooling system consisting of two fans was installed, in some instances, the Tec, temperature measured inside the electrical cabinet (where the datalogger was located), exceeded the ambient temperature, reaching 47 degrees Celsius as shown in Table V. The operating temperature of the entire connectivity system (router and modem) recommended by the manufacturer was 10 ºC - 40 ºC. As the maximum operative conditions of the system were reached, by all accounts, it was an equipment failure in the connectivity system due to the high temperatures. After inspecting the system it was found that, in effect, the data delivery system (consisted of the nanorouter and the modem) stopped working. The connectivity system was not broken, but it was necessary to reset the nanorouter and configure it again manually.

C. *Data* visualizations

As the main novelty of this work, the remote visualization of the data in real time via web or smartphone stands out, due to the incorporation of connectivity to the system via 3G. The parameters monitored are processed and analyzed to produce information that can be understood easily by users; the information is represented in graphs. Fig. 14 shows a view of the dynamic charts integrated in the website.

Fig. 15 shows the visualization of data measured and sent to the cloud on 23/01/2017 in Alcalá de Henares. The open cloud platform selected, ThingSpeak™, allows to monitor up to eight parameters and to locate the monitoring system on the map via www.

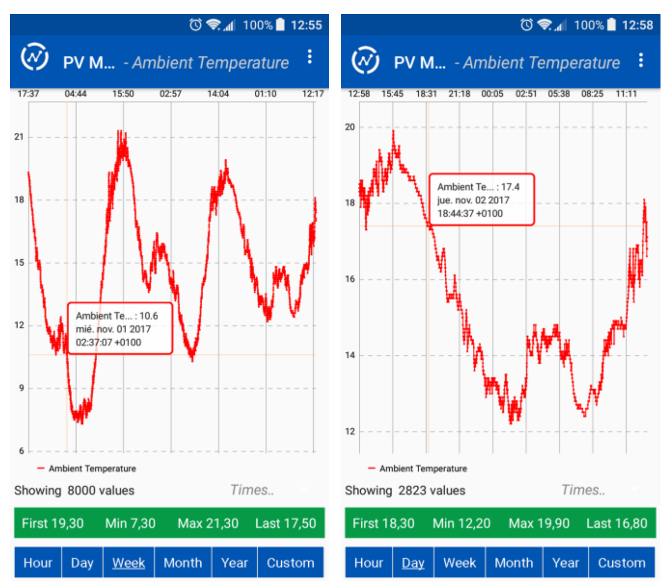

Fig.16. Screenshots on an Android smartphone using Thingview™ App: weekly (a) and daily (b) ambient temperature monitored by the datalogger located in Alcalá de Henares.

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Fig.16 shows the daily variations of the irradiance and the module temperature using the mobile application ThingView™.

VIII. Cost Estimation of the First Prototypes

TABLE VI
BUDGET FOR THE LOW-COST DATALOGGER

Board	Components	Price [€]
Arduino™ UNO	Stocked board	17.95
Ethernet Shield	Ethernet Shield W5100 for Arduino™ UNO	7.95
ADC Board	2 MCP3424	6.84
	RTC DS1307	1.58
	Precision resistors, Capacitors	1.80
	Wires, connectors	0.70
Power consumption	NPN transistor	0.29
Adaptor for high current sensing	3 LTS-15NP LEM	18.86
	9 Resistors SMD	5.40
	3 Voltage reference	2.79
Adaptor for high voltage sensing	3 Differential Amplifiers	11.31
	6 Resistors SMD	3.60
Connectivity system	TL-MR3020 router from TP-LINK	23.74
	MA260 modem from TP-LINK	37.9
	Total	**140,71**

The ultimate goal of this work was to develop an IoT-based prototype of a datalogger that uses a mobile communication transmission system and is low-cost, accurate and autonomous. Table VI describes the budget of the monitoring system. The final cost of the new prototype, including sensing and connectivity, was approximately 141 €. Table VII shows the budget for the low cost sensors. The budget of low-cost sensors (including the low-cost weather station) was approximately 268 €. Total costs could be reduced considerably when mass produced and introduced in the market.

TABLE VII
BUDGET FOR LOW COST SENSORS AND LOW-COST WEATHER STATION COMPONENTS

Components	Price [€]
3 Digital temperature sensors DS18B20	10.50
Irradiance sensor	39.90
Rain gauge sensor	35.20
Anemometer	120.00
Temperature and humidity sensor DHT22	2.69
Solar radiation shield for temperature sensor	59.88
Total	**268.17**

This monitoring system has a maintenance cost due to the use of a 3G SIM card. This maintenance cost depends on the fee of the contracted telephone service. As the information transmitted is very low, with a cheap data plan should be sufficient, so this expense is not significant.

IX. Conclusions

A novel datalogger for monitoring SAPV systems via website and mobile applications has been designed, built and tested incorporating wireless technology in it, concretely 3G, along with IoT. Two types of data storage were tested: a dedicated server (conventional method) and a cloud service platform (novel application of IoT). Both alternatives of storage allow to monitor the system in a remote way. The integration of an open cloud-based IoT platform allowed to monitor small stand-alone PV systems remotely in real time via web or mobile app at low cost.

The novel datalogger based on free software and hardware has been installed as an experimental prototype in multiple sites: Alcalá de Henares (Madrid, Spain), Linares (Jaén, Spain) and Oaxaca (Oaxaca, Mexico). The datalogger was tested under real and different conditions demonstrating the robustness of the system, working with 14 variables with low uncertainty. An outdoor campaign of over ten months was performed. Considering the low number of failures and their origin (the most of the failures were due to external factors), the experimental results showed that the datalogger is highly reliable. The cost of the monitoring system is considerably lower than commercial devices and allows high accurate remote monitoring.

The main novelty presented by this work is that the datalogger complies with the IEC standard accuracy requirements and it is designed based on wireless communications taking into account the limitations in rural areas of developing countries. The integrated solution has been tested and it works, so the datalogger could be installed solving the problem of monitoring of PV systems located in isolated regions, all at low cost.

As future works, to avoid the loss of information in case of failures (network, access…), a backup system based on a micro SD card would add value to the system; it would prevent the loss of data, storing the measured parameters in the disconnection period. In addition, it was proven that the connectivity system, working in extreme conditions (temperatures above 40 º C) fails. As a future line, another type of cooling system more effective and another 3G connectivity system that supports higher temperatures could be tested. To power the monitoring system using a solar cell could be another future improvement. Due to the stackable hardware design (by adding boards) several SAPV systems installed close enough can be monitoring using a single datalogger as a central node. The development of these networks is another future work.

Acknowledgment

The authors acknowledge funding from the University of Jaén, 'Ayudas Propias para la Cooperación Internacional y la Educación para el Desarrollo', 2016 call.

M. Vivar acknowledges funding from the Spanish Ministry of Economy and Competitiveness, 'Ramon y Cajal' Programme, Grant number RYC-2015-17306.

A. López-Vargas acknowledges funding from the Spanish Ministry of Economy and Competitiveness, 'Ayudas para la Promoción de Empleo Joven e Implantación de la Garantía Juvenil en I+D+i' Programme, Grant number PEJ-2014-A-42354.

REFERENCES

[1] IEA. Energy Access Outlook 2017 report.

[2] <http://www.iea.org/> (accessed 19.09.2018)

[3] R. Kempener, O. Lavagne, D. Saygin, J. Skeer, S. Vinci, and D. Gielen, "Off-Grid Renewable Energy Systems: Status and Methodological Issues", International Renewable Energy Agency, 2015.

[4] N.J. Williams, E. Ernest van Dyk, F.J. Vorster, "Monitoring solar home systems with pulse width modulation charge control". J Sol Energy Eng 2011;133:021006- 1–021006-7.

[5] M.Fuentes, M. Vivar, H. Hosein, J. Aguilera, E. Muñoz-Cerón, 'Lessons learned from the field analysis of PV installations in the Saharawi refugee camps after 10 years of operation', Renewable and Sustainable Energy Reviews, Vol 93, pp.100-109, 2018..

[6] R. Mukaro, X. Carelse, and L. Olumekor, "First performance analysis of a silicon-cell microcontroller-based solar radiation monitoring system", Sol. Energy, vol. 63, no. 5, pp. 313–321, Nov. 1998.

[7] E. Koutroulis and K. Kalaitzakis, "Development of an integrated data-acquisition system for renewable energy sources systems monitoring", Renew. Energy, vol. 28, no. 1, pp. 139–152, 2003.

[8] N. Forero, J. Hernández, and G. Gordillo, "Development of a monitoring system for a PV solar plant", Energy Convers. Manag., vol. 47, pp. 2329–2336, 2006.

[9] G. M. Tina and A. D. Grasso, "Remote monitoring system for stand-alone photovoltaic power plants: The case study of a PV-powered outdoor refrigerator", Energy Convers. Manag., vol. 78, pp. 862–871, 2014.

[10] M. Benghanem, "Low cost management for photovoltaic systems in isolated site with new IV characterization model proposed", Energy Convers. Manag., vol. 50, no. 3, pp. 748–755, Mar. 2009.

[11] M. Demirtas, I. Sefa, E. Irmak, and I. Colak, "Low-cost and high sensitive microcontroller based data acquisition system for renewable energy sources", 2008 Int. Symp. Power Electron. Electr. Drives, Autom. Motion, pp. 196–199, 2008.

[12] M. Benghanem and A. Maafi, "Performance of stand-alone photovoltaic systems using measured meteorological data for Algiers", Renew. Energy, vol. 13, no. 4, pp. 495–504, Apr. 1998.

[13] M. Benghanem, A. H. Arab, and K. Mukadam, "Data acquisition system for photovoltaic water pumps", Renew. Energy, vol. 17, no. 3, pp. 385–396, Jul. 1999.

[14] M. Benghanem, "Measurement of meteorological data based on wireless data acquisition system monitoring", Appl. Energy, vol. 86, no. 12, pp. 2651–2660, Dec. 2009.

[15] F. Touati, M. A. Al-Hitmi, N. A. Chowdhury, J. A. Hamad, and A. J. R. San Pedro Gonzales, "Investigation of solar PV performance under Doha weather using a customized measurement and monitoring system", Renew. Energy, vol. 89, pp. 564–577, 2016.

[16] A. Purwadi, Y. Haroen, F. Y. Ali, N. Heryana, D. Nurafiat, and A. Assegaf, "Prototype development of a Low Cost data logger for PV based LED Street Lighting System", Proc. 2011 Int. Conf. Electr. Eng. Informatics, no. July, pp. 1–5, 2011.

[17] M. Ikhsan, A. Purwadi, N. Hariyanto, N. Heryana, and Y. Haroen, "Study of Renewable Energy Sources Capacity and Loading Using Data Logger for Sizing of Solar-wind Hybrid Power System", Procedia Technol., vol. 11, no. Iceei, pp. 1048–1053, 2013.

[18] M. Fuentes, M. Vivar, J. M. Burgos, J. Aguilera, and J. A. Vacas, "Design of an accurate, low-cost autonomous datalogger for PV system monitoring using Arduino™ that complies with IEC standards", Sol. Energy Mater. Sol. Cells, vol. 130, pp. 529–543, Nov. 2014.

[19] A. López-Vargas, M. Fuentes, M. Vivar and F.J. Muñoz-Rodríguez, "Low-cost datalogger intended for remote monitoring of solar photovoltaic stand-alone systems based on Arduino™", Submitted.

[20] IEC61724-1. Photovoltaic System Performance- Part 1: Monitoring. 1st Ed., International Electrotechnical Commission (IEC), Switzerland, Geneva, 2017.

[21] N. Lethaby, "Wireless connectivity for the Internet of Things : One size does not fit all." , Report, Texas Instruments.

[22] R. I. S. Pereira, I. M. Dupont, P. C. M. Carvalho, and S. C. S. Jucá, "IoT embedded linux system based on Raspberry Pi applied to real-time cloud monitoring of a decentralized photovoltaic plant," Measurement, vol. 114, no. August 2017, pp. 286–297, 2018.

[23] "Harnessing the Internet of Things for Global Development" report. ITU, 2016.

[24] S. C. W. Krauter and T. Depping, "Remote PV-system monitored via satellite", Sol. Energy Mater. Sol. Cells, vol. 82, pp. 139–150, 2004.

[25] P. Papageorgas, D. Piromalis, K. Antonakoglou, G. Vokas, D. Tseles, and K. G. Arvanitis, "Smart solar panels: In-situ monitoring of photovoltaic panels based on wired and wireless sensor networks", Energy Procedia, vol. 36, pp. 535–545, 2013.

[26] N. Ahmed, H. Rahman, and I. Hussain, "A comparison of 802.11ah and 802.15.4 for IoT ", ICT Express, vol. 2, pp. 100–102, 2016.

[27] J. Hua, X. Lin, L. Xu, J. Li, and M. Ouyang, "Bluetooth wireless monitoring , diagnosis and calibration interface for control system of fuel cell bus in Olympic demonstration" vol. 186, pp. 478–484, 2009.

[28] S. Rosiek and F. J. Batlles, "A microcontroller-based data-acquisition system for meteorological station monitoring", Energy Convers. Manag., vol. 49, no. 12, pp. 3746–3754, 2008.

[29] ICT facts and Figures 2016, International Telecommunication Union [Online] Available: https://www.itu.int , Accessed on: Jan. 8, 2018.

[30] World Bank Group Flagship Report, 2016. [Online] Available: http://documents.worldbank.org , Accessed on: Feb. 27, 2018.

[31] M. Nique and K. Opala, "The Synergies between Mobile, Energy and Water Access: Africa," GSMA Report, 2014.

[32] United Nations University. [Online]. Available: https://unu.edu Accessed on: Feb. 20, 2018.

[33] R. Tejwani, G. Kumar, and C. Solanki, "Remote Monitoring for Solar Photovoltaic Systems in Rural Application using GSM Voice Channel," Energy Procedia, vol. 57, no. 1959, pp. 1526–1535, 2014.

[34] V. Villagrán, A. Montecinos, C. Franco, and R. C. Muñoz, "Environmental monitoring network along a mountain valley using embedded controllers," vol. 106, pp. 221–235, 2017.

[35] P.P. Ray, "A survey of IoT cloud platforms", Future Computing and Informatics Journal, vol 1, pp. 35-46. 2017.