Experimental Analysis and Monitoring of Photovoltaic Panel Parameters

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Abstract—**In this article, we establish a technique based on the internet of things to simultaneously monitor the main values that characterize a photovoltaic solar panel. This technique allows to discover the problems and the monstrosities during the operation. This study also allows to collect the parameters and quantities measured for analysis. This method is based on exploiting the advantages of IoT technology. For this it will be a good choice to use and exploit the Esp32 microcontroller, because the two WIFI and Bluetooth modules are integrated. The design process began by creating a system to measure the intensity of the electric current delivered by the photovoltaic panel. A current sensor was implemented for this purpose. To prevent damage to the microcontroller, a voltage divider was proposed to decrease the voltage at the pin level of the Esp32 for measurement. Next, the power and energy values were calculated to estimate the production capacity. In the final stage, a low-power Bluetooth link was created to transmit the four quantities to a smartphone or other compatible device. Real-time values were presented as graphs on the free ThingSpeak platform and displayed on both, an LCD screen and the serial monitor of the Esp32 microcontroller. The system was tested without any problems or errors.**

Keywords—Current sensor; bluetooth low consumption; photovoltaic panel; Esp32 microcontroller

I. Introduction

Currently, the exploitation of renewable energies is experiencing an intense and remarkable increase, to reduce and minimize costs and expenses in the energy field [1]. In this realization we strongly noted this last report between the electric energy and the energy generated by the photons coming from the sun, this report exceeds 25% [2], [3].

The proper functioning of solar panels is sensitive to being affected by climatic problems. As a result, the distortion negatively influences and can reduce the performance of photovoltaic panels [4], [5], [6], [7], [8]. To regularly detect the operating problems of photovoltaic systems, proactive management is necessary to ensure real-time monitoring of the values of the main parameters of this system. In this article, a design has been processed to measure and supervise the values of the quantities that characterize a photovoltaic panel, which will then be transmitted through low-consumption Bluetooth connectivity. Our document is ordered as follows. In the first section we have elaborated a summary. In Section II, similar studies have been presented which have dealt with the same objectives. Section III is reserved for the hardware part in which the essential characteristics of the Esp32 microcontroller and the ACS712-30A current sensor have been exposed. In the same section, we have exposed a detailed conception of our realization. Section IV brings together the results and the discussion via diagrams and curves which represent the results obtained experimentally. Noted here that the values of the parameters are collected and stored on the ThingSpeak platform which is reserved for connected objects while we exploit the HTTP protocol. Finally, in the last section a conclusion closes this study.

II. Related Work

A. Transfers Data with Bluetooth Modules, HC-06 and HC-05

In recent years and thanks to the technological revolution in the field of the Internet of Things, several scientific studies have integrated the Arduino microcontroller with the two external Bluetooth modules HC-05 and HC-06 [9], [10], [11], [12], [13]. These Bluetooth modules are greedy because they consume a large amount of energy, and we have noticed the non-compatibility with the Arduino card, which in many cases complicates the proper functioning of these modules to achieve connectivity via Bluetooth.

B. Use of the F031-06 Voltage Sensor for the Measurements

In the same design, other delicate researches have used the F031-06 voltage sensor as the main element to measure the potential difference that characterizes the photovoltaic panel [14], [15], [16], [17], [18], thus, the operating principle of this sensor is essentially based on the structure of a resistive divider, therefore, we quickly concluded that this sensor is characterized by the non-stability of the measurements, moreover, over a given measurement range the output of this sensor is always a linear function, in the research we have done, we have noticed a wide sensitivity to noise and the values measured with this sensor are slightly different to the real values.

C. Transfers Data with WIFI Module

In the same context, other research has integrated the WIFI module to transmit the different measured quantities of photovoltaic panels such as current, voltage and energy [19], [20], [21], [22], [23]. Noted here that in the studies used by the integrated WIFI module of the Esp32 microcontroller, the IP address is assigned dynamically by a DHCP server, so this address changes its value at each restart, this becomes a major problem and complicates the situation in the case where a web server is installed on the Esp32 microcontroller. In most cases, this inconvenience is overcome by integrating the Wifi.config function to set the IP address, this function accepts the following attributes, Ip, gateway, dns, and subnet. In general, these studies are very successful, while the Wi-Fi network coverage space remains a challenge.

D. Arduino Mega as Main Processing Element

In other scientific research, the hardware design consists of an Arduino Mega board, therefore an ATMega2560 microprocessor [24], [25], [26], [27], [28]. These studies profusely reduce the hardware complexity and make the model clearer, We noted here that the Arduino Mega2560 board is characterized by several advantages such as the number of input / output (54 pins), a large number of analog pins (16 pins), serial ports (3 ports), an I2C port and an SPI port, compared to the ordinary Arduino board, the Mega2560 is characterized mainly by a large memory predisposition, let's also add compatibility with the majority of Arduino modules. the IoT.

III. Materials and Methods

In this section, the material design used in this realization is presented, it is based mainly on the following elements:

A. Microcontrôleur Esp32

In this study, the Esp32 Microcontroller plays a key role, because it is created to promote and ensure the learning and development of connected objects, and embedded applications [29], it is characterized by a large computing capacity in comparison to the Arduino, this microcontroller wakes up regularly when a specific condition is verified, In practice, experiments show that the Esp32 microcontroller greatly minimizes the amount of energy consumed thanks to the reduced duty cycle, The ESP32 microcontroller integrates the WROOM-32 microprocessor (Tensilica Xtensa LX6) which particularly works under a clock frequency of 240 MHz. Also noted that the Bluetooth (Bluetooth Low Energy) and WIFI modules (WIFI: 802.11 n width 2.4 GHz) are integrated.

B. ACS712 30a Current Sensor

The ACS712 current sensor is essentially based on the ascending Hall effect. Whatever the nature of the electric current (direct (DC) or alternating (AC)), the ACS712 sensor is connected in practical embodiments in series with the load, with a sensitivity of around 66mV per ampere, see Fig. 1, [30][31].

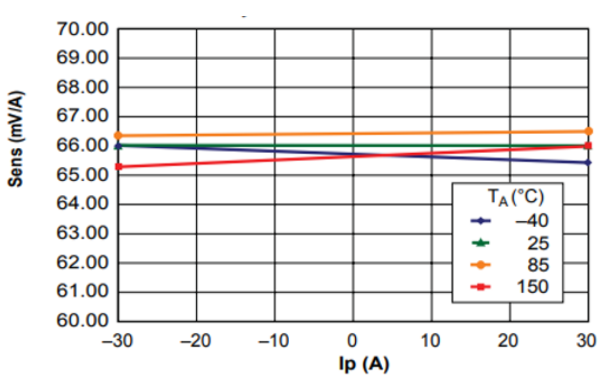

Fig. 1. Sensitivity of the ACS71230-a sensor

Among the advantages of the ACS712 sensor, the authors have noted that this sensor accepts the passage of electric current in both directions, this makes it possible to measure a positive or negative electric current in specific situations. The current inside this sensor generates a magnetic field; at the output, a DC voltage propositional to the current will be obtained. It is equally important to note that a calibration with a blank reading is strongly recommended. Note also that an external magnetic field (like for example) can negatively influence the measurements made. In practical implementations, the ACS712 Hall effect current sensor (10nF) is distinguished by intense noise corresponds to 130mA, the authors have greatly limited this noise by adding a 470nF capacitor, also have profusely limited this noise by adding a 470nF capacitor. The pins of the ACS712 are denoted in Fig. 2, the technical characteristics are given as follows: Dimensions: 31x13x15mm, Chip: ACS712ELEC-30A, Measured current range: -30A to +30A, Vref at 0A: Vcc/2 i.e. 2.5V, Sensitivity: 66mV/A, Insulation: 2.1KV, Consumption: 10mA, Error: 1.5 % at 25°C, Power supply: 5VDC (4.5-5.5VDC).

C. Autres Elements

Since the photovoltaic panels in our realization generate a maximum voltage equal to 42V, and since the voltage at the terminals of the ESP32 microcontroller must not go above 5v, next, we installed a voltage divider to lower the voltage to avoid unbuttoning the ESP32 microcontroller. The value of resistors R1 and R2 are calculated to identify the two conditions (the maximum voltage at the microcontroller terminals must not exceed 5V and the maximum voltage of the PVs equal to 42V) ie R1=1kΩ, R2=12KΩ. The voltage value at pin R2 is measured by ESP32 pin number 34 see Fig. 4. Other hardware elements are used, an LCD display to display the measured quantities like the current intensity value, voltage, power, energy. Finally, we have a rectangular photovoltaic panel with an area equal to 1.6 m².

D. Comparison of Wireless Techniques

Table I, summarizes a comparison between five standard wireless technology, Bluetooth, RF 433MHz, ZigBee, and WIFI, therefore, the association standards, power consumption, bandwidth and throughput are represented in table1[32].

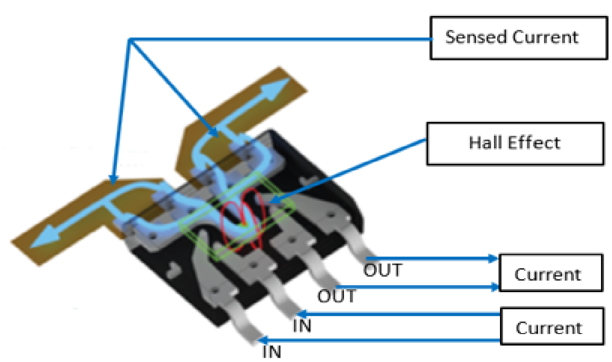

Fig. 2. Designation of the pins of the ACS712 sensor

TABLE I. COMPARISON BETWEEN STANDARD WIRELESS TECHNOLOGIES

Technologies	RF	WI-Fi	BlueTooth	ZigBee
Standards Association	IEEE 802.15.4	Low	433 MHz	4-9 Kb/s
Energy consumption	IEEE 802.11	High	2.4GHz	---
Frequency	IEEE 802.15.1	Low-High	2.4GHz	<24 Mbps
Debit	IEEE 802.15.4	High	2.4GHz	<1Mb/s

E. Formula Evaluation

To carry out this study, we chose an open area characterized by the absence of obstacles which can negatively influence the propagation of UHF waves, this place is also characterized by the absence of radio emissions on the 2.4 GHz frequency so no interference phenomenon, the weather conditions are very favorable with a very clear sky and a temperature of 29C. At first, we studied the aspect of propagation of UHF radio waves which constitutes a principle of bidirectional exchange for Bluetooth technology on a frequency band of 2.4 GHz, therefore, we studied the attenuation of these UHF waves to reduce obstacles and unwanted effects that can negatively influence the UHF signal coverage area. Note here that the undesirable epiphenomena of Ultra High Frequency wave attenuation are defined by Eq. (1) in [33], [34].

$$PL_{dB} = 10\, log_{10}\left(\frac{p_t}{p_r}\right) \qquad (1)$$

- PLdB : Wave attenuation in dB,
- pt : Transmitted power
- pr : received power

Note that the distances related to attenuation are well determined, Fig. 3 presents this attenuation corresponding to ultra-high frequency waves (UHF)

In practice, in the UHF signal damping equation in dB, a coefficient is added to determine a true ratio between the acquired power P and the separation distance d, this coefficient is denoted by n and equation (2) in [36] represents this mutation (n: path factor , n=2 free space, X_δ: Gaussian random variable, δ: standard deviation).

$$PL(d) = x_\delta + PL(d_0) + 10n\, log_{10}\left(\frac{d}{d_0}\right) \qquad (2)$$

In the field of telecommunications and signal transmission, the Friis Eq. (3) explains an interesting relationship between the distance d between the transmitter and the receiver in a free space, as well as the power and the antenna gain [37].

$$\frac{p_r}{p_t} = G_t G_r \frac{\lambda^2}{(4\pi d)^2} \qquad (3)$$

- P_t: Power delivered by the transmitter (W)
- P_r: Power delivered by the receiver (W)
- G_r: Receiver Gai

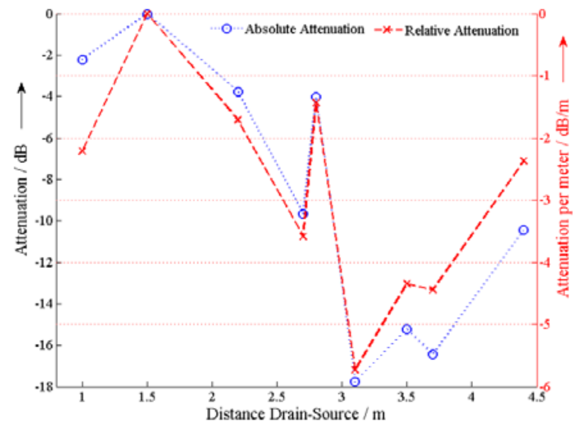

Fig. 3. Attenuation of UHF wave determined in time domain [35]

- G_t: Transmitter Gain
- λ: Signal Wavelength
- d: Distance between (transmitter, receiver).

Scientifically, an important interpretation allows to exchange enormously to believe that the free space attenuation is proportional to the square of the frequency. Therefore, these expressions appear only in formulas where the antenna gain expression is represented. On the other hand, this help has totally disappeared the condition where we have antennas with a fixed surface. [38]. It is therefore concluded that the antennas are the cause of a loss of gain due to non-compliance. Equation (4) represents this effect.

$$\frac{p_r}{p_t} = G_t G_r (1 - |s11|^2)(1 - |s22|^2)\left(\frac{\lambda^2}{(4\pi d)^2}\right) \qquad (4)$$

- s11/s22: reflection coefficients on the transmit/receive antenna.
- Gr/Gt: Receiver/Transmitter Gain
- λ: Signal Wavelength
- d: Distance between (transmitter, receiver).

F. The Main Design Proposal

In this section, we will develop the main diagram of our realization, as well as the advantages which draw the strong point of this monitoring system.

- The design and implementation are very easy.
- The use of data transfer via a low-consumption Bluetooth link and very useful in places far from communication networks (absence of GSM and Internet for example).
- Wireless monitoring – secure and reassured data exchange.

We have proposed the following general scheme for measuring current and voltage, in order to calculate power and energy, see Fig. 4. These four values will be sent via a low-power Bluetooth link that we must create in the next section.

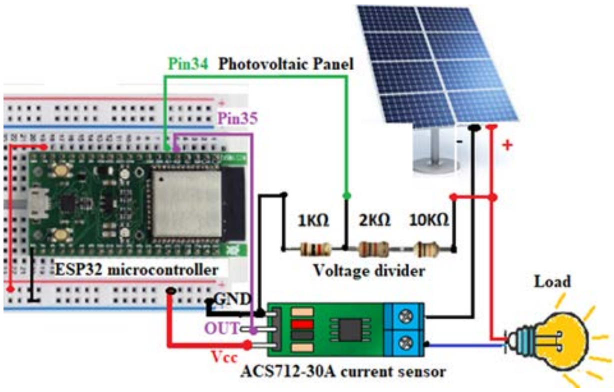

Fig. 4. Main design diagram

In this section, the main diagram of this study is proposed. It was started by measuring the current intensity with the ACS712-30A sensor at the level of pin35 of the Esp32 microcontroller, see Fig. 4. After an aid to lower the potential difference was developed, thanks to a voltage divider so as not to exceed the 5v threshold which represents the maximum voltage that the Esp32 microcontroller can support. The measurement is therefore carried out at the resistance level R2, therefore, the pin34. Note that to know the voltage between the terminals of the photovoltaic panel, the mesh law and Ohm's law was used. And finally, the values of the voltage (V) and the current (I) we used to calculate in an exact way the two other parameters: the instantaneous power (P) and the energy (E).

G. Creation of the Bluetooth Link

The classic HC-05 and HC-06 external modules are outdated despite the simplicity of integration in IoT projects, these two modules have major drawbacks, such as large power consumption, another thing is that these two modules use the old Blutooth V2.0, this is a heavily outdated version. To remedy this problem linked to high energy consumption, the Esp32 was used because the Bluetooth module is integrated into the body of this microcontroller by the manufacturer. The choice to use an Esp32 is highly difficult because it is characterized by a flow rate of around 1Mb/s and the consumption will be reduced 10 times thanks to the new cell construction technology [39]. In the main code, to establish and ensure a connection via Bluetooth Low Energy, first the BluetoothSerial.h library was declared; this library compromises all the functionality necessary to guarantee the serial connection via Bluetooth technology. Subsequently, the declaration of a BluetoothSerial class object is mandatory, this object is called SerialBT.

To initialize the Bluetooth module, it is must to interact with this SerialBT object. To listen to the client connection event, in the second step the callback function and the void setup() function should be configured. Still in the code, started the serial communication with a rate equal to 115200 baud, naming the begin() method on the BluetoothSerial object allows us to initialize the Bluetooth interface. It receives the name of the Esp32 microcontroller as input, in our realization "ESP32_iosm". Finally in the void loop() function, a verification of the reception of data via the Bluetooth module. The working process of our study is shown in Fig. 5.

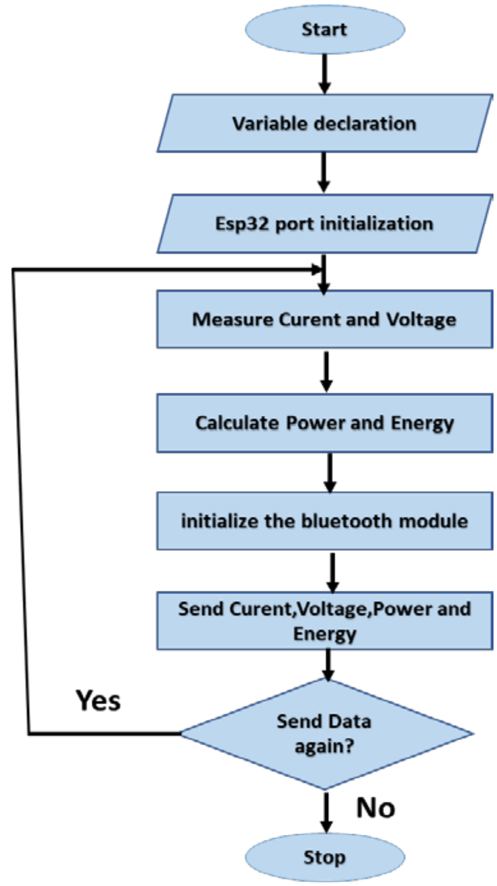

Fig. 5. Operation process flowchart

IV. Results and Discussion

This achievement has been implemented correctly, see Fig. 6 , the transfer of data via this Bluetooth link is a good affirmation of this success, the screenshots in Fig. 8 and Fig. 9 express and describe in real time the quantities transmitted (Energy, Power, Voltage and Current).

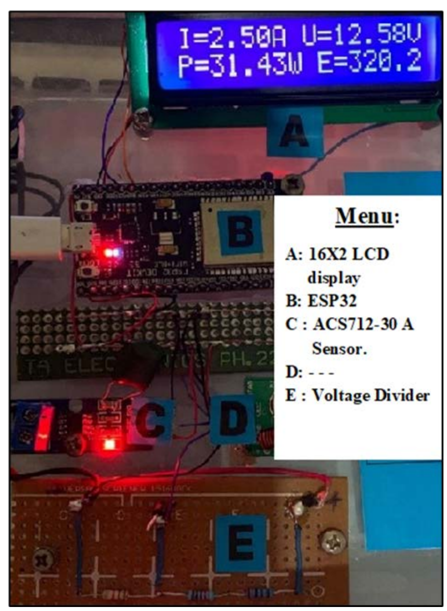

Fig. 6. Practical realization of the study[29]

A. Experimental Results

The Arduino Integrated Development Environment (IDE) was used to compile and upload the code, our Esp32 microcontroller will be immediately recognized and detected by other Bluetooth devices under the name we assigned in the previous section “ESP32_iosm”, see Fig. 7.

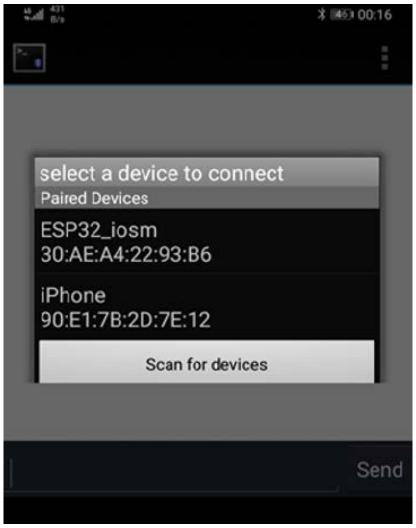

Fig. 7. Detection of the Esp32 microcontroller on smartphone

A new COM port will be available to perform the pairing when the pairing action is completed. After a discovery operation, Fig. 8 exposes on a smartphone the data received as a result of a low-power Bluetooth communication.

Fig. 8. Receiving data on a smartphone

The different experimental results are grouped in Table II, these results imprint the first five loops of this achievement, these values are displayed in real time on the serial monitor of our microcontroller, see Fig. 9.

TABLE II. MEASUREMENT- EXTRACT

Loop number	Current (A)	Voltage (V)	Power (W)	Energy (Ws)
1	1.53	14.59	22.33	102.70
2	2.68	14.63	39.29	141.99
3	1.53	14.62	22.49	164.42
4	1.46	14.60	21.37	185.79
5	1.52	14.60	22.17	207.96

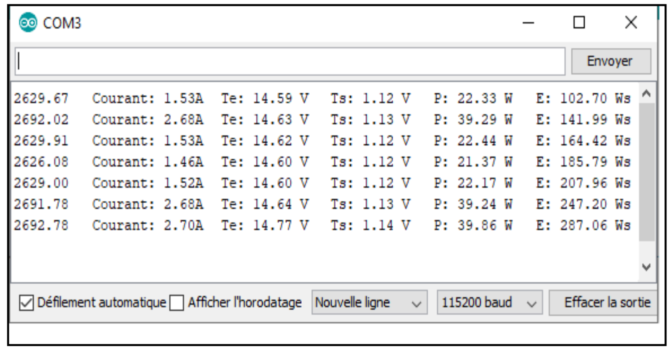

Fig. 9. Preview of the result on the serial monitor

Finally, to facilitate the comparison and make the data clearer in the form of representative graphs, we made use of a free "open source" web application, the TingSpeak platform, which is reserved for the realization of the Internet of Things and the embedded electronics projects, Fig. 10, we used the http protocol to collect the data to transfer the connected objects. In the Fig. 11, we have presented the variations of energy / second and Fig. 12 displays a representation of the total energy of our photovoltaic panel.

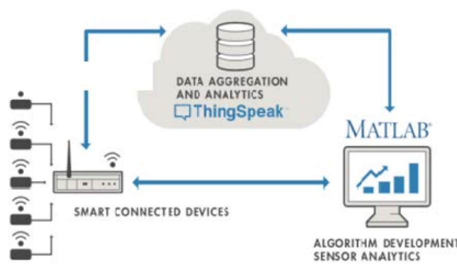

Fig. 10. TingSpeak plateforme

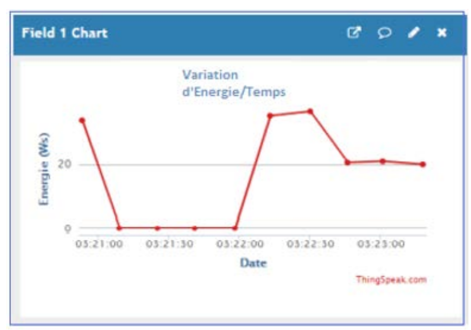

Fig. 11. Energy variations/second

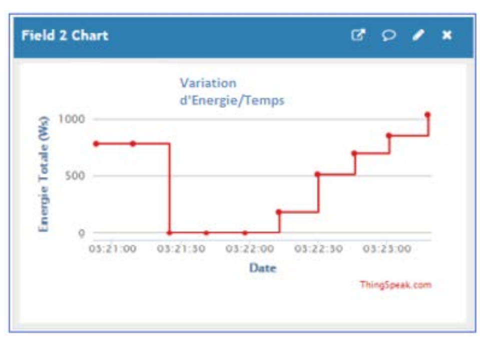

Fig. 12. Energy total variation

V. Conclusion

The experimental results of this study show that monitoring the main parameters of photovoltaic panels with low-power Bluetooth modules is still a good choice in isolated places, or when GSM or Internet network coverage is absent. Note that the implementation of these projects is simple, easy and not expensive. The monitoring of these parameters in real time and in distinct intervals allows us to discover and see operating strangeness. This greatly increases the credibility of the system and guarantees its proper functioning.

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