INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

Solar photovoltaic remote monitoring

Youssef DELLY - a49137

Work oriented by:

Prof. Dr. José Luís Sousa de Magalhães Lima

Prof. Thadeu Vinícius de Brito (CeDRI)

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Dedication

I dedicate this Modest work : To my mother, my reason for being, my reason for living, the lantern that lights my way and illuminates me with sweetness and love.
To my father, as a sign of love, recognition and gratitude for all the support and sacrifices he has shown to me.
To my dear brothers. No words can describe your dedication and your sacrifices.
To all my friends, In testimony to the sincere friendship that has bound us and the good times spent together, I dedicate this work to you, wishing you a bright future full of good promises.
To all the people who believed in me and who give me the desire to move forward,
I thank you all, your support and your encouragement give me the strength to continue.

Acknowledgements

I thank Almighty God for the will, the health and the patience he gave me during all these years of study. Before starting the presentation of this work, I take this opportunity to thank all the people who have contributed directly or indirectly to the realization of this graduation project.

First of all. I would also like to express my sincere thanks to my supervisors Professor Dr. José Luís Sousa de Magalhães Lima and Professor Thadeu Brito for agreeing to supervise me for my work, as well as for their support, relevant comments and encouragement.

I also thank all the teachers and administrators of the IPB. Finally, I will not forget to thank the members of the jury who has honoured me with evaluating of this work.

Abstract

Renewable energy systems are quickly becoming one of the most efficient way to generate electricity. Solar energy is one of the most appealing renewable energy sources for electrification. Harnessing solar energy requires a photovoltaic system that converts light energy from the sun into direct electricity. Therefore, to evaluate its performance, real-time monitoring system is needed. Some of photovoltaic system are installed in inaccessible locations and thus unable to be monitored from a dedicated location, so the monitoring must be remotely using web based interfaces. This project proposes to develop a prototype based on IoT technology for monitoring remotely and evaluating the performance of a solar photovoltaic system. This will facilitate preventive maintenance, fault detection, historical analysis, in addition to real time monitoring. For the project development, an ESP32 device is used to measure a set of sensors and transmit them through the MQTT protocol via WiFi technology to a MQTT Broker that manages and publishes data to a flow editor named Node-RED to be collected and sent to a database named InfluxDB, where data are stored and secured, and finally a visualization platform named Grafana, displays the measurements to be analyzed over time.

Keywords: Monitoring System, Internet of Things, Grafana, InfluxDB

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Acronyms

ADC Analogue-to-Digital Converter.

CeDRI Research Center in Digitization and Intelligent Robotics.

CoAP Constrained Application Protocol.

DAQ Data acquisition.

I^2C Inter Integrated Circuit Bus.

IDE Integrated Development Environment.

IoT Internet of Things.

M2M Machine to Machine.

MQTT Message Queue Telemetry Transport.

OS Operating Systems.

PV Photovoltaic.

SCL Serial Clock Line.

SDA Serial Data Line.

SOC Consumption System-Onchip.

SPI Serial Peripheral Interface.

TCP Transmission Control Protocol.

UART Universal Asynchronous Receiver Transmitter.

UDP User Datagram Protocol.

Wi-Fi Wireless Fidelity.

Chapter 1

Introduction

Among renewable energy sources, solar energy is considered the most fascinating source that is widely available throughout the world and can contribute to minimize the dependence on energy imports and that could balance the gap between consumption and production, thanks to the remarkable decrease in its cost and the progress in this technology [1]. Photovoltaic technology has seen a rapid evolution during the past few decades, and because of it, the market potentials have seen huge growth.

1.1 Theoretical framework

Photovoltaic systems operates over long periods of time and produce performance data in terms of voltage and current during the availability of sunlight. The traditional data collection technique uses a manual method with conventional tools such as digital multimetre and other analogue measurement devices, which is a time-consuming process. Due to rapid changes in environmental conditions, accurate measurement of performance data is difficult to record over a long time-period. Using sensors in the data acquisition process hence become necessary to give a quick response with precision in real-time instead of manual measurement of the photovoltaic system performance [2]. Monitoring of photovoltaic system parameters helps ensure system stability, to provide information on energy potential, fault detection, and energy harvested for extensive analysis under climatic conditions. And so, to develop remote monitoring system for solar photovoltaic panels, Internet of Things (IoT) present a good approach, which actually envisions a near future where everyday objects will be armed with microcontrollers and transceivers for digital communication [3].

1.2 Objectives

The main objective in this work is to monitor the state of a photovoltaic system capable of providing real-time information, through a low cost IoT solution that embraces the data acquisition, processing functions, data analysis and visualization of the photovoltaic station performances.

1.2.1 Specific objectives

The specific objectives of this work are the following :

- Use sensors to measure parameters of the photovoltaic system such as voltage, current, and power and the parameters that influence the photovoltaic system, such as temperature, humidity, and light.
- Elaboration of a collection, visualization and monitoring system of the measured parameters.
- Investigation of the environmental effects on photovoltaic module output performance.

1.3 Document structure

The document structure is presented as follows:

- Chapter 1 gives an introduction to the subject of study and a presentation of the objectives of the Master's Thesis.

- Chapter 2 presents the state of the art, and concepts associated with photovoltaic, Internet of Things, and monitoring.
- Chapter 3 presents the statement of the problem and the proposed solution, an overview of the used hardware and softaware components, and a description of the monitoring system.
- Chapter 4 describes the implementation of the hardware and the monitoring system, carried out according to the proposed solution.
- Chapter 5 presents the results obtained according to the implementation done in chapter 4 and gives an analyse from the collected data.
- Chapter 6 brings the conclusions of this work and mention proposals for the future work.

Chapter 2

State of art

The aim of this chapter is to define some notions of the photovoltaic effect, the Internet of Things (IoT) and mention the link between them, and also the importance of photovoltaic monitoring will be addressed.

2.1 Photovoltaic technology

The photovoltaic effect was discovered by Becquerel in 1839, when he obtained an electric current by exposing silver electrodes in an electrolyte to light radiation [4]. Then, for several decades, the Photovoltaic (PV) effect remained uninteresting until the invention of the transistor and the development of the physics of a PN junction by Shockley, Bardeen and Brattain in 1949, the year the semiconductor era began [4]. Photovoltaic technology has become a huge industry, based on the enormous applications for solar cells. In the 19th century, when photoelectric experiences started to be conducted, it would be unexpected that these optoelectronic devices would act as an essential energy source, fighting the ecological footprint brought by non-renewable sources, since the industrial revolution [4].

2.1.1 Photovoltaic effect

PV systems are energy conversion systems designed to supply electric power through the conversion of sunlight into electricity. In a PV system this conversion is assured by solar photovoltaic panels through a process known as the photovoltaic effect. The photovoltaic effect is a specific case of the photoelectric effect, where the excitement of electrons to a higher energy state occurs upon the exposure of light (photons) to a certain material. What distinguishes both effects is that in the photovoltaic effect, the excited carriers, or free electrons, are still contained inside the material and are not ejected out. In a solar panel, or module, the solar cells are responsible for carrying out this effect. These are made of a semiconductor material typically in the form of a p-n junction [5].

2.1.2 Photovoltaic cells

The photovoltaic cell is a means of transforming light into electrical energy by using the photovoltaic effect process. The PV cell is made of two silicon layers, one P-doped (boron-doped) and the other layer N-doped (phosphorus-doped) providing a P-N junction with a potential barrier, as it is described in Fig. 2.1 [6]. When photons are absorbed by the semiconductor, they transmit their energy to the atoms of the P-N junction in such a way that electrons from these atoms are liberated and create electrons (negatively charged) and holes (positively charged), which creates a potential difference between the two layers. It is measured between the terminals of the positive and negative connections of the cell. The maximum voltage of the cell is about 0.45 to 0.58 V at zero current [6], it is called the open circuit voltage V_{oc}. Whereas, the maximum current produced is the short-circuit current I_{cc} attained when the terminals of the cell are short-circuited.

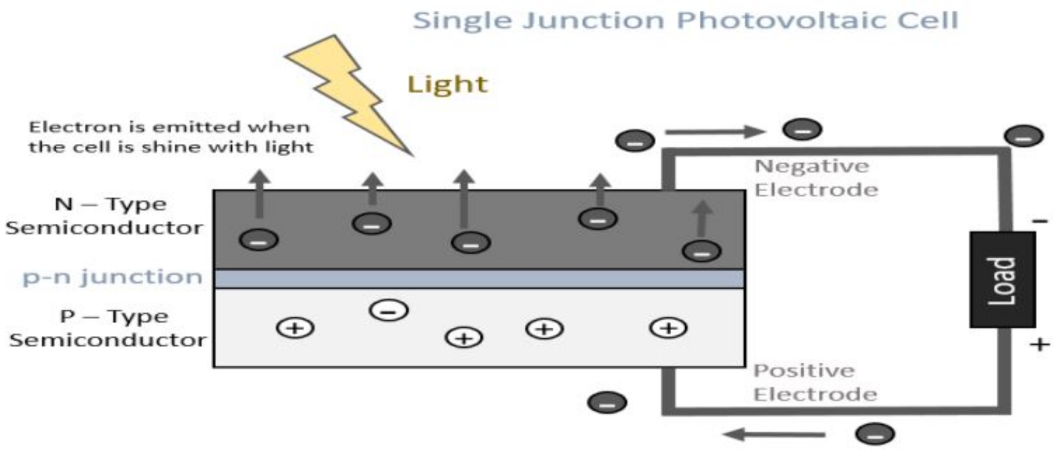


Figure 2.1: Schematic representation of a solar cell [6].

2.1.3 Different types of PV cells

Reference [7] presents a wide range of materials used for PV applications, such as the Cadmium telluride, Copper indium gallium selenide, Organic and polymer materials. However, crystalline silicon photovoltaic cells dominates the PV markets, since they are manufactured with different performances and forms, each model has its benefits compared to other models. The most commonly used types of crystalline silicon PV cells are shown in Fig. 2.2 [8], which are:

1. Mono-crystalline (single crystalline) cells:
   Mono-crystalline solar panels are generally considered as a premium product thanks to its high efficiency (18–19%) and aesthetic performance. It is considered as the expensive crystalline silicon (0.83€ to 1.25€ per watt) [9][10].

2. Poly-crystalline (multi-crystalline) cells:
   It is made from the wafer cut of recrystallised silicon and as its name indicates, it is made up of a large number of crystals in a disordered manner. Poly-crystalline cells have a low efficiency (around 16–17%) compared to mono-crystalline cells, at a cost around 0.75€ to 0.83€ per watt [9][10].

3. Amorphous cells (Thin-film):

   It is formed by depositing a silicon film on a glass substrate. In this technology, less silicon is used in the production process compared to mono- or poly-crystalline cells, but this saving is at the detriment of the conversion efficiency (around 9%), which reflects its cost at 0.58€ to 0.83€ per watt [9][10].

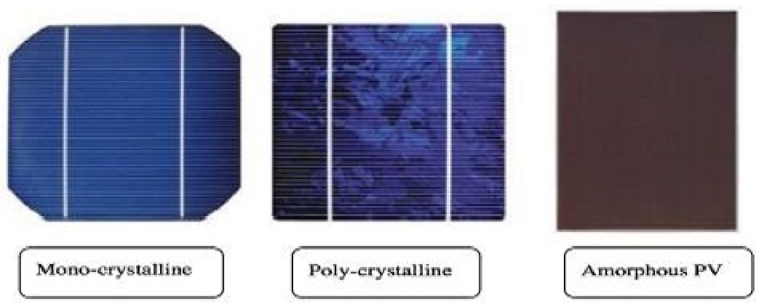


Figure 2.2: Different types of PV modules.

2.1.4 Equivalent circuit

The solar cells are represented based on diode models: single diode model [11] [12], two diode model [13], and three diode model [14]. In general, the single-diode model is the most used since it offers a good trade-off between simplicity and precision over other models. For the two-diode model, an extra diode is used to reflect the effect of carrier recombination. A three-diode model is applied to consider the influence of grain boundaries and large leakage currents across the peripheries. Fig.2.3 represent the equivalent single diode circuit of the PV cell [15].

- I_L represents the light generated current in the cell (photocurrent).
- I_{sh} represents the current lost due to shunt resistances.
- I_D represents the voltage-dependent current lost to recombination.
- R_s and R_{sh} represents the series resistance and the shunt resistance, respectively.

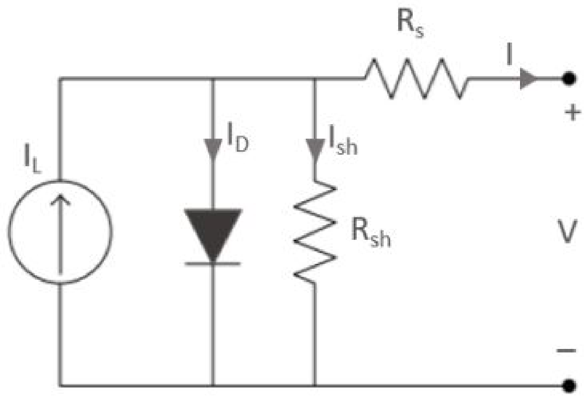


Figure 2.3: Single diode equivalent circuit models.

2.1.5 Influence of temperature and irradiance on the solar panel

The output characteristics of a photovoltaic system depend on the level of the irradiance and the temperature. Based on Fig. 2.4, increasing the solar irradiance level causes the increasing of the PV output current with a slight increase in the PV output voltage. While in Fig. 2.5, the increase of the cell temperature causes a reducement of the PV

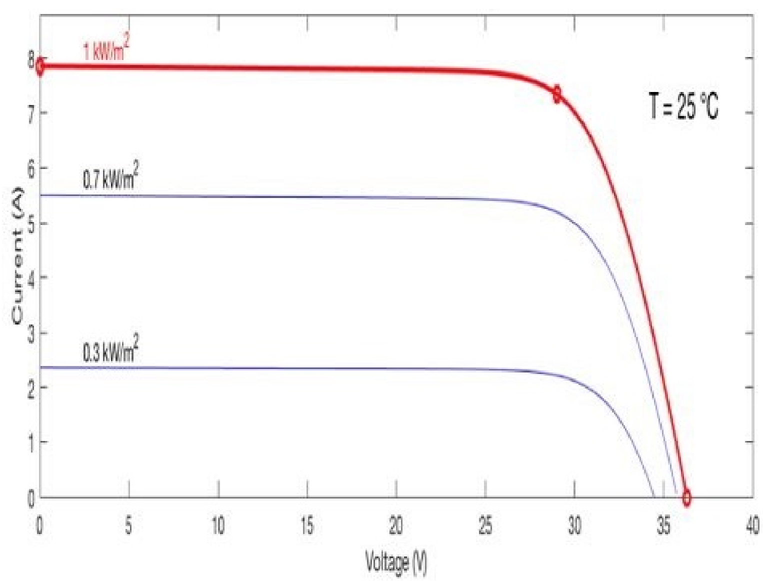


Figure 2.4: I-V curves of a PV module traced at different solar irradiance levels and 25°C [16].

output voltage. It can be concluded that a photovoltaic cell generates a higher amount of output in the coldest place with a highest level of solar irradiation [17].

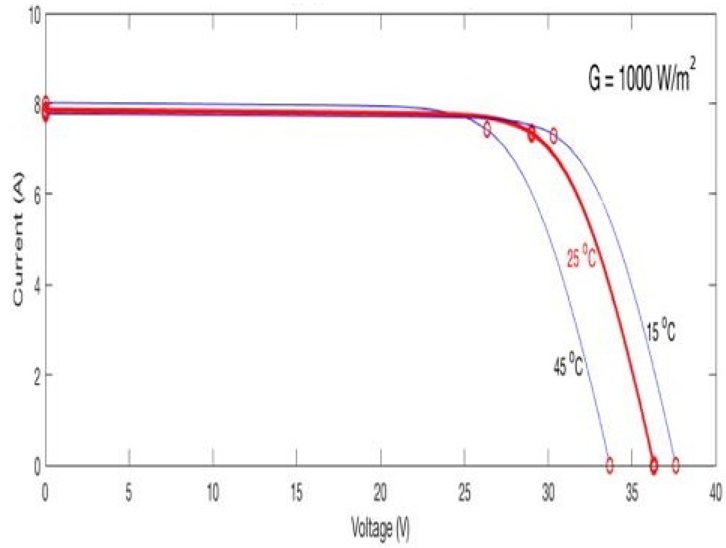


Figure 2.5: I-V curves of a PV module traced at different temperature levels and $1000\,W/m^2$ [16].

PV output power is directly proportional to the quantity of the reflected solar irradiation, and inversely proportional to the temperature, as shown in Fig. 2.6. In addition, it is obvious that the change in atmospheric conditions results a change in the position of the Maximum Power Point (MPP), which affect the system efficiency [17].

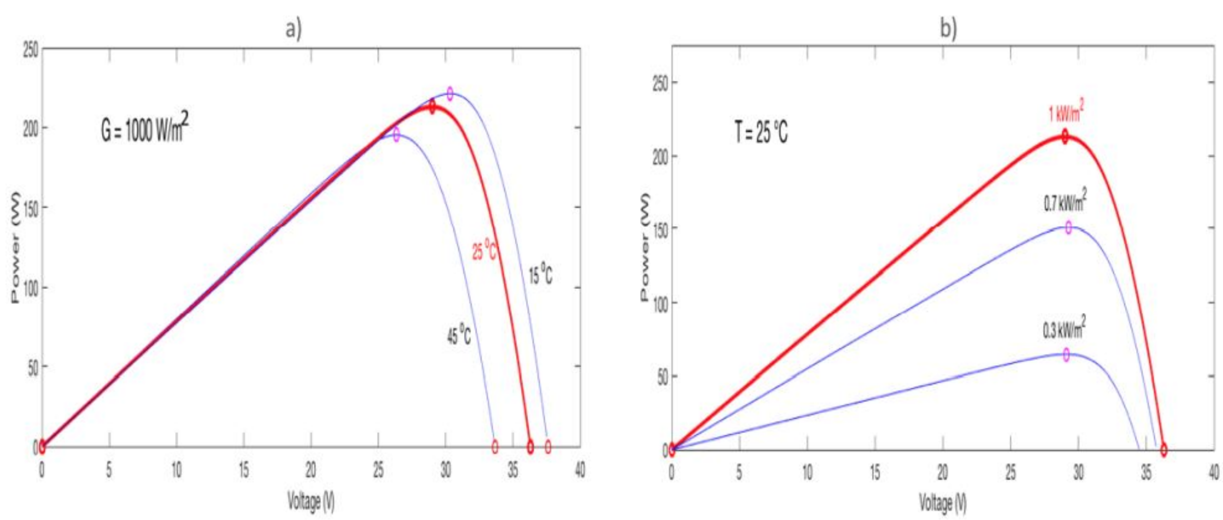


Figure 2.6: P-V curves of a PV module in: a) Different temperature levels at $1000\,W/m^2$; b) Different solar irradiance levels at 25°C [16].

2.2 Photovoltaic Monitoring

Photovoltaic technology is facing some problems which obstruct its growth, significant expense and low productivity. Besides these factors, optimum reliability is another issue in PV technology [18]. However, it is realized that the observation of PV variables in outdoor conditions is necessary for optimum utilization, reliability, and execution enhancements of a PV system. The monitoring systems of PV is very important for analysis the data, troubleshooting and decision-making [19]. In 2006, Aristizabal proposed an observing system using Virtual Instrumentation (VI), the proposed system is fit for gathering information about performance of PV system parameters and also estimating surrounding factors, which contain solar radiation and temperature [20]. Also, in 2009 Anwari introduced a portrayal of monitoring system for 5 kW PV system, which contains sensors, remote passageway, and PC. It empowers managers for getting to PV variables by means of a wireless link [21]. Additionally, In 2005, Van Dyk, Gxasheka, and Meyer has built up a PC-based monitoring system for PV system that permits sketch of the I–V qualities of a PV system in real climatic test conditions [22]. Those are different innovations depend on the on-board web server to process the information through Ethernet. Most of data acquisition systems are wired and accessible only near the PV systems, and they are manually controlled [23]. There are some wireless data acquisition systems, but they depend on license-based software and cloud services. There are very few wireless data acquisition systems using open-access software, which are monitored and recorded fewer parameters at a very high cost [23].

2.3 Need for Monitoring PV Module and Weather Parameters

Energy predictions form the photovoltaic systems either before the installation or after the installation is not an easy job. This is because of the influence of various local and global parameters. However, knowing such parameters would help in analyzing the energy predictions or the possibility of estimation. It should adopt methodologies for analyzing the energy generations, feasibilities etc [24]. Many simulation studies suggested many tools for evaluating the performance of solar PV systems in specific to the project design and in financial point of view [25]. Although, the possibility of energy prediction accuracy is quite less with the simulation tools than the practical evaluation due to the various input data chosen for the studies. So, the only left option would be the practical studies implemented in the outdoor field where PV systems are planned to install. Also, studies should be implemented on suitable PV technology-based module and considering the various means of energy variation possibility including the ambient conditions of the location. The same procedure is followed for various PV technologies, this allows the user to do analysis and choose the best module that can work effectively for the site ambient conditions [26]. During this evaluation one should identify the relation between the actual energy that is expected and what is the final energy that is available as output [27]. This relation gives the scope for analyzing the PV behavior over the long term. So, the measurement of various characteristic parameters of the PV is needed. Also, module performance is affected with the luminosity, temperature, humidity etc [28].

2.4 Internet of Things

Internet of Things is a concept that refers to objects and devices that are capable of interacting with each other and with the human being, analyzing, receiving and transmitting information or data in a means of communication to or from the Internet. These objects and devices interact through smart devices (intelligent devices) that must be composed of the following elements: controller (computer component that allows data and information to be processed), sensors (allow the physical variables of our environment to be measured and transformed into data that can be processed digitally) and actuators (electronic elements that modify or generate changes in the physical environment). This set of elements make up an IoT prototype, currently the costs of these electronic devices have decreased considerably at the same time that there have been increasing advances in these technologies and added to the fact that the presence of the Internet in the world is considerable, it opens up the possibility of connecting any object and device to the internet in such a way that it acts as a source of information on the conditions of our environment, allowing decisions to be made that contribute to the development of humanity. How authors Raj, Singh, Vishvakarma, and Singh describe it “IoT is an interconnected network of processing devices, computers, smart devices, mobile phones, and other electronic devices that are equipped with intelligence and communication protocols” [29]. IoT allows the ability to collect and exchange information between the system administration of all connected physical objects and allows also, discovering, accessing and managing objects in remote places with the use of personal computers and smartphones competently and economically without the need to interact with the user [29].

2.4.1 IoT Communication

The communication model used on the Internet is based on two main elements: client and server. The server is in charge of managing the communication between clients, while the client triggers the server whenever it needs to communicate with another client or server [30]. In IoT, nodes can perform both functions in such a way that they can communicate with each other. Wireless communication networks can be classified according to the distance they cover into [30]:

WMAN *(Wireless Metropolitan Area Network)*, Wireless Metropolitan Area Networks, designed to cover distances of several kilometers.

WLAN *(Wireless Local Area Network)*, wireless local area networks, these networks have a coverage that goes between meters and hundreds of meters.

WPAN *(Wireless Personal Area Network)*, Wireless Personal Area Network, with a range in the order of tens of meters.

2.4.2 Network communication protocols

There are a variety of communication protocols developed for the Internet of Things, such as the family of protocols present in the IEEE 802.15 standard, developed for wireless personal area networks known as WPAN, among the protocols that are part of this standard we have: Bluetooth, ZigBee, 6LOWPAN, WirelessHart and ISA100.11A. In addition to these protocols, such as the WiFi protocol that has been developed for WLAN networks and adopted in IoT, despite the fact that it was not designed for use [30].

The WiFi and Bluetooth Communication have been widely accepted for IoT applications, consolidating themselves in the market and offering low-cost products, allowing the viability for use in IoT.

2.4.3 Data communication protocols

IoT devices require routines for communication between devices under the Machine to Machine (M2M) protocol that allows communication between two or more remote devices [31]. M2M establishes the conditions that allows devices to exchange information with an application through a communication network in such a way that the device or application can function as a base for the exchange of information, for IoT applications the following protocols stand out:

Message Queue Telemetry Transport (MQTT) is a data communication protocol based on publish-subscribe messaging that allows communication between multiple devices managed by a central component called a broker. This protocol uses a star network topology, where all nodes connect directly to the broker. The messages are sent using the Transmission Control Protocol (TCP) [31].

Constrained Application Protocol (CoAP) is a client-server protocol in which the client device can address another device through a CoAP message. The server device interprets the message and decides what action to take based on its programming. Unlike MQTT, CoAP messages are sent via User Datagram Protocol (UDP) [31].

2.5 IoT and its need for photovoltaic system

IoT can solve complex problems that modern science and engineering systems would encounter. When it comes to the photovoltaic system used for power generation, there are many components whose operational behavior varies. To be more precise, the solar intensity varies over time and depends on the weather conditions, so throughout the operation of the system it's impossible to have a constant energy production [32]. This has an indirect impact on the operation of other system components such as the battery state of charge, power converter voltage levels, and energy demands by loads etc. Sometimes, the dust accumulation, and other environmental conditions can leads to poor performance of the photovoltaic system. Therefore, these problems in longer terms results in the failure of the system. Monitoring such failures is difficult for humans because they must visit the plant site frequently and keep a record of operational data. It is quite difficult job when the plant is located in faraway places. As a result, dealing with these problems takes a long time and, in some cases, may not be possible due to lack of sufficient information about the system failure or poor performance [33]. Hence, a continuous monitoring system could be installed alongside the PV system to monitor the system parameters and store them in cloud platform. The stored data will help in understanding its performance and reasons for poor performance. This allows making troubleshooting and maintenance operation when the performance is poor due to some faults. In this way the need for IoT is essential in performance monitoring and optimizing the system parameters with a remote-monotoring option [34].

2.6 IoT architecture for photovoltaic systems

The IoT architecture for photovoltaic systems is divided into three layers:
First layer is the PV system design environment, second layer is the gateway linkage, and third layer is the remote monitoring and control layer. Fig 2.7 clearly shows the IoT architecture for photovoltaic systems.

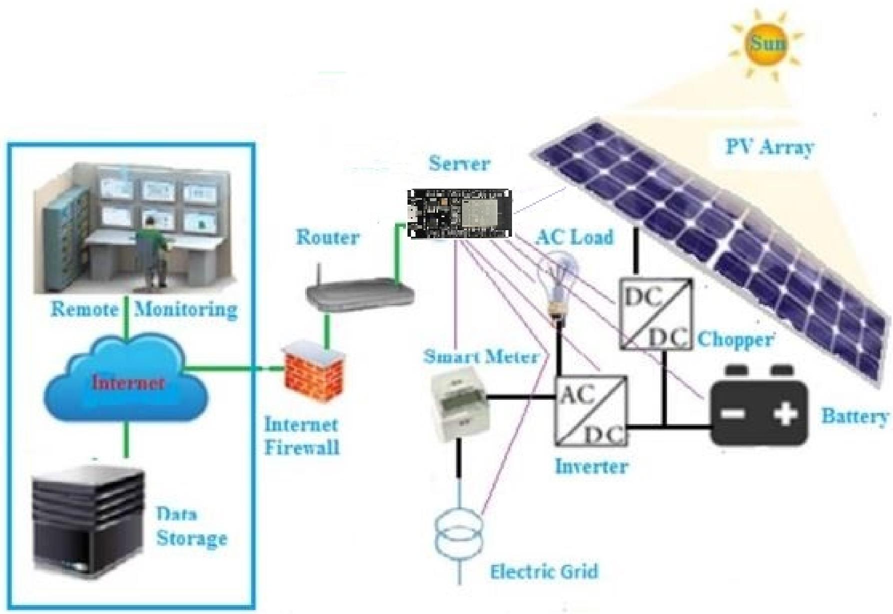


Figure 2.7: IoT architecture for photovoltaic systems [35].

- The first layer includes the PV system design environment, where all of the components were connected according to the required configurations to meet the user's requirements. In this case PV system components are linked to the micro-controller server which is the second layer of the IoT architecture.

- This second layer is defined as gateway linkage that connects the hardware designs of the PV system and the web server through a router. The micro-controller server is the major component that helps in integrating the web server through Ethernet or wireless router module.

- The information from the server will be given to the third layer, which is the remote monitoring and control layer. Here the server will deliver the gathered information regarding the PV system into storage devices from which periodical reports could be generated. The data can also be retrieved in the form of reports or visual graphs using an Android interface with the cloud data through Wireless Fidelity (Wi-Fi) network [34].

Chapter 3

Materials and methods

This chapter provides a detailed description of the entire architecture of the problem in question, the tools and devices used in this work, pointing some characteristics and functionalities about all elements of the system and also the used softwares.

3.1 Problem and proposed solution

Solar photovoltaic systems are installed in various rural areas. Owing to the effect of the surrounding system, variable voltages are issued because they are not adequately monitored and cleaned on a regular basis. With the advancement of IoT technologies, the use of those technologies to monitor the conditions of environments is becoming more and more common. Furthermore, the value that can be extracted from the data collected by IoT devices to make decisions has contributed to its adoption in different scenarios, residential, industrial or urban. It may be useful to monitor the performance of individual components in order to refine and improve the system performance, or be alerted to a loss of performance over time for preventive action.

The proposed IoT solution includes an appropriate and effective data acquisition system for monitoring and collecting operational parameters of the PV system under environmental conditions for a long period in order to assess its performance.

3.2 Proposed system design

The proposed IoT Data acquisition (DAQ) system has been planned for collecting, processing, storing, analyzing data of PV system's variables. The system consists of an ESP32 DEVKITC board, temperature and humidity sensor DHT11, light sensor BH1750, voltage and current sensor INA219. The ESP32 acts as the microcontroller that collects and analyses the data coming from the sensors, then processes and upload it to the cloud database via Wi-Fi using MQTT protocol. The block diagram of the proposed IoT solution is illustrated in Figure 3.1.

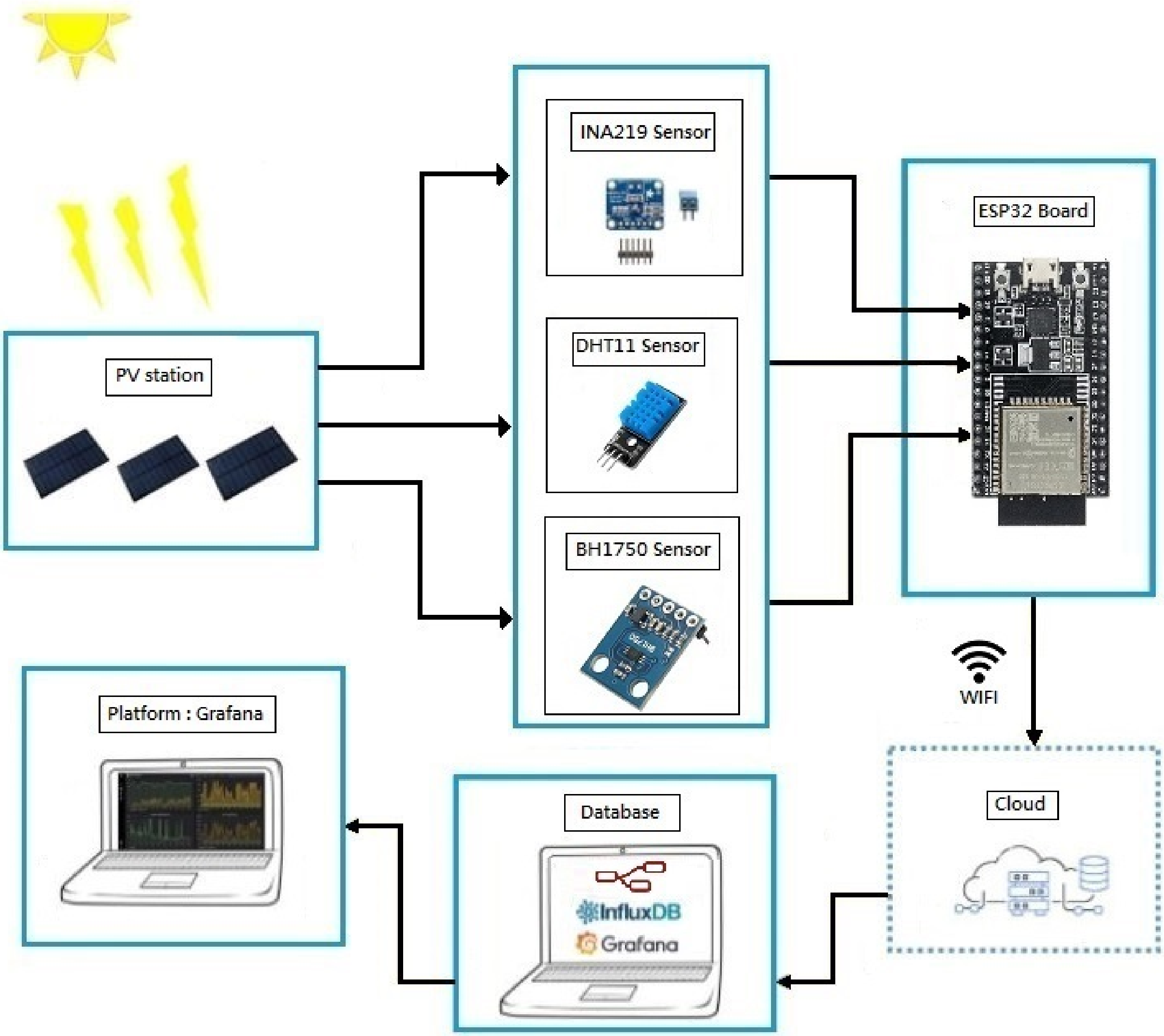


Figure 3.1: Block diagram of the system.

Design Specifications:

- The project is made up of an IoT platform and sensors to measure temperature, humidity, light intensity, electrical voltage ,current and power of the solar panel.
- The energy that powers the microcontroller is from a battery.
- The interconnection of the elements that make up the proposed topology is carried out through WiFi technology in a wireless local area network.
- All items must be connected to the WLAN via the Wi-Fi gateway or access point.
- The measurements are backed up and stored in a database.
- The data communication protocol chosen to manage the messages containing the measurements is the MQTT protocol.
- The registered measurements are managed by the server called Broker MQTT and addressed by the element called Flow Editor that serves as an intermediary between the broker and the database.
- The measurements are saved and stored in a database.

Characteristics of the approach:

- Implementation of the prototype outside the Research Center in Digitization and Intelligent Robotics (CeDRI), for the monitoring of the desired variables: It is essential to present in a coordinated and at the same time in orderly manner a set of tools allowing the monitoring of the variables in a specific region context.
- Development of a system for collecting, visualizing and monitoring the parameters measured by the prototype : provides versatility to the system, as it allows the user to have a history of the data collected and a friendly graphical interface that allows visualizing recorded data in real time.

3.3 Hardware Components

The data acquisition is made by the hardware of the system that is composed by the ESP32 microcontroller and the three sensors which are DHT11, BH1750 and INA219. These sensors were chosen due to the fact that they present a good stability and precision of the measured parameters, in addition to their low cost.

3.3.1 ESP32 Board

ESP32 is a low-cost, low-power Consumption System-Onchip (SOC) microcontroller, with integrated Wi-Fi and dualmode Bluetooth and low power support, all in a single chip. This board is selected because it reduces the cost of the monitoring system and thanks to its high processing performances. ESP32 board is based on Tensilica 32-bit dual-core CPU Xtensa, LX6 Microcontroller [36]. One of its most significant features is that it can be programmed using a variety of opensource platforms and languages. In this project, the Arduino Integrated Development Environment (IDE) was used to develop the code that was uploaded then directly to the board. Fig 3.2 shows the ESP32 DEVKITC board used in this project.

Figure 3.2: ESP32 DEVKITC board [36].

Contrary to the ESP32, many Linux based boards like Raspberry Pi, Beaglebone, etc.

supports Operating Systems (OS), but require an external Analogue-to-Digital Converter (ADC) devices to read analog measurements and also have a higher cost and more energy consumption. Moreover, the ESP32 provides the benefits of low-cost boards such as Arduino that requires extra shields to connect to Wi-Fi. Furthermore, ESP32 supports real-time operating systems (RTOS) like freeRTOS, making it operate optimally the tasks required, it integrates 16 ADC channels of 12 bits and in-built Wi-Fi and other features as shown in table 3.1.

Feature	**Value**
Operating voltage	2.2-3.6V
Digital I/O pins (GPIO)	39
Analog input pins (ADC)	16
Analog outputs pins (DAC)	2
UART	3
SPI	2
I^2C	2
Flash memory	4MB
SRAM	520 KB
Clock speed	240MHz
Wi-Fi	802.11 b/g/n

Table 3.1: ESP32 Specifications.

3.3.2 Photovoltaic System

In this experimental, the photovoltaic system is composed of two PV panels one for the supply and the other for the test, a DC–DC Buck converter, and a Lithium ion battery.

Photovoltaic panels

Photovoltaic panels consist of a number of parallel and series photovoltaic cells that convert the energy of light into DC electricity.

Figure 3.3: PV supply panel.

In this prototype, one mini monocrystalline PV panel for the supply (Fig 3.3) and one mini polycrystalline PV panel (Fig 3.4) for the test were used, the specifications of the two panel are shown in table 3.2 and table 3.3 respectively.

Feature	**Value**
Dimensions	70x55x3mm
Typical voltage	5.5V
Typical current	100mA
Open-circuit voltage	8.2V
Maximum load voltage	6.4V

Table 3.2: PV supply panel Specifications.

Figure 3.4: PV test panel.

Feature	Value
Dimensions	136mmx110mmx5mm
Typical voltage	12V
Typical current	160mA

Table 3.3: PV test panel Specifications.

DC-DC converter

To get the maximum of energy produced by the panel and reduce the power losses, a phase of adaptation is required. therefore, a dc–dc converter is placed between the PV generator and the battery. The LM2596 DC-DC (Fig 3.5) is a buck switching converter that transform a greater input voltage into a stabilized lower output voltage, it's a power module features a high-precision potentiometer and is capable of driving a load up to 3A with great efficiency. It can be used with the ESP32, as well as other boards and basic modules [37].

Figure 3.5: DC-DC buck converter.

Regulator TP4056

For the battery charging, TP4056 (Fig 3.6) is the best choice in this case, while it's cheap, less power consumer and short circuit protected.

Feature	Value
Voltage Supply	4V to 8V
Charging current	130mA to 1A
Full charging voltage	4.2V

Table 3.4: TP4056 Specifications.

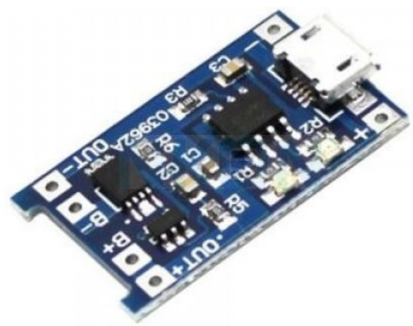


Figure 3.6: Regulator TP4056.

Lithium battery

Lithium batteries feature a metallic lithium anode and are used as primary batteries. Lithium-metal batteries are another name for these types of batteries. Their high charge density and expensive cost per unit set them apart from other batteries.

Figure 3.7: Lithium battery.

This type of battery has an overload protection circuit, an overcurrent detection at the battery output level to prevent short circuit, an excessive discharge protection to prevent battery destruction. The specifications of the used battery are shown in table 3.5.

Feature	Value
Dimensions	70x55x3mm
Typical voltage	3.6V
Capacity	1500mAh

Table 3.5: Battery specifications.

3.3.3 INA219 sensor

The INA219 sensor (Fig 3.8) is a power and current sensor, it monitors both shunt voltage drop and bus supply voltage with filtering and a programmable digital conversion. This

Figure 3.8: INA219.

chip can handle high side current measuring, up to +26V DC, even though it is powered with 3 or 5V. It will also report that high side voltage, which is great for tracking battery life or solar panels. It has an I2C bus, that features 16 programmable addresses to retrieve measurements [38]. The main specifications of the INA219 are shown in table 3.6.

Feature	Value
Power supply	3-5V
Input range voltage	0V to 26V
Input range current	-3.2A to 3.2A
Frequency	2,56 MHz
Resolution (ADC)	12 bit
I2C Addresses	0x40 to 0x4F

Table 3.6: INA219 Specifications [38].

3.3.4 BH1750

BH1750 is a digital ambient light sensor integrated circuit with digital output in Lux (Lx), and it's considered as a lux meter that gives a wide range of light intensity measurement with high resolution from 1 to 65535 lux [39]. This sensor sends the measured data to the

Figure 3.9: BH1750.

ESP32 via the I2C communication protocol and consumes a very low amount of current. Table 3.7 shows the features of the BH1750 sensor.

Feature	Value
Power supply	2.4-3.6 V
Current consumption	0.12 mA
Measuring Rang	1 to 65535 lux
Accuracy	±20%

Table 3.7: BH1750 Features [39].

3.3.5 DHT11

The DHT11 is a sensor with digital signal calibration that is able to provide temperature and humidity information. This sensor is classified as a component that has a very good level of stability and is widely used in embedded projects, it incorporates a thermistor that measures the temperature and is calibrated using another reliable thermometer, to ensure measurement accuracy [40].

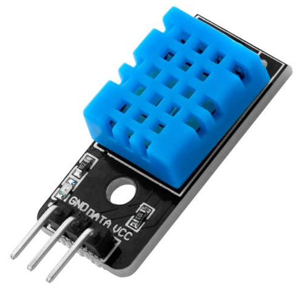


Figure 3.10: DHT11.

3.4 Softwares components

In this section a presentation of the used softwares will be addressed.

3.4.1 MQTT

MQTT is an open source “machine to machine” (M2M) protocol widely used in IoT due to its simplicity based on TCP/IP, useful for applications where small amounts of information are sent [41]. The operation of this protocol is based on a publish-subscribe messaging service, based on publisher and subscriber communicated through a central server called broker, transmitting information through a payload chain with a hierarchical tree structure, similar to a directory of folders and at the same time to define well the specifications of the message. The parties involved in this process are:

Broker: Central server that distributes and filters information according to a topic. Since the person who publishes the information does not need to know anything about the node that will receive it, furthermore, although the communication of information is usually in real time, the broker has the ability to store messages for clients that are not available at any time.

Topic: Name of the message that serves as your identifier and where customers will subscribe.

Publisher: Client that sends information to the broker to distribute it to clients who subscribe to it.

Subscriber: Customers who subscribe to a topic and will receive information about it from the broker.

Client: The client can be a publisher and a subscriber, receiving information from the medium or performing some interaction function.

The process is divided into four steps which are connection, authentication, communication and termination. The client initiates a connection with the broker, by default on port 1883, and sends it a message for the connection that is serviced by the latter. Once the connection is established, the client publishes messages with the topic and payload, which represent the topic and information. On the other hand, the subscriber must also connect with the broker and subscribe to the topic they want to receive.

3.4.2 Node-RED

Node-RED is a software used as a programming and data visualization tool. Open software and based on flows that was developed for hardware, API and online services integration for IoT applications. Originally developed by IBM Corporation, but now part of the JS Foundation Invented in the 70's by J. Paul Morrison, it is a flow-based programming tool, with a network of "nodes", where each node has its well-defined functionality. The network is responsible for the flow of data between nodes. Node-RED provides a browser-based editor, with a wide range of nodes in the palette and flows being implemented with a single click. Java Script functions can be created in the editor using a rich text editor [42].

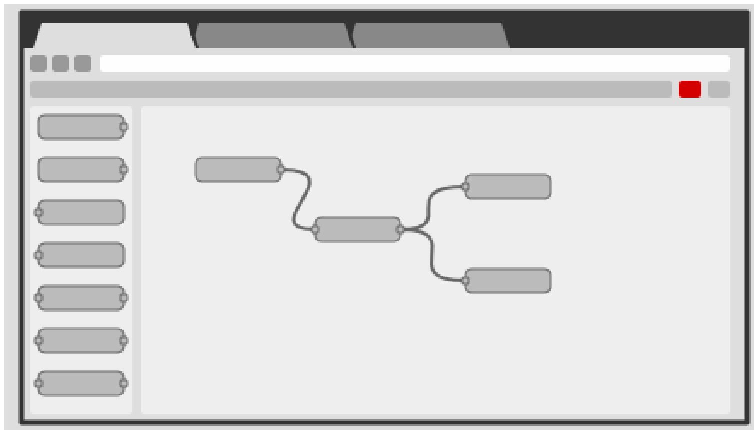


Figure 3.11: Node-Red Screen Illustration [42].

3.4.3 InfluxDB

Another fundamental software for the infrastructure of a supervision and control system is the database service. The database configured in this work was InfluxDB which, in addition to being an open source software, is a time series database, which means that it stores information with a date and time stamp produced by the sensors. Fundamental requirement for monitoring and future analysis of photovoltaic variables [43].

Figure 3.12: InfluxDB [44].

3.4.4 Grafana

Grafana is an open source platform for monitoring and visualization of data, delivered with a web server allowing access from anyplace. This platform generates its graphs and dashboards from different time series databases like InfluxDB, Graphite and OpenTSDB and also it’s a fundamental tool for creating alerts and has a full HTTP API, that makes it more effective [45].

Figure 3.13: Grafana [46].

3.5 Monitoring system description

The proposed strategy for the monitoring is described in Figure 3.14, according to the following process:

1. In the protoype, the PV parameters will be measured by the ESP32 and sends this parameters in a message to the "MQTT Broker" through the gateway (wireless communication medium).

2. The broker manages the messages sent by the prototype and publishes them.

3. The messages published by the broker are collected by the “Flow Editor” and sent to the “Database”.

4. Finally, the messages stored in the database can be viewed and analyzed in the element called "visualization".

The prototype will remain on the rooftop of the CeDRI laboratory in adequate environmental conditions, so the PV parameters registered need to be stored in a server

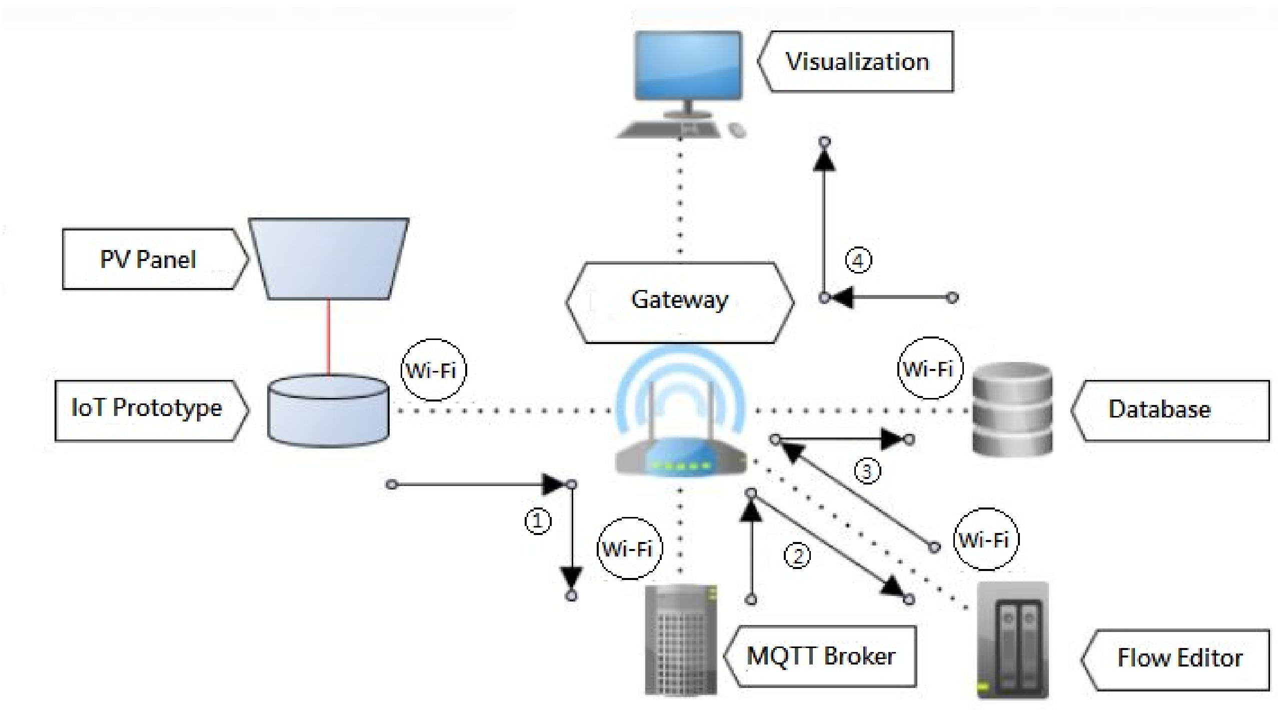


Figure 3.14: Monitoring strategy.

external to the device, this leads to the measurements being sent to a database, For this, a time series database will be used, free and open source software called InfluxDB, where the measurements will be stored and safeguarded for later use. The interconnection of the prototype with the database, is done through WiFi communication technology, The data communication protocol used to communicate the measurements of the prototype to the database is the MQTT protocol, specifically a star-type MQTT architecture has been used whose central element is the broker, this is implemented through the pub/sub model where the ESP32 publish the parameters to a topic to send messages to the MQTT broker. The flow of messages will be collected and sent to the database using the visual development tool called Node-RED (free and open source software). Finally, to view the measurements stored in the database, we have chosen to use free software called Grafana.

Chapter 4

Implementation

In this chapter, the place where the prototype will be put into operation is described, the process of implementing a solution for an IoT prototype is addressed, as well as the softwares components implementation.

4.1 Site Description

The project is implemented outside the Research and Innovation Laboratory (L2I) of the Research Center in Digitalization and Intelligent Robotics (CeDRI), of the Higher School of Technology and Management (ESTiG) of the Polytechnic Institute of Bragança (IPB). ESTiG has an infrastructure for the correct development of these devices, since it has wireless means of communication, as well as servers for the management and processing of data in real time. The emplacement identified in figure 4.1, is located on the ground floor of the ESTIG. The building has a flat roof without obstacles, in addition to an open field in the surroundings, this allows arrange an optimal location for the prototype, since there are no obstacles that prevent the capture of solar energy.

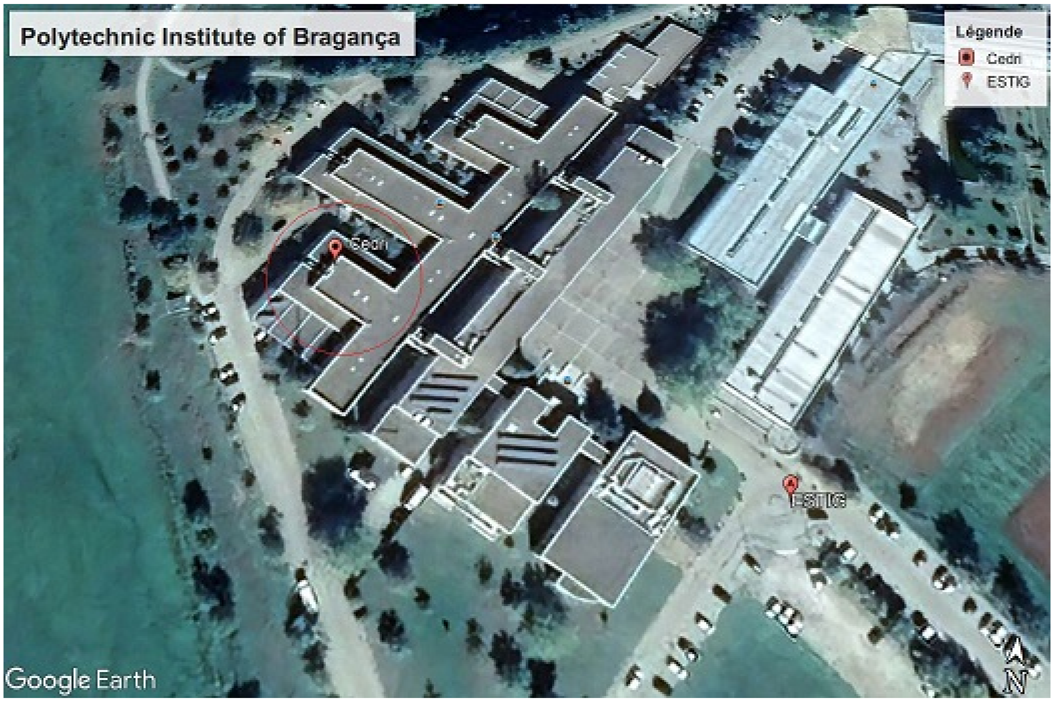


Figure 4.1: Higher School of Technology and Management (ESTiG) [47].

4.2 Prototype Implementation

This section describes how the implementation of the IoT prototype was carried out to measure the PV parameters, including the electrical circuit.

4.2.1 DHT11

For the ambient temperature and humidity monitoring, the DHT11 sensor was used, capable of taking readings between 0°C and 50°C with an accuracy of ±2°C, digital output signal and operating voltage 3 to 5V DC.

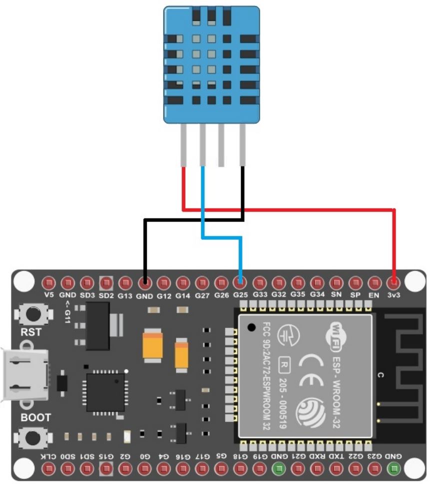


Figure 4.2: Connection between ESP32 and DHT11.

Figure 4.2 shows the connection between ESP32 and DHT11 where the Vcc pin is connected to 3.3V of the ESP32 board, the ground pin is connected to the ESP32 ground and the analog pin of the DHT11 is connected to the GPIO25 of the ESP32.

4.2.2 INA219 and BH150

The Communication between the ESP32, the BH1750, and the INA219 sensors is done through the two communication lines (Serial Data Line (SDA) and Serial Clock Line (SCL)) of the I^2C bus. The ESP32 represents the master unit in communication, which contains the routines for reading the measurements offered by the sensors, while the BH1750 and the INA219 digital sensors connected to the I^2C bus are slave units, which are identified with a 7-bit address that identifies them so that there can be an understanding between the devices, the INA219 sensor was assigned the address 0x40, the BH1750 sensor was assigned the address 0x23, Figure 4.3 shows the topology of the I^2C bus for the connection of the ESP32 with the BH1750, and the INA219 sensors.

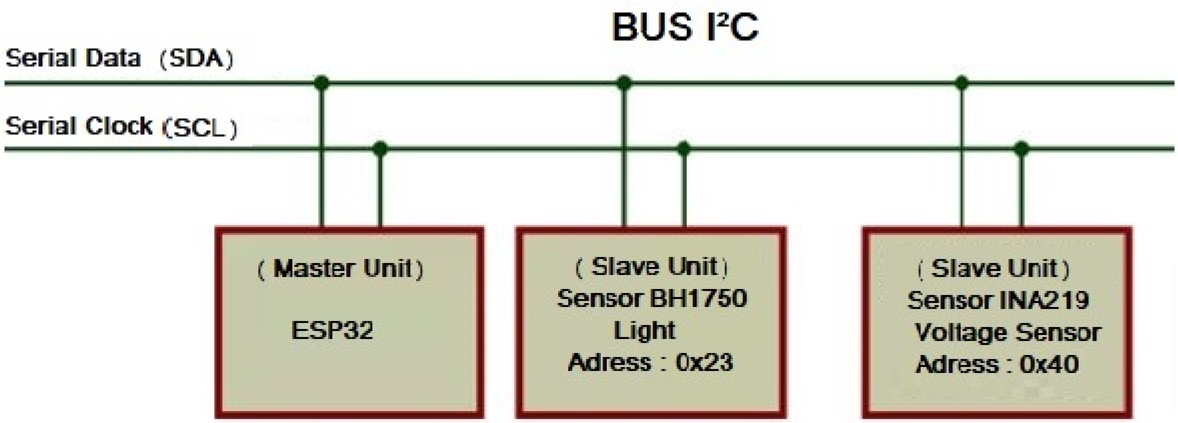


Figure 4.3: I^2C topology.

For data communication, the GPIO22 pin have been used as a serial clock line and the GPIO21 pin as a serial data line of the ESP32, these lines are connected to a positive source through the internal pull-up resistors of the ESP32.

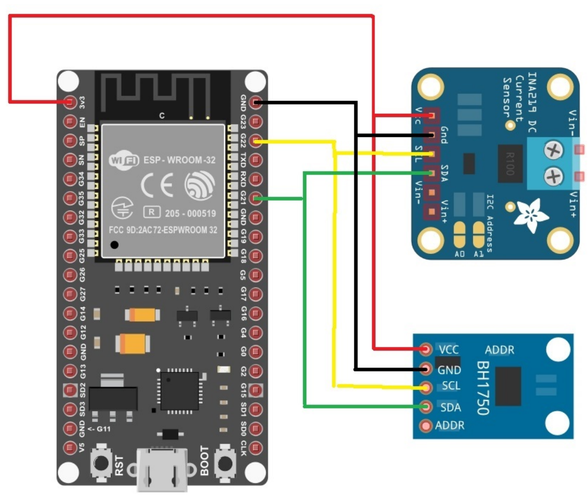


Figure 4.4: Connection between INA219, BH170 and ESP32.

4.2.3 The load

To read the current value generated by the PV panel, a 60 Ω resistor with 20 W rated power, that can support the panel test, was chosen as a load, which give more resolution to the current and power readings that makes it suitable for having the desired results.

4.2.4 Electrical circuit

To power the ESP32 board, a PV panel with a peak power of 0.5 W and 5 V output will charge a 3.7-4 V lithium battery. As the ESP32 requires 5 V to power up, the output of the TP4056 will be connected to a 0.9-5 V DC-DC step-up Booster circuit to boost the voltage to 5 V. Figure 4.5 shows the final implementation of the electrical circuit.

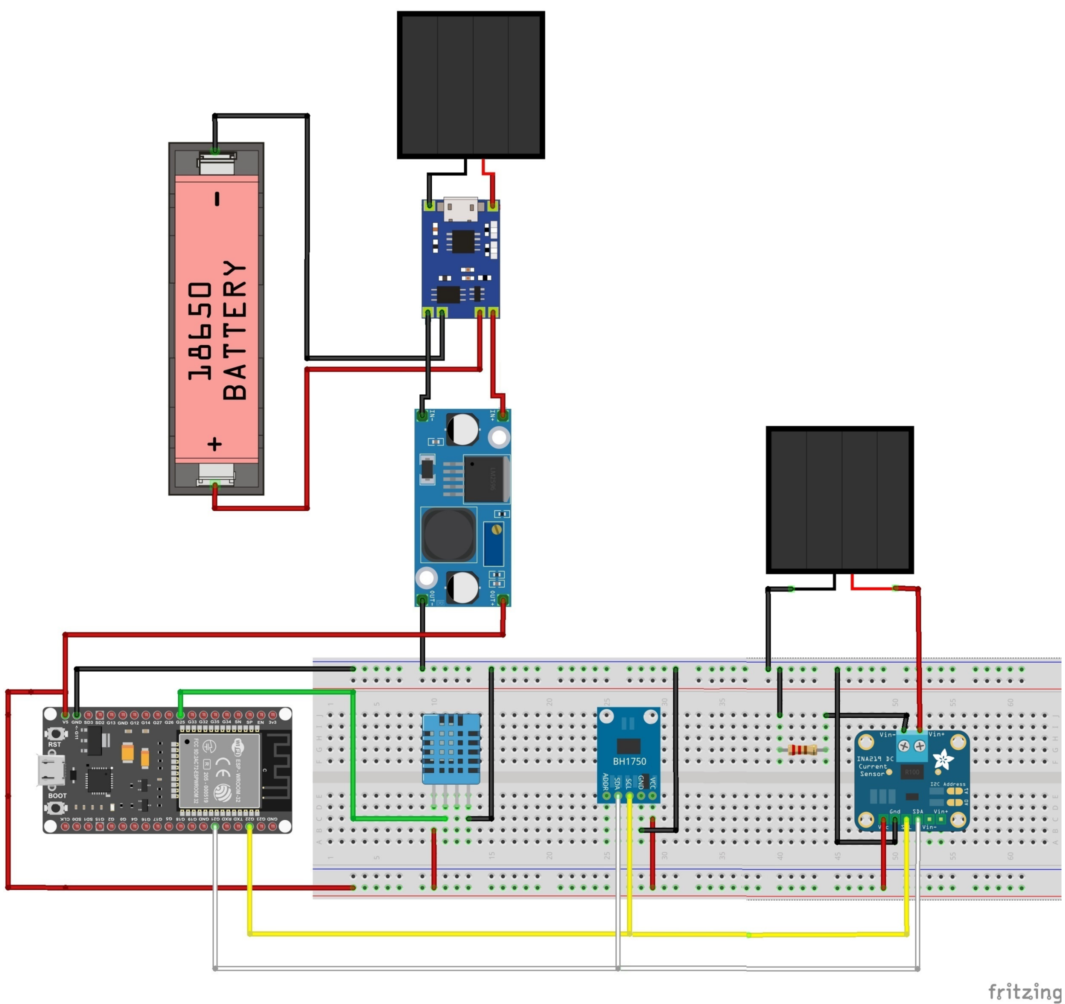


Figure 4.5: Implementation of the electrical circuit.

4.3 Implementation of the monitoring system

For the development of the monitoring system, a series of softwares are used that fulfill the function of database, flow editor, MQTT Broker and visualizer, these elements are implemented in a computer (server) with an operating system Windows running the different softwares in parallel. Figure 4.6 shows the connection topology of the monitoring system.

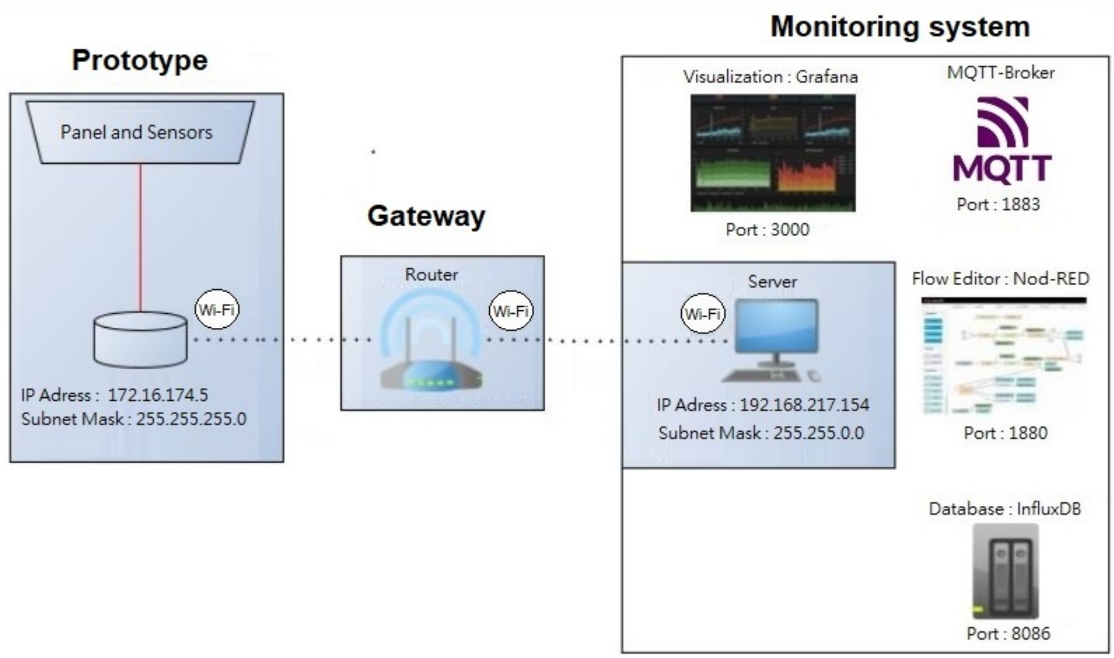


Figure 4.6: Connection topology of the monitoring system.

The transfer of data from the prototype to the monitoring system is done through the gateway router, then the data are stored in the database influxDB using MQTT protocol through Node-RED platform. Then, stored data are sent to Grafana to be visualized.

4.3.1 Implementation of the MQTT Broker

The figure 4.7 shows the the flowchart of the Arduino IDE code develop to receive the data read by the sensors and send to MQTT topic. As shown in chart, the algorithm start to initialise some parameters, to import the libraries of the ESP32 and the sensors, to set pins that will receive the data of each sensor, and to configure the Wi-Fi and also the MQTT. Then the loop starts checking if WiFi and MQTT client are connected, if not, it will call the respective functions to reconnect. Finally, for all the parameters measured a MQTT topic on Node-RED will receive the information. The default software port setting is 1883.

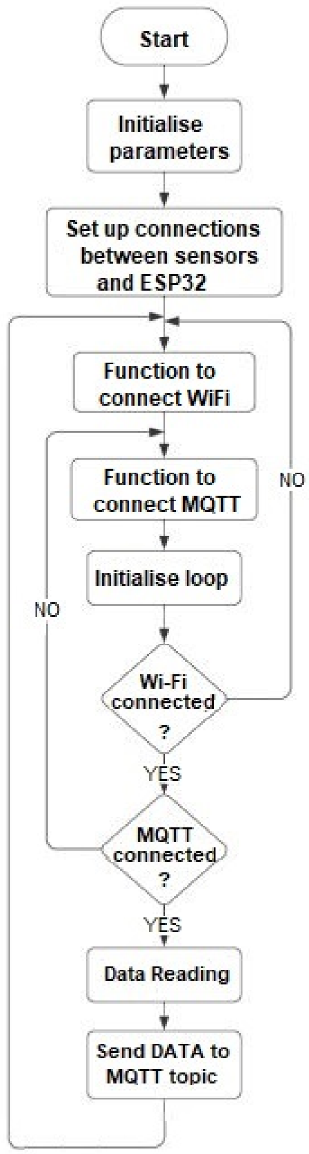


Figure 4.7: Flow chart of the algorithm developed in the Arduino IDE.

4.3.2 Implementation of the Node-RED

This has been done to interface the MQTT Broker with the database. The implementation of this tool was carried out by installing the Node-RED software [48]. After execution, the workspace was defined in three blocks as shown in figure 4.8.

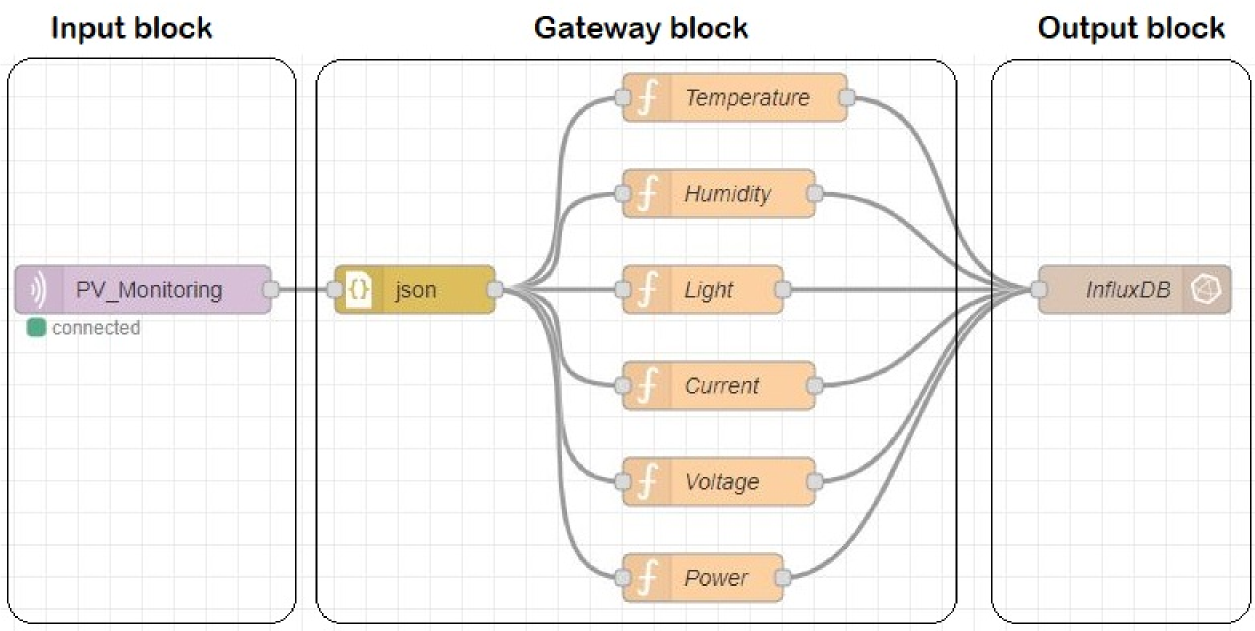


Figure 4.8: Nod-RED implementation.

Input block: this block is responsible for receiving the measurements recorded by the sensors, this was done using the "MQTT in" module, which subscribes to the topic where the recorded measurements are published.

Gateway block: it is a "function" modules that contains functions to extract and divide the measurements received by the input block corresponding to each measurement.

Output block: Finally, after the measurements of each parameter are obtained, they are sent to the database through the "influxdb out" module, for which the name of the database is defined, where the measurements will be stored.

4.3.3 Implementation of the influxDB

The database was implemented on the server, for this the installation of InfluxDB software [49] was carried out and put into operation using the following command :

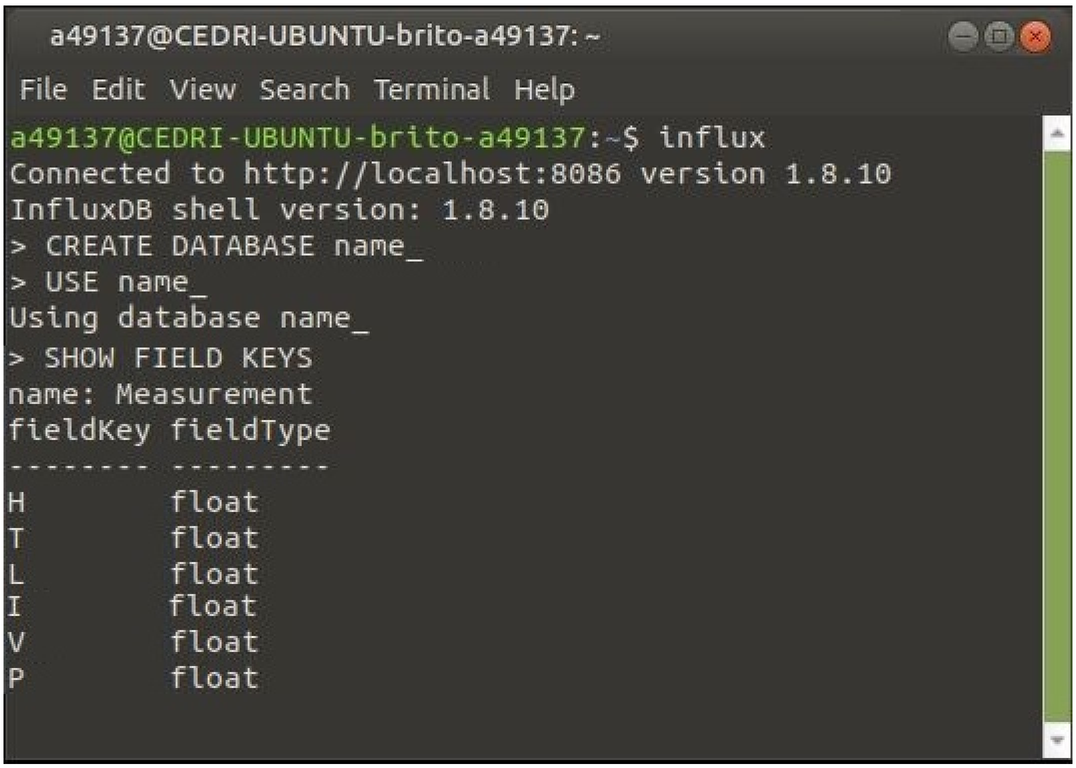


Figure 4.9: InfluxDB implementation.

- **INFLUXD**: For starting influxDB.
- **INFLUX**: For connecting to InfluxDB.
- **CREATE DATABASE**: For creating the name of the database.
- **USE**: For selecting the database .
- **SHOW FIELD KEYS**: For returning the different measurements and the type of their values.

The transmission of the data to the InfluxDB database is essential for enabling the final step of the use case that consists of creating a professional dashboard for data analytics.

4.3.4 Implementation of the Grafana

To visualize the obtained measurements stored in influxDB in real time, a visual development tool called grafana (free software) was used, which is installed on the server [50]. By default the software is configured on port 3000, access to grafana is achieved with a web browser through the network address and port ”http://192.168.217.154:3000”. When accessing the graphical interface, the data source of the InfluxDB database was configured. The interface created for the purpose of this project is made up of graphs that vary over time according to each measurement variable, and of panels that indicate the current value of the parameters as shown in figure 4.10.

Figure 4.10: Grafana implementation.

Chapter 5

Results and Discussion

This chapter presents the tests performed with the selected hardware and software components, the results obtained during the development of the project, and an analyze of the relation between obtained measurements.

5.1 Final Prototype

After the code implemented in the ESP32 was working correctly, and the electrical schematic of the entire circuit was designed in Fritzing, the final prototype was realized. Figure 5.1 presents the final result of the prototype placed at the rooftop of the Cedri laboratory, and that includes the ESP32, panels and sensors that make up the data acquisition stage of the system.

Figure 5.1: Final prototype.

5.2 MQTT test

For this test, it was verified that the the operation of the MQTT broker is successful and the ESP32 sent the message with the measurements correctly. The first test was performed through the serial monitor console, where according to programming of the ESP32 it must print the data on the serial port. In figure 5.2, we can observe the operation of the DHT11, BH1750, and INA219 sensors, where the measured parameters are satisfactorily shown.

After that the Broker's operation was tested, for this the MQTTlens software was used that allows to subscribe to the topic and thus verify if the messages are accepted and disseminated by the Broker. Figure 5.3 shows how the messages are received by the MQTTlens application [51], which allows us to infer that the broker is running.

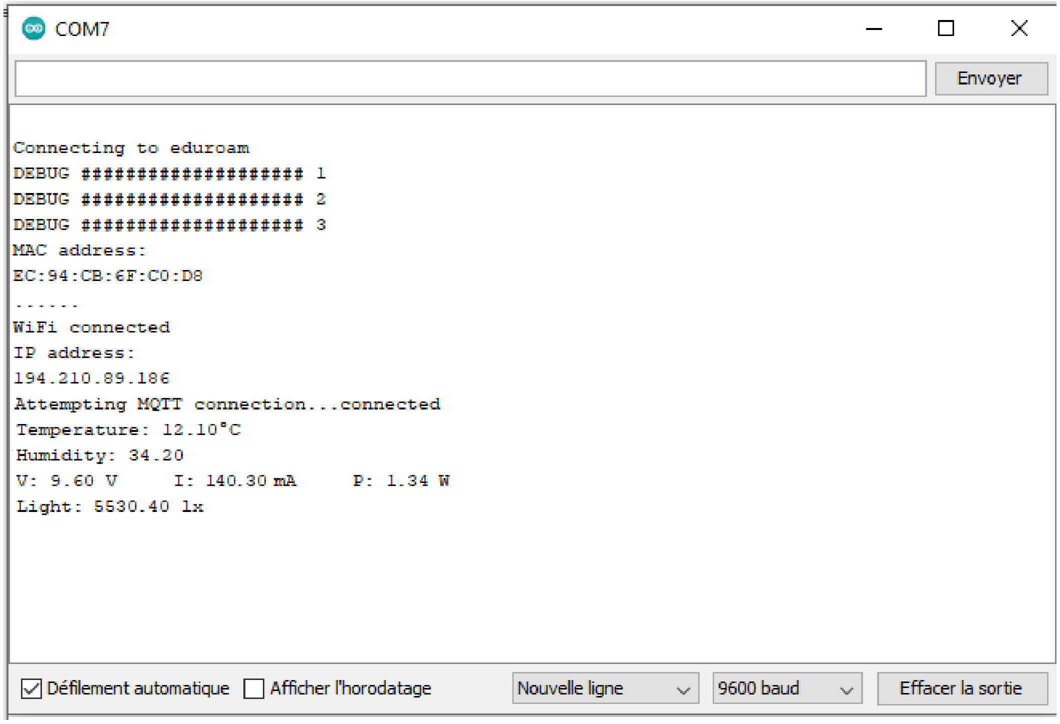


Figure 5.2: Test results of the DHT11, BH1750, and INA219 sensors.

Figure 5.3: Results of the subscription to the “PV_monitoring” topic.

5.3 Flow editor test

To verify the operation and the correct implementation of the Nod-RED flow editor, a module called debug available in the Node-RED interface was used, as shown in figure 5.4, which allows verifying the information received in each implemented block.

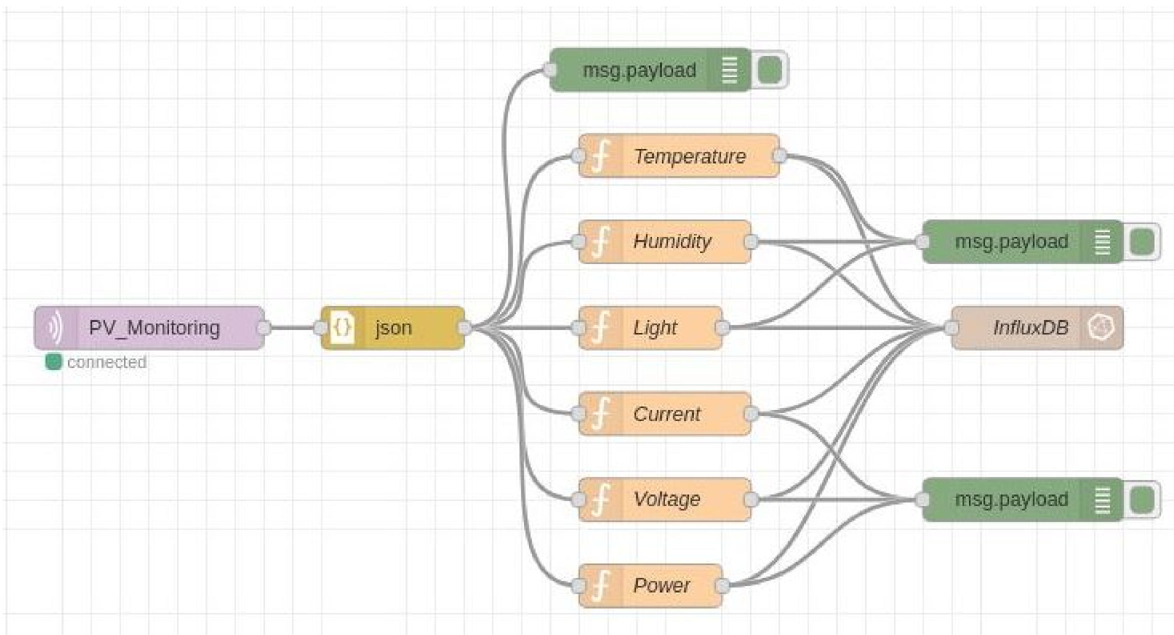


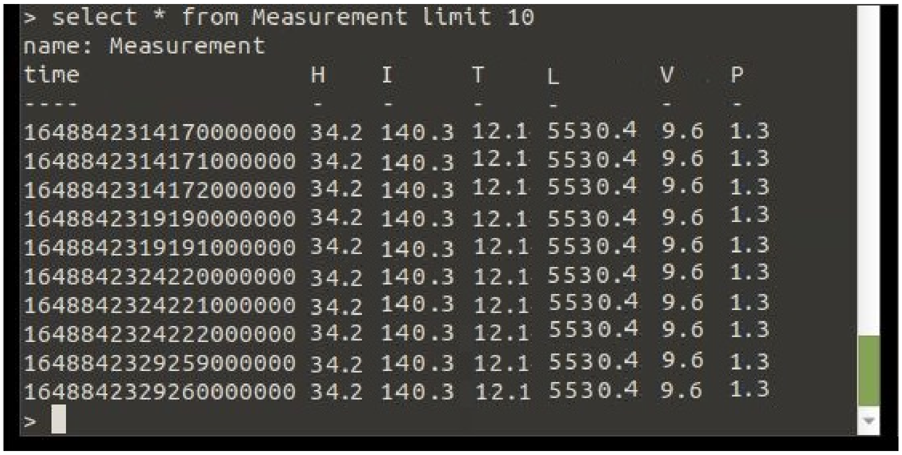
Figure 5.4: Test implementation of the flow editor.

In figure 5.5 we can see the information that is received in each block of the workspace, the first value received corresponds to the MQTT message (issued by the ESP32) and the following values correspond to the values extracted from the input block that correspond to each measured parameter.

Figure 5.5: Results obtained from the debug.

5.4 Database test

The database operation test consists of verifying that the data is received and stored in the database, for which the database software was invoked and the commands shown in figure 5.6 were executed to verify that the variables of the measurements are created satisfactorily within the "InfluxDB" database and that within the variables contains the measurements recorded by the different sensors. In figure 5.6, we can see that the set of variables that store the measurements corresponding to the measured parameters are correctly stored in the database.



```
> select * from Measurement limit 10
name: Measurement
time                H    I     T    L      V   P
----                -    -     -    -      -   -
1648842314170000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842314171000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842314172000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842319190000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842319191000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842324220000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842324221000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842324222000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842329259000000 34.2 140.3 12.1 5530.4 9.6 1.3
1648842329260000000 34.2 140.3 12.1 5530.4 9.6 1.3
>
```

Figure 5.6: Database performance test.

5.5 Visualization system tests

Figure 5.7 shows the developed graphical interface, where we can see the correct implementation. The graphical interface presents a set of displayed graphs that contain the history of the parameters over time, as well as panels that indicate the current value of the parameters.

Figure 5.7: Graphical interface developed for monitoring.

5.6 Comparison of PV Panel performance monitoring

In this section a comparison of the performance of PV panel based on the Grafana platform and on manually recorded data (multimeter) at the rooftop of CeDRI from 03:00 pm to 06:30 pm, is done, the result is recorded every 30 minutes. The objective is to collect the data manually from PV panel and from Grafana platform which monitor the performance of PV panel regularly through Internet of Thing (IoT) concept in order to evaluate the data of the PV panel such as voltage, current, and power.

Time	Platform Reading			Data Manually Reading		
(Hours)	Voltage (V)	Current (mA)	Power (P)	Voltage (V)	Current (mA)	Power (P)
3.00 pm	8.85	135.1	1.19	8.97	135.3	1.21
3.30 pm	8.30	127	1.05	8.43	128.3	1.08
4.00 pm	8.34	127.3	1.061	8.46	128.6	1.08
4.30 pm	6.98	113.5	0.792	7.02	115.2	0.80
5.00 pm	6.13	100.4	0.615	6.26	101.4	0.63
5.30 pm	5.26	86.8	0.456	5.43	87.2	0.47
6.00 pm	3.44	59.5	0.204	3.56	60.7	0.21
6.30 pm	1.81	33.4	0.06	1.93	34.7	0.07

Table 5.1: Comparison of data manually reading and platform reading.

By using this equation :

$$\frac{|\text{ Platform Reading - Data Manually Reading}|}{|\text{ Data Manually Reading }|} \times 100\% \tag{5.1}$$

and based on the results from table 5.1, the difference between manually recorded data and the platform recorded data shows an error of 1.5% from the voltage reading, an error of 2% from the current reading, and an error of 1.75% from the power reading, that is explained because of the possibility of instruments error when taking an inaccurate reading. Around 98% of results displayed on the dashboard matched with those using millimeters. Therefore, the IoT approach presents a good solution for this project.

5.7 Data analysis

The analyze scenario represents the variation in the characteristics of the solar panel, according to changes in light intensity conditions and ambient temperature over a period of 24 h. Those measurements are used as real data recorded over 24 h as shown in Figure 5.8.

Figure 5.8: Test results.

It can be seen from the results, a consistent variation in light intensity and ambient temperature which begins to increase when the sun appears at the horizon, then reaches their maximum values at midday with 54613 lux for light intensity and around 38°C for ambient temperature, then the two variables begin to decrease in the second part of the day to reach 18°C for temperature and 250 lux for light . Also, it's obvious that with the change of light intensity, the output voltage and current of the solar panel change, the increase of light intensity from 250 lux to 54613 lux, results an increase in the current output of the PV panel from 3 mA to more than 120 mA and when the light intensity reaches the maximum, the output voltage of the PV panel reaches 8 V, and the power remains fluctuating at about 1 W.

A threshold in red line is implemented on the PV power histogram (0.7 W as an example in this case), makes the operator able to be alerted whenever the output power is below this line (a fault occurrence), this event shows the reliability of this IoT monitoring system as it makes the PV system under control over time to do the intervention or the maintenance when it requires in order to maintain the PV system in safe state and high working performances. It can be seen also from figure 5.8 that from 11:50 am to 01:45 pm there is a drop in light intensity due to a presence of some clouds that causes a shading state. This drop has led to a descent in the output power and its value has fallen below the predefined threshold, in this case an alert notification is displayed in the dashboard.

5.8 Data correlation

In order to to assess the effect of individual variation in light intensity and ambient temperature on the power generated by the solar panel, a correlation study is performed for this purpose. Correlation study is a method used to evaluate the linear relationship between different variables. The Figure 5.9 shows the correlation matrix of power, light intensity, ambient temperature and humidity, made with Matlab software.

According to reference [52] a correlation coefficient table will be used for the evaluation of the correlation matrix.

Correlation coefficient	**Indication**
±0.90 to ±1.00	Very high correlation
±0.70 to ±0.90	High correlation
±0.50 to ±0.70	Moderate correlation
±0.30 to ±0.50	Low Correlation
±0.00 to ±0.30	Negligible correlation

Table 5.2: Correlation coefficient table [52].

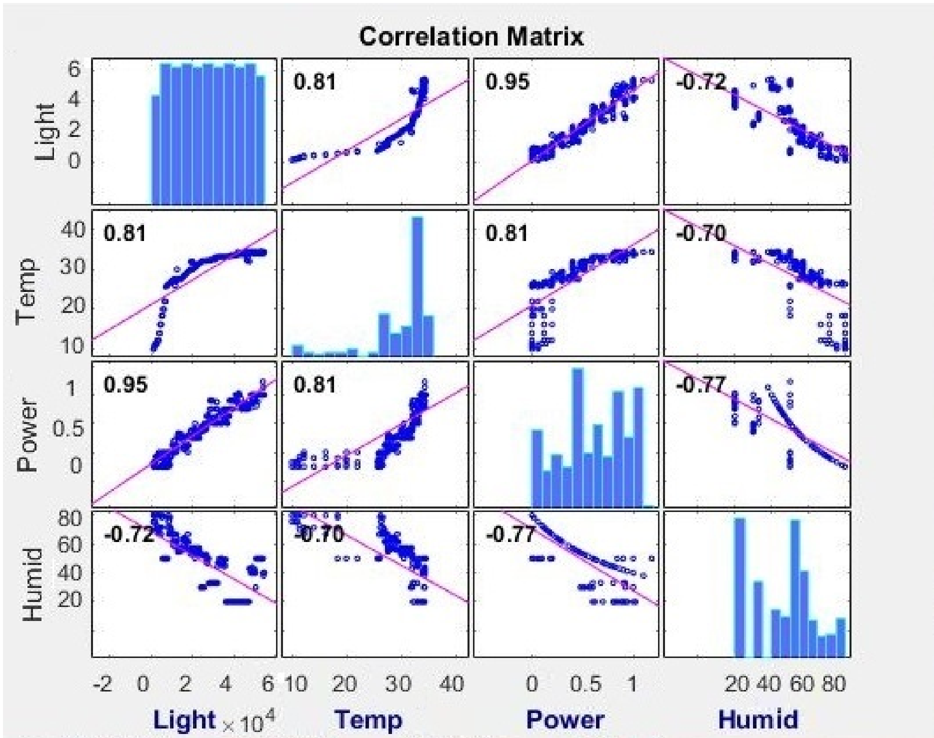


Figure 5.9: Correlation between measurements.

5.8.1 Effects of light intensity on the PV power

PV panel generates the maximum amount of electricity when the light intensity is high. Therefore, the power generated has a strong relationship with the light intensity. Figure 5.9 shows that the correlation coefficient between those two measurements is 0.95, which indicates a very high degree of association between them. It can be seen that the light intensity has a huge impact on the power generation performance of the solar photovoltaic cells, and the lower the light intensity is, the less the power generation capacity is.

5.8.2 Effects of ambient temperature on the PV power

Considering that ambient temperature surrounding region where PV panel is mounted have a directly influence on the PV power output. Figure 5.9 shows that the correlation coefficient between the two measurements is 0.81, which confirms that a high correlation exists between ambient temperature and output power. It can be concluded that an increase in ambient temperature increases the generation of electron-hole pair in the solar cell which thus results an increase in the mobility within the p-n junction leading to a larger photo-current. The application of photovoltaic technology in the conversion of solar energy to electricity is favorable during high ambient temperature period than low ambient temperature period.

5.8.3 Effects of humidity on the PV power

Also, Figure 5.9 shows a negative correlation between the output power and the humidity with a coefficient of -0.7, the output power decreases linearly with the increase in relative humidity. This occurring due to the reduction of output current and voltage with increase in humidity in the environment. Humidity in the atmosphere provides a diffraction path for incoming sunlight, this can be explained by the creation of water vapor particles which reduces the amount of insolation so that the light hitting the water droplets is diffused by reflection. This may affect the performance of PV panels which are constantly operating in high humid zone areas.

Chapter 6

Conclusions

This work carried out the development and implementation of an IoT solution for monitoring the electrical and environmental parameters of photovoltaic system. The implementation process started with the choice of a set of low-cost sensors making up a prototype capable of measuring the main parameters responsible for the monitoring, such as ambient temperature, humidity, light intensity, voltage, current and power. Then, the data were stored in an InfluxDB database, going through a process where they were first sent to NodeRED through the MQTT communication protocol over Wi-Fi and later forwarded to the database with the help of tools provided by NodeRED. The data were stored for a period where they were constantly monitored through Grafana. From the gathered data, an analyze of the relation between the ambient temperature, light intensity, humidity and the power output of the system was done using the correlation method, in order to see the effects of those measurements on the photovoltaic system performance. In conclusion, the work exposed a good solution for real time remote monitoring that can facilitate preventive maintenance and also give a historical analysis.

6.1 Future works

The prototype achieved has a system for collecting, displaying and monitoring the parameters measured by the used sensors. It is recommended for future work to:

- Include solar irradiance sensors to get the irradiance values instead of light intensity values. The idea of using this type of sensors was still in mind for this work, however it was not possible due to logistic problems.
- Evaluate in greater detail the components available on the market in order to seek better alternatives in terms of quality, cost and efficiency.
- Test and compare the pros and cons of protocols other than those used for communication (WiFi) and data transmission (MQTT).
- Monitor large-scale photovoltaic systems.
- Develop an application to make the monitoring and control of the system more practical and accessible.

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Appendix A

Appendices

```
#include <Wire.h>
#include "Adafruit_INA219.h"
#include "esp_wpa2.h"
#include <WiFi.h>
#include <PubSubClient.h>
#include <BH1750.h>
#include <ArduinoJson.h>
#include "DHT.h"
#define DHTPIN 25
#define DHTTYPE DHT11
BH1750 lightMeter(0x23);
Adafruit_INA219 ina219;
// The default address is 0x40, if jumpers A0 and A1 are open
//Adafruit_INA219 ina219 (0x41);  // if jumper A0 is connected
// Adafruit_INA219 ina219 (0x44); // if jumper A1 is connected
//Adafruit_INA219 ina219 (0x45);
//if jumper A0 and A1 is connected
DHT dht(DHTPIN, DHTTYPE);
```

```
#define MQTT_PUB_BUFFER
char JSONmessageBuffer [100] ;
WiFiClient espClient;
//////////////////////////////////
PubSubClient client(espClient);
//////////////////////////////////

void reconnectmqttserver() {

while (!client.connected()) {

Serial.print("Attempting MQTT connection...");

String clientId = "ESP32Client-";

clientId += String(random(0xffff), HEX);

if (client.connect(clientId.c_str())) {

Serial.println("connected");

} else {

Serial.print("failed, rc=");

Serial.print(client.state());

Serial.println(" try again in 5 seconds");
```

```
delay(5000);

}

}

}

char temp[50];

char hum[50];

char lux_[50];

char V_[50];

char A_[50];

char P_[50];
///////////////////////////////////////////
const char* ssid = "eduroam"; // your ssid
//#define EAP_ID "a49137@alunos.ipb.pt"
#define EAP_USERNAME "a49137@alunos.ipb.pt"
#define EAP_PASSWORD "********"
void setup(void)
{ Wire.begin();

Serial.begin(9600);
```

```
dht.begin();
ina219.begin();
lightMeter.begin();
//By default, the calibration is at (32V, 2A).

//If you want precise current readings, use settings of 32V, 1A
//ina219.setCalibration_32V_1A ();

// If you want more precision, use the 16V, 400mA settings
ina219.setCalibration_16V_400mA();

Serial.println();

Serial.print("Connecting to ");

Serial.println(ssid);

// WPA2 enterprise magic starts here

WiFi.disconnect(true);

WiFi.mode(WIFI_STA);
// NOTE - besides the examples this line was necessary
//in order to work... and avoid reboot

//Serial.println("DEBUG ##################### 0");

//esp_wifi_sta_wpa2_ent_set_identity((uint8_t *)
//EAP_ID, strlen(EAP_ID));
```

```
Serial.println("DEBUG ##################### 1");

esp_wifi_sta_wpa2_ent_set_username((uint8_t *)EAP_USERNAME,
//strlen(EAP_USERNAME));

Serial.println("DEBUG ##################### 2");

esp_wifi_sta_wpa2_ent_set_password((uint8_t *)EAP_PASSWORD,

//strlen(EAP_PASSWORD));

Serial.println("DEBUG ##################### 3");

esp_wifi_sta_wpa2_ent_enable();

// WPA2 enterprise magic ends here

Serial.println("MAC address: ");

Serial.println(WiFi.macAddress());

WiFi.begin(ssid);

while (WiFi.status() != WL_CONNECTED) {

delay(500);

Serial.print(".");
```

```
}

Serial.println("");

Serial.println("WiFi connected");

Serial.println("IP address: ");

Serial.println(WiFi.localIP());

client.setServer("193.136.195.56",1883);
}

void loop(void)
{
float v_shunt = 0;
float v_bus = 0;
float current = 0;
float v_load = 0;
float power = 0;

v_shunt = ina219.getShuntVoltage_mV();
v_bus = ina219.getBusVoltage_V();
v_load = v_bus + (v_shunt / 1000);
current = ina219.getCurrent_mA();
power = v_load * current;
float lux = lightMeter.readLightLevel();
float t = dht.readTemperature();
```

```
float h = dht.readHumidity();
Serial.print(F("Temperature: "));
Serial.print(t);
Serial.println(F(" C "));
Serial.print(F("Humidity: "));
Serial.println(h);

Serial.print("Vsh: ");
Serial.print(v_shunt);
Serial.print(" V      ");



Serial.print("V: ");
Serial.print(v_load);
Serial.print(" V      ");

Serial.print("I: ");
Serial.print(current);
Serial.print(" mA      ");

Serial.print("P: ");
Serial.print(power);
Serial.println(" mW");

Serial.print("Light: ");
Serial.print(lux);
Serial.println(" lx");

if (!client.connected()) {
```

```
reconnectmqttserver();
}

client.loop();

StaticJsonBuffer <300> JSONbuffer ;

JsonObject& JSONencoder = JSONbuffer.createObject( ) ;

JSONencoder ["T"] = t ;

JSONencoder ["H"] = h;

JSONencoder ["I"] = current;

JSONencoder ["L"] = lux;

JSONencoder ["V"] = v_load ;

JSONencoder ["P"] = power ;

JSONencoder.printTo(JSONmessageBuffer,sizeof(JSONmessageBuffer));

client.publish ("esptest",JSONmessageBuffer);

 }
```

Listing A.1: ESP32 Programming.