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Remote Monitoring and Control of Photovoltaic Energy Production by Arduino-Gsm Sim900

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***Abstract*— *The monitoring system is a key element in any energy production installation, making it possible to monitor operating parameters in real time and optimize production. In this article, we present a model of a monitoring system based on the Arduino microcontroller and the GSM module, compatible with any type of solar installation. Our monitoring system uses current, voltage and temperature sensors to measure the operating parameters of a photovoltaic system. We simulated the operation of this system using Proteus software, and the simulation results demonstrated the correct operation of our model. Based on these results, we created a prototype of our monitoring system. The latter is capable of sending measured operating parameters as SMS notifications to a smartphone, thus enabling real-time remote monitoring.*

Keywords*— *Renewable energies, photovoltaics, microcontroller, Arduino, GSM, monitoring, surveillance, optimization

I. INTRODUCTION

Renewable energy production has become a global priority to reduce greenhouse gas emissions and combat climate change. Among the different sources of renewable energy, photovoltaic solar energy is one of the most promising, thanks to its modularity, reliability and low maintenance cost.

However, to optimize solar energy production and guarantee the reliability of installations, it is essential to set up an effective monitoring system, making it possible to monitor operating parameters in real time and quickly detect possible malfunctions.

In this context, our research aims to present a model of a monitoring system based on the Arduino microcontroller and the GSM module, compatible with any type of autonomous solar installation. This system makes it possible to remotely monitor the operation of the installation, to identify possible beginnings of problems, and to receive alerts by SMS in the event of a critical situation or sudden breakdown. Indeed, for a large photovoltaic installation, one day without production can generate a huge loss of turnover. It is therefore important to be informed without any delay.

The proposed system is linked to a GSM/GPRS network, which allows real-time remote communication. As an option, numerous sensors can be added to better identify the beginnings of a drop in performance of a component or to diagnose a problem: wind direction and intensity, air temperature, panel temperature, solar irradiation, etc.

In this article, we present the Arduino-GSM SIM900 monitoring system model, then we describe the steps of its simulation with the Proteus software. Finally, we present a prototype that we created to demonstrate how our system works. The results obtained show that our monitoring system offers a simple, economical and effective solution for monitoring and optimizing autonomous solar energy production. We hope that this contribution will contribute to the global energy transition towards cleaner and more sustainable energy sources.

II. METHODOLOGY

2.1. Harnessing solar energy

Photovoltaic energy has become an increasingly promising solution among energy options, thanks to its advantages such as abundance, lack of pollution and availability in large quantities worldwide. This is all the more important given the increase in the cost of conventional energies and the limitation of their resources.

2.1. 1. Photovoltaic solar cell

The photovoltaic cell is the basic element of photovoltaic solar panels. It is a silicon-based semiconductor device which delivers a voltage of around 0.5 to 0.6 V.

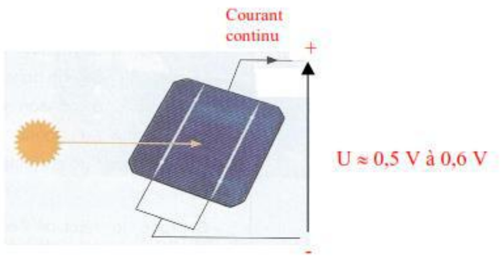

Figure 1: Photovoltaic cell

2.1.2 . Solar or photovoltaic module

The solar module or photovoltaic panel is the series and parallel association of numerous cells to obtain greater current and voltage. In order to obtain the voltage necessary for the inverter, the panels are connected in series and then form a chain of modules or "string". The chains are then combined in parallel and form a photovoltaic field. It is also necessary to install diodes or fuses in series on each string of modules to prevent damage in the event of a shadow on one string.

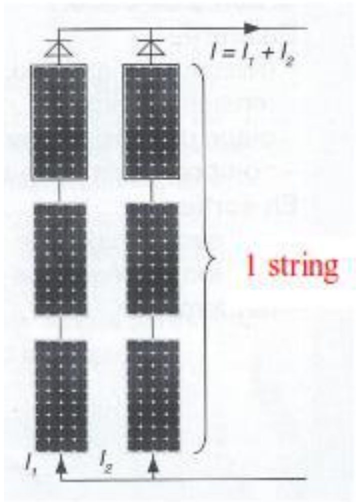

Figure 2: Photovoltaic field

2.1.3 . Photovoltaic solar power plant

A photovoltaic solar power plant can be autonomous or connected to a network. Solar power plants connected to the grid have an installed power of more than 100 MWp in 2012, unlike stand-alone photovoltaic solar systems whose power rarely exceeds 100 kWp .

For autonomous photovoltaic solar systems intended to supply electricity to buildings or isolated installations, it is necessary to install charge accumulators or batteries to store the energy supplied by the solar modules and meet all of the needs. This type of installation is suitable for sites that cannot be connected to the network.

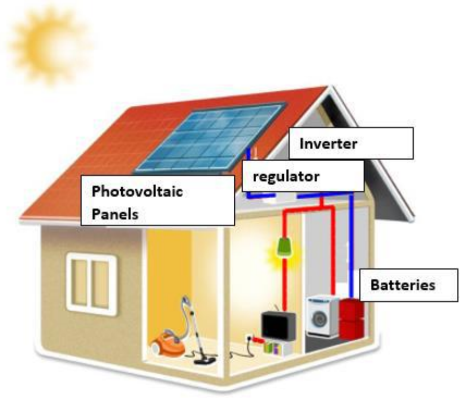

Figure 3: Standalone installation example

In this installation:

- photovoltaic panels produce direct electric current;
- the regulator optimizes the charging and discharging of the battery according to its capacity and ensures its protection;
- the inverter transforms direct current into alternating current to power the AC receivers;
- the batteries are charged during the day to be able to power at night or on bad weather days;
- specific DC receptors can also be used; these devices are particularly economical.

For installations connected to the public distribution network, there are two options: total injection and surplus injection.

- In the case of total injection, all the electrical energy produced by the photovoltaic sensors is sent to the distribution network to be resold. This solution is achieved with two connections to the public network: one for the consumer and one for the injection of the energy produced.
- In the case of surplus injection, the user consumes the energy he produces with the solar system and the surplus is injected into the network. When photovoltaic production is insufficient, the network provides the necessary energy. This solution is achieved with a single connection to the public network and an additional meter to measure the injected energy.

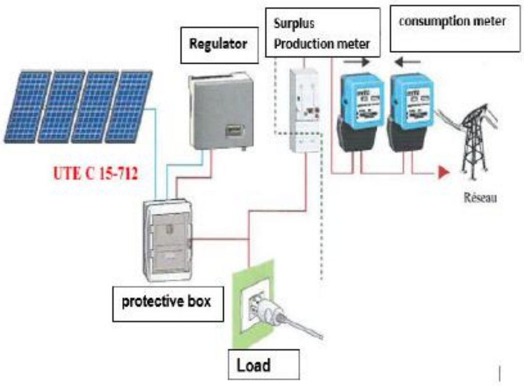

Fig.4: Facilities connected to the public distribution network with surplus injection

In a large photovoltaic power plant, there is a control room equipped with electronic and computer equipment to process instantaneous data from the plant on site.

2.1.4. Control and monitoring devices

To ensure the proper functioning of a photovoltaic power plant, it is necessary to install control and monitoring devices.

2.1.4.1. Plant status management device

In a photovoltaic power plant, the system state management device makes it possible to give the instantaneous production of electrical energy (kW), the production of electrical energy (kWh/day), the estimate of the reduction in emissions of CO_2 and the operating position of the solar photovoltaic system (failed, in service, waiting and stopped).

2.1.4.2. Environmental measurement system

Environmental measuring devices, including solar radiation measuring instruments and temperature sensors, are installed within the solar power plant. These instruments make it possible to record the climatic conditions in the area where the photovoltaic modules are installed. The collected data is saved in a computer.

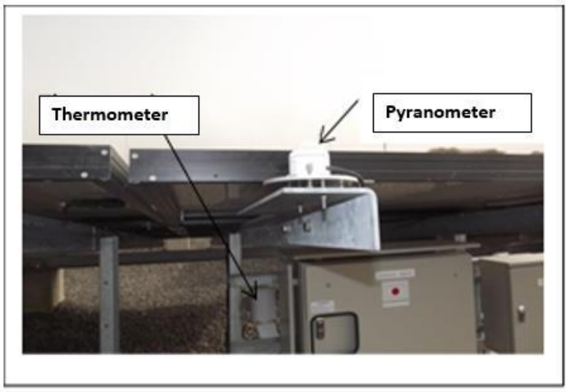

Fig.5: Environmental measurement system

II.1.4.3. Data acquisition equipment in a solar power plant

A computer allowing the acquisition and processing of data from the various equipment of the photovoltaic solar power plant is often installed. This data is composed of:

- the amount of solar radiation received by the panels;
- the outside air temperature;
- energy production from DC panels and AC inverters;
- the voltage in DC and AC;
- the current in DC and AC;
- the frequency of the inverters;
- reducing CO_2 emissions .

The computer allows this data to be observed in real time using software. Data is recorded in log form by minute, hour, day, week, month and year.

2.1.5. Upkeep and maintenance operation in a photovoltaic solar power plant

To ensure the proper functioning and lifespan of a photovoltaic solar power plant, it is necessary to carry out regular upkeep and maintenance operations.

Fig.1: Mops to use for cleaning

2.1.5.1. Connection control

Connection control consists of the visual inspection of the various installations of the solar power plant to ensure production. The sections to check are:

- the rows of photovoltaic modules;
- junction boxes;
- cabinets in the control room;
- the load switch;
- billboards.

This type of check is carried out regularly or irregularly, for example after rain or strong wind which could cause damage.

2.1.5.2. Component control

It is a control which consists of periodically carrying out a visual and electrical inspection of the various components of the photovoltaic solar power plant.

2.1.5.3. Cleaning

To ensure the performance of installed modules, it is necessary to protect them against dust and shade. Monthly cleaning is therefore very useful to remove dust and possible debris.

2.2. Microcontrollers

Microcontrollers are microprocessor-type information processing units to which internal peripherals are added, allowing their components to perform assembly without requiring the addition of additional components. They are today widely used in many public or professional applications, depending on their needs.

Among the most common microcontrollers, we can cite:

- CMOS microcontrollers, such as Microchip PICs ;
- Motorola's 16HC11, which features numerous peripherals such as counters, pulse width modulation (PWM), analog-to-digital converters (ADC), digital I/O, and serial links;
- microcontrollers based on Intel's 8051 architecture (like those from ST, Atmel or Philips), which offer advanced computing capabilities. This family of 8-bit microcontrollers is an industrial standard in its own right;
- Raspberry Pi microcontrollers , which are advanced platforms.

2.2.1. Arduino microcontroller

Arduino is an open-source programmable electronics platform, which consists of a microcontroller board (from the AVR family) and software which constitutes an integrated development environment (IDE). This allows you to write, compile and transfer the program to the microcontroller card.

Arduino can be used to build independent interactive objects (rapid prototyping) or be connected to a computer to communicate with its software.

2.2.1.1. Hardware part

An Arduino board is generally built around an Atmel AVR microcontroller (like the ATmega328 or ATmega2560 for recent versions, or the ATmega168 or ATmega8 for older versions), as well as complementary components that facilitate the programming and interfacing with other circuits. Each card has at least a 5V linear regulator and a 16 MHz crystal oscillator (or a ceramic resonator in some models). The microcontroller is pre-programmed with a “boot loader” which eliminates the need for a dedicated programmer.

There are thirteen versions of Arduino boards to date. Among the most used in the fields of training and research, we can cite the Arduino Uno and the Arduino Mega 2560. The following table summarizes their main characteristics.

Table 1: Arduino UNO vs Mega 2560 Comparison Chart

	Arduino Mega 2560	Arduino Uno
Microcontroller	ATmega2560	ATmega328
Dimension	101mm*53mm	69mm*54mm
Operating voltage	5V	5V
Supply voltage (recommended)	7-12V	7-12V
Supply voltage (limits)	6-20V	6-20V
Digital I/O Pins	54 (14 of which have a PWM output)	14 (6 of which have a PWM output)
Analog Input Pins	16 (usable as digital I/O pins)	6 (usable as digital I/O pins)
Maximum current available per I/O pin (5V)	40 mA (WARNING: 200mA cumulative for all I/O pins)	40 mA (WARNING: 200mA cumulative for all I/O pins)
Maximum intensity available for 3.3V output	50 mA	50 mA

Maximum intensity available for 5V output	Power supply function used – 500 mA max if USB port used alone	Power supply function used – 500 mA max if USB port used alone
Flash Program Memory	256 KB of which 8 KB are used by the boot loader	32 KB (ATmega328) of which 0.5 KB is used by the boot loader
SRAM (volatile memory)	8 KB	2 KB (ATmega328)
EEPROM (non-volatile memory) memory	4 KB	1 KB (ATmega328)
Clock speed	16 MHz	16 MHz
SPI/I2C	AVAILABL	AVAILABLE

2.2.1.2. Software part

The Arduino programming environment is actually an IDE dedicated to the Arduino language. This software allows you to write programs (or “sketches”), compile them and transfer them to the Arduino card via a USB connection. It also includes a serial port monitor.

The advantage of Arduino language is that it is based on C/C++ languages, which means that it supports all standard C language syntaxes and some C++ tools. Many libraries are also available free of charge to communicate with the hardware connected to the card (LCD displays, 7-segment displays, sensors, servomotors, etc.).

To write a program with the Arduino language, it is important to respect certain rules. First of all, the execution of an Arduino program is sequential, which means that the instructions are executed one after the other. Then, the compiler checks for the existence of two mandatory structures:

- the initialization and input/output configuration part;
- the main part which runs in a loop and contains the loop () function.

The variable declaration part is optional.

Figure 6 shows the graphical interface of the Arduino IDE, as well as the structure of a program created with the Arduino language.

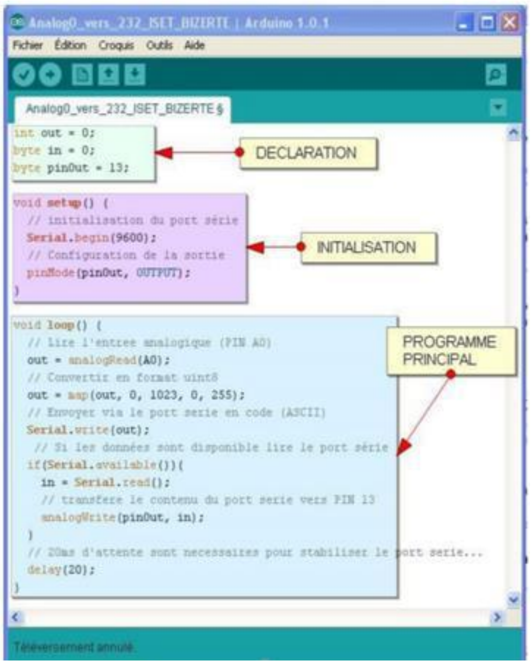

Fig.6: Program structure on the Arduino IDE

2.2.2. Arduino Mega 2560 board

The Arduino Mega 2560 board is based on an ATmega2560 microcontroller and features:

- 54 digital input/output pins, 14 of which can be used as PWM output;
- 16 analog inputs, which can also be used as digital I/O pins;
- 4 hardware serial ports (UART);
- 1 crystal 16 MHz;
- 1 USB connection;
- 1 jack power connector;
- 1 ICSP connector (“in-circuit” programming);
- 1 reset button.

This board contains everything a microcontroller needs to function. It is also compatible with printed circuits designed for Arduino Uno, Duemilanove or Diecimila cards .

Figure 7 shows the Arduino Mega 2560 microcontroller board.

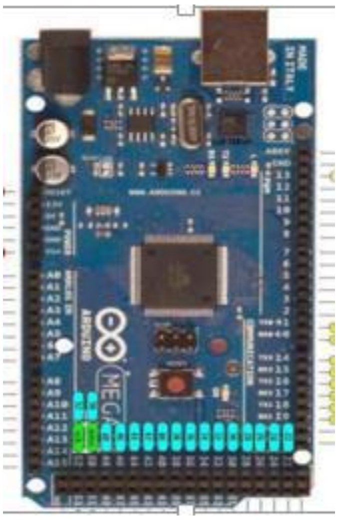

Fig.7: Arduino MEGA2560 board

2.2.3. GSM/ GPRS module

The GSM/GPRS module is an interface board compatible with Arduino. It allows you to send and receive SMS, data or voice communications from the mobile network. This module is based on the SIM900 circuit and is controlled via AT commands from an Arduino board.

Fig.8: Sim900

The module has a remote patch antenna and communication between the module and the Arduino board is carried out via an asynchronous serial link (UART) or a software serial link.

Here are the main characteristics of the SIM900 module:

- Quad-band: 850/900/1800/1900 MHz;
- GPRS data rate: up to 85.6 kbps;
- Serial interface: UART, with TTL or RS-232 voltage level;
- Power supply: 3.4 to 4.4 V;
- Power consumption: 1.5 mA in standby and 2 A in communication;
- Operating temperature: -20°C to +70°C;
- Dimensions: 57 x 55 x 11 mm.

2.2.4. Sensor

A sensor is a technical component which detects a physical event linked to the operation of a system (presence of a room, temperature, etc.) and translates it into a signal usable by the system (generally electrical, in the form of a low voltage signal).

The information detected by a sensor can be very varied, which implies a wide variety of sensor needs. Among the most common and frequent are position, presence, speed, temperature and level sensors.

2.2.5. Mounting the control system on Proteus

The proposed system consists of communication module circuit, battery level indicator circuit, ammeter module, temperature sensor, photo resistor and microcontroller module.

The battery level indicator circuit measures voltages across the solar panel batteries and across the solar panels themselves.

The ammeter module allows you to measure the current used by the load and the current supplied by the PV modules.

The temperature sensor allows you to know the temperature inside the inverter.

The photoresistor mounted on the surface of the solar modules makes it possible to monitor the solar irradiation received by the module.

The current (p1, p2) and voltage (V1, V2) communication buses are connected to the photovoltaic installation (figure 10).

For the simulation, we propose an installation of 4 12V/100W solar collectors in parallel and two 12V/150Ah batteries also in parallel. A 300W load is connected to the batteries.

Figure 10 shows the data processing circuit diagram.

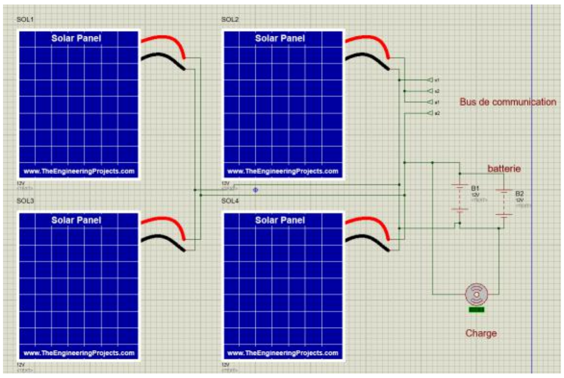

Fig.10: Solar installation on Proteus ISIS

III. RESULTS

We simulated a solar collector with a nominal voltage of 12V on ISIS by connecting it to a 12V/10W lamp (Figure 11). The illumination of the lamp and the intensity increase as the voltage across the solar panel rises from 12 to 18V (Figure 12).

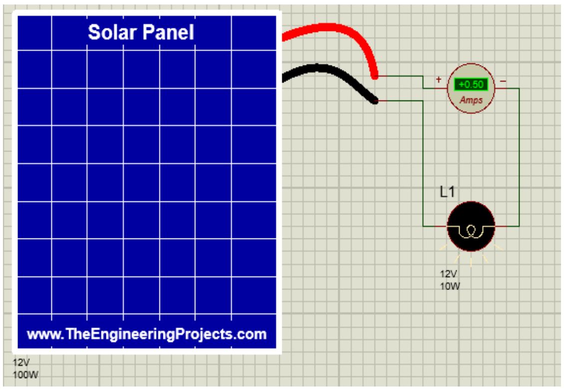

Fig.11: 12V solar collector with load

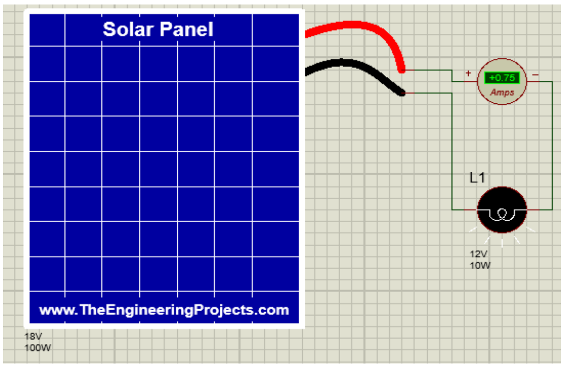

Fig.12: 18V solar collector with load

3.1. Simulation of the GSM module with the Arduino

To simulate the GSM SIM 900 module with the Arduino Uno, we used the "GSM Arduino-PROTEUS" library on the PROTEUS software. To visualize the process and the SMS, we used a virtual Rx / Tx interface from Arduino (Figure 13).

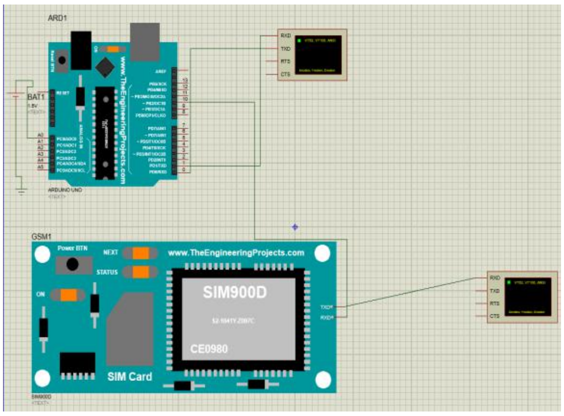

Fig.13: Simulation of the SIM900 GSM module

We verified the SMS transmission of the GSM/Arduino system by uploading the program in Appendix 1 to the microcontroller. Proteus virtual interfaces show the SMS sent by the system to a recipient (Figure 14).

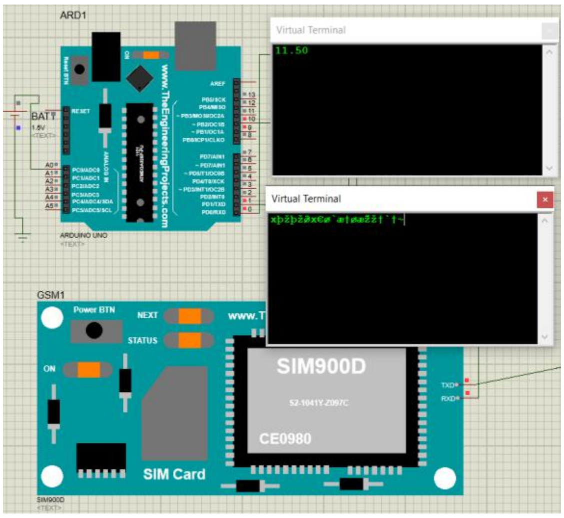

Fig.14: Observation of the sent SMS

3.2. Temperature sensor simulation

Arduino UNO has a built-in UART for serial communication. The Rx and TX pins (0 and 1 respectively) can be used to communicate serial data with any device (like Bluetooth, GSM, GPS, etc.). We connected the output of the LM 35 temperature sensor to the analog channel A0 of the Arduino (Figure 15).

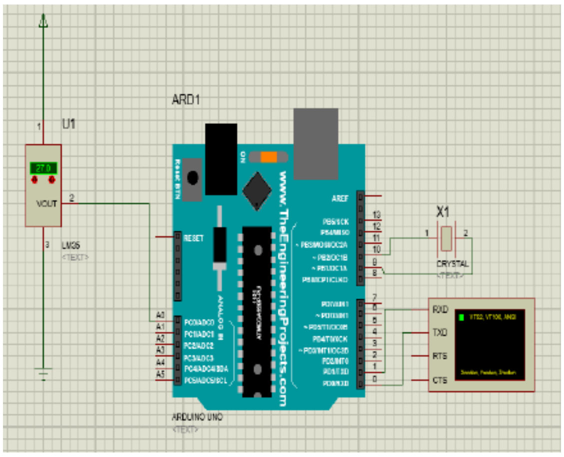

Fig.15: Arduino-temperature sensor on Proteus ISIS

By programming the Arduino, the digital output of the temperature sensor is displayed on the Proteus virtual terminal every 1 second (Figure 16).

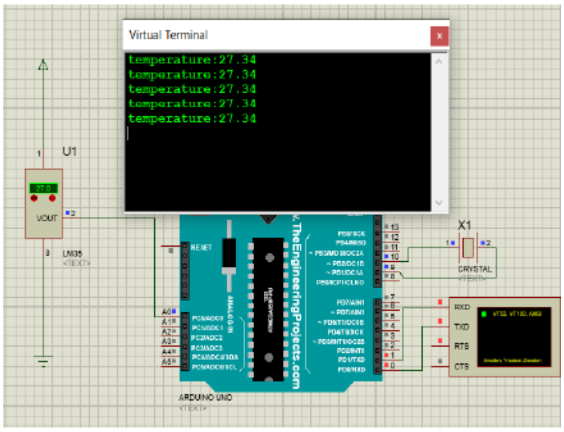

Fig.16: Temperature sensor simulation on ISIS

3.3. Current/voltage module simulation

The ACS712 current sensor interfaces with the Arduino for measuring AC and DC current. The ACS712 is a cost-effective solution for current sensing in industrial, energy and communications applications.

To calculate the current from the output voltage of the ACS712 current sensor, we performed the following calculations:

- When there is no current flowing through the sensor, the output voltage will be Vcc/2. Where Vcc is the supply voltage supplied to the ACS712.
- If Vcc = 5 volts, then the current sensor output voltage will be 2.5 when there is no current passing through a sensor.
- 2.5 volts is the offset voltage or base voltage of the sensor which must be subtracted from the measured voltage.
- The output voltage decreases as current begins to flow through the sensor.

So we calculated the direct current using the following commands:

Adcvalue = analogRead (A0);

Voltage = (Adcvalue / 1024.0) * 1000;

Current = ((Voltage - voltage_offset) / mVperAmp);

The measured numerical value is stored in the variable " Adcvalue ". In the second line, we convert the digital value of voltage to analog voltage in milliamps by multiplying it by the resolution factor and dividing by 1000 to convert it to voltage in milliamps. In the third row, the measured voltage is subtracted from the offset voltage voltage_offset and divided by the sensitivity factor mVperAmp to obtain the measured voltage current.

As shown in Figure 18, the voltage shows the voltage across the ACS 712 and the current shows the measurement which is exactly the same current that we measured with a virtual ammeter in Proteus.

Fig.17: ACS712 ACS Module

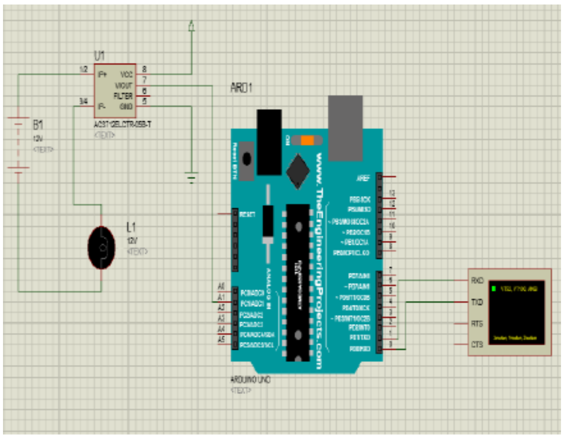

Fig.18: Arduino and ACS 712 on Proteus

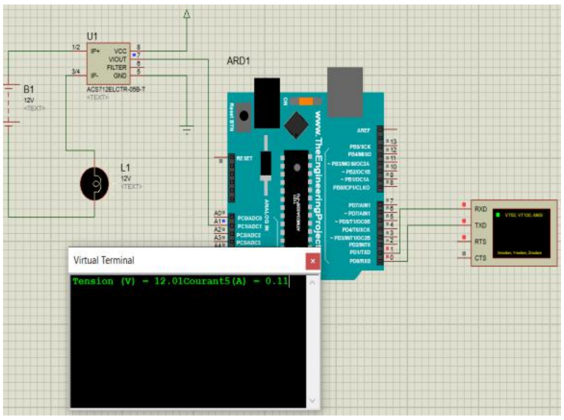

Fig.19: ACS712 simulation on Proteus

3.4. Creation of a prototype

We created a prototype to test the operation of the system experimentally. Figure 20 shows the completed prototype of the control system of a photovoltaic installation as a whole. In this prototype, we used a 12V/5W solar panel, a 12V/4Ah battery, an Arduino Uno board, a SIM900 GSM module, an ACS 712 module for current measurement and a voltmeter module for voltage measurement .

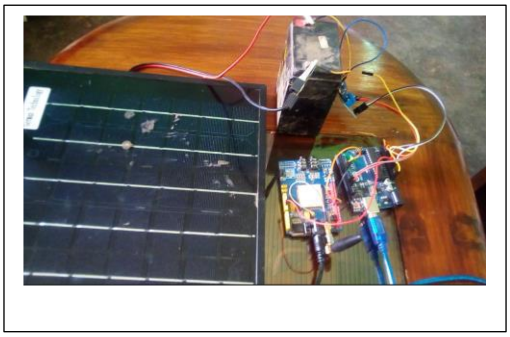

Fig.20: Prototype

The system automatically sends an SMS notification in the event of a sudden outage or wiring anomaly between the photovoltaic sensor and the energy storage system (Figure 21). The system also indicates the state of charge (charged or discharged) of the battery (Figure 22).

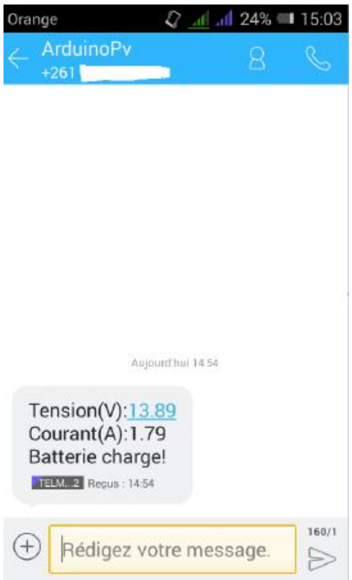

Fig.21: Cutoff status

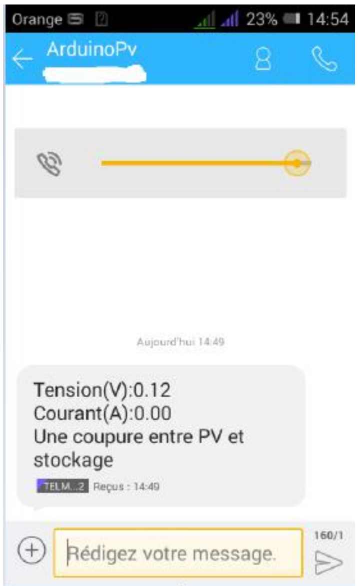

Fig.22: Loaded state

IV. DISCUSSION

The results obtained during the simulation and creation of the prototype showed that the control system of a photovoltaic installation, based on the Arduino platform and the SIM900 GSM module, is functional and meets the remote monitoring needs of the status of the power plant.

The system is able to detect technical failures and transmit SMS notifications to predefined recipients, allowing rapid and efficient intervention by maintenance technicians. In addition, the system makes it possible to monitor the state of charge of the batteries, which is essential to guarantee the continuity of the electrical supply in the event of a power outage.

The Arduino platform and the SIM900 GSM module are reliable and proven components, which guarantee the sustainability of the system over time. However, it is important to note that the lifespan of each component used in the electrical installation can have an impact on the overall reliability of the system.

The target groups that can use this remote control platform are numerous. Firstly, technicians in a photovoltaic plant can benefit from this system to monitor and maintain the installation remotely, reducing costs and travel time. Additionally, home users can also use this platform to monitor and control their own PV installation, allowing them to maximize their solar energy production and reduce their electricity bill.

V. CONCLUSION

As part of this project, we carried out photovoltaic system control system simulations with the use of Arduino and SIM 900 on Proteus software. We also designed a prototype to test how the system works.

The main objective of this project is the automatic management of a photovoltaic system using an electronic command and control platform. Thanks to this system, we can remotely monitor energy production, be informed in the event of an anomaly or malfunction, and know the available energy storage capacity.

The system is based on the use of Arduino for data collection and processing, as well as the use of SIM 900 for remote communication via SMS. The simulations carried out on Proteus made it possible to validate the operation of the system and to correct any bugs or errors.

In terms of improvement prospects, we can consider the use of another electronic system such as Raspberry Pi instead of Arduino, which would allow broader and more complex management of the photovoltaic system. We could also consider presenting the different parameters (current, voltage, energy, temperature, etc.) in the form of curves or graphs for more intuitive visualization and deeper analysis of the data.

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