IoT and MQTT based web monitoring of a solar living laboratory

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***Abstract*—This paper describes the tools used for the web-monitoring of a solar energy living lab referred to as *SOLLAB*. A low-cost electronic control unit (ECU) developed internally is presented and its use as an IoT is discussed. Based on this affordable hardware, the open source MQTT protocol and Node-Red framework are performed to ensure data communication locally and further distant monitoring through internet. The overall hardware and software architecture and configuration are explained in the context of the SOLLAB.**

Keywords — Internet of Things, MQTT, SCADA, Web Monitoring, Solar energy, Node-Red, ESP32.

I. Introduction

Nowadays, a new technology disruption is exploring the fourth industrial revolution where everything is connected to everything with the emergence of Internet of Things (IoT) [1] in particular, and 75 billion IoT connected devices will be deployed by 2025 [2] in different sectors like transport, energy, medical, agriculture and industry.

Cyber physical systems need to be supervised to ensure a suitable, real-time, and optimal monitoring and control. Therefore, in both the research and industrial fields, many Supervisory Control and Data Acquisition (SCADA) systems are developed such as:

a) Commercial SCADA software operating with their specified IoT devices: LabVIEW - National Instrument [3], MicroSCADA - Hitachi Energy [4],

b) Hybrid SCADA solutions: web interface based-on ThingSpeak middleware with Message Queuing Telemetry Transport (MQTT) communication protocol [5][6],

c) Supervision systems based-on a single communication protocol like MQTT without a secure TLS/SSL certificate [7][8][9][10].

d) SCADA system using ESP32 with OLED, Things Board running on Raspberry Pi and MQTT protocol [11].

The SCADA system in a) is an expensive solution, owned by commercial companies, that costs about thousands of euros, communicates only with their specified locked-up IoT devices and disabling open communication with other IoTs using gateways and bridges. The second SCADA system in b) is a hybrid solution with locked-up, expensive cyber layer tools (web interface, communication protocols and servers) owned by commercial companies. The third supervision systems in c) are based on a single, unsecure MQTT communication protocol exposed to cyber threats and lack of interoperability with different communication protocols. The last SCADA system in d) is an open-source, low-cost and IoT-based solution using different microcontrollers (ESP32 and Raspberry Pi) to ensure cyber physical layers communication.

The supervision tool we consider in this work is a low-cost open-source, secure, scalable, and flexible solution though requiring skills which are however capitalized for the subsequent improvements and the integration of other systems.

This paper is structured as follows: after this general introduction, Section 2 presents the solar living lab (SOLLAB) to be monitored. The SOLLAB is further seen as a cyber physical system with IoT modules, and the hardware architecture is addressed in Section 3. A supervision framework for web monitoring of the SOLLAB is described in Section 4 based on low cost and open-source tools. Experimental results from the overall platform are discussed in Section 5. The paper ends with a conclusion and future perspectives.

II. Presentation of the SOLLAB

SOLLAB is viewed as an open platform for research and development on innovative solar energy technologies covering the various components of the chain: Collection; Conversion; Storage; Intelligent and connected sensors; Metering; Communication; Stand-alone operation or injection into the Grid or Micro-Grid; Use of energy in electrical form in storage, injection or self-consumption; Use of energy in thermal form in storage, for domestic hot water (DHW) or for heating / cooling; Graphical User Interface; Supervision and optimal management of the installation; locally or in secure remote access via the web.

To cover a wide range of technologies, we chose PV/T hybrid panels that provide heated air/water in addition to electricity.

Figure 1 shows the experimental setup at SOLLAB roof to be monitored where the three blocks (PV/T-air and PV/T-water hybrid panels, tilting PV panels) are installed with different configurations and equipped with IoT modules.

Block 1: Four PV/T-air hybrid panels are connected with two maximum power point tracker (MPPT) (each MPPT device is connected to two batteries in series) and one DC/AC inverter to supply different AC loads.

Block 2: Two parallel groups of PV/T-water hybrid panels mounted in series are connected to two MPPT devices (each group is connected to MPPT device), the two parallel MPPT devices are connected to two parallel batteries and one DC/AC inverter to supply different AC loads.

Block 3: One 2 axis tilting PV panel is connected to an MPPT device that connects one battery and one DC/AC inverter to supply different AC loads.

Table I presents the main technical characteristics of the three different PV block-panels configurations.

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Figure 1: Different PV panels on SOLLAB roof

TABLE I: OVERVIEW OF SOLLAB KEY TECHNOLOGIES AND CHARACTERISTICS

	PVT-Air	PVT-Water	Tilting PV
PV system	**Type:** Silicone Monocrystalline **Electrical total power:** 1.2 kWp **Thermal total power:** 2.4 kW	**Type:** Silicone Monocrystalline **Electrical total power:** 1.2 kWp **Thermal total power:** 2.4 kW	**Type:** Silicone Monocrystalline **Electrical total power:** 300 Wp
MPPT	2	2	1
Energy Storage	**Electrical storage:** 4.8 kWh lead-acid	**Electrical storage:** 1.5 kWh Li-ion BESS **Thermal storage:** 421 L hot water tank	**Electrical storage:** 1.2 kWh lead-acid BESS
Use of electricity	Smart lighting; e-cycle; …		
Use of heat	Air heating	Hot water	
Environment	Weather station; Motorized camera; Automatic panel cleaning system; Shading simulator; Albedo effect simulator		

III. THE SOLLAB AS CYBER PHYSICAL SYSTEM

The figure 2 describes the architecture of SOLLAB as a cyber physical system. Each block has a universal board based on an ESP32 microcontroller that enables communication with IoTs by sending and receiving data using the different functions enumerated below and various technologies as shown in the following figures:

The ESP32-based board as electronic control unit (ECU) is a low-cost (realized with less than 20 euros), low-power system on a chip (SoC) series with Wi-Fi & dual-mode Bluetooth capabilities based-on a dual-core or single-core Tensilica Xtensa LX6 microprocessor with a clock rate of up to 240 MHz [12], that has native RTC for real time with battery cell, an SD card for data storage, CAN Bus controller (3-pin terminal block or DB9), analog as well as digital inputs/outputs with different programmed functions: GPS, SIM card for datalogging, sending/receiving SMS, GSM calls, sending/receiving by GPRS to a website, data display on color touch screen in real time, ambient temperature, humidity, voltage and current measurements, two-way ESP32 communication using ESP-NOW.

An industrial measurement central unit (MCU) was integrated into the SOLLAB pilot for educational illustration, namely DIRIS-60 which collects inverters data (electric voltage, current, power and frequency). Similarly, a temperature MCU collects wireless temperature sensors data through Radio Frequency Identification (RFID) communication protocol, then MCUs communicates with the supervision system to display the data through the web interface. However, the mentioned MCUs can be easily replaced by low-cost IoT boards proposed in Figure 3.

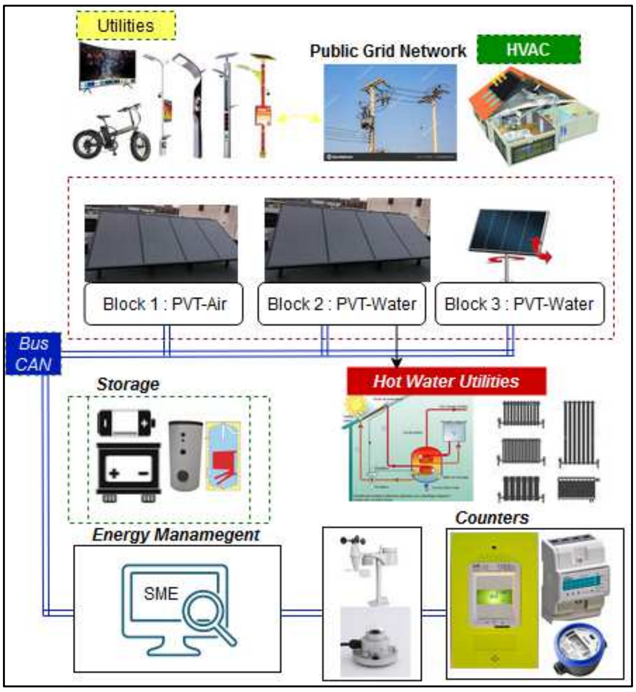

Figure 2 PV/T blocks with different communication technologies

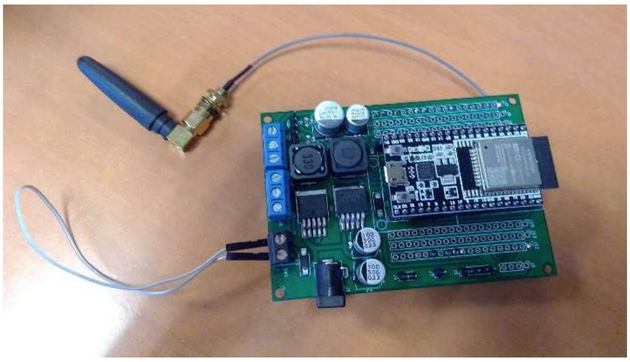

Figure 3: IoT in an ESP32-based board

Figure 4: DIRIS A60 MCU of Tilting PV Inverter

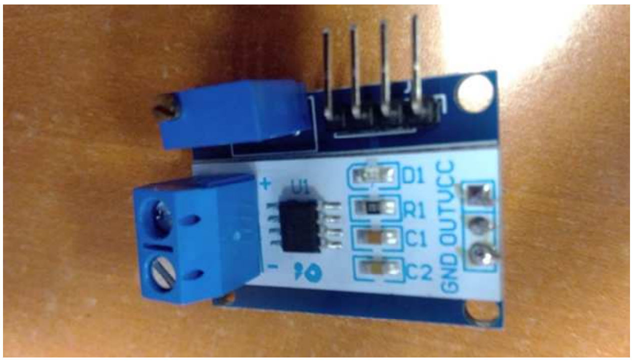

Figure 5: Electric current and voltage sensor shield

Table II enumerate different devices mounted at SOLLAB to receive sensor data and to control actuators remotely through the proposed supervision system.

IV. FRAMEWORK FOR WEB MONITORING OF THE SOLLAB

The proposed supervision tool of the SOLLAB uses a visual flow programming, flexible, scalable, and secure SCADA web-platform enabling the interoperability of different existing communication protocols included in a unique web interface. The supervision system flexibility allows the integration of more IoT devices without starting from scratch. The Figure 5 shows the description of our proposed web monitoring framework with both hardware and software architectures. The three hardware blocks are communicating to a secure cloud-based platform (web interface based-on Node-Red visual flow-based programming) [1] through different communication protocols (MQTT, MODBUS TCP, ZMQ, RFID).

The ESP32 ensures the connection between the physical and cyber layers by collecting sensors information (temperature sensors for both PV/T-air and PV/T-water hybrid panels), controlling actuators (brush DC motors for tilting PV panel and Camera) and communicating with secure MQTT server by publishing sensors data and subscribing to control values through defined topics.

DIRIS-60 MCU and Temperature MCU sends collected information to local Node-Red user interface through MODBUS TCP and ZeroMQ (ZMQ) peer to peer communication protocols respectively, and the local user interface communicates with secure MQTT server by publishing inverters data.

SOLLAB secure web monitoring interface based-on Node-Red receives measured data by subscribing to a secure MQTT server and sends the control values by publishing them to the same server.

A. *MQTT Communication protocol*

MQTT is an acronym for Message Queuing Telemetry Transport developed by IBM in 1999. It is a standardized lightweight publish / subscribe messaging protocol running over TCP. In MQTT, every client can be a publisher or a subscriber. If the client publishes messages to a topic, a MQTT broker acts as the server to receive all the messages from clients and publishes these messages to the clients who are subscribing to this specific topic [13].

Figure 7 shows that MQTT clients (ESP32, Node-Red web interface and mobile application) can communicate (publish and subscribe) with UPJV secure MQTT server only by providing TLS/SSL certificate and user / password login.

TABLE II: SYSTEM CONTROL AND DATA MONITORING

Block	Measurement	Control
PVT-Air	• Voltage, Current • Panel temperature	Air flow rate
PVT-Water	• Voltage, Current. • Panel temperature	
Tilting PV	• Voltage, Current. • Panel temperature. • Angular positions (orientation, inclination)	DC motors for the 2 axis control
Weather Station	• Position of the Sun • Diffuse and direct irradiation. • External temperature and humidity. • speed and direction of the wind • Visibility. • Thickness of the clouds particles	Water flow rate
DC-DC converters	• Voltage, Current • temperature	Energy management
Inverters		
MPPT		
Batteries		
Hot water tank	• Temperature, level and flow of water	Electric resistance
Lighting system	• Brightness, presence detector, current, voltage	Illuminance

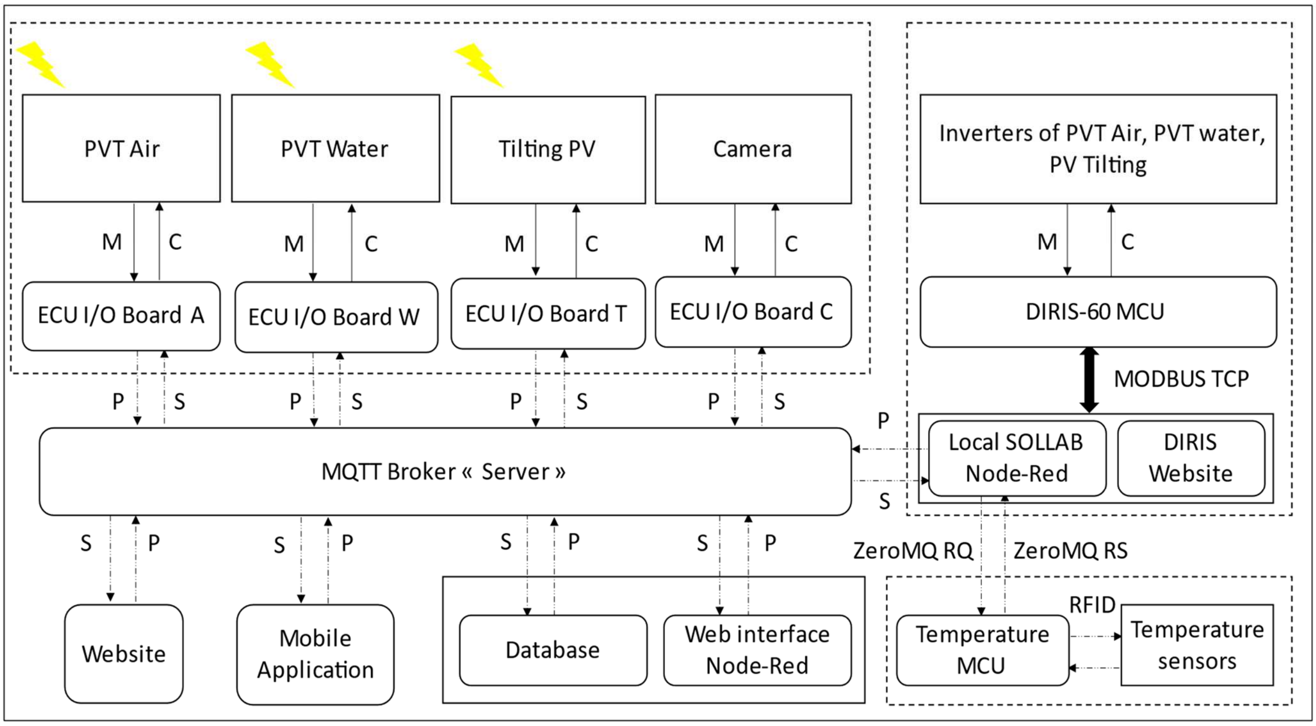

Figure 6: SOLLAB web monitoring framework overall architecture: S: Subscribe, P: Publish, M: Measure, C: Control, RQ: Request, RS: Response

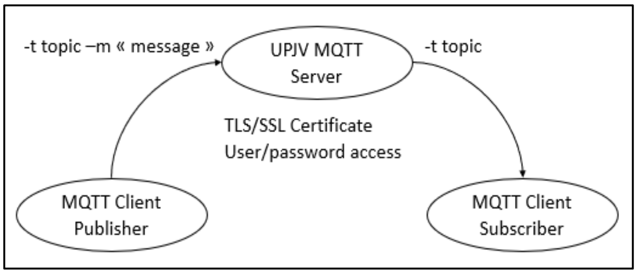

Figure 7 MQTT communication protocol

B. *Web interface based on Node-Red*

Node-RED is an open-source flow-based development tool for the integration of IoT hardware devices, APIs (Application Programming Interfaces) and online services developed by IBM Emerging Technology [14]. Node-RED is a free JavaScript-based tool, built on Node.js platform, which provides a visual browser-based flow editor [15]. Secure Node-Red programming tool is accessible only with user / password login and hosted by UPJV server.

The different functions (nodes) needed for this work and beyond are provided by Node-Red libraries such as: MQTT subscribe and publish, dashboard elements (button, switch, and charts), MODBUS read and write, data storage and ZMQ peer to peer communication functions. Figure 8 shows the back-end visual flow-based programming platform of PV/T-water hybrid panel part using Node-Red functions.

V. EXPERIMENTAL RESULTS

This section highlights the SOLLAB SCADA system graphical user interface (GUI) for remote, real-time monitoring and control by implementing the framework that has been mentioned previously.

SOLLAB GUI has three tabs: PV/T-Air hybrid panel block, PV/T-Water hybrid panel block, tilting PV panel and their associated IoT modules.

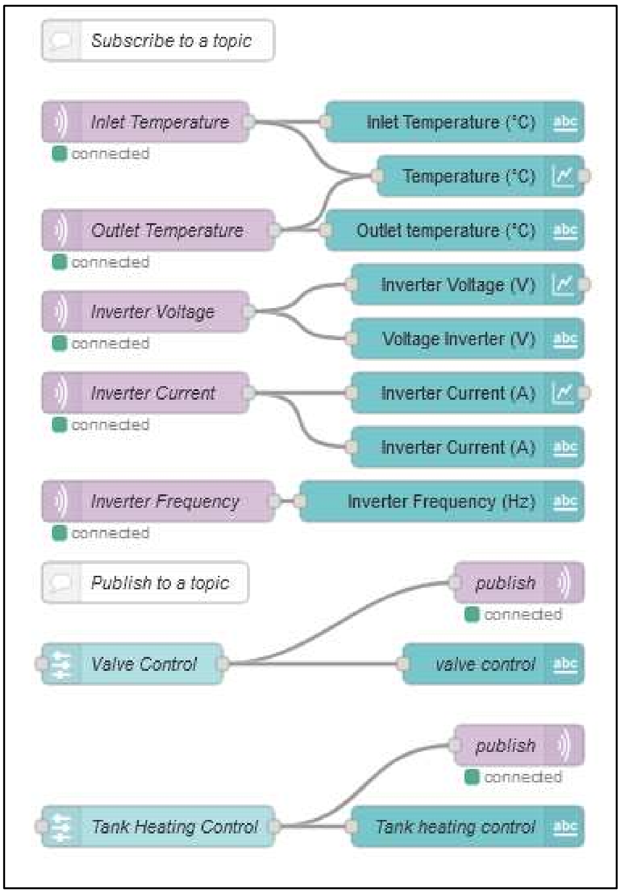

Figure 8: Node-Red back-end programming platform – PV/T water block

Figure 9 shows inlet and outlet temperature sensor data of hot distribution system located in SOLLAB (the same charts are displayed for inlet and outlet temperature sensor data of water storage tank).

Figure 10 shows valve servomotor position to switch incrementally from three different water flows (closed fluid flow at storage tank level for heating at 0°, no flow at 45°, closed fluid flow between storage tank and radiator at 90°), the valve servomotor position is controlled remotely by the user with slider in GUI.

Figures 11 and 12 show respectively, the electric voltage (230 V AC at 50 Hz) and electric current of tilting PV panel inverter output. At the presence of solar radiation, the activated street post lamps (at 11:46) are consuming 7.86 A to light up. The same charts are displayed for air and water hybrid PV panels inverters outputs.

The tilting PV panel and camera DC motors (raise/lower functionality for camera, tilt, and orientation positions of the tilting PV panel) are also controlled remotely by the user with sliders in GUI.

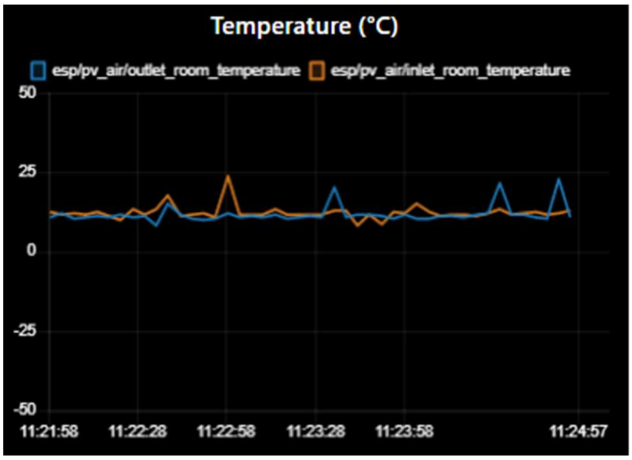

Figure 9 Temperature values chart – PV/T air hybrid panel part

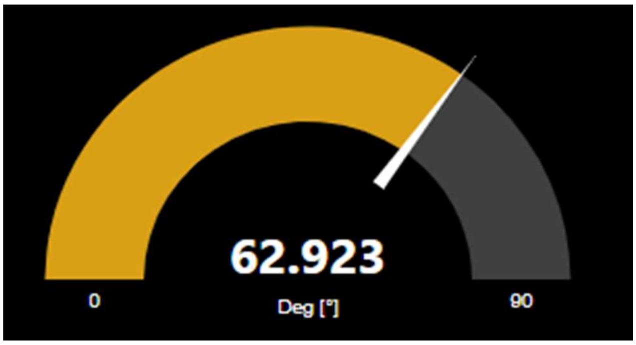

Figure 10: Valve servomotor position - PV/T-water hybrid panel part

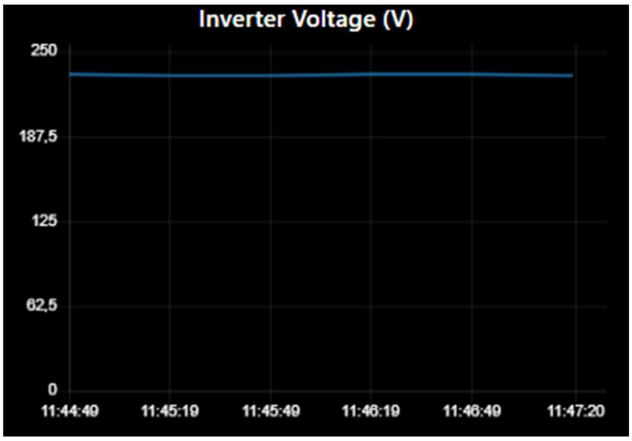

Figure 11: Inverter voltage chart - tilting PV panel part

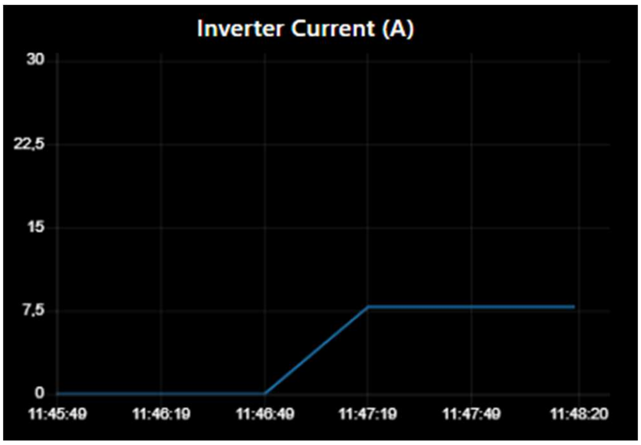

Figure 12 Inverter current chart - tilting PV panel part

VI. Conclusion

SOLLAB includes IoT blocks for PV/Ts, storage, MPPT, smart measurements and IT communication through CAN Bus and web access. Most tools are 'homemade' using low cost and open-source hardware and software. The proposed tools can easily be used for other applications and processes. The next step is the optimization and the energy management of the SOLLAB as an open and shared cyber physical solar energy platform with web-access.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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