PV monitoring system : data logger based on PcDuino a single board computer

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***Abstract* — A monitoring system using IoT technologies is considered in a photovoltaic (PV) system as a crucial part for observing and inspecting the stability and the performance of the system. The photovoltaic data logger is extensively required in a remote PV system for collecting all parameters, estimating and analyzing the system performances and for optimization purposes. Thus, in order to ensure the reliable and stable operation of any PV system, an effective and optimal monitoring system is essential. In this paper, a Bluetooth based wireless system is presented for PV system monitoring, which could collect data in an intelligent manner and monitor in real-time the produced power. The communication between the main components of the system is wireless considering the harsh environmental conditions. The inverter's output power and status are being monitored by the mini-computer PcDuino then the information is transferred over Wi-Fi to a remote host for data storage. To evaluate its performance, the system has been implemented on a 3×2kW PV plants based on monocrystalline, polycrystalline and amorphous silicon technologies.**

Keywords — Photovoltaic installation - IoT - Bluetooth protocol - Real time monitoring - PcDuino board

I. INTRODUCTION

Nowadays, renewable technologies have been given a lot of interest due to their benefits in many aspects, especially the solar photovoltaic systems as they have a potential to shape a clean, reliable, efficient and affordable electricity system for the future. While the number of installed photovoltaic fields is increasing, the necessity of management and optimal energy harvesting from PV plants is of high importance. In order to attain this purpose, a PV monitoring system is required to develop efficient management service by applying IOT technologies. The PV monitoring system provides information about the energy potential, extracted energy, historical analysis of the plant and the status of the PV system. As the data being monitored and stored, it could be used for analyzing the performance of the system, fault detection, sending warnings to the user for equipment damage prevention, and also for AI applications.

The PV power plants are generally built in outdoor environment such as rooftop or desert, so the wireless communication technology is always regarded as the best option over conventional wired system since the wires are exposed to the harsh weather circumstances, and those limitations increases the installation and maintenance cost.

Most of the commercial inverters integrate monitoring options, but they have some limitations that can come into play when considering more advanced monitoring requirements. While designing a monitoring system, the cost and the lifespan are of much importance. Thence, in order to enhance system capabilities an optimal architecture is always pursued.

In this paper, a Bluetooth based wireless system is being developed in an optimal way for real-time data logging. The PV and the output power of the grid inverter are being monitored via Bluetooth protocol and then transferred via internet to a remote database for data storage. As for the evaluation of the proposed system performances, the system has been tested on a 3×2kW PV plants based on monocrystalline, polycrystalline and amorphous silicon technologies at the faculty of science and techniques of Hassan 2 University, Morocco.

II. LITERATURE REVIEW

In order to achieve the prime objective of designing an optimal and low-cost monitoring system, a number of previous works which are related to IoT systems for solar energy have been reviewed.

Even though the proposed system collects data directly from the computing system implemented in the inverters, the monitoring systems that include a weather station and collects data using sensor nodes are presented here in order to gain a better picture on this area of work.

An IoT experimental prototype and open source solution for PV monitoring and data logging have been developed in [1], based on ESP32 board. The ESP32 microcontroller acquires and processes data measured by sensors via the I2C protocol then sends the data to the InfluxDB database using Wi-Fi technology, the data are visualized in Grafana open source platform.

Another IoT system for PV monitoring presented in [2], a Renewable Energy Monitoring System collects data from PV module (Voltage, Current, PV Temperature, solar Irradiance, Ambient temperature, Humidity) and communicate with a developed cloud server. The system consists of a microcontroller-based analog to digital converter of PIC18Fxx5x family which reads the measurements of the analog sensors, and a Raspberry pi in charge of reading the digital sensors and collecting the ADC microcontroller data. The data are transmitted to a cloud server for storage and visualized on a free software web monitor.

Furthermore, an IoT monitoring system to measure an off-grid PV module has been presented in [3]. The data packets are transmitted from node to another one until they reach the central hub, then stored in a local database and displayed in an HTML GUI. The computing system selected to be the central hub is Raspberry pi, which communicates with the Arduino Uno based nodes network to gather the data via Zigbee which had a communication distance up to 50m. In [4], LoRa technology is implemented to assure the data transmission between Arduino Uno based nodes and the central hub (Raspberry pi), for PV plants monitoring.

A real-time monitoring system for a PV system was developed in [5], with an experimental validation on a test bench. The system architecture is an ATmega328P-PU based nodes network, which communicates wirelessly with the main brain via Radiofrequency technology (RF-315). The main brain consists of an SDcard reader used for data storage and a Bluetooth module which communicates with a mobile user interface.

III. SYSTEM ARCHITECTURE

A. Proposed system design

The system is designed to overcome the disadvantages of the existing commercial systems like high installation cost, wired connections and difficult maintenance. The introduced system will have a wireless connection between the main components, and the computing unit that manages the data logging task which is based on a low-cost small-scaled computer (PcDuino).

The PcDuino board acts as the bridge between the PV installation and the internet, it acquires and processes the incoming data from the inverters then they are transmitted to a remote database via Wi-Fi. The photovoltaic installation in which the system will be implemented, consists of three strings composed by three different silicon technologies, every string power outlet is connected to an inverter that collects the energy potential data of the two sides DC and AC and the device status. Data transmission occurs in two steps: The first one is the communication between the inverters and the PcDuino board and the second step is sending the data to a remote database.

In the first place, the monitoring system get the measurements of the total extracted energy per hour, the electrical parameters of the DC and AC sides (voltage, current, Power) and the status (temperature, grid relay status) of the inverter via a wireless Bluetooth technology. The exchange of messages is based on a client and server requests. As the client sends a request for connection and the right commands to get the data, the server is replying with the demanded data. Then they are stored either locally or sent via internet protocol to a distant host. The block diagram illustrated in the figure 1 below, expose the architecture of the system.

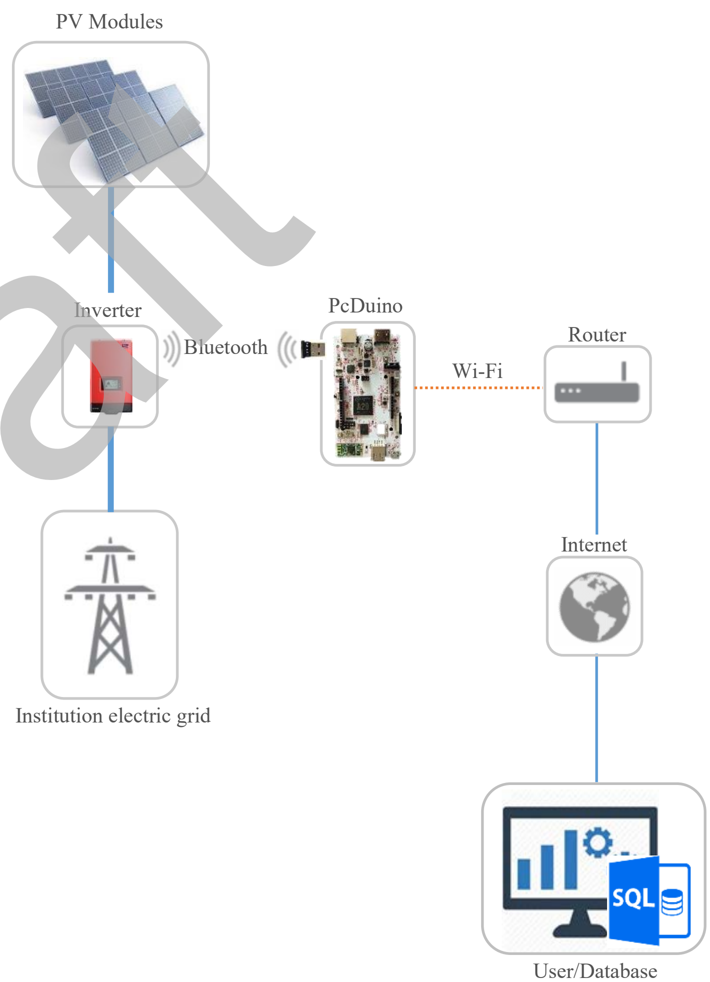

Fig. 1. Block diagram of the overall system

B. *Hardware and software design*

a) *Hardware design:*

The developed system consists mainly of PcDuino Board and a Bluetooth dongle. The inverters installed in the PV strings are from SMA sunny-boy 2000HF series. They have an internal embedded system which measures the parameters of the extracted energy, monitor the performances of the inverter and can communicate wirelessly using Bluetooth protocol.

PcDuino [6] is a high performance, cost effective small computer. It's a Linux-based IOT board compatible with the operating systems Ubuntu and Android. There are multiple versions of this board, the one that we had chosen is PcDuino version 3B (121mm x 65mm) with ARM Cortex A7 Dual Core, 1GHz processor, 4GB Flash and a micro SD slot up to 32GB. It's a mini PC electronic platform **Fig. 2.** with the characteristics of Raspberry Pi, and has an Arduino interface with a built-in Wi-Fi module.

The connection to the internet network is available using either Wi-Fi module or RJ45 ethernet jack. The access to the desktop can be feasible using HDMI port, LVDS LCD interface, serial debugging port or via a graphical desktop-sharing server using internet.

The PcDuino provides an easy tool chains and supports a lot of programming languages such as C/C++, Java, Python and more. Besides, it possesses an API developed to allow access to the functions of the Arduino platform. This board is selected because it reduces the system cost, and considering its multiple features which allows it to connect easily with another hardware, in case we want to extend our system by adding another sensor node.

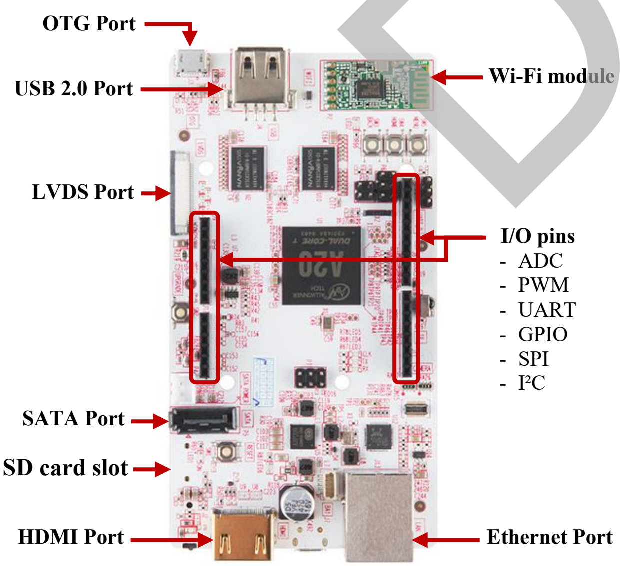

Fig. 2. The mini-computer board used in the system - PcDuino 3B

The Bluetooth Dongle used for this solution is a low energy wireless USB adapter, CSR version 4.0, compatible with all the OS systems with a data rate of 3Mbps and a range of receiving and transmission from 20m to 50m.

b) *Software design:*

The developed software was programmed to interact with a commercial inverter which has a very special circuit architecture and communication protocols. The flexibility of the PcDuino board used as the main controller of the system allows the user to employ different programming languages. In the proposed monitoring system, the software architecture **Fig. 3.** is programmed using Python which is a high-level programming language with simple syntax and a rich open-source library support, also as the controller support Linux based operating system, then Python option is the best choice.

The data logging task is the process of collecting data from the PV system which in the actual case, is managed by the Python software on PcDuino. The program was written to handle the connection with one or many inverters at the same time via Bluetooth technology, and to be adaptable with any modifications or extensions in the monitoring system. At start-up of the PcDuino OS, the program starts running and the communication is established with the network service to get data every 5 minutes, since it's the sampling time of the measurement system inside the inverter. The inverter in our case is the server advertising the service in order for the client to be connected. The client is the PcDuino which sends request messages to the inverter to retrieve the system data. The protocol stack for Bluetooth communication implemented in the inverter's embedded system has an advanced level of security, the client should get authentication from the server in the first place in order to access the device. After the connection is initialized and the system log in to the inverter, a set of requests are sent to get the data measured. The data collection is saved with a timestamp, as the time is an important parameter while collecting data, for this reason the mini-computer must be synchronized for the data to be archived and stored. The date and time are provided from the time server on internet at the start-up of PcDuino and the program is designed to run from the sunrise to the sunset time.

The micro-system in the inverters is designed to operate in the daytime, and to shutdown at the dusk time. The program of the present monitoring system includes a function that calculates the sunrise time and the sunset to define the operating time interval of the system.

As for data storage, the program connects with the remote database over internet via Wi-Fi technology, and proceed with data transmission and storage in MySQL database installed in a remote host located in the laboratory of the faculty.

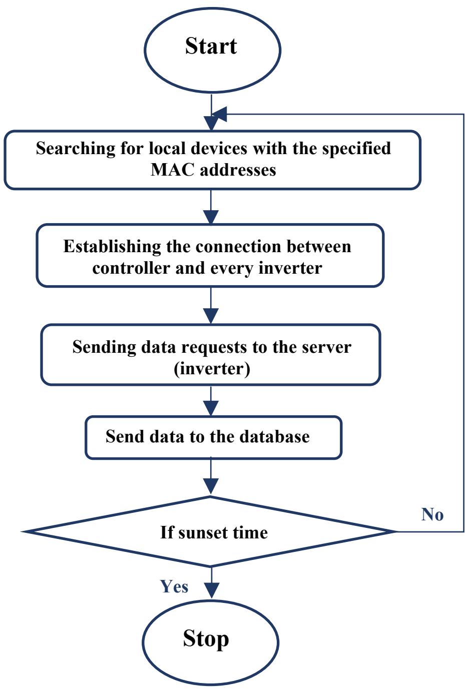

Fig. 3. The flow chart of the software architecture

IV. RESULTS

The system is tested and the real-time data collected from the inverters for half an hour are stored in a database which are shown below **Fig. 4.** A simple selection query in MySQL workbench shows the collection of data with the various rows. Three main parameters are monitored namely Power, voltage and current.

datetime	Serial	Pdc	Idc	Udc	Pac	Iac	Uac	EToday	ETotal	Frequency
2021-03-20 16:16:51	2120246855	0.586	2.482	235.69	0.55	2.39	230.19	2.235	21218.9	49.98
2021-03-20 16:16:55	2120246382	0.577	2.459	234.89	0.533	2.317	230.24	3.136	21338.6	49.98
2021-03-20 16:21:09	2120246855	0.507	2.119	239.85	0.474	2.032	232.62	2.273	21218.9	49.96
2021-03-20 16:21:12	2120246382	0.504	2.146	234.91	0.461	1.983	232.51	3.173	21338.6	49.97
2021-03-20 16:25:26	2120246855	0.376	1.544	243.86	0.347	1.513	229.85	2.315	21219	49.98
2021-03-20 16:25:29	2120246382	0.39	1.676	234.91	0.354	1.536	230.51	3.214	21338.6	49.97
2021-03-20 16:29:43	2120246855	0.988	4.097	241.39	1.059	4.562	232.2	2.366	21219	49.99
2021-03-20 16:29:47	2120246382	1.23	5.147	239.15	1.342	5.777	232.34	3.264	21338.7	50
2021-03-20 16:34:00	2120246855	1.41	5.846	241.32	1.346	5.815	231.62	2.472	21219.1	49.98
2021-03-20 16:34:04	2120246382	1.391	5.82	239.07	1.322	5.699	232.14	3.368	21338.8	49.98
2021-03-20 16:45:17	2120246855	1.383	5.757	240.43	1.324	5.71	231.34	2.549	21219.2	49.99
2021-03-20 16:45:21	2120246382	1.36	5.893	230.73	1.291	5.577	231.54	3.443	21338.9	49.99
2021-03-20 16:49:34	2120246855	1.33	5.659	235.09	1.269	5.482	231.61	2.64	21219.3	49.99
2021-03-20 16:49:38	2120246382	1.307	5.467	239.1	1.239	5.357	231.02	3.533	21339	49.99
2021-03-20 16:53:52	2120246855	1.251	5.369	233.27	1.195	5.157	231.93	2.725	21219.4	49.99
2021-03-20 16:53:55	2120246382	1.238	5.272	234.89	1.175	5.067	231.94	3.617	21339	49.99
2021-03-20 16:58:09	2120246855	1.214	5.124	237.16	1.158	4.958	233.71	2.81	21219.5	50
2021-03-20 16:58:12	2120246382	1.196	5.093	234.91	1.134	4.852	233.82	3.7	21339.1	50.01

Fig. 4. Caption of a data selection on the database

The displayed data are for two inverters each one has a serial ID. The Etotal refers to the total energy extracted since the first installation of the inverter and EToday is the energy extracted in each day. The values of those two parameters change every second while the energy is produced. The DC side power, voltage and current of the first inlet are displayed, the second DC inlet of the inverter is not supplied. In the AC side, the power, voltage and current displayed are for one phase.

datetime	OperatingTime	FeedTime	BTSignal	GridRelay	Temperature
2021-03-20 16:16:51	27042.947	25779.2	71.09	Fermé	24.36
2021-03-20 16:16:55	27165.377	25892.781	67.97	Fermé	26.18
2021-03-20 16:21:09	27043.018	25779.271	69.53	Fermé	24.36
2021-03-20 16:21:12	27165.449	25892.852	71.88	Fermé	25.18
2021-03-20 16:25:26	27043.09	25779.343	69.14	Fermé	24.63
2021-03-20 16:25:29	27165.52	25892.923	71.48	Fermé	25.18
2021-03-20 16:29:43	27043.161	25779.414	69.53	Fermé	24.45
2021-03-20 16:29:47	27165.592	25892.995	71.09	Fermé	24.72
2021-03-20 16:34:00	27043.232	25779.486	69.92	Fermé	24.45
2021-03-20 16:34:04	27165.663	25893.066	71.09	Fermé	24.81
2021-03-20 16:45:17	27043.304	25779.557	71.09	Fermé	24.72
2021-03-20 16:45:21	27165.734	25893.138	71.88	Fermé	27.18
2021-03-20 16:49:34	27043.376	25779.629	70.7	Fermé	25.45
2021-03-20 16:49:38	27165.806	25893.209	71.09	Fermé	26.63
2021-03-20 16:53:52	27043.447	25779.7	71.09	Fermé	25.72
2021-03-20 16:53:55	27165.877	25893.281	71.48	Fermé	28.09
2021-03-20 16:58:09	27043.518	25779.771	70.31	Fermé	26.18
2021-03-20 16:58:12	27165.949	25893.352	71.48	Fermé	28.18

Fig. 5. Caption of data stored in the database

The caption **Fig. 5.** above shows the temperature of the inverter, the grid relay status, the Bluetooth signal strength, the operating time of the inverter and the feeding time. Those information are related to the status of the hardware in the PV installation, so that we can take counter measures in case of fault detection.

The system presented in this paper is an extensible and optimal platform in terms of size and cost, since it's based on an electronic board that doesn't require more external units like ADC thanks to its Arduino interface. That gives us the advantage to use it for other purposes and applications, such as a weather station or if we want to add a sensor node network to collect other data about the health of PV plants. Owing to its multiple features and high computation performances, it was chosen to acquire, process and transmit in real time the collected data. To summarize, the proposed IoT solution has the ability to monitor and supervise the actual PV system and the flexibility to react with another hardware platforms.

V. CONCLUSION

In this paper, the development of a low-cost and wireless monitoring system of PV generated power is exposed, after a discussion and a study of the literature survey of previous works. The main objective of the presented IoT solution is to monitor a PV system and collect its electrical parameters then send the data to a remote computer. The system will be tested and implemented on a PV installation of three strings, each one has an inverter which has an embedded system that measures the energy parameters. The software was developed using Python language, which gets the data from the inverter using Bluetooth protocols and sends it to the database located in a remote computer.

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