REAL-TIME COLLECTION OF THE FUNCTIONAL PARAMETERS FOR A PASSIVE HOUSE

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Abstract - This paper explores the concept of a real-time collection of functional parameters for passive houses and its significance in achieving energy efficiency and occupant comfort. In this case, both the specific parameters of the HVAC system and the electrical parameters will be analyzed with high accuracy. In addition, the microgrid power system application includes wind power, solar power and batteries connected online to the grid to help ensure continuous power supply for the house. The implemented solution aims at various technologies, sensors, and smart meters used for collecting meaningful information in passive houses. It also discusses the role of data analytics and visualization techniques with the purpose of providing a user-friendly interface. For straightforward analysis, all collected information will be stored both in the cloud and on a personal server.

Key words - Passive House; Sensors; Smart Meter; Real-time data; Cloud

1. Introduction

Passive houses have emerged as a groundbreaking concept in sustainable building design, completely changing the paradigm by which we relate to energy-efficient houses. The novelty elements found in this project are highlighted by the inclusion of several control, monitoring, and reporting equipment from several manufacturers, in a unitary, comprehensive, and user-friendly whole. The main advantage being scalability and the possibility of versatile upgrades in the future. A passive house is, in fact, a concept of a house with the highest level of comfort, without substantiating any energy standard. Instead, it must comply with the ISO 7730 standard which refers to perceived thermal comfort. These comfort indices must be achieved under very good indoor air quality conditions, by post-heating or post-cooling the fresh air introduced, without the need for additional recirculation.

To comply with the passive house standard, several things must be met: 120 kWh/m^{2}yr (conventional primary energy consumption); 0.6 air changes per hour (through leaks); The indoor temperature can deviate by a maximum of 10% of the time from the comfort temperature during the summer period [1].

This concept comes with the promotion of scenarios where a home becomes smart, interconnected, secure, automated, save energy, environmentally friendly, and very well monitored. This entire conceptual assembly must be consistent with Directive 2018/844 (EU) of the European Parliament and the Council amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. According to the analyzes carried out by the European Union, it was found that approximately 50% of the final energy consumption is used for heating or cooling. Of this total, 80% is represented by buildings [2].

According to the latest strategic approaches, the ZERO PLUS Energy buildings concept was adopted, which complements the general concept of Nearly Zero emission buildings (nZEB). Also, attention is focused on the Next-generation Energy Performance Assessment and Certification (LC-SC3-EE-5-2018-2019-2020) [3].

Passive houses need to be properly planned and constructed with optimal energy management that is continuously monitored by automated systems. In contrast to conventional methods that use heating sources derived from gas or fossil fuels and air conditioners. Both produce toxic gasses that contaminate the environment. When using geothermal sources, they are best suited for winter heating and should not be suitable in the summer. The solution for Passive House prioritizes using sources entirely from renewable energy sources in conjunction with subterranean air sources to supply the houses with a temperature differential (warmer in the winter and cooler in the summer) and conserve energy sources that are required for air cooling or heating. In the Passive House, it is possible to save 75% of energy when warming the air compared to previous conventional methods [1]. In addition, using IoT to monitor, track and automatically adjust temperature in real time helps save energy more specifically and clearly.

It is necessary to implement an on-site power generation system from renewable energy sources or use of Combined Heat and Power system in addition to an already high-efficient building, in this case, a Passive House. Applied to this situation, it means that the energy produced during a year must exceed the consumption during this period. In order to fulfill the electrical needs of end users, a smart grid is a sort of electricity network system that uses digital technology to monitor and regulate the transportation of electricity from all generation sources. The main advantages over a conventional electricity system are its efficiency and sustainability. Advanced metering infrastructure and grid automation lead to a very good integration of renewable energy sources and support the development of electric transport infrastructure.

This building is actually a two-storey duplex (EAST House + VEST House) that has 2 sources. In addition, wind power can be used in hybrid with solar power, moreover, the battery-powered storage system converts battery power into AC power via an inverter that is connected to the grid online to support the home's continuous power supply. This kind of micro grid system is used in smart houses right now. Considering that, this microgrid source as well as two distinct HVAC solutions [4].

EAST House has installed a 4 kW photovoltaic system alongside an efficient HVAC system equipped with a soil-air heat exchanger and the VEST House has a 3 kW photovoltaic system which adds a ground-water heat pump. Administering the flow of electricity produced by the photovoltaic system is realized by an Inverter/Charger Victron MultiPlus for both houses. The first house has a hybrid system that is simultaneously ON/OFF-GRID connected to a 12 kWh battery pack, and the second house has an ON-GRID system connected to a 10 kWh battery pack. Monitoring of electricity produced, consumed, or injected into the grid is achieved in several ways. The real-time data about these energy parameters are taken over by the Cerbo GX communication center of the manufacturer Victron and they are transmitted via Modbus TCP IP to an online flow-based programming tool. The second way of transmitting energy parameter information is made with 3 smart meters connected via Modbus Serial to a Programmable Logic Controller (PLC). It also collects temperature values from resistive temperature sensors mounted on the HVAC system, as well as airflow. The PLC forwards the received information to the same online flow-based programming tool, NodeRed.

This monitoring solution is based on Decentralized Smart Architectures that exchange data through a bundle of MQTT (Message Queuing Telemetry Transport) subscribers and publishers. The proprietary e!COCKPIT software is used to configure the PLC, where we can find an MQTT library that allows us to store the data on the local network. For both safety and remote information access, entire data will be saved on Cloud. Grafana represents an open-source analytics and monitoring solution. With this online platform, we can create real-time graphs and statistics with all parameters. Figure 1 shows the infrastructure of a passive house.

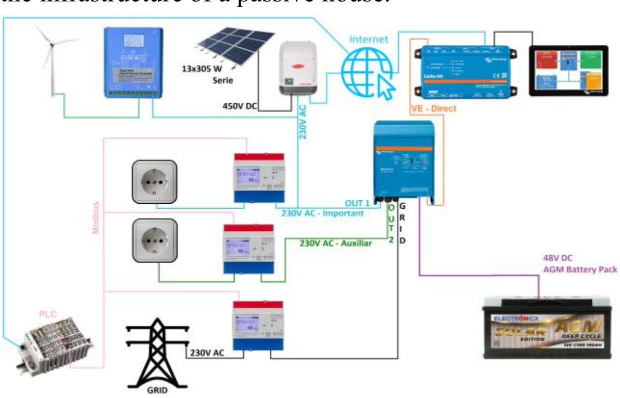


Figure 1. *Hybrid power system from EST Passive House*

2. The passive house case study

In the realm of sustainable design and energy efficiency, passive houses stand as a testament to our ability to harmonize residential living, environmental responsibility, and the highest level of technology. This case study delves into the intricacies of a real-world passive house, offering detailed insights into its design, equipment configuration, programming tools, and performance aspects. From the initial concept stages to the house's day-to-day operation, this case study aims to highlight the challenges encountered, solutions implemented, and the results achieved. We will mainly discuss the most complex installation, that of the EST passive house [5].

It all started with the physical mounting of electrical equipment and sensors. In the first stage, smart energy infrastructure was created. It is about the Hybrid photovoltaic system that can work both as an OFF GRID and ON GRID system simultaneously. This photovoltaic system and wind turbine are AC coupled. In ON GRID mode, the energy from the photovoltaic panels [6] is taken via MPPT and converted into 230V AC. This energy is taken by the bidirectional "OUT 1" port of the main inverter and distributed to the important and auxiliary equipment, also on the battery.

Surplus energy is injected into the Grid and measured with the help of a bidirectional Smart Meter. This is possible through a legal agreement with a prosumer contract. Important equipment will be powered even in the event of a power outage. This energy mixture is created by combining the energy generated by the solar system or from a wind turbine as appropriate, with the energy drawn from the battery. The main inverter behaves like a UPS and the switch to the battery is made in 20ms, practically no electrical equipment will feel this.

In the event of a power failure, the auxiliary equipment will be disconnected instantly in order not to consume energy unnecessarily. In its current form, this equipment can also work OFF GRID, completely in the absence of the GRID. By simply disconnecting the main inverter from the power, a Micro-Grid is created instantly, where the MPPT varies its voltage, current, frequency, and harmonics parameters, according to consumer needs. The communication between the MPPT and the main inverter is done through an IP address using the Cerbo GX communication center. Data exchange is in real-time directly through the network switch. The retrieval of information about electrical parameters of the energy infrastructure is carried out in 2 distinct methods.

The first method concerns the acquisition of Smart Meter data with a PLC. Their connection is on Modbus RTU and in the programming software of the PLC, e!COCKPIT, where is a library of block diagrams, with predefined functions implemented. A basic principle in programming a communication interface, applied in this case, is that the main entities that exchange data through the Broker are the Publisher and the Subscriber. The data flow is transmitted in one direction and starts when the publisher gives a message on a certain topic. We used the “FbMbServerSerial” block, which allows setting the baud rate, parity, address of the smart meters, and the code function that will be accessed. Also, it is responsible for managing the serial communication interface and the Modbus protocol. It sends Modbus requests to the slave devices, waits for responses, and handles any errors or exceptions that occur during communication.

After the PLC has been configured to take data from the smart meters, it will send the information to an online processing platform. The PLC may connect with other gadgets, servers, or systems via MQTT. This can make a variety of features possible, including data recording, remote PLC monitoring and control, and PLC integration with other systems for Internet of Things applications. Typically, library functions supplied in the e!COCKPIT programming environment are used to create the MQTT capability in this PLC. To develop an MQTT client that can connect to a broker or server, use the “FbClientMQTT” function block. This function block handles the details of establishing the connection, including parameters like the server's IP address and port number, as well as the client's username and password for servers that require authentication. Then we will use the “FbPublishMQTT” function block to publish messages to a topic on the MQTT broker. Finally, it is necessary to implement the “FbSubscribeMQTT” function block for subscribing to a topic from the broker.

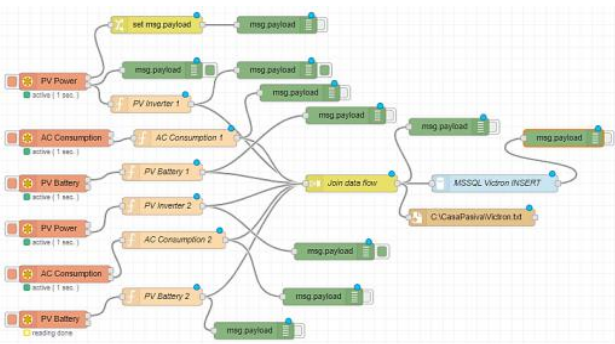


Figure 2. *NodeRed - data flow from Victron comunication-center*

Once subscribed, it can receive any messages that are published on that topic. In this case, data is collected on active and reactive power, frequency, voltages, current, also active and reactive energy… in Figure 2, these signals will be encoded into data flow sent to the Victron communication center.

The JavaScript code can be run against the messages that are passed through it, by using the function node. Therefore, the message will transit to an object called msg. The “msg.payload” property will contain the body of the message. Figure numbered 3,4,5 represents an example for the implementation of a complete program in NodeRed, they show that signals from measurement sensors are encoded as data flow for simpler information processing. A flow of acquisition data from various equipment is displayed here, with the aim of storing it in a database and later publishing it in an online portal. The JOIN function is used to combine multiple messages coming from multiple sources into one. In this case, concretely, we have several different sensors, or several smart meters, as the case may be, and the data published by them want to be entered into a common database with a single entry.

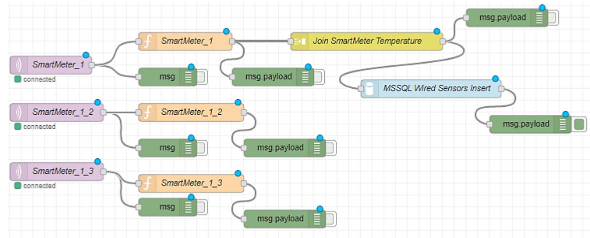


Figure 3. *NodeRed - data from Smart Meters*

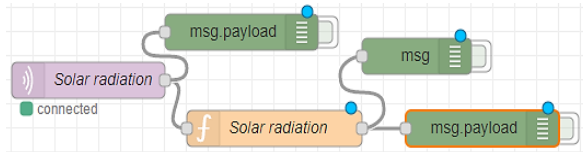


Figure 4. *NodeRed - data flow from pyranometer*

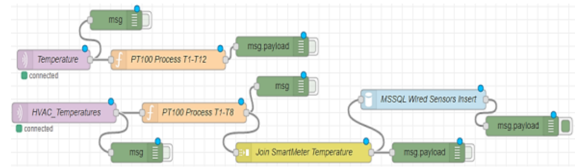


Figure 5. *NodeRed - data flow from temperature sensor*

The second method of data acquisition is from Cerbo GX through the Modbus TCP IP communication protocol. There is a platform owned by the manufacturer where all the data about the entire infrastructure of the photovoltaic system are displayed in real-time. VRM Portal is an online interface that allows system configuration. We can have remote access, also it can generate graphs and statistics about electricity production, consumption, voltage, battery state of charge, and many other information. Both from the PLC and from the VRM Portal interface we export the data to NodeRed.

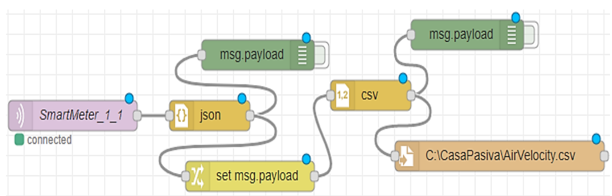


Figure 6. *NodeRed - data flow from air velocity sensor*

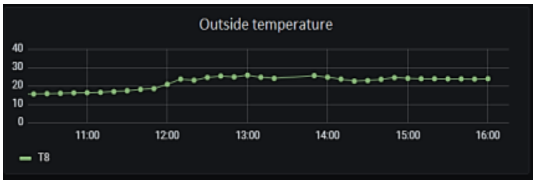
The temperature sensors are positioned strategically to achieve the most accurate measurement. Each HVAC system sensor is mounted as close as possible to the central ventilation unit to precisely determine its efficiency. A popular open-source real-time values analytics software is Grafana. Applications have a lot of panel types, like a histogram, graphs, gauges, tables, heatmaps, and custom text. Alerts can also be sent to various other platforms when deviations are recorded from analyzed parameters, whose limits have been set by the user. In a single graph, combine data from many sources. In addition to a time series structured values and also have a graph that displays information from a SQL (Structured Query Language) database. Grafana supports a wide variety of data sources, including Microsoft SQL. This was also used in our project to display the values measured by smart meters, and all other sensors.

The messages are sent in JavaScript Object Notation (JSON) to any network devices that subscribe to predetermined topics. JSON is an accessible information structure and easy to corroborate between various programming languages. The software is then set up to establish a connection to the database and translate the JSON formatted messages. These are taken over from MQTT subscriber nodes and subsequently converted into SQL requests.

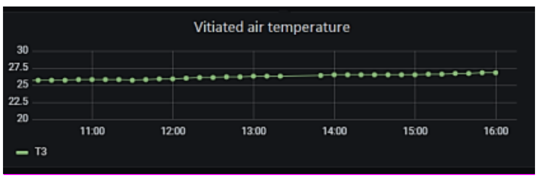
In NodeRed the MSSQL database is created which will then be added as a data source in Grafana. Thus, dashboards can be created using information present in the respective database. SQL is used to communicate with a database and can perform various tasks on it like executing queries, retrieving data, updating records, creating, and modifying databases, tables, stored procedures, and more. At the same time, the graphs can be easily customized and allow the user to decide how the analyzed data is displayed.

For even more accuracy to understand the logic behind the creation of this system, it is necessary to create an algorithmic flow diagram Figure 6.

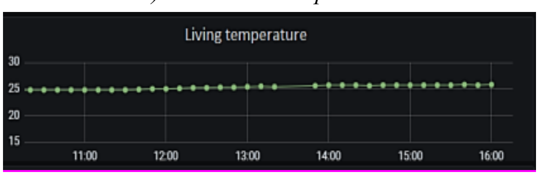
Figure 7 briefly expresses the structure of the studied technical model and the main communication protocols used. In this context, the PLC plays the role of publisher for the MQTT communication protocol. The NodRed application subscribes to the messages from the Broker that mediates all the communications.



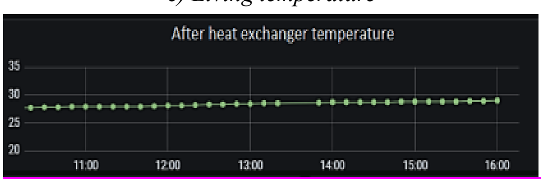
a) Outside temperature



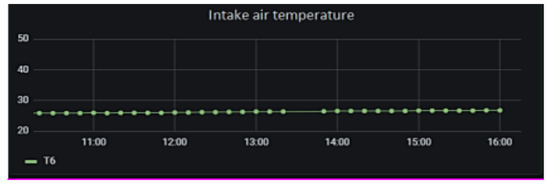
b) Vitiated air temperature



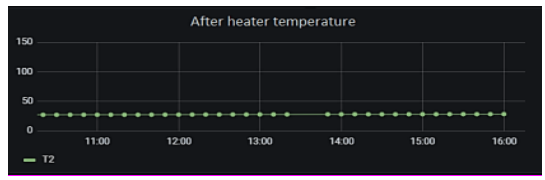
c) Living temperature



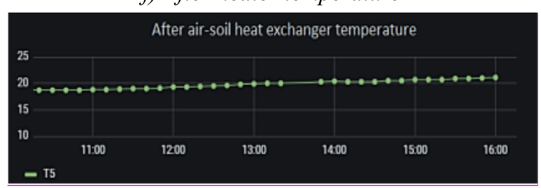
d) After heat exchanger temperature



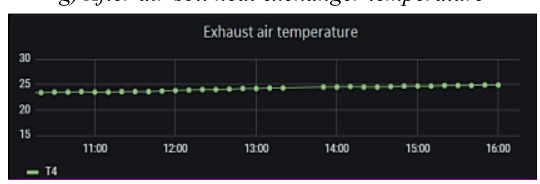
e) Intake air temperature



f) After heater temperature



g) After air-soil heat exchanger temperature



h) Exhaust air temperature.

Figure 7. *Grafana - Graphs of HVAC system temperatures*

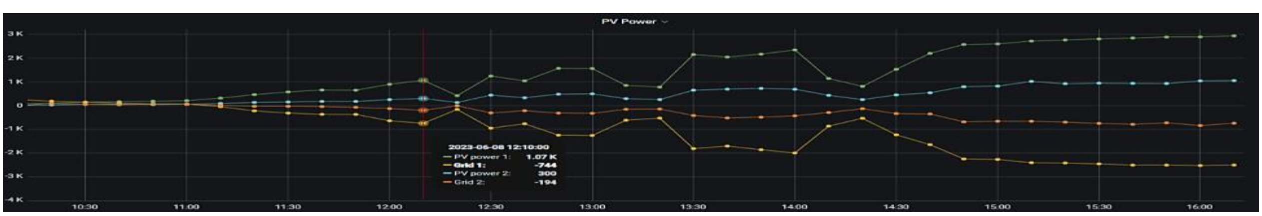


Figure 8. *Grafana – PV Power graphs*

3. Results of collection data

All the data obtained after the measurements of the functional parameters in the passive house are stored in the database, on the personal server, and are displayed both in Grafana and in the VRM Portal. Each graph is explicit and expresses a parameter customized by each user. Also, their update time can be modified by the user to adapt to his needs, it can be every 10 minutes, or every 100 ms.

Figure 8 represents the temperature variations recorded by the sensors that are mounted in various positions on the ventilation system with heat recovery. At the same time, the outside and the living room temperature is also observed here. These temperatures are expressed in degrees Celsius.

Figure 8 shows the variation of the power injected or consumed from the grid for both houses, EAST and WEST House. These powers are expressed in KW. Figure 9 shows the voltage variation on one of the system's battery packs, as well as the variation of the electric current absorbed from them. The display scales and the analysis period can be customized by the user directly from Grafana.

The analysis of the observed values is accelerated significantly by integrating all this data into one platform, which also enables the development of an energy efficiency improvement strategy. The patterns of HVAC system use and temperature fluctuations may then be identified and compared. These statistics can be accessed remotely even from your smartphone. For security, all data can be stored on third-party devices.

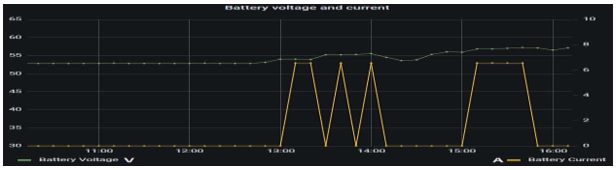


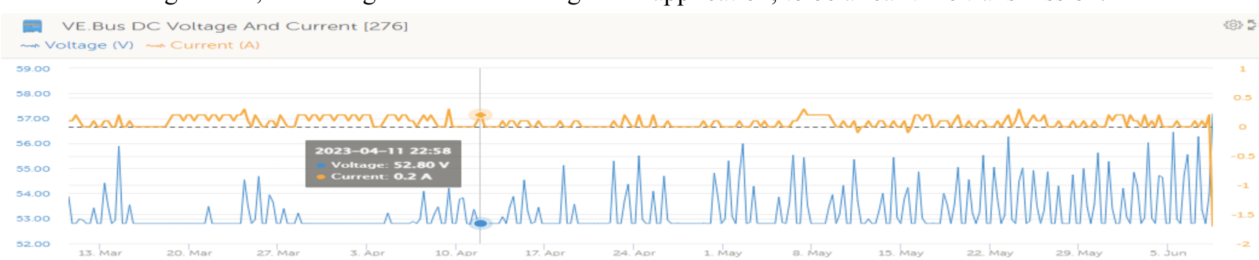
Figure 9. *Grafana – Battery voltage + current graphs*

The purpose for which the analysis of electrical parameters is carried out by two methods is to create a more diversified overview of the methodologies that a user can apply to their system, or that he wants to build it. In practice, there is already an advanced and complex system for monitoring electrical parameters directly from Victron equipment, but to extend the investigation to other equipment from different brands, it is necessary to implement an assembly like the one presented previously.

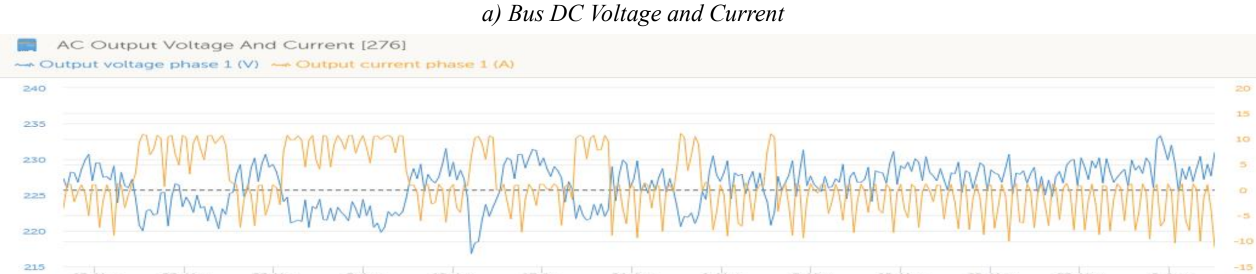
Figure10 is taken from the VRM Portal and highlights various electrical parameters output including DC voltage and current in Figure 10a, AC voltage and current in Figure 10b and output load power in Figure 10c but this time the measurements are taken by the main inverter and reported via the Cerbo GX communication center. The figure shows the values for the power absorbed or injected into the network, as well as the AC voltage and current, but the DC voltage and current measured by dedicated sensors on the battery pack.

The limitations of this equipment are also important to know. The maximum baud rate that the Modbus RTU protocol on RS485 can reach is 115200, and that of the MODBUS TCP/IP protocol is 100 Mbit/s. Regarding the reliability of message delivery, the MQTT protocol allows the adjustment of some parameters. For example, QoS (quality of service) level 2 ensures that each message is sent exactly once to the receiver. Referring to data security, MQTT allows users to implement special security measures, such as username and password login, TLS encryption, and client certificate authentication. The speed of data transmission can be influenced by several factors, including: PLC processing speed, network capacity and latency, MQTT protocol optimization, chosen communication security, and message size and frequency.

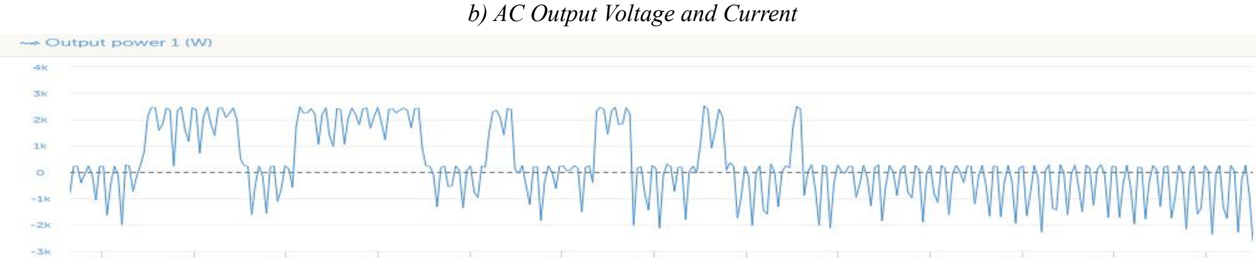
As a result, the transmission speed between a PLC and a server also depends on the nature of the installation in which the ensemble operates. Applied to this project, the reception of information in the Grafana platform is carried out in the order of milliseconds, considered, for this type of application, to be a real-time transmission.



a) Bus DC Voltage and Current



b) AC Output Voltage and Current



c) Output power 1

Figure 10. *VRM Portal graphs*

4. Conclusions

The real-time data retrieval procedure aims to analyze the electrical and thermal parameters of the passive house to create an efficient and applied plan to increase energy efficiency and reduce environmental impact by lowering energy consumption. The Hybrid system for managing the flow of electricity produced from renewable sources is one of the most advanced and versatile systems that allow simultaneous ON GRID and OFF GRID operation. Using PLCs to acquire data from a multitude of sensors or measuring devices represents an efficient and scalable solution that allows the configuration of the most laborious databases. The MQTT protocol, which manages the Internet of Things devices, is used for communication between the sensors, smart meters, and PLC. The protocol served as a foundation for data transfer between IoT devices. The online cloud data processing platform as well as the graphical data monitoring and analysis solution is a user-friendly, open source, and very customizable solution for users, allowing remote access at any time.

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REFERENCES

[1] Passipedia, “The Passive House – definition”, *Passipedia.org*, 2023. [Online]. Availabe: https://passipedia.org/basics/the_passive_house_-_definition, [Accessed: June 02, 2023].

[2] The European Union, “The energy performance of Buildings Directive -2018/844”, *eur-lex.europa.eu,* 2018. [Online]. Availabe: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG; [Accessed: June 02, 2023].

[3] The European Union, “High energy performing buildings: Support for innovation and market uptake under Horizon 2020 Energy Efficiency”, *op.europa.eu,* 2020. [Online]. Availabe: https://op.europa.eu/en/publication-detail/-/publication/d8e3702d-c782-11e8-9424-01aa75ed71a1; [Accessed: June 03, 2023].

[4] *Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*, ISO 9060:2018, 2018.

[5] V. Tanasiev, G.C. Patru, D. Rosne, G. Sava, H. Necula, and A. Badea, “Enhancing environmental and energy monitoring of residential buildings through IoT”, *Automation in Construction,* vol. 12, no. 103662, pp. 1-13, 2021.

[6] M. Q. Duong, N. T. N. Tran, G. N. Sava, and V. Tanasiev, “Design, performance, and economic efficiency analysis of the photovoltaic rooftop system”, *Rev. Roum. Scie.–Techn. Électrotechn. et Énerg*, vol. 64, no. 3, pp. 229-234, 2019.