Implementação de sistema inteligente de aquisição de dados com indicadores de desempenho para miniusina solar fotovoltaica

Implementation of intelligent data acquisition system with performance indicators for solar photovoltaic mini-plant

DOI:10.34117/bjdv7n4-078

Recebimento dos originais: 07/03/2021
Aceitação para publicação: 05/04/2021

Ivan Alan Soares
Mestre em Engenharia Química, UNIFAL, Brasil
Endereço: Rodovia José Aurélio Vilela, BR 267, Km 533 11999 - Cidade Universitária, Poços de Caldas/MG, 37715-400
E-mail: ivan.devwork90@gmail.com

Izabella Carneiro Bastos
Doutora em Engenharia Elétrica, Montanuniversitaet Leoben, Áustria
Endereço: Rodovia José Aurélio Vilela, BR 267, Km 533 11999 - Cidade Universitária, Poços de Caldas/MG, 37715-400
E-mail: izabella.carneiro@unifal-mg.edu.br

Daniel Oliveira Guimarães
Mestre em Engenharia Química, UNIFAL, Brasil
Endereço: Rodovia José Aurélio Vilela, BR 267, Km 533 11999 - Cidade Universitária, Poços de Caldas/MG, 37715-400
E-mail: doguimaraes03@gmail.com

ABSTRACT
The electricity generation performance in a photovoltaic system can be improved by precise monitoring of electrical and meteorological parameters. Disruptions in electrical parameters are caused by unreliable climatic variables, degradation of the photovoltaic system, and errors. The main purpose of the present work is the development of a data acquisition and monitoring system for time series data storage for subsequent analyses of the solar photovoltaic mini-plant located at the Poços de Caldas campus of the Federal University of Alfenas. The developed system exhibits the collected parameters as well as the performance metrics calculated by numerical modeling. For this purpose, a data logger, web server, REST API and a responsive web application were created.

Keywords: Photovoltaic systems, Cloud-Based Data Acquisition System, Performance Indicators.

RESUMO
O desempenho da geração elétrica em um sistema fotovoltaico pode ser aprimorado pelo monitoramento preciso dos parâmetros elétricos e meteorológicos. As interrupções nos parâmetros elétricos são causadas por variáveis climáticas não confiáveis, degradação do sistema fotovoltaico e erros. O objetivo principal do presente trabalho é o desenvolvimento de um sistema de aquisição e monitoramento para armazenamento de dados de séries temporais para análises posteriores da miniusina solar fotovoltaica

localizada na Universidade Federal de Alfenas, campus Poços de Caldas. O sistema desenvolvido exibe os parâmetros coletados, bem como as métricas de desempenho calculadas por modelagem numérica. Para tanto, foram criados um registrador de dados, servidor web, API REST e uma aplicação web responsiva.

Palavras-chave: Sistemas Fotovoltaicos, Sistema de Aquisição de Dados Baseado em Nuvem, Indicadores de Desempenho.

1 INTRODUCTION

Rising energy demand and the innumerous studies aimed at reducing environmental effects from the use of non-renewable energy have led to clean energy-generation technologies having a major global presence. Among the various renewable technologies, solar energy is clean, unlimited, and durable. Photovoltaic (PV) technology is currently the most effective way to harness solar energy to produce electricity (PARIDA et al., 2011).

Companies or homes can use energy generated by solar PV systems. Despite the high initial acquisition cost of these systems, when properly designed, their low maintenance and service costs leads to better investment returns and excellent cost efficiencies (BALFOUR et al., 2016).

While the solar energy received by a PV system is high, there are many factors affecting its output of electrical energy; for example, location, solar irradiation rates, climate conditions, and various types of power loss throughout the plant/system (WOYTE et al., 2014).

The electrical parameters and deviations related to the PV design and the numerical modeling are associated with climatic conditions, and degradations and errors in PV components, among other things. Innumerable variables, such as sensitivity to the PV components, environmental conditions (RAHMAN et al., 2015), and the consumption period, can cause this deterioration (AZIZI et al., 2018).

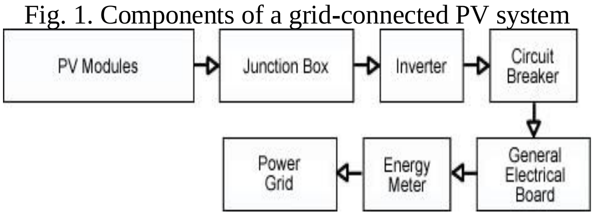
In contrast to the design data of the PV system, effective monitoring of electrical and meteorological parameters may detect reduced efficiency in the PV system, by indicating faults or differences in relation to the expected result. The data acquisition system will periodically collect these parameters through the use of sensors and recorders, and the information gathered can be easily presented on a computer interface (ULIERU et al., 2011).

The aim of this present study was the development of a remote data management and monitoring system for a solar PV mini-plant at the Poços de Caldas campus of the Federal University of Alfenas, to assist in visualizing and verifying the empirical data and numerical modeling data required by the system, as well as comparing the developed system with a commercial data acquisition system already available on the market.

2 GRID-CONNECTED PV SYSTEMS

Grid-connected PV systems account for a much larger share of the world's installed PV capacity than autonomous or independent systems. Grid-connected PV systems transmit the energy generated directly to the grid, thus eliminating the need to store it locally. Due to their practicality, grid-connected systems require minimal maintenance and reinvestment, which is very profitable (KOURO et al., 2015). Figure 1 shows the principal components of a grid-connected PV network.

Fig. 1. Components of a grid-connected PV system



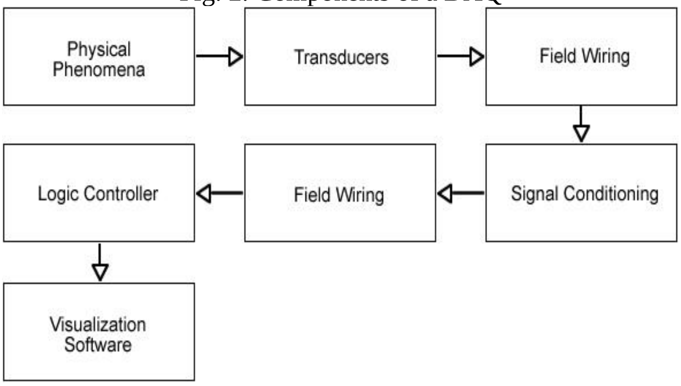
The energy production of the PV modules is concentrated in the junction box or string box, which is the component responsible for the union of the PV strings. Due to the standard used by the power grid, it is then necessary to convert the direct current produced by the modules into alternating current. After the current conversion by the inverter, the energy flows through the meters and is transmitted to the power grid. The circuit breaker is an important electromechanical device that guarantee the safety of the PV system and disconnect it from the power grid when necessary (KUMAR et al., 2018).

3 DATA ACQUISITION SYSTEM

Data acquisition systems (DAQ) aid in the control and validation of applications. They are used in many types of projects, to collect data about physical phenomena and present these data intelligibly to the user. They are commonly used by engineers and scientists who need to evaluate time series to forecast future events or to make decisions about current behaviors. DAQ use devices capable of calculating current and voltage signals for data collection. The basic components of a DAQ are as follows (EMILIO, 2013):

- Sensors and transducers
- Field wiring
- Signal conditioning
- Hardware
- Software
- Computer (with an operational system)

Fig. 2. Components of a DAQ



4 ENERGY EVALUATION IN PV SYSTEMS

Meteorological conditions and other irregular variables have a significant effect on the efficiency of solar PV systems; therefore, it is very important to ensure that the system is operating as intended. The location of the plant, the level of solar radiation or temperature conditions, and various types of energy loss can affect the efficiency of the PV system (WOYTE et al., 2014). The quality evaluation of the solar PV system can be done using performance parameters (HAIBAOUI et al., 2017) such as total energy provided by the PV system, conversion efficiency of the DC/AC inverter, yield of the inverter and the PV array, system yield, performance rate, and capacity factor. These performance parameters can be the result of measurements or obtained by mathematical modeling. The parameters detailed in the following subsections were used in this present study.

4.1 DC/AC INVERTER CONVERSION EFFICIENCY

The DC/AC inverter conversion efficiency represents how much DC power has actually been converted to AC. This metric is given by the ratio between the AC output power and the DC input power of the inverter (Pearsall, 2016). The DC/AC inverter conversion efficiency is obtained using Equation 1:

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} \quad (1)$$

where ηinv is the inverter's DC/AC conversion efficiency,PAC is the ACoutput power, and PDC is the inverter's DC input power.

4.2 INVERTER YIELD

The inverter yield is the ratio between the inverter's output power and nominal power, and it is used for comparisons between PV equipment (THERISTIS et al., 2018). The inverter yield is obtained using Equation 2:

$$Y_{inv} = \frac{E_{AC}}{P_{nom}} \quad (2)$$

where Yinv is the yield of the inverter, EAC is the power output of the inverter, and Pnom is the inverter's nominal AC power.

4.3 PV ARRAY YIELD

The yield of PV arrays or modules can assist with comparisons of PV components. This parameter is the ratio between the direct current produced by the device/module and the nominal power (IEC, 2017). The PV array yield is obtained using Equation 3:

$$Y_A = \frac{E_{DC}}{P_{nom}} \quad (3)$$

where YA is the yield of the PV array, EDC is the energy generated by the PV array, and Pnom is the nominal DC power of the array.

4.4 FINAL YIELD OF THE PV SYSTEM

The final yield of the PV system can assist in comparisons between PV plants (IEC, 2017), by enabling the performance of systems to be verified in relation to their nominal power. The final yield of the PV system is obtained using Equation 4:

$$Y_f = \frac{E_{AC}}{P_{nom}} \qquad (4)$$

where Yf is the final PV yield, EAC is the total energy generated by the PV system, and Pnom is the nominal AC power of the PV system.

4.5 CAPACITY FACTOR

The capacity factor is normally used to measure the performance of solar PV systems. This metric measures the output produced if all the installed power in the system is generated without interruption (IEC, 2016). Equation 5 shows the definition of the capacity factor.

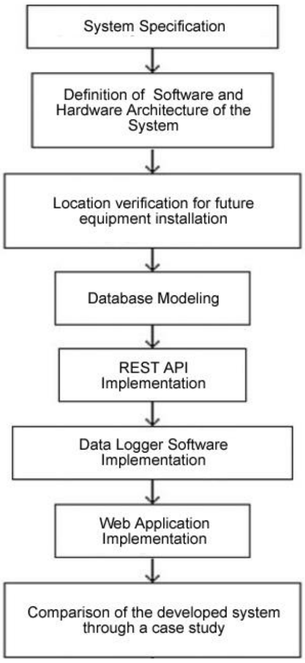
$$CF = \frac{Y_f}{\Delta T} \qquad (5)$$

where CF is the capacity factor, Yf is the final yield of the PV system, and ΔT is the time period measured.

5 MATERIALS AND METHODS

Figure 3 illustrates the technical approaches for constructing the DAQ for the PV mini-plant.

Fig. 3. Methodological procedure



- In order to define all the appropriate system actors and functionalities, the data management system has been defined. The documentation was developed using of UML notation and text representation diagrams.
- The architecture and technologies used for the development of the system were defined with the purpose of enabling the construction of the system within the expected time and with current technologies.
- Database modeling was conducted to allow quick queries and to maximize long term data storage.
- A REST API has been developed to facilitate connectivity and to allow communication between the web application (Interface) and the database.
- The Data logger is responsible for storing and transferring data from measurement devices to the server network remotely.
- To make it possible to view and download the collected data, a web application was implemented.
- Comparison of the system developed with a commercial data acquisition system through a case study of the photovoltaic solar mini-plant installed at the Federal University of Alfenas, Poços de Caldas campus.

5.1 THE SOLAR PV MINI-PLANT

The case studied in this work was the solar PV mini-plant installed at the Poços de Caldas campus of the Federal University of Alfenas, which is located in the city of Poços de Caldas, at latitude -21.8203908 and longitude -46.6619972 (see map in Fig. 4).

Fig. 4. Location of the Poços de Caldas campus of the Federal University of Alfenas.

The PV mini-plant is operating in buildings F and G of the university campus. It consists of PV modules with a maximum capacity of 84.36 kWp. The project was set up as a grid-connected system with no batteries available. Figure 5 shows the PV modules that have already been installed in building F.

Fig. 5. PV modules installed in building F

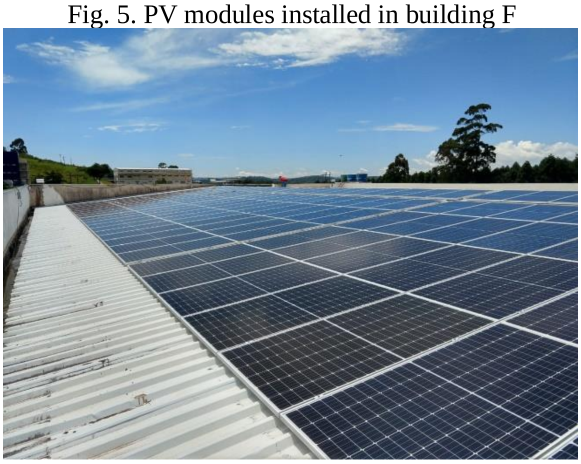


Figure 6 shows the inverters previously installed in building F.

Fig. 6. Inverters installed in building F

Table 1 shows the general specifications for building F components.

Table 1. DC power generated by building G strings

Inverter	Modules	Module power	Total power
Fronius Symo 15 kW 3F/N 220/127V	38	370 W	14.06 kW
Fronius Symo 15 kW 3F/N 220/127V	51	355 W	18.105 kW
Fronius Symo 15 kW 3F/N 220/127V	51	295 W	15.045 kW

The PV modules installed in building G can be seen in Figure 7.

Fig. 7. PV modules installed in building G

The inverters installed in building G are shown in Figure 8.

Fig. 8. Inverters installed in building G

ISSN: 2525-8761

Table 2 shows the general specifications for building G components.

Table 2. DC power generated by building G strings

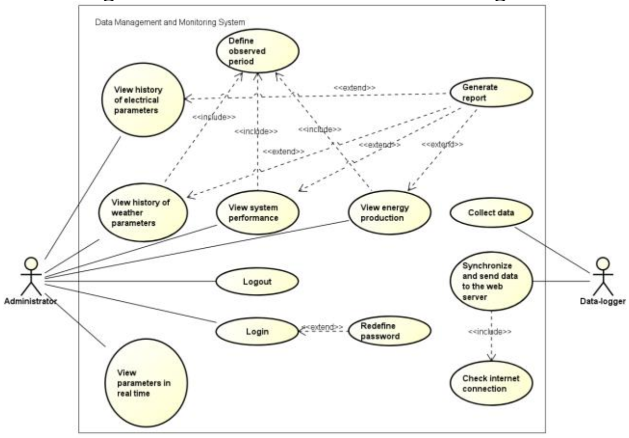
Inverter	Modules	Module power	Total power
Fronius Symo 15 kW 3F/N 220/127V	51	295 W	15.045 kW
Fronius Symo 15 kW 3F/N 220/127V	51	300 W	15.300 kW
Fronius Symo 5 kW 1F/N 220/127V	15	355 W	5.325 kW

5.2 THE DATA ACQUISITION SYSTEM (DAQ)

5.2.1 Data Acqusition System Features

A diagram of use cases, as can be seen in Figure 9, was built to show all the functionalities of the system

Fig. 9. PV modules installed in building G



.

Figure 9 shows the representation of two actors in the system. The actors, use cases and their respective objectives in the monitoring system are presented in Table 3.

Table 3. Use cases and their objectives

Actor	Use Case	Objective
Administrator	Login	Allow user access to the system.
Administrator	Logout	Logout and prevent user access to the system.
Administrator	View parameters in real time	Present in table format electrical and meteorological parameters captured at each time period.
Administrator	View history of weather parameters	Present, in table and graph format, the meteorological parameters acquired through the solarimetric station.

Administrator	View system performance	Present in table format and charts evaluations about the performance of the photovoltaic system.
Administrator	View energy production	Present in a table and chart format information about the energy production of the system.
Administrator	Define observed period	Select the time period for delimiting the information presented.
Administrator	Generate report	Issue reports regarding the chosen information.
Data-logger	Collect data	Capture, validate and save data in the local database.
Data-logger	Synchronize and send data to the web server	Synchronize the web server database with the local database.
Data-logger	Check internet connection	Checks for internet connection.

5.2.2 Measurement Equipment

5.2.2.1 Energy meters for measuring electrical parameters

The measurement equipment and sensors used to capture electrical parameters were installed in the mini-plant's automation system. Table 4 lists the equipment (meters) used.

Table 4. Equipment for measuring the electrical parameters

Equipment	Usage
SCK-M-I-8S-20A	Direct current measurement for each string.
SCK-M-U-1500V	Measurement of continuous strings' voltage.
MA250	Measurement of inverters' electrical parameters (e.g., current, voltage, frequency, harmonics, etc.).
MA600	Measurement of electrical parameters associated with general electrical board and energy input (e.g., current, voltage, frequency, harmonics, etc.).

5.2.2.2 Solarimetric station for measurement of meteorological parameters

The solarimetric equipment installed was used for weather measurements such as ambient temperature, solar radiation, relative humidity, and wind velocity. Data were collected at 10-minute intervals, in the period between February 6th 2020 and February 13th 2020. Figure 10 shows the solarimetric platform.

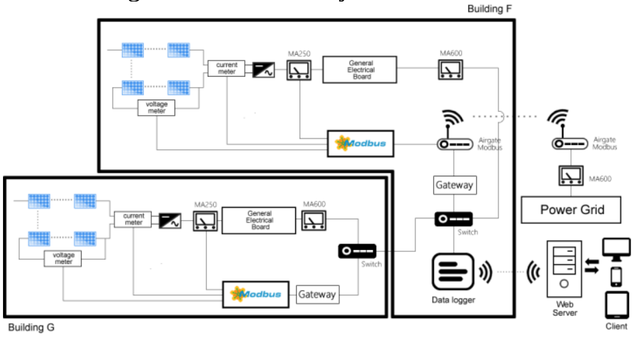
Fig. 10. Solarimetric platform

The Ammonit Online Report (AmmonitOR) program is used to view data obtained by the solarimetric station. AmonitOR is a commercial application that enables data from the solarimetric station, which is stored in its cloud, to be accessed over time (Ammonit Measurement GmbH, 2019). The application programming interface (API) provided by the manufacturer (AmmonitOR API) was used to automatically access the data.

5.2.3 General automation architecture of the DAQ

The general architecture for the automation of the solar plant's DAQ includes measurement instruments and a data recorder, with the objective being the collection of electrical parameters. The data gathered were transmitted via a human–machine interface to a database server, where they could be downloaded by the user. A client–server structure was required to build the project. While it is possible to build structures that merge the front- and backend, this can lead to potential losses; for example, increased development time for other platforms like desktops or mobile devices, given that there would be no common data source between them. In this project, it was decided to isolate the work between the frontend and the backend, thereby providing a common repository that provides all information to client devices. The flow paths and device elements of the system are shown in Figure 11.

Fig. 11. Automation system architecture



Power meters with DC and AC measurement parameters were present in each building. Building F used three current meters (SCK-M-I-8S-20A) and three voltage meters (SCK-M-U-1500V) — the green devices in Figure 12 — for the measurement of energy parameters in DC.

Fig. 12. Current and voltage meters

The initials R, S, and T were added and cataloged to the current meters, with each device measuring individual strings for the respective inverter. The first meter (from left to right) was used to measure strings 1 and 2 of inverter 1; the second meter measured the current of strings 1, 2, and 3 of inverter 2; and the third meter measured the current of strings 1, 2, and 3 of inverter 3. The voltage meters measured each string set, because devices have the same voltage value in parallel. Three Phoenix EEM-MA250 meters were used to individually measure AC parameters for each inverter. Figure 13 shows the meters.

Fig. 13. AC meters

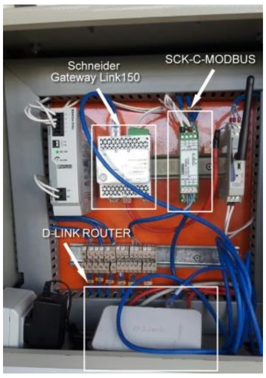
The data was sent to a specific link for all used instruments and attached to the SCK-C-MODBUS equipment. The strings meter for the inverter 01 was connected to input T2, inverter 2 to input T3 and inverter 3 to input T1 of the SCK-C-MODBUS converter.

Fig. 14. MA600 electrical parameter meter

For the input of each building, a Phoenix EEM-MA600 meter was used to measure all electrical parameters. The MA600 meter was connected (through the device's IP address) directly to a D-LINK router. The architecture was replicated so that it could be used in both buildings.

A SCK-C-MODBUS device was connected to a Schneider Gateway Link150 converter, thus grouping all the data in an Ethernet connection, which could be accessed through a D-LINK router. The equipment is shown in Figure 15.

Fig. 15. Modbus to ethernet converter



5.3 DATA LOGGER

A data logger was developed for the system, in order to record the data collected by the measurement instruments. The single-board Raspberry Pi 3 Model B was selected as the controller, because it supports more sophisticated programming languages in the implementation of the Modbus TCP communication protocol.

Fig. 16. Raspberry Pi 3 Model B

Installation of an operating system was required in order to access all of the Raspberry Pi tools. The Raspberry Pi Foundation's official operating system, Raspbian, was installed using the NOOBS installer. The programming functions of Raspbian include various pre-installable features, software support, mouse, keyboard, Wifi internet, web browsers, programming languages, etc. Both the operating system and the data records are stored on a SanDisk MicroSD Class 10 card with 32 GB for storage and an IO speed of 80 MB/s.

The data logger scans the data accessible via the communication protocol every 60 seconds, and stores them in a PostgreSQL database after verification. Data access was via the D-LINK router's ethernet cable. Table 5 shows all of the current parameters obtained.

Table 5. Electrical parameters measured

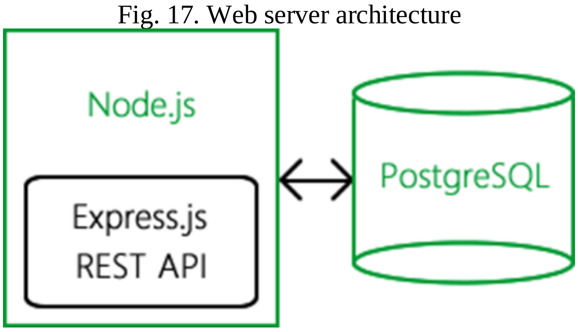
Type	Parameter	Unit
DC	Voltage	V
DC	Current	A
DC	Power	kW
AC	First phase voltage	V
AC	Second phase voltage	V
AC	Third phase voltage	V
AC	Frequency	Hz
AC	First phase current	A
AC	Second phase current	A
AC	Third phase current	A
AC	Active power (P)	kW
AC	Reactive power (Q)	kvar
AC	Apparent power (S)	kVA
AC	Power factor	-
AC	Active energy	kWh
AC	Reactive energy	kWh

5.4 WEB SERVER FOR DATA MANAGEMENT

A cloud server was chosen for this project, due to its high scalability and adaptability by installing new software and increasing processing capacities, memory, or storage over time.

The server delegated most of the application's business rules, following the client-server model and being made available to the human–machine interface through use of an API developed specifically for the system. Figure 17 shows the web server's architecture.

Fig. 17. Web server architecture



Version 12.11.1 of Node.js, a JavaScript runtime environment that can execute Javascript-encoded scripting without a browser, was installed to provide code execution on the server.

All client requests are sent to the server by calling the system's REST API. This API was developed using the Express.js development platform. According to the official website of Express (2019), the structure provides a wide array of resources for web and mobile applications.

The developed API provides energy evaluation parameters specified in the IEC (2016) standard, including ambient temperature, radiation, wind speed, energy produced, power factor, and equipment efficiency, among other things. Chapter 4 of this work provides the expressions for measuring each parameter.

All routes are safeguarded, and any client requests must apply a valid security token on its header.

Table 6 shows the routes and approved HTTP methods the present work.

Table 6. API Resources

Route	HTTP Method
api/parameters	GET
api/parameters	POST
api/live	GET
api/live	POST
api/weather	GET
api/weather	POST
api/login	POST
api/logout	DELETE

The api/parameters route returns selected electrical parameters in JSON format if requested using the HTTP GET method. If requested through the HTTP POST method, it stores all received electrical parameters. The api/live route returns all electrical parameters collected in the last 5 seconds in JSON format when requested using the HTTP GET method. If requested using the HTTP POST method, it stores all received electrical parameters. The api/weather route returns all weather parameters in JSON format when requested using the HTTP GET method. When requested using the HTTP POST method, it captures all the meteorological parameters available through the solarimetric station by connecting to the AmmonitOR API and stores in the server database. The api/login route generates a session to the client into the system upon confirmation of the user and password. The api/logout destroys the session of the client and logs the user out of the system.

5.5 WEB APPLICATION FOR VIEWING COLLECTED DATA

The web application is implemented through the React development library, and is subdivided into directories with various tools, files, libraries, and settings. The REST API developed for this project was necessary in order to search for the data made available by the server. The consumption of the REST API was determined using the Axios library in JavaScript. The Bootstrap framework was used to allow the web application to work for different resolutions and device sizes. Bootstrap enabled responsive development with greater ease, and the execution of the web application on desktop computers, mobile phones, and tablets, with no need for specific development for each platform. Data and information were presented through graphs and text. All charts on the interface were created with the modern libraries ApexCharts and Dygraphs. According to the official library websites, all visual items available are responsive, interactive, dynamic, and high-performance. Charts in area, column, bar, and pie format were used to graphically display the data and information in this project.

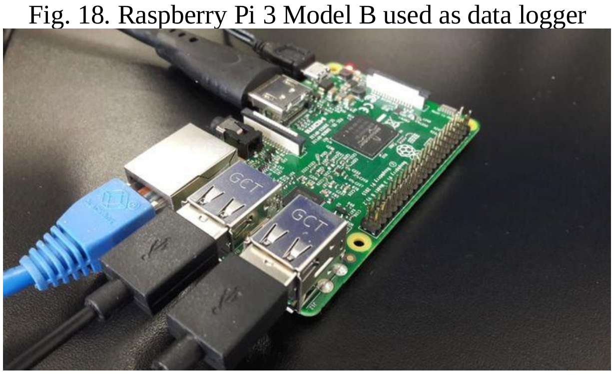
6 RESULTS AND DISCUSSION

This chapter will present and discuss the results achieved through the use of the data acquisition and monitoring system, and comparisons between the system developed and a commercial data acquisition system.

6.1 DEVELOPED DATA LOGGER

The single-board Raspberry Pi 3 Model B functioned appropriately during data collection. The ability to install an operating system with a graphical interface made it easier to connect and send data between the data logger and the developed API during system development. Figure 18 shows the data logger used.

Fig. 18. Raspberry Pi 3 Model B used as data logger



The use of a single-board computer resulted in lower power consumption than conventional computers, which further increases the efficiency of the acquisition system and reduces future energy costs.

6.2 WEB SERVER FOR DATA MANAGEMENT

A web server was designed, and the communication API was built to handle data gathered by the data logger. The cloud web server functioned appropriately for storing and processing the data and the software application's output parameters. All the necessary routes for the application and data logger to operate were configured correctly, and their access was tested throughout the process. It is worth mentioning that storing data in the cloud allows you to scale and increase disk space, maintaining only the necessary amount, without risk of data loss.

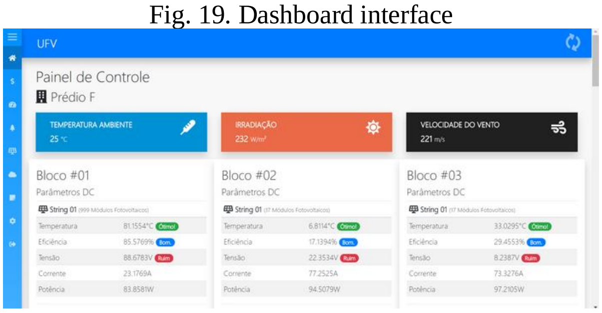
6.3 WEB APPLICATION FOR DATA PRESENTATION

A web application was developed to display the data obtained by the recording system and stored on the cloud server. The web application was divided into several pages such as dashboard, production, system performance, weather and measured parameters. In the control panel tab, the software presents information about the PV system installed in buildings F and G of the university, separated by blocks. The application enables the display of direct and alternating current, as well as environmental measurements such as air temperature, humidity, wind intensity, and solar radiation. Every page block represents an inverter and includes the number of modules installed.

6.3.1 Dashboard

The dashboard page presents the data collected from the system in real time. The parameters can be observed live and organized by building, inverter, and PV arrangement. Figure 19 shows the interface for the dashboard page.

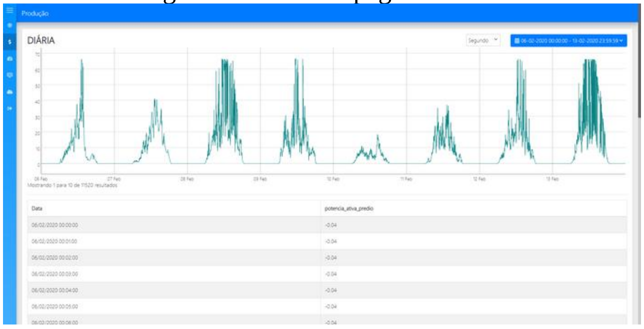
Fig. 19. Dashboard interface



6.3.2 Production page

Besides efficiency, the Production also page displays the power output of the system separated by the mini-plant modules. The interface allows the definition of a period of time and the visualization of the data in a graph, in daily or accumulated format. An example can be seen in Figure 20.

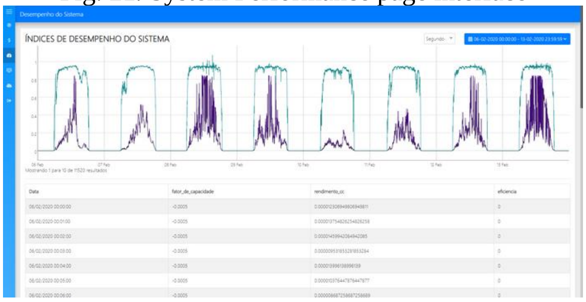
Fig. 20. Production page interface



6.3.3 System Performance page

System performance indexes can be viewed on the System Performance page. The user can choose the observed period and the data grouping format. The parameters shown in the daily chart are the capacity factor, the DC throughput, and the DC/AC conversion efficiency of the system. An example can be seen in Figure 21.

Fig. 21. System Performance page interface



6.3.4 Measured Parameters page

The Measured Parameters page provides a choice of multiple parameters that have been collected over the period. Electrical and meteorological parameters can be chosen from a selection box.

Fig. 22. Measured Parameters page interface

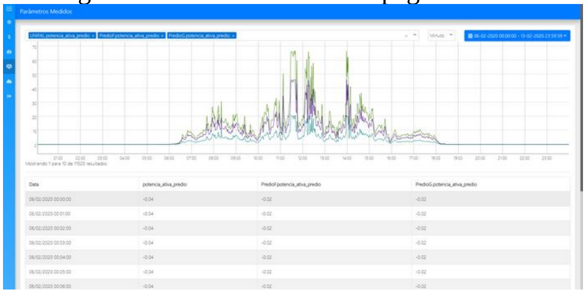


Figure 22 shows the chart of the active powers of the system for the accumulated observed period.

6.4 SYSTEM IMPLEMENTATION

The DAQ was effectively installed in the solar PV system on the premises of the Poços de Caldas campus of the Federal University of Alfenas. Parameters were collected between February 6th and February 13th 2020 for subsequent mini-plant analysis. During the test steps, all electrical parameters were collected and saved on the remote server and in a local database.

Table 7 presents the DC power data generated by building F's strings.

Table 7. DC power generated by building F's strings

Inverter	String 1	String 2	String 3
1	168.48 kW	168.9 kW	-
2	142.92 kW	143.67 kW	142.99 kW
3	122.64 kW	123.96 kW	122.01 kW

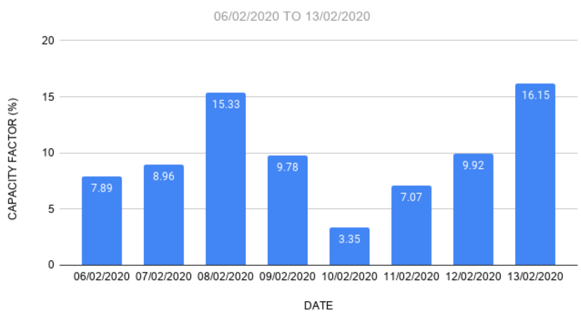
The DC power data generated by building G's strings can be seen in Table 8.

Table 8. DC power generated by building G's strings

Inverter	String 1	String 2	String 3
1	118.33 kW	120.56 kW	122.34 kW
2	Inverter was disconnected	Inverter was disconnected	Inverter was disconnected
3	57.16 kW	65.29 kW	-

Figure 23 shows the chart of the system's capacity factor. The lowest value (3.35%) occurred on February 10th 2020, while the highest value (16.15%) occurred on February 13th 2020.

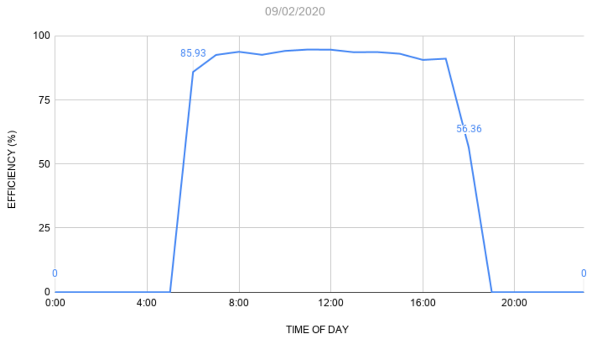
Fig. 23. System's capacity factor



According to the chart, the lowest efficiency (88.34%) occurred on February 10th 2020, while the highest efficiency (93.89%) occurred on February 8th 2020.

Figure 24 shows the system's efficiency, when converting direct current to alternating current, at various times of the day on February 9th 2020. Peak efficiency (94.69% conversion) was attained at 11:00 am; while the lowest efficiency (56.36%) occurred at 6:00 pm.

Fig. 24. Efficiency of DC/AC conversion system at different times of the day on February 9th



6.5 COMPARISON BETWEEN DATA OBTAINED IN THE PRESENT WORK AND DATA FROM THE FRONIUS SOLAR.WEB SYSTEM

Fronius inverters installed in the mini-plant provide access to the Solar.Web system, which is a web application that allows users to view their production and energy consumption in the form of reports and graphs (FRONIUS INTERNATIONAL GMBH, 2020) for branded products. For data validation, a comparison was made between the data obtained from the acquisition system in the present work and the data collected by the commercial Solar.Web system.

6.5.1 System's daily AC power

The graph in Figure 25 shows the comparison for the daily AC power collected by the data acquisition system of the present work and that of the Solar.Web system, for the period between February 6th 2020 and February 13th 2020.

Fig. 25. Comparison of systems' AC power on different dates

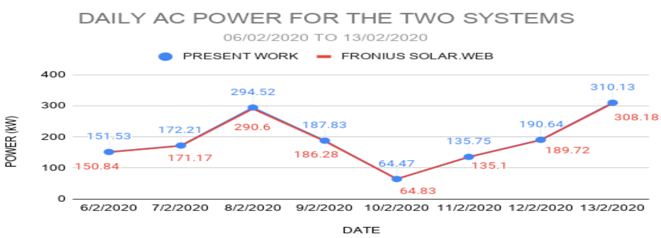


Table 9 shows the systems' daily AC power data in tabular format for better visualization.

Table 9. Comparison of systems' daily AC power generated

Date	Present study (kW)	Fronius Solar.Web (kW)	Percentage variance (%)
6/2/2020	151.53	150.84	0.4574383453
7/2/2020	172.21	171.17	0. 6075831045
8/2/2020	294.52	290.6	1.348933242
9/2/2020	187.83	186.28	0.8320807387
10/2/2020	64.47	64.83	-
11/2/2020	135.75	135.1	0.5552984729
12/2/2020	190.64	189.72	0.4811250925
13/2/2020	310.13	308.18	0.4849251529
			0.6327470959

It can be seen that the maximum variation (1.3489%) between the systems occurred on February 8th 2020; while the least variation (0.4574%) occurred on February 6th 2020. The average percentage variation for the analyzed period was approximately 0.5361%.

7 CONCLUSIONS

Besides comparing the system developed with a commercial acquisition system, this project involved the implementation of a full data acquisition system, by building a data logger, configuring a web server, and developing a REST API for web service, as well as a data visualization web application.

The data logger, which was created with the Raspberry Pi 3 Model B single-board computer, functioned well and was cost efficient, considering its inexpensive equipment and possible adaptation to the architecture throughout the project.

The configuration of the web server and the implementation of the REST API ensured allocation of most of the business rules on the server instead of the human–machine interface, thus enabling evolution of the system or the development of new applications without the need for code replication.

The web application was in agreement with what was proposed in the objectives: it enabled visualization of electrical, meteorological, and performance parameters; and the generation of reports in XLS or CSV format.

Between February 6th 2020 and February 13th 2020, the mini-plant was monitored, and its electrical parameters were collected. For the purpose of comparing the

DAQ developed in this present work, the data collected by it were compared with the data from the Fronius Solar.Web commercial system. Compared with the commercial system, the system developed by us had a low average percentage variation (0.5361%) in the monitoring of the total AC power generated by the PV system.

In view of the low average percentage variation, we consider the remote monitoring and DAQ developed by us to be a valid mechanism for assisting in monitoring the performance of PV systems, with the advantage of it being coded in free languages, using freely available technologies.

ACKNOWLEDGMENTS

The authors are grateful to Brazilian Electricity Regulatory Agency (ANEEL), Municipal Department of Energy of Poços de Caldas (DMED) and the Applied Research Laboratory in Energy Efficiency of the Federal University of Alfenas for their support in the development of this research.

REFERENCES

AMMONIT MEASUREMENT GMBH. Ammonitor - Ammonit Online Report. Ammonit. 2019. Disponível em: https://www.ammonit.com/en/ammonit-customerlogin/110-ammonitor. Acesso em: 11 out. 2020.

AZIZI, A. et al. Impact of the aging of a photovoltaic module on the performance of a grid-connected system. Solar Energy, v. 174, p. 454-455, 01 nov. 2018.

BALFOUR, J.; SHAW, M.; NASH, N. B. Introdução ao projeto de sistemas fotovoltaicos. Rio de Janeiro: LTC, 2016.

EMILIO, M.D.P. Data Acquisition Systems: From Fundamentals to Applied Design. Berlin: Springer Science & Business Media, v. 1, p. 135, 2013.

EXPRESS. Express - Node.js web application framework. Express. 2019. Disponível em: https://expressjs.com/. Acesso em: 11 out. 2020.

FRONIUS INTERNATIONAL GMBH. Por Que Fronius Solar.Web?. Fronius Solar.web. 2020. Disponível em: https://www.solarweb.com/. Acesso em: 11 out. 2020.

HAIBAOUI, A. et al. Performance Indicators For Grid-Connected PV Systems: A Case Study In Casablanca, Morocco. Journal of Electrical and Electronics Engineering, v. 12, p. 11, mar. 2017.

IEC. 61724-1 Photovoltaic system performance – Part 1: Monitoring. 2017.

IEC. TS 61724-3 Photovoltaic system performance – Part 3: Energy evaluation method IEC. International Electrotechnical Commission, 2016.

KOURO, S. et al. Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology. IEEE Industrial Electronics Magazine, v. 9, n. 1, p. 47-61, 19 mar 2015.

KUMAR, N. M.; SUBATHRA, M. S. P; MOSES, J. E. On-Grid Solar Photovoltaic System: Components, Design Considerations, and Case Study. In: INTERNATIONAL CONFERENCE ON ELECTRICAL ENERGY SYSTEMS (ICEES). 2018. 4. ed, Chennai, India, 2018.

NODE.JS FOUNDATION. About. Node.js. 2019. Disponível em: https://nodejs.org/en/about/. Acesso em: 11 out. 2020.

PARIDA, B.; INIYAN, S.; GOIC, R. A review of solar photovoltaic technologies. Renewable and Sustainable Energy Reviews, v. 15, n. 3, p. 1625-1636, 11 jan 2011.

PEARSALL, N. The Performance of Photovoltaic (PV) Systems: Modelling, Measurement and Assessment. Cambridge: Woodhead Publishing, 2016. 366 p.

RAHMAN, M.; HASANUZZAMAN, M.; RAHIM, N. A. Effects of various parameters on PV-module power and efficiency. Energy Conversion and Management, v. 103, p. 348-358, 06 jul. 2015.

RASPBERRY PI FOUNDATION. Raspbian. Raspberry Pi. 2019. Disponível em: https://www.raspberrypi.org/downloads/raspbian/. Acesso em: 11 out. 2020.

RIZZARDI, Giovani André et al. Monitorando energia elétrica em residências no ambiente de cidades inteligentes. Brazilian Journal of Development, v.7, n.3, p.26676-26693, 2021.

THERISTIS, M. et al. Energy Yield in Photovoltaic Systems. McEvoy's Handbook of Photovoltaics: Fundamentals and Applications, London: Academic Press, p. 671-713, 01 jan. 2018.

ULIERU, V. D. et al. Data Acquisition in Photovoltaic Systems. Renewable Energy - Trends and Applications, London: IntechOpen, p. 213-230, 09 nov. 2011.

WOYTE, A. et al. Analytical Monitoring of Grid-connected Photovoltaic Systems: Good Practices for Monitoring and Performance Analysis. International Energy Agency, 2014