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SCADA System for Online Electrical Engineering Education

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Abstract: Renewable energy sources are increasingly being integrated into small-scale production systems, so plants with multiple supply sources are becoming more common. This improvement in technology added to a greater social awareness of energy saving and resource usage, which makes flexible systems to manage these facilities necessary. Modern energy management can be more accessible to the interested public if it is located in universities, making it available to teachers and students alike. Furthermore, as it is a developing field of study, its location on campus facilitates research, maintenance, and financing. In this scenario, a SCADA system is proposed, capable of monitoring and centrally storing the values of the most important production and consumption parameters. In addition, by using this system, it is possible to control the state of the different energy sources in a centralized way, as well as their distribution in the plant where it is implemented. This study focuses on the management of a flexible, modern, and accessible solution to the advances in electrical systems because of technological development in this field, which broadens the experience of university teachers and students in their engineering careers. The systems have been put into practice in the facilities of a research and teaching laboratory at the University of Almeria, which integrates renewable and conventional energy resources.

Keywords: energy monitoring; renewable energy; sustainability; electrical engineering; online learning; virtual laboratories

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1. Introduction

Over the past thirty years, sustainability has emerged as a growing consideration for the academic community and policymakers [1,2]. One of the approaches from the point of view of sustainability is online teaching [3] and virtual laboratories [4,5]. The evolution of the COVID-19 pandemic over the world in general and in Spain, in particular, has forced the interruption of face-to-face lessons in universities where this was the usual type of teaching [6]. On April 2, the Spanish Minister of Universities presented a public declaration in which he stated that "The final decisions on the adaptation of university education to the emergency health conditions in which we find ourselves correspond to the universities in the exercise of their autonomy in collaboration with the competent supervisory authority, namely the Autonomous Community to which they belong. However, any decision must respect the health measures decided and implemented by the Spanish Government and in particular by the Minister of Health" [7]. Furthermore, it was expressly mentioned that 'The classroom practices that are an essential part of some courses must be adapted to the possibilities of implementation, both in terms of form and timing, . . . " [8]. In the end, this situation has led to the interruption of face-to-face classes and the sudden adaptation of universities to a non-presential format. That is to say, online teaching. This change in higher education towards online or less face-to-face models has not only been in Spain but also in numerous countries such as China [9]. With the spread of COVID-19 around the world, by September 2020, 52 countries worldwide have implemented school closures affecting more than 850 million learners, which is almost half of the world's students (48.6%) [10]. In this short period of time, many millions of teachers started online teaching. While all universities have remote teaching platforms [11], this was not the majority format for laboratories, especially in engineering grades [12]. While the advantages of online teaching are well known, there is also a need for adequate teacher skills and, in particular, to enhance student motivation [13]. In this context, the monitoring of real systems, where the student can have access in real-time to the data while they are being generated, is an undoubted advantage for the motivation of the student.

This article presents teaching under the conditions defined in the COVID protocol, so it is appropriate to place more emphasis on the consequences generated, among other things, by the proposed online teaching model. In previous studies at the University of Almeria [14], from 2002 to 2010, three teaching models were analyzed in engineering degrees: face-to-face, blended and virtual. The study was performed for 10 years of the same subjects. It was found that the best model, in terms of performance, was the face-to-face model, then the virtual model, and finally the blended model.

Due to the COVID-19 pandemic, Spanish universities and Almeria University specifically were forced to stop face-to-face teaching and adopt online teaching. The sudden shift to online-only methods of teaching has increased anxiety levels in students, especially those in their final academic year [15].

More recent surveys [16], in the academic year 2019–2020, in the same university on the perception of students about the university environment have shown that the students of the University of Almeria have expressed an excellent disposition towards the new virtual modality, to which 49% of those surveyed gave a rating of good. In addition, 70% of those surveyed said that this virtual mode makes it easier for them to carry out autonomous work. However, 72% of those surveyed do not see the execution of group or collaborative tasks as favorable, and finally, 80% of the students surveyed rate the online modality and the evaluation process as more demanding than the face-to-face system.

Technological development in electricity production opens up several alternatives to the conventional way [17]. These alternatives, such as renewable energy sources, are increasingly being used by the population to decouple themselves from fossil fuels and aim for a more sustainable way of life [18,19]. Renewable energy depends on the weather conditions of the place where they are to be used [20,21]. Therefore, the optimal way to use these resources is to combine them, and it is increasingly necessary to have systems that facilitate the coordination of production, being able to monitor and control the status of various sources at all times from the same place [22,23].

Currently, many industrial firms are using continuous control of each component involved in the production process of the factory. Thus, control engineering has been moving forward in the field of industrial processes, and of course, these can be performed centrally, fast, and remotely using the appropriate software. Thus, the engineers of the future need to monitor and control the systems they operate.

A modern solution to handle this situation is the use of SCADA systems [24,25]. SCADA is the acronym for "Supervision, Control and Data Acquisition" and refers to a system from which a set of devices can be controlled and monitored with the aim of centralizing these actions [26]. The SCADA systems meet all the above-mentioned skills so that the industrial processes can be displayed from a control and monitoring center, which also has data acquisition to be analyzed, and then make possible adjustments to correct possible errors in the processes. Within the field of SCADA systems, there is a great range of software tools for their development, but each manufacturer has its own design standards that make each software different in terms of graphic programming features, licensing costs, etc.

In this way, it is possible to display and analyze the most important parameters of an installation's equipment in order to make the right decisions. The real practices in the laboratory are essential for an engineering student to acquire the skills related to the experimental aspects of automation, control, and instrumentation in engineering degrees. This important technological component of engineering education must be accompanied, on the one hand, by practical equipment and also by software solutions in line with the industrial environments where they will develop their future work in the industry.

In this study, a SCADA system is implemented for online teaching at the laboratory of electrical engineering at the University of Almeria. The main specific skills to be acquired in industrial engineering degrees related to SCADA systems are:

- Basic knowledge of the use and programming of computers, operating systems, databases, and computer programs with engineering applications.
- Knowledge of automatic regulation and control techniques and their application to industrial automation.
- Ability to design industrial automation and control systems

So, Engineering education curricula have become increasingly integrated with real-world laboratory-scale process-based experimentation and computer-aided learning. Most of these industrial-scale facility-scale laboratories have been developed for distance learning to meet the current requirements of the engineering curricula. Therefore, the development of distance experimentation facilities or virtual laboratories is motivated by the fact that currently, the demand for access to instructional laboratory facilities is growing rapidly in all engineering departments.

A goal of the SCADA laboratories is to help students to develop the skills needed to design and analyze professional automatic control systems in process engineering, plant, and manufacturing technologies [27]. A lot of remote labs have a client-server architecture and use LabVIEW software to provide remote access to the experimental workbench. The advantage of using SCADA software for remote laboratory development has the added advantage of having students work in more realistic simulated industrial environments, where SCADA is commonly used in the automation of manufacturing processes [28].

A simple, low-cost SCADA system can be used in learning embedded systems projects, USB communication, data acquisition, and creating supervisory systems. In addition, the use of SCADA has motivated the students in project development and has contributed to the achievement of the specific skills of the degree of an engineer [29]. A set of laboratory experiments based on the principles of SCADA systems, regardless of any specific application area, is useful to provide students with an understanding of the subject matter [30]. Other studies show that it is highly recommended to configure the learning environment to allow students to interact with the various components of a SCADA system [31]. A study of the implementation of problem-based learning in the process control laboratory for a flow control plant was successfully carried out for final year students of Electrical Engineering, which could be operated with SCADA or DCS, the latter being more suitable for the group work task [32]. Table 1 summarizes the above examples of SCADA used at a laboratory scale that has been applied at the teaching level.

Table 1. SCADA at Laboratory-scale.

Goal	Topics	Reference
SCADA automation system laboratory	Automation, Laboratories, SCADA systems, Electrical equipment industry, Education, Digital control, Drives, System testing, Automatic control, Induction motors	[27]
SCADA for development of remote laboratories	Visualization, Reliability, Indexes, Remote laboratories, SCADA systems, Local area networks	[28]
Low cost SCADA system for education	Universal Serial Bus, Microcontrollers, Data acquisition, Prototypes, SCADA systems, Engineering education	[29]
Development of a SCADA Course for Engineering Undergraduates	Industries, SCADA systems, Software, Smart grids, Sustainable development, Standards, STEM	[30]
Incorporating SCADA Cybersecurity in Undergraduate Engineering Technology	Integrated circuits, Knowledge engineering, Industrial control, Education, Computer security, Information technology, Engineering students	[31]
Supervisory Control and Data Acquisition (SCADA) vs Distributed Control System (DCS)	Tuning, Process control, Electrical engineering, Engineering education, Decentralized control	[32]

After reviewing the literature, SCADA systems for laboratories related to electrical power systems are found, which are summarized in Table 2. However, one that combines everything has not been observed.

Table 2. SCADA for electrical power systems.

Laboratory	Topics	Reference
Laboratory Scale Long Transmission Line	Power transmission lines, Transmission line measurements, Integrated circuit modeling, Engines, Voltage measurement, Current measurement	[33]
Monitoring of Wind Turbine Generators	Wind turbines, Generators, Monitoring, Condition monitoring, Wind speed, Temperature distribution, SCADA systems	[34]
Monitoring of Wind Turbines	Databases, Condition monitoring, Wind turbines, Testing, SCADA systems, Wind farms, Industrial economics, Discrete event simulation, Laboratories, Frequency	[35]
Monitoring of electrical power supply networks	Databases, Condition monitoring, Wind turbines, Testing, SCADA systems, Wind farms, Industrial economics, Discrete event simulation, Laboratories, Frequency	[36]
Hybrid AC/DC Laboratory-scale Smart Microgrid	Microgrids, Control systems, Inverters, Field programmable gate arrays, Power harmonic filters, Power supplies, Mathematical model	[37]
Monitoring of electrical power supply networks	Circuit faults, Steel, Conductors, SCADA systems, Power supplies, Surges, Remote control	[38]
Small System Electricity	Protocols, IEC Standards, Testing, Logic gates, Standards, SCADA systems, Prototypes	[39]
Electrical substations	Substations, Software, Protocols, SCADA systems, Redundancy, Synchronization, Computer architecture	[40]

The distribution of electricity in the laboratory of the University of Almeria and the equipment that makes up the installation are known. The electrical supply is obtained from the combination of renewable sources, such as wind and solar sources, and the conventional supply through the power network. Furthermore, these sources are expected to satisfy the different energy consumption needs of the laboratory. The variety of sources and sinks available in the laboratory brings it closer to the real global panorama in terms of electrical systems. Furthermore, it enhances the usefulness of a system from which the entire installation can be controlled and monitored in a centralized way to manage the electrical resource in the best possible manner. The main goal of this study is to help the online teaching of electrical engineering, showing students:

- To integrate renewable, photo-voltaic (PV), and wind generation in a local smart grid.
- To store parameter data for several years.
- To monitor in real-time the production and consumption state neatly and clearly.
- To minimize surplus electrical energy in the system.
- To ensure supply quality by using corrective elements to reduce both the reactive energy of the system and the harmful harmonics of the electrical signal.

2. Materials and Methods

2.1. Study Site

The SCADA developed through this study is implemented in the electrical engineering laboratory of the University of Almeria. It is a 203 m^2 area for teaching and research in the field of electrical engineering and renewable energy, where the electrical energy produced by a solar plant, a wind plant, and the conventional distribution network converge. The laboratory is divided into six areas according to the nature of its functions and equipment, as shown in Figure 1.

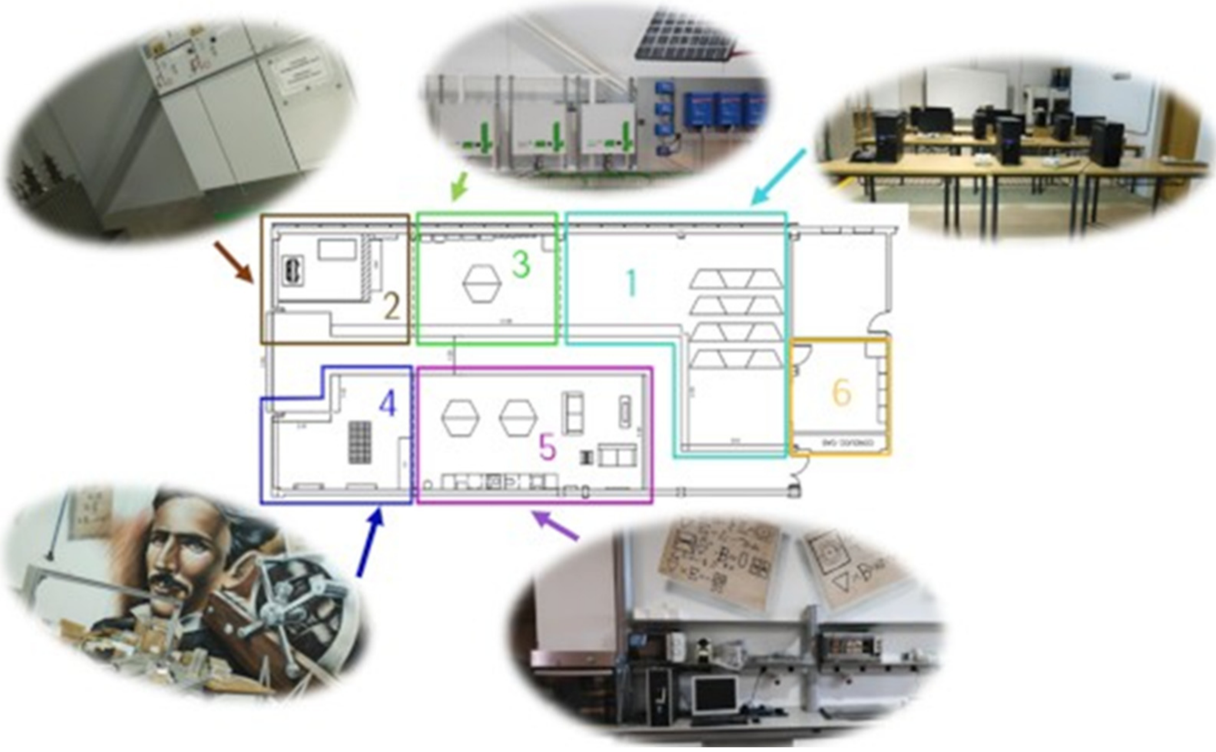

Figure 1. Laboratory layout.

The different areas are summarized below:

1. Teaching Area. Area for teaching with computer equipment for students.
2. High Voltage Area. Location for the laboratory's LV/MV/HV equipment (transformers, protections, etc.). It contains a power transformer that works as a link between the university campus' power station and the general low-voltage panel of the laboratory. From this station, two different connections are made to the laboratory. One of them starts from the high voltage area of the transformer station and provides a power of around 100 kW. It goes through the laboratory transformer and is used in case of supply voltage modifications through the transformer taps. It is also used for measuring both the electric supply acquired through the transformer station and the surplus electricity injected into the network. The second connection wires the transformer station directly to the general panel of the installation without passing through the transformer and providing a power of 200 kW. It is used to supply energy for heavy consumption.
3. Renewable Energy Area. This area is where the electricity produced by the PV and wind plants is injected/see Figure 2). The first one is composed of 18 poly-crystalline 270 W solar panels, and the wind power plant hosts three 1500 W wind turbines. In this zone, solar and wind charge controllers adapt the voltage of the electricity produced by the renewable generators to a 12 V direct current voltage. Once transformed, this electricity can be directed to the batteries of the laboratory or to the local electrical consumption. In the latter case, the power inverters will transform it again up to 230 V alternating current. The inverters are three single-phase devices that can be combined to supply three-phase currents when required. In this area, there is also a capacitor bank and active filters, both aimed at improving the quality of the power supply.
4. Electrical Machine Area. In the fourth zone, there are industrial loads and electrical machine motor type consumption. This is the heaviest consumption of the laboratory.
5. Power Quality Area. A household-type consumption zone hosts lighter and, therefore, less critical devices. These are mainly used to test and reproduce power quality events and issues related to harmonic or transient behavior of the device.

6. Control Room Area. Finally, the sixth zone is where the main screen of the SCADA system designed in this study is located, as well as the Beckhoff PLC, which manages the input and output information from consumption and production to the SCADA and vice versa. In order to handle all the information that is to be shown on the main screen of the SCADA, decentralized periphery is used. In this case, there are four main spots that group relevant data of each zone of the laboratory under study. Thus, zones 2, 3, 4, and 5 have an EtherCAT Coupler with input and output cards that manage the flow of information from the peripherals to which they are connected. The aim of equipping these zones with their own EtherCAT Coupler is to sort out data by area and minimize the amount of wire used for connections.

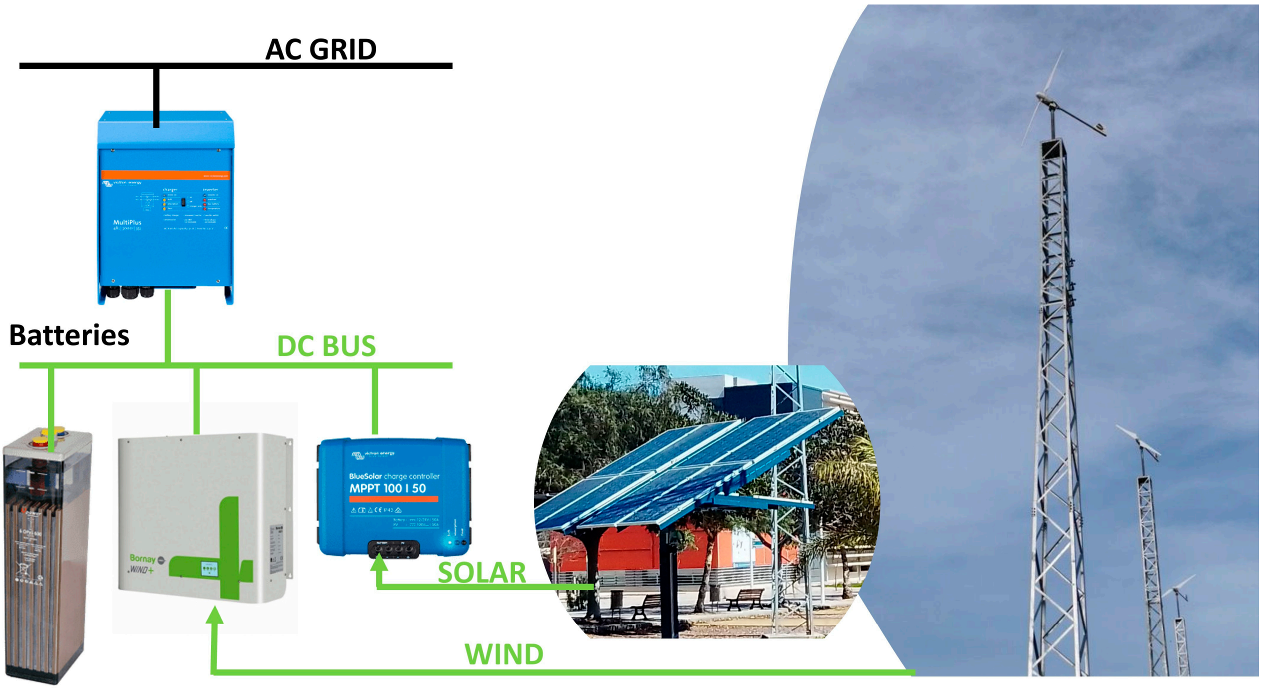

Figure 2. Laboratory layout.

2.2. TwinCAT 3 Software

Once the laboratory and its equipment have been presented, the SCADA software that will be used to design its interface is decided. The chosen software is the Beckhoff TwinCAT 3 software. The decision has been made considering the following advantages:

- It comes from the same manufacturer as the PLC, so compatibility is guaranteed. This is an important point due to the myriad of protocols and licenses from different providers that can cause interconnection problems.
- It has high accessibility. One of the objectives of this study is to bring the use of SCADA for energy management closer to students and teachers. Therefore, it is important that the software is accessible to all types of users. This is achieved because TwinCAT 3 is free software, and the only system requirement is to have a Windows operating system, starting from Windows 7.
- It also has a simple and straightforward framework that allows programming in C, C++, and Mat- lab®/Simulink® languages, which are especially familiar to engineering students at the University of Almeria.
- Flexibility and contemporaneity are offered. With this software, it is possible to create a web server to access the SCADA interface from mobile devices or smartphones. Since the SCADA is located on the campus, it is expected to be used by many people. This last option would be of great help in controlling the plant from multiple access devices.

2.3. Standards

Table 3 shows the standards used for SCADA systems.

Table 3. SCADA standards.

Standard	SCADA Use	Reference
IEEE C37.1	Communication	[41]
IEEE Std. 999–1992	Communication	[42]
NCS TIB 04–1	Architectures and protocols	[43]
IEC-61850	Authentication, authorization, encryption	[44]
ISO/IEC 27002	Cyber security	[45]
ISO/IEC 27002	Cyber security	[45]

3. Results

3.1. Communication Map

In order to design the SCADA interface, it is necessary to structure the data flow across the different devices and equipment in the laboratory. The final objective of these communications is to show the energy management variables on the SCADA screen and to be able to communicate the control orders through its interface. The communication between equipment that handles data is performed by different communication protocols according to each apparatus and is structured in a communication map. This map classifies them in the first three levels of automatic control according to their function, as depicted in Figure 3.

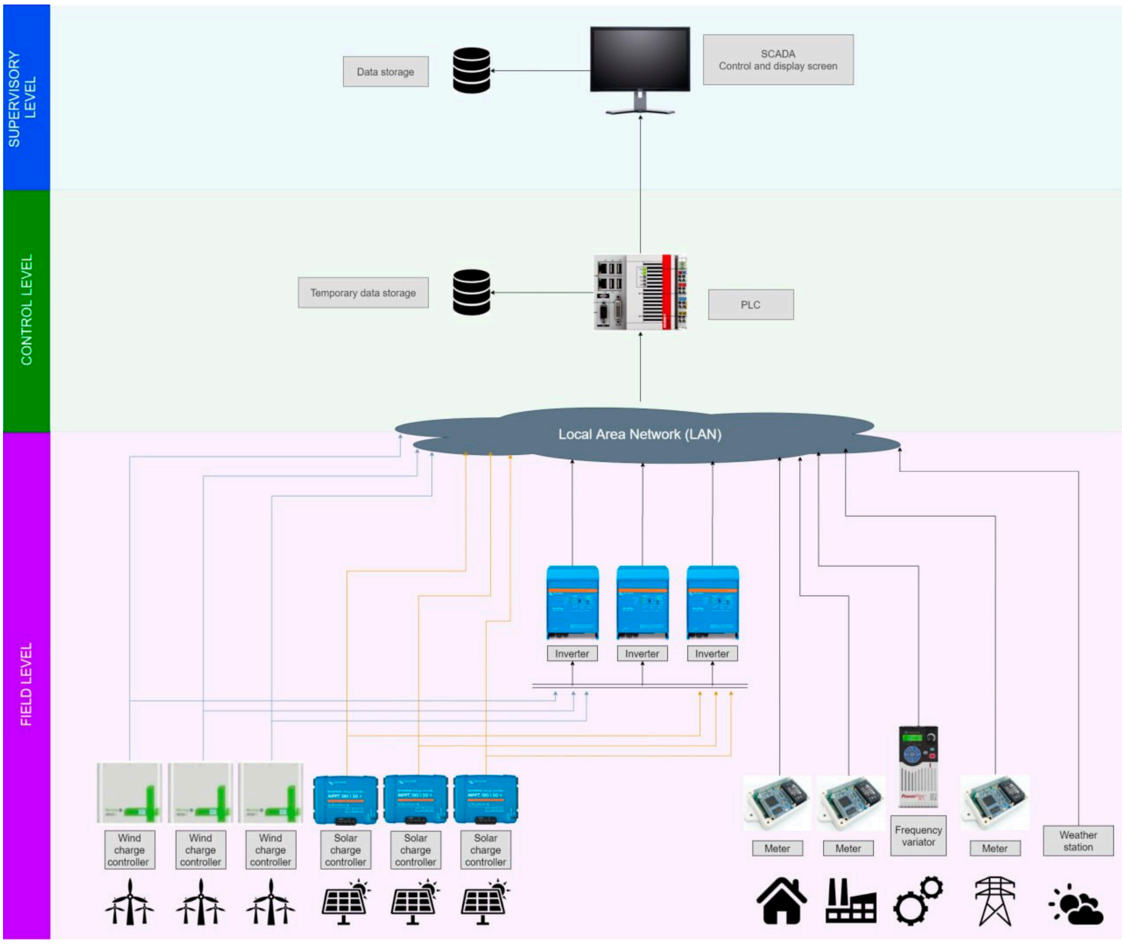

Figure 3. Data flow map for communication network.

The device level is the lowest. It includes the devices that collect real-time data and send it to the EtherCAT Couplers. Each wind controller collects the electricity supply data provided by a wind turbine.

For solar production, solar controllers offer the same function for each PV group. Both types of controllers communicate with the higher level by Mod-bus protocol, as well as the inverters. The inverters are in charge of directing the energy to the batteries or to the electrical consumption, and through them, we obtain information about the energy supplied to the consumption coming from renewable generation.

At this same level, there is a frequency inverter for each motor through which to obtain information from them and which communicates with the upper level through Ethernet/IP protocol. In the case of household and industry type consumption openZmeters [24,25] obtain the power consumed by them. These meters communicate with the upper level through an Ethernet wire connection. They are also placed in the transformation area of the laboratory and are in charge of measuring the current supplied to the installation from the distribution network of the University. The final component of the device level is the weather station with various sensors that obtain data on solar radiation, wind speed and direction, humidity, or rainfall in real-time. It communicates with the control level via Ethernet protocol.

The level above the device level is the control level, where the PLC and the PC are located. The controller communicates with the lower level by handling input and output data through EtherCAT protocol and through Ethernet cables. In addition, the PLC has a temporary data storage called local SCADA that stores the data collected over the last week. The PC communicates with the on-screen visualization of the SCADA control and visualization system via an Ethernet cable.

The last level of the communication map is the supervision level. This is where all the data are gathered and where the control commands are sent, all through the SCADA's human–machine interface (HMI), which can be viewed from an infinite number of screens. The SCADA, unlike the PLC, stores the data collected in recent years in the so-called global SCADA. In the study laboratory, there is a main screen as an HMI, although it is also possible to show this interface on the screens of the desktop equipment of students and teachers.

3.2. SCADA Interface

As a result of this study, the design of the interface of the SCADA system is observed. It groups the information collected by the laboratory equipment designing a system of visualizations that is easy to be used by students, teachers, and maintenance personnel. The visualizations are organized into seven screens, as shown in Figure 4.

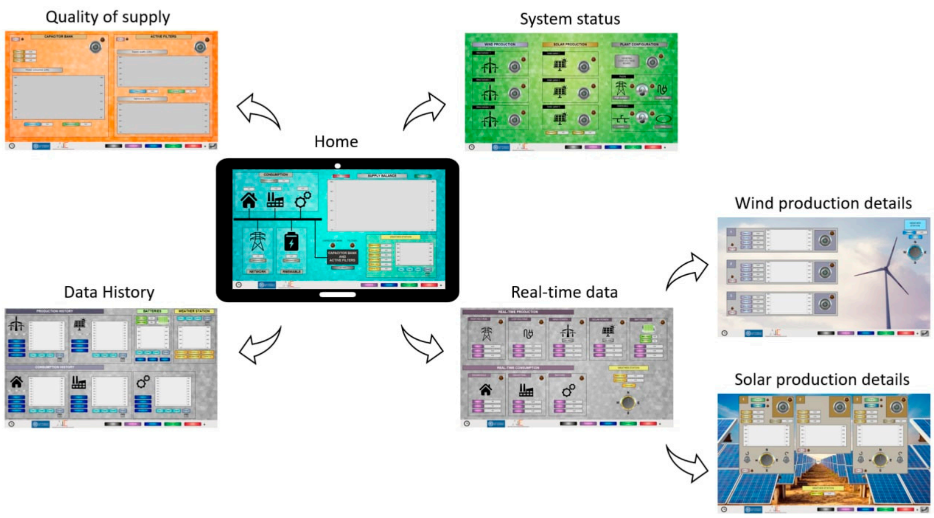

Figure 4. General view of the developed SCADA.

All the windows of the interface have a common screen footer from which the user can access any main window at any time and can always go back to the previous screen by using the return arrow. The data shown on each screen are shown in detail below.

3.2.1. Home

This is the main window of the HMI where the most important production and consumption data are displayed (see Figure 5). The upper left side shows the real-time value of the total active power consumed, as well as this same value for each group of consumer equipment individually. Under this group, the values of the active power provided in real-time by the distribution network of the university and the renewable production sources in real-time are shown. With the values of active power consumed and contributed, it is possible to make an energy balance where the proportion of renewable energy used can be observed. This can be consulted in the Supply balance graph on the screen. There it is also possible to know the energy and monetary savings that the use of renewable energy sources provides.

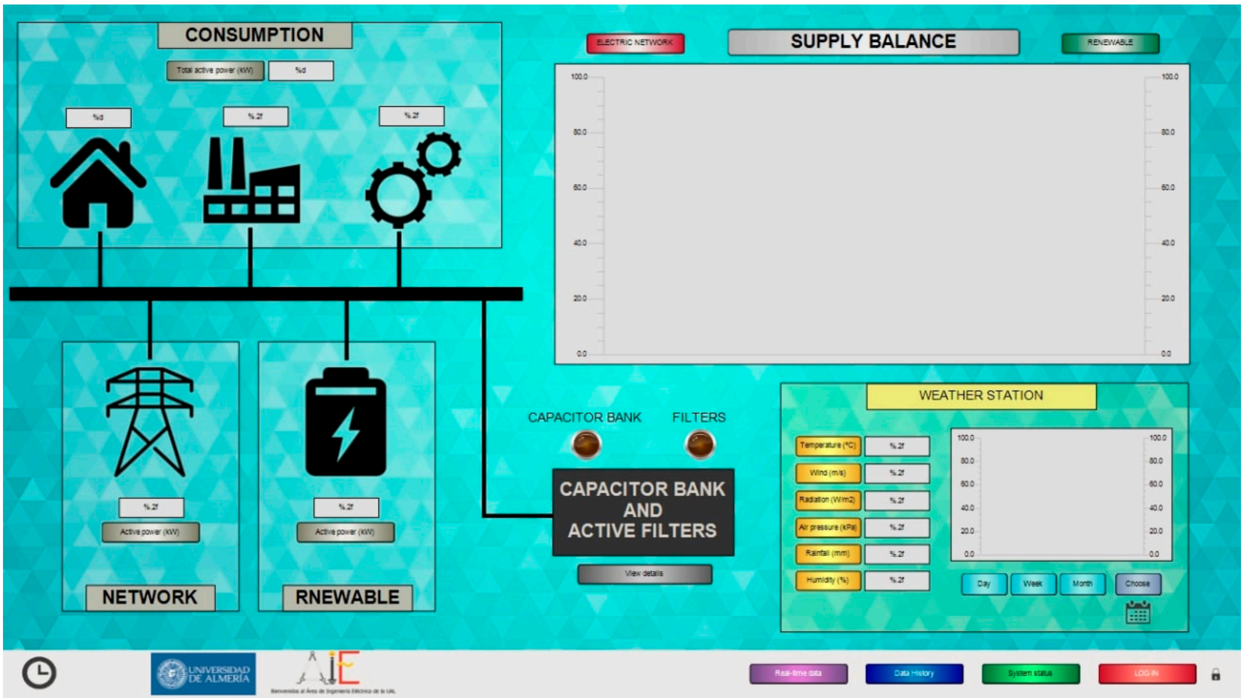

Figure 5. Main view of the SCADA.

In the lower right corner, the data of the magnitudes collected by the weather station in real-time are shown, as well as the historical data of these values in the last day, week, month, or date range chosen. Finally, in the bottom center of the screen, there is information about the status of the capacitor bank and the active filters. The two lights placed over the black box indicate whether they are operational or not, and through the button view details, you can access the specific data that affect this equipment.

3.2.2. Quality of Supply

The amount of electric equipment connected to the power grid, which incorporates power electronics, is continually increasing, then is particularly relevant for the quality of supply [46]. The system shows the information that must be known in order to know when to activate or deactivate the capacitor bank or the active filters (see Figure 6). The window is divided in two, and the left one groups the data relevant to the capacitor bank and the right one to the active filters. The capacitor bank section includes real-time values of the voltage and current of the supplied electricity, the phase angle between them and the active and reactive power supplied, which can be seen under the graph entitled power consumed (24 h). This graph shows the values of active and reactive power consumed in the laboratory during the last 24 h. On the other hand, the right half of the screen consists of two graphs. The upper graph shows the waveform of the supply voltage and/or current, as selected by the operator, and under which the real-time value of these two magnitudes can be consulted. The lower graph shows the status of the harmonics detected in the supply signal in real-time.

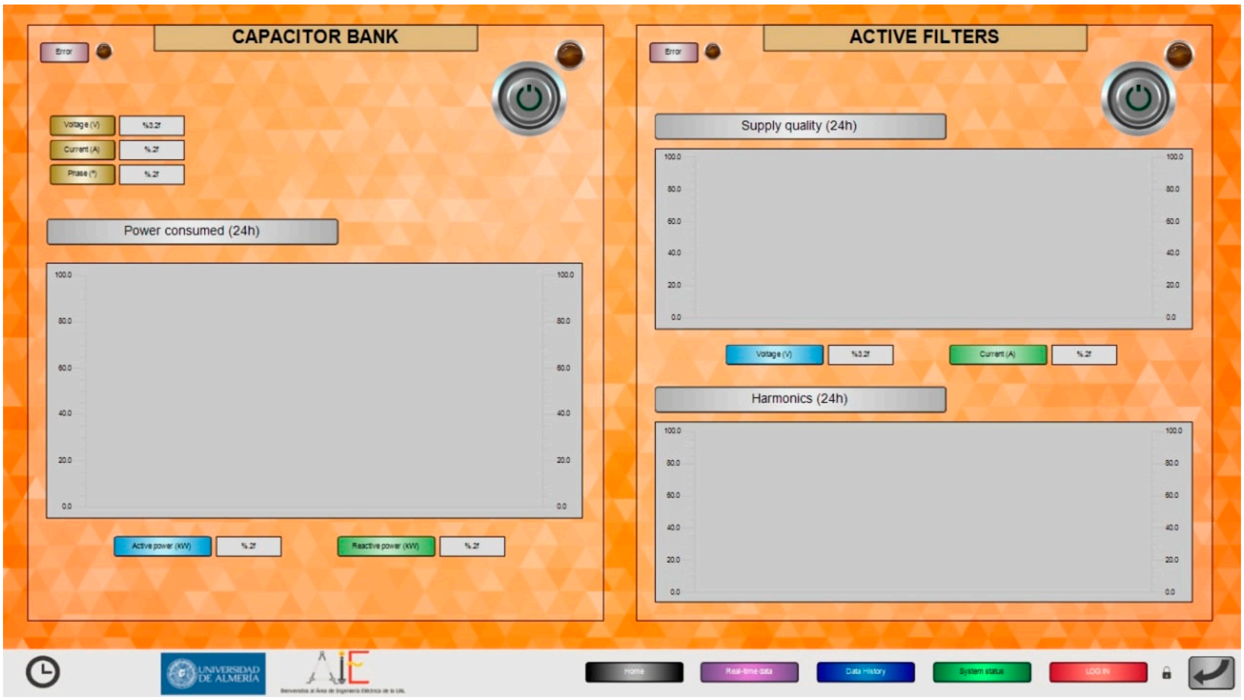

Figure 6. Power quality supply view.

Both parts of the screen have a light that shows if there are any faults in the capacitor bank or the active filters. The specific information about the detected faults can be consulted by pressing the red button located to the left of this light. In addition, for each piece of equipment, there is an on/off switch that can be activated by the user.

3.2.3. Real-Time Generation and Consumption Data

This screen is divided horizontally into two sections, one for production and the other for consumption (see Figure 7). The upper half shows the voltage, current, and power parameters of the energy from the different supplies in real-time. These supplies are the one provided directly from the university's transformer supplying 200 kW (high voltage supply), the low voltage supply referred to the one obtained through the laboratory's transformer, the wind and solar renewable sources where the user can access the details through the buttons of View details and finally, the status of the battery bank fed by the renewable production whose icon changes for percentages between 0–25, 25–50, 50–75 and 75–100. Under the battery charge indicator icon, the percentage of battery charge and the state of charge are displayed. The lower half of the screen shows the power consumed in real-time by the laboratory equipment destinations. This consumption groups the household area, the industrial area, and the motor area. Of these, the voltage, current, and power parameters of the energy being consumed are shown.

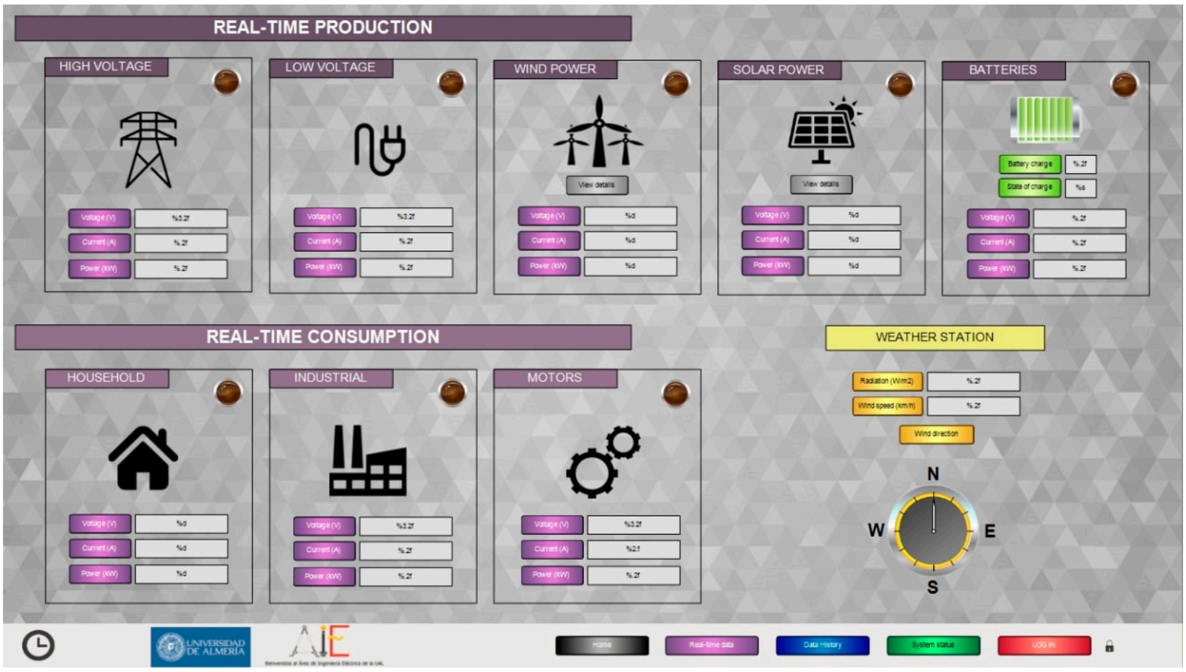

Figure 7. Real-time production and consumption view.

Finally, in the lower right-hand corner, real-time data on solar radiation, wind speed, and wind direction can be consulted, as these are the most relevant information for wind and solar production. As mentioned above, detailed information on wind and solar production can be consulted through the buttons View details and which show the following screens.

3.2.4. Wind Production Details

Wind energy is now one of the most promising renewable energies [47]. Power generated by wind turbines is erratic due to the stochastic nature of wind [48]. This screen shows the specific production data for each of the three wind turbines (see Figure 8 left). These data are the real-time values of the supply voltage, intensity and power, and the speed of rotation of the wind turbine. The data are accompanied by a graph that shows the data history of the variable selected by the user over the last few minutes. Each wind turbine has a fault notification function, as well as a Quality of Supply screen. It is also possible to activate or stop the motors of each wind turbine through this screen. On the other hand, in the upper right-hand corner of the window, wind speed and direction data are displayed.

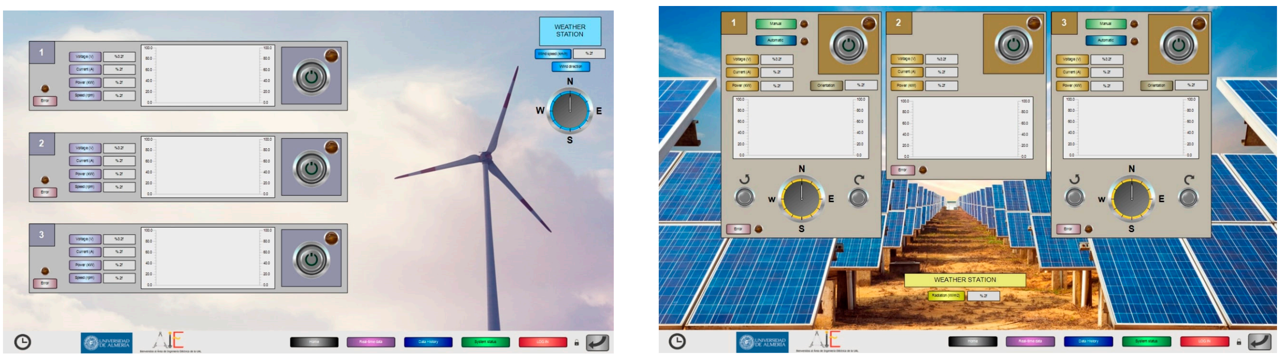

Figure 8. View of the wind (**left**) and pv (**right**) systems.

3.2.5. Solar Production Details

Solar energy has been studied and installed in the majority of developed countries for power supply in rural areas and for energy dispatch to the grid [49]. This window provides the data for each of the three groups of solar panels, consisting of six panels each and installed on two supports (see Figure 8 right). One bracket contains the first group of six panels and three panels of the second group, while the other bracket contains the other half of the second group's panels and the third group of six panels. Each support has a solar tracker, which excludes the individual orientation of the second solar group, whose panels are divided between the two supports. This situation can be useful when comparing production values of the different solar groups and when simulating the shadow effect for research purposes by students and teachers.

The information that can be consulted for each group is real-time values of voltage, intensity, and power of the electrical production, the orientation of the panels, and historical data of these variables over the last minutes. On the other hand, the first and third groups of panels can be automatically oriented toward the point of maximum power by the solar tracker or manually by the operator. In the case of manual orientation, this can be performed by introducing the corresponding value of the desired orientation and by use of the hourly and anti-clockwise rotation buttons placed on both sides of the compass showing the panel's orientation. In addition, each group has the same fault notification function as the previous screen, as well as individual buttons to activate or deactivate the consumption of PV generation. Finally, the lower part of the window displays the most relevant data from the weather station for real-time PV production and solar radiation.

3.2.6. Data History

Graphs representing the production, consumption, battery status, and weather station magnitudes collected over a chosen time period are displayed in Figure 9. The screen is horizontally divided into two areas, as is the real-time data window, separating production and consumption. In the production zone, the values collected of voltage, intensity, and power supplied are shown, as well as the speed of rotation in the case of wind turbines. In addition, it is possible to display the data of the wind turbines and solar panel groups desired. In the lower half of the window, the consumption data are displayed. It groups together household, industry, and motor consumption. Each one of them presents its own history graph where the value of voltage, intensity, active power, and total power consumed can be shown. In addition, in the case of household consumption, there are three buttons to select which household to display the data from, as the laboratory has three household consumption groups.

3.2.7. System Status

The last window of the SCADA HMI designed in this study allows the user to observe and modify the state of the configuration and the main components of the laboratory installation (see Figure 10). On the left side, the status of each wind turbine can be consulted and modified. These actions can also be carried out regarding the groups of solar panels, as well as their orientation. Finally, on the right side of this window, the configuration of the general low-voltage panel of the laboratory is indicated, and it is possible to decide which of the two connections is going to supply electricity to the laboratory from the university's transformation center. It is also possible to choose the configuration of the electrical distribution within the laboratory, which can be in a ring or linear form.

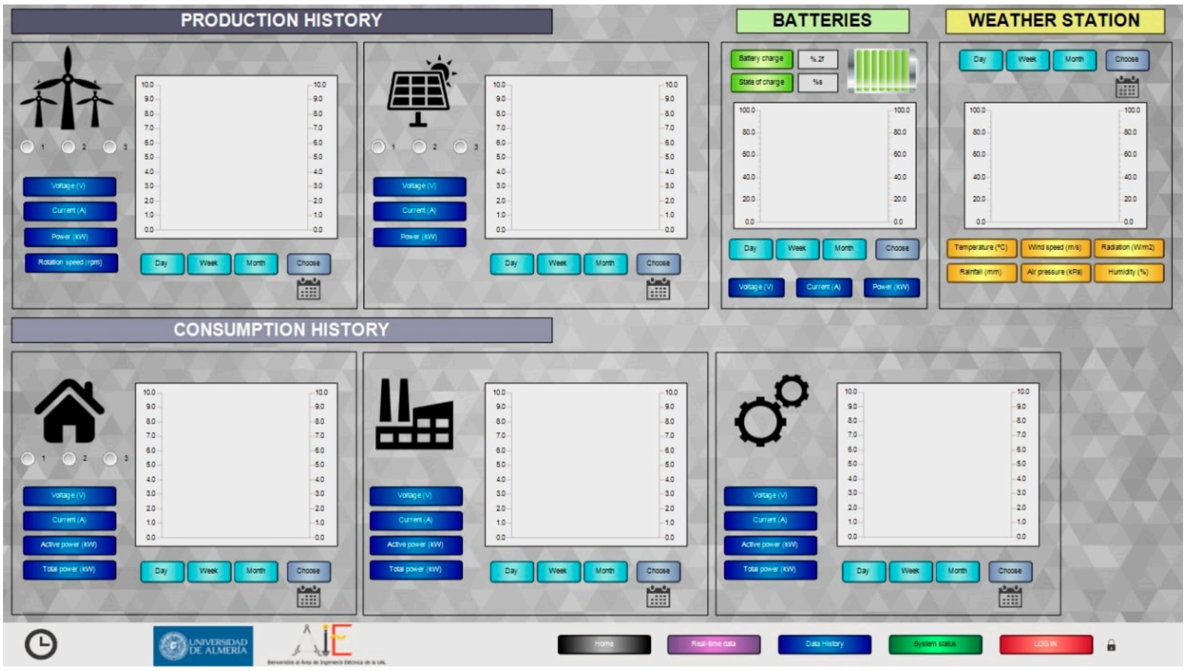

Figure 9. Data history for energy production and demand.

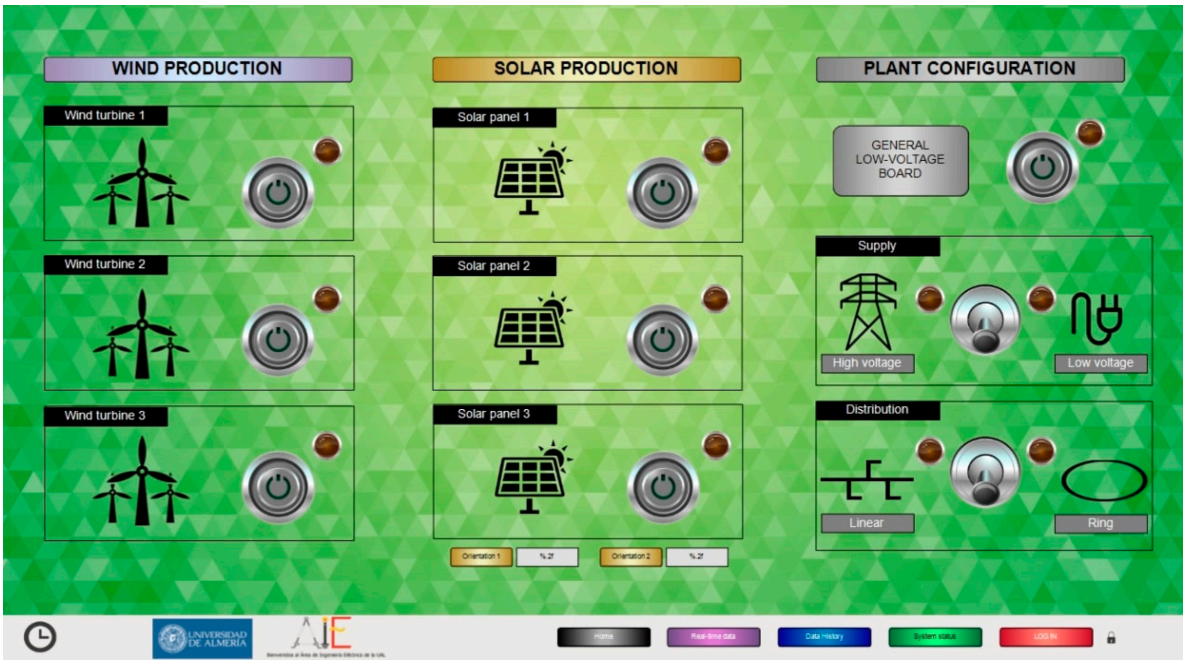

Figure 10. System status view.

3.3. User Management

In addition to this, SCADA HMI, a user management procedure, has been designed due to the large number of people who will be able to use this service as part of the university. The actions that differ when defining these user groups are control, configuration, and visualization activities. The control operations are those referred to as the configuration of the installation, such as the starting up and stopping of the renewable energy sources. Configuration actions refer to the modification of the HMI, for example, creating a new window screen. On the other hand, display actions are those which can be carried out by a user who only views the data collected by the SCADA from the HMI.

With this in mind, there are three defined user groups. The first is the Administrator type group, which can perform all types of operations, control, configuration, and display actions. Due to the importance of the management of this user group, a time limit has been established, after which the user will be automatically logged out to prevent other users from accessing these facilities without due permission. The next user group is the Visualization group, which can perform display actions only. The purpose of the existence of these users is to avoid the malfunctioning of the SCADA when several people access the HMI simultaneously, as happens in lectures. The last defined user group is the Maintenance group, which can perform control and display actions only. By this classification, the different uses to which the SCADA will be subjected are covered.

4. Conclusions

A SCADA system has been designed to monitor and control a hybrid generation laboratory in a centralized manner. It is a solution that facilitates supervision, control, and maintenance tasks of the plant, and it is a good application of the current resources for realistic energy management in an installation. This type of solution is increasing in interest due to the growing social concern about the sustainability and management of energy resources, including electrical resources. The use of a SCADA system for this laboratory at the University of Almeria is a small-scale representation of what the introduction of different energy sources into the global system implies. In addition, this study aims to bring interactive SCADA systems closer to students and teachers to improve their experience in engineering studies.

On the other hand, the extensions and improvements to this work can be infinite. TwinCAT 3 software has alarm programming functions that cannot alert users via email or SMS to the occurrence of failures in the system without the need to access the HMI. Alarms can also be programmed to warn when maintenance of laboratory equipment is required to ensure its durability. With the programming of alarms, it is easier to know when dangerous values of wind speed, harmonics in the signal, or reactive power occur so that they can be solved as soon as possible.

This was a good way to make the system even more accessible to all interested students so that they become familiar with the use of SCADA systems for energy management. Finally, for more ambitious future projects, the SCADA control, and visualization system could be extended to the scope of more than one laboratory of the University of Almeria or even the entire university campus. This will result in a project that is closer to the concept of a Smart Grid and the management of the electricity resource on a larger scale. It will be possible to observe real consumption patterns and manage the electricity resource efficiently. The greatest potentials of this type of system are the possibility of bringing electricity consumption management closer to everyone

In view of the remarkably wide scale of online teaching, this developed system opens up new perspectives for the online teaching of engineering studies in general and electrical engineering studies in particular. This possibility of online teaching helps to motivate students to ensure that they can participate in subjects actively and successfully.

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