# Small wind turbines study and integration in a peri-urban microgrid

## Estudio e integración de pequeños aerogeneradores en una microrred periurbana

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ABSTRACT: The use of wind resources has always gone hand in hand with high wind speeds in open fields. This paper develops the decisions to be taken for the selection, installation, and connection of small wind turbines in peri-urban environments, where wind speeds are medium or low. The guidelines are detailed throughout the document, starting with the study of the wind resource, the selection of the turbine, installation, and real-time monitoring of production for integration into a micro power grid. The installation of small wind systems in places as close as possible to the point of demand makes it possible to achieve a reduction in the cost of the electricity bill. This is thanks to the instantaneous control of generation and demand at a particular level through the installation of software, in this case, Home Assistant. The novelty of this paper is the use of this software Home Assistant to integrate of a small wind turbine in a microgrid and its control system.

RESUMEN: El uso del recurso eólico siempre ha ido de la mano de altas velocidades de viento en campo abierto. En este documento se desarrollan las decisiones a tomar para la selección, instalación y conexión de pequeñas turbinas eólicas en entornos periurbanos donde las velocidades del viento son medias o bajas. Las pautas se detallan a lo largo del documento, comenzando con el estudio del recurso eólico, la selección de la turbina, su instalación y seguimiento en tiempo real de la producción para su integración en una microrred. La instalación de pequeños sistemas eólicos en lugares lo más cercano posible al punto de la demanda, hace que se pueda conseguir una reducción en el coste de la factura eléctrica gracias al control instantáneo de la generación y demanda a nivel particular mediante la instalación de un software, en este caso, Home Assistant. La principal novedad de este artículo es el uso de Home Assistant para integrar un pequeño aerogenerador en una microrred y en su sistema de control.

## 1. Introduction

The implementation of renewable sources of energy generation is growing, increasing the percentage of non-fossil energy in the energy market. The most mature technologies are large-scale solar photovoltaic and wind energy [1], but the current trend is towards generating as close as possible to the source of demand, which means generating near or within urban centres. For years, we have seen how the installation of solar panels on buildings has been increasing in new buildings to reduce the demand bill, but we must not forget other possibilities such as the installation of small wind turbines on the roofs of buildings and the potential that this technology has.

Traditionally, small wind turbines were used for pumping and in systems isolated from the electricity grid (rural electrification [2] and telecommunications). However, in recent years their applications have grown in systems connected to the electricity grid, coinciding with the development of electrical microgrids based on distributed

generation systems [3]. In this way, wind energy can be used in places with low or medium winds where previously there was no installation of this technology [4]. This allows the production of green energy in a decentralized way, promoting energy independence, saving fossil fuels, reducing $CO_2$ emissions, and saving energy costs by avoiding losses in transport [5, 6].

It must be taken into account that when connecting a small wind turbine to a microgrid, it is just as important to select a model suitable for the characteristics of the site, as its exact location to maximize its production. Particularly in this type of site, it is more complex to find the best location. This is since we are faced with a turbulent wind resource that notably accentuates the variations in speed over short distances, thus being more affected by the architectural nature of the cities.

This document is based on the paper "Integration of small wind turbines in a smart microgrid in a peri-urban environment" presented at III Ibero-American Congress on Smart Cities (ICSC-CITIES 2020). It explains how a small wind turbine has been integrated into CEDER's electric microgrid, with special emphasis on their monitoring and integration into the microgrid's control system, to allow efficient control of the microgrid. The rest of the paper is as follows: section 2 describes the microgrid and the wind turbine under study, the different criteria for the location of a wind turbine in peri-urban environments, and a comparison of a wind turbine power curves (power vs wind speed) open-field and peri-urban environment. Section 3 discusses the selection of wind turbines for peri-urban environments. Section 4 describes the installation of wind turbines and their connection to the electrical grid. Section 5 presents the integration of the wind turbine in the real-time control system of the CEDER microgrid using the free software Home Assistant. Section 6 shows the conclusions obtained with this work, and section 7 the approach of the future work.

## 2. Case of study: CEDER microgrid

Eight transformation centres with multiple distributed generation systems, different mechanical and electrochemical storage systems, as well as several loads connected to each transformation centre form the CEDER's microgrid. There is also a control system to monitor all the elements of the microgrid developed in Home Assistant, which is a robust and affordable software solution with great potential that allows communication with the different components of generation, storage, and loads, through different communication protocols and their integration into a single interface.

### 2.1 Wind turbine description

The Wind Energy Unit carries out different tests on small wind turbines, so at CEDER there are always several wind turbines installed, some connected to the grid and others to batteries. Currently (March 2020), there are two wind turbines connected to the microgrid. We will focus on a special one for its particular location. The wind turbine ENAIR EPRO70 is a three-bladed wind turbine of 3.5 kW, 4.3 meters in diameter. It has a horizontal axis and works upwind. It is located on the roof of the Wind Component Testing Laboratory (LECA) building (see Figure 1 - N41º36'12.746" O2º30'26.748").

As will be seen in the following sections, the selection of a wind turbine suitable for the site, as well as the exact location of the wind turbine, are keys to achieving optimum efficiency. In peri-urban environments, the selection of the wind turbine is a complex decision due to all the parameters to be considered: type of wind turbine, nominal power, operating regime, weight, rotor diameter, tower height, etc. [7]. The most suitable wind turbine to install can vary from one location to another depending on the characteristics of the wind in each one of them (speed, laminar or turbulent regime) within the same location.

### 2.2 Criteria for the location of wind turbines in peri-urban environments

At CEDER, the installation of wind turbines is done for research purposes and to carry out different tests, and therefore its main objective is not production. In fact, in general terms, it is not a good location since the wind resource is not particularly good since the annual average wind speed is relatively low.

Therefore, although general considerations have been taken into account (as we will see below) for the selection of the specific location of each wind turbine, these were chosen based on other criteria in addition to the purely productive ones.

Before installing a wind turbine, it is necessary to evaluate and characterize the wind resource of the site, and this is especially important in peri-urban environments given the peculiarities of wind in these environments [3–8]. To do this, it is necessary to have wind surveys for at least one year, to avoid seasonal variations.

To characterize the wind resource, it is necessary to carry out measurements of different wind variables such as speed, direction, and a series of meteorological variables that have a great impact on the production of power by a wind turbine, such as atmospheric pressure, ambient temperature and relative humidity. To carry out these measures, a meteorological mast is installed

**Figure 1** Enair EPRO70 Wind Turbine on the roof of LECA building

with all the necessary sensors (cup anemometer, vane, thermo-hygrometer, and atmospheric pressure sensor) to measure these variables.

The wind speed sensor should be at the same height as the wind turbine rotor. If not possible, measured values must be extrapolated to rotor height using Equation 1, according to the vertical wind profile, which varies according to the roughness of the terrain:

$$\frac{V_1}{V_2} = \frac{\ln\left(\frac{h_2}{Z_0}\right)}{\ln\left(\frac{h_1}{Z_0}\right)} \tag{1}$$

Where:

$V_1$: is the wind speed at altitude 1.
$V_2$: is the wind speed at altitude 2.
$h_1$: is the height 1.
$h_2$: is the height 2.
$Z_0$: is the roughness of the terrain.

The height at which 100% of the wind resource is obtained increases in peri-urban environments with respect to open fields, as the roughness increases. Thus, in an urban area, 100% of the resource is not obtained until more than 350 meters high, while in a rustic area, it is reached at just over 250 meters.

For the position, this extrapolation is much more complicated in peri-urban environments than in the open field. It is because wind characteristics vary significantly from one point to another, even on the same roof, depending on whether the location is closer to the building wall or more indoors, on one side of the building with one shape or another with a different shape, so that the vertical component of the wind changes or turbulence is generated, etc. All this makes it very difficult to choose an optimal location for the installation of a wind turbine in a peri-urban environment; the installation of a wind turbine in an incorrect location can cause the power output to decrease to zero even when the wind is high [9].

Before installing the EPRO70 wind turbine on the roof of the LECA building, weather towers with sonic anemometers were mounted in different positions of the building to know the wind in each position. This type of sonic anemometer allows the measurement of the three components of the wind speed, which makes it especially interesting in this location given the vertical component of the wind on the roof after it hits the building.

This measurement procedure is expensive, which means that it cannot always be carried out in peri-urban environments. When wind cannot be monitored, it is advisable to carry out a study using Computational Fluid Dynamics (CFD) techniques [3–9] which simulate the behaviour of the wind using numerical methods and allow the wind resource on the site to be estimated.

Finally, we must take into account a series of considerations regarding the wind resource that does not occur in open fields but in peri-urban environments, which will be more notable the higher the density of buildings and the greater the height:

- The wind flow in open country is practically laminar, while in peri-urban environments, it is mostly turbulent. This means that there is a significant change over a relatively short distance.

- Obstacles can change the wind speed:

    - Increasing it: the streets can serve as air ducts that by Venturi effect increase the wind speed.

    - Decreasing it: when the wind hits the buildings, it slows down.

- The wind flow around the perimeter of a building's roof has a turbulent behaviour due to the collision with the building. For this reason, a wind turbine should not be placed near the perimeter of the building. Exceptionally, buildings with an appropriate geometry can improve wind behaviour.

For all these reasons, from a wind energy point of view, peri-urban sites are complex and difficult to evaluate as they depend on the shape, distance, and height of the nearby buildings. It is necessary to make a detailed study

of each site where a wind turbine is to be installed.

Besides, cities have not been built in such a way that they have a good orientation to the prevailing wind, but generally try to protect themselves from it. This causes significant problems of access to an undisturbed wind component suitable for the placement of wind turbines.

In this study case, the wind turbine was not selected based on wind surveys, but one that had previously been certified in our open field facilities to know its power curve and be able to compare it with the obtained in a peri-urban environment. Wind surveys help us to choose the specific location in the roof for this wind turbine.

Generally, wind surveys provide information on the characteristics of the wind at the specific location where the measurement was made, wind speed, turbulence, vertical component, etc. The selection of the wind turbine will be developed based on these characteristics. For instance, for laminar winds with a little vertical component, the most suitable wind turbine would be a Horizontal Axis one. For turbulent winds with a significant vertical component, the best option would be a Vertical Axis Wind Turbine (Darrieus for high speeds and Savonious for low speeds).

## 2.3 Wind turbine efficiency in peri-urban and open field environments

We have seen that the conditions of the wind resource change significantly between peri-urban environments and open fields, which means that the efficiency of the same wind turbine will change from one environment to another [3, 4].

The CEDER wind power unit has performed two power curve tests according to IEC 61400-12-1 Annex H on the Enair EPRO70 wind turbine at different sites. One of the locations was an open field, and the other a peri-urban site (see Figure 2). Table 1 shows values obtained.

One of the first differences we can observe (see Table 1) between the two studies carried out is that in open field, speeds higher than 15 m/s are obtained, while in the peri-urban environment during the test no values higher than 12 m/s were obtained.

Figure 3 shows the different behaviour of the wind turbine in an open field and peri-urban environment. For low wind speeds, the wind turbine produces almost the same energy in peri-urban environments as in the open field. In both locations, the cut-in wind speed is 4.0 m/s. However, for high wind speeds (over 7.5 m/s), it produces about 30% more energy in open fields than in a peri-urban

**Table 1** Power data in the open field and on deck in a peri-urban environment. Enair EPRO 70

| V (m/s) | Peri-urban environment Output power (W) | Open field Output power (W) | Dif. Open field – Peri-urban (W) | Dif. Open field – Peri-urban % |
|---|---|---|---|---|
| 4.0 | 238 | 69 | -168.8 | -244.64 |
| 4.5 | 280 | 149 | -130.8 | -87.79 |
| 5.0 | 430 | 268 | -161.7 | -60.34 |
| 5.5 | 510 | 436 | -73.6 | -16.88 |
| 6.0 | 680 | 622 | -57.8 | -9.29 |
| 6.5 | 987 | 875 | -112.3 | -12.83 |
| 7.0 | 1225 | 1148 | -77.5 | -6.75 |
| 7.5 | 1460 | 1431 | -28.8 | -2.01 |
| 8.0 | 1526 | 1740 | 213.8 | 12.29 |
| 8.5 | 1685 | 2089 | 404.4 | 19.36 |
| 9.0 | 1924 | 2469 | 544.9 | 22.07 |
| 9.5 | 2146 | 2866 | 720.3 | 25.13 |
| 10.0 | 2160 | 3239 | 1078.8 | 33.31 |
| 10.5 | 2376 | 3445 | 1069.3 | 31.04 |
| 11.0 | 2342 | 3456 | 1113.9 | 32.23 |
| 11.5 | 2346 | 3453 | 1107.5 | 32.07 |
| 12.0 | 2504 | 3433 | 929.0 | 27.06 |
| 12.5 | 2436 | 3416 | 979.6 | 28.68 |
| 13.0 | - | 3389 | - | - |
| 13.5 | - | 3362 | - | - |
| 14.0 | - | 3336 | - | - |
| 14.5 | - | 3304 | - | - |
| 15.0 | - | 3274 | - | - |
| 15.5 | - | 3233 | - | - |
| 16.0 | - | 3212 | - | - |
| 16.5 | - | 3176 | - | - |
| 17.0 | - | 3154 | - | - |
| 17.5 | - | 3141 | - | - |
| 18.0 | - | 3142 | - | - |
| 18.5 | - | 3145 | - | - |
| 19.0 | - | 3156 | - | - |
| 19.5 | - | 3131 | - | - |
| 20.0 | - | 3161 | - | - |
| 20.5 | - | 3169 | - | - |
| 21.0 | - | 3189 | - | - |
| 21.5 | - | 3178 | - | - |
| 22.0 | - | 3173 | - | - |

environment [10]. This difference remains practically constant up to cut-out wind speed, in which, for safety reasons, the wind turbine stops producing.

Combining these differences reflected in the power curve, the annual energy production will be of the order of 40% less in the peri-urban environment.

It is important to note that this is only valid for the exact location of the wind turbine in the peri-urban environment where the power curve test was carried out, as when changing location, the wind conditions can change and the power curve can be modified. In the open field, as the power curve is standardized, it is always the same.

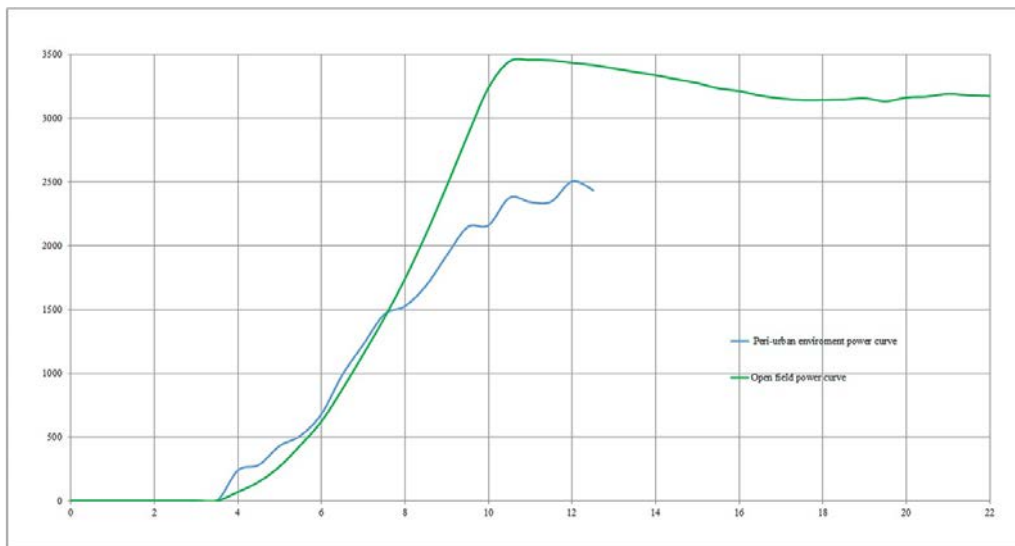**Figure 2** Enair EPRO70 Wind Turbine in an open field and peri-urban environment



**Figure 3** Wind turbine power curves in an open field and peri-urban environment

## 3. Selection of small wind turbines

There are several definitions of mini wind turbines, but the most widely used is the one established by the International Electrotechnical Commission (IEC) [11] in its Standard IEC 61400-2:2013 Small wind turbines. It considers a wind turbine to be of small power when the area swept by its rotor is less than $200m^2$. This is equivalent to approximately 16 meters in diameter and a power of 65 kW.

The selection of the wind turbine should be made according to the selection of the location. There is no single best wind turbine for every location, but depending on the characteristics of the wind, one model or another may be better suited. In addition, factors such as the installed power must be considered, which is closely related to the dimensions of the wind turbine. The height of the tower of the wind turbine also has an important influence.

Requirements to integrate a small wind turbine into a microgrid are different in a peri-urban environment than in an open field:

- High efficiency in low and turbulent winds: The average wind speed in an optimal location for a wind turbine in the open field can be higher than 10 m/s, while in a peri-urban environment, it barely reaches 4 m/s. Because of that, it is necessary to choose wind turbines specially designed for a peri-urban environment, which would be larger and

more expensive than one for open fields, where wind speed is higher. These wind turbines should maximize their production with low wind levels.

- Safe operation: The risk to people is greater than in the open, so machines must be designed to be safe.

- Low noise and vibration emission. The TSR (Tip speed rate) should be between three and five. If it is less than three, a blade design with a large area leads to low efficiency and if it is more than five, it produces a lot of acoustic noise.

- Robust and reliable machines with low maintenance.

At present, there are several models of small wind turbines to choose the one that best suits our specific needs. Table 2 shows a summary of the characteristics of the different types of small wind turbines on the market [12–14], which can be classified into three main groups:

- HAWT (Horizontal Axis Wind Turbine): the axis of rotation is parallel to the ground, and its principle of operation is to lift.

- VAWT (Vertical Axis Wind Turbine) Darrieus type: the axis of rotation is perpendicular to the ground, and its principle of operation is to lift.

- VAWT (Vertical Axis Wind Turbine) Savonius type: the axis of rotation is perpendicular to the ground, and its principle of operation is to drag.

**Table 2** Summary of characteristics types of wind turbines

| | HAWT | VAWT Darrieus | VAWT Savonius |
|---|---|---|---|
| Efficiency | High | Low | Very low |
| Visual impact | Low | Medium | High |
| Level of development | High | Low | Low |
| Noise and Vibrations | High | Low | Low |
| Reliability | Medium | Low | High |
| Orientation | Presents problems | No need for orientation | No need for orientation |
| Cut-in wind speed | High | Low | Low |
| Operation with turbulent wind | Bad | Good | Good |
| Use of the vertical wind component | Unusable | Usable | Usable |

To summarize, the best option for a peri-urban environment is VAWT (Darrieus type). They have better characteristics for everything than Savonius type, except reliability. Comparing with HAWT, Darrieus type has lower efficiency in open field but almost the same in peri-urban areas due to they are able to generate with low speed and turbulent winds. In addition, Darrieus type does not need an orientation system and noise and vibration levels are lower.

# 4. Installation of the wind turbine and connection to the electricity grid

Once the location and model of the wind turbine has been decided, it must be installed and connected to the electricity grid. To connect a small wind turbine to a microgrid, there are generally two possibilities depending on the type of electric generator. If it is an induction generator, it can be connected directly or through an AC/DC converter. If it is a permanent magnet synchronous generator (PMG), it is connected via a rectifier and a DC/AC converter. Usually, induction generators are competitive for big wind turbines and permanent magnet synchronous generators for small wind turbines.

In Europe, the EN 50438 standard defines the tests required for the DC/AC converter. Some countries do allow the connection directly, such as the United Kingdom, Denmark, Greece, Ireland, or Portugal, and other countries that do not allow it (the distribution grid operator must give prior permission for the connection) such as Spain, Germany, France, Italy, etc.

Besides, there are a set of international standards for small wind turbines. Standard IEC 61400 is an international standard published by the International Electrotechnical Commission [11] that aims to ensure the safety and efficiency of each wind turbine.

However, these rules are not compulsory for the installation of a wind turbine in all countries. Furthermore, each country has its own rules or criteria. For example, in Spain, there are no mandatory rules for the installation of a small wind turbine beyond the CE (Conformité Européenne) mark, while in other countries such as Great Britain, the United States, Japan or Denmark, certification is required.

To install a small wind turbine on the ground, no special installation precautions should be taken, but when installing on the roof of a building, care should be taken to reinforce the roof structure, if necessary, before starting installation work. Then a concrete base must be built to install the supporting structure for the tower. The next step is the erection of the tower with the turbine (depending on its size, this may require the use of a crane). Subsequently, electrical wiring must be made, connecting wind turbine output to the control box and then to the inverter, and the inverter to the microgrid. Finally, before commissioning the system, final electrical safety and performance should be checked.

# 5. Integration of wind turbines into the microgrid control system

Once the wind turbine is installed and connected to the grid, it is necessary to monitor it with the control software that manages the microgrid in which it is incorporated, to see its production in real-time and to be able to define the most appropriate strategies for the control of the microgrid together with the rest of its components.

As wind turbines are non-dispatchable generating elements [15, 16], that is, their primary energy source is neither controllable nor storable, their integration into a microgrid is particularly complex, as their variability makes it difficult to maintain a balance between electricity generation and demand [17–19]. This variability is because its operation depends exclusively on the meteorological conditions existing at each site, which implies uncertainty in the prediction of production.

The production of a wind turbine can be regulated by acting on the inverter (see Figure 4), giving it the appropriate instructions to limit it. However, this does not make sense from an energy point of view since we would be wasting generation capacity, except in very specific cases where we want to avoid injection into the distribution network and all storage systems are at maximum capacity.

From the point of view of the integration of the wind turbine into the microgrid management system, the fact that production cannot be regulated makes the work easier as it is not necessary to develop a SCADA (Supervisory Control and Data Acquisition) for its control, but we will only need to monitor the desired variables.

The simplest case would be to monitor only the instantaneous power of the wind turbine, for which it would be sufficient to communicate with the wind inverter (Enair 5 kW) and read this value. As with this inverter, it is usual for all current equipment to allow communication to be established with it, using the Modbus TCP/IP protocol, based on client/server architecture and allowing communication over an Ethernet network without CRC (Cyclic Redundancy Checksum).

Figure 5 shows the communications scheme of the microgrid with Enair EPRO70 under study and anemometry acquisition system.

In our case, in addition to the instantaneous power, we are also interested in monitoring the wind speed to be able to determine and study the power curve of the wind turbine in a peri-urban environment.

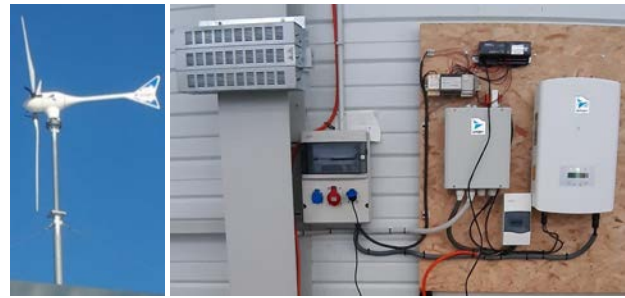For this purpose, it is necessary to install an anemometer



**Figure 4** Enair EPRO70 Wind Turbine and equipment necessary for connection to the network

at the same height as the axis to be as precise as possible regarding the speed received (see Figure 6). In our case, a sonic anemometer has been installed. Unlike the most common cup anemometers, this one allows measuring the horizontal and vertical components of the wind. This last component is of special interest in urban and peri-urban environments.

To read the values recorded by the anemometer, it is necessary to define and install a data acquisition system (DAQ) that allows the microgrid management system to communicate with it. In our case, we use a National Instruments data acquisition system, a FieldPoint model.

We can record multiple variables from the wind turbine and its meteorological mast (power, voltage, wind speed, wind direction, etc.), and it allows communication via Ethernet. Using the Modbus TCP/IP protocol, we can communicate the anemometer with the microgrid control centre.

First of all, to communicate the wind turbine with Home Assistant, the DAQ must be defined in the configuration file by assigning it a name and indicating the type of communication to be used (in this case, it is Modbus TCP/IP), the IP and the port (by default, Modbus TC/IP uses port 502).

```
- name: Enair       # name assigned to the wind
                      turbine in Home Assistant
  type: TCP         # protocol type
  host: 192.168.15.75  # IP address
  port: 502         # communication port
```

Once the DAQ is defined, we must read the records that contain the desired information in their corresponding directions (monitor), that is, the power of the wind turbine and the wind speed. This is also done in the Home Assistant configuration file, and for this, it is necessary to have the address where DAQ stores the variables that we want to read. For instance, to read instantaneous power, the following definition must be included in the
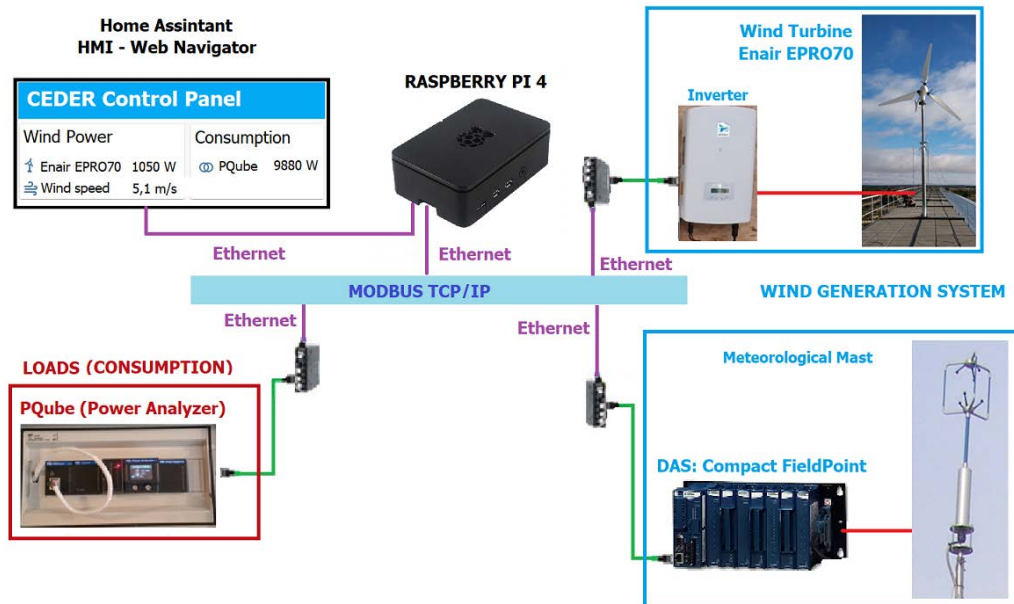
**Figure 5** Scheme for monitoring wind turbine power and anemometry using Modbus TCP/IP



**Figure 6** Meteorological mast for Enair EPRO70 Wind Turbine

configuration:

```
- platform: Modbus          # Modbus
scan interval: 1            # scan interval
registers:
- name: Enair Power         # monitored parameter
hub: Enair                  # element defined previously
register type: holding      # type of register (input, holding, etc.)
unit of measurement: W      # unit of the parameter
slave: 1                    # Modbus Id
register: 2008              # Modbus address
count: 1                    # number of addresses affected
scale: 1                    # scale (x1, x10, etc.)
data type: uint             # unsigned integer
```

Once monitored, all that remains is to incorporate it into the control panel in Home Assistant to see all the values collected in real-time. Figure 7 shows the real-time values of the power of the wind turbine, the wind speed, as well as the demand in each of the eight transformer centres that make up the CEDER microgrid. The EPRO70 is producing 1610 W for a wind of 8.9 m/s. The total demand of CEDER is 41668 W, 21853 W consumed from the distribution network, and the 19815 W remaining are produced by the wind systems (Atlantic 182005 W and Enair 1610 W) of the microgrid.
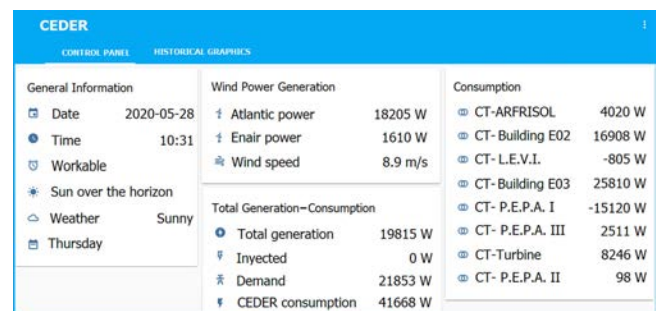


**Figure 7** Control panel in Home Assistant

The values obtained for each variable can also be represented graphically, as shown in Figure 8.

## 6. Conclusions

This paper explains how to integrate small wind turbines into a microgrid. It takes into account all aspects related to the assessment of the wind resource, with a special
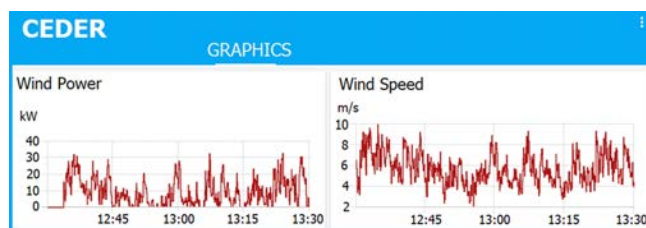
**Figure 8** Graphic representation in Home Assistant

emphasis on its peculiarities in peri-urban environments, the selection of the wind turbine best suited to the site, its connection to the electricity grid, and its monitoring and integration into the microgrid control system to supervise its operation in real-time.

The integration of wind turbines into electrical microgrids is of great interest as distributed generation systems allow the generation to be brought closer to the points of demand. However, it presents certain difficulties that are not easy to solve.

On the one hand, they are non-dispatchable generation systems since they depend on the wind at any time, and this makes the control of generation-demand difficult and makes storage systems necessary to optimize it. Moreover, the great variability of the wind resource further complicates the control of the microgrid, as significant changes in wind speed can occur in two consecutive seconds.

It should also be taken into account that most microgrids are located in urban or peri-urban environments, which makes it very difficult to determine exactly the ideal location for each wind turbine to be incorporated into them, given the peculiarities of the wind in these types of environments. Besides, most wind turbines are designed to operate in open fields, and the more specific designs for urban environments are in the process of maturing, trying to improve their efficiency, noise levels, and safety.

Once a solution to these problems has been found, and a series of standards have been established to ensure the technical quality of wind turbines, they will make it possible to produce "green" energy in a decentralized manner with a high efficiency that will improve the efficiency of the microgrid to which they are integrated.

## 7. Future work

Paying attention to one of the main difficulties in the installation of a wind turbine in a peri-urban environment is to select its optimal location, which is immensely influenced by the layout of buildings and streets doing

the wind resource to take on a turbulent regime. Future research work includes the definition of optimum location ranges for the parameters necessary to make this decision, such as distance from the perimeter of the roof, distance from the central position of the roof, orientation according to the wind study carried out, among many others.

## 8. Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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## 10. Author contributions

Conceptualization, O.I-M.; Methodology, O.I-M., P.P-C. and L.H-C.; Software, O.I-M, G.M-J..; writing—original draft preparation O.I-M. G.M.J. and P.P-C.; writing—review and editing, L.H-C.; supervision, L.H-C.

## 11. Data Availability Statement

Data were collected at CEDER-CIEMAT from May to September 2019. We used a grid analyser to measure wind turbine power and a cup anemometer to measure wind speed. The data acquisition system was a compact Fieldpoint from National Instruments integrated in the CEDER's microgrid energy management control system developed with Home Assistant.

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