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Sizing of Hybrid Photovoltaic-Wind Energy Systems Based on Local Data Acquisition

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Abstract

Although there are different alternatives to provide energy, there are still remote regions with no nearby possibilities of having an electricity supply that meets their basic needs. Colombia, like many countries, does not have uniform environmental conditions; therefore, applying models for the dimensioning of energy systems based on renewable energy can be inefficient and expensive, making it difficult to access electricity in isolated places. The research aims to develop a sizing strategy for a hybrid system based on locally acquired environmental information to size a system that takes advantage of the natural resources available in the local in the best possible way. Information is collected through a data acquisition system on local environmental conditions, system requirements are established based on energy demand, and a mathematical model is sought that represents the electrical behavior. The model makes it possible to analyze the system's behavior under variable environmental conditions in the region, thus

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guaranteeing an adequate dimensioning for a constant supply of low-power energy suitable for residential use. This article presents an alternative to characterize a hybrid power generation system (photovoltaic/wind turbine) through data collected on-site, which, when properly processed, allows the dimensioning of a more appropriate hybrid system to the environmental conditions the environment. The system was implemented in an experimental farm of the University of Pamplona located in the north of Colombia. Based on this strategy, a hybrid system was designed and installed to meet energy demands efficiently.

Keywords: Hybrid energy systems; renewable energy; solar−wind based hybrid systems; solar photovoltaics; wind turbine.

Dimensionamiento de sistemas de energía híbridos fotovoltaica-eólica basados en aquisición de datos locales

Resumen

Si bien existen diferentes alternativas para proveer energía, aún hay regiones remotas sin posibilidades cercanas de tener un suministro eléctrico que cubra sus necesidades básicas. Colombia al igual que muchos países no tiene condiciones ambientales uniformes, por tanto, aplicar modelos para el dimensionamiento de sistemas energéticos basados en energías renovables, pueden resultar ineficiente y costoso, dificultando el acceso de energía eléctrica en lugares aislados. La investigación tiene como objetivo desarrollar una estrategia de dimensionamiento para un sistema hibrido, basado en información del ambiente adquirida localmente con el fin de dimensionar un sistema que aproveche los recursos naturales disponibles en el local de la mejor forma posible. A través de un sistema de adquisición de datos se recolecta información de las condiciones ambientales locales, se establecen requerimientos del sistema a partir de una demanda energética y se busca un modelo matemático que represente el comportamiento eléctrico. El modelo permite analizar el comportamiento del sistema ante condiciones ambientales variables en la región y así garantizar un dimensionamiento adecuado para un suministro constante de energía de baja potencia apta para uso residencial. Este artículo presenta una alternativa para caracterizar el comportamiento eléctrico de un sistema híbrido de generación de energía (fotovoltaica/ turbina eólica) a través de datos recolectados en el local, que procesados adecuadamente permiten dimensionar un sistema hibrido más adecuado a las condiciones ambientales del entorno. El sistema se implementó en una finca experimental de la Universidad de Pamplona ubicada en el norte de Colombia, basado en esta estrategia se proyectó e instalo un sistema hibrido para cubrir las demandas energéticas de forma eficiente.

Palabras clave: Sistemas de energía híbrida; Energía renovable; energía solar fotovoltaica; sistemas híbridos; turbina eólica.

1 Introduction

Currently, there are different alternatives to generate clean energy that mainly solve supply problems in the commercial, industrial, and residential sectors [1]. If we observe, the agricultural sector, despite having easy access to alternative energy resources (solar, wind, and hydroelectric), requires to customize solutions, where environmental factors directly influence the sizing of the system [2]. Remote regions and climatic variability as a result of observed fluctuations in the climate for relatively short periods are considered the main barriers to implementing renewable energy systems [3]. In this sense, it is necessary to study the electrical behavior of the systems against changes in environmental conditions [4].

The demand for energy increases every day, and its efficiency improves with the inclusion of new technologies, increasing the number of alternatives to implement renewable energy generation systems in places with severe conditions [5]. Within this context, the construction and validation of models allow the generation of hybrid alternatives that manage to take advantage of the characteristics of climate variability in different periods [6].

A hybrid system based on renewable energy ranks as the best option in terms of cost, reliability, and efficiency compared to a system that uses a single source [7]. In demand for customized systems for regions with specific environmental characteristics, multiple solutions can be an alternative in the construction of hybrid systems [8]. If we look at solar and wind energy sources, they naturally complement each other and offer advantages within the climatic variability present in various regions.

Different authors agree in their research in stating that hybrid power generation systems are an optimal solution in terms of energy efficiency and costs, which contribute to reducing dependence on fossil sources [9],[10]. Another reason to highlight hybrid systems implementation is the advantage of having unlimited natural resources to complement each other in case of climatic variability [11]. The main disadvantage lies in estimating the real load that tends to increase with time, causing optimized systems to be at their limit of operation over time. Climatic conditions directly influence the system's performance; due to the variability of the environment, the most influential natural resources at different stages of the year must be identified to size a system mainly on these characteristics.[12].

In developing countries, there are remote regions that, due to topographic conditions and difficulty accessing, compromise their production systems because they do not have electricity [13],[14]. Solutions based on only renewable energy sources would present intermittency due to weather conditions, and their implementation would be more expensive than using hybrid systems[15]. Combining the different energy generation sources can reach an economically viable and technically developable system configuration for these environmental conditions [16].

Hybrid systems are designed to enhance the potential and characteristics of renewable fuels [17]. The information used to project the system is usually taken from meteorological data produced by satellite observation [18]. The local data acquisition system proposed in this investigation seeks to complement the information obtained satellite and be an alternative to nurture additional data about the installation site of the hybrid system [19],[20]. New lines of investigation are derived in this context, seeking to define control strategies to increase performance, develop optimization, and dimensioning algorithms to install future energy systems.

Wind and solar systems are scalable, allowing to increase capacity as demand increases. A correct configuration of the hybrid system reduces the size of the battery bank [21]. The battery bank plays an important role when renewable energy sources cannot meet the load demand; in this case, the batteries supply energy to the system and maintain the flow until its capacity is exhausted[22]. The hybrid system's performance depends on the correct selection and integration of each element, but it is essential to independently analyze the individual operation of the photovoltaic system and the wind turbine system. In order to evaluate each component's contribution, the individual electrical behavior is obtained, and an appropriate combination that meets the required demand is evaluated[23].

Different dimensioning alternatives are documented with potential benefits for standardized approaches, using typical solar and wind energy patterns [2]. Many of these systems dimensioned from these models to guarantee the supply and constant load profile use minimum energy values, which show that a considerable amount of energy when these factors are meeting their maximum is disregarded wasted [24]. This could be the main reason for the increase in the cost of installing clean energy systems [25]. In addition to presenting an alternative for dimensioning the local surroundings of regions outside these patron regions, an attempt is being made to establish a procedure to install a hybrid system that will supply the necessary power requirements. In this investigation, there is an emphasis on the climatic variation that, in many cases, does not address seasonal behaviors.

The design of strategies that seek to overcome the barriers that limit the implementation of energy systems based on renewable sources is the focus of different investigations. Chauhan et al.[25] addresses within his research methodologies of dimensioning and control of systems for the management of energy flow; This research identifies several parameters of economic viability, development of strategies that improve the use of natural resources, and dispositions for integration. The objective of sizing energy systems based on renewable sources involves reliability indices, cost analysis, and optimization techniques. [26],[27].

The variation in environmental conditions means that energy systems based on these resources present the same variability; load factors are critically affected since energy demand remains constant. Reliability analyzes mitigate this uncertainty effect. Data acquired on the behavior of variables related to environmental conditions can help develop these analyses. The dependence of renewable energy resources with geographical location and environmental conditions justify the study of hybrid systems; however, the initial cost, need for maintenance, and system efficiency are challenges to be conquered. Samaniego et al. [28] manages to relate the viability of a system based on its technical and economic aspects, using a simulation to perform an analysis and through tests with different configurations. A combination of factors within sizing directly influences performance.

The construction of suitable models that allow the generation of behavior analysis in hybrid systems links several of its components within the models. The role of the components within the system can generate different strategies, as is the case of implementing battery storage charge models and projecting strategies based on the availability of resources such as wind and accessibility of sunlight. Among the key aspects to analyze a hybrid system is the system's configuration concerning the available resources and optimization of the system's output power. It is essential to highlight that contributions can be derived from a correct interpretation of the data acquired at the installation site.

Environmental data such as temperature, radiation, and wind speed acquired for a specific location are difficult to acquire and require processing to be converted into information and knowledge [29]. The development of a module for data acquisition allows to record variables, useful for sizing; it can systematically produce this information, also returning operating variables of the system. For the estimation and selection of components that make up the hybrid energy system, the metrological data are pretty helpful. They can positively affect economic, technological, and environmental factors associated with the hybrid system's sizing process [7].

The simulation of the performance of hybrid solar photovoltaic- wind power systems requires climate data, which in some cases can be found in nearby web sources and weather stations; the best option is through a reliable solution, meteorological data obtained at the location particular installation. Typical meteorological year (TMY) is an observation technique that selects particular months of different years using the precision system[30]. Bianchini A et al.[31] They emphasize metrological data in the form of solar irradiance and wind distribution to optimize a hybrid renewable energy system such as a photovoltaic panel fusion, horizontal axis wind turbine, and a diesel generator.

This paper describes the installation and implementation of a hybrid power generation system, based on renewable energy (Solar and Wind), for a farm located in the rural area of northeastern Colombia. From the geographical location of the farm, the parameters considered in the selection of the solar panel and the wind turbine are presented, such as solar radiation, average wind speed, temperature, irradiation, among others. The sizing and installation of hybrid systems are based on the characterization and identification of the parameters and variables involved in the generation and supply of renewable energy (solar and wind).

2 Methodology

The objective of sizing is to achieve a configuration of elements such as a turbine, solar panel, battery bank, regulator, controller, and other components of the system that operate simultaneously to maintain the flow of energy necessary to satisfy the required demand. A computational method is developed to size the system that contains the entire hybrid system sizing procedure, helpful in projecting its use in other remote locations with difficult access and energy deficiencies. The data acquisition system transmits the acquired data to the sizing interface via Ethernet protocol. The acquisition module collects the current values of environmental variables such as temperature, access to sunlight, radiation, and wind speed to create a model that takes advantage of the natural resources characteristic of the location under study. A remote region with unpredictable climatic conditions characteristic of the location is chosen as a typical case study. Sizing is developed to meet an energy requirement for a low power system.

Different computational techniques and tools are available to aid the sizing of hybrid systems, but the lack of information in remote regions limits their application [32],[33]. A flexible solution is proposed that can support optimization techniques with new criteria and restrictions obtained from the experience of this implementation in the future [34],[35].

The applied methodology starts with a data acquisition module that captures the meteorological characteristics of the installation location. These data are the inputs to the sizing system to build models that describe the electrical behavior and generate a selection criterion for the equipment involved in the hybrid system [36],[37]. The data acquisition module is designed to work for long periods, thus building a helpful dataset for future research.

The methodology followed for sizing is exposed through the scheme presented in Figure 1. In the first phase, *Acquire environment variables*, activities related to data acquisition are developed. The primary function is to record, store, and transmit the current values of variables such as temperature, wind speed, radiation, and access to sunlight used in constructing the model that describes the system's dynamic behavior. The data acquisition module is designed and developed to fulfill this function. The second phase determines the mathematical model of the system.

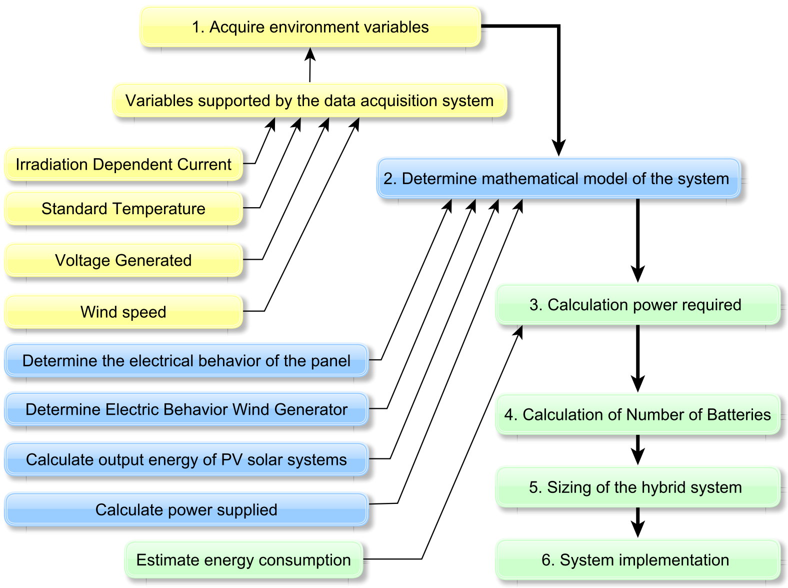

Figure 1: Methodology for system implementation.

The acquired data is processed. The mathematical model is analytically estimated to be used in a simulation environment and to analyze the electrical behavior of the hybrid system under current environmental conditions. In the third phase, *Calculation power required*, the required power is calculated, considering the equipment to be connected to the system and the anticipated energy consumption for the premises. In the fourth phase, the battery bank is projected, the type of batteries is selected, and the number of batteries necessary for the installation of the system. In the fifth phase, *Sizing of the hybrid system*, the sizing of the hybrid system is completed with the ideal distribution of the components of the hybrid system. In the last *System implementation phase*, the activities necessary for implementing and starting up the system in the facilities with their functional tests are developed. The energy demand profile is projected for residential use taking into account possible future variations in the demand for electrical load [38]. Due to the geographic location of the project execution, no-load profiles are associated according to weather stations, but it is considered a factor that represents slight variations.

The environmental variables wind speed, solar radiation, and temperature, acquired in the local electrical behavior models, are estimated and included in a simulation environment to analyze their behavior. The models allow the correct selection of equipment and the correct configuration of the hybrid system, defining the number of solar panels, selecting the appropriate wind turbine, projecting the battery bank, and choosing the regulator for the charging process. The integration of the elements must guarantee the delivery of the required energy and the best development of natural resources [39].

For the realization of the project, a cabin belonging to the University of Pamplona, located at kilometer forty-nine on the Pamplona-Cúcuta road, North of Santander, Colombia, was used as a place of testing and analysis of conditions.

3 Implementation of the data acquisition system

The analysis of the environment variables and the parameters of the power generation system provide helpful information to build the model of the electrical behavior of the hybrid system. In the construction of the model, an electronic module was developed to acquire samples of data from the environment. The module internally contains a conditioning circuit connected to an Arduino Mega development board. The module captures physical signals through sensors and converts them into digitizable electrical signals. A preprocessing is applied to eliminate disturbances before storing and sharing the data through the ethernet communication protocol.

The data acquisition system is proposed as a measurement and capture mechanism for the parameters associated with power generation in the installation environment. With the collected data, we seek to obtain a mathematical model that describes the main characteristics of the hybrid generation system. The model facilitates the study of the system against the changing environmental conditions characteristic of the region. Some parameters used in the study need to be monitored for prolonged periods, stored as a backup in connection loss, and transmitted via the internet for remote processing. Figure 2 presents a system scheme that shows the module for data acquisition used in this project's development.

A circuit composed of a voltage follower is established as a voltage measurement mechanism, operating together with an operational amplifier that acts as a voltage level translator. The circuit provides isolation through a common-impedance coupling, short circuit protection, and calibration mechanisms to guarantee each variable's measurement. The circuit is connected to a processing module in charge of converting the physical signal into a numerical value. The module offers storage support on an SD card and controls communication via ethernet to transmit the captured data.

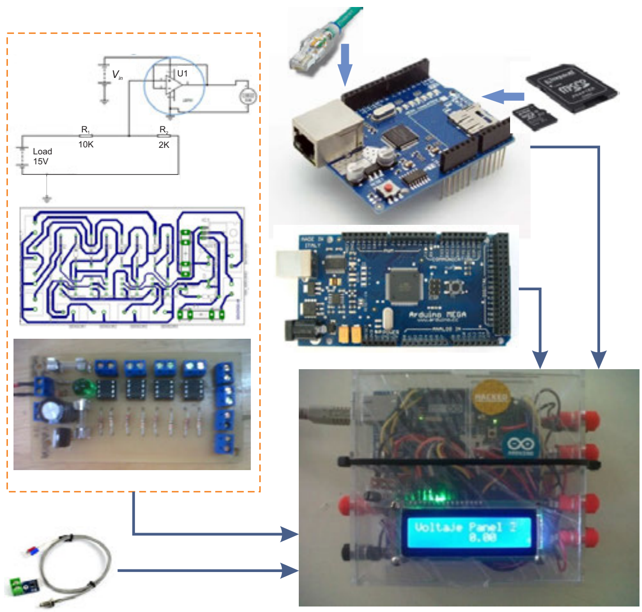

Figure 2: Data acquisition System to model hybrid power system.

4 A mathematical model to describe the electrical behavior of the hybrid power generation system (wind-solar)

The electromagnetic radiation of solar energy can be converted directly into electricity through the photovoltaic effect [40]. Each photovoltaic module groups together a set of interconnected photovoltaic cell units both in series and in parallel to form photovoltaic arrays. In the construction of the mathematical model, it is based on an equivalent electrical circuit of a solar cell. The electrical system is made up of an irradiation-dependent current source (G), a parallel diode with saturation current I_o, two resistors R_s and R_{sh}.

The module can be modeled mathematically with the Equations (1),(2) and (3). [4]. The Photogenerated current, I_{ph} is determined with the Equation (2), the series and shunt resistance, R_s and R_{sh} are to represent the real internal voltage drop voltage drops and internal losses[41]. The saturation current, I_o varies with temperature, is determined with the Equation (3). The thermal voltage is given by Equation (5).

$$I = I_{ph} - I_o{\cdot}((e^{v+I\cdot R_s}/n{\cdot}V_t) - 1) - V + I{\cdot}R_s/R_{sh} \tag{1}$$

$$I_{ph} = A{\cdot}(j_{sc}(G/0.1)) - \alpha_{SC}(T - 298) \tag{2}$$

$$I_o = I_{o_{298}}{\cdot}T/298^{3/n}e^{q\cdot Eg/n\cdot K(1/T)-1/298} \tag{3}$$

$$I_{o_{298}} = I_{SC}(298)/q{\cdot}V_{OC}/e^{n\cdot K\cdot 298} - 1 \tag{4}$$

$$V_t = K{\cdot}T/q \tag{5}$$

Figure 3 shows a graph representing the current (I) generated by a solar cell as a function of voltage (V). It can be seen that the cut-off points on the axis (I) coincide with the cell's short-circuit current; on the other hand, for the axis (V), it goes through the open-circuit voltage value of the solar panel. The characteristic equation of an electric charge delivered by the solar panel is a function of resistance, therefore the lower it is, its behavior will be constant, and when the value of the resistance increases, the current flow will be less, tending to zero.

Figure 3 shows the point of the maximum power delivered by the cell. The electric current capacity depends directly on the number of cells in series and parallels that the panel has. Assuming similar electrical behaviors for each cell, the current generated by the module is determined by

Table 1: Parameters Used to Calculate the Mathematical Model

Parameters	Symbol	Unit	Quantity
Boltzmann constant	K	$J/°K$	$1.38e^{-23}$
Electron charge	q	C	$1.60e^{-19}$
Ideality factor	n	-	1.95
GAP Energy	E_g	V	1.12
Irradiation	G	W/cm^2	-
Series resistance of a cell	R_S	Ω	$1.2e^{-4}$
Cell area	A	cm^2	243.36
Open circuit voltage	V_{oc}	V	0.6
Temperature	T	$°K$	298
Open circuit voltage	V_{OC}	V	0.6
Short circuit current	I_{sc}	A	3.21
short circuit current density	J_{sc}	A/cm^2	$13.22e^{-3}$

multiplying the cell current by connecting them in parallel. The voltage delivered by the panel is obtained by multiplying the cell voltage by the number of them connected in series. This result allows us to have a panel selection criterion, adapted to the conditions and electrical requirements.

Regarding the wind turbine's electrical behavior, wind density is determined by the Equation (6). With the result obtained, the ideal wind power is estimated for the location of the system through the Equation (7). The power coefficient should be considered to estimate the actual available wind power (8). The maximum value that the power coefficient can take, known as the Betz limit is 59.26%. A summary of the parameters used in the calculations is presented in the Table 2.

$$\rho = P_0/R{\cdot}T{\cdot}e^{-g\cdot z/R\cdot T} = 1.0593Kg/m^3 \tag{6}$$

Based on the measurements taken, the wind speed is obtained together with the air density. An average value for the wind speed is established, and through Equation (7), the wind power is determined. The mechanical power of the wind turbine is also obtained.

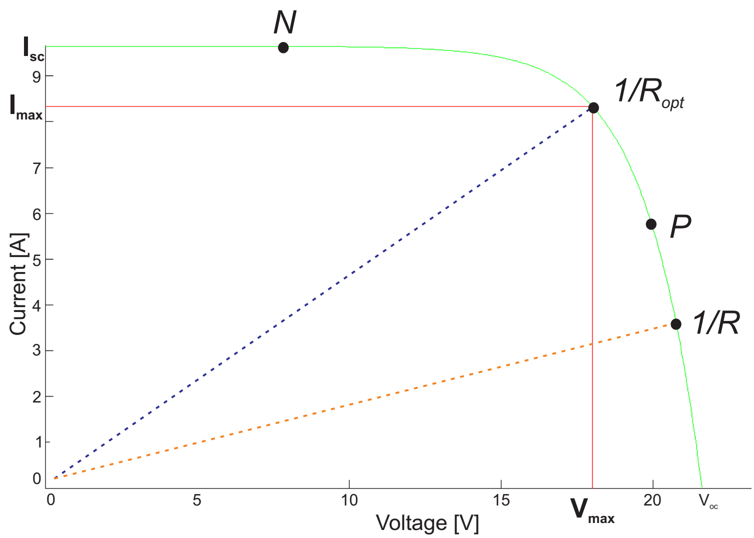

Figure 3: Characteristic curve of the solar panel.

$$P_v = 1/2{\cdot}\rho{\cdot}A{\cdot}V^3 = 48.59W \tag{7}$$

With the Equation (8) the power coefficient is obtained, a necessary parameter to determine the real power available from the wind. The power coefficient C_p, can be expressed as the ratio of the power extracted by the wind turbine and the power available from the wind.

$$C_p = P_{turbine}/P_v \tag{8}$$

The power generated by the turbine as a function of the wind speeds obtained at the installation site is determined using the Equation (9).

$$P_{Turbine} = 0.5926{\cdot}1/2{\cdot}\rho{\cdot}A{\cdot}V^3 \tag{9}$$

Table 2: Parameters Used to Calculate the Mathematical Wind Turbine's Model

Parameters	Symbol	Unit	Quantity
Standard atmospheric pressure	P_o	KPa	101.235
Air constant	R	J/KgK	286.9
Gravity	g	m/sg^2	9.8
Temperature	T	$^\circ K$	298
Altitude	Z	m	–
Surface the wind turbine	A	m^2	1.07
Wind speed	V	m/s	3.5

5 Functional description of the developed interface

Based on the mathematical model described above, a Matlab program was created for simulation and system sizing. The model provides answers about the electrical behavior of the system and responses to different environmental conditions.

Figure 4 shows an IDEF0 (Integration Definition for Function Modeling) scheme to present each of the related activities in the research development. Each block represents an essential activity with inputs subject to modification, mechanisms that allow the outputs of each activity to be generated, and control parameters that guarantee that the results obtained are as expected. These activities were implemented in the interface to facilitate future sizing of hybrid systems in premises with different environmental conditions. The knowledge base of the environment uses the data transferred remotely to create the mathematical models that govern the electrical behavior of the system. As a result, the models generate the power delivered by the photovoltaic cell and the wind turbine, helpful information to scale the system to the required power.

Figure 5 shows the interface developed in Matlab to process the acquired data. The interface allows interpreting the data received from the acquisition module, generating information, and offering a visualization of the data within the context of the investigation.

Through the developed interface, the hybrid system can be simulated, and the response of the electrical behavior can be obtained according to

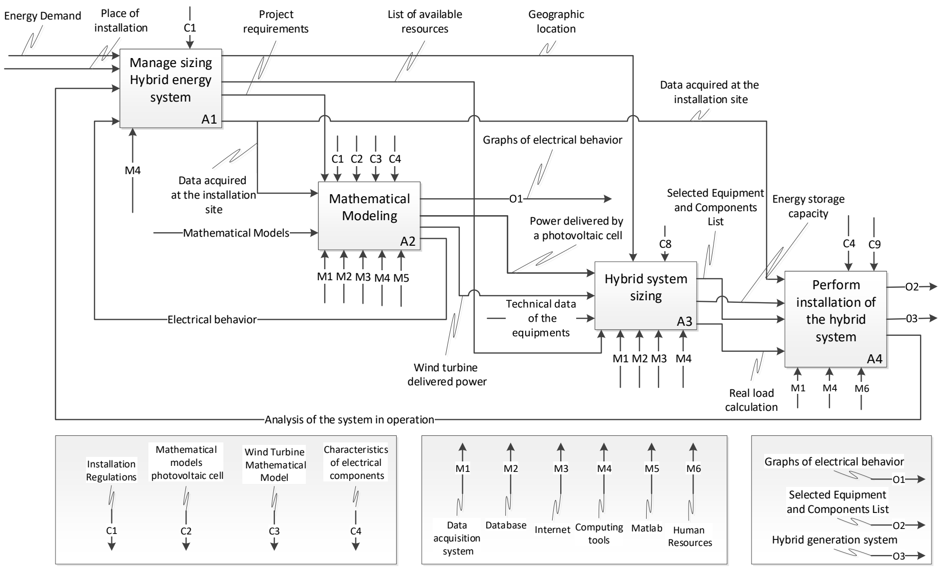

Figure 4: IDEF0 Schema of the Structure of the developed interface.

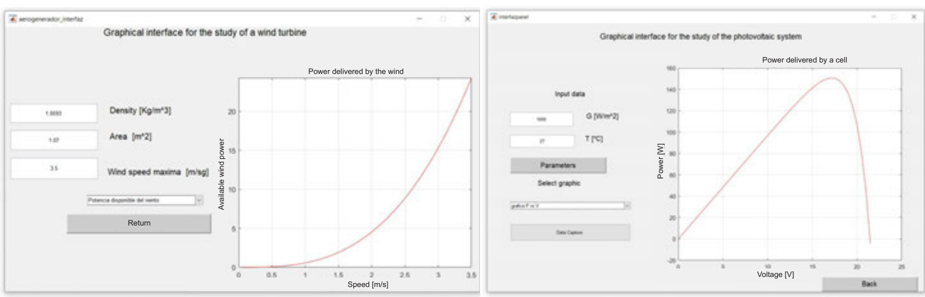

Figure 5: Interface developed in Matlab.

the variables of the installation environment. The interface allows us to dimension the hybrid power generation system based on the mathematical models, the responses obtained, and the project requirements given to meet the energy demands.

6 Demonstration of the developed interface for sizing hybrid energy system

To demonstrate the characterization and dimensioning strategy of a hybrid system presented in this article, a cabin in the rural area of northern Santander were used as a case study. The cabin belongs to the experimental farm of the University of Pamplona, Colombia. Figure 6 shows the cabin in which the hybrid power generation system dimensioned in this investigation was implemented.

The data acquisition system implemented and operating for a long time at the installation site allowed capturing important information necessary to model the electrical behavior according to the environment's parameters and conditions. Table 3 summarizes the data acquired, characteristic of the region where the installation will be carried out.

Figure 6: Experimental farm used for sizing or hybrid system.

For calculating the number of photovoltaic modules, the lowest value of the daily global radiation that affects the site, the values of the daily consumption taken from the system load, and the peak power of the photovoltaic module to be used use must be taken into account.

The Table 4 shows a summary of the different operating points of the photovoltaic system found in a certain period through the data acquisition system.

Table 3: Tables of Average Irradiation in the Different Months of the Year

Month	**T** $°C$	**Irradiance** KW/m^2	**Wind-force** m/s
January	24.2	828.16	2.611
February	25.0	818.18	2.444
March	25.6	1000	2.388
April	26.7	1000	4.138
May	26.1	898	2.805
June	26.5	818.20	6.972
July	27.1	944.44	8.333
August	27.4	820.10	6.305
September	27.4	945.12	5.611
October	26.0	950.22	3.388
November	24.9	1000	2.333
December	24.4	1000	2.388

Table 4: Parameters Used to Calculate the Mathematical Wind Turbine's Model

Voltage	**Ideal Current**	**Ideal Power**	**Local Current**	**Power**
09.6	9.64	092.54	9.16	087.90
10.8	9.63	103.97	9.14	098.76
12.0	9.60	115.25	9.12	109.46
13.2	9.56	126.18	9.08	119.81
14.4	9.47	136.40	8.99	129.45
15.0	9.40	141.02	8.92	133.78
16.2	9.16	148.46	8.68	140.65
16.2	9.16	148.46	8.68	140.65
18.6	7.81	145.27	7.33	136.31
19.2	7.09	136.04	6.60	126.79

The interface determines the power of the wind with the data taken at the installation site to select the aerogenerator. This parameter presents significant variations for which the data acquisition system allows us to generate this variable's histories. Equation (10) allows us to evaluate the frequency of occurrences of load conditions.

$$P(V_{rot}) = \pi/2{\cdot}V_{rot}/V_{pro}{}^{2}{\cdot}e^{-\pi/2\cdot V_{rot}/V_{pro}{}^{2}} \tag{10}$$

where:

$P(V_{rot})$:It is the probability of the occurrence of the wind speed of the wind turbine.

V_{rot}:It is the average speed in a time interval.

V_{pro}:It is the value of the annual average speed.

The acquired data allows obtaining an average speed. Power generation starts when the wind speed exceeds $2.9m/s$. When the wind speed is $4.5m/s$, the power produced is approximately $54Watts$ for a power coefficient of 0.5926. Figure 7 shows the power delivered as a function of the wind speed necessary to estimate the power delivered by a generator installed on the premises.

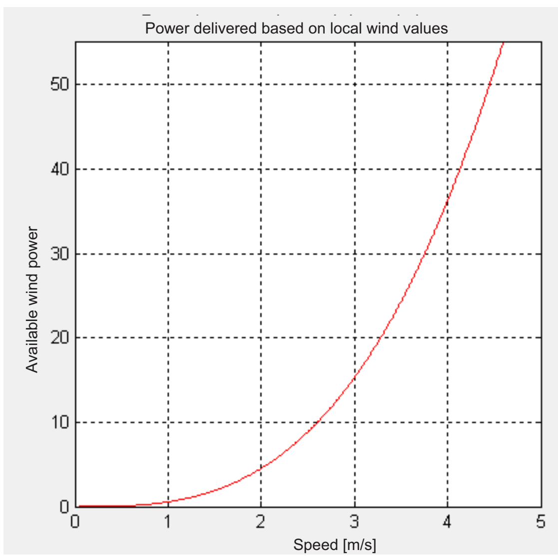

Figure 7: Power delivered based on local wind values.

Figure 8 shows the current versus voltage curve that represents the behavior of the solar panel. Figure 8 allows determining the maximum power point indicated by the value of the point where the V_{max} and I_{max}

intersect. The graph plotted in blue represents the current generated by the solar cell. The cut-off point of this graph with the x-axis represents the value of the open-circuit voltage V_{oc} and on the y-axis represents the short-circuit current I_{sc}. This response obtained is characteristic of a solar panel.

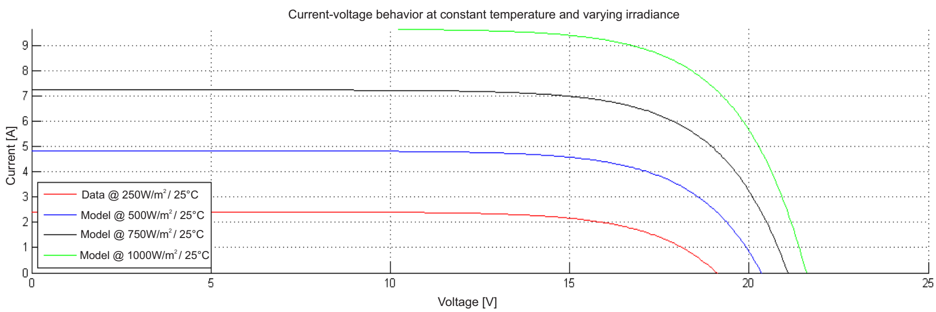

Figure 8: Graph showing the behavior of the C-V in the photovoltaic system.

The Figure 9 shows the power versus voltage curve that represents the behavior of the solar panel.

The graphs represent the current and power delivered by the solar panel with an irradiation value of $950W/m^2$; the electrical behavior is observed for different temperature values. An analysis of the system was also considered, keeping the temperature values constant at $25°C$, varying the irradiation parameter, to analyze the power variation as a function of both the change in temperature and different values of irradiation (see Figure 10). The concussions allow an adequate selection of the components based on the environment's variables, obtaining a better performance by design tailored to the needs.

Figure 10 shows the changes in radiation values, temperature, and the ideality factor present different hypothetical situations that could occur as irradiation effects and the effects of changes in the environment's temperature. These models are helpful in the analysis because they allow predicting situations by simulating variable environmental conditions as is characteristic in this region. The decisions made in sizing consider extreme situations, avoiding incorrect sizing.

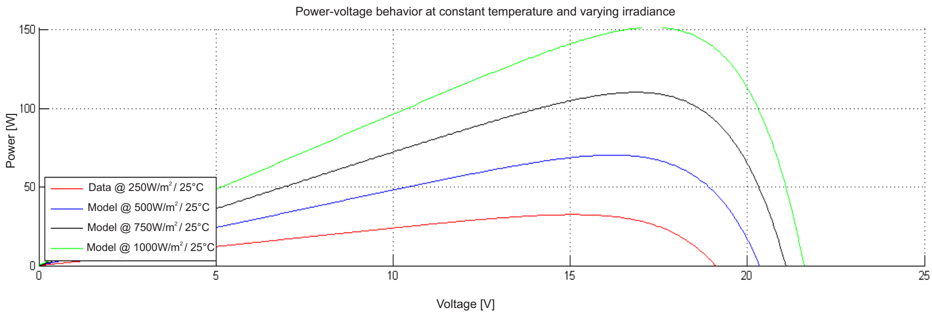

Figure 9: Graph showing the Power-Voltage behavior at constant temperature and varying irradiance.

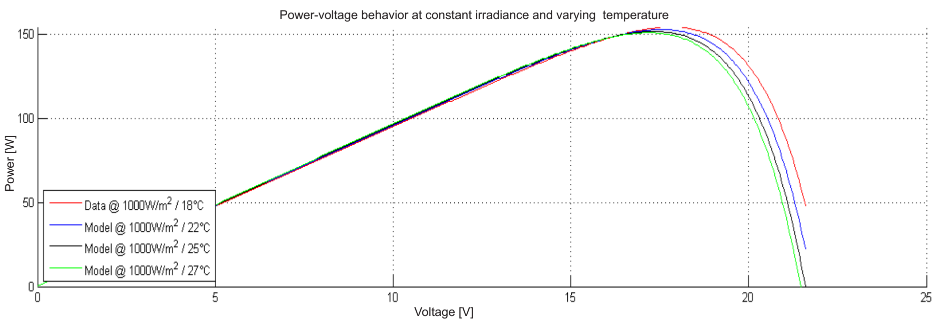

Figure 10: Graph showing the Power-Voltage behavior at constant irradiance and varying temperature.

After determining the daily consumption and estimating the total consumption, it is necessary to consider the batteries' losses and the regulation system. The next step is to calculate the value of the maximum load that must be supported by the hybrid system powered by both the solar panel and the wind turbine. The actual load C_r can be estimated from DC loads C_{dc} AC loads C_{ac} using the Equation (11).

$$C_r = \frac{\frac{C_{dc}}{\eta_{bat}} + \frac{C_{ac}}{\eta_{inv}\eta_{bat}}}{V_{bat}} \tag{11}$$

According to the specifications obtained, the selection of batteries should consider a capacity of 4 times the total consumption. The battery capacity $C_{bateria}$ can be determined with the Equation (12).

$$C_{bateria} = \frac{\frac{C_d d}{P_d \eta_{bat}}}{V_{bat}} \tag{12}$$

The selection of the charge controller must consider the current in continuous operation that must be supported. As a maximum value, the short-circuit current of the modules must be considered multiplied by the number of modules or panels in parallel [42]. However, it is also acceptable to consider that the maximum current of the regulator is at least 20% higher than the maximum nominal current. The maximum intensity to be supported in nominal regime by the regulator I_{max} can be calculated by Equation (13), from the Short circuit current I_{sc}.

$$I_{max} = N_{pp} I_{sc} 1.2 \tag{13}$$

7 Results

The approach to sizing presented in this document is considered an easy-to-implement alternative that can be scaled up to promote accessibility to electricity in remote regions. An approach such as that proposed by Borowy et al. [43] uses a graphic development technique to analyze the optimal arrangement of the hybrid system, demonstrating that it is possible to establish a relationship between the cost of the system and the arrangement of its components. Our goal is to reduce cost by arranging and selecting components suitable for the installation environment. Another important strategy in sizing is the probabilistic approach, helpful in changing conditions [44]. In this approach, wind speed and solar radiation values are taken as inputs to the model based on probabilistic approximations. Bagul et al. [45], based on probabilistic methods, manage to overcome traditional models' restrictions for actual demand data. Tina et al. [46], use this probabilistic technique to compare the simulations of hybrid systems. This method may represent difficulty in describing the dynamic behaviors of the system. Zhou et al. [47] used an interactive approach to optimize and size hybrid systems. It consists of creating an arrangement of possible configurations, it has decision variables that allow establishing performance metrics, and with an objective function, it minimizes the cost using linear programming to obtain an optimal solution. A group of methods derived from intelligent approaches is gaining relevance [48]. Yang et al. [49] propose a method to optimize the solar photovoltaic and wind hybrid system based on the iterative process with intelligent techniques. Several possible system configurations are created. A structure for optimization with decision variables and an objective cost minimization function is used to determine the optimized solution [47].

The method presented in this work shows the procedures followed to obtain the model representing the hybrid system's electrical behavior. The created model can be used with any approach to find optimal configurations of components that allow the best use of natural resources arranged in a specific place. The electrical behavior model allows estimating the power delivered by both the wind turbine and the photovoltaic system.

Table 5: Summary of Important Parameters that Characterize the Sizing of the System

Obtained parameter	**Value**
Estimated radiation	$3.5 Kw{\cdot}h/m^2$
Daily energy consumption	$3186.4 watts{\cdot}h/day$
Real electric charge	$243.575 A{\cdot}h$
Average irradiation	$950 W/m^2$
Local temperature range	$[17°C - 27°C]$
Number of photovoltaic modules	4
Maximum Current in the Regulator	$11.58A$
Battery capacity	$608.93 A{\cdot}h$
Average air velocity	$4.5 m/s$
Air density	$1.0593 Kg/m^3$
Wind power	$48.59 Watts$
Power coefficient	0.5926
Wind turbine power ratio	$160 Watts$ to $12.5 m/s$

The procedure to determine the number of photovoltaic modules uses the dynamic behavior to estimate the daily electricity consumption, the value of solar radiation, and the peak power value of the module, with these data and the interface's help to determine the number of modules photovoltaic to install. The battery bank is projected by calculating the value of the capacity required to support the system's demands, and with the environmental data obtained, a charging strategy for the hybrid system is designed. The data needed to determine the storage capacity of the batteries are the available charge hours, the depth of discharge value, the battery efficiency, and the actual system charge. The maximum current in continuous operation allows the charge controller to be selected. The number of panels connected in parallel and the value of the short-circuit current of the selected panel is used to determine the storage capacity. Some of the parameters are provided in the technical data of the equipment, being necessary to enter them in the interface for processing within the energy system sizing process. Table 5 presents a summary of the relevant parameters in the sizing of the system.

8 Conclusions

Two types of contributions can be highlighted in this research; the first of a procedural type encompasses a strategy to size hybrid systems based on the acquisition of environmental data such as temperature, wind speed, hours of access to sunlight, and the estimation of radiation out through the module. This procedure allows for an arrangement of the hybrid system components more adjusted to the natural resources determined for the installation site. This procedure can promote lower-cost installations avoiding oversizing, and with the help of the interface, it can be a tool that promotes access to electricity in remote regions. As a typical case, an experimental farm at the University of Pamplona was used to acquire environmental data and to size a hybrid system based on these data. The second type of contribution is documentary; the mathematical models obtained are exposed, and an interface in Matlab with the equations that allow determining these dynamic models is built to support future research. Data take on greater relevance in this new digital era, so the strategy of installing a module to acquire variables from the environment and transmit them remotely can be implemented constantly; this will allow to analyze the electrical behavior of the system over time and produce knowledge leading to new developments. Below are other conclusions derived from these two contributions.

The technique applied for the sizing of the hybrid system exposed in this article allows us to obtain a model and simulate the electrical behavior of the system. The model uses values for parameters taken from the environment in order to create a model that reflects the actual operating conditions. The relevant calculations to scale the system to an operating point that meets the energy demand and ensure the continuity of the electric fluid are described.

The data acquisition system used in sizing manages to continually provide data to extract relevant information in the study of hybrid power generation systems. Combining power generation systems with different operating principles demonstrates in this research to be a good selection for regions with changing environmental conditions. Analyzing power, current and voltage curves such as those acquired from the real system generated new research approaches and glimpses new alternatives for the sizing of hybrid systems, giving importance to data analysis and the generation of information from its processing.

This research showed that the implementation of a hybrid photovoltaic/wind energy system to satisfy a low power energy demand requirement is appropriate for rural sectors and communities. A hybrid system is a viable option with advantages, easy implementation, low maintenance, sustainable, and easily scalable. The system can reduce costs and can become profitable if it enables new production systems. The methodology can be used to size a new hybrid system and evaluate the performance of an already completed installation. The results are expected to promote the implementation of hybrid systems in the region.

This research made it possible to identify two new lines of research that can contribute to facilitating access to electricity in remote places. The first line of research consists of improving the environmental data acquisition process in two ways, better autonomy in data capture, establishing mechanisms for data persistence and remote transmission, device portability, and tolerance to harsh environmental conditions. Establish an expert system that processes the data and transforms it into information that allows extracting more information about the natural resources available at the installation site. The second line of research is to apply different approaches to optimal sizing based on local information using statistical, interactive, and intelligent approaches, build a comparison of results and optimize the process by minimizing cost variables, maximizing power generation, and determining load strategies to support energy demands.

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