EOLUSOFT - SIZING SMALL WIND AND PHOTOVOLTAIC SYSTEMS

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Abstract. In this work, we describe the methodology to size stand-alone wind and photovoltaic systems employing a computer tool developed for Windows called Eolusoft . The program counts with several options for the user to define the type of land and the local atmospherical properties. Besides that, it also allows to determine the form and the scale factor, which are important to describe the types of wind, their distribution and frequency. The application has a data bank that presents the power out put curve from different commercial wind turbines. To size photovoltaic systems the information on the local energetic resources is required, employing the monthly average of daily radiation incident on the photovoltaic modules. The program presents a data bank with information from commercial catalogues such as voltage, current and nominal power. According to the electrical load, the energetic resources and type of module, the photovoltaic systems are sized satisfying the conditions in the critical months and the other months of the year.

Keywords. renewable energy, wind energy, photovoltaic energy.

1. Introduction

Aware of the energy deficit problem, the Renewable Energy Laboratory (NUTEMA) from PUCRS, has lead several activities in the solar and wind energy fields (Alé, 1998). In the same way, themes related to the sizing of small wind and photovoltaic systems have been brought to discussion (Alé, García 1999). Such studies have allowed the identification of methodologies for the modeling of the different components for wind and photovoltaic systems. These methodologies are appropriate for the sizing of such systems.

Based on such studies we have verified a demand for computer tools to help on the sizing of wind and photovoltaic systems that are from low cost and easy to reach according to the reality found in Brazil. There are some commercial tools and software for sizing photovoltaic systems (SolarSizer and SolarCad), wind resource and wind farm analysis (Wasp, WindMap, WindFarm) or hybrid systems (Hybrid2). The tool presented here (Eolusoft) integrates the sizing of stand alone wind and photovoltaic system, being able to define which one is the best option for the same location.

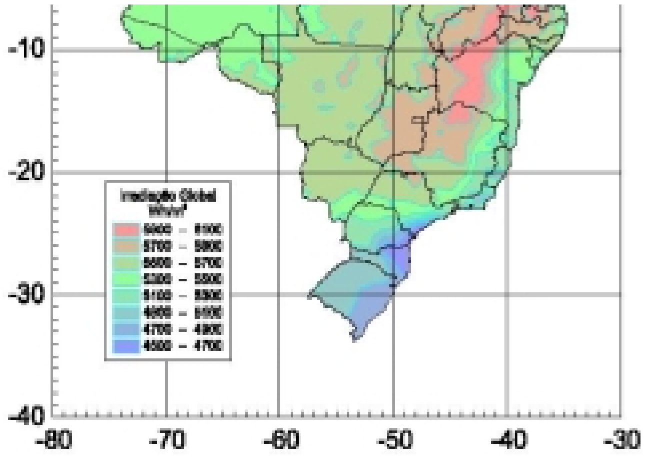
The development of the computer code proposed will turn it possible to count with a tool that helps on the sizing of these systems and on coming to efficient decisions on the best option for the use of wind and photovoltaic systems, in areas where energy is most scarce in the RS and Brazil. This work describes the application with the goal to present its potential to be employed as a project tool, as well as a didactic tool to the learning of the use of renewable energy sources, specifically when we discuss the contents of the systems sizing.

2. Methodology for Stand Alone Wind and Solar Systems Sizing

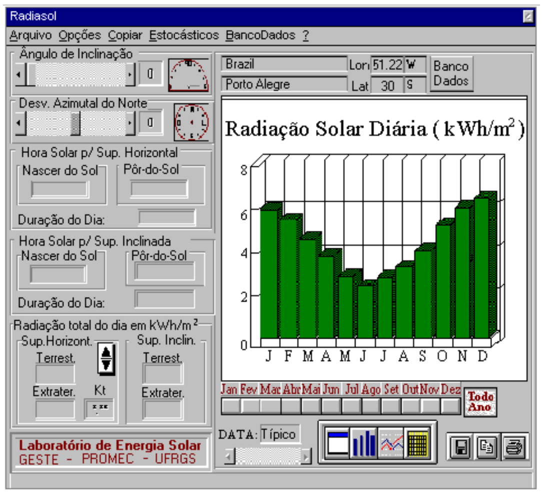
2.1. Solar and Wind Resources

The sizing of stand-alone wind and solar systems is the process of determining the cheapest combinations of PV array size or wind turbine size and storage capacity that will meet the load requirements with an acceptable level of security over expected lifetime of the installation. The size and cost of the system depends on: (a) the amount of power required (in watts) and the amount of time the power is required (in hours); (b) the amount of radiation available or the wind energy available at the location. The first item is obtained estimating wattage and hours of use for AC and DC appliances (demand of energy). The second is obtained using local meteorological information.

Solar and Wind energy are the main information necessary to size the systems with confidence. Solar horizontal irradiation can be obtained in the Brazilian Atlas of Irradiation from LabSolar web site (www.labsolar.ufsc.br). To size wind and solar systems it is necessary to have the mean daily irradiation on the plane of the array for the site for every month of a typical year. Horizontal and inclined surfaces irradiation can be obtained in on-line tools from CEPEL web site (www.cresesb.cepel.br/sundatn.htm) or using specific software as RADIASOL developed by UFRGS Solar Energy Laboratory (www.labsolar.ufsc.br). Eolusoft uses this information, which is stored in a data base with the mean daily irradiation for each month of the year for different localities of Rio Grande do Sul and Brazil.



source: www.labsolar.ufsc.br

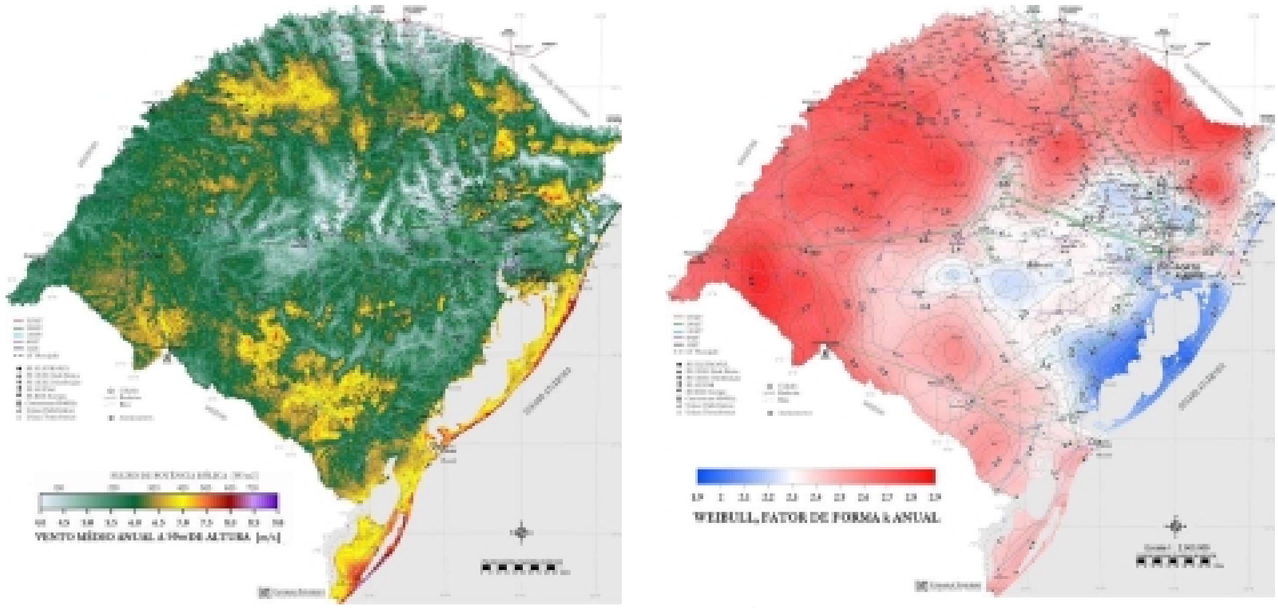


Ângulo de Inclinação: 0
Desv. Azimutal do Norte: 0
Brazil
Porto Alegre
Lon 51.22 W
Lat 30 S
DATA: Típico

source: www.mecanica.ufrgs.br/solar

Figure 1. Examples of solar energy resources: Brazilian Solar Irradiation Atlas and SOLARCAD tool.

Wind energy resource can be obtained in the Brazilian Wind Atlas from CEPEL (www.cresesb.cepel.br) and Brazilian Wind Atlas from CBEE (www.eolica.com.br/atlas.html). Regional Wind information can be obtained from different state wind atlas as Ceará, Bahia, Paraná and Rio Grande do Sul. Figure 2 shows Rio Grande do Sul Wind Atlas (www.semec.rs.gov.br/atlas).



Source: Wind Atlas of Rio Grande do Sul SEMC, 2002. www.semec.rs.gov.br/atlas.

Figure 2. Example of wind energy resources: RS Wind Atlas.

Eolusoft has a data base with monthly average wind speed for different localities of Rio Grande do Sul and Brazil. To size wind systems it is used the distribution function of the wind speed obtained with the annual average wind speed. For example, we can use Fig. (2) to determine the annual average wind speed measured at 50 m height and the form factor of the Weibull function to RS.

2.2. Loads and Energy Demand

The load of appliances presents a nominal power (Pu). The demand (Ca) is obtained with the equals quantity of appliances (Q) and number of hours used (Nu) in a typical day of the month, as can be seen in Eq. (1).

$$C_a = QxP_uxN_u \qquad \text{(Wh)} \tag{1}$$

The mean daily load requirements (Dmd) is obtained using all DC and AC appliances as shown in Eq. (2):

$$D_{md} = \frac{\left(\sum Ca\right)_{DC}}{\eta_B} + \frac{\left(\sum Ca\right)_{AC}}{\eta_B \eta_{inv}} \qquad \text{(Wh)} \tag{2}$$

where η_B is the battery bank efficiency and η_{inv} is the inverter efficiency. Appliances and estimated hours of use can be found in web sites as www.cspe.sp.gov.br/racionamento/consmens.html and www.bigfrogmountain.com/calculators.

2.3. Stand Alone Wind System Sizing

A stand-alone wind power system consists in a wind turbine generator and a battery bank to energy storage. The wind turbine is formed by the tower, yaw mechanism, gear box, electrical generator and control system. If necessary, the system uses DC/AC converters. The power output wind turbine depends of the air density, wind speed velocity, the area swept by the wind turbine rotor and the conversion efficiency. The turbine power is a cubic function of the wind speed. The variations of wind speed are described by the Weibull probability distribution function using two parameters: the shape parameter (k) and the scale parameter (c). At most sites, the wind speed calculated using Weibull distribution with k=2 is known as Rayleigh distribution. Wind speed varies with height above the ground. The wind shear at ground surface causes the wind speed to increase with the height. The power law uses the surface roughness exponent. This exponent is low for smooth terrain and high for rough ones. The wind power varies linearly with air density. The air density varies with pressure and temperature, and these both with the altitude. The air density at sea level is 1,225 kg/m^3. The annual energy output (AEO) supplied by the turbine is one of the main information that can be determined from the power output curve of the turbine. We can represent this energy by the following expression (Eq. (3)):

$$AEO = \overline{P}T \tag{3}$$

Where *T* is the number of hours in a year (*T=8760h*) and $\overline{P}$ is the average power output given by Eq. 4:

$$\overline{P} = \int_{Vci}^{Vco} P(V)\, f(V)\, dV \tag{4}$$

P(V) is the power output curve of the turbine; *f(V)* represents the distribution function of the wind speed; V_{ci} is cut-in wind speed and V_{co} is cut-out wind speed. Fig. (3) shows the typical *P(V)* of a small wind turbine, the typical Weibull distribution *f(V)* and annual energy output.

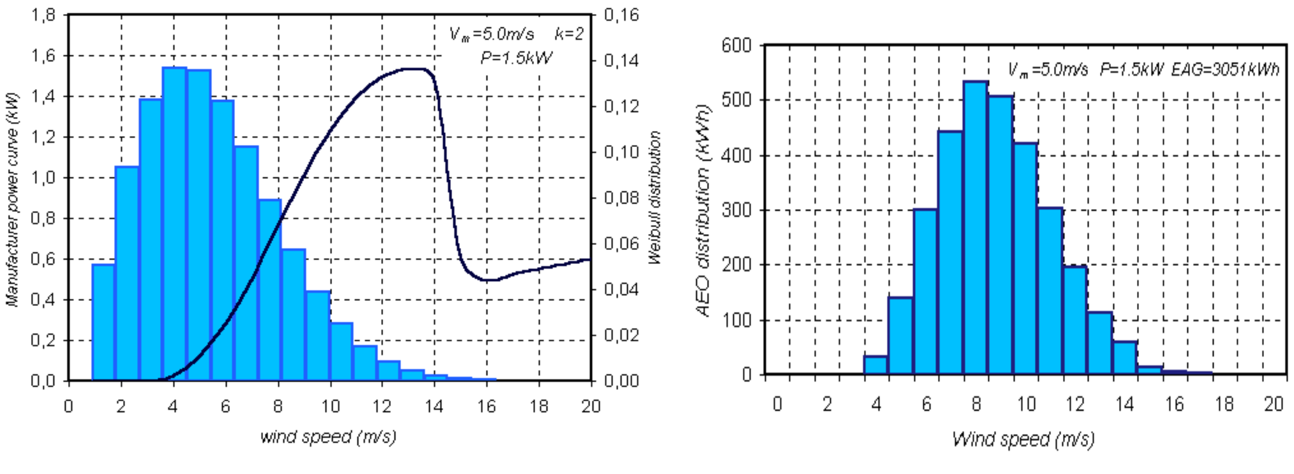


Figure 3. Example of wind turbine curve, Weibull distribution and Annual energy output

2.4. Photovoltaic Stand-Alone System

A photovoltaic system consists in an assembly of modules and other components, designed to convert solar energy into electricity to provide energy to a particular use, either alone or in combination with back up supply. A typical 50W at 15.5V photovoltaic module have 36 series connected monocrystalline silicon cells. The modern crystalline silicon modules present a conversion efficiency of 10% to 17%. The modules in a PV array are connected in series string to provide the required voltage. If one string is not enough to provide the required power, two or more strings are connected in parallel. The typical PV stand-alone system has a solar photovoltaic array and battery energy storage. The array powers the load and charges the batteries during daytime. The batteries power the load after dark. The inverters convert the DC power of the array into 60 or 50 Hz power. Stand-alone PV systems installed in developing countries provide energy to supply basic resources such as lighting and water pumping. The PV array can be mounted at a fixed angle from the Horizontal or on a tracking sun mechanism. For most locations, a tilt angle near the latitude angle will provide the most energy over a full year. Tilt angles of latitude ± 15º will be skew energy production toward winter or summer, respectively (Sandia, 1995).

The first step in designing a PV system is to determine the daily usage in watt-hrs (energy demand). Then, the array is sized large enough to produce the same watt-hrs as the daily load. The battery bank is sized large enough to hold the daytime array output and return it at night to power loads. In summer, days are long and nights are short. This reverses in winter. When days are long, the PV array receives more light and produces more electricity. When days are short, less PV electricity is produced. The longer nights results in greater loads due to increased lighting demands. To accurately size a PV system for a remote home, it is necessary to determine the loads and this change throughout the year.

In a typical PV sizing system the steps below must be followed:

(a) Site monthly mean daily irradiation (kWh/m^2). (b) Monthly mean daily load requirements (Wh) and appliances nominal voltage. (c) Monthly mean daily amp hours to load requirements. (d) Selection of photovoltaic modules and nominal power, current and voltage. (e) Determination of parallel and series modules. (f) Sizing the battery storage.

The monthly mean daily amp hours to load requirements is given by Eq. (5):

$$I_{md} = \frac{D_{md}}{V_n} \qquad \text{(Ah)} \qquad (5)$$

where Vn represents the nominal voltage of the system. D_{md} is the mean daily load requirement. Using the poor month of irradiation (critical month) we determine the total current in the photovoltaic system:

$$I_T = F_s \frac{I_{md}}{E_r} \qquad \text{(Ah/kWh/m}^2\text{)} \qquad (6)$$

where Fs is a security factor ($F_S \cong 1{,}2$) of the system. I_{md} represents mean daily amp hours to the poor monthly. E_r is the monthly mean daily irradiation in the modules surfaces (kWh/m^2). The quantity of parallel modules is given by:

$$N_{MP} = \frac{I_T}{I_{mp}} \qquad (7)$$

where I_{mp} is the maximum current of the module in one hour consume over a irradiation of one kWh/m^2. The total series modules (N_{MS}) is obtained using nominal voltage of the appliances (V_{na}) and the nominal voltage of the photovoltaic (V_n) modules, $N_{MS}=V_{na}/V_n$. Finally, the total number of modules to the photovoltaic array is given by $NT=N_{MP}xN_{MS}$.

2.5. Battery Storage Energy

Due to the variability of the solar energy and wind energy, it is necessary an appropriate way of storing the excess energy during the active period to carry the load during the inactive hours, or periods of low irradiance or low winds. When sizing battery storage, an important variable is the number of days of storage, which is the number of consecutive days the stand-alone will meet a defined load without solar energy input or wind energy input. Battery storage in the electrochemical form is the most widely used device for energy storage. Lead-acid and nickel-cadmium batteries are the more common use today. The nickel-cadmium batteries are more suited to operations in wind and solar systems than the lead-acid types, but are more expensive. The lead-acid rechargeable battery is the most common type used today because of its maturity and high performance over cost ratio, even though it has the least energy density by weight and volume. The lead-acid shallow-cycle is used in automobiles. The deep-cycle is suitable for repeated full charge and discharge cycles (more appropriate to wind and solar stand-alone systems). The lead-acid battery is basically formed by lead negative electrode, a lead dioxide positive electrode and aqueous sulphuric acid electrolyte solution. They consist of one or more battery cells, each of which is rated 2V. The most common configuration has six cells connected in series to obtain batteries with nominal voltage of 12 V. The battery is affected by the depth of discharge. That is the percentage of the total capacity that has been withdrawn, that determine its effective cycle of life.

The battery design depends on the following system requirements: system voltage and current; charge and discharge rates and duration; operating temperature during charge and discharge; life according to the number of charge and discharge cycles; cost, size and weight constraints. The battery design proceeds in the following steps: select the best battery type for the requirements; determine the number of series cell required to meet voltage requirement; determine the Ah discharge to meet the load demand; for the required number of charge/discharge, determine the maximum allowable depth of discharge. The total Ah battery capacity is then determined by dividing the Ah discharge required by the allowable depth of discharge calculated above. Finally, determine the number of battery packs required in parallel for the total Ah capacity.

The total battery capacity (C_{TB}) considering the days of the storage (about 4 to 8 days) is given by :

$$C_{TB} = \left(\frac{D_{md}}{V_{Na}}\right) N_d \qquad \text{(Ah)} \tag{8}$$

where D_{md} is the mean daily load (Wh/day); N_d is the autonomy days of the system, and V_{Na} is the nominal voltage of the system (V). The number of parallel batteries can be obtained by:

$$N_{BP} = \frac{C_{TB}}{C_{Bu} P_{des}} \tag{9}$$

C_{TB} is the total Ah capacity; C_{Bu} is the nominal battery capacity (Ah), and P_{des} is the recommended depth of discharge of the battery. To batteries with shallow-cycle, a 20% depth of discharge is recommend, and 80% to deep-cycle batteries. The number of series batteries (N_{BS}) is obtained dividing the nominal voltage of the system (V_{na}) by the nominal voltage of the batteries (V_{nB}), or $N_{BS}=V_{na}/V_{nB}$. The total (series and parallels batteries) is given by $N_{TB}=N_{BP}xN_{BS}$.

3. EoluSoft Tool

The Eolusoft is a computer tool that approaches the sizing of stand alone wind and photovoltaic systems. The application turns it possible to survey information on the energy demand, considering the energy consumption of appliances installed in a specific project. With information on the necessary demand, the sizing of the systems can be defined. The computer program is developed for Windows employing the Delphi language. The theoretical foundations related to the sizing of wind systems can be found in Spera (1994). The theoretical foundations for the sizing of photovoltaic systems can be found in Sandia (1995). Other considerations about the sizing of wind and solar systems can be found in Patel (1999).

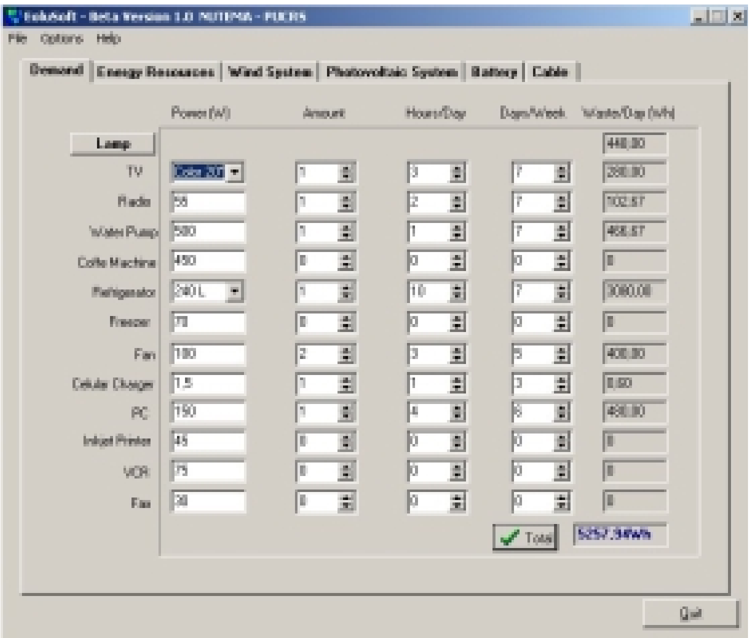
To have an analysis of the wind systems, information on the local wind resources, where the wind turbines will be installed, is employed. After the sizing of the system, the capacity of the wind generator and the annual energy generated are given. The computer code presents graphic output data necessary to a more precise analysis from the system functioning and the system outcome. In the methodology, a statistical analysis of the wind resource and factors of interest to the sizing, such as type of land, height of the turbine’s installation and the wind potential in the region, are included.

To size a photovoltaic system, information on the local energy resource is necessary, employing the monthly average of daily radiation incident on the photovoltaic modules. The program presents a data base with information from commercial catalogues such as voltage, current and nominal power output in the modules. Such factors are fundamental to the sizing of a system. So, through the energy demand, the energy resource and the type of module, we size the photovoltaic system satisfying the conditions in the critical months and, therefore, the other months of the year.

The current version of Eolusoft presents the following modules: (i) Demand or energy consumption; (ii) Energy resources (iii) Sizing and graphic output data of the wind system. (iv) Sizing and graphic output data of the photovoltaic system. (v) Sizing and capacity of the batteries for the wind and photovoltaic systems.

3.1 Energy Consumption

To size a wind or photovoltaic system it is necessary to determine its energy consumption. To do so, the power output of the appliances used, such as light bulbs, TV sets and refrigerators, must be identified. The application turns it possible to measure the energy consumption considering the quantity of appliances, operating hours in a day and number of operating days in a week. The result represents average energy consumption. We consider this analysis as the representative of a month of major consumption. In Fig. (4) the module of energy consumption is shown.



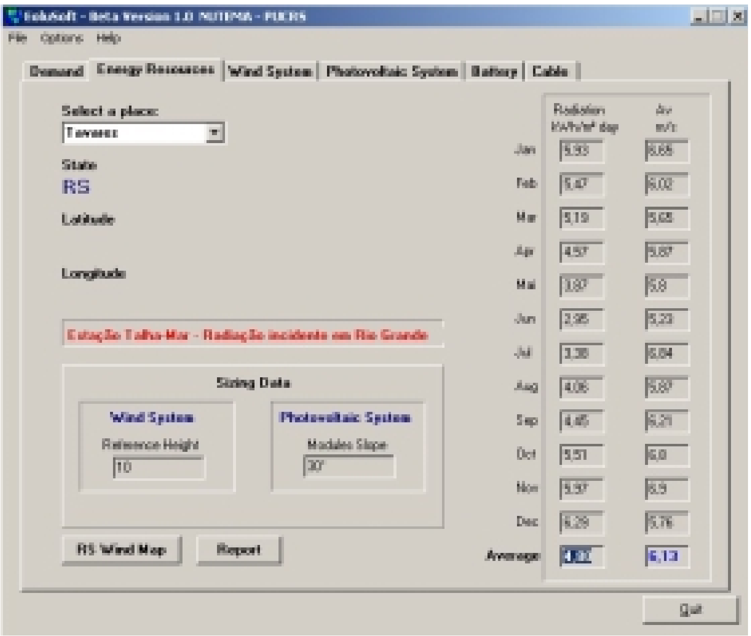
	Power (W)	Amount	Hours/Day	Days/Week	Watts/Day (Wh)
Lamp					440,00
TV	[illegible]	1	3	7	280,00
Radio	55	1	2	7	102,67
Water Pump	500	1	1	7	466,67
Coffe Machine	450	0	0	0	0
Refrigerator	240 L	1	10	7	3080,00
Freezer	70	0	0	0	0
Fan	100	2	3	5	400,00
Celular Charger	1,5	1	1	3	0,60
PC	150	1	4	6	480,00
Inkjet Printer	45	0	0	0	0
VCR	75	0	0	0	0
Fax	30	0	0	0	0

Total: 5257,34Wh

Figure 4. Module - Energy consumption.

3.2 Energy Resources

In this module, the user can choose the city in which the system will be installed. It is shown general information about the locality, including its geographic coordinates, monthly average wind speeds and average annual radiation. The information provided in this module is taken from the cities data base. This data base can be modified or brought up to date, using the cities cadastre system, which is also new in the software. The cadastre system allows the user to include new cities or to modify the current existing data. Figure (5) shows the graphic interface of the Energy Resources Module.



Select a place: Tavares

State: RS

Latitude

Longitude

Estação Talha-Mar - Radiação incidente em Rio Grande

Wind System – Reference Height: 10

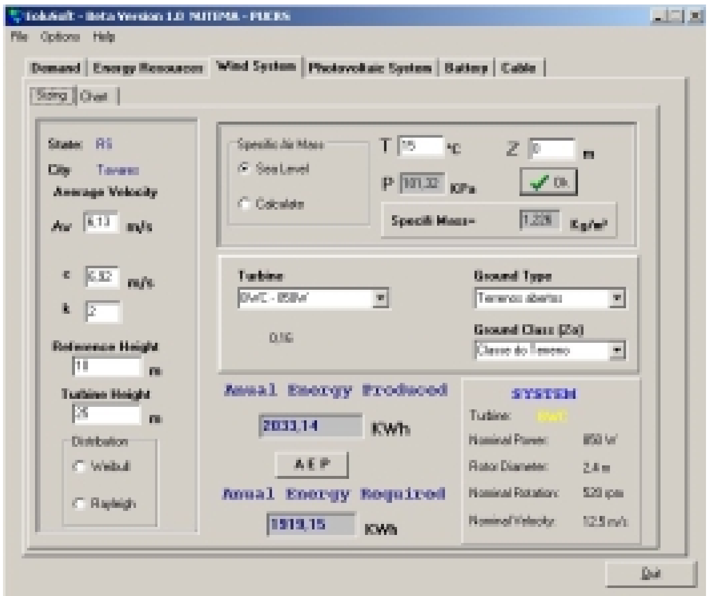
Photovoltaic System – Modules Slope: 30°

	Radiation kWh/m² day	Av m/s
Jan	5,93	6,65
Feb	5,47	6,02
Mar	5,19	5,65
Apr	4,57	5,87
Mai	3,87	5,8
Jun	2,95	5,23
Jul	3,38	6,04
Aug	4,06	5,87
Sep	4,45	6,21
Oct	5,51	6,0
Nov	5,97	6,9
Dec	6,29	5,76
Average	[illegible]	6,13

Figure 5. Energy resources module.

3.3 Wind System Sizing

This module allows to determine wind speed distribution after information supplied by the user about local wind speed, type of land and height of the site being studied. The program presents a data base with different commercial wind turbines that allows to determine the energy output employing the speed distribution and the power output curve of the turbine. There is an option, in the program, for the user to work either with the Weibull or the Rayleigh distribution. The work environment for the sizing of the wind system is presented in Fig. (6). There is a graphic option to visualize the power output of the turbine, the speed distribution and other necessary technical details. At the moment, there is a data base with 25 different models of small wind turbines.



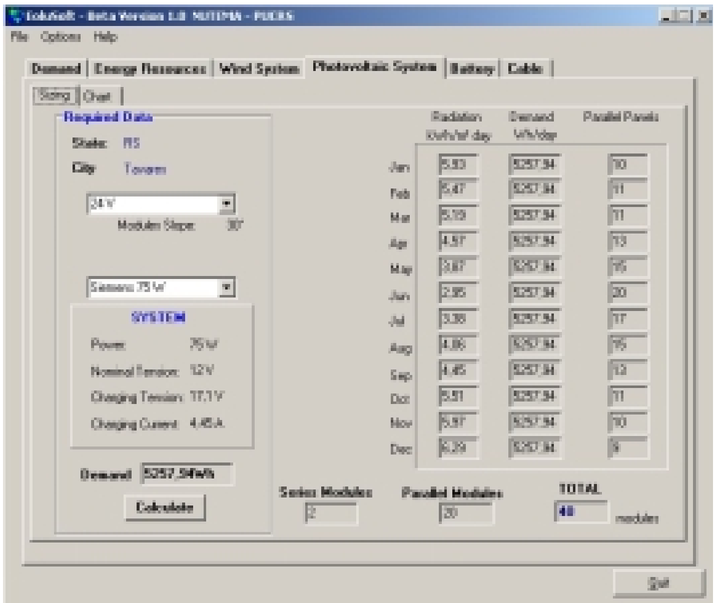
State: RS
City: Tavares
Average Velocity
Av 6.13 m/s
c 6.92 m/s
k 2
Reference Height 10 m
Turbine Height 25 m
T 15 °C
Z 0 m
P 101.32 KPa
Specifi Mass= 1.226 Kg/m³
Turbine BWC - 850W
0.16
Ground Type Terrenos abertos
Ground Class (Zo) Classe do Terreno
Anual Energy Produced 2033,14 KWh
Anual Energy Required 1919,15 KWh

SYSTEM
Turbine: BWC
Nominal Power: 850 W
Rotor Diameter: 2.4 m
Nominal Rotation: 520 rpm
Nominal Velocity: 12.5 m/s

Figure 6. Module for the sizing of a wind system.

3.4 Photovoltaic System Sizing

The photovoltaic system module allows the sizing of the photovoltaic system after basic information supplied by the user. It is defined the location to be studied in RS and the Program employs sub-routines and data base to search for the monthly average of daily solar radiation for the location. The user can also select the manufacturer and the size of the photovoltaic system to be used. With such information and with the energy consumption previously calculated, the program defines the sizing of the system for each month specifying the number of photovoltaic modules for the critical month. In Fig. (7) the structure of the calculation window is presented to the user.



Required Data
State: RS
City: Tavares
24 V
Modules Slope: 30°
Siemens 75 W

SYSTEM
Power: 75 W
Nominal Tension: 12 V
Charging Tension: 17.1 V
Charging Current: 4.45 A

Demand 5257,94Wh

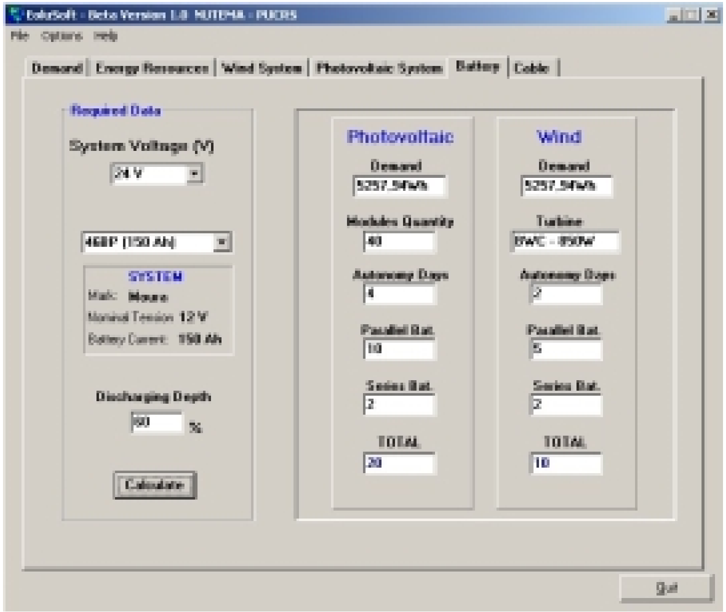
	Radiation KWh/m² day	Demand Wh/day	Parallel Panels
Jan	5.83	5257.94	10
Feb	5.47	5257.94	11
Mar	5.19	5257.94	11
Apr	4.57	5257.94	13
May	3.87	5257.94	15
Jun	2.95	5257.94	20
Jul	3.38	5257.94	17
Aug	4.86	5257.94	15
Sep	4.45	5257.94	12
Oct	5.51	5257.94	11
Nov	5.97	5257.94	10
Dec	6.29	5257.94	9

Series Modules 2
Parallel Modules 20
TOTAL 40 modules

Figure 7. Module for the sizing of the photovoltaic system.

3.5 Batteries Capacity Sizing

This module (Fig. (8)) allows de user to choose a commercial battery from a data base specifying its nominal tension and capacity in Ah. The depth of the discharge is a parameter that can be modified by the user. The results of the wind and photovoltaic systems sized with the required energy demand are presented. The user selects the days of autonomy required for the wind and photovoltaic system. With such information the program determines the number of batteries associated in series or in parallel. The program also includes a module that permits to specify the diameter of the electric wires according to the loss of limit tension.



Required Data

System Voltage (V): 24 V

468P (150 Ah)

SYSTEM
Mark: Moura
Nominal Tension: 12 V
Battery Current: 150 Ah

Discharging Depth: 80 %

	Photovoltaic	Wind
Demand	5257.54Wh	5257.54Wh
Modules Quantity / Turbine	40	BWC - 850W
Autonomy Days	4	2
Parallel Bat.	10	5
Series Bat.	2	2
TOTAL	20	10

Figure 8. Module for battery sizing of the photovoltaic and wind systems.

3.6 Graphic Output Data of the Application

The application presents several graphic output data. In the sizing of a wind system, the manufacturer's power output curve (Fig. (9)) and the curve of the speed distribution function are presented. In the module of photovoltaic sizing, (Fig. (10)) the average monthly radiation curve and the energy demand curve are presented. In the wind system module, the tool shows graphic output of the average monthly wind speed and energy demand.

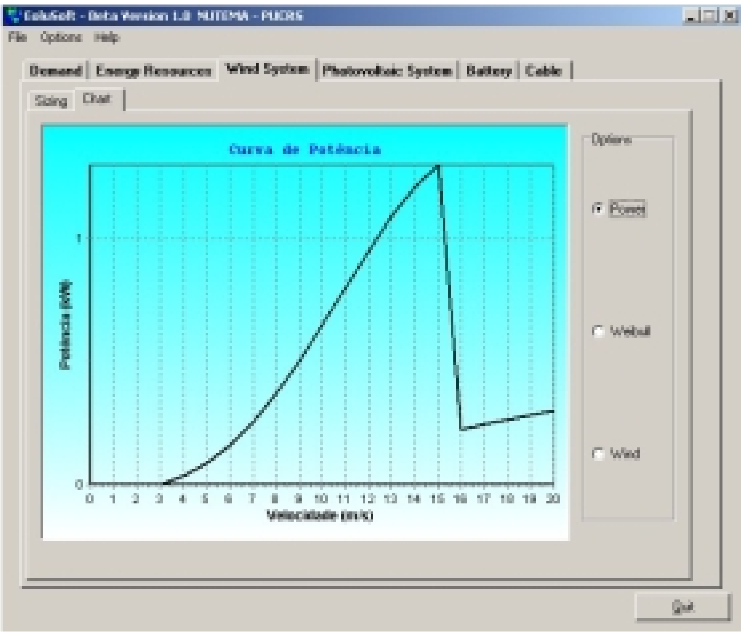
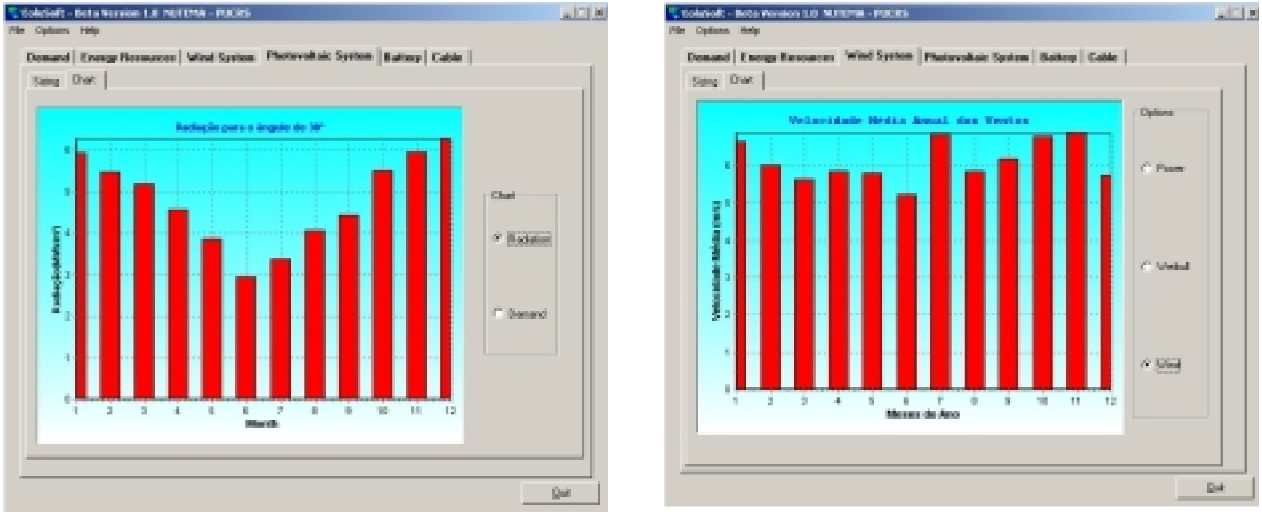


Figure 9. Graphic of the turbine power output curve.



(a) Solar Resource

(b) Wind Resource

Figure 10. Graphic information of wind and solar resources.

3.7 Sizing Sample

We are going to show the utilization of the software describing each step that must be followed on the sizing of an hypothetical system. The first step to be taken is to estimate the daily energy demand. It is specified which devices are used and how long they are used. On Fig. (4), we can see the appliances used in this example. The total daily demand resulted on 5257,94 Wh. On the next module (Fig. (5)), we have selected the city of Tavares for the installation of our system. It is shown the average wind speed and radiation for each month. Using this data, annual average wind speed and radiation are calculated, and in this situation, they are 6,13 m/s and 4,8 kWh/m^2.

Now, we can proceed with the sizing of the wind system (Fig. (6)). We adopt a 25 meters high turbine tower. The annual average wind speed in Tavares is 6,13 m/s (10 meters high – software's data base information). Using the Rayleigh distribution (scale factor k=2), the software calculates the shape factor (c=6,92m/s). Considering a temperature of 15ºC and sea level, the density is calculated (1,26 kg/m^3). The ground type is also selected. Making use of the turbine data base, we choose a BWC-850W wind turbine. The software shows, for this turbine, the nominal power (850W), the rotor diameter, the nominal rotation and nominal velocity. The graphic of the turbine power output is shown in Fig. (9). Considering the wind energy resource of Tavares city, this turbine provides 2033,14 kWh of energy per year, being, therefore capable to supply the annual energy demand, which is 1919,15kWh.

In Fig. (7) we can see the Photovoltaic System Module, in which we select a Siemens 75W photovoltaic module, using a tension of 24V. Using the daily demand, the software calculated that it would be necessary 40 photovoltaic modules (2 in series and 20 in parallel). This number is too big, making the usage of solar energy very expensive. The problem comes from the fact that the software makes this calculation considering the critical month radiation, which is too low (2,95 kWh/m^2 in June, Fig. (5)). If the annual average radiation was used in this calculation, the number of photovoltaic modules in parallel would be reduced to 13 (April – 4,57kWh/m^2 – Fig. (5)), making a total of 26 modules.

Finally, the tool proceeds with the battery sizing for the photovoltaic system and wind system (Fig. (8)). Using a 150Ah battery with 60% discharging depth, it would be necessary 20 batteries for the photovoltaic system (four autonomy days) and 10 batteries for the wind system (two autonomy days). All the proceedings described above lead us to two options: a wind system with a 850W wind turbine (BWC-850W) and a 1500Ah battery bank (10x150Ah); or, a 3.0 kW photovoltaic system (40x75W) and a 3000Ah battery bank (20x150Ah).

In this sizing example, the solar energy resource in the critical month is low and the photovoltaic system is too expensive, leading us to adopt the wind system.

4. Conclusions

EoluSoft presents an structure adequate to the sizing of stand-alone small Wind and PV systems. However, it is a version that must be improved in order to allow an integrated analysis of the systems being studied (hybrid PV-Wind systems). We must include a cost and benefit analysis for each system, making it possible to come to the most appropriate decision on the installation of the system, according to the existing energetic resources. Finally, the inclusion of temperature and irradiations effects in the I-V module and graphical output of I-V module are some of the improvements about to be made.

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