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Modeling and Simulation of a Hybrid System Solar Panel and Wind Turbine in the Quingeo Heritage Center in Ecuador

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Abstract**—**In this article, we present the modeling, simulations, and energy conversion analysis of the solar-wind system for the Quingeo Heritage Center in Ecuador. A numerical model was constructed based on the 19 equations, it was coded in MATLAB R2017a, and the results were compared with the experimental data of the site. The model is built with the purpose of using it as a computer development for the optimization of resources and designs of hybrid systems in the Parish of Quingeo and its surroundings. The model obtained a fairly similar pattern compared to the data and curves obtained in the field experimentally and detailed in manuscript. It is important to indicate that this analysis has been carried out so that in the near future one or two of these power generation systems can be exploited in a massive way according to the budget assigned by the Parish GAD of Quingeo or other national or international organizations with the purpose of preserving this unique colonial helmet in Ecuador.

Keywords**—**Hybrid system, wind turbine, modeling, simulation, Smart Grid, Quingeo Azuay Ecuador.

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I. Introduction

THE methods of generating renewable and non-conventional energy, such as wind, solar, biomass, thermal storage and recovery of waste heat, can be effective solutions for energy supply in the heritage areas of Quingeo. In our case, for example, the use of solar panels that keep the respective aesthetics can avoid the long aerial wiring that gives a bad aspect to the patrimonial areas and archaeological sections. Other Quingences areas are highly valued for their age and uniqueness in Ecuador, such as the towns of Loma de Guaman, Curiquinga, Pillachiquir, Puntahacienda, Cochapamba, Cortepamba and Macas.

The hybrid system of renewable energy is an integrated system of two or more renewable energy systems, it can complement each other, and it provides a reliable source of energy and higher quality. In this particular case, we ask it to be independent of the distribution network of the public company [1]-[5]. The plants are the wind turbine and the photovoltaic one, they turn into an increasingly attractive option in rural sectors of the Province of Azuay and particularly in Quingeo, since the price of the fossil fuels is high and very polluting to the environment [4]-[8].

Neira and Velecela [1] presented and discussed the electrification of the rural area in the Parish of Quingeo specifically in the Community of Garauzhi. In addition, [11], [29] presented and analyzed the viability and importance of the use of wind energy in global electrification. Another study was proposed by [10] for the implementation of hybrid systems in the rural area of Molleturo disconnected from the electricity grid. In our case, we will analyze and compare the theoretical part of the proposed system with the experience and measurements made in the field [9].

This document describes the simulation and validation of a combined wind and solar system for the generation of electrical energy with energy storage facilities using batteries. The multivariable meteorological data, which include wind speed and direction, solar radiation, rain and humidity, as well as temperature, were obtained using a meteorological station installed in Loma de Guamán, a well-known site in the Parish of Quingeo. In addition, the simulation model includes a modern charge and inverter controller.

The following describes the simulation model, the energy conversion equations and the linear programming principles, as well as the validation of data with the support of MATLAB [30]-[35].

Another study was proposed by Colak [20] for its implementation in rural areas disconnected from the network. Both wind and photovoltaic energies represent today one of the cheapest energy sources and with a technology of fully mature use and development in several countries. Consequently, in Ecuador, there is a fairly significant percentage in the use of this type of energy. Energies are quite credible when the constructions of great importance in Ecuador are observed according to the change of the productive matrix. Similar experiences of hybrid wind-photovoltaic systems have been considered in other countries such as the one in Ethiopia with the purpose of supplying uninterrupted energy to a remote area promoted by Bekele and Tedesse [24]. In addition, other studies were presented on hybrid PV-battery-wind and hybrid PV-wind-diesel-battery for rural electrification in Ecuador [18]-[25]. In addition, the energy conversion equations that describe the total power generated by a hybrid system of photovoltaic solar energy and wind turbine were presented by Sami and Icaza [28] and integrated simultaneously. To validate this simulation model, specialized software such as MATLAB was considered.

II. Location of Research

The Quingeo Parish is part of the Cuenca Canton in the

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Province of Azuay-Ecuador, and its Historical Heritage Center which is 28 km away from the Cuencana city, constitutes a transcendental testimony of the Ecuadorian culture, for which it deserved to be declared Cultural Patrimony of the Ecuadorian State, the 11th September 2009, through Ministerial Agreement No. 224, issued by the Minister of Culture, Ramiro Noriega Fernández. At that time, the President of the Proclamation Committee Quingeo Cultural Heritage was Eng. Daniel Icaza Alvarez, who was also elected by popular vote Vocal of the Local GAD of Quingeo, who had the support of several and generous inhabitants of the town.

A Rural Parish near Santa Ana that takes care of its order in its colonial helmet avoiding aerial wiring that alters the wonderful vernacular architecture is the reason why it becomes attractive for the use of renewable energy in these very important areas, see Fig. 1.

Fig. 1 Location of Quingeo Parish in Ecuador

It is adopted as a delimitation of the Historic Heritage Center of Quingeo for purposes of control and administration as shown in Fig. 2. Next in Fig. 3, the hybrid system is presented.

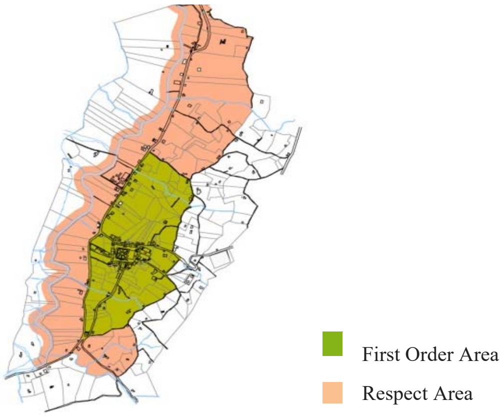

Fig. 2 Quingeo delimitation areas

III. Mathematical Modeling

In the mathematical model that is expressed below, it is translated as a simplified model with the most representative parameters between the mechanical and electrical systems that will directly influence the final objective that is the generation of energy. Several studies in Ecuador analyzed hybrid systems which have given us excellent results in this sense since the topic dealt with in this article is not the only one and rather there is already a previous experience with which we propose this new study in the Parish of Quingeo. Later, we work with the energy transformation equations of each contribution to obtain the results of the system in design mode [12]-[17] This process allows us, in the end, to compare with the results product of field measurements and corresponding tests.

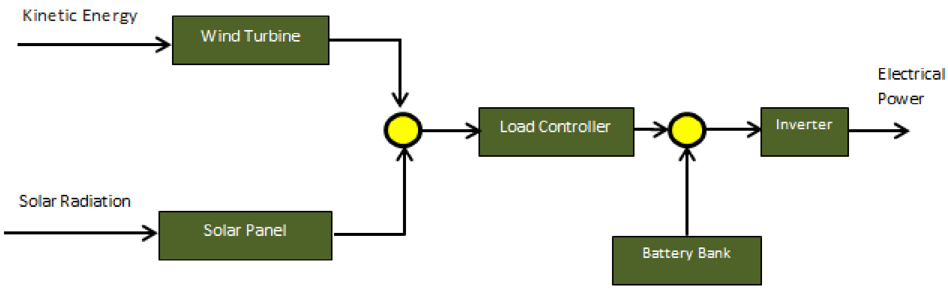

Fig. 3 Electric Power Conversion Energy

A. Wind Turbine Simulation

The power of a particular wind turbine is given by [3]

$$P_x = 0.5 * C_{p1} * \rho_{air} * A * v^3 * \eta_x \tag{1}$$

where P_x is the wind power sweep produced by the blades per unit area, C_{p1} is the Betz power coefficient, ρ_{air} is the air density, A is the area swept by the blades of the wind turbine, and v is the wind velocity [26], [27].

Taking into account the internal performance of the wind turbine, the following can be written

$$\eta_x = \eta_a.\eta_b.\eta_c \tag{2}$$

where η_a, η_b are the mechanical friction and generator efficiencies respectively, and the efficiency speed multiplication box is η_c.

The power output of the wind turbine in (3) can be expressed in single-phase power AC as

$$P_1 = \sqrt{3}.\eta_{c1}.U_{line}.I_{line}.Cos\varphi \tag{3}$$

With single phase, AC power is P_1, line current I_{line}, represents power factor $Cos\varphi$, and the electric conversion efficiency is referred to as η_{c1}.

B. Photovoltaic PV System

The thermal energy absorbed by the PV solar collector is [1], [3].

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \quad (4)$$

where η_{pvg} is the PV solar collector efficiency, A_{pvg} is the PV solar collector area (m^2), and G_t is the solar irradiation (W/m^2), and η_{pvg} can be defined as [1]

$$\eta_{pvg} = \eta_r \eta_{pc}[1 - \beta(T_c - T_{c\,ref})] \quad (5)$$

where η_{pc} is the power conditioning efficiency which is equal to one when maximum power point tracking (MPPT) is used, β is the temperature coefficient (0.004 – 0.006 per °C), η_r is the reference module efficiency, and $T_{c\,ref}$ is the collector reference temperature.

The behavior of the I-V curve of the photovoltaic cell is described by (6)-(8), [3], [4].

$$I = I_L(G_1, T_1) - N_p I_0 \left[e^{\left(\frac{V+IR_s}{V_t} - 1\right)} \right] - \frac{V + IR_s}{R_p} \quad (6)$$

$$V_t = mN_s k \frac{(T_1 + 273)}{qe} \quad (7)$$

$$I_o = \frac{I_{sc} - \frac{V_{oc}}{R_p}}{e^{\left(\frac{V_{oc}}{V_t}\right)} - 1} \quad (8)$$

where: N_s is the number of solar cells in series. N_p is the number of cells in parallel. K is the Boltzmann constant. qe is the charge of the electron. m is the diode ideality factor; 1 <m <2. T1 is the working temperature of the solar panel in ° C. R_s is the series resistor. R_p is the resistance in parallel. I_L (G1, T1) is the photogenerated current and approximately equal to the short-circuit current Isc (G1, T1). Io is the inverse saturation current of the diode. Voc is the open circuit voltage [22].

The electric PV power output in DC taking into account the efficiency of conversion to electric energy is

$$P_{PV}(t) = \eta_{c2} I_{PV}(t) . V_{PV}(t) \quad (9)$$

where η_{c2} is the efficiency of conversion to DC and referred to $V_{PV}(t)$, and $I_{PV}(t)$.

C. Controller

Generally, the controller power output is given by

$$P_x = V_{bat}(I_c + I_{PV}) \quad (10)$$

where V_{bat} is the multiplication of the nominal voltage DC in the battery for any particular system, and I_c and I_{PV} represent the output current of the rectifier in DC and currents of PV.

D. Battery Charging and Discharging Model

The battery stores excess power going through the load controller. The battery keeps voltage within the specified voltage and thus protects over discharge rates, and prevents overload.

During the charging period, the voltage-current relationship can be described as follows [14], [19]

$$V = V_r + \frac{I\left(\frac{0.189}{(1.142 - soc) + R_i}\right)}{AH} + (soc - 0.9)\ln\left(300\frac{I}{AH} + 1.0\right) \quad (11)$$

and

$$V_r(V) = 2.094[1.0 - 0.001(T - 25°C)] \quad (12)$$

However, during the discharging process and using (11), the current-voltage can be

$$V = V_r + \frac{I}{AH}\left(\frac{0.189}{soc} + R_i\right) \quad (13)$$

and R_i is given by

$$R_i(\Omega) = 0.15[1.0 - 0.02(T - 25°C)] \quad (14)$$

where, $V_r(V)$, I: the terminal voltage and current respectively, $R_i(\Omega)$: Internal resistance of the cell and T is the ambient temperature. AH: Ampere-hour rating of the battery during discharging process.

Finally, the power produced by the PV array can be calculated by,

$$P = V\, I_{rect} \quad (15)$$

where I_{rect} represents the total output current of the rectifier in DC (10).

E. Inverter

The characteristics of the inverter are given by the ratio of the input power to the inverter P_i and inverter output powerP_o. The inverter will incur conversion losses and to account for the inverter efficiency losses, η_{inv} is used;

$$P_i . \eta_{inv} = P_o \quad (16)$$

The AC power of the inverter output P(t) is calculated using the inverter efficiency η_{inv} , output voltage between phases, neutral V_{fn}, for single-phase current I_o and $cos\varphi$ as follows;

$$P(t) = \sqrt{3}\, \eta_{inv} V_{fn} I_o \cos\varphi \quad (17)$$

Finally, the hybrid system energy conversion efficiency for harnessing energy from wind turbine and PV is given by;

$$\eta_{sistem} = \eta_{PV} * \eta_{wind} \quad (18)$$

$$\eta_{sistem} = \frac{P_{1f}}{P_1 + P_{PV}} \qquad (19)$$

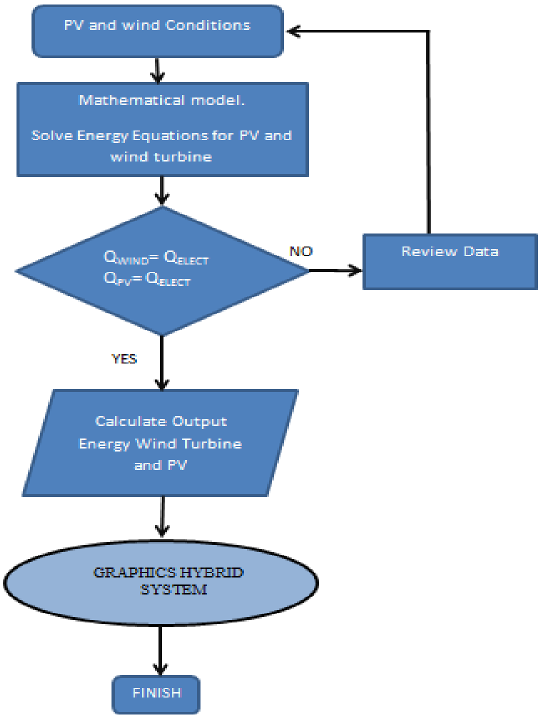

Fig. 4 Flow diagram of Hybrid system calculation

IV. Results and Discussion

To solve the aforementioned equations from (1)-(19) and taking into account that the total power may not be simultaneous, and for data validation purposes, this model was used for the simulation, and the aforementioned equations were coded in MATLAB with formulations of finite differences. In addition, the intension in this type of projects is to validate and fine-tune the simulated output results predicted, the data were used to validate the simulation program in various operating conditions of the hybrid system. In the following sections, we present the analysis and discussions of the predicted numerical results as well as the validations of the simulation model proposed based on field measurements.

Figs. 4 and 5 present the profiles of radiation and wind speed profiles at the site during several months of the year 2017 at different times of the day.

A. Wind Turbine Simulation

The impact wind speed at the electrical power output generated by the wind turbine is illustrated in Fig. 7. The predicted results shown in these figures show that at a lower cutting speed of 2.5 m/s and a cutting speed higher than 9.3 m/s, the wind energy generated is 40 and 1400 watts, which coincides with the specifications of the wind turbine provided by the manufacturer. In addition, Fig. 7 has been constructed to show the impact of wind speed on the energy conversion efficiency of wind energy to electric power, this demonstration is a key element for the different projects that are carried out in the Ecuadorian Austro. It is very clear that the higher wind speed results in higher energy conversion efficiency and produces more electrical output power. However, for the wind turbine that we take as reference for the current investigation, we determine that the minimum wind speed is 2.5 m/s, the output power and the conversion efficiency are significantly low but economically viable.

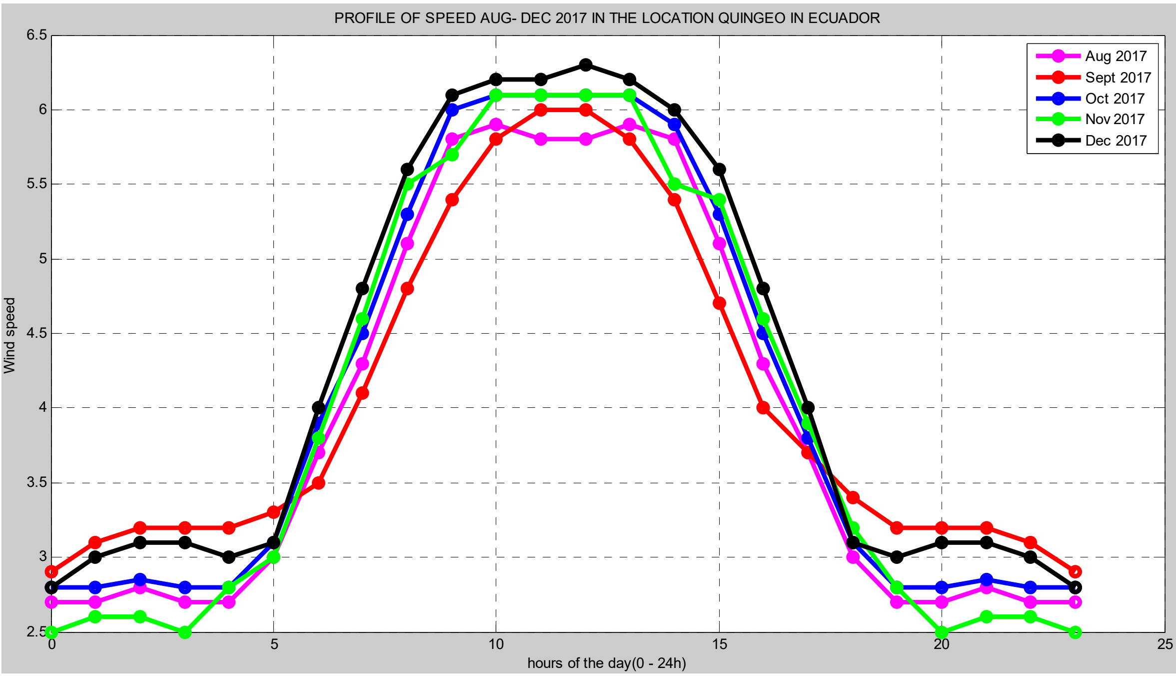

Fig. 5 Profile of Speed in m/s Aug2017- Dec 2017

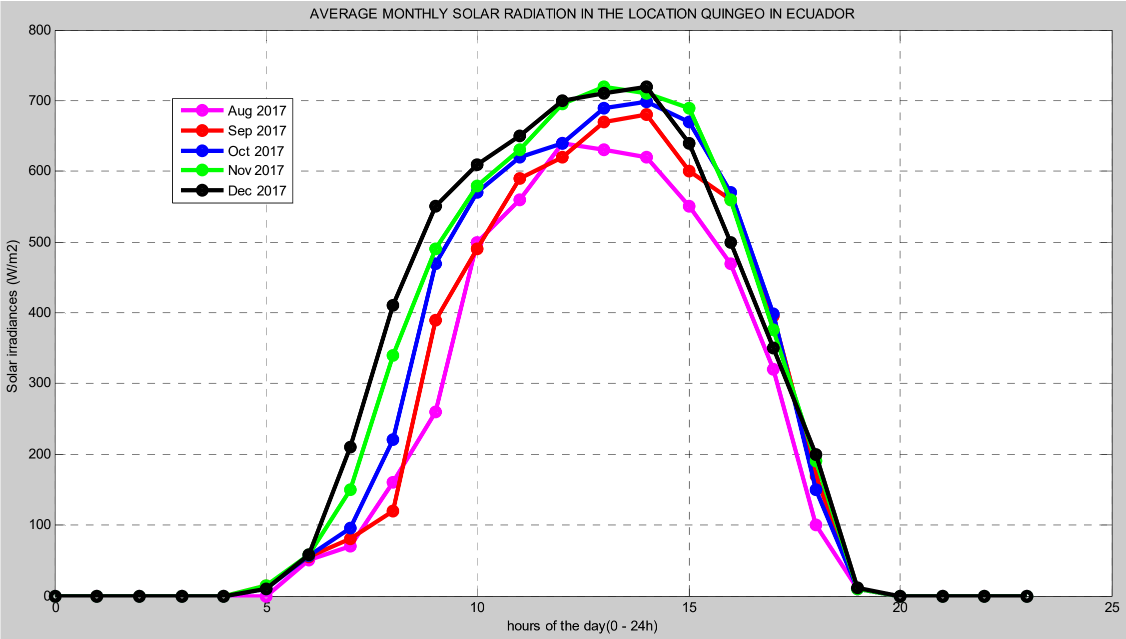

Fig. 6 Solar irradiances (W/m^2) Profile Aug 2017-Dec 2017

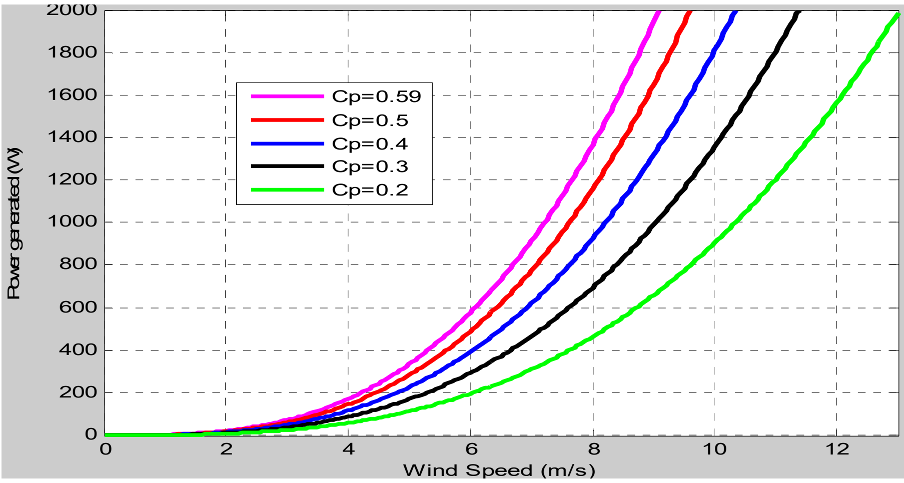

Fig. 7 Power-speed curve for different values of Betz

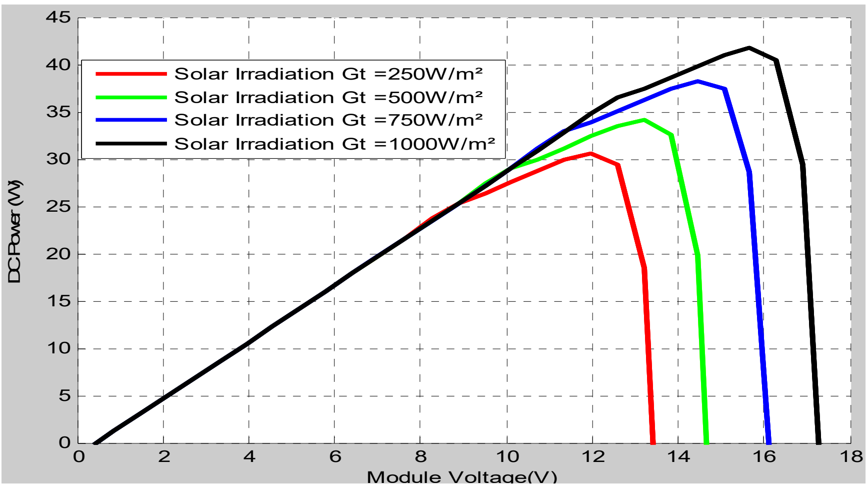

Fig. 8 Voltage-DC Power curve for different values of coefficient

B. PV Simulation.

The basic concept of energy conversion from solar insolation to electrical energy as shown in Fig. 8 as part of the hybrid system is presented and analyzed in this section and illustrates the conversion of solar energy into electrical energy in terms of volts, amperes and power in terms of solar irradiance. It is worth noting that the numerical simulation presented here includes the variation of PV cell temperatures from 15 °C to 42 °C.

C. Validation of Simulation Model

In order to validate our numerical model prediction described in (1)-(19), we have constructed Figs. 9 and 10 to compare the predicted results with data presented in the literature for PV and wind turbine.

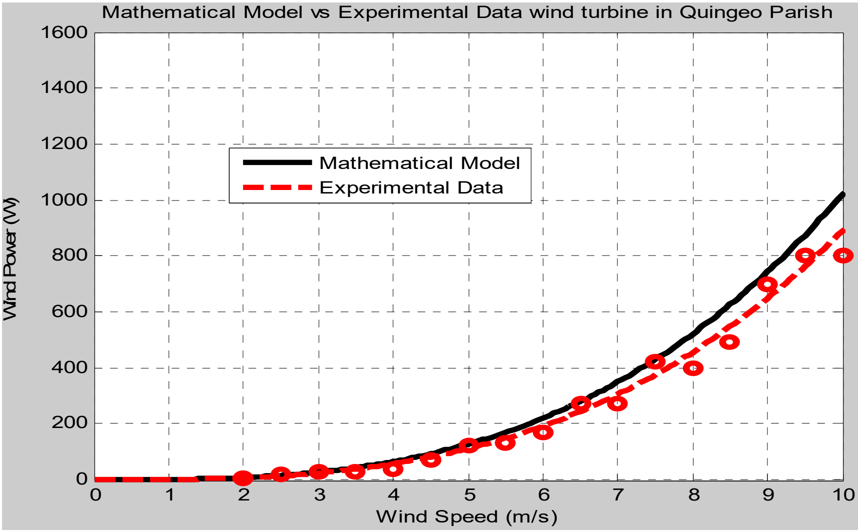

Fig. 9 Comparison of wind speed – wind power

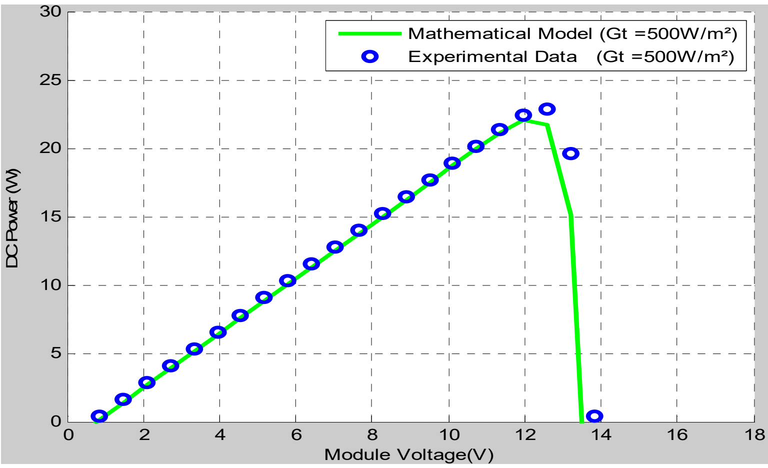

Fig. 10 PV output data compared to model prediction at 500 W/m^2

V. Conclusions

Although the production of electric energy due to the wind source is not of higher incidence, we managed to identify that the theoretical curve indicated in Fig. 7 that comes from (1) has a pattern of behavior quite similar to the data of power-speed measured at the remote station.

In Fig. 9, there are good results in the analysis of the model used with the data taken in the field in direct relation to the energy production referring to the variation of temperature, which is the reason why our model is very accurate and very reliable.

Furthermore, the PV study results showed that the higher the solar radiation the accelerated increase in the PV cell temperature. The more solar radiation increases, the electric power generated by the solar panel also increases, meaning that the output current also increases. In the design of this hybrid generation system, it is important to take into account more of the solar radiation also the ambient temperature where the equipment is located, which must also be perfectly protected against external agents that may reduce its useful life.

One can see in Fig. 11 a simulation in Dialux about the physical work that will be carried out in the Quingeo Heritage

Center.

Fig. 11 Simulation in DIALUX of the Quingeo Heritage Center

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