

# Renewable Energy System Eolic-Photovoltaic for the Touristic Center La Tranca-Chordeleg in Ecuador

Christian Castro Samaniego, Daniel Icaza Alvarez, Juan Portoviejo Brito

**Abstract**—For this research work, hybrid wind-photovoltaic (SHEF) systems were considered as renewable energy sources that take advantage of wind energy and solar radiation to transform into electrical energy. In the present research work, the feasibility of a wind-photovoltaic hybrid generation system was analyzed for the La Tranca tourist viewpoint of the Chordeleg canton in Ecuador. The research process consisted of the collection of data on solar radiation, temperature, wind speed among others by means of a meteorological station. Simulations were carried out in MATLAB/Simulink based on a mathematical model. In the end, we compared the theoretical radiation-power curves and the measurements made at the site.

**Keywords**—Hybrid system, wind turbine, modeling, simulation, validation, experimental data, panel, Ecuador.

## I. INTRODUCTION

THE methods of renewable and non-conventional energy generation, such as wind, solar, hydroelectric, biomass, geothermal, thermal storage and waste heat recovery are very important options for the generation of energy in isolated areas of Ecuador. At the Tranca-Chordeleg Tourist Center, it has been convenient to implement a hybrid system since it is a new and clean energy source.

The hybrid renewable energy system is an integrated system of two or more renewable energy systems, which can complement each other and it provides a reliable and higher quality power supply, regardless of the network of the public distribution company [1]-[6]. The plants consisting of wind turbines and photovoltaic panels, become an increasingly attractive option since the price of fossil fuel oils in Ecuador is too expensive [4]-[8].

Banerjee et al. [1] presented and discussed the electrification of the rural area and a review of the autonomous system of power such as solar and wind. In addition, [11], [29] presented the development that leads to the implementation of these systems for the use of renewable energy and their level of penetration in recent times worldwide.

Another study was proposed by reference [10] for the implementation of hybrid systems in the rural area disconnected from the electrical network. In our case, we will analyze and compare the theoretical part of the system proposed with the experience in the field [9].

This paper describes the simulation and validation of a combined wind and solar system for electric power generation

with energy storage facilities. Several studies have been carried out by the University in rural areas of the Province of Azuay in Ecuador, but this is the first one that was carried out in a Rural Tourist Center of this Region.

The multivariable meteorological data, which include wind speed and direction, solar radiation, rain and humidity, as well as temperature, were obtained after installing a meteorological station in the Tranca-Chordeleg. In addition, the simulation model in MATLAB includes a modern charge and inverter controller purchased specifically for this study.

Another study was proposed by Colak [20] for its implementation in remote rural areas and far from the commercial distribution network. The hybrid system consists of a wind turbine and 15 photovoltaic panels. In addition, among the experiences in the Province of Azuay, another hybrid photovoltaic - wind system has been suggested to provide uninterrupted power to a remote location in Molleturo by Icaza [24]. In addition, other studies were presented on PV-battery-wind hybrids and PV-wind-diesel-battery hybrids for rural electrification [19]-[25]. The energy conversion equations described in the formulation for a hybrid system of photovoltaic solar energy, wind turbine and turbine and integrated simultaneously [25]-[31]. To validate this simulation model, the energy conversion equations were used in the model with MATLAB/Simulink.

## II. LOCATION OF RESEARCH

The Tranca Tourist Center is located in the Tranca Sector, hence the origin of its name, in the Luis Galarza Orellana parish (Delegsol) of the Chordeleg canton in the province of Azuay, see Fig. 1.

The Delegsol parish is located south east of the Chordeleg Canton. It limits to the North, with the Parish San Martin de Puzhio to the East with the Parish of Remigio Crespo Toral and Luis Cardero Vega Al Sur, with the Main Parish and to the West with the Parish of Güel del Cantón Sigsig.

The sector La Tranca is 13 km from Chordeleg canton whose road is paved and 3 km far from the parish center Delegsol on paved road through the community of Chocar, few people who live in the sector are engaged in craftsmen such as making hats straw toquilla, livestock, and agriculture.

Next, in Fig. 2, we can identify the scheme where the contributions of energy, photovoltaic and wind turbine are studied and, in the future, can increase other contributions of another type of renewable energy [30]. It is clear that, in our case study, we contemplate it without connection to the electrical network of the local commercial company.

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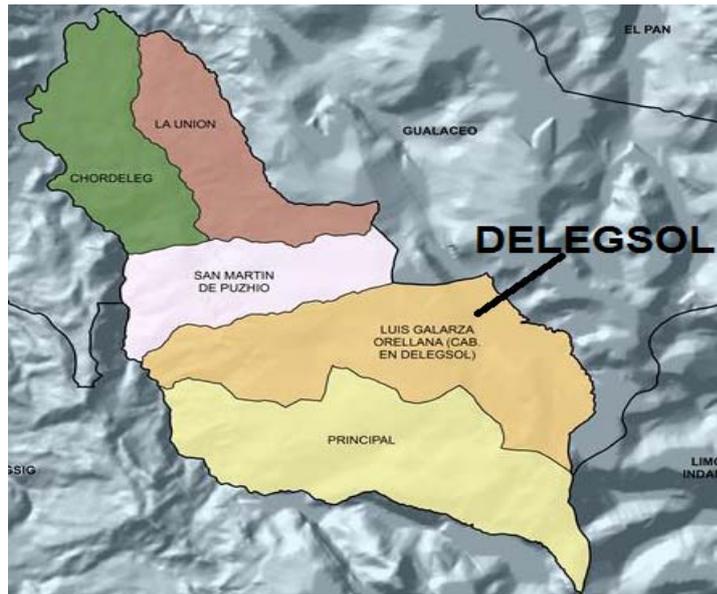


Fig. 1 Location of Molleturo Parish in Ecuador

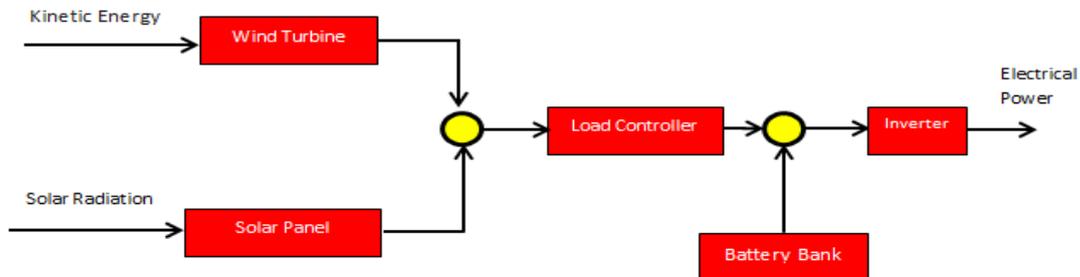


Fig. 2 Electric power conversion energy

### 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 [12]-[18]. This process allows us, in the end, to find the best design option of the hybrid system so that this research can lead to better developments based on much more advanced mathematical models.

#### A. Wind Turbine

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

$$P_1 = 0.5 * C_{p1} * \rho_{air} * A * v^3 * \eta_w \quad (1)$$

where  $P_1$  is the wind power sweep produced by the blades per unit area,  $C_{p1}$  is the Betz power coefficient,  $\rho_{air}$  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

$$\eta_w = \eta_x \cdot \eta_y \cdot \eta_z \quad (2)$$

where  $\eta_x$ ,  $\eta_y$  are the mechanical friction and generator efficiencies respectively, and the efficiency speed multiplication box is  $\eta_z$ .

The power output of the wind turbine in (20) can be expressed in single-phase power AC as;

$$P_e = \sqrt{3} \cdot \eta_1 \cdot U_l \cdot I_l \cdot \cos\phi \quad (3)$$

With single phase AC power is  $P_e$ , line current  $I_l$ , represents power factor  $\cos\phi$ , and the electric conversion efficiency is referred to as  $\eta_1$ .

#### 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  $\eta_{pvg}$  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  $\eta_{pvg}$  can be defined as [1]

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

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

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

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

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

$$I_0 = \frac{I_{sc} - \frac{V_{oc}}{R_p}}{e^{\left( \frac{V_{oc}}{V_t} \right)} - 1} \quad (8)$$

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;  $1 < m < 2$ .  $T_1$  is the working temperature of the solar panel in °C.  $R_s$  is the series resistor.  $R_p$  is the resistance in parallel.  $I_L(G_1, T_1)$  is the photogenerated current and approximately equal to the short-circuit current  $I_{sc}(G_1, T_1)$ .  $I_0$  is the inverse saturation current of the diode.  $V_{oc}$  is the open circuit voltage [22].

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

$$P_{PV}(t) = \eta_2 I_{PV} V_{PV} \quad (9)$$

where  $\eta_2$  is the efficiency of conversion to DC and referred to  $V_{PV}$ , and  $I_{PV}$ .

#### C. Controller

Generally, the controller power output is given by

$$P_C = V_{bat}(I_r + I_{PV}) \quad (10)$$

where  $V_{bat}$  is the multiplication of the nominal voltage DC in the battery for any particular system, and  $I_r$  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;

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

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;

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

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 the following equation,

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

where  $I_{OUT}$  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  $P_{in}$  and inverter output power  $P_{op}$ . The inverter will incur conversion losses and to account for the inverter efficiency losses,  $\eta_{inv}$  is used;

$$P_{in} \cdot \eta_{inv} = P_{op} \quad (16)$$

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

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

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

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

$$\eta_{system} = \frac{P(t)}{P_e + P_{PV}} \quad (19)$$

## IV. BLOCKS DIAGRAMS IN SIMULINK

### A. Wind Turbine

Fig. 3 shows the mathematical model of a wind turbine developed in Simulink (MATLAB R2015a), the simulation is developed according to the characteristics of the wind turbine, geographic and meteorological background of the place.

### B. Photovoltaic PV System

Fig. 4 shows the mathematical model of a photovoltaic solar module developed in Simulink (MATLAB R2015a), the simulation is developed according to the characteristics of the photovoltaic module, geographical and meteorological background of the place of analysis, in this way the system has the following input data:

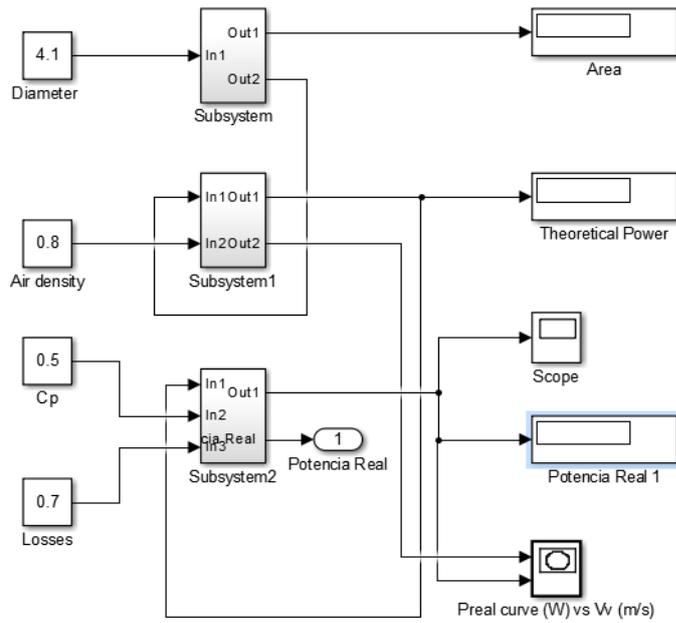


Fig. 3 Modeling in MATLAB/Simulink of the wind turbine

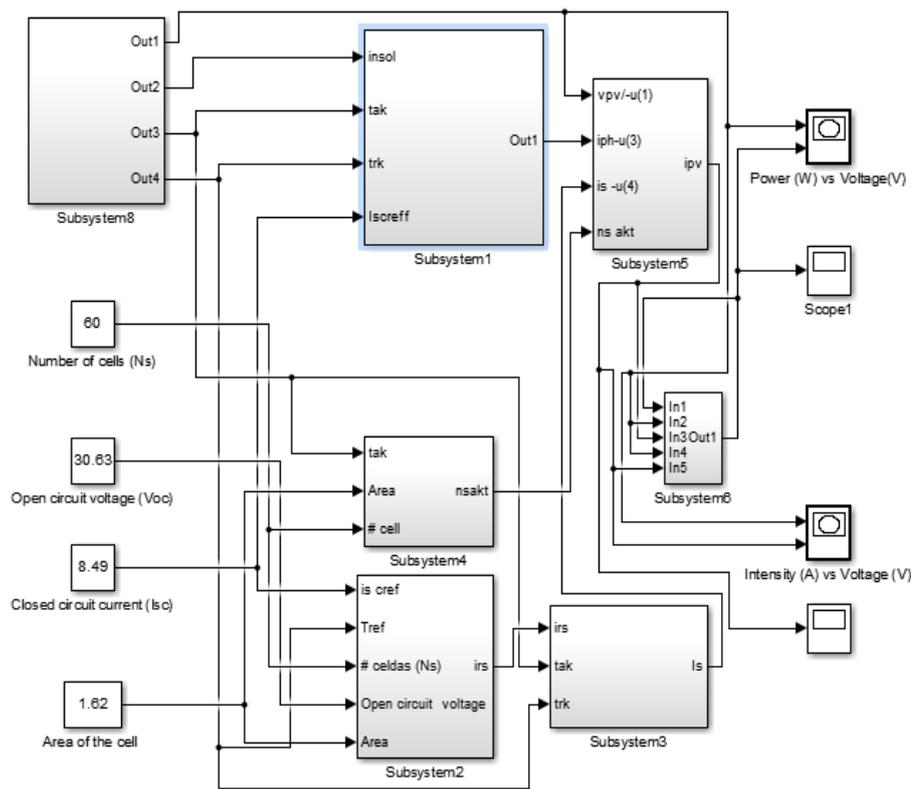


Fig. 4 Modeling in MATLAB/Simulink of PV

V. RESULTS AND DISCUSSION

To solve the aforementioned equations (1)-(19) and taking into account that the two systems do not necessarily provide us with energy simultaneously and at maximum generation,

and for validation purposes, this model is used with the use of specialized software such as MATLAB/Simulink and the coding of the aforementioned equations. Furthermore, in order to validate and fine-tune the simulated results, the most coherent data are fed back to reality and, based on the

measurements made; the data were used to validate the simulation program under various conditions. In this same section, the analyses and discussions of the predicted numerical results as well as the validations of the proposed simulation model specified from the MATLAB/Simulink are presented.

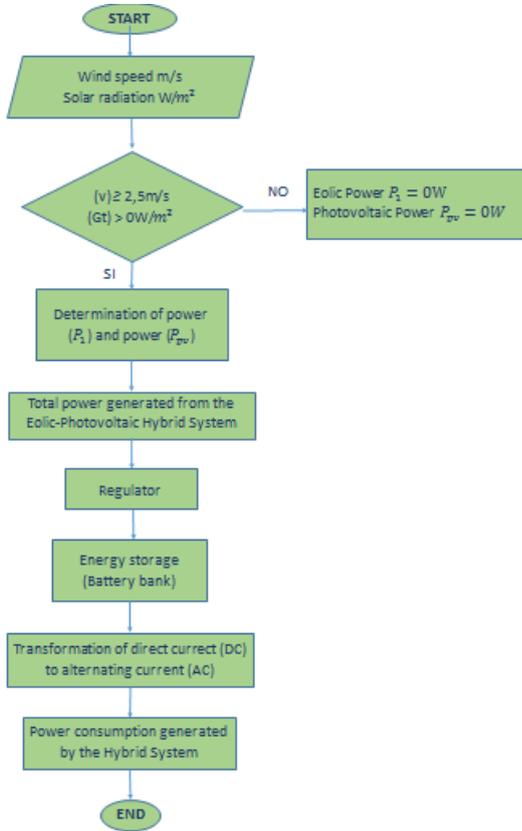


Fig. 5 Flow diagram of hybrid system calculation

Figs. 6 and 7 show the radiation profiles and the wind speed profiles measured at The Tranca Tourist Center during several months of the year 2017 at different times of the day.

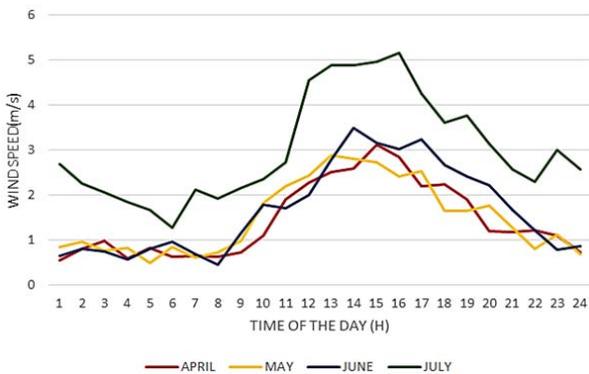


Fig. 6 Profile of Speed in m/s April 2017- July 2017

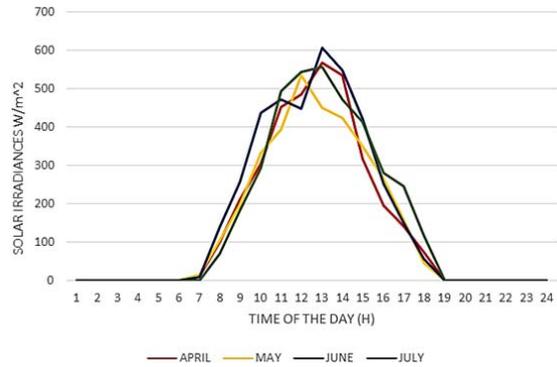


Fig. 7 Solar irradiances ( $W/m^2$ ) Profile April 2017-July 2017

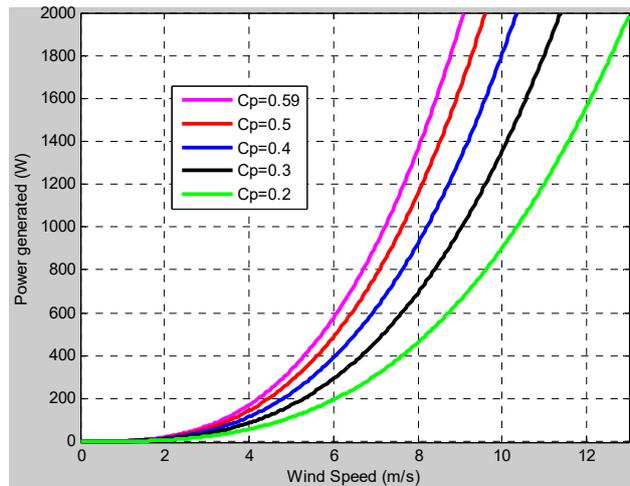


Fig. 8 Power-speed curve for different values of Betz

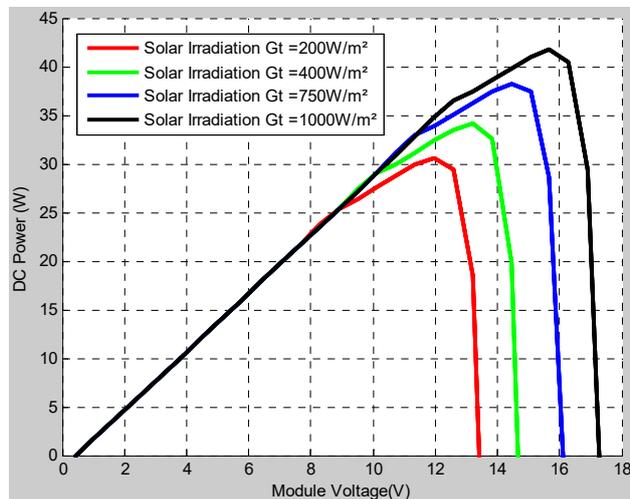


Fig. 9 Voltage-DC power curve for different values of solar irradiation

A. Wind Turbine Simulation

The wind speed which is directly linked to the output of electric power generated by the wind turbine is illustrated in Fig. 8. The predicted results depicted in these figures show

that, at a lower cutting speed of 2.3 m/s and a speed with a cut-off higher than 8 m/s, the generated wind energy is 50 and 1800 watts, which coincides with the specifications of the wind turbine provided by the manufacturer. In addition, Fig. 8 has been constructed to show the impact of wind speed on the conversion efficiency of wind energy into electricity for the Tranca-Chordeleg. It is quite clear that while the higher wind speed results in higher energy conversion efficiency and produces more output power. However, for the wind turbine under investigation, the minimum wind speed to start producing electrical energy is 2.3 m/s, in this particular condition, the power output and the conversion efficiency are significantly low but economically viable for the supply of energy in the Tourist Center to contribute to the hybrid system at times when there is no supply of the photovoltaic system.

**B. PV Simulation**

Fig. 9 shows the influence of solar radiation on the production of electrical energy as part of the hybrid system, is represented and analyzed between generated voltage and electrical power. In this section, we illustrate the conversion of solar energy into electrical energy with the variation of the temperatures of the PV cells. It is worth noting that the numerical simulation performed in the MATLAB and represented here includes the variation of the temperature.

**C. Validation of Simulation Model**

To validate our numerical model prediction described in (1)-(19), Figs. 10 and 11 were constructed to compare the results of the model used with the experimental results of the hybrid system.

Next, in Figs. 12 and 13, we represent in DIALUX the distribution of load to be supplied from the solar-wind hybrid generation system in the Tourist Center La Tranca-Chordeleg.

Next, Table I presents where the degree of contribution of each wind and photovoltaic system is established to supply the load of the Tourist Center.

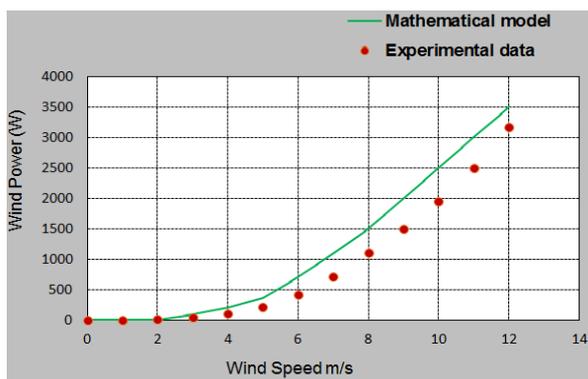


Fig. 10 Comparison of wind speed – wind power

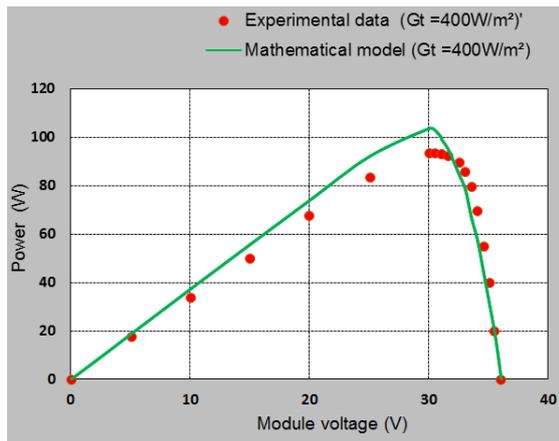


Fig. 11 PV output data compared to model prediction at 500 W/m²



Fig. 12 General view of the Tourist Center La Tranca-Chordeleg



Fig. 13 Simulation of the lighting system of the Tourist Center La Tranca-Chordeleg

**VI. CONCLUSIONS**

The hybrid system dealt with in this article can be of significant consideration in remote places such as the one studied in Centro Turistico La Tranca-Chordeleg and can serve as an important experience to develop other projects in nearby places or areas that have similar characteristics.

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. 10 that comes from (1) has a pattern of behavior quite similar to the data of power-speed measured at the remote station.

In relation to the production of solar energy shown in Fig. 11, there are good results in the analysis of the model used with the data taken in the field in direct relation with the

production of energy referred to the variation of temperature, so that 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 greater the solar radiation, the higher the PV power and the PV amperage are. It is important for the design of the solar radiation system to consider the influence of temperature due to solar radiation and the ambient temperature where the equipment is located, especially the solar panels.

TABLE I  
ELECTRIC POWER GENERATED BY THE HYBRID SYSTEM TO COVER THE PROJECTED LOAD

|                  |         |            |        |
|------------------|---------|------------|--------|
| Wind system      | 58.07   | kWh/ month | 12.15% |
| PV System        | 419.5   | kWh/ month | 87.84% |
| Hybrid system    | 477.57  | kWh/ month |        |
| Required Energy  | 470.114 | kWh/month  |        |
| Generated Energy | 477.57  | kWh/ month |        |

This project avoids the use of electric generation systems using fossil fuels and pretends that the generation system is using clean renewable energy and that it does not cost more than the initial investment.

#### REFERENCES

- [1] Banerjee P, et al” Designing and Simulation of Standalone Micro Grid for Rural area using Renewable Energy Resources”, IEEE Power Electronics (ICPE), 7th India International Conference, Patiala 2016.
- [2] Icaza Alvarez, Daniel Orlando. Modelado, simulación y construcción de una turbina de viento DIAWIND-A2 como una nueva alternativa de generación eléctrica en áreas rurales de Ecuador. *Killkana Técnica*, 2018, vol. 1, no 3, p. 9-16.
- [3] Peterseim. J. H, Hellwig. U, Tadros. A, White. “Hybridisation optimization of concentrating solar thermal and biomass power generation facilities”, Science direct Solar Energy vol. 99, pp. 203– 214, 2014.
- [4] Pedram Asef, R. Bargasallo Perpina, Bereket T. Habte, A. Babaeian, “An Alternative Organic growth through Acquisitions Investigation on wind Energy”, International conference –Alternative and renewable Energy Quest, AREQ 2017, Energy Procedia, 1-3 February 2017, Spain.
- [5] Iftekhar Hussain, C.M. Duffy, A. & Norton, B. (2015), “A Comparative Technological Review of Hybrid CSP-Biomass CHP Systems in Europe”, International Conference on Sustainable Energy & Environmental Protection, Paisley, UK, 11-14 August.
- [6] Department of Energy, “Potential Benefits of Distributed Generation and Rate Related Issues that may Impede their Expansion. A Study Pursuant to Section 1817 of the Energy Policy Act of 2005” 2007.
- [7] Binayak, B., Shiva, R. P., Kyung-Tae L., Sung-Hoon A., “Mathematical Modeling of Hybrid Renewable Energy System: A Review on Small Hydro-Solar-Wind Power Generation”, International Journal of Precision engineering and Manufacturing-green Technology, Vol. 1, No 2, pp. 157-173, 2014.
- [8] Kavitha Sirasani, S. Y. Kamdi, “Solar Hydro Hybrid Energy System Simulation” International Journal of Soft Computing and Engineering (IJSCE), Volume-2, Issue-6, pp. 500-503, January 2013.
- [9] GARCÍA, M., “Modelado de Sistemas Fotovoltaicos Autónomos”. En: Fundamentos, dimensionado y aplicaciones de la energía solar fotovoltaica. Madrid: Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), 2006, p.13, ISBN: 9788478345144.
- [10] WENHAM, S.; et al., "Applied Photovoltaics". 2nd. ed., London: Earthscan, 2007, 134 p., ISBN: 978-184407-401-3.
- [11] Icaza D. Sami S., “Modeling, Simulation and Stability Analysis Using MATLAB of a Hybrid System Solar Panel and Wind Turbine in The Locality of Puntahacienda-Quingeo In Ecuador”, International Journal of Management and sustainability, 2018 vol. 7, No 1, pp 1-24 ISSN(e): 2306-0662. ISSN(p): 2306-9856. DOI: 10.18488/journal.11.2018.71.1.24.
- [12] Ramazan Bayindir et al., “A Comprehensive Study on Microgrid Technology”, International Journal of Renewable Energy Research, Vol. 4, No. 4, 2014.
- [13] Penyarat Chinda, Pascal Brault; The hybrid solid oxide fuel cell (SOFC) and gas turbine (GT) systems steady state modeling, International Journal of Hydrogen Energy, Volume 37, Issue 11, June 2012, Pages 9237–9248.
- [14] Dustin McLarty, Jack Brouwer, Scott Samuelsen, Fuel cell–gas turbine hybrid system design part I: Steady state performance, Journal of Power Sources, Volume 257, 1 July 2014, Pages 412–420.
- [15] Atideh Abbasi and Zhenhua Jiang, Design and analysis of a fuel cell/gas turbine hybrid power system , Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE.
- [16] Yoshimasa Ando, Hiroyuki Oozawa, Masahiro Mihara, Hiroki Irie, Yasutaka Urashita, Takuo Ikegami, Demonstration of SOFC-Micro Gas Turbine (MGT), Mitsubishi Heavy Industries Technical Review Vol. 52 No. 4 (December 2015).
- [17] Icaza D., Modeling, simulation and construction of the D-ICAZA-A1 wind turbine destined for the rural areas of Ecuador. Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America), 2017 IEEE PES. Quito 2017/12/4
- [18] Fargali, H., M., Fahmy, F.H. and Hassan, M.A., “A Simulation Model for Predicting the Performance of PV/Wind- Powered Geothermal Space Heating System in Egypt”, The Online Journal on Electronics and Electrical Engineering (OJEEE), Vol.2, No.4, 2008.
- [19] J. R. Howell, R. B. Bannerot, and G. C. Vliet (Solar-Thermal Energy Systems: Analysis and Design, McGraw-Hill, Inc., New York, 1982.
- [20] Colak I, Bayindir R, Fulli G, Tekin I, Demirtas K, Covrig CF. Smart grid opportunities and applications in Turkey. Renew Sustain Energy Rev 2014;33:344–52.
- [21] Saha, N.C., Acharjee, S., Mollah, M.A.S., Rahman, K.T., and Rafi, F. H. M.,” Modeling and Performance Analysis of a Hybrid Power System”, Proc. of International Conference on Informatics Electronics & Vision (ICIEV), pp. 1-5, 2013.
- [22] Mustafa, E., “Sizing and Simulation of PV-Wind Hybrid Power System”, International Journal of Photoenergy, Vol 2013, Article ID 217526, 10 pages, 2013.
- [23] Colak I, Sagiroglu S, Fulli G, Yesilbudak M, Covrig CF. A survey on the critical issues in smart grid technologies. Renew Sustain Energy Rev 2014. submitted for publication.
- [24] Icaza D, Córdova F, Toledo J, Carlos C, Lojano A, Modeling and simulation of a hybrid system solar panel and wind turbine in the locality of Molleturo in Ecuador. ICRERA 2017. San Diego CA USA pp 620-625. DOI: 10.1109/ICRERA.2017.8191134.
- [25] Fadaeenejed, M, Radzi, M. A., AbKadir, M. Z. and Hizam, H.,” Assessment of Hybrid Renewable Power Sources for Rural Electrification in Malaysia”, Renewable and Sustainable Energy Reviews, Vol. 30, pp. 299- 305, 2013.
- [26] F. Viola, P. Romano, R. Miceli, D. La Cascia, M. Longo, “Economical evaluation of ecological benefits of the demand side management”, ICRERA 2014, Milwaukee 19-22, 2014.
- [27] Fabio Viola, Pietro Romano, Eleonora Riva Sanseverino, Rosario Miceli, Marzia Cardinale, Giuseppe Schettino “An economic study about the installation of PV plants reconfiguration systems in Italy”, pubblicato in 2014 International Conference on Renewable Energy Research and Application (ICRERA), DOI: 10.1109/ICRERA.2014.7016534.
- [28] Sami, S. and Icaza, D. “Modeling, Simulation of Hybrid Solar Photovoltaic, Wind turbine and Hydraulic Power System”, IJEST, International Journal of Engineering Science and Technology, Volume 7, Issue 9, September 30, 2015.
- [29] Whiteman, C. D, “Meteorología de Montañas: Fundamentos y Aplicaciones”, Oxford, Oxford University Press, 2000.
- [30] Von Hippel, Eric. The sources of innovation. En *Das Summa Summarum des Management*. Gabler, 2007. p. 111-120.
- [31] Icaza Álvarez, D. (2017). EJE 07-10 Sistemas de seguridad ciudadana por georeferenciación y geolocalización para zonas rurales del cantón Cuenca incorporados al SIS ECU 9-1-1 del Ecuador. *Memorias Universidad Del Azuay*, 1(XVI), 413 - 418. Recuperado a partir de <http://revistas.uazuay.edu.ec/index.php/memorias/article/view/88>.