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Modeling, simulation and construction of the DIAWIND-A2 wind turbine as a new alternative of electric generation in the rural areas of Ecuador

Modelado, simulación y construcción de una turbina de viento DIAWIND-A2 como una nueva alternativa de generación eléctrica en áreas rurales de Ecuador

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Abstract

This paper presents the mathematical model, the simulations performed before the construction of an 800W wind turbine for the rural areas of Ecuador. Subsequently, the project went to a laboratory research stage and using the MATLAB some simulations were carried out seeking the highest possible performance. The simulations were based on the characteristic parameters of the wind turbine, which should provide energy to rural households, outside the network of conventional electrical distribution. The power generation is possible at very low speeds because the rotor of an alternator was used for this case, permanent magnets were coupled and has a dynamic orientation system product of sensation of greater wind flow through a weather vane. At the end the wind turbine was submitted to functional tests in the town of Puntahacienda of the Quingeo Parish of the Canton of Cuenca-Ecuador.

Key words: Smart Grids, Wind turbine, Modeling, renewable energy, Puntahacienda of Quingeo, Innovation.

Resumen

Este artículo presenta el modelo matemático, las simulaciones realizadas antes de la construcción de una turbina eólica de 800 W para las áreas rurales de Ecuador. Posteriormente, el proyecto pasó a una etapa de investigación de laboratorio y con el MATLAB se llevaron a cabo algunas simulaciones buscando el mayor rendimiento posible. Las simulaciones se basaron en los parámetros característicos de la turbina eólica, que debería proporcionar energía a los hogares rurales, fuera de la red de distribución eléctrica convencional. La generación de energía es posible a velocidades muy bajas porque el rotor de un alternador se usó para este caso, los imanes permanentes se acoplaron y tiene un sistema de orientación dinámica producto del censado de mayor flujo de viento a través de una veleta. Al final, la turbina eólica se sometió a pruebas funcionales en la localidad de Puntahacienda, en la Parroquia de Quingeo, en el cantón de Cuenca-Ecuador.

Palabras clave: Redes inteligentes, Turbina eólica, Modelado, Energía renovable, Puntahacienda de Quingeo, Innovación.

I. Introduction

The Renewable energy sources such as solar, hydro, wind, biomass and photovoltaic, among the main ones, are being used increasingly by many countries in the world and particularly in Ecuador, there is a growing research and implementation of these generation systems, not only as a technical-economic alternative to the oil crisis, but as a response to the negative effects that originate on man and nature [1].

The alternative energies are gaining place in the present society since nowadays the increment of the fossil fuels and environmental problems have returned the have the leading role to these energies to be clean and inexhaustible. Among these options is the wind with the placement of generators wherever there is fairly constant wind. Its use is viable in areas where the electricity grid does not reach, such as farms and, in particular, rural houses. To mention examples in Ecuador such as the Villonaco de Loja Project and Baltra Island in Galapagos [2].

Today we are obliged to look for new alternatives of electric energy due to the increasing consumption of an energy that has a constant increment on prices, which in some cases, are prohibitive for the most dispossessed classes, and with a demand that increases with extraordinary speed [1].

The renewable energies are for Ecuador a binding part of the National Plan for Good Living (PNBV) and within its objectives for the year 2021 is that less than 60% of installed capacity must be covered with renewable energy. Projects like the one developed in this article contribute to this objective and also to the integration of the rural areas that does not have access to the distribution lines [3].

Ecuador is on the path to progress in the development of projects involving renewable energies, and sources of energy supply that have not yet been widely exploited, especially in the rural areas of our country, where in many cases energy is still used on the basis of gasoline or diesel generators.

II. SIMPLIFIED MATHEMATICAL MODEL

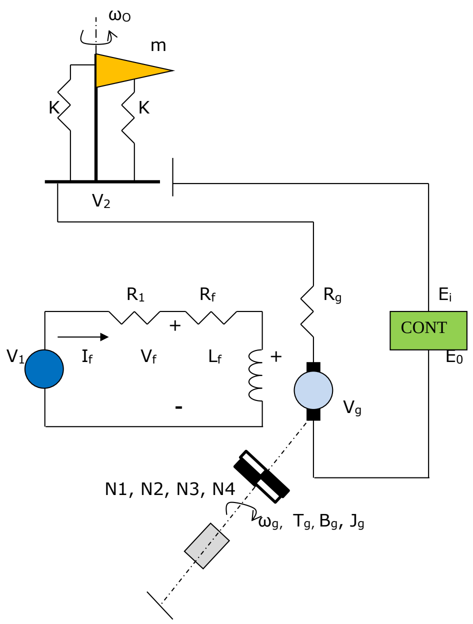

FIG. 1. Simplified mathematical model of the DIAWIND-A2 wind turbine.

where

ω_0 = Angular velocity produced by wind to wind vane.
k = Spring constant given in N/m.
V_2 = Contact voltage drop.
R_g = Generator resistance (Alternator).
V_g = Generated electromotive force.
CONT = Controller selected.
E_i = Input voltage to the controller.
E_0 = Output voltage of the controller.
ω_g = Angular velocity produced in the generator.
ω_1 = Angular speed of entrance to the blades.
R_f, L_f = Stator-related impedance.
V_1 = Utility voltage max. 12V.
R_1 = Stator input resistance.
N_1, N_3 = Number of turns of gears driven.
N_2, N_4 = Number of turns of conductive sprockets.
K_s = Sensor constant (wind vane).

$$\omega_0 = \sqrt{\frac{k}{m}} = \sqrt{\frac{10\mathrm{N/m}}{0.4\mathrm{kg}}} = 5\mathrm{rad/s}, \quad (1)$$

$$v_2(t) = K_b\omega_2(t), \quad (2)$$

$$v_2(s) = K_b\omega_2(s), \quad (3)$$

$$V_f(t) = R_f i_f + L\frac{di_f}{dt}, \quad (4)$$

$$V_f(s) = (R_f + sL_f)I_f(s), \quad (5)$$

$$V_g(t) = K_g i_f(t), \quad (6)$$

$$V_g(s) = K_g I_f(s), \quad (7)$$

$$V_g(t) = R_g i_a + V_2(t) + K_c E_0(t), \quad (8)$$

$$V_g(s) - V_2(s) = R_g I_a(s) + K_c E_0(s), \quad (9)$$

$$V_1(t) = R_1 i_f(t), \quad (10)$$

$$V_1(s) = R_1 i_f(s), \quad (11)$$

$$T_m(t) = T_L(t) + T_e^1(t), \quad (12)$$

$$T_e^1(t) = \frac{N_2N_4}{N_1N_3}T_e(s), \quad (13)$$

$$T_L(t) = J_{eq}\frac{d\omega_m}{dt} + B_{eq}\,\omega_m, \quad (14)$$

$$T_L(s) = [B_{eq} + J_{eq}(s)]\omega_m(s), \quad (15)$$

$$B_{eq} = B_m + \left(\frac{N_2N_4}{N_1N_3}\right)B_L, \quad (16)$$

$$J_{eq} = J_m + \left(\frac{N_2N_4}{N_1N_3}\right)J_L. \quad (17)$$

III. TRANSFER FUNCTION

Using the principles of block reduction to feedback systems related to an output $C(s)$ and input $R(s)$ [4], we have:

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}. \quad (18)$$

Applying (18) to our system [5, 6, 7, 8], first between $V_3(s)$ and $V_2(s)$, we have:

$$\frac{V_3(s)}{E_0(s)} = \frac{\frac{1}{R_f + sL_f}\frac{1}{B_{eq} + sJ_{eq}}K_b\frac{N_2N_4}{N_1N_3}}{1 + K_s\frac{1}{R_f + sL_f}\frac{1}{B_{eq} + sJ_{eq}}K_b\frac{N_2N_4}{N_1N_3}}. \quad (19)$$

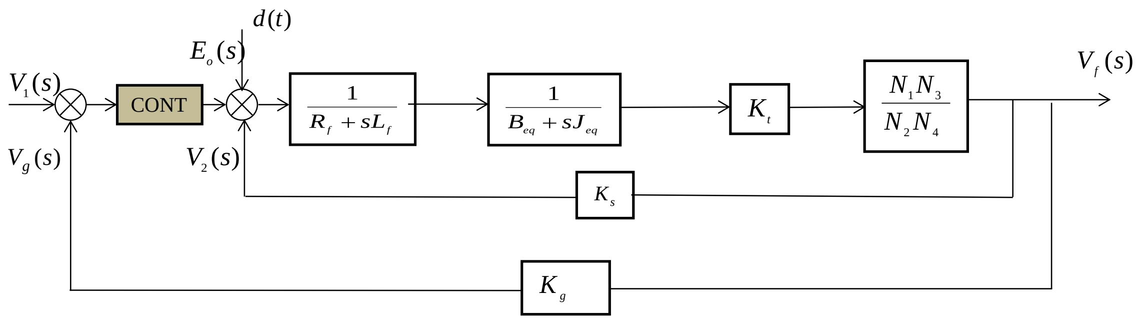

FIG. 2. Block's diagram of the DIAWIND-A2 wind turbine.

Organizing terms, we have:

$$\frac{V_3(s)}{E_0(s)} = \frac{K_b N_2 N_4}{N_1 N_3 (R_f + sL_f)(B_{eq} + sJ_{eq}) + K_b N_2 N_4 K_s}. \tag{20}$$

Finally applying (18) between the output $V_f(s)$ and the input $V_1(s)$, we get the transfer function:

$$\frac{V_f(s)}{V_1(s)} = \frac{K_b N_2 N_4 \text{ CONT}}{[N_1 N_3 (R_f + sL_f)(B_{eq} + sJ_{eq}) + K_b N_2 N_4 K_s]s + \text{CONT } K_b N_2 N_4 K_g}. \tag{21}$$

Evaluating with:

$$i = \frac{N_2 N_4}{N_1 N_3} = \frac{10.10}{20.300} = \frac{1}{6}.$$

L_f=0.2 H
$R_f = 4\Omega$
$K_s = K_g = 1$
$B_{eq} = 0.6$ N·m/rad/s
$J_{eq} = 1.2$ Kg·m^2

$$\frac{V_f(s)}{V_1(s)} = \frac{\text{CONT}}{[60(4+0.2s)(0.6+1.2s)+1]s + \text{CONT}}. \tag{22}$$

Organizing terms.

$$\frac{V_f(s)}{V_1(s)} = \frac{\text{CONT}}{14.1s^3 + 295.2s^2 + 145s + \text{CONT}}. \tag{23}$$

Evaluating (20)

$$\frac{V_3(s)}{E_0(s)} = \frac{1}{14.4s^2 + 295.2s + 145}. \tag{24}$$

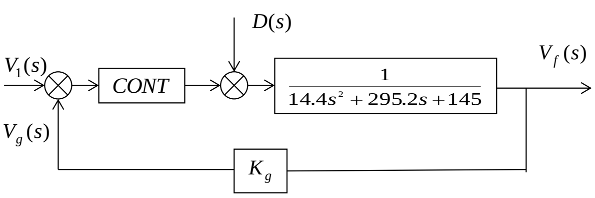

FIG. 3. Simplified block diagram.

Starting from (23)

$$V_1(s) = \frac{12}{s},$$

$$V_f(s) = \frac{\text{CONT}}{14.4s^3 + 295.2s^2 + 145s + \text{CONT}} \frac{12}{s}. \tag{25}$$

$D(s)$= Possible disturbance that can be generated by turning the wind vane.

$$\frac{V_f(s)}{D(s)} = \frac{1}{14.4s^3 + 295.2s^2 + 145s}.$$

Taking the transfer function (23) we must now determine the appropriate controller so we perform the following analyzes.

We tested with different controllers and the one that manages to satisfy is a $[PI]$ for CONT=$K_p + \frac{K_I}{s}$.

$$\frac{V_f(s)}{V_1(s)} = \frac{K_p + \frac{K_I}{s}}{5s^3 + 202.5s^2 + 101s + \left(K_p + \frac{K_I}{s}\right)},$$

$$\begin{aligned} V_f(t=\infty) &= \lim_{s\to 0} V_f(s) \\ &= \lim_{s\to 0} \frac{K_p s + K_I}{5s^4 + 202.5s^3 + 101s^2 + K_p s + K_I} \\ &= \frac{K_I}{K_I} = 1. \end{aligned}$$

The characteristic equation is:

$$5s^4 + 202.5s^3 + 101s^2 + K_p s + K_I = 0.$$

It satisfies the stability of the system since all the coefficients of the equation are different from zero [4].

Therefore we select a [PI]

$$\frac{V_f(s)}{V_1(s)} = \frac{K_p s + K_I}{14.4s^4 + 295.2s^3 + 145s^2 + K_p s + K_I}, \quad (26)$$

with values $K_p = 1$ and $K_I = 0.5$, the transfer function is finally evaluated:

$$\frac{V_f(s)}{V_1(s)} = \frac{s + 0.5}{14.4s^4 + 295.2s^3 + 145s^2 + s + 0.5}, \quad (27)$$

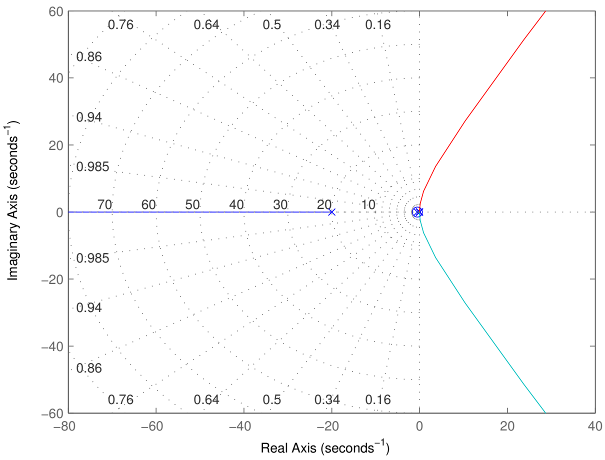

FIG. 4. Simulation of the LGR of the DIAWIND-A2 Wind Turbine.

As shown in Fig. 4 the poles are in the left plane with respect to the imaginary axis so the system is stable.

Starting from (25) before a step entry, we obtain the graph Fig. 5 in MATLAB.

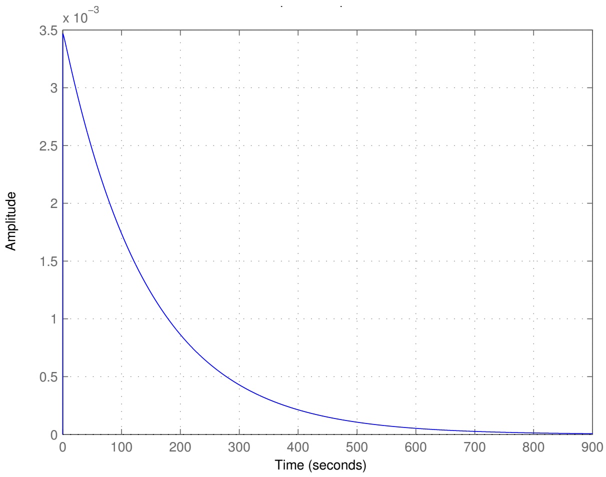

FIG. 5. Response to impulse DIAWIND-A2 Wind Turbine.

Fig. 5 shows that the system stabilizes after 700 seconds.

IV. CASE STUDY

A. *Description*

After the study and analysis of stability, it was thought in a next stage that is the design of the wind turbine DIAWIND-A2 as an improved version but very close to another wind turbine built by the author, the D-ICAZA-A1. Figure 6 shows the general design of the DIAWIND-A2 wind turbine, which is in accordance with the parameters presented in sections II to III of this article [9, 10, 11, 1]. What is explained here is just a summary of the most important, but the study goes further with a detailed analysis and design and that because of its short extension is not possible to describe step by step in this document. However, this study establishes a model and design that is quite reliable but leaves a door open to researchers who like to design technologies in the field of renewable energy so that they can improve it, with little research is able to optimize the resources and greater efficiency in energy production. Then design the wind turbine in a simplified way.

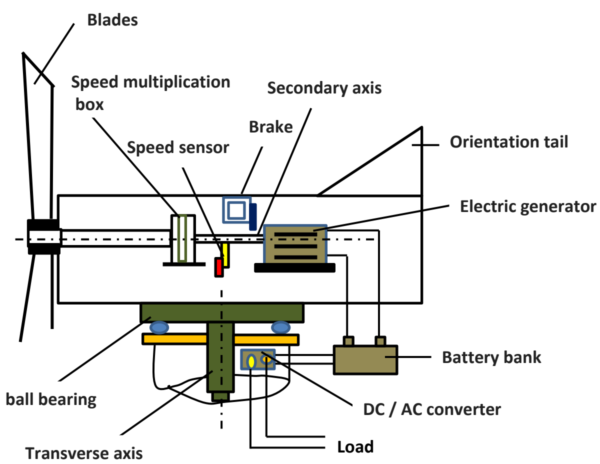

FIG. 6. Internal structure of the DIAWIND-A2 wind turbine.

V. CONSTRUCTION AND ASSEMBLY

The design of each of the main and complementary elements must guarantee the stability of the wind turbine as well as support the different efforts, proper to the interaction of the kinetic chain. On the other hand, it must also consider the deformations that its elements/parts can suffer because of external factors such as temperature and push-ups produced by the wind. In many cases, small variations can lead to welding between elements or frictions that threaten the normal functioning of the wind turbine. In this particular case we have taken into account the geometric and dimensional tolerance levels at the time of construction of the wind turbine, which is why we must consider the surface of its elements, especially the input, secondary and vertical axes. These processes are carried out using by chip cutting, and using machine tools, such as the parallel lathe, the universal milling machine, the grinding machine, the slitter, etc. To get the pieces of the geometric configuration and surface finishes of good quality. Making a wind turbine with a vision requires of many resources such as time, money and machinery, as well as patience to initially construct a prototype. Due to the extension of this article, it is not possible to provide very detailed information regarding the construction of the model. In the construction of the DIAWIND-A2 wind turbine, the multiplication system has been improved. This system helps amplify consequently to the alternator where the electric energy is generated in direct current. The details of the machining and construction of the most important parts are detailed below.

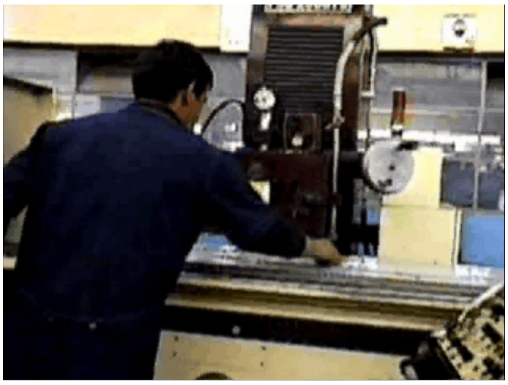

FIG. 7. Surface finishing of flat parts.

In Fig. 7, surface finishing operations are performed on flat pieces where the roughness ranges are quite demanding. This consists of polishing the surfaces with a grinding stone located in the flat grinding machine.

FIG. 8. Tower and wind turbine to be assembled.

Fig. 8 shows the tower with the wind turbine mounted on the top. The tower will also serve as a support for the positioning system depending on the wind direction where the wind flow is best used.

In Fig. 9, the entire set of the sealed orientation system is observed. Here, the internal iron spheres allow the entire structure of the wind turbine to be oriented according to the maximum wind currents sensed by the wind vane. The orientation system can rotate maximum 180 degrees so you should take the decision in its implementation if we install it to windward or leeward.

Once the wind turbine is positioned according to the

FIG. 9. Detail of the dynamic positioning system.

maximum wind current, the energy is generated, passed through a charge controller and then stored in 12v DC batteries [12, 2].

In Fig. 10, observed all their complements, such as tower elevation, batteries, weather vane, charge controller, etc.

FIG. 10. Overview of the DIAWIND-A2 wind turbine and the project author.

After its construction, functional tests were carried out in the town of Puntahacienda-Quingeo, in the Canton of Cuenca, as shown in Fig. 11 [7] and the results in Fig. 12. For this purpose we based both the formulas: The defined wind power conversion [10, 11, 1, 13] and the data measured during the tests, as follows:

FIG. 11. DIAWIND-A2 wind turbine installed for performance testing in Puntahacienda-Quingeo [7].

The power of the turbine is given by [13, 14];

$$P = \frac{1}{2} C_p \, \rho_{air} \, A \, v^3 \, \eta_{aer}, \tag{28}$$

where P is the power produced by sweeping the blades per unit area, Cp = Betz coefficient, ρ_{air} = Air density, A is the area swept by the blades of the wind turbine and v is the speed of the wind.

$A = 7.06$ m^2
$C_p = 0.5$
$\rho_{air} = 1.01$ Kg·m^{-3}
$\eta_{aer} = 0.57$

The simulated electrical power curve vs. the average power curve of the generation measured in the field is then shown in Fig. 12 as a function of the above parameters.

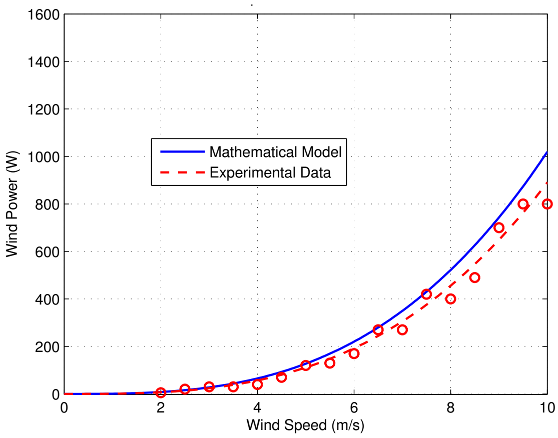

FIG. 12. Comparative curves between the theoretical mathematical model and the experimental curve of the DIAWIND-A2 wind turbine.

Fig. 13 shows that speeds between 1.8 m/s and 10.1m/s generate different power values in proportion, while from 10 m/s to 17 m/s the generated power is 800 W. There is a small peak between 10m/s and 13 m/s that exceeds the value of 800 W, we consider it as a transient power. It is also important to indicate that by protecting the elements that integrate the wind turbine when it exceeds the speed of 17 m/s will act a dynamic brake in kind of shoe to the secondary axis.

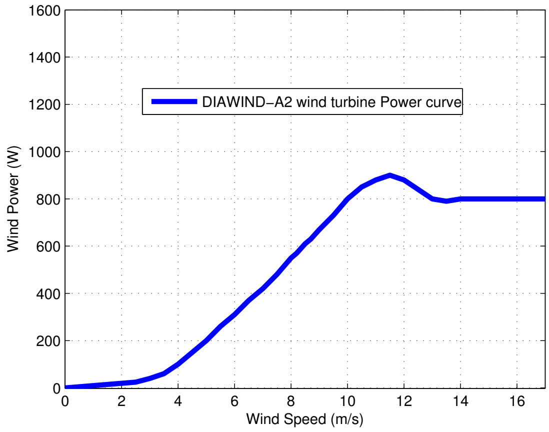

FIG. 13. Experimental Stabilized Power-Velocity Curve for the DIAWIND-A2 wind turbine.

VI. CONCLUSIONS

The DIAWIND-A2 wind turbine is an alternative version to the D-ICAZA-A1 wind turbine built by the same author and has been transformed into a passion to experiment with projects like the one indicated.

The mathematical model used for the construction of the wind turbine was very efficient and therefore the final results were very positive at the time of performing field tests.

The implementation of a multiplication box with a higher transmission ratio, in our case its ratio 1/60 gives us interesting results such as the wind turbine at a speed of 1.8 m / s and starts to generate energy, however in the characteristic curve of power generation Power-speed the wind turbine DIAWIND-A2 behaves with a pattern very similar to the wind turbine D-ICAZA- A1.

According to this new experience it is possible to make substantial improvements to the mathematical model as the design of the wind turbine with the inclusion of other variables and input values The machinery for the construction of the DIAWIND-A2 wind turbine exists in our environment, the workforce as well. We would lack investment and promotion.

As I can see despite being a rather small machine in size it is possible to start a power generation with fairly small wind speeds around 1.8 m /s and opens up a fairly important option of installing these machines in various places in Ecuador.

The generation of energy we have available in direct current but we can transform it into alternating current through an inverter equipment.

The calibration of the multiplication box with the adjacent elements must be considered since a level of friction and offset of the cogwheels can generate an imbalance of the system and therefore a wind turbine efficiency much lower than usual.

VII. Recommendations

It is recommended to the researchers that for the transport of the field wind turbine is done with the utmost care and especially the blades must maintain their balance, hitting their parts can cause a malfunction.

VIII. Gratitude

I am grateful to the Universidad Católica de Cuenca for giving me the opportunity to lead the electrical engineering career and to participate in research. On the other hand, I also thank the Politécnica Salesiana University for providing me with the laboratories which at the time were of great support to carry out this and other similar investigations.

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