Fuzzy Control for Solar Photovoltaic Tracking System

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***Abstract*—The worldwide use of renewable energies sources is steadily growing, due to demand to get new means that allows the support of massive use that it give in the common life, with the final purpose of decrease the use of nature reserve to produce it, in this case is exhibited the necessity to create systems to generated resources in an efficient way, using unlimited power infeed, as example we found the solar energy. This work shows the results obtained by perform a comparative analysis between the static behaviors and the design of a fuzzy logic controller for solar photovoltaic tracking system, defining the photovoltaic position from the maximum solar irradiation presented in 90 degrees; for verification of the result obtained by the controller, we make de simulation of a solar irradiation based in the data of the weather station of the *Corporación Autónoma Regional de Cundinamarca (CAR)*, situated in the campus of the Nueva Granada Military university.**

***Index Terms*—renewable energies sources, DC micro-grids, fuzzy control, photovoltaic solar energy, solar irradiance**

I. Introduction

Actually, the current methods for energy production are not sustainable, due to environmental problematics and the lack of nature resources [1]. This and the increase demand in 2012, has led to implement some kind of renewable energy or rational used in 138 countries to generated global changes [2]. In this moment, the green energy accounted for 1.470GW, which modern renewable energy sources accounted for 480GW, by the end of 2013, solar power had added 36.7GW of new capacity to the total in last year. All this demand growing is also increasing the interest of how the meteorological condition plays significant role in the performance of renewable energy systems, whereas these systems produce optimum output under certain desired weather conditions which are essentially location [3]. Thus we need apply an intelligence network that allows the integration of large amounts of green energy, improving reliability, quality of supply and ensuring safety, due to the great advantages and developments on renewable energy, it is necessary to analyze how energy should be used in a micro-grid [4].

The micro-grids are composed by the distribution network that can be supply energy and operate in an independently way [5]. In addition, it is a hybrid system consisting of a set of conventional generators or renewable ones, operating as processes able to provide continuous energy to the electricity grid [6]. The current tendency is to project this kind of systems with renewable sources to provide the 80 to 90 percent of the energy needs in remote or non-connected areas to the main electrical grid, so in [7], the use of a different medium scale sources and small distance distribution, such as wind and solar energy close to the loads, reduces the local storage requirements and energy losses.

In order to implement a set of solar panels in a smart grid as renewable energy system, it is necessary to perform a static analysis of the maximum solar irradiance that allows determined the position values of the panels to obtained the most possible amount of energy to supply the actual loads, that are around 7KW necessary in the application at the Nueva Granada Military university campus. The implementation of the photovoltaic solar system will be complemented with a tracking solar position system using photosensitive resistances, embedded system and stepper motors. Considering that the system must be switched off at night or cloudy days, besides the perpendicular location to the incision of the sunlight in the development system [8]. Considering the previous information, this work shows the mathematical model of a photovoltaic system, beside the implementation of fuzzy logic in a control for solar position tracking; the system will determine the ideal position using the maximum possible irradiance using a pyrometer. As a main contribution: this article presents the results of comparison system efficiency between a static configuration of the panel and the fuzzy control solar tracking system, proposed in this work.

II. Mathematical Model

The mathematical model of complete system was divided in two parts: first was the photovoltaic panel model and the second was mechanics system, which was representing by DC motors model. Combinations of these parts make the solar tracking system. A photovoltaic module is represented as two electrical circuit nodes with the sunlight as current source (photocurrent), beside it use a diode and two resistances, as is shown in the Fig. 1a.

Manuscript received November 6, 2015; revised March 17, 2016.

doi: 10.18178/ijoee.4.2.133-136

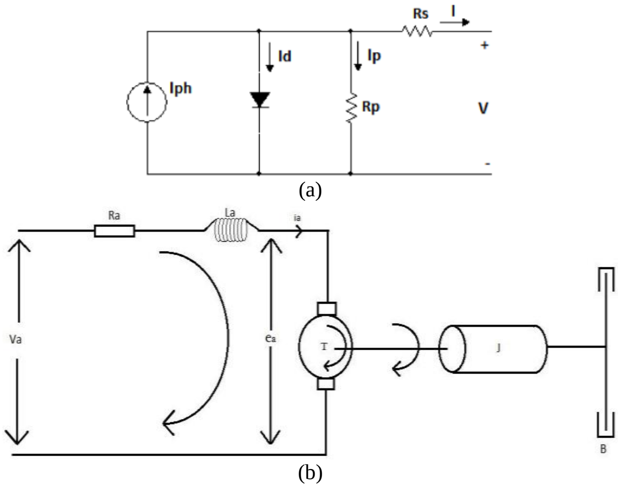


Figure 1. Simplified models: a) photovoltaic panel b) DC motors.

According to the model depicted in the Fig. 1a, the equation that defines the photovoltaic model dynamics in terms of an output current through Kirchhoff's current law is shown in (1).

$$I_p = \frac{V + R_s * I}{R_p} \quad (1)$$

The current through the parallel resistance can be defined by Ohm law (2), and the photocurrent as a relative value of the reference and the variation produced by the cells temperature is shown in (3).

$$I_{ph} = \frac{G}{G_{ref}}(I_{ph,ref} + \mu_{sc} * \Delta T) \quad (2)$$

$$I = I_{ph} - I_d - I_p \quad (3)$$

where, V is the diode voltage, G is the irradiance, G_{ref} is the irradiance at Standard Test Conditions (STD), ΔT is the temperature change and μ_{sc} is the temperature coefficient of short circuit current. And the final current is given by the Shockley ideal diode (4).

$$I_d = I_o\left[exp(\frac{V + I * R_s}{a})\right] \quad (4)$$

$$| \quad a = A * N_s * V_T$$

where A is the ideal factor for monocrystalline silicon cells, N_s is the number of photovoltaic cells connected in series and V_T is the thermal factor. Therefore, the (1), (2), (3) and (4) are used to obtain the photovoltaic module output current. The photovoltaic parameters to implement are given to a Bosch c-Si M60-M260 photovoltaic cell.

The second part (mechanics system) consist in a motor that allows move a photovoltaic system in order to obtain the maximum energy using the irradiance that depends of the position and sunlight parameters. In order to get the ideal mathematical representation is necessary use the diagram shown in the Fig. 1b, where the mathematic model of the motor, is necessary take into account a system make by an electrical and mechanical part [9]. In this case are represented by (5) and the coefficients are obtaining of [9].

$$\begin{aligned} v_a(t) = {} & \frac{R_a * J}{K_m} * \frac{dw(t)}{dt} + \frac{R_a * B}{K_m} * w(t) + \frac{L_a * J}{K_m} \\ & * \frac{d^2 w(t)}{dt} + \frac{L_a * B}{K_m} * \frac{dw(t)}{dt} + K_e * w(t) \end{aligned} \quad (5)$$

III. Fuzzy Logic Control with Solar Tracking System

To develop a fuzzy controller, it's necessary to define the input and output variables in the system. The output is determinate by the maximum forward move of ten degrees that generates a soft and constant behavior in the photovoltaic move to arrive to the desire points in an appropriate way [10]. While the input is defined by the error values taken between the current angle in the system and the desire angle given by the maximum irradiance. Considering the variables to handle in the input and the output signals in the controller. The controller uses the clusters structure. In the Fig. 2a, the input variable, is defined by five clusters, four of them are trapezoidal and one triangular, in the ranges of values from -90 to 90, due a study of case the variations are between 45 and 135 degrees that determinate a maximum difference of 90 degrees.

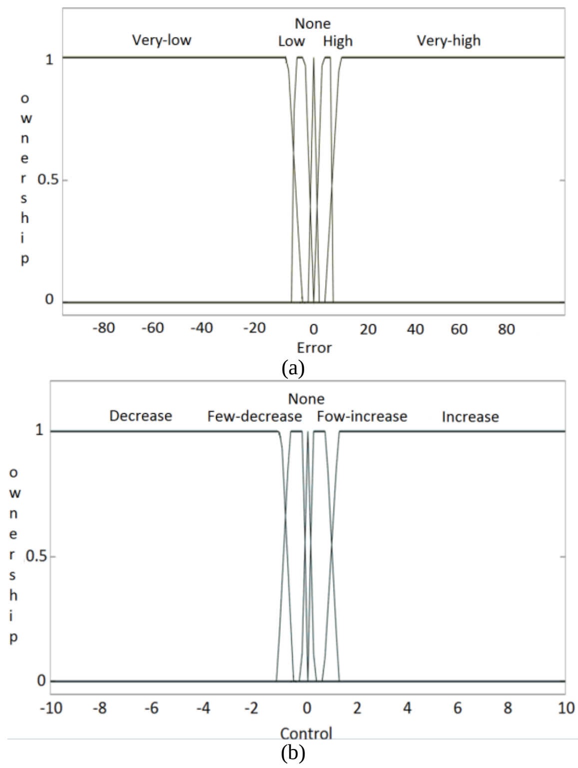


Figure 2. Fuzzy sets: a) inputs, b) outputs.

In the controller output variable case, the Fig. 2b shows five clusters, four of them are trapezoidal and the last one is triangular, it defines a range of values from -10 to 10, considering an increase in the controller output signal when the input is positive it rises the system position, while if the system error is negative then the controller output has to decrease in angle until arrive to the reference panel position. When the variables fuzzy sets are defined, it proceeds with the rules that define the relationship between the error and control signals, considering behaviors when the error is negative then the controller has to handle a decrement signal until the system fits an error of zero. The rest of the rules are designed to define the total behavior of the controller. Then, it proceeds with the inference system, which helps to get the membership in the final clusters when the rules are applied; sequentially it made the defuzzification by centroid method [11].

The Fig. 3 shows the general diagram of the simulation made in simulink® of Mathworks. In this diagram the input is the position of the sun trajectory obtained in the dates by the weather station, the simulation uses a random day. The structure of the fuzzy control has a general form of the close loop control, where the input to the controller is the error signal, and output is the voltage used by the reorientation mechanic system. In the simulation is computed the irradiance obtained by the solar panels according to the inclination angle of mechanic structure, irradiance of weather station and position of sun in the day. To obtain the total power the irradiance is introduced in the photovoltaic solar panel model to produce the current for the DC micro grid.

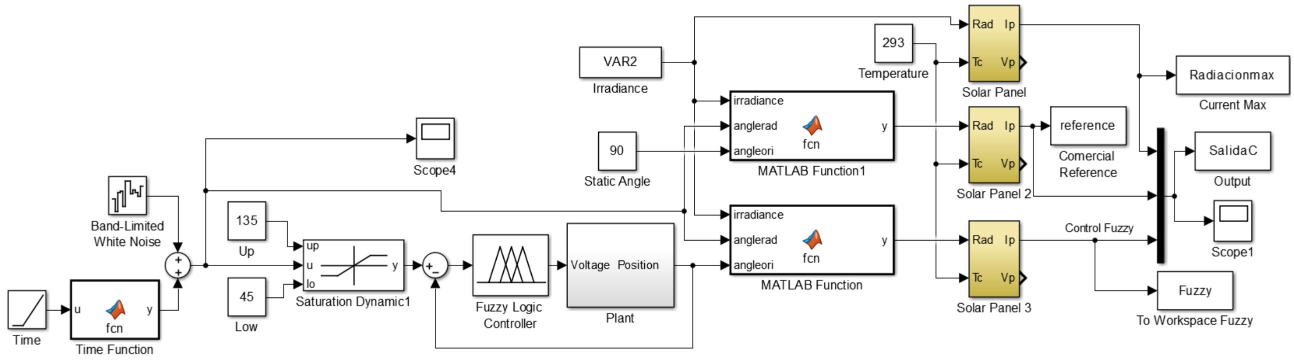


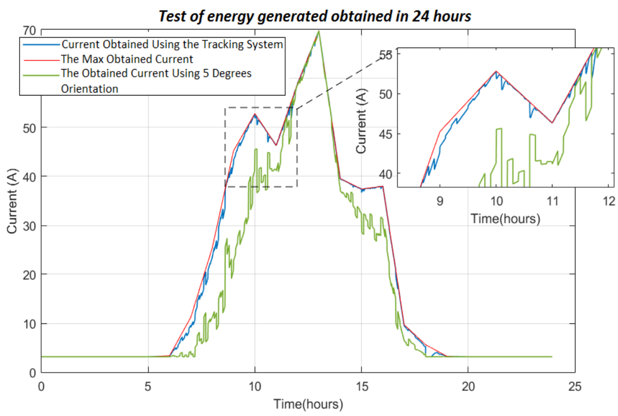
Figure 3. Schematic of solar tracking system using fuzzy control.

IV. Results

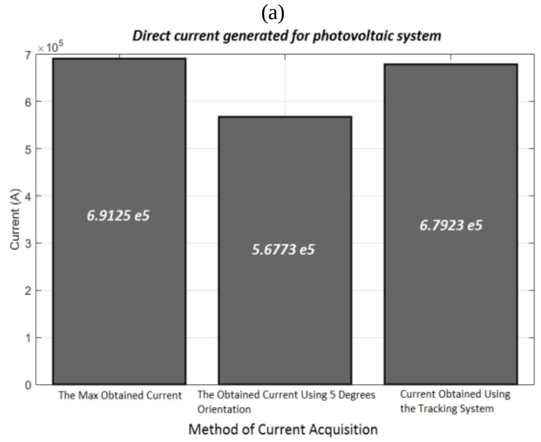
The result of the simulation is that the tracking fuzzy controller always tends to follow the maximum theoretical transfer of irradiance to the photovoltaic panel that occurs when the position of the sun and the photovoltaic panel are perpendicular (90 degrees). The Fig. 4a shown the test between static position of structure (the second bar), the maximum irradiance that can be obtained (the first bar) and the solar tracking Fuzzy controller (the third bar), where the total current generated with the static position of structure correspond to 82,13% and the solar tracking with a fuzzy controller obtained a 98,26% of the maximum current that can be obtained, this results are shown in the Fig. 4b.

V. Conclusion

According with the results obtained by the solar tracking system using a fuzzy controller is possible to determine the it is an efficient solution, because it takes almost the maximum energy that can be generated by photovoltaic panel, if the development is used into DC smart grid it can improve the efficiency in 16% of the extra current in a random day (view the Fig. 4a). In a specific application it helps to save energy consumed by traditional loads. Also it is possible to determine that the control signal depends on the area of the fuzzy sets (trapezoid, quadrate, and triangle), intersections and number of sets of the input and output, so it's necessary to stabilize the correct range of the variable to work properly in a solar tracking system.



(a)



(b)

Figure 4. Comparative results between static position, maximum transfer of irradiance and solar tracking Fuzzy control for photovoltaic panels. a) Graphic of current obtained in test. b) Bar comparative graphic of total current obtained in test.

ACKNOWLEDGMENT

This work was financially supported by Nueva Granada Military University, through the project ING-1577 titled “Development, automation and control of a hybrid renewable resources plant” (2014-2015).

REFERENCES

[1] A. L. Rogers, J. F. Manwell, and J. G. McGowan. (2009). *Wind Energy Explained*. [Online]. Available: http://onlinelibrary.wiley.com/book/10.1002/9781119994367

[2] Global Wind Energy Council, “Global wind report: Annual market update 2013,” Brussels, Belgium, 2014.

[3] K. Uchida, T. Senjyu, N. Urasaki, and A. Yona, “Installation effect by solar heater system using solar radiation forecasting,” in *Proc. Transmission Distribution Conference Exposition: Asia and Pacific*, 2009.

[4] K. Shah, P. Chen, A. Schwab, K. Shenai, S. Gouin-Davis, and L. Downey, “Smart efficient solar DC micro-grid,” in *Proc. IEEE Energytech*, 2012.

[5] A. S. Dobakhshari, S. Azizi, and A. M. Ranjbar, “Control of microgrids: Aspects and prospects,” in *Proc. International Conference on Networking, Sensing and Control*, 2011, pp. 38-43.

[6] J. P. Fossati, “Literature review of microgrids,” *Memoria de Trabajos de Difusión Científica y Técnica*, no. 9, pp. 1-20, 2011.

[7] K. Strunz, E. Abbasi, and D. N. Huu, “DC microgrid for wind and solar power integration,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 2, pp. 115-126, 2014.

[8] F. R. Liu, L. Xiao, and W. J. Li, “The design of automatic tracking system for solar cell,” in *Proc. 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce*, 2011.

[9] E. Xargay and R. C. Castelló, “Modelado de una planta diseñada para ilustrar el principio del modelo interno,” Barcelona, 2004.

[10] T. A. Vidal, “Introducción a la Lógica Difusa,” 2014.

[11] S. Halgamuge, T. Runkler, and M. Glesner, “On the neural defuzzification methods,” in *Proc. Fifth IEEE International Conference on Fuzzy Systems*, 1996.

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