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GAINS OBTAINED IN HYBRID SYSTEMS OF ENERGY GENERATION SOLAR PHOTOVOLTAIC AND WIND POWER FOR RURAL ELECTRIFICATION WITH THE USE OF FUZZY LOGIC CONTROLLERS BASED

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Abstract: This paper presents the gains from the application of fuzzy logic control in a hybrid power generation wind-photovoltaic for small rural. The use of alternative and renewable energy has been increasingly discussed in all sectors of society. The interest in these sources of energy, alternative and renewable, is of fundamental importance, both in terms of the shortage, as the price of oil, and the environmental issues involved in the use of renewables. The variability in the intensity of wind and solar energy can be circumvented by complementation between a source and one or more stability set by the generation system. When using a fuzzy control system, is expected to reach the point of maximum power generation, transferring substantially all the energy generated to load and / or batteries when their use is not immediate. The operation of the fuzzy controller was simulated using the MATLAB® software, through the *Fuzzy Logical Toolbox*. It was

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found through simulations that this model can be used efficiently in hybrid power generation, providing better utilization of alternative energy sources.

Key words: *fuzzy logic, photovoltaic solar energy, wind energy, rural electrification.*

INTRODUCTION

Global warming, fossil fuel depletion, the growth of large new economies, and the latent risks of terrorism and international conflict are weaving an uncomfortable stranglehold on the world's energy outlook.[1]

The sun as a source of heat and electricity is one of the most promising sources of energy to meet the energy crises of this millennium, since there are several technologies available for the utilization of this energy source. Energy from the sun is responsible for numerous natural phenomena that occur on this planet, including the formation of zones of high pressure responsible for the flow of wind, for example.[2]

There are various energy alternatives, which may be non-renewable options such as clean coal, nuclear, and renewable options such as hydroelectric, biomass / biofuels, geothermal, thermal energy conversion, wave, tidal, wind, solar, and other .[3]

Figure 1 shows a comparison between booked renewable and nonrenewable energy. Total recoverable reserves are shown for non-renewable resources. The annual potential is shown for renewables. The volume of each bead is the total quantity of energy involved.[1,3]

About 1 to 2 per cent of the energy coming from the sun is converted into wind energy. That is about 50 to 100 times more than the energy converted into biomass by all plants on earth.[4]

Solar and wind are renewable and non-polluting, and is optional alternative resources for power generation. Many countries, with wind speeds averaging in the range of 5 to 10 ms^{-1}, are using systems conversion of wind energy into electrical energy (wind generators), in an effort to minimize their dependence on fossil fuels that are not renewable.[5]

Currently thousands of photovoltaic systems in regions with average daily solar radiation in the range 3-6 $kWhm^{-2}$, are installed around the world, providing small powers, independent applications across individual systems or in isolated regions.[6]

Secondly, a common drawback for wind and solar energy resides in dependence on climatic variations. Both forms of energy, regardless if used, would have to be oversized to become reliable, resulting in a total cost much higher. However, a combination of solar and wind power generation system in a hybrid individual can mitigate the fluctuations of these forms of energy, increasing global energy production and significantly reducing the need for energy storage. Due to this combination, the overall expenditure for autonomous systems can be drastically reduced to a large number of cases.[7]

Mathematical models implemented in computer programs have shown significant results in nonlinear systems and complexes in several areas, including the control theory model for recognition and decision analysis. These programs are able to resolve issues that the classical models, as a rule, are not able to do so. They are called intelligent systems, among which stand out the Neural Networks and Fuzzy Logic.[8]

Information vague, uncertain, qualitative, verbal communications, ability to learn and formulate strategies of decision making are human characteristics. Therefore, the fuzzy theory is often referred to as "smart", due to the fact simulate human intelligence.[9]

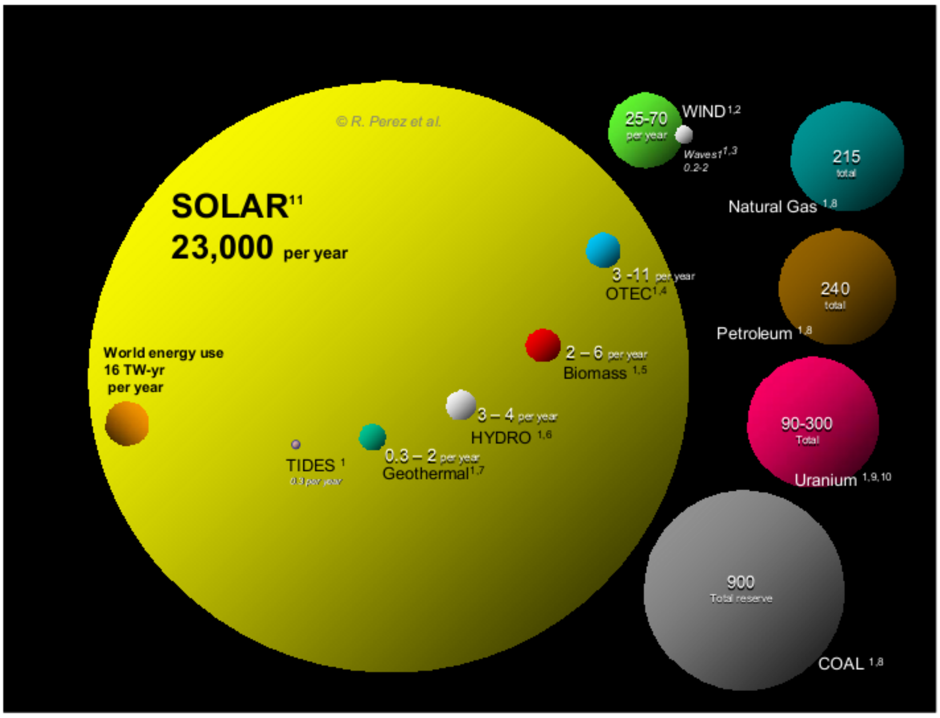

Figure 1. Comparing finite and renewable planetary energy reserves (Terawatt - years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables [1,3]

In this context, this paper aims to describe how the use of fuzzy logic for controlling a hybrid power generation wind-photovoltaic small in the energy supply required by a resident of a rural property, you can make the most energy to produce electricity.

MATERIAL AND METHODS

The work was developed in the Laboratory of Rural Empowerment, Lageado Experimental Farm, located in Botucatu, Brazil, with geographical location defined by coordinates: 22°51' South Latitude (S) and 48°26' West Longitude (W) and an average elevation of 786 meters above the sea level. The monthly average wind speed at 10 m height is 3,1 ms^{-1} and solar global monthly average daily rate is 4772 Whm^{-2} .[10]

To generate electricity from solar energy using three photovoltaic modules I-100 Isofoton the rated power of 100Wp each, totaling 300Wp. [11,12]

For the generation of electricity from wind energy available on site, we used a wind turbine AIR-X model of rural SOUTHWEST WINDPOWER rated power of 400W and has an internal charge controller. This turbine was mounted on a tower 14 meters high.[12]

The aero-generator and the photovoltaic modules that constitute the hybrid system can be seen in Figure 2.

Figure 2. wind turbine and photovoltaic hybrid system

Meteorological data and electrical data

Tables 1 and 2 are examples of weather data collected and calculated [12,13,14].

Table 1. Characteristics of wind speed and wind power from 01/07 to 31/07/2005

Day / Month	*Daily Average Wind Speed (ms^{-1})*	*Total Wind Energy Available Daily (Wh)*
1/7	*3,5*	*2,2*
2/7	*2,6*	*19,5*
3/7	*4,5*	*420,5*
4/7	*2,8*	*4,7*
...	...	...
28/7	*0,0*	*0,0*
29/7	*3,0*	*29,7*
30/7	*2,6*	*111,2*
31/7	*2,1*	*22,5*

It is observed that there is a direct and proportional to the wind speed at the wind energy available. This is due to the intermittent characteristic of wind, gusts and other factors that cause not all will generate wind energy. Another important condition which can limit wind generation is that the battery is charged. If so, then the turbine automatically stops working. This fact is one of the justifications for the use of more batteries and management through a fuzzy controller.

Examples of data from electricity generation and performance of the hybrid system will be the period September 2004 to August 2005, are shown in Table 3. [12,14]

Table 2. Characteristics of solar irradiance and solar energy from 01/07 to 31/07/2005

Day / Month	Daily Average Solar Irradiance ($W.m^{-2}$)	Total Solar Energy Available Daily (Wh)
1/7	610,3	13.293,2
2/7	582,8	12.693,1
3/7	275,3	5.698,0
4/7	164,0	3.600,8
...	...	...
28/7	463,8	10.770,5
29/7	626,1	14.426,3
30/7	626,2	14.427,4
31/7	617,2	13.886,4

Table 3. Summary of electricity generation by wind-PV hybrid system in the period from 01/07 to 31/07/2005

Day / Month	Solar + Wind Available (Wh)	Total Daily Energy Generated by Hybrid System (Wh)	Efficiency Hybrid System (%)
1/7	13.295,4	1.066,6	8,0
2/7	12.712,7	1.064,4	8,4
3/7	6.118,5	511,9	8,4
4/7	3.605,4	343,0	9,5
...	...	...	...
28/7	10.770,5	844,7	7,8
29/7	14.456,0	1.169,0	8,1
30/7	14.538,7	1.048,2	7,2
31/7	13.909,0	1.095,3	7,9

To simulate the energy gain by the proposed system was regarded as a condition, the higher throughput of the system during the period of data collection which was from September 2004 to August 2005. Analyzing data from the cited period arrives to the highest value of daily income that was 12.8% and was verified on 22/12/2004.

Modeling of fuzzy controller for hybrid system

The modeling strategy for the controller is shown in Figure 3.

In MATLAB® software through the *Toolbox Fuzzy Logical*, was held to build the fuzzy inference system.

The same software defined the membership functions associated with input variables (Wind Speed, Solar Radiation and Charge Battery - A, B and C) and output variable (Charge Battery Bank) fuzzy controller. The map of rules was drawn up identifying all its details and features, and will assist in identifying the decisions to be taken during the operation of the process.

The final step consisted in performing the defuzzification which was translated into a discrete value the result of linguistic variable output controller that was inferred by fuzzy rules. Generally speaking, this process is nothing more than an inverse transformation that translates the output of fuzzy domain to the discrete domain.

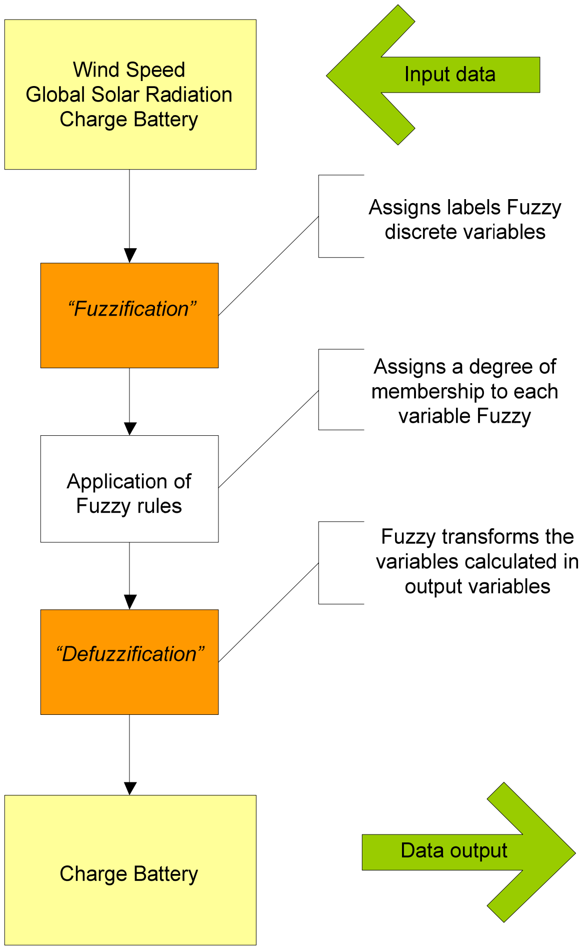

Figure 3. Fuzzy model for a control system for energy generation hybrid solar-photovoltaic and wind

RESULTS AND DISCUSSION

As a result of the proposed fuzzy control system, has been gaining energy generated using the control that enables the use of efficient alternative energy sources (solar photovoltaic and wind) and also manage the storage of energy not used by the loads, using a battery bank. Also as a result, has been the development of a methodology to design a controller using fuzzy logic system to manage a hybrid power generation.

Table 4 is presented, for the period September 2004 to August 2005, the generation of electricity with and without using fuzzy controller, and the energy gain and percentage of gain when using the fuzzy controller. [14]

Table 4. Summary of electricity generation by wind-PV hybrid system with and without fuzzy controller, from September 2004 to August 2005 and the gain and percentage gain when using the fuzzy controlled

Day / Month	Total Daily Energy Generated by Hybrid System (Wh)	Energy Generated by the Hybrid System with Fuzzy (Wh)	Gain of Energy (Wh)	Percentage Gain (%)
Sep/04	25.533	38.190	12.657	33,1
Oct/04	27.884	41.968	14.083	33,6
Nov/04	27.370	40.188	12.818	31,9
Dec/04	27.249	41.353	14.104	34,1
Jan/05	26.441	36.740	10.300	28,0
Feb/05	27.541	41.678	14.137	33,9
Mar/05	27.815	43.130	15.315	35,5
Apr/05	29.901	44.322	14.421	32,5
May/05	30.276	41.201	10.925	26,5
Jun/05	29.598	39.685	10.087	25,4
Jul/05	30.391	46.029	15.638	34,0
Aug/05	30.732	43.777	13.045	29,8
Annual	340.731	498.262	157.530	31,6

Considering the total analyzed period, the total energy generated in the period is 341 kWh to 498 kWh, something around 157 KWh of energy gain generated in the period, representing 31.6% gain. This gain can be seen in Figure 4.

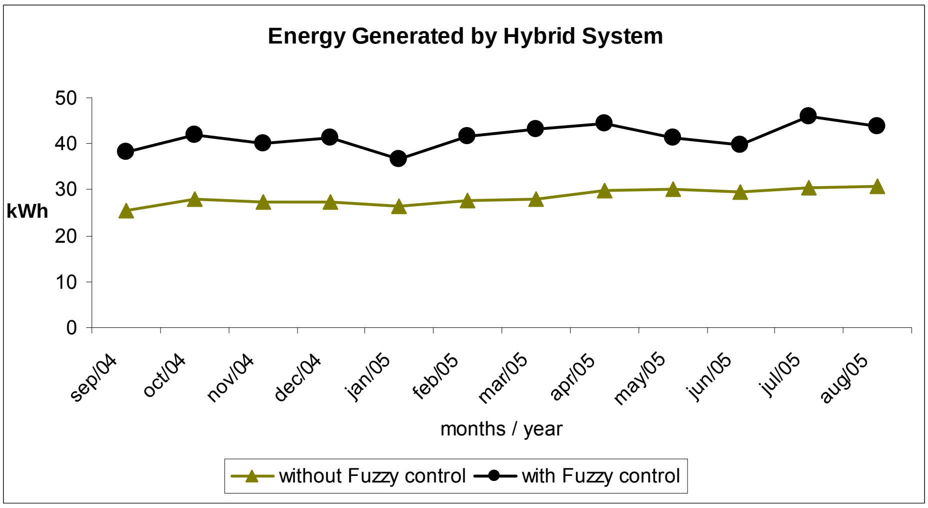

Figure 4. Energy generated without the Fuzzy controller and Energy generated by the Fuzzy controller

CONCLUSIONS

Considering the various factors that influence the efficiency of generation hybrid (solar-photovoltaic and wind), using a fuzzy control system for managing and using additional batteries, represents a significant increase in use of renewable energy.

The great advantage of using fuzzy theory is the ability to model and manipulate mathematically vague, imprecise and intermittent nature of human language, and that are provided by experts, not mathematicians, to characterize the processes studied.

This manipulation can be done easily from the junction of variables chosen to model mathematically the proposed system, when the implication of independent variables is set dependent on a set of linguistic rules based on knowledge from experts.

The gain in power generation was estimated at 31.6% in the analyzed period and suggests that beyond simply using alternative sources of energy, we can also optimize its use, extracting the maximum energy available.

What we could see is that the fuzzy control, which is one of the most widely used parts of the theory of fuzzy sets, enables control and manage a hybrid power generation satisfactorily.

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DOBICI DOBIJENI U HIBRIDNIM SISTEMIMA ZA PROIZVODNJU STRUJE U POLJOPRIVREDNIM OBJEKTIMA IZ SOLARNE ENERGIJE I ENERGIJE VETRA KORIŠĆENJEM KONTROLERA NEPRECIZNE LOGIKE

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Sažetak: Ovaj rad prezentuje dobitke dobnijene korišćenjem kontrolera neprecizne logike u hibridnim sistemima za proizvodnju struje iz solarne energije i energije vetra za male poljoprivredne objekte. Korišćenje alternativnih i obnovljivih izvora energije se sve više primenjuje u svim oblastima društva. Razumevanje alternativnih i obnovljivih izvora energije je od fundamentalnog značaja, kako u pogledu ograničenja kao što je cena nafte, tako i u pogledu uticaja na životnu sredinu. Variranje u intenzitetu vetra i solarnoj energiji se može izbeći putem dopunjavanja između izvora i jednog ili više stabilnih uređaja podešenih od strane generatora. Kad se koristi kontroler neprecizne logike očekivano je da sistem postigne tačku maksimalne proizvodnje struje i da postepeno prebaci svu proizvedenu energiju ili potrošačima ili baterijama tokom perioda niske potrošnje. Rad kontrolera neprecizne logike je simuliran korišćenjem programa MATLAB® kroz *Fuzzy Logical Toolbox*. Kroz simulaciju je utvrđeno da se ovaj model može uspešno koristiti u hibridnoj proizvodnji struje kao i da pruža mogućnost za bolje korišćenje alternativnih izvora energije.

Ključne reči: *neprecizna logika, solarna energija, energija vetra, elektrifikacija poljoprivrenih objekata*

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