International Journal of Applied Mathematical Research, 5 (4) (2016) 176-181

International Journal of Applied Mathematical Research

Website: www.sciencepubco.com/index.php/IJAMR
doi: 10.14419/ijamr.v5i4.6720
Research paper

Fuzzy logic application in the evaluation of performance of a prototype vehicle powered from solar energy and water electrolysis process

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Abstract

The purpose of this paper is to evaluate the performance of a prototype vehicle that uses a reversible fuel cell capable of producing and storing hydrogen and oxygen by breaking the water molecule - the electrolysis process, made possible with the use of solar panels. The vehicle shown only uses two main sources of energy: solar and hydrogen cells, both clean and renewable energy sources. Water is the only residue generated. The Fuzzy Logic was used in the establishment of linguistic variables and on the composition of inference rules based on power, solar panel area and solar irradiation. The Fuzzy Logic provides a method of translating verbal, vague, imprecise and qualitative expressions, common in human communication in numeric values. This enables the conversion of the human experience in a way understandable by computers. Thus, the technology made possible by the fuzzy approach has a practical value. In view of the severe environmental degradation in which the planet is going through and the scarcity of energy sources, especially fossil fuels, one of the great challenges of the scientific community is to develop new technologies that use clean and renewable energy sources, that are economically viable and promote sustainable technologies and processes.

Keywords: *Automobile Industry; Fuzzy Logic; Renewable Energy; Sustainability.*

1. Introduction

According to Vitousek apud Pompelli et al [12], the evolution of man is directly proportional to the increasing demand of natural resources. With the industrialization of society, energy usage has grown exponentially.

In accordance with Pompelli et al [12], the first source of energy used by mankind was the fossil energy, used to the present days. This non-renewable type of energy includes petroleum, coal and natural gas. With the increase of population, the usage of this type of energy has also increased. As a result, fossil fuels have quickly and intensely changed human society, increasing the concentration of gases that alter the energy balance on Earth.

To Réquia Jr and Abreu [14], the high accumulation of pollutants in the air generates significant impacts to the environment and human health. In accordance with Wang et al apud Réquia Jr and Abreu [14], the vehicles' fuel burning is the biggest agent in the issuance of air pollutants. Moreover, the quality of fuel used in vehicles is directly related to the concentration of pollutants emitted. As registers Escobat et al apud Pompelli et al [12], fossil fuels cause great detriment to the environment through global warming and the greenhouse effect, causing changes in the intensity and distribution of rainfall, rising sea levels, among other phenomena.

In "Os Transportes e o Meio Ambiente" ("Transports and Environment"), produced by the Brazilian's Ministry of Environment (MMA) [10], it is said that the car engine launches in the air a lot of toxic substances. When gasoline is burned in the engine, it causes the emission of gases and particles that disperse in the air, causing damage to people's health and to the environment. The usage of new technologies in the manufacturing of cars and the improvement of fuels reduced the emissions from gasoline engines. Those solutions, however, do not reach the cause of the problem and supports the dependence on non-renewable source of energy, harmful to people's health and to the environment.

In June, 2016, the Brazilian's Ministry of Mines and Energy (MME) [11], along with the Brazilian's Energy Research Company (EPE) [11], released the National Energy Balance, with last year's data. It was observed that in 2015, total air emissions related to the Brazilian energy matrix completed 462.3 million tons of carbon dioxide (CO2), with the majority of this total - 194.0 million tonnes - generated in the transportation sector. The Brazilian's National Confederation of Transport (CNT) [4] released on July 11th, 2016, an Environmental Report, with some important data to the Brazilian scene. It was reported that the road transport sector participates in 7.8% of total CO2 emissions in the atmosphere.

According to Nass et al apud Pompelli et al [12], facing this scenario, governments around the world are looking for new sources of energy that are renewable and environmentally clean. Can be found solar energy generated from sunlight, wind power generated by the wind, biofuels generated from different kinds of raw materials (such as sugarcane, oilseed plants, forest biomass and other organic materials), among others.

To Inatomi and Udaeta [8], sustainability is an important issue currently because of the awareness of academics that environmental impacts stimulated by humanity trying to develop their coun-

tries can cause reversible and irreversible damage to species and to the world. Sustainable development has become inevitable throughout the world, as one of the chances for the future generations to survive. For this to happen, life on Earth needs natural resources so they can stay balanced. Mankind needs energy, but it is necessary to find ways of energy that does not wear out the environment.

2. Hydrocar

2.1. Energy from water

According to Queiroz et al [13], the increase in electricity demand for various purposes has generated the need for new investments to fill the gap. Hydropower is one of the most used alternatives for generating electricity. This energy is produced by the force caused by the movement of water. This movement causes the transformation of kinetic energy into electrical energy, in hydroelectric plants. However, despite the abundance of water resources in the world, the creation of hydroelectric plants generates environmental and social impacts.

Working in an integrated way, the hydraulic power plants consist of dam, powerhouse, spillway and capture and feedwater system. Dams - barriers made to retain large amounts of water - interrupt the normal course of the river and deflect it to a different location, forming large water storage tanks and allowing the formation of large falls. The waterfalls produce the force used to move turbines and activate the electric generator. (PANZERA, GOMES and MOURA apud QUEIROZ et al [13])

Hydroelectrics, by using water as an energy source, can be considered a form of clean energy. But it is not: the dams can not be conceptualized as a positive ecological solution. The construction of hydroelectric dams affect the environment: causes flooding in huge green areas, interferes with the flow of rivers, destroys plant species, affects the wildlife and reaches human occupation. The flooding of forests covers up vegetation, which decomposes, changing the biodiversity and causing the release of methane, one of the gases responsible for the greenhouse effect and the destruction of the ozone layer. (INATOMI and UDAETA [8])

According to Inatomi and Udaeta [8], with the construction of hydroelectric plants, hydrology is impacted by changing the current flow, extending the riverbed, flow change, higher water table and generation of wetlands. The climate is affected by temperature increases and humidity, precipitation and winds. In seismology, it causes land tremors. In flora, causes loss of soil and trees, high concentrations of organic matter and decreased oxygen. The wildlife is impacted by the loss of biodiversity and relocation of animals that lose their natural habitat.

The solution to this problem can be the usage of water as an energy source, but through another process. One of them being the implementation of hydrogen cells. The production of hydrogen through water has generated great interest from the scientific community in recent years. The hydrogen production occurs through the water electrolysis process, with the breaking of the water molecule - whose representation is H2O - into hydrogen and oxygen gases. (BOTTON and MEDEIROS [1])

According Botton and Medeiros [1], adding an electrolyte in the water makes of it a conductor of electrical energy, enabling the process of electrolysis, which is given by passing direct current through the water. The electric charge breaks the chemical bond between the hydrogen and oxygen atoms, separating the atomic components and creating charged particles - ions. Ions are formed in two poles: the anode (positively polarized) and the cathode (negatively polarized). Hydrogen focuses on the cathode and the anode attracts oxygen.

The water electrolysis process is the source of energy used for the operation of the prototype studied in this paper.

2.2. Hydrocar operation

Hydrocar, developed by Horizon Fuel Cell Technologies, is a futuristic prototype car, which operates entirely through the clean fuel produced by a reversible fuel cell. This cell converts water into hydrogen by the electrolysis process. The energy needed for the electrolysis process to happen is given by a solar panel.

In Hydrocar's User Manual [7] it is said that hydrogen is the most abundant element to be found on Earth and the one that carries more energy per unit of weight. After being used, it can be converted many times back into energy. It can be produced locally and in an unlimited quantity. When consumed in the fuel cell, hydrogen results in electricity and water. The water produced can then be used to produce hydrogen and oxygen repeatedly, causing the cycle to be continuous and natural, with no toxic emissions.

Hydrocar's operating procedures start with the assembly of the vehicle, following the instructions found in the product's User Manual. After reading and following the assembly steps, the structure of Hydrocar is complete and will be equal to what can be seen below in Figure 1 and Figure 2.

Fig. 1: Top View from Hydrocar.

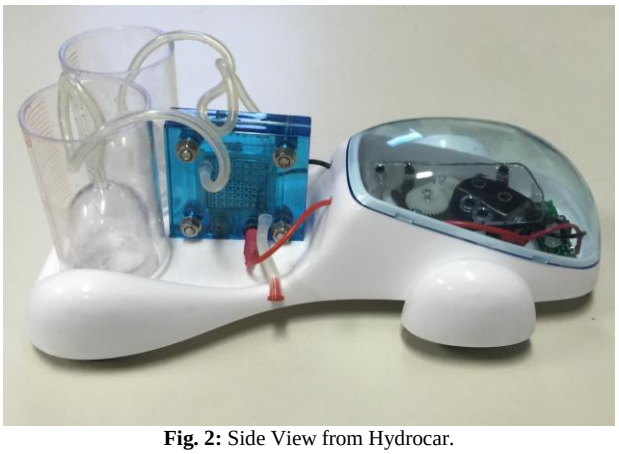

Fig. 2: Side View from Hydrocar.

Through the images, it can be observed that the structure of the vehicle is formed by its front chassis, where the motor of the car is located, by a reversible fuel cell, in the center of the structure, from where two long and two short tubes come out. Long tubes are connected to the internal and external cylinders: an internal cylinder and an external for hydrogen storage; an internal cylinder and an external storage for oxygen. The inner cylinder is coupled to the outer cylinders. In addition, there are the connectors that make the car engine connection with the fuel cell. The connectors and the ends of the short tubes are represented by the colors black and red; such colors are related to gases subsequently produced: hydrogen is represented by the color black and oxygen is represented by the color red.

After finishing the assembly of Hydrocar structure, it is started the process of adding water to the procedure. Water should fill the two outer cylinders to the upper mark of 20 centimeters. To assure good conductivity, it is necessary to moisturize the fuel cell. For this, a syringe with water is used and placing the tip of the syringe into the red short tube - the oxygen one -, water is inserted into the fuel cell until filling it. It is recommend to leave the fuel cell moisturizing for ten minutes.
As seen in the previous section, electrolysis is the process responsible for breaking the chemical binding of water and separating oxygen from hydrogen. For the operation of Hydrocar, electrolysis is performed by solar energy. According to Hydrocar's User Manual [7], the vehicle uses a photovoltaic solar cell for the electrolysis process, in order to capture renewable energy from the sun. The solar panel is coupled to the fuel cell by separate connectors. After that, the solar panel is placed in direct sunlight. A few minutes later, hydrogen and oxygen gases are produced in the inner cylinder. Within ten minutes, the internal hydrogen cylinder is filled. The electrolysis process is complete when the water in the inner cylinders is completely displaced in a 2: 1 ratio - two parts of hydrogen to one part of oxygen. Therefore, the hydrogen cylinder will have more gas. When bubbles come out of the cylinder and rise to the surface of the water, the solar panel must be disconnected from the fuel cell. The energy of hydrogen is then stored in the reversible fuel cell. The structure of the solar panel coupled with the prototype can be seen in Figure 3.

Fig. 3: Solar Panel Coupled with Hydrocar.

Thus, after the assemble of the structure and completion of the electrolysis process, the next step is to run the vehicle. For that, the connectors leaving the chassis must be plugged into the corresponding colors on the fuel cell. Once they are connected, blue LED lights on front of the vehicle will start to flash. The car will run and find its way through a surface, even deviating from possible obstacles. Hydrocar will run on its own until all the hydrogen gas stored in the inner cylinder is consumed.
Proven the functionality and the efficiency of Hydrocar - the vehicle that works only with hydrogen produced through the use of a fuel cell, the process of electrolysis and solar energy - it will be studied and analyzed the performance and the performance of the vehicle running under this technology.

3. Fuzzy logic and its applicability in hydrocar

3.1. Fuzzy logic

According to Cosenza et al [5], fuzzy logic was a breakthrough for Mathematics. Filed by Engineer and Professor Lotfi Zadeh, in 1965, such logic approaches sets nor entirely true nor entirely false: it is a mathematical theory that expresses uncertainty.

In accordance with Zadeh [16], a fuzzy set is a class of objects with a continuum degree of membership, such a set being characterized by a membership function that assigns to each object a note of membership ranging between zero and one.
Cloudiness is the kind of ambiguity found in the definition of a concept or a word. Fuzzy logic helps in modeling the imprecise reasoning, which is an intrinsic aspect of man. Fuzzy logic concepts use linguistic terms instead of numbers, changing the way that a man thinks into a control systems of rules. (CHAMOVITZ and COSENZA [3]; ZADEH apud COSENZA et al [6]; LIBRANTZ et al [9])
To Cosenza et al [5], fuzzy logic used the mathematical concept of defined to undefined, allowing better presentation of vague values and supporting qualitative modeling of linguistic variables, assimilating verbal expressions that summarize emotions and thoughts.
According to Shaw and Simões [15], the characteristic of fuzzy logic is to represent an innovative way of handling inaccurate information, providing a method to translate verbal, vague, imprecise and qualitative expressions and converting human experience in an understandable way for computers. The fuzzy logic is useful also in decision-making tasks where individual variables are not defined in exact terms.
In the next item it will be addressed the practical application of fuzzy logic in a software. For the operation of such a program, it is necessary to stipulate rules of inference, between the steps of fuzzification and defuzzification. These three processes are actually basic principles of fuzzy logic and will be described below.

3.1.1. Inference rules

To Shaw and Simões [15], the logical implication is significant factor in the thinking of human beings, represented in formulating connections between cause and effect or condition and consequence. These cases are followed by rules of inference, consciously or unconsciously, where: IF CAUSE1 = A and CAUSE2 = B then THEN effect = C, A, B and C being sets. In fuzzy logic, there is a reasoning with numbers and fuzzy sets, and the claims can be considered as practical rules.

3.1.2. Fuzzification

The operation of the activities performed by man requires an approximation of data and sensory information through vague or inaccurate terms. The human brain encodes inaccuracies through sets and fuzzy numbers. There is no need to give accurate and defined values to a variable: the information can be classified as a whole. The variable speed, as an example, may be classified into low, medium and high. These sets represent fuzzificated values of the exact speed values. (SHAW and SIMÕES [15])

3.1.3. Defuzzification

According to Shaw and Simões [15], the human being is capable of working with values or uncertain characteristics - considered fuzzificated. However, machinery and industrial controls require a real number that represents the corresponding reference value. Therefore, it is critical to have a process of transformation of the fuzzy value to a real value - the defuzzification process.

3.2. Appicability in Hydrocar

To apply the Fuzzy Logic in this case of study, it was used the InFuzzy software, provided by the University of Santa Cruz do Sul (UNISC). It all starts with the choice of two input variables - solar panel are and solar radiation - and an output variable - power. Along with that, a rule block was inserted. Below in Figure 4, the said process can be seen.

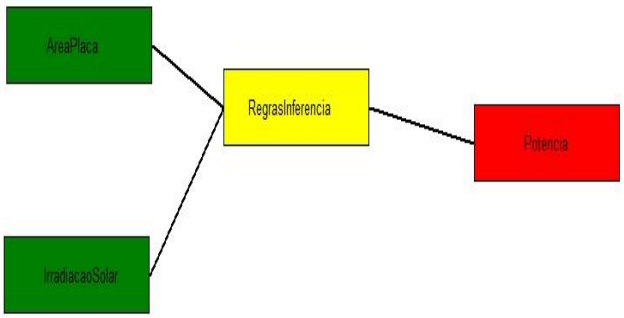

Fig. 4: Hydrocar's Operation Process.

The first block whose information will be filled is the block named "AreaPlaca", which represents the information in the solar panel area used in the electrolysis process. To determine the area of the panel - a rectangular form - its long side and its wide side was measured. The panel has 0.155 m length and 0.065 m width. The area of the rectangle is the product of the length by the width (area = length x width). Thus, the area of the solar panel is 0.010075 m² or 10,075 µm². This will be considered the maximum value of the solar panel area for this project.

With that determined, the universe of the solar panel used was 0 µm² to 10,075 µm². The characteristic of a low solar panel area, represented by the red line was assigned to values from 0 µm² to 4,000 µm². The characteristic of a medium solar panel area, represented by the blue line was assigned to values from 3,000 µm² to 8,000 µm². The characteristic of a high solar panel area, represented by the green line, was assigned to values from 7,000 to 10,075 µm². Below in Figure 5, it can be seen the fuzzification graph of the variable "solar panel area".

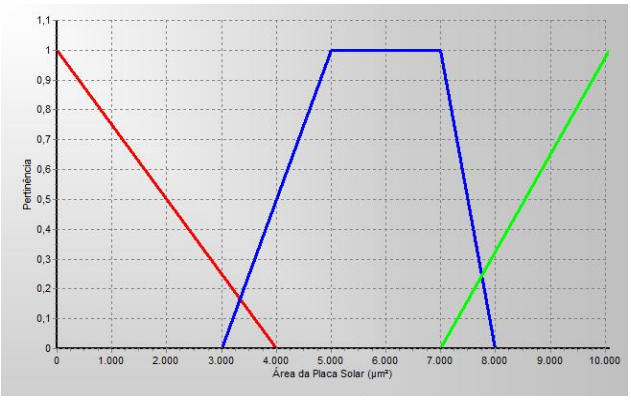

Fig. 5: Fuzzification Graph of Solar Panel Area.

The second block whose information will be filled is the block named "IrradiacaoSolar", which represents the solar irradiation information from where the photovoltaic solar panel was located and used. To determine this value, it was used a tool from the webpage of Solar Energy and Wind Sergio Brito Research Center (CRESESB) [2], in partnership with the Wind Energy Research Center (CEPEL) [2]. In this tool, with the latitude and longitude information from the location where information is needed, it can be found the monthly average values of daily sunlight. For this paper, the photovoltaic solar panel was located at the SENAI-CETIQT University, in Rio de Janeiro. This precise location was not available and as the City Center is the closest to the Riachuelo available, it was used as an information source for this paper. The monthly average of daily solar irradiation value obtained was 4. 06 kWh/m². This will be considered as the maximum solar radiation for this project.

With that determined, the universe of the solar irradiation used used was 0 kWh/m² até 4, 06 kWh/m². The characteristic of a low solar irradiation, represented by the red line was assigned to values from 0 kWh/m² to 1, 5 kWh/m². The characteristic of a medium solar irradiation, represented by the blue line was assigned to values from 1, 0 kWh/m² to 3, 0 kWh/m². The characteristic of a high solar irradiation, represented by the green line, was assigned to values from 2, 5 kWh/m² to 4,06 kWh/m². Below in Figure 6, it can be seen the fuzzification graph of the variable "solar irradiation".

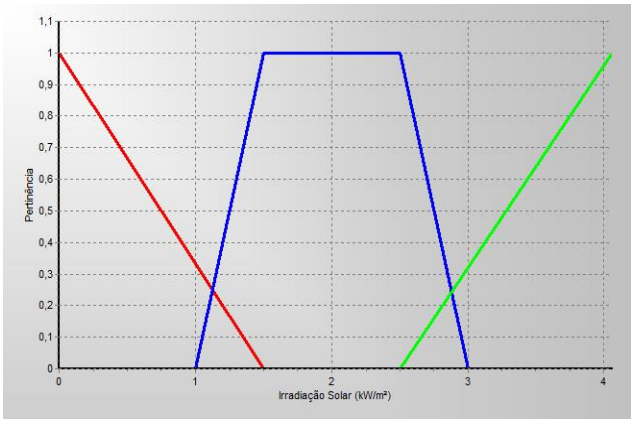

Fig. 6: Fuzzification Graph of Solar Irradiation.

After determining the input variables, the formulation of the output variable is described - the power of the vehicle. To establish what will be the maximum power value, the mechanical power (P) set was used and its formula, shown below in Figure 7, with its attendant consequences, based on the knowledge on Physics.

$$W = \int P * dt$$

$$P = \frac{W}{dt}$$

$$P = \frac{F * d}{t}$$

$$P = F * \frac{s}{t}$$

$$P = F * v$$

$$P = m * a * v$$

$$P = m * \frac{v}{t} * v$$

$$P = m * \frac{s}{t} * \frac{1}{t} * v$$

$$\boldsymbol{P = m * \frac{d}{t^2} * \frac{d}{t^2}}$$

Fig. 7: Power Sets.

The mass (m) of the Hydrocar is 0.350 kilograms when it has its two cylinders filled with water to the top mark of twenty centimeters. The vehicle moved 1.5 meters of distance (s) during the time (s) of 10 seconds. Thus, P = 0,35 * 1,5/(10)² * 1,5/10. The unit measure of power, determined by the International System of Units (SI) is Watts (W). The end result of this equation is, then, P = 0.0007875 W. Applying scientific notation, it will be P = 788 * 10-6 W, or P = 788 µW. This value, rounded to P = 790 µW, is considered the maximum power for this project.

With that determined, the universe of power used was 0 µW até 790 µW. The characteristic of a low power, represented by the red line was assigned to values from 0 µW até 300 µW. The characteristic of a medium power, represented by the blue line was assigned to values from 200 µW até 700 µW. The characteristic of a high power, represented by the green line, was assigned to values from 600 µW até 790 µW. Below in Figure 8, it can be seen the fuzzification graph of the variable "power".

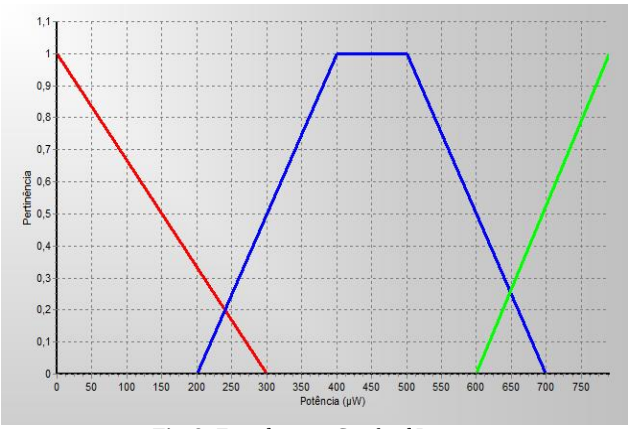

Fig. 8: Fuzzification Graph of Power.

In the block named "RegrasInferencia", inference rules were created in a table so it could generate, at the end of process, a defuzzification chart. Those rules relate the solar panel are and the solar irradiation, generating consequences in the power values. Below, in Table 1, it can be seen the table of rules applied in the Hydrocar operation process.

Table 1: Inference Rules Table Generated By Infuzzy

Nro	Se	Antecedentes	Então	Consequentes
1	Se	(AreaPlaca = baixa) AND (IrradiacaoSolar = baixa)	Então	(Potencia = baixa)
2	Se	(AreaPlaca = media) AND (IrradiacaoSolar = baixa)	Então	(Potencia = baixa)
3	Se	(AreaPlaca = alta) AND (IrradiacaoSolar = baixa)	Então	(Potencia = media)
4	Se	(AreaPlaca = baixa) AND (IrradiacaoSolar = media)	Então	(Potencia = baixa)
5	Se	(AreaPlaca = media) AND (IrradiacaoSolar = media)	Então	(Potencia = media)
6	Se	(AreaPlaca = alta) AND (IrradiacaoSolar = media)	Então	(Potencia = alta)
7	Se	(AreaPlaca = baixa) AND (IrradiacaoSolar = alta)	Então	(Potencia = media)
8	Se	(AreaPlaca = media) AND (IrradiacaoSolar = alta)	Então	(Potencia = alta)
9	Se	(AreaPlaca = alta) AND (IrradiacaoSolar = alta)	Então	(Potencia = alta)

In the software InFuzzy, simulations are performed in order to generate a defuzzification graph. In this simulation, random values for power were generated based on the values provided for solar panel area and solar irradiation. After all the simulations are applied and after running the software it is obtained a defuzzification graph of the variable power. Below in Figure 9, the defuzzification graph can be seen.

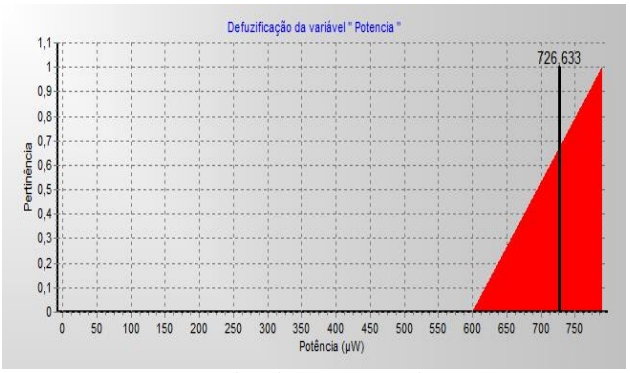

Fig. 9: Defuzzification Graph of Power.

It is seen in Figure 9 that the defuzzification graph generated the final amount of 726.63 µW for the variable "power". In Figure 8, it can be seen the fuzzification graph for variable "power" and the parameters established for each value assigned to this variable. The power of 726.63 µW was inserted in the high-power characteristic, which represents power values above 600 µW.

It is concluded, then, that for the parameters of this project, with the working time and distance travelled by car, with the variables established of solar panel are and solar irradiation, under the rules of inference and the simulation table, that within the power of 726.63, the Hydrocar vehicle operated at high power during its path.

This result demonstrates the high performance high efficiency in which the vehicle moved through the reversible fuel cell is able to achieve. Thus, the vehicle that uses this kind of technology can be considered the solution to the pollution problem caused by the transport sector, if it receives the necessary investment.

4. Conclusion

This paper has demonstrated the possibility of incorporating the vagueness and complexity of the human thought through the fuzzy logic in the assessment of performance of a solar powered prototype car and the process of electrolysis of water. The need for a decision support model is based on the difficulty of properly assessing a compromise between the solar panel area, the intensity of solar irradiation and the power developed by the prototype. This assess difficulty evidences the nebulous nature of the problem on screen.

In the process of mathematical modeling presented, the establishment of linguistic variables, of the fuzzy inference rules and of the defuzzification were proved successful to the extent that was incorporated the judgment of a possible specialist. Thus, it was possible to develope an Expert Fuzzy System, able to support the decision regarding the efficiency of the developed prototype.

This research can be thickened with the inclusion of more linguistic variables and the refinement of the fuzzy inference rules, in order to play more reliably the boundary conditions of the problem. This can be made possible with the usage of artificial neural networks, that are necessary for more complex systems, computational algorithms are able to acquire knowledge through its own experience.

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