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CONSIDERATIONS REGARDING HYBRID SYSTEMS OF POWER GENERATOR FROM RENEWABLE ENERGY SOURCES

Raluca-Andreea FELSEGHI[1*], Attila PAPP[2]

[1] Faculty of Building Services, Technical University of Cluj-Napoca, Boulevard December 21, no. 128-130, 400604, Cluj-Napoca, Romania
[2] Faculty of Environmental Science and Engineering, Babeş-Bolyai University, Cluj-Napoca, Romania
** Corresponding author: raluca.felseghi@insta.utcluj.ro*

ABSTRACT. The hybrid systems which combine two or more technologies to generate power with the purpose of optimizing the global efficiency of involved processes, aspects regarding the energetic efficiency of processes, at the same time aspects regarding reducing of polluting emissions. There is a wide range of possible configurations to conform a hybrid system, and the present paper analyzes a system that uses the technology based upon the fuel cell (Hydrogen Fuel Cell), hybridization being performed with the technology of wind farm turbines, respectively the technology of solar panels. In this context the optimal configurations were determined by simulations of autonomous hybrid systems for residential consumers, with a standardized profile of electric energy consumption, having as placement Cluj-Napoca.

Key words*: fuel cell; hybrid systems; hydrogen energy; renewable energy sources; wind and solar energy.*

INTRODUCTION

A defining characteristic of XXI century represents the dependency of world economy on energetic resources.

The problem's context represents the burn out of fossil fuels in a not so far future, the high volatility of prices for traditional energetic resources, satisfaction of economic and social necessities, problem regarding the energetic dimension of economic increase to cover the energy necessary in the conditions of environment protection by reducing the polluting emissions (Badea, 2012).

The possible solutions are: exploitation of energetic sources from natural environment, theoretically no exhausting and nonpolluting, which regenerates by natural processes, energetic technologies based upon conversion systems of renewable energies, which should offer a maximum yield, high reliability and minimum pollution.

Due to the fact that the hybrid systems produce energy using renewable sources it is imposed look into the following aspects: intermittencies in producing energy because of weather conditions and stocking the extra energy. From economic and environmental point of view, hydrogen and fuel cells can represent the solution to cover the intermittencies in producing energy and top consumption, also stocking extra energy with returning it to the system when needed. A first step to use hydrogen and fuel cells inside buildings is introducing them in autonomous hybrid systems as an environment buffer of energy stock and then usage.

The present article deals with a solution, on which HOGA software functions, in which the energy from renewable sources produced by photovoltaic panels and wind farm turbines is used to meet the energy demand of a residential consumer, and the extra energy will be used by on-site electrolyze when producing hydrogen, used later by the fuel cell when producing electrical energy. This extra energy can cover the necessary consumption during rush hours or can be introduced in the national network of energy supply.

MATERIALS AND METHODS

In the informatics domain, artificial intelligence, a genetic algorithm represents a search method that imitates the process of natural evolution. This research process is currently used to generate useful solutions for optimization and search problems (Mitchell, 1996).

In a genetic algorithm, a population of candidate solutions (called individuals or phenotypes) for an optimization problem is evolved to better solutions. Each candidate solution has a set of properties (chromosomes or genotype), which can be changed (Whitley, 1994).

Evolution usually starts from a population of individuals generated randomly and it is an iterative process, with population from each iteration called generation. In each generation, each individual's aptitude is evaluated, the aptitude being the value of objective function in the optimization problem. The most proper persons are selected from the actual generation and the genome of each individual is modified to create a new generation. The new generation of candidate solutions is then used in the next iteration of algorithm. Usually, the algorithm ends when a maximum number of generations were produced or a satisfying level of population aptitude was reached.

Once genetic representation and aptitude function are defined, a genetic algorithm proceeds to initiate a population of solutions, and then to improve it. The individual solutions are selected by a process based upon aptitude, and the process of generation is repeated until a condition of termination was reached (Mitchell, 1996).

The hybrid system may comprise the following elements (Fig.1.): photovoltaic panels - 1, wind turbines - 2, fuel cell - 3, H_2 tank and electrolyze - 4, inverters (DC/AC converter) - 5, rectifier (AC/DC converter) - 6 and AC-DC load - 7. All elements may be present simultaneously, and the user may decide to include only some of them as part of the desired hybrid system (Dufo et al., 2012).

In the study of hybrid system proposed in this article, the HOGA program was used - Hybrid Optimization by Genetic Algorithms - which is a simulation and optimization program developed in C++ for Hybrid Renewable Systems for generation of electrical energy (DC and/or AC) and/or Hydrogen. Optimization is achieved by minimizing total system costs throughout the whole of its useful lifespan, when those costs are referred to or updated for the initial investment (Net Present Cost, NPC). Optimization is therefore financial (mono-objective). However, the program allows for multi-objective optimization, where additional variables may also be minimized: CO_2 emissions or unmet load (energy not served) (Bernal et al., 2009).

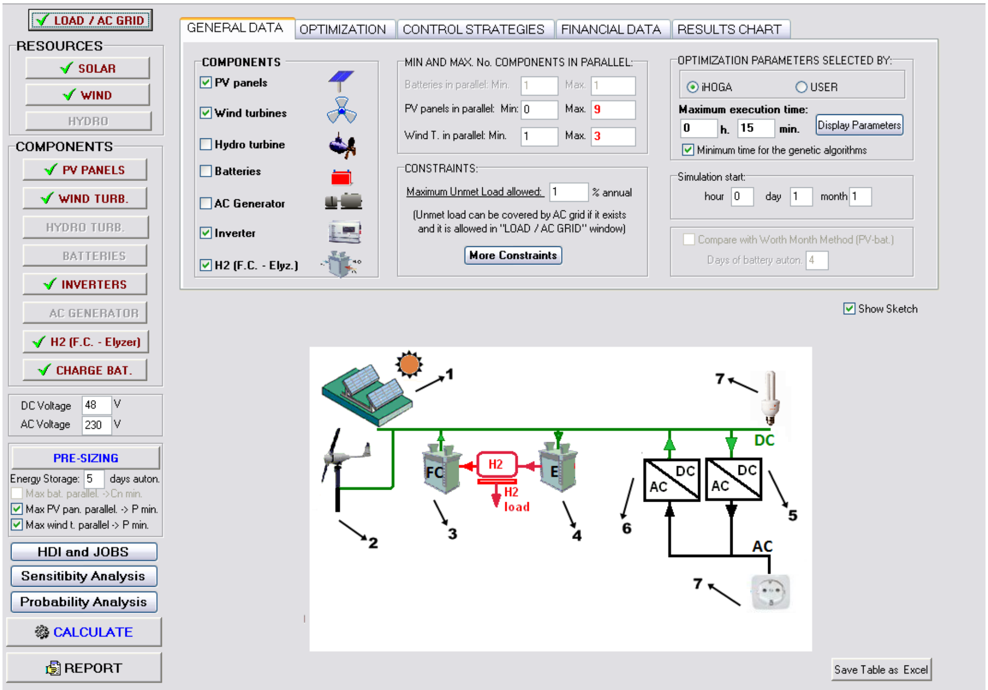

Fig. 1. *Interface of HOGA simulation program. Diagram of hybrid system.*

The HOGA program, with interface presented in Fig. 1 has more sections:

a) Establishing the electrical energy necessary which the hybrid system must cover.

The electrical energy necessary is preset by software depending on the consumers, but with the possibility to perform a consumption profile by the program's user. To perform the proposed simulations in the present paper I have chosen the hour necessary of standardized energy for calculation of energetic performance which is applied to all categories of residential buildings, being illustrated in Fig. 2 by graphic representation of energy hour necessary for December 7th and in Fig.3 by graphic representation of energy hour necessary for the entire month of December.

b) The resources that the hybrid system uses for producing electrical energy.

Solar resource. During this section official data is introduced regarding solar irradiation hich is used to calculate the produced energy by the photovoltaic panels and geographical data to place the photovoltaic panels. Thus for Cluj-Napoca city climate data location are: latitude = 46,76 °N, longitude = 23,60 °E, elevation = 523 m, heating design temperature = - 9,52 °C, cooling design temperature = 24,26 °C, earth temperature amplitude = 19,79 °C according to NASA Surface meteorology and Solar Energy: RETScreen Data (Climate data location NASA).

Depending on the above data, the optimal inclination of photovoltaic panels is calculated and then the hour irradiation is calculated in relation to the values of solar irradiation. The calculated data is presented in diagrams its reference to the daily hour solar irradiation, the variation of medium monthly level (Fig.4.) and the variation of yearly medium level of irradiation level (Fig.5.).

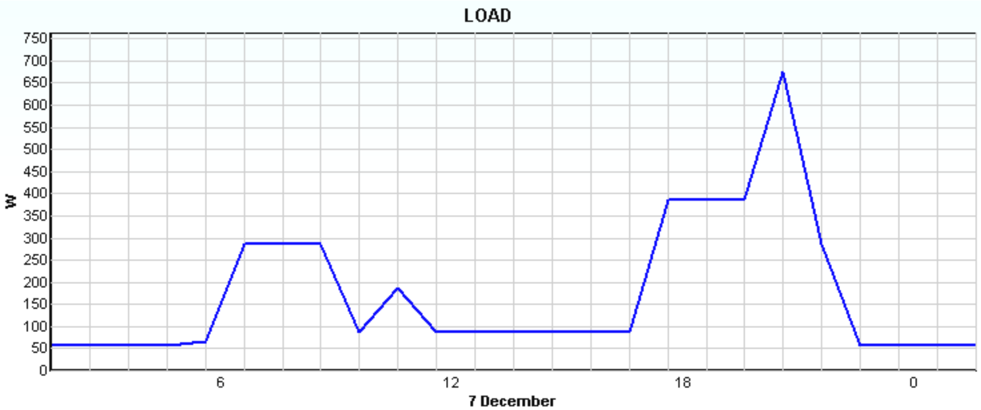

Fig. 2. *Variation graphic of standard energy hour necessary for a day.*

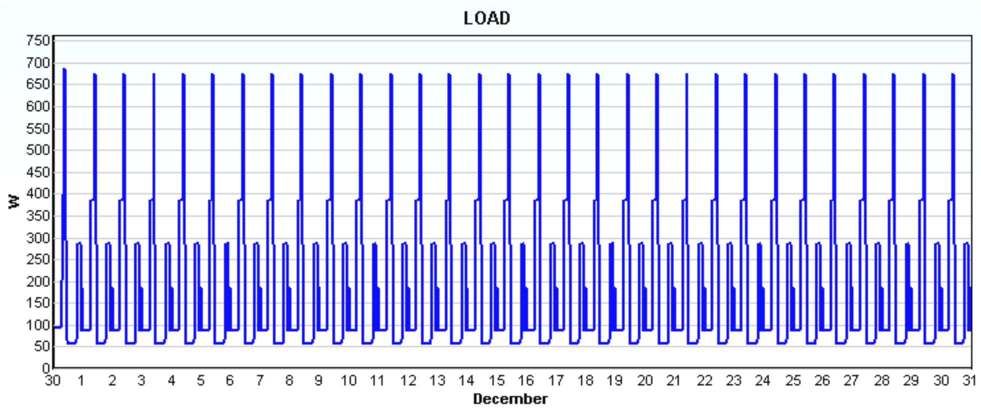

Fig. 3. *Variation graphic of standard energy hour necessary for a month.*

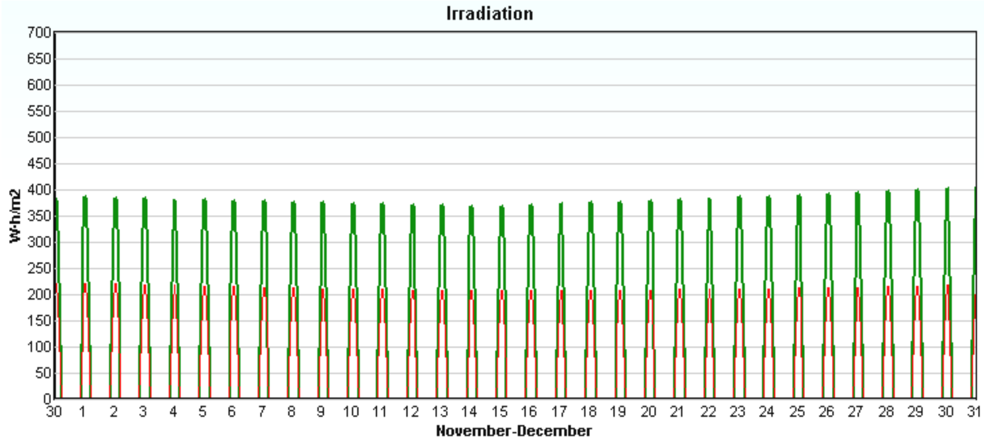

Fig. 4. *Variation graphic of monthly medium level of solar irradiation.*

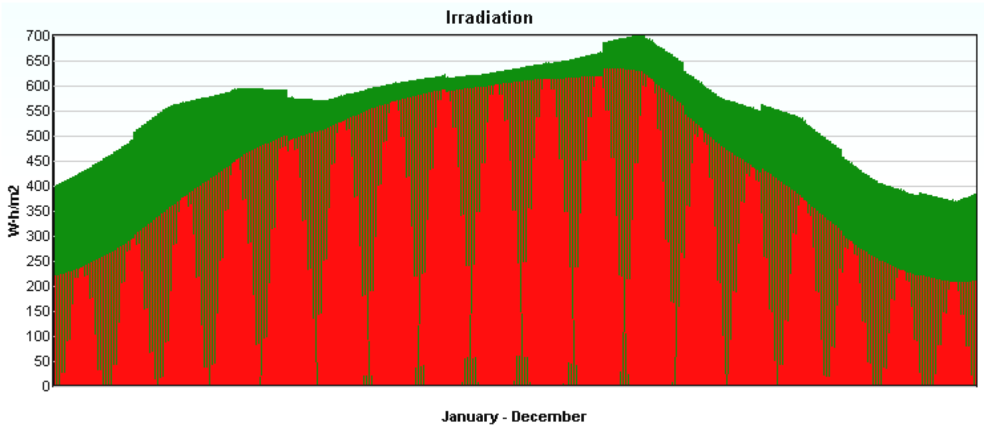

Fig. 5. *Variation graphic of yearly medium level of solar irradiation.*

On horizontal, in Cluj-Napoca the daily average irradiation is 3,3 kWh/m² and total annual irradiation is 1204,65 kWh/m², and on the photovoltaic panels surface the daily average irradiation is 4,0 kWh/m² and total annual irradiation is 1461,41 kWh/m². For the mentioned location the azimuth of photovoltaic panels is 0°, the soil's reflecting plane is 0,2, and the panels do not have a system that follows the Sun (Dufo et al., 2012).

Wind resource. Information regarding the speed of wind in the area of system's placement is introduced in the section destined for wind farm resource. The values from the table represent the monthly averages of wind speed, at a distance of 10 m above the ground. The wind's speed for Cluj-Napoca can be observed in the Variation Graphic of average speed wind (Fig. 6.) calculated for December and in the variation graphic of yearly average speed wind (Fig. 7.)

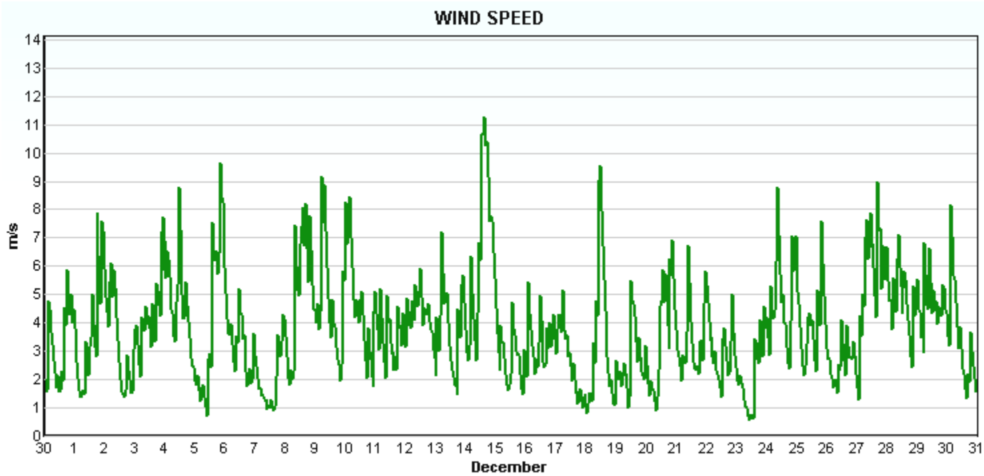

Fig. 6. *Variation graphic of monthly average speed wind.*

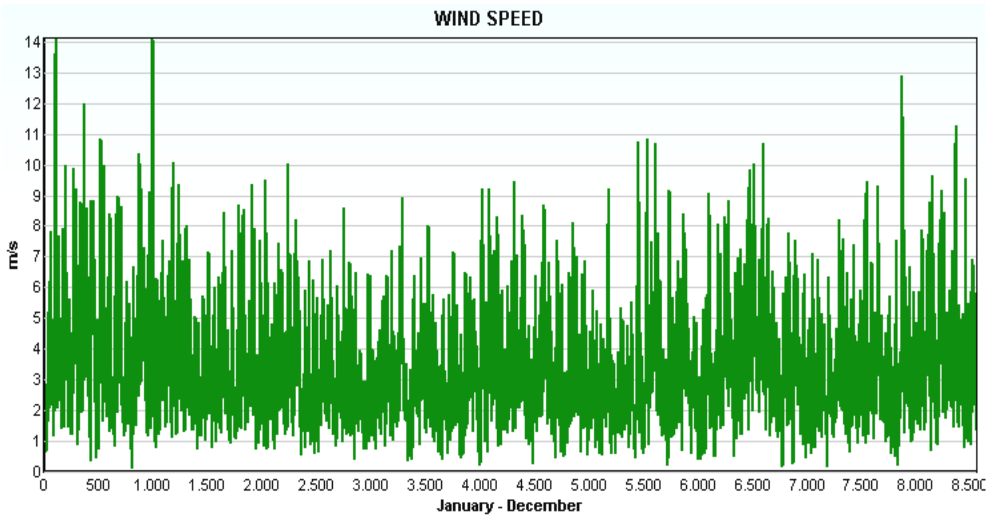

Fig. 7. *Variation graphic of yearly average speed wind.*

c) System's components. For the hybrid system's configuration in the section dedicated to them, the types of equipments are chosen to be submitted to analysis.

The photovoltaic panels chosen to enter the hybrid system's configuration are presented in Table 1.

Table 1. *Types of photovoltaic panels used in hybrid system.*

Type U.M.	Nominal Voltage [V]	Shortcut power [A]	Nominal power [Wp]	Acquisition cost [euro]	Lifespan [years]	CO2 emissions manufacturing [kg CO2/kWp]
PV1	12	8,23	135	249,6	25	800
PV2	24	4,86	150	416	25	800
PV3	12	8,73	135	321,1	25	800
PV4	24	5,46	190	309,4	25	800

The compensation factor for losing power after shadowing and dust is considered to be 1,2, and the equivalent emissions of CO_2 for manufacture of panels of 800 kg CO_2/kWp.

Wind farm turbines taken into consideration in the study have the characteristics according to Table 2.

Table 2. *Types of wind farm turbinesused in the hybrid system.*

Type U.M.	Height [m]	Power at 4 m/s [W]	Power at 6 m/s [W]	Power at 14m/s [W]	Acquisition cost [euro]	Life span [ani]	CO2 emissions manufacturing [kg CO2/kWp]
WH1	9	13	50	547	1228,5	10	350
WH2	11	25	100	925	3724,5	15	650
WH3	13	250	600	1660	6337,5	15	900

The maximum speed of wind where the turbines are put out of service is of 22 m/s.

The fuel cells that enter in the analyzed hybrid system's configuration are presented in Table 3.

The hydrogen consumption of fuel cell depends on the nominal power of fuel cell and the real power delivered in the system. P_{max_ef} represents the delivered power in the system by the fuel cell at maximum efficiency, and A and B represent the coefficients of consumption curve.

The efficiency of fuel cell is determined as being the report between the delivered power in the system by the fuel cell and the product between the hydrogen consumption at the fuel cell and the calorific power inferior to hydrogen (Ştefănescu, 2010).

Table 3. *Types of fuel cells used in the hybrid system.*

Type U.M.	Power [kW]	A [kg/kWh]	B [kg/kWh]	Pmax_ef [% Pn]	Acquisition cost [euro]	Life time [hours]
FC1	1	0,05	0,004	20	9100	15000
FC2	2	0,05	0,004	20	15600	15000
FC3	3	0,05	0,004	20	19500	15000

The hydrogen producing system necessary for the fuel cell to function is composed by **electrolyzers**, which enter in the hybrid system configuration. The electrolyzers characteristics chosen for the study are presented in table 4.

The electrical energy consumption of an electrolyzer depends on the nominal flow, on hydrogen and real hydrogen flow produced by it.

The electrolyzer's efficiency is determined as being the report between the real flow of produced hydrogen multiplied with the inferior calorific power of hydrogen and the consumption of electrical energy of electrolyzer, identical in the fuel cells case (Iordache and Ştefănescu, 2011).

Table 4. *Types of electrolyzers used in the hybrid system.*

Type U.M.	Power [kW]	A [kg/kWh]	B [kg/kWh]	Pmin [%]	Acquisition cost [euro]	Life time [years]
Elec 1	1	40	10	20	9360	20
Elec 2	2	40	10	20	17550	20
Elec 3	3	40	10	20	23400	20

Other component:

Static convertors or continue voltage variators of continue power having constant parameters in continue power, but whose parameters can be changed and can be bigger than the entering power.

Invertors are important components with a high influence on the system's function and cost. These transform the continue power produced by the hybrid system into alternative necessary to consumers. The performance of an invertor is powerfully dependent to the apparent power in any moment.

The program offers the possibility to automatically select the necessary invertor depending on the system's definition; the interface has the Select the minimum inverter required to supply the maximum AC load option.

For the hybrid system configured in the present study, the program suggested invertor has the characteristics presented in table 5 and the diagram of efficiency in relation to the produced power is illustrated in Fig. 8 (Dufo et al., 2012).

Tabel 5. *Characteristics used invertor in hybrid system.*

Type U.M.	Power [Ah]	Efficiency [%]	Acquisition cost [euro]	Life time [years]
1	1600	98	1872	10

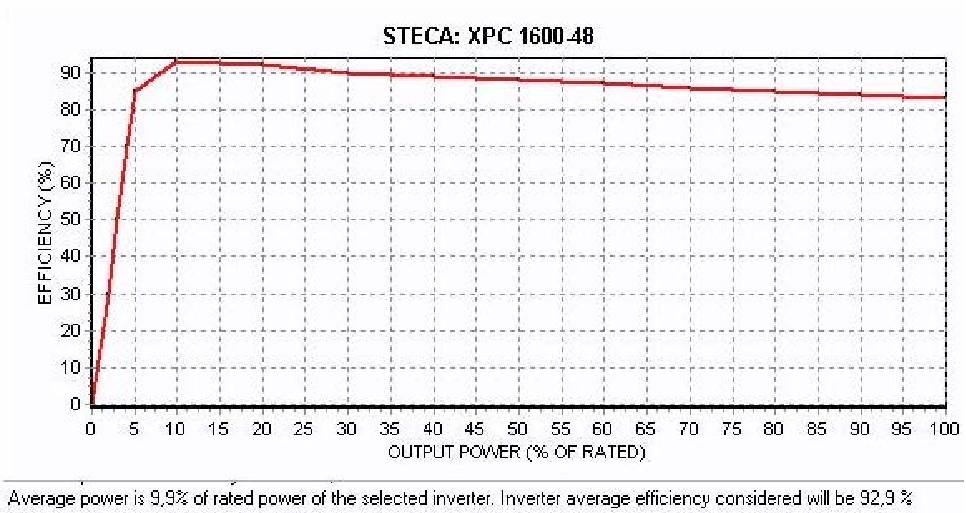

Fig. 8. *Diagram of invertor efficiency in relation to produced power.*

The HOGA program performs simulations for each combination of components and variables of control for a year, and the results are transposed on the entire life duration of hybrid system. At the same time, from the analysis of obtained results after simulations is established the best solution that can be adopted for the hybrid system.

When the number of possible combinations of components and control strategies is too high, the enumerative method (evaluating all the possible combinations) would imply a very high optimization time. In these cases, the Genetic Algorithm technique can help the designer to obtain a good combination (the optimal or a combination near the optimal), in a reasonable run time (Bernal et al., 2009; Dufo et al., 2012).

RESULTS AND DISCUSSION

For determination of hybrid system configuration a minimum and maximum number of approved components in the system's structure was introduced, to produce from renewable sources enough electrical energy so that it covers the energy necessary for the proposed consumers. For performing the program, simulations have been analyzed and performed in the purpose of presenting the best solution. In determining this objective, the software has performed simulations in which it evaluated 3240 possible configurations, presenting at the end the best 9 solutions (Fig. 9), optimization being made taking into consideration the total cost of system and the CO_2 emissions.

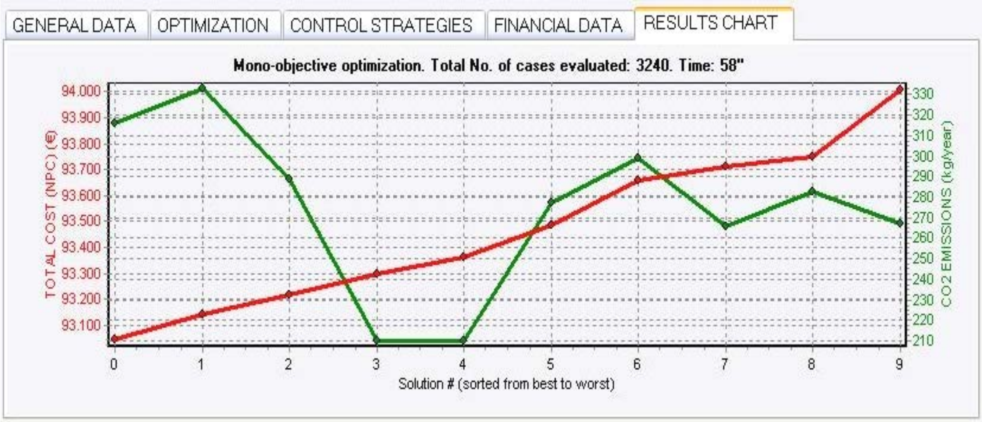

Fig. 9. *Solutions.*

The proposed optimal hybrid system, graphic illustrated in Fig.10, has the following components:

- Photovoltaic panels (PV1 - table 1), with a number of components: 4 series x 8 paralel and P total = 4,32 kW, 70° slope;
- 2 Wind Turbines (WH3 - table 2) by P total = 3,32 kW;
- 1 Fuel Cell (FC1 - table 3), rated power = 1 kW;
- 1 Electrolyzer (Elec1. - table 4), rated power 1 kW + H2 tank of 10kg (40,4 d.aut.)
- 1 Invertor XPC 1600-48, rated power 1600VA.

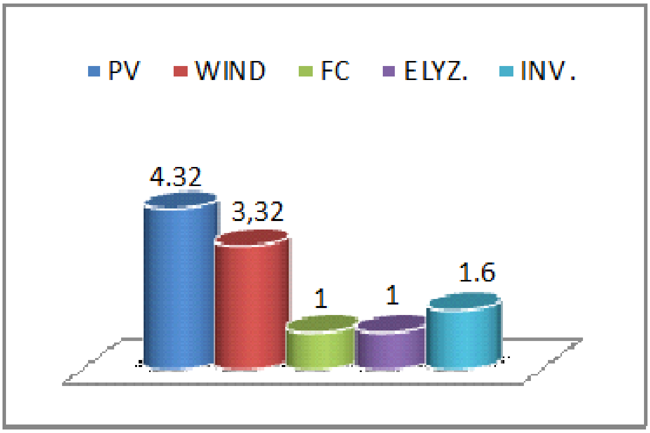

Fig. 10. *Power generated by components of hybrid system.*

The analysis results are observed in the structure configuration hybrid system an important share of energy production by solar panels, followed by wind turbines.

If power delivered by renewable sources is higher than load: charge. The electrolyzer generates H2 with the spare power from renewable.

If power delivered by renewable source is lower than load: discharge. The whole not supplied power to meet the load is supplied by the Fuel Cell. If the Fuel Cell cannot supply the whole, the rest will be unmet load.

The energetic balance of hybrid system during 1 year, graphic illustrated in Fig. 11, can be characterized by the following parameters:

- Overall Load Energy: 1398 kWh/yr. From Renewable: 99,8%.
- Unmet load: 2,4 kWh/yr. (0,17% demand).
- Excess Energy: 4315 kWh/yr.
- Energy delivered by PV generator: 3848 kWh/yr.
- Energy delivered by Wind Turbines: 3978 kWh/yr.
- Energy delivered by Fuel Cell: 410 kWh/yr.
- Hours of Fuel Cell operation: 1860 h/yr.
- Energy at Electrolyzer: 2310 kWh/yr.
- Hours of Electrolyzer operation: 3163 h/yr.
- Energy sold to AC grid: 3319 kWh/yr.
- Energy purchased from AC grid: 2 kWh/yr.
- Total CO_2 emissions: 316 kg CO_2/yr.
- H_2 sold in one year: 9,9 kg H_2/yr

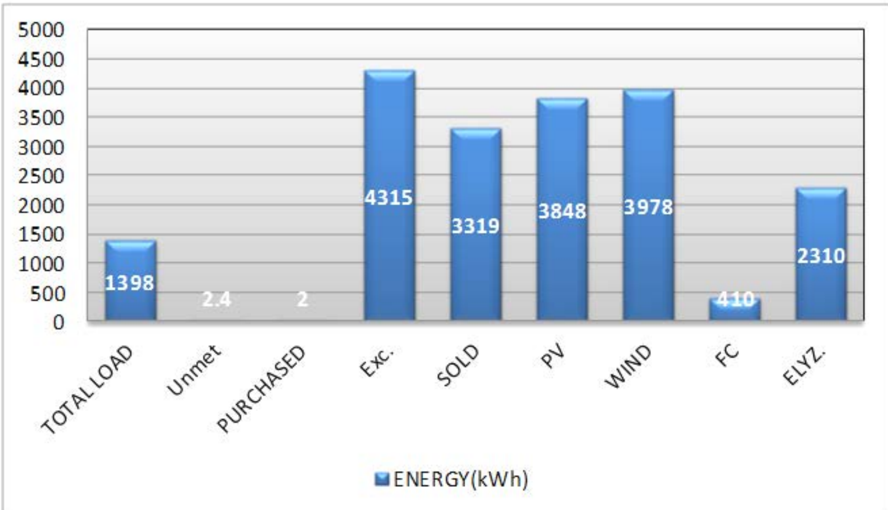

Fig. 11. *The energetic balance of hybrid system.*

The energetic balance of hybrid system simulated during one year of operation highlights the overall load energy, the energy produced in excess, the energy delivered by photovoltaic generator, by wind farm turbines and by fuel cells, also the energy consumed by the electrolyzer.

In a careful analysis of the obtained values is observed that there is a significant amount of excess energy that can be sold.

Whit al, are outlined the operating times of fuel cells and of electrolyzer, also the total CO_2 emissions hydrogen sold in one year.

The initial costs of investment for hybrid system are illustrated in Fig. 12, being calculated by the program depending on the chosen components for the optimal chosen system.

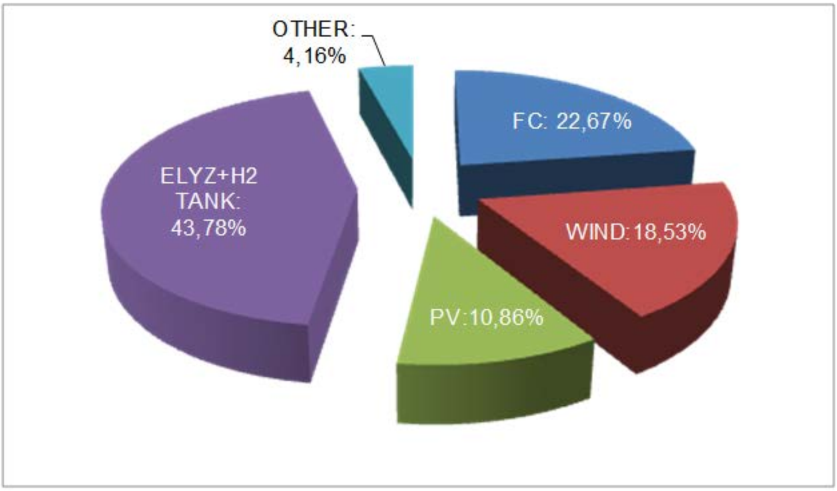

Fig. 12. *Graphic of initial investment.*

Total System Costs (NPC): 93045 euro.
Levelized cost of energy: 2,66 euro/KWh (25 years lifetime).
PV Generator Costs: 10732 euro.
Wind Turbines Costs: 18295 euro.
Fuel Cell Costs: 22391 euro.
Electrolyzer + H_2 tank Costs: 43252 euro.
Inverter Costs: 4107 euro.

From the results obtained after simulations in order to determine the best solution, was obtained for a total cost over the entire lifetime is 93045 euro, a relatively acceptable costs considering that combines new technologies and cleaner production energy. On is observed that the largest share of the cost of the equipment is owned by electrolysis and hydrogen storage tank. Production technology and hydrogen storage continue to be developed for the equipment to arrive at competitive costs.

To perform an optimization of the hybrid system mentioned above, on proposed the main objectives that: reduce total system cost, reduce the amount of energy produced in excess and reducing CO_2 emissions and the secondary objective is optimization variables of characteristic components (objectives to be developed in a future papers).

CONCLUSIONS

Following the situation analysis it can be concluded that fuel cell technology can play a key role in producing the electricity to power various autonomous hybrid consumptions of the optimal system configuration depending on the availability of renewable sources.

Incorporate the fuel cells technology in hybrid systems made the whole system more efficient by using hydrogen as energy storage medium to cover consumption peaks and periods of intermittent energy production, resulting in the reduction of excess energy produced by the system and the reduction of CO_2 emissions.

The simulations performed in order to determine an optimal configuration of hybrid systems with the fuel cells showed their important location in areas with high potential of renewables sources.

The universality of this approach makes it possible hydrogen as secondary energy carrier synthetic fuel, "energy vehicle" and storage medium for electricity produced from renewable sources. Fuel cell technology hydrogen has real potential to become a solution to provide access to every citizen of the planet clean, unpolluted, at a reasonable cost.

Energy efficiency by primary energy savings, reduce network losses, reduced price and the cost of electricity to consumers, reduce environmental impacts, in particular greenhouse gas emissions, all together contribute to security of energy supply to consumers. Development of energy systems based on fuel cells is the focus of various demonstration projects that will allow validation of these technologies for energy production as alternatives to classical.

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