THE USE OF GENETIC ALGORITHM IN DIMENSIONING HYBRID AUTONOMOUS SYSTEMS

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Abstract - In this paper is presented the working principle of genetic algorithms used to dimension autonomous hybrid systems. It is presented a study case in which is dimensioned and optimized an autonomous hybrid system for a residential house located in Cluj-Napoca. After the autonomous hybrid system optimization is performed, it is achieved a reduction of the total cost of system investment, a reduction of energy produced in excess and a reduction of CO_2 emissions.

Keywords: genetic algorithms, wind turbines, photovoltaic panels, batteries, hydrogen, fuel cells.

1. INTRODUCTION

In computer science, artificial intelligence, a genetic algorithm represents a search method, of discovery that mimics the natural process of evolution as heredity, mutation and selection. This research process is currently used to generate useful solutions to optimization problems [1].

In a genetic algorithm, a population of candidate solutions (called individuals or phenotypes) to an optimization problem is evolved toward better solutions. Each solution candidate has a set of properties that can be modified and changed [2].

The evolution usually starts from a population of randomly generated individuals and is an iterative process, with the population of each iteration called generation. In every generation, each individual aptitude of the population is evaluated, the aptitude is usually the value of the objective function in the optimization problem. The right people are randomly selected from the current population and each individual's genome is modified to form a new generation. The new generation of candidate solutions is then used in the next iteration of the algorithm. Usually, the algorithm ends when either was produced maximum number of generations, or when it has reached a satisfactory level of skills of the population.

Once the genetic representation and the aptitude function are defined, a genetic algorithm proceeds to initialize a population of solutions, and then to improve it by repeated application of operators of mutation, crossover, inversion and selection.

Initially, many individual solutions are randomly generated to form the initial population. Population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions. Traditionally, the population is generated randomly, allowing the whole range of possible solutions. Occasionally, the solutions may be sought in areas where optimal solutions are likely to be found.

During each successive generation, some of the existing population is selected to reproduce a new generation. Individual solutions are selected through a process based on skill. Certain selection methods assess the aptitude of each solution and preferentially select the best solutions. Aptitude function is defined over the genetic representation and measures the quality of the solution represented.

In some problems, it is difficult or even impossible to define the aptitude expression. In these cases, a simulation can be used to determine the value of an aptitude function of a phenotype or are used interactive genetic algorithms .

This generation process is repeated until a termination condition is reached. Common conditions for closing are:

- providing a solution that meets the minimum criteria;
- it has reached the required number of generation;
- it has reached budget (time/money);
- it has reached the highest aptitude solution in rank;
- it has reached in an area where successive iterations do not produce better results;
- it has reached some combination of the above.

A program that runs on genetic algorithms is Hoga (Hybrid Optimization by Genetic Algorithm), a software developed in programming language C ++ [3-9]. Hoga, version 1.96, is a simulation and optimization program of hybrid systems in order to produce electricity.

The aptitude function of the genetic algorithm is performed in ratio to minimizing total system costs for the lifetime, the best solution is represented by the system with the lowest total cost. However, the program allows optimization of variables required by the user, such as overall demand for energy or reduction of CO_2 emissions. Because distinguishing variables (cost, energy demand and emissions) in the simulations, the program presents the best solution for many cases. Some of these solutions offer the lowest system cost, while other solution presents the best performance when applied to reducing CO_2 emissions.

The software performs optimization of both system components - the main algorithm - and control strategy - secondary algorithm. The main algorithm optimize the main components that are comprised in the hybrid system in order to reduce system costs and the secondary algorithm ensures the control strategy (combination of control variables) for the components indicated in the main algorithm.

The hybrid system subjected to optimization can include the next elements: wind turbines, photovoltaic panels, hydraulic turbines, electrolysers, hydrogen storage tank and fuel cells. All these components uses for energy production, renewable resources. In addition the program offers the users the opportunity to equip the hybrid system with AC generator if biogas is used that is considered as renewable source. For proper operation of the hybrid system, the program has in is his componence charging batteries, inverters for converting DC to AC and rectifiers, which complements hybrid configurations. All components that can form an autonomous hybrid system are shown in Figure 1, the user having the possibility to choose each desired item in its system configuration.

The Hoga program performs simulations for each combination of components and control variables on an annual period, following that results obtained to be transposed throughout the lifetime of the hybrid system. To define system behavior for this time of year are collected all variables that are based on characteristics of the system components, the control variables and weather reports [10]. It is assumed that the system is semi-stationary, so that for any hourly period, the system variables remain unchanged.

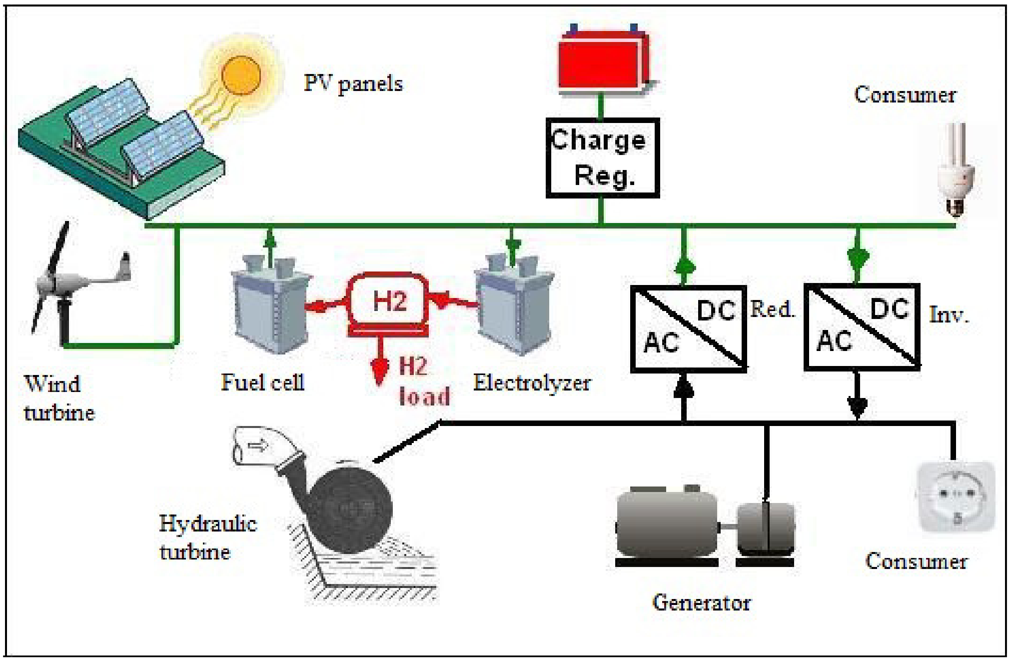

Fig.1. Scheme of an autonomous hybrid system

In short, Hoga is a software tool for optimal dimensioning of hybrid systems, with the ability to include renewable energy (solar, wind, hydro) storage systems in batteries or hydrogen, fuel cells and generator.

The instrument uses genetic algorithms to study the costs and emissions, in order to establish an optimum ratio for the number and type of photovoltaic panels, wind turbines, batteries, AC generators, electrolyzers, fuel cells, storage tanks for hydrogen, and inverters, power rectifier, regulator current for battery charging and general system control strategy.

2. DETERMINATION AND OPTIMIZATION THROUGH SIMULATIONS OF AN AUTONOMUS HYBRID SYSTEM FOR A RESIDENTIAL HOUSE LOCATED IN CLUJ-NAPOCA

Because autonomous hybrid systems generate electricity using renewable sources (wind source, solar source, etc.) there are two major problems. The first issue is caused by discontinuity in energy production due to weather conditions, and the second is due to excessive energy storage in hot and windy season. From economic and environmental point of view, hydrogen and fuel cells are the best solution to meet the discontinuity in energy production and consumption peaks, they can store the excess energy and return it into the system when needed.

Analyzing the issues outlined above can be considered that the transition to an economy based on hydrogen and fuel cell technology will be a long process, which will include mainly many technological obstacles, but one of the key points will be the acceptance of these technologies by the end user. A first step towards the use of hydrogen and fuel cells in buildings is their introduction into autonomous hybrid systems as energy storage buffer and then use [11].

Next will be treated a solution, on the Hoga software principle, where the energy produced from renewable resources is stored in batteries until a certain degree of battery charge. Then, if the electricity produced by photovoltaic panels and wind turbines is greater than the energy demand, excess existing energy will be used by the electrolyzer to produce hydrogen, and then by the fuel cell to produce electricity from hydrogen when needed.

Thus it was determined and optimized through simulations, optimal configuration of an autonomous hybrid system for a residential house located in Cluj-Napoca [12].

To determine the configuration of autonomous hybrid system was introduced a minimum and maximum number of admitted component into the system structure, to produce and store from renewable resources, sufficient electricity, to cover the energy needs for the proposed consumers. Then, the software analyzed and conducted simulations in order to submit the best solution. In determining this goal, the program has conducted about 2,550 simulations, in which evaluated approximately 29.81 million possible configurations, presenting only the best 15 solutions.

In achieving optimization of the autonomous hybrid system the program was rolled again for the same inputs as for determining the optimal configuration. For the optimization of the hybrid system, the software made about 3550 simulations, in which he analyzed about 33.45 million possible configurations, in which were selected only the best 15 solutions. Optimization of the autonomous hybrid system had as main objective reducing the total system cost, pursuing the possibility of reducing the energy produced in excess and the quantity of CO_2 emissions. Next to this, was conducted an optimization of the characteristic variables of component equipment in function of the intersection point of the cost of energy supplied by batteries and fuel cell, minimum power of fuel cell recommended by the manufacturer and minimum rate of battery charge recommended by the manufacturer.

The results obtained after determining and optimizing the systems were presented comparative for a better view of the differences and for highlighting the need for autonomous hybrid system optimization.

Table 1 presents input and output data, which were the basis for determining and optimizing the autonomus hybrid system that serves the residential house located in Cluj - Napoca.

Tabel 1. Determination and optimization of autonomous hybrid system configuration

Input data				
	Minimum components permissible		Maximum components permissible	
PV panels	0		14	
Wind turbine	0		3	
Batteries	0		2	
Output data				
	Determination of the autonomous hybrid system		Optimization of the autonomous hybrid system	
	Number of components	Capacity on component	Number of components	Capacity on component
PV panels	4 series x 9 parallel	140 Wp	4 series x 9 parallel	140 Wp
Wind turbine	0	900 W	0	900 W
Batteries	4 series x 2 parallel	144 Ah	4 series x 1 parallel	144 Ah
Fuel cell	1	1 kW	1	1 kW
Electrolyzer	1	1 kW	1	1 kW
Storage tank	1	33,29 kg	1	33,29 kg
Invertor	1	1000 VA	1	1000 VA

Analyzing the configuration of results is noted that in the structure of the hybrid system were not included wind turbines, which is due to low wind potential for the site of the residential house in Cluj-Napoca. As a result of comparison between the determination and optimization of the autonomous hybrid system is observed that the only change that has occurred is the number of batteries connected in parallel, where it was reduced from 2 to 1.

In Table 2 are presented compared, before and after optimization of the hybrid system, overall system costs, initial costs of investment and total costs of equipment components over a life of 25 years. In Figures 2 and 3 are shown as percentage costs of equipments of system components, and in Figure 4 is presented a comparative diagram of the autonomous hybrid system costs before and after optimization.

Tabel 2. Costs of the autonomous hybrid system before and after optimization

Investment	Determination of the autonomous hybrid system	Optimization of the autonomous hybrid system
	Cost [Euro]	
The total cost of the system lifetime	78.205	74.522
Initial investment	26.893	25.718
PV panels	8.568	8.568
Wind turbine	0	0
Batteries	6.586	5.815
Fuel cell	14.764	11.924
Electrolyzer and storage tank	43.033	43.033
Invertor	2.413	2.413
Auxiliary components	1.007	1.007

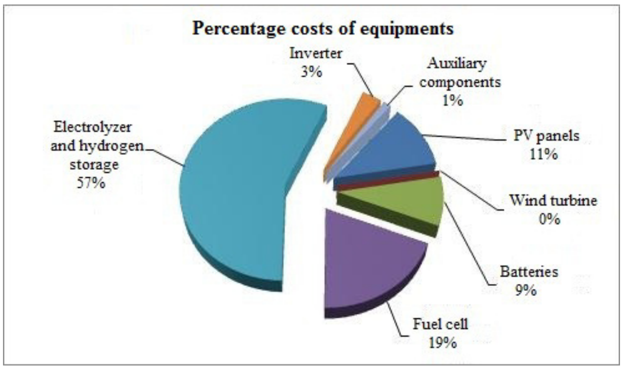

Fig. 2. Percentage costs of equipments before the optimization of the hybrid system

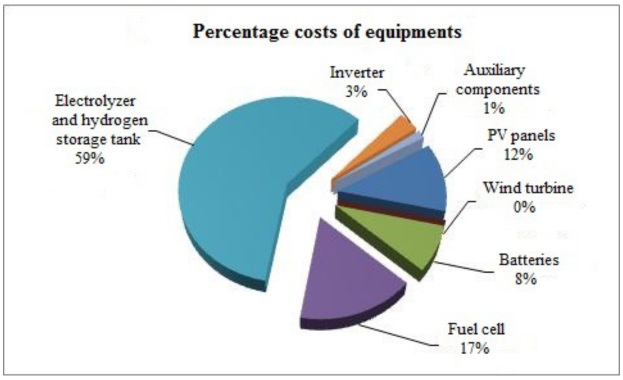

Fig. 3. Percentage costs of equipments after the optimization of the hybrid system

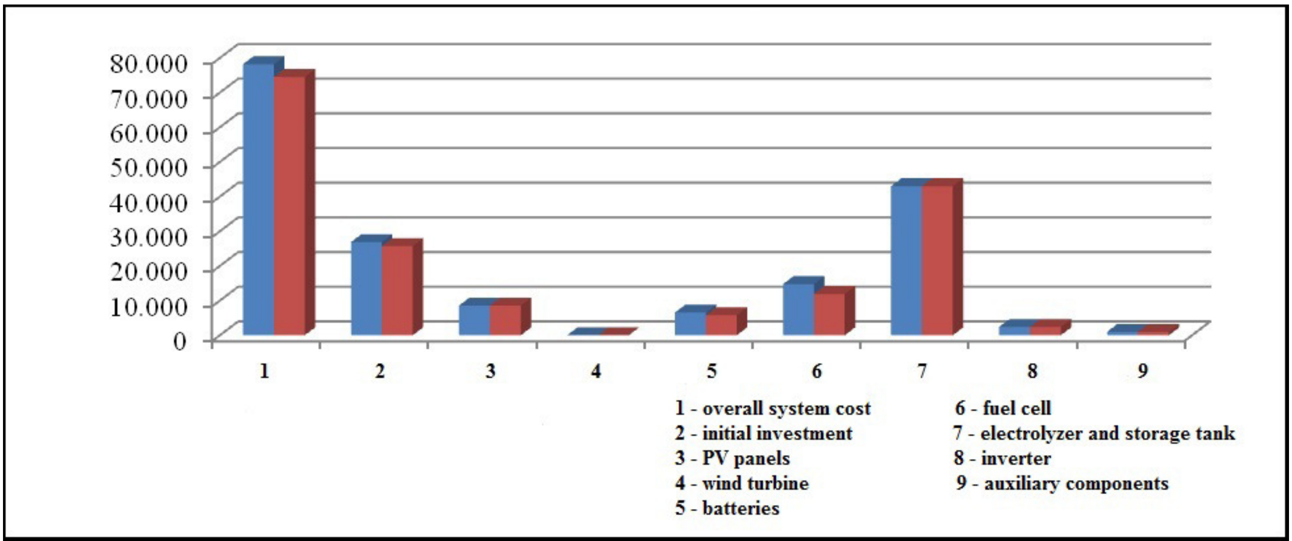

Fig. 4. Comparative diagram of autonomous hybrid system costs before and after the optimization

From the results obtained following simulations regarding the determination of the autonomous hybrid system the best solution was obtained for the system whose total cost over the lifetime is € 78.205, cost relatively acceptable considering that combines new and cleaner technologies of energy production (like hydrogen and fuel cells). It can also, be noticed that the largest share of the cost of equipment is owned by the electrolyzer and hydrogen storage tank. The technology for producing and storing hydrogen must be further developed for that the equipments to reach a competitive cost.

As for the total costs of the hybrid system autonomously, following optimization, it is noted that there is a reduction of 4.71%, decrease that can be seen from the comparative diagram costs of the system throughout lifetime. Another decrease that occurs, after optimization, this time with 4.37% is in the case of initial investment cost. All these decreases are due to reduce the number of batteries from the configuration of the hybrid system optimized. Following the elimination of a series of batteries is achieved a 11.7% reduction in the cost and therefore of the fuel cell 19.24%. As for the costs of other equipments it can be noticed that they maintain their values before optimization, the most expensive equipment, as can be seen from the figure of costs percentage of equipments, is the electrolyzer and the hydrogen storage tank.

In Table 3 is presented comparative, before and after optimization, the energy balance of the autonomous hybrid system, in which is highlighted the energy produced in excess, the energy generated by the fuel cell, the operating hours of fuel cells and the CO_2 total emissions.

Tabel 3. Energy balance of the hybrid system, before and after optimization, for a year of use

Energy balance of the system	Values obtained after determining the system	Values obtained after optimization the system	Unit of measurement
Total energy demand	2.383	2.383	kWh/year
Energy demand that could not be covered by the system	0	0	kWh/year
Excess energy	**254**	**251**	kWh/year
Energy generated by photovoltaic panels	3.742	3.742	kWh/year
Energy generated by wind turbines	0	0	kWh/year
Energy generated by fuel cells	**507**	**611**	kWh/year
Number of operating hours of the fuel cells	**1.673**	**1.231**	h/year
Energy used by electrolyzer	1.000	1.085	kWh/year
Number of operating hours of the electrolyzer	1.185	1.517	h/year
Energy charged in batteries	1.136	1.218	kWh/year
Energy used from batteries	1.144	1.222	kWh/year
Battery lifetime	6,58	3,58	years
Total CO_2 emissions	**297**	**279**	kg CO_2/year

At a careful analysis of the values obtained, after determining the hybrid system, from the above table it can be observed that there is a significant amount of energy produced in excess, 254 kWh/year, almost half of the energy produced by the fuel cells, 507 kWh/year. The total amount of CO_2 emissions generated by the manufacturing of equipment and using them for a period of 25 years, is estimated by the software to be 7425 kg of CO_2, quantity that must be reduced in order to match the current environmental conditions.

3. CONCLUSION

The main objective of optimization involves reducing total cost of the system, but in addition it also aims to reduce the amount of energy produced in excess and CO_2 emissions. The secondary objective is focused on optimizing the characteristic variables of equipment component. Following optimization of the hybrid system, the main objective was achieved by reducing the amount of energy produced in excess with 1.2%, and the amount of CO_2 emission with 6.1%. But the most conclusive results are obtained by optimizing the characteristic variables of equipment for fuel cells case, where the operating hours of its decreased by 26.42%, while the amount of energy delivered by the fuel cells had increased by about 17%. If the fuel cells works fewer hours and delivers greater amount of energy, the more beneficial is the autonomous hybrid system, because the fuel cells have a limited operating hours, and if this range is exceeded the fuel cells should be replaced, raising in this way the total cost of the hybrid system.

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