Design of a residential microgrid in Lagos del Cacique, Bucaramanga, Colombia

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Abstract. In this paper is presented a model that analyses the options to provide energy to an interconnected house in Lagos del Cacique, Bucaramanga, Colombia. Three power supplies were considered: photovoltaic, 1 kW wind turbine, and a 2.6 kW gasoline generator, as well as a battery for energy storage. The variables considered for the sensitivity analysis correspond to the price of gasoline and the variation in loads. The simulation results suggest an optimal configuration of microgrids in generator-photovoltaic panel-battery. Sensitivity variables were specified in order to evaluate the effect of uncertainty. The simulation was done through the Homer software and the results of the combinations of sources are suggestions of the same.

1. Introduction
The fast growth of global energy demand has led to an increase in pollution and global warming. Alternative energies represent a clean source of generation and therefore their development is crucial to minimize the effects of climate change; likewise, its use has implied the concept of distributed generation, which associates the technical and environmental elements that must be considered with special attention [1-4]. Thus, it is of interest to estimate the correct type of energy for a given project, according to the specific conditions of the area, seeking the execution of the optimized system, which in a first phase must be carried out under computational techniques [5-7].

The modelling and planning of microgrids represent the crucial stages and critics in the process of design and execution [8-10], given the large number of components to integrate and the characteristics of each one. From the Homer software, a simulation of a microgrids was done for a house without interconnection in Lagos del Cacique, Bucaramanga, Colombia, on which the elements are integrated according to the specific characteristics of the zone. The work details the costs of investment, operation and maintenance, and the configuration with better environmental and economic benefits.

2. Planning parameters
The scheme of the hybrid power system is shown in Figure 1(a). The components include wind turbines, photovoltaic panels, a generator, the low primary load for a residential stratum 5 and converters (AC to DC). Figure 1(b) shows the load profile used in the present work.

The generator selected is from Kipor brand, with a capacity of 2.6 kW, with single-cylinder OHV engine and output regulation system that allows for stable voltage. The investment and replacement costs are assumed as US $1282.84/kW. In reference to the costs of maintenance and operation of the generator, were assumed as $0.05 USD/hr.
The cost of fuel for the generator is assumed as $0.69 USD/l. The wind turbine selected corresponds to a Bornay AE-BOR-B15.48, of 1.5 kW and 48 v, two blades, with digital regulator. The cost of maintenance and operation were assumed as $1,000 USD/year. The estimated life of the equipment is 20 years. Investment and replacement costs were assumed as $4,967.89, according to market prices.

The photovoltaic panel is Eco-Worthy of 1 kW. The useful life is assumed of 25 years, with a reduction factor of 90%. The investment cost of the panel is $1,447 USD, with an equal replacement cost, and an operation and maintenance cost were assumed of $72 USD/year.

The inverter corresponds to a "Horizontal Grid Inverter", with a capacity of 1 kW, and works in full wave, what improves the system. The efficiency of the inverter is assumed as 90%, with a useful life of 15 years. Investment and replacement costs are estimated at $270.11 USD in the market, the cost of operation and maintenance are disregarded.

The last of the components corresponds to the battery, was selected a Trojan L16P 420 Ah, 6 V, of deep cycle. His cost of investment and replacement are $319 USD and his cost of maintenance and operation are $20 USD/year. For the present study was located 8 batteries in series, with initial and final charge of 100% and 30% respectively. The performance of the battery life is 1,075 kWh.

On the other hand, according to the Solar Radiation Atlas of Colombia, the city of Bucaramanga presents an average daily radiation between 4.5 and 5.5 kWh/m², with stable behavior throughout the year, which coincides with the values predicted by HOMER, according to NASA’s database [11], which establishes an average radiation of 5.16 kWh/m²/day. Figures 2(a) and 2(b) show the solar resource profile during the 12 months of the year. Wind statistics are obtained according to Homer, by NASA’s database; was found that the average wind speed in the selected area is approximately 2.15 m/s. The Figure 2(b) shows the profile of the wind resource.

The variables considered for the sensitivity analysis correspond to the values of load and the price of gasoline. The discount rate and inflation are assumed as 8% and 2% respectively. Was assumed the lack of annual capacity of 2% and the project life cycle of 25 years.
3. Analysis and discussion of results
Economic aspects play an important role in any simulation and Homer is no exception. The Net Annual Cost (CAN), include the initial cost, replacement components, maintenance and others cost, within the lifetime of the project. Table 1 shows the first 8 grid configurations, with better cost-benefit according to the CAN.

| Cost/CDE (USD) | Cost/CAN (USD) | Cost/ Operating Cost (USD) | Cost/ Initial investment (USD) |
|----------------|----------------|---------------------------|-------------------------------|
| 0.926525       | 43718.37       | 2952.34                   | 5551.947                     |
| 1.119128       | 52806.38       | 3767.269                  | 4104.947                     |
| 1.27527        | 60.174         | 3840.967                  | 10519.84                     |
| 1.467517       | 69245.27       | 4654.601                  | 9072.838                     |
| 1.601744       | 75578.79       | 5747.117                  | 1282.838                     |
| 1.636236       | 77206.3        | 5740.186                  | 2999.948                     |
| 1.992439       | 94013.87       | 6767.969                  | 6520.837                     |
| 2.005599       | 94634.8        | 6704.069                  | 7967.837                     |
| 0.926525       | 43718.37       | 2952.34                   | 5551.947                     |

Two initial microgrid configurations stand out, as they represent the highest profitability. Thus, the first configuration of HOMER suggests a hybrid system of a solar panel, a gasoline generator of 2.6kW, 8 batteries and an inverter. For this case, the average cost per kWh of useful electrical energy produced by the system is $0.927USD, the lowest of all other configurations. The second configuration suggests the generator power output of 2.6kW, 8 batteries and an inverter. This configuration presents an average cost per kWh of energy produced by the system of $1.12USD.

The best possible system architecture in terms of profitability and operation evidences a total CAN of $34,375USD, with 0% excess electricity and a maximum renewable penetration value of 227.7. Figure 3 shows the monthly average of electricity production with this configuration.

Figure 3. Monthly average of production with more optimal configuration.

The sensitivity analysis seeks to evaluate the way in which the fluctuations of certain variables affect the optimal configuration of the system [12]. In the present study, the variables fuel cost (gasoline) and load values were evaluated.
For the initial study, an approximate gasoline cost of $0.69/l was estimated. In order to evaluate the effect of the variations of this cost on the system, prices increased by US $0.05/l. For the second variable, an annual scaled average of 10kWh/d is established, with an increase of 1kWh/d.
According to the result of the sensitivity analysis for wide ranges of gasoline prices and charge prices, was observed that, with any of the fluctuating values, regardless of the change of the variables, the system generator- photovoltaic panel- battery is the best option.
Based on the results of the simulation it is possible to determine what type of distributed generators to use in a wide range of changes of the established variables. Figure 4 shows the costs of different systems and the different configurations suggested by Homer, finding that the lowest cost is $42,582.28 USD.

![Costs according to configuration](image)

**Figure 4.** Costs according to configuration.

### 4. Conclusions
It was possible to establish, by Homer simulation, the optimum microgrid configuration, which provides the greatest technical and financial benefits. This led to the determination that the configuration that integrates generator, photovoltaic panels and battery, with a final cost of $42,582.28 USD, represents the microgrid of greater viability according to the established parameters, for future projects.

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