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Optimality sizing of hybrid electrical power plant composed of photovoltaic generator, wind generator and biogas generator

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Abstract

This article propose sizing and optimization model for hybrid renewable energy plant, composed of photovoltaic generator, biogas generator, wind generator, without storage, for rural and peri-urban area decentralized electrification. Technico-economic optimization is carried out by the genetic algorithm. The Hybrid plant model developed here incorporates environmental considerations, calculating carbon dioxide emissions, before and after biogas upgrading to electricity. The simulation is performed with Ouahigouya's site characteristics, located in Sahelian zone of Burkina Faso. The simulation results give a photovoltaic field peak power of 50MW, coupled with 7MW inverter, 5 wind turbines of 7.5MW each and 3 biogas generators of 1MW each, for an electricity demand at the site of 1463 MWh per day with peaks of 182MW. The cost per kWh of electricity generated by this hybrid power plant is 0.508$. Using biogas in addition to solar energy and wind power as hybrid power station energy sources has made it possible to reduce the polluting gases and greenhouse gas emissions in a very significant way.

Keywords: Electrical hybrid power plant, biogas, optimization, genetic algorithm, greenhouse gas.

Introduction

All human energy activities must face today to fossil fuel resources depletion and to greenhouse gases emissions challenge, responsible of climate change. Renewable energies are inexhaustible on a human scale and their conversion has a low impact on the environment. They are a relevant answer to the current and future energy problem[1].

However, the exploitation of renewable energies still faces a relatively high cost per kilowatt-hour produced[2]. Hybrid electrical systems that combine several energy sources will maximize power generation systems from the technical, economic and environmental points of view[3]. Hybrid electrical systems overcome inconsistency, uncertainty and total or partial unavailability of each renewable energy source, which increases the reliability of these systems[2,4]. Hybrid systems are interesting solution for areas electrification where the electricity network does not exist, or its extension requires a relatively high cost[5].

The development of hybrid electric systems requires that they become more economically attractive. J. Dipama et al, in their paper, shows that the energy optimization of industrial systems offers enormous advantages, from the economic or environmental point of view[6]. It is therefore essential to carry out a detailed technical-economic analysis, based on realobservations[3] or on predictions of cost evolution of the various components of the hybrid system[7].

Several studies have been conducted on hybrid electrical systems optimal sizing of. Kouam et al. studied in turn the possibility of using the photovoltaic system and a high-speed gas micro-turbine under Matlabenvironment[8]. The supervision, the economy and the environmental impact of an electrical system associated with a photovoltaic power station was the subject of Alkhalil's study in his thesis[1].

Research based on the genetic algorithm was conducted by Bao et al. on the optimal capacity of an autonomous wind-photovoltaic-diesel-battery system[9]. Olatomiwa et al. studied Hybrid Electrical System optimization for a telecommunications relay station in Nigeria[10]. Optimal configuration studies of a mini distribution network, using diesel generator as main electrical source, were conducted by Li et al.[11]. They made a comparison between results obtained under Homer software environment and those obtained using genetic algorithm. The study shows that it is advantageous to use diesel generator as main electrical source. For an autonomous power plant, gas micro-turbines are preferred over diesel generators because of their better dynamic performance and lower emissions[12].

The optimal definition of the generating elements of a hybrid electric system that uses renewable sources includes the modeling steps of the energy resources available on the site, definition of an optimization methodology, modeling of each element of the system and definition of constraints[8].

Different criteria are used for hybrid electrical system optimization according to the installation site: lost of load probability, minimum system cost, minimum harmful emissions and loss of power supply probability[13,14].

Optimization procedures use either genetic algorithms, or heuristics algorithms or surfaces algorithms or commercial software[5,8,15-17]. For electricity production, genetic algorithm is most used for Hybrid Electrical System multi-objective optimization[4,14,18-22].

The overall objective of this work is to contribute to the development of populations in rural and peri-urban areas through the exploitation of endogenous renewable resources in order to increase the supply of electricity[8]. To validate work done, results obtained by genetic algorithm sitting are compared with those obtained with HOMER software.

Methodology

For the technical-economic analysis, we will parameterize the genetic algorithm in the Matlab environment.

Matlab presentation: Matlab is an abbreviation of Matrix Laboratory**.** Matlab is an environment for scientific computing, which has several mathematical, scientific and technical functions. Matlab toolboxes solve problems in signal processing, automation, optimization, and more. Matlab allows links with other conventional programming languages. In Matlab, no declaration of numbers is made. This feature makes the programming mode very easy and very fast.

Optimization methods: There are ~~a~~ multitude of optimization methods for multi criteria problems. There are two main optimization methods families: deterministic methods and stochastic methods. Simulated annealing and genetic algorithms are the most popular stochastic methods used to design energy conversion systems[18,22]. Genetic algorithms are an optimization method proposed by Holland, then developed by other researchers such as De Jong[23,24]. Genetic algorithms evolve by iterations and consist in: creating a set of individuals called populations, evaluating individuals (solutions), combining (crossing of parents) to give a new population, making mutations in order to improve new selected population quality. We use here the genetic algorithm as an optimization method. The structure of the genetic algorithm used in this work is given in Figure-1.

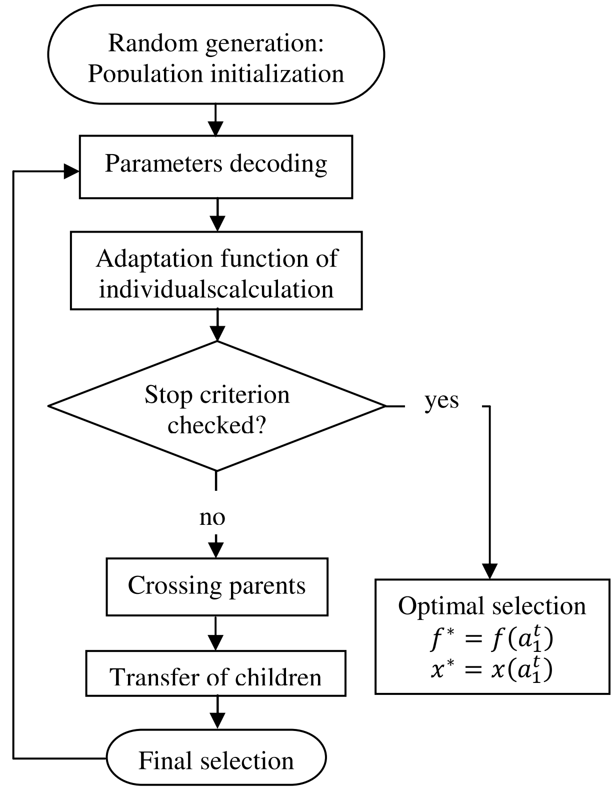

Figure-1: Genetic algorithm structure.

This method is also used by Koto minimize hybrid power plant life cycle cost[15]. According to Deb K. et al., in a problem with strong interactions parameters, the Non-dominated Sorting Genetic Algorithm-Two (NSGA-II) give better results, hence NSGA-II choice[25].

Genetic algorithm set up in the Matlab environment: A technical and economic optimization sizing program written in Matlab environment consists of a series of files. Figure-2 shows the structure of the program with the genetic algorithm[21].

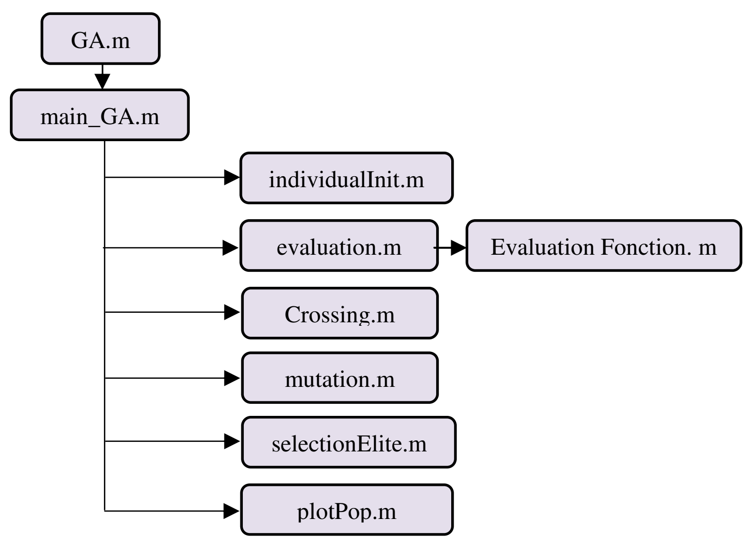

Figure-2: Genetic algorithm program structure[21].

The parameter configuration file (GA.m) and the evaluation file (evaluation Function.m) are to be modified for easy use of the program. The setting of only two files allows obtaining very good results with a reasonable calculation time.

HOMER software presentation: Homer means: Hybrid Optimization of Multiple Energy Resources. It is software for hybrid energy systems (PV, wind, grid, storage and diesel) optimization[26]. It performs the optimization task by performing an hourly simulation of the energy flow between the load and the other components of the system over a period of one year[17].

For each configuration of the hybrid system, the Homer software performs a time analysis of the installation. At each time step, the software observes the consumption and compares it with the photovoltaic production which has priority. In the case of a lack of this energy, the Homer software must choose between use generator or Batteries. The main features of Homer software are: taking into account the hourly load profile as well as controllable loads, time simulation of a multi-source production system, production system economic optimization and sensitivity analysis. The operation of Homer is analyzed for hybrid systems comprising: photovoltaic installation, one or two generators, with or without an electrochemical storage unit. For parameters such as number of devices and powers, Homer software simulates the operation of the system for each of the parameterized values[26].

Homer software presents a financial analysis on project life cycle, based on comparison results of produced kWh costs by different sources[26]. Thus, for each architecture and configuration, it is possible to observe the following outputs: global cost of the updated kWh (LCOE: Levelized Cost of electricity), distribution of the items of expenditure, the detail corresponding to each source, daily charts over the life of the system, sensitivity analysis graphs, an economic analysis compared to a reference installation, sensitivity analysis presented in graphical form.

Hybrid power plant architecture and modeling: The architecture of the studied installation is alternative bus. It consists of a combination of photovoltaic, wind and biogas generators, as shown in Figure-3.

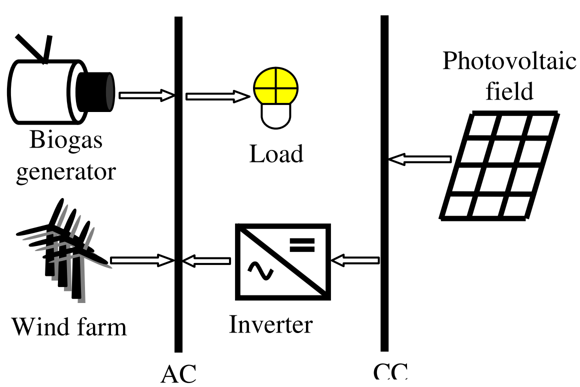

Figure-3: Studied system synoptic architecture.

Several parameters make it possible to describe the performance of biogas engines, among which are specific consumption and efficiency. The Specific Consumption (CS) is equal to the amount of gas consumed during one hour to produce 1 kW of electrical power[27]. For biogas generators, it is expressed in g/kWh or Nm^3/kWh. It is given by relation(1)[22].

$$CS = aP^2(t) + bP(t) + c \tag{1}$$

Where: a, b and c are generator constants characteristic, P (t) is generated power by generator at time t.

Biogas generator overall efficiency η_{GBio} sets the efficiency of chemical energy converting biogas into electrical energy. It is directly related to specific consumption by the relation (2)[22].

$$\eta_{GBio} = \frac{3600}{PCI \cdot CS} \tag{2}$$

Where: PCI (MJ/kg) is biogas lower calorific value, CS (g/kWh) is generator specific.

Photovoltaic generator performance depends on illumination, temperature and load to be supplied. The maximum power P_{mp} at the output of the generator is given by the equation (3)[2].

$$P_{mp} = \eta_{PV} A_{PV} G_S \tag{3}$$

Where: A_{PV} (m^2) is photovoltaic generator area, A_S (W/m^2) is the solar illuminance, and η_{PV} is photovoltaic module efficiency given by equation (4)[2].

$$\eta_{PV} = \eta_{ref}\left[1 - \alpha\left(\frac{G_S}{18} + T_a - 20\right)\right] \tag{4}$$

Where: α is the temperature coefficient for power correction (α = 0,0042), η_{ref} is PV module reference efficiency and T_a is the ambient temperature.

The input power P_{out} of an inverter is the power produced by the photovoltaic generator. Output power can be expressed from input power P_{in} and efficiency η_{inv} according to equations (5)-(7)[2].

$$P_{out} = \eta_{inv} P_{in} \tag{5}$$

With: $$\eta_{inv} = \frac{p}{p + p_0 + kp^2} \tag{6}$$

$$p = \frac{P_{out}}{P_n} \tag{7}$$

Where: η_{inv} is the efficiency of the inverter, p_0 and k are coefficients calculated from the data provided by the manufacturer, p is the reduced power.

A wind turbine is characterized by a power curve that allows an analysis of steady-state behavior and calculation of produced energy taking into account the specific conditions of each location. The power delivered by a wind turbine as a function of the range of variation of wind speed is given by equation (8)[11].

$$P(V)=\begin{cases} P_n \dfrac{V-V_{start}}{V_n-V_{start}} & V_{start}\langle V \langle V_n \\ P_n & V_n \langle V \langle V_{\max} \\ 0 & V \rangle V_{\max} \end{cases} \qquad (8)$$

Where: P_n is wind generator nominal power, V_{start} represents wind turbine starting speed, V_n is wind turbine nominal speed, V_{max} represents wind generator maximum permissible speed.

Technical and economic analysis: In the technical-economic analysis, investment, maintenance, operating and renewal costs as well as the residual value of generators in the hybrid power station are considered to calculate the cost per kilowatt-hour (kWh) electricity produced by the hybrid power station[13]. We propose here the minimization of a cost equation expressed as a function of the optimal size of each generator (digester, biogas generator, photovoltaic field, inverters and wind turbine), while respecting the energy constraints of the hybrid power station[5].

Hybrid power plant optimal configuration determination: The different powers of the hybrid power plant elements (digester, biogas generators, photovoltaic, inverters and wind turbines) to be determined, which satisfy the demand of the load, are, x_1, x_2, x_3, x_4 and x_5. We have in addition, for each system component, five types of cost: initial cost, maintenance cost, operating cost, renewal cost and residual value of the components[14].

Initial cost is related to system purchase cost and to installation cost according to equation (9).

$$C_I = a_1 x_1^{1-b_1} + \frac{D_{\max}}{\beta} a_2 x_2^{-b_2} + a_3 x_3^{1-b_3} + a_4 x_3 x_4^{-b_4} + a_5 x_5^{1-b_5} \qquad (9)$$

where: a_1 is the acquisition coefficient 1 of the digester, a_2 is the acquisition coefficient 1 of the biogas generators, a_3 is the acquisition coefficient 1 of the PV field, a_4 is the acquisition coefficient 1 of the inverters, a_5 is the acquisition coefficient 1 of the wind farm, b_1 is the acquisition coefficient 2 of the digester, b_2 is the acquisition coefficient 2 of the biogas generators, b_3 is the acquisition coefficient 2 of the PV field, b_4 is the acquisition coefficient 2 of the inverters, b_5 is the acquisition factor 2 of the wind farm, x_1 is the peak power of the digester, x_2 is the peak power of the biogas generators, x_3 is the peak power of the PV field, x_4 is the peak power of the inverters, x_5 is the peak power of the wind farm, $D_{\max}$ is maximum load, β is load rate.

The maintenance cost is initial cost percentage of each component for one year. Relation (10) gives the equation of plant maintenance cost.

$$C_M = m_{PBio} PW(i,a,d) A(a,n_{PBio}) a_1 x_1^{1-b_1} + N(a_0+b_0 x_2) PW(i,a,d) \sum_{t=1}^{24} X_t + \\ + m_{PV} A(a,n_{PV}) C_{I-PV} + m_{TE} PW(i,a,d) A(a,n_{TE}) a_5 x_5^{1-b_5} \qquad (10)$$

where: a_0 is biogas generators maintenance coefficient 1, b_0 is biogas generators maintenance coefficient 2, m_{PBio} is digester unit percentage corresponding to maintenance cost, m_{GBio} is biogas generator percentage corresponding to maintenance cost, m_{PV} is PV field percentage corresponding to maintenance cost, m_{TE} is wind turbines percentage corresponding to maintenance cost, $A(a,n_{PBio})$ is annualization factor of investment cost, $PW(i,a,d)$ is discounting factor of investment cost, X_t is biogas generators number in operation at time t.

The operating cost is given by the relation (11).

$$C_{Ex} = E_{PBio} PW(i,a,d) A(a,n_{PBio}) a_1 x_1^{1-b_1} + C_0 x_2 N(a_6\beta + b_6) PW(i,a,d) x_2 \sum_{t=1}^{24} X + \\ + E_{TE} PW(i,a,d) A(a,n_{TE}) a_5 x_5^{1-b_5} \qquad (11)$$

where: C_0 is 1 Nm^3 biogas cost, a_6 and b_6 are consumption parameters of each biogas generator, E_{PBio} and E_{TE} are respectively percentages corresponding to operating cost of digester and wind turbines, $A(a,n_{PBio})$ and $A(a,n_{TE})$ are digester and wind turbines factors of investment cost annualization.

The renewal cost of the components is given by the relation (12).

$$C_R = PW(i,\bar{a}_1,d) a_2 \frac{D_{\max}}{\beta} x_2^{-b_2} + PW(i,\bar{a}_2,d) a_4 x_3 x_4^{-b_4} \qquad (12)$$

where: $PW(i,\bar{a}_1,d)$ is the adjusted discount rate for the replacement of the biogas generators and, $PW(i,\bar{a}_2,d)$ the adjusted discount rate for the replacement of the inverters, $D_{\max}$ is maximum load, β is load rate.

Hybrid plant residual value at project end is given by relation (13).

$$V_R = S(a,d)\frac{nr_{PBio}}{n_{PBio}} a_1 x_1^{1-b_1} + S(a,d)\frac{nr_{GBio}}{n_{GBio}} \frac{D_{max}}{\beta} a_2 x_2^{-b_2} + S(a,d)\frac{nr_{PV}}{n_{PV}} a_3 x_3^{1-b_3} \qquad (13) \\ + S(a,d)\frac{nr_{OND}}{n_{OND}} x_3 a_4 x_4^{-b_4} + S(a,d)\frac{nr_{TE}}{n_{TE}} a_5 x_5^{1-b_5}$$

where: nr_{PBio} is biogas plant remaining lifetime, n_{PBio} is biogas plant total lifetime, nr_{GBio} is biogas generators lifetime, n_{GBio} is biogas generators total lifetime, nr_{PV} is photovoltaic modules remaining lifetime, n_{PV} is photovoltaic modules total lifetime,

nr_{OND} is inverters remaining lifetime, n_{OND} is inverters total lifetime, nr_{TE} is wind turbines remaining lifetime, n_{TE} is wind turbines total lifetime, D_{max} is maximum load, β is load rate.

The model developed is based on an objective "cost" function definition, which takes into account all the expenses incurred by the system during its lifetime. The definition of this function goes through the standard stages of the financial analysis of engineering projects. We can write the objective function *F(x)* according to relation (14).

$$F(x) = C_I + C_M + C_{Op} + C_R + V_R \quad (14)$$

where: C_I is acquisition cost, C_M is maintenance cost, C_{OP} is operating cost, C_R is replacement cost, V_R is hybrid power plan generators residual value.

The formulation of the constrained optimization problem can be in the form of equation (15).

$$\begin{cases} Min F(x) \\ x_2 X + q_0 G(t) x_3 + \eta_{OND} x_4 + F_{TE} x_5 = D(t),\ t = 1:24 \end{cases} \quad (15)$$

where: *F(x)* is objective function, *G(t)* is solar radiation, *D(t)* is power demand in each hour, η_{OND} is inverter efficiency, F_{TE} is losses recorded on the wind farm factor, x_2 is biogas generators peak power, x_3 is PV field peak power, x_4 is inverters peak power, x_5 is wind farm peak power, t is duration of a day.

Quantity of equivalent carbon dioxide emitted: The Photovoltaic field and the wind farm, in their operation, do not produce greenhouse gases. In our study, the amount of carbon dioxide (CO_2) equivalent is calculated by considering only the methane consumed and the gases emitted after combustion in the generators, taking into account their global warming potential. The amount of CO_2 equivalent is calculated according to equation (16)[12].

$$m_{CO_2\_équivalent\_i} = m_{CO_2\_i} + 3m_{CO\_i} + 25m_{CH_4} + 298m_{NO_x\_i} \quad (16)$$

where: $m_{CO_2\_i}$ is carbon dioxide mass , m_{CO_i} is carbon monoxide mass, m_{CH_4} is methane mas , $m_{NO_x\_i}$ is nitrogen oxide mass.

Results and discussion

The chosen site for application of our hybrid power plant model is Ouahigouya, located in the north-west of Burkina Faso. Its geographical coordinates are: 2.30° west of longitude, 13.35° north of latitude and 339 m altitude. Through this work, we want to exploit endogenous renewable resources in order to increase the electricity supply by modeling an autonomous hybrid power plant, composed of solar photovoltaic, wind power and biogas generator. The study is done for project duration of 20 years. Tables-1 to 6 present the values of the different simulation parameters that were used in this study.

Table-1: Biodigester simulation parameters.

Biodigester	Parameters	Values	Units
Peak power	x_1	80000	[kW]
Lifetime	n_{PBIO}	15	[years]
Acquisition coefficient 1	a_1	80601	[$/kW]
Acquisition coefficient 2	b_1	-0,479	[$/kW]
Maintenance percentage	m_{PBio}	2	[%]
Operating coefficient	E_{PBio}	2	[%]

Table-2: Simulation Parameters for Biogas Generators.

Biogas generators	Parameters	Values	Units
Peak power	x_2	100000	[kW]
Lifetime	n_{GBio}	10	[years]
Acquisition coefficient 1	a_2	4747.9	[$/kW]
Acquisition coefficient 2	b_2	0.2925	[$/kW]
Maintenance percentage	m_{GBio}	2	[%]
Maintenance coefficient 1	a_0	22.204	[-]
Maintenance coefficient 2	b_0	0.0049	[-]
Biogasconsumption coefficient 1	a_6	3.8	[kg/h]
Biogas consumption coefficient 2	b_6	0.96	[kg/h]
biogas cost coefficient	C_0	0.17	[$/Nm^3]
Maximum load	D_{max}	9800	[kW]
Load rate	β	80	[%]

Table-3: Photovoltaic generator parameters.

Photovoltaic generator	Parameters	Values	Units
Peak power	x_3	96000	[kW]
Lifetime	n_{PV}	25	[years]
Acquisition coefficient 1	a_3	5654	[$/kWc]
Acquisition coefficient 2	b_3	0.03	[$/kWc]
Maintenance percentage	m_{PV}	2	[%]

Table-4: Inverter Simulation Parameters.

Inverter	Parameters	Values	Units
Peak power	x_4	15000	[kW]
Lifetime	n_{OND}	20	[years]
Acquisition coefficient 1	a_4	1398	[$/kW]
Acquisition coefficient 2	b_4	0.27	[-]
Yield	η_{OND}	0.95	[%]

Table-5: Wind Farm Simulation Parameters.

Wind Farm	Parameters	Values	Units
Peak power	x_5	45000	[kW]
Lifetime	n_{TE}	20	[years]
Acquisition coefficient 1	a_5	17465	[$/kW]
Acquisition coefficient 2	b_5	0.973	[-]
Maintenance coefficient	m_{TE}	2	[%]
Operating coefficient	E_{TE}	2	[%]

Table-6: Parameters for simulating inflation and discount rates.

Rates			Units
Inflation rate	i	4	[%]
Discount rate	a	8	[%]

Results with the genetic algorithm: The optimization problem that we have to solve has 29 decision variables (unknowns) namely: x_1 is biogas plant power, x_2 is biogas generator nominal power, x_3 is PV field peak power, x_4 is inverters rated power, x_5 is wind turbines rated power and X (t = 1: 24), is biogas generators number running every hour per day.

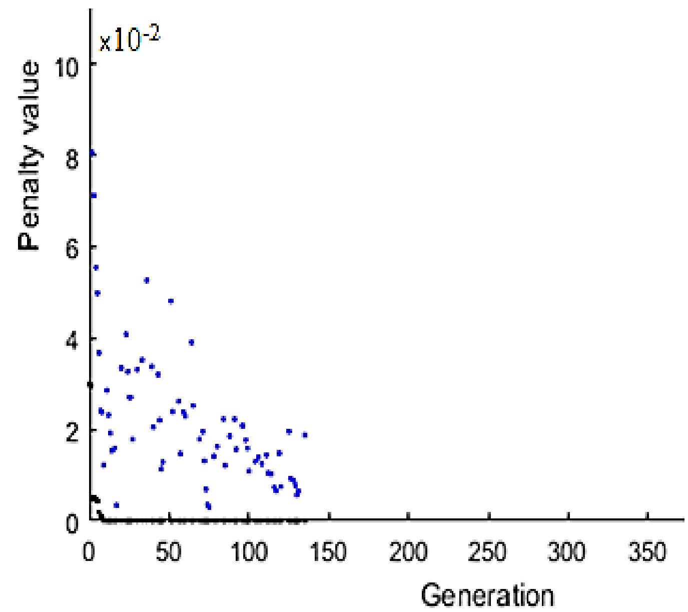

Figure-4: Screenshot graph of results obtained with genetic algorithm set up in the Matlab 7.1 environment.

Figure-4 (Matlab screenshot) presents the results of the process of finding the optimum of objective function by genetic algorithms set up in the Matlab7.1 environment. Here, the number of calculation iterations of the objective function is 150. The blue dots are the last generation populations of the children; the black dots are the last generation populations of parents.

Optimal values of the five decision variables: x_1, x_2, x_3, x_4, x_5 corresponding respectively to the power of the biogas plant, the nominal power of a biogas generator, the peak power of the PV field, inverters nominal power and wind turbines nominal power are: 8611, 3, 1386, 5950 and 4330. The optimal value of Minimum cost of kWh(fval), (obtained by implementing the objective function over the project duration), corresponding to the cost per kWh, is 0.536.

Table-7 summarizes the optimal results of the generator powers, obtained after simulation. Figure-5 shows the setting of the load profile in the Homer software.

Table-7: Hybrid power plant generators power.

x_1	x_2	x_3	x_4	x_5	fval
Digester power [kW]	Biogas generators power [kW]	PV generator power [kW]	Inverter power [kW]	Wind generator power [kW]	Minimum cost of kWh [$]
8611	3000	1386	5950	4330	0.536

Results with Homer software: Figure-5 shows load profile on the studied site.

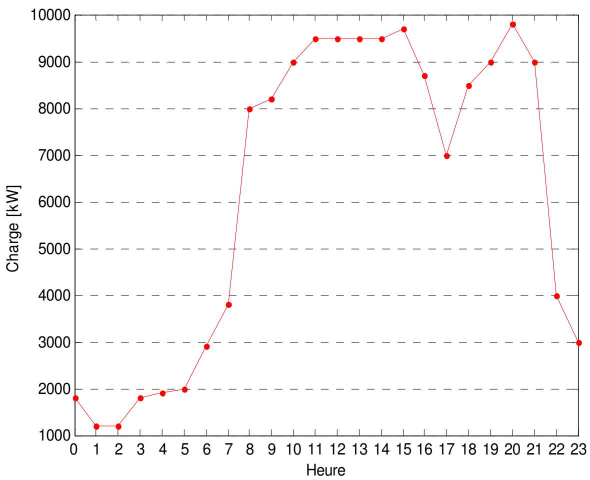

Figure-5: Load profile.

Once all the parameters are introduced, we move on to the simulation stage. Hybrid power plant architecture, sized in Homer software is shown in Figure-6[26].

We want a hybrid power station that uses the wind energy, sun and biogas. Our choice is the configuration that combines the generators using these energies. Table-8 shows power optimal values of hybrid power plant elements.

Table-10 gives the generators optimal size of the hybrid plant, obtained by simulation with the genetic algorithm and with the Homer software.

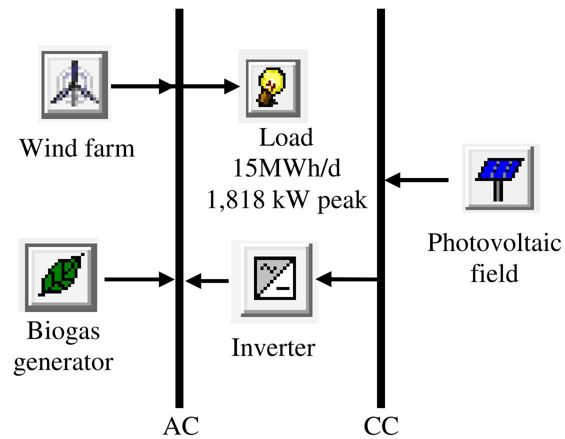

Figure-6: Installation architecture dimensioned in Homer software[26].

The comparison of the optimal power of the generators of the hybrid power plant shows differences between the values obtained by the genetic algorithm and the Homer software, for the photovoltaic generator (PV), the inverter and the wind farm. However, we have the same power value for biogas generator optimal power, for genetic algorithm and HOMER software. The difference observed between the optimal values of the generating powers of PV, wind and the inverter, comes from fact that genetic algorithm allows sizing and optimization, while Homersoftware is only for optimization. Table-11 gives comparison between the cost of the kWh obtained by the Genetic algorithm and that obtained by the Homer software.

Table-8: Hybrid power plant optimal size calculated by Homer software.

PV power [kW]	Inverter power [kW]	Wind farm Power [kW]	Turbines number of [-]	Power of generator 1 [kW]	Power of generator 2 [kW]	Power of generator 3 [kW]
50000	7000	7500	5	1000	1000	1000

Table-9: Hybrid Power Plant Costs Calculated by Homer.

Initial capital [$]	system total cost [$]	Operating and maintenance cost [$/yr]	kWh cost [$]
88247536	259536624	13399384	0.508

Table-10: Generators optimal sizes obtained with the two models comparison.

Power Model	PV generator power [kW]	Inverter power [kW]	Biogas generator power [kW]	Wind generator power [kW]
Genetic algorithm	1386	5950	3000	4330
Homer software	5000	7000	3000	7500

Table-11: Comparison of kWh costs obtained.

Model	Genetic algorithm	Homer
kWh cost	0.536$	0.508$

The difference between the different power values of the generators has also resulted in a difference between kWh costs obtained with these two models. The results obtained show that cost per kWh calculated by Homer is 0.508$ while it is 0.536$ with the model developed and simulated with the genetic algorithm. This corresponds to a difference of about 5.22% between the two results. This gap of 5.22% seems acceptable and indicates that the model developed can very well serve as a decision-making tool in implementing hybrid PV systems, biogas generator, wind generator and without electrochemical electricity storage. Genetic algorithm used to solve our problem has required a large number of attempts to reach the global optimum. The gap observed between the model developed and the Homer software could be refined if other tests were performed. Table-12 gives the nature and quantities of the greenhouse gases produced during the combustion of biogas in the generators, obtained with the simulation in the commercial Homer software.

Table-12: Emission gas quantities from biogas generators.

Pollutant	Emissions [kg/yr]
Carbon dioxide	14,480
Carbon monoxide	357
Unburned hydrocarbons	37.1
Particulate matter	40.2
Sulfur dioxide	0
Nitrogen oxides	2,901

The amount of CO_2 equivalent is calculated by considering the effect of each gas in Table-12 on global warming, according to Equation (16). That is the equivalent of 880.98 tons of CO_2 emitted per year by our hybrid power station. The amount of biogas consumed by the generators is eighty-two thousand and seventy-six (82076) tons (Table-12).The CO_2 equivalent of this amount of biogas is one million twenty-seven thousand five hundred and eighty (1027580) tons per year. This amount of CO_2 could have been emitted into the atmosphere, if it was not valued in electricity terms. Compared to the equivalent amount of CO_2 emitted by the hybrid plant of eight hundred and eighty-one (881) tons per generator per year, we avoid the emission of the difference between the amount of CO_2 equivalent of CH_4 and that produced by the generators, that is to say about one million twenty-four thousand nine hundred and thirty-seven (1024937) tons of CO_2 per year, in the atmosphere.

Conclusion

Sizing and optimization model development for hybrid renewable energy plant, composed of photovoltaic generator, biogas generator, wind generator, without storage was carried out. The problem has been addressed for a hybrid power plant.

Using the project lifecycle cost equation, we defined an objective function, taking into account the investment, maintenance, operating and residual value of the plant elements, for 20 year life of the project.

The model developed with the genetic algorithm is a model that, in addition to giving the overall configuration of the system (PV peak power, biogas generators nominal power and number, wind turbines rated power and number, inverters rated power and number) also simulates the dynamics of the system.

The site chosen for the validation of the proposed model is the Ouahigouya site, in Burkina Faso. Owing to its large number of livestock, the Ouahigouya site has a biogas production capacity of nearly 225 tons per day. This amount of biogas makes it possible to operate high-power generators. The use of biogas generators increases the energy availability of the hybrid power plant.

The simulation carried out with the characteristics of Ouahigouya city shows that we have an optimum (that is to say, a low cost of production of kWh) for a photovoltaic penetration rate of about 51% (of the load maximum).

Also, a comparison of the results obtained with the homer software shows a difference of 5.22% between them for the simulated case, which seems encouraging. The model developed can therefore very well serve as a decision-making tool for decentralized rural electrification operators.

The choice of the method of resolution also seems to us essential for the quality of the results obtained. Thus, the increase in the number of iterations in the genetic algorithm program and the use of optimization methods other than the genetic algorithm used here, could better examine the quality of the results.

The work carried out here, is positioned as a draft software or software package able to make the technical-economic analysis of photovoltaic hybrid systems, biogas, wind and non-electrochemical storage with intelligent management of electricity production and electricity demand.

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