

# Technical-ecological optimization of the operation of a multi-source electrical system injecting into a distribution network using homer software and genetic algorithms

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**Abstract**—This work consisted in positioning and sizing a photovoltaic solar power plant with or without storage in an existing hybrid system consisting of a Diesel power plant, a hydroelectric power plant and an infinite network. Genetic algorithms and Homer software inspire the tools used. The objectives of this study are the minimization of losses, voltage deviations, greenhouse gases and the cost of energy distributed to the customer. From this study, it emerges that the optimal hybrid system is that consisting of 2.11 MW photovoltaic (1.71 MW at node 169 and 0.4 MW at node 110), 1 MW hydroelectricity, 4 MW Diesel and 1 MW Network. Greenhouse gas emissions have improved by 20.96% and the cost of hybrid energy has dropped from 166 FCFA to 120 FCFA, a decrease of 28.75%.

**Index Terms**— Decentralized sources, Genetic algorithms, Greenhouse gas, Homer software, Micro-production of renewable energy.

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## I. INTRODUCTION

Improving the massive access of populations to electrical energy associated with the development of energy infrastructure in conditions that respect the environment, constitutes an undeniable lever for the social and economic development of any country. This energy emergence allows modern changes in people's lifestyles, especially in developing countries where access to energy remains a challenge [1]. However, more and more, the planet's resources are becoming limited. Thus, optimizing and increasing energy efficiency are measures that can help ensure sustainable development [2]. Indeed, fossil fuels today represent more than three quarters of world energy consumption [3]. Large amounts of harmful and greenhouse gases are emitted into the atmosphere by thermal power plants. All countries are aware of the need to reduce the impact of these gases by reducing the share of thermal production in their energy mix. The various conferences that there have been on the climate, in particular the COP 21, 22, 23 and 24 have helped to further strengthen this energy vision, which advocates sustainable and clean energy development for

the well-being of the populations. However, the intermittent nature of renewable energies requires the adoption of an alternative solution to alleviate this problem.

Hybrid systems have proven to be well suited to answer this question. Compared to systems with a single source, they offer a high level of energy security and reliability thanks to an integrated production set [1]. However, since the electrical distribution networks are not designed in the integrated system to receive micro-productions of renewable energy, the electric power companies, in their drive to preserve the ecosystem and biodiversity by reducing thermal production of electrical energy generally face difficulties in sizing and optimal positioning of decentralized sources in current distribution networks. This difficulty is further accentuated in hybrid systems made up of hydroelectric, diesel and infinite grid power plants. Indeed, for example, the incorrect positioning of a photovoltaic power plant in a network can lead to damage such as oversizing, overloads, excessive operating costs, losses, excessive environmental pollution and prohibitive costs of kWh.

Several authors have been interested in the technical and economic optimization of hybrid systems in order to determine the configuration of the hybrid system with the best current net cost and emitting the least amount of greenhouse gases. In 2016, Ieberi R. Gbalimene and al. [4] worked on the technical and economic study of the integration of renewable energy production in the distribution network. According to the optimization results, it was observed that solar and wind energy could be exploited to meet the load profile of the Center for Satellite Technology Development and that the grid power system alone seems the most profitable. HOMER software was used as a simulation tool.

In 2017, Mohammed BOUSSETTA and al. [5] also used the HOMER software to carry out the technical and economic study of a hybrid electrical energy production system (photovoltaic / wind / battery), connected to the electricity grid. The case study is the power supply of a villa, with an installed power of 13.82 kW, located in the city El Hajeb, in Morocco. Authors have also studied the optimal integration of decentralized energy sources in distribution networks. Thus, Hung and al. [6] presented in 2014 a methodology for the integration of distributed (distributed biomass) and non-dispatched (wind) production units of renewable energy into electricity networks with a view to minimizing annual energy losses. This work will focus on the technical-ecological optimization of the operation of a multi-source electrical system (PV- Diesel - Hydroelectricity - storage) injecting into a distribution network using Homer software and genetic algorithms.

## II. MATHEMATIC MODELS

### A. Modeling of the PV-Diesel-Hydro hybrid system

#### 1. Diesel generator model

A diesel group is characterized by its fuel consumption and its efficiency. So if the generator is running for a given hour, HOMER calculates the fuel consumption for that hour using equation [7]:

$$F = AP_g + BP_{ng} \quad (1)$$

- $F$  the amount of fuel consumed to produce electricity in [L/hr];
- $P_g$  the power generated in [kW];
- $P_{ng}$  the nominal power of the generator in [kW];
- $A$  and  $B$ , the coefficients of the consumption curve in [L/hr/kW].

For our study, the values of  $A$  and  $B$  were taken respectively equal to 0.0169 L/hr/kW and 0.2486 L/hr/kW.

The efficiency of a diesel generator can be calculated from equation [7]:

$$\eta = \frac{3600P_{ng}}{\rho \cdot F \cdot P_c} \quad (2)$$

- $\eta$  Electrical efficiency;
- $\rho$  Fuel density in [kg/m<sup>3</sup>];
- $P_c$  the calorific value of the fuel in [MJ/kg].

The respective values of density and calorific value of diesel are: 820 kg/m<sup>3</sup> and 43.2 MJ / kg. Equations 1 and 2 were used for the modeling of the diesel generators in the case of the hybrid system studied. These equations are integrated into the HOMER software used for the simulations.

#### 2. Model of a micro-hydroelectric plant

HOMER calculates the electric power generated by a micro-hydroelectric plant using equation [1].

$$P_{MHP} = \frac{9.81 \cdot \eta_{Hydro} \cdot Q \cdot \rho_{Water} \cdot h_{nette}}{1000} \quad (3)$$

- $P_{MHP}$  the electrical power generated at the turbine outlet in [kW];
- $\eta_{Hydro}$  the efficiency of the turbine in [%];
- $Q$  the flow in [m<sup>3</sup>/s];
- $\rho_{Water}$  the density of water in [1000 kg/m<sup>3</sup>];

- $h_{nette}$  the net fall height in [m]

The turbine used in this study is the Pelton turbine. It is used for hydroelectric plants with high falls and its maximum efficiency varies between 84% and 90% [1]. In this study, we worked with 84%. As for the flow, we used the average annual flow of the Kiatiko river which is  $0.481 \text{ m}^3/\text{s}$ .

HOMER calculates the net height of the fall using equation [1]:

$$h_{nette} = h(1 - f_h) \quad (4)$$

- $h$  the gross height ;
- $f_h$  the pressure losses.

As part of a preliminary study of a small hydraulic power station, the pressure drops to be considered represent around 10% to 15% of the gross head [1]. Therefore, we chose 15% to put ourselves in the extreme case.

### 3. Model of a PV power plant

HOMER calculates the electric power generated by a PV power plant using equation [4]:

$$P_{solar} = P_{STC} \cdot f_{PV} \left( \frac{\bar{G}_T}{\bar{G}_{STC}} \right) [1 + \alpha_p (T_c - T_{c,STP})] \quad (5)$$

- $P_{STC}$  the electrical power generated by the panels under standard test conditions ;
- $f_{PV}$  the downgrade factor (80 %);
- $\bar{G}_T$  the incident radiation ;
- $\bar{G}_{STC}$  the radiation under standard test conditions ( $1000 \text{ W/m}^2$ ) ;
- $\alpha_p$  the power temperature coefficient in [%/°C], its value varies between 0.4 and 0.5 %/°C for the case of crystalline silicon cells. For this study, we used 0.5 %/°C to put in the extreme case.
- $T_c$  the temperature to which PV cells are subjected in [°C]. The annual average temperature in Natitingou is equal to 26.8 °C.
- $T_{c,STP}$  the temperature to which PV cells are subjected under standard test conditions [25° C].

### B. PV plant insertion model

For a PV power plant, the reactive power is not considered. In the power flow, the active power injected at node  $i$  where a PV power plant is connected is defined according to equation 6 :

$$P_D^* = P_{Di} - P_{Vi} \quad (6)$$

With  $P_{Di}$  the active power of the load at node  $i$  and  $P_{Vi}$  the active power of the PV power plant.

### C. Economic models

#### 1. The current net cost

The current net cost ( $C_{NPC}$ ) represents the life cycle cost of the system. HOMER calculates ( $C_{NPC}$ ) according to equation (7). This current net cost is given by [7].

$$C_{NPC} = \frac{C_{ann,tot}}{CRF} \quad (7)$$

With  $C_{ann,tot}$  the total annualized cost of the system and  $CRF$  the capital discount factor.

#### 2. The discount factor

The capital discount factor is given by the equation [4]:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (8)$$

With  $i$  the real interest rate and  $N$  the number of years (the life of the project is fixed at 20 years). For this study, the real interest rate is 8%.

#### 3. The real interest rate

The annual interest rate can be calculated using the equation 9. It is given by [4]:

$$i = \frac{i' - f}{i' + f} \quad (9)$$

With  $i'$  the nominal interest rate and  $f$  the annual inflation rate.

#### 4. The levelized cost of energy (LCOE)

HOMER defines the levelized cost of energy (LCOE) as the average cost per kWh of useful electrical energy produced by the system. The LCOE is calculated by the equation [7]:

$$LCOE = \frac{C_{ann,tot}}{E} \quad (10)$$

With  $E$  the total amount of energy supplied by the system.

## III. POWER FLOW STUDY

The Newton-Raphson method was used for the study of the power flow of the HTA network from Natitingou. The strong convergence and the simplicity of this method are the main reasons of this choice. The Newton-Raphson algorithm implemented in Matlab allowed us to obtain figure 1.

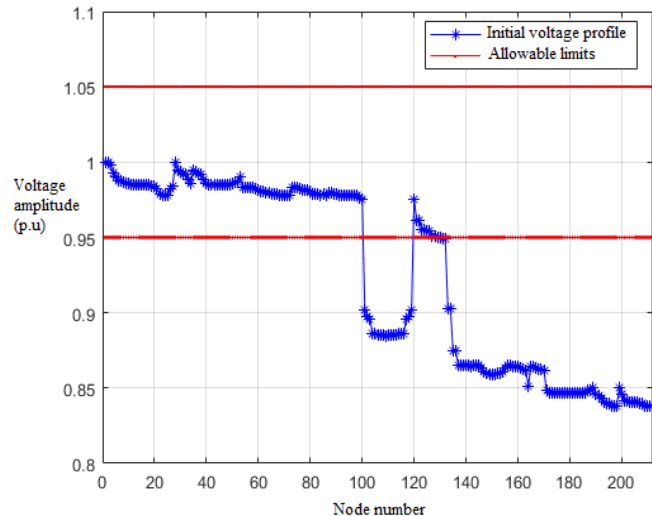


Fig. 1 : Voltage profile of the Natitingou HTA network

The area delimited by the two red lines is the range specified by standard NF EN 50160, and in which the voltages must be located.

On examining the figure 1, we note that 107 nodes out of 211, or approximately 50.71 % of the nodes are not in the range specified by standard NF EN 50160. The lowest tension is that of node 211 and its value is 0.8378 p.u or 16.756 kV (instead of 20 kV). The voltage drops are composed between 1 % and 16.22 % of the nominal voltage, which is not in accordance with the specifications of standard NF EN 50160, which stipulates that the voltages must be in the proportions of  $\pm 5\%$  of the nominal voltage. The active losses in this network are estimated at 407.1 kW while reactive losses are estimated at 351.4 kVar.

#### IV. OPTIMIZING THE DIMENSIONING AND POSITIONING OF THE PV POWER PLANT

The HTA departure from Natitingou is too long and therefore generates huge technical losses. In this study, the NSGA II genetic algorithm was used to find the optimal position and size of the PV power plant, to be injected into the network in order to reduce losses and improve the voltage profile.

##### A. Optimization criteria

- Minimization of active losses

One of the main goals for economic reasons is to minimize online losses. The function to minimize is:

$$f_1 = P_{loss} = \sum_{j=1}^{n_b} R_j I_j^2 \quad (11)$$

- $R_j$  the resistance of branch  $j$  ;
- $I_j$  the current in branch  $j$  ;
- $n_b$  the number of branches.

- Minimization of voltage deviation

This objective consists in improving the network voltage profile.

$$f_2 = \sum_{i=1}^n |V_i^{ref} - V_i| \quad (12)$$

- $V_i$  the voltage at node  $i$  ;
- $V_i^{ref} = 1$  p.u, the reference voltage ;
- $n$  the number of nodes.

- Minimization of the cost of the PV plant

The cost of the PV plant is proportional to the size of the latter. It is formulated by equation (13).

$$f_3 = 1000 \cdot C_{PV} \cdot P_{PV} \quad (13)$$

With  $C_{PV}$  the cost of the PV plant in \$/kW and  $P_{PV}$  the total power supplied by the plant in MW

- Weighting of objectives

The weighting of the objectives was carried out using an aggregate method (the weighted average method) to combine the objective functions  $f_1$  and  $f_2$ .

$$F_1 = \omega_1 \cdot f_1 + \omega_2 \cdot f_2 \quad (14)$$

With  $\omega_1 = \omega_2 = 0.5$

The objective functions finally retained for the NSGA-II algorithm are  $F_1$  (equation 14) and  $F_2 = f_3$

##### B. Constraints

The optimization of the functions listed above was carried out under the following constraints:

$$P_{slack} + P_{thermal} + P_{hydro} = \sum_{i=2}^n P_D + P_{loss}$$

$$Q_{slack} = \sum_{i=2}^n Q_D + Q_{loss}$$

$$P_{PV} \leq 0,3 * \sum_{i=2}^n P_D (i)$$

## V. RESULTS AND DISCUSSIONS

Figure 2 shows the voltage profiles for different scenarios. The solution chosen from the Pareto front indicates that a 2.11 MW PV power plant must be positioned at node 169 of the Natitingou distribution network for efficient supply of active power and reduction of active and reactive losses. The voltage profile after positioning of the 2.11 MW PV plant at node 169 is shown in black. However, despite this optimal positioning, nodes 101 to 119 still don't have their tensions in the normative range. Thus, a PV power of 1.71 MW was injected at node 169 and another 0.4 MW at node 110. This made it possible to bring all the voltages back to the normative range recommended by standard NF EN 50160. Active losses on the network went from 407.1 kW to 100.2 kW, a reduction of 75.39 % while the reactive losses went from 351.4 kVar to 83.6 kVar, i.e. a reduction of 76.21 %.

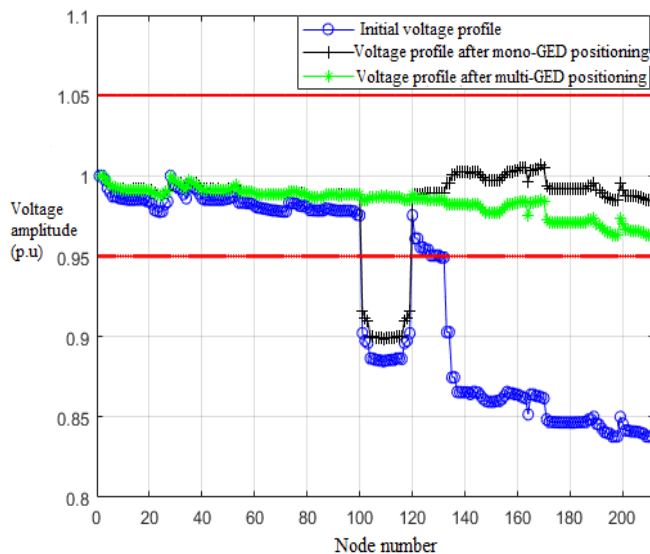


Figure 2 : Voltage profiles

The photovoltaic power obtained from the NSGA II was passed as a parameter to the HOMER software, in order to determine the different combinations of hybrid systems that can effectively respond to the load profile at the Bérécingou substation, with a minimum of pollutant rejection and an affordable cost of energy.

The table I shows the results of the different simulation scenarios. It is observed that this is the scenario consisting of PV (2.11 MW) + hydro (1 MW) + Diesel (4 MW) + Network (1 MW) which offers a lower energy cost of 120 FCFA with a harmful gas emission of 20,464,022 (kg/year), i.e. a reduction of 20.96%. Compared to the diesel alone option in the network, this option also allows a reduction in losses of almost 80.47%.

**Table I :** Simulation results of injection scenarios in the network.

Systems	LCOE (FCFA /kWh)	CO <sub>2</sub> emissions (kg/year)	Active losses (kW)
PV (2.11 MW) + hydro (1 MW) + Diesel (4 MW) + Network (1 MW)	120	20,464,022	79.5
PV (2.11 MW) + hydro (1 MW) + Diesel (4 MW) +	142	20,854,724	-
Hydro (1 MW) + Diesel (4.5 MW)	152	23,256,810	-
PV (2.11 MW) + Diesel (4.5 MW)	157	23,486,774	-
Diesel (4.5 MW)	166	25,890,416	407.1

## VI. CONCLUSION

This technico-ecological optimization work is a rational and efficient technique for operating a multi-source and ecologically efficient system. It can minimize the proportion of diesel in an energy mix and reduce substantially the cost of electrical energy. The combination of the two tools Homer software and NSGA II is effective and can be used to optimize and reduce progressively depending on the vagaries of demand, the share of thermal in a multi-source system (hydro-thermal- PV). The results obtained of this study are economically viable and sustainable, and can be implemented in island electrical systems in order to improve their efficiency and minimize costs and greenhouse gas pollution.

## REFERENCES

- [1] Issa DAGNON. Etude de faisabilité technico-économique d'une centrale électrique hybride hydroélectrique-solaire-PV-stockage : Cas de la localité de Farako au Mali. Mémoire de Master en Génie électrique, 2IE, 2018, 79 p.
- [2] Nassim HOCINI & Elyazid TAZAMOUCHE. Sur la maîtrise de l'insertion des ressources renouvelables aux réseaux électriques. Mémoire de master en électrotechnique, Université ABDERAHMANE MIRA DE BEJAIA, 2015, 88 p.
- [3] GEO. *Les énergies fossiles* [en ligne]. (Modifié le 19 Juin 2012). Disponible sur : <https://www.geo.fr/> (Consulté le 22/11/2019)
- [4] Ileberi R. Gbalimene, Adikankwu O. Henry, Timi A. Ekubo, and Adenekan I. Olanrewaju, « Grid Integration of Renewable Technology: A Techno-economic Assessment. » American Journal of Mechanical Engineering vol. 4, no. 5 (2016): 182-190. doi : 10.12691/ajme-4-5-3.
- [5] Mohammed BOUSSETTA, Ilyas KHELAFAT, Saad MOTAHHIR, Abdelaziz ELGHIZAL, Aziz DEROUICH, Optimisation technico-économique d'un système hybride PV/Eolien/Batterie connecté au réseau pour l'électrification d'une villa, 2ème Colloque franco-marocain sur les Energies Renouvelables et leur intégration aux réseaux de transport et de distribution, Avril 2017
- [6] Duong Quoc Hung, N. Mithulanathan, Kwang Y. Lee, « Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss », *Electrical Power and Energy Systems* 55 (2014) 179–186
- [7] Makbul A.M. Ramli, Ayong Hiendro & Sennoga Twaha. Economic analysis of PV/diesel hybrid system with flywheel energy storage, *Renewable Energy* 78 (2015) 398-405. Available on <www.elsevier.com/locate/renene>
- [8] Oloulade Arouna and al. "Multi-objective Optimization of the Voltage Static Stability Margin of a Distribution Network by Genetic Algorithms." *American Journal of Engineering Research (AJER)*, vol. 9(04), 2020.