DYNAMIC SIZING OF HYBRID RENEWABLE ENERGY SYSTEMS FOR SUPPLYING AN INDIVIDUAL HABITATION

Toufik SEBBAGH
Département de Génie Mécanique, Université 20 Aout 1955 – Skikda, Algérie
BP 26, Route el hadaïek, Skikda, Algérie, sebb_t@yahoo.fr

Abdelouahab ZAATRI
Département de Génie Mécanique, Université Constantine 1 – Constantine, Algérie
BP, 325 Route de Ain El Bey, Constantine, Algérie, azaatri@yahoo.com

Ridha Kelaiaia
Département de Génie Mécanique, Université 20 Aout 1955 – Skikda, Algérie
BP 26, Route el hadaïek, Skikda, Algérie, RidaKelaia@hotmail.com

Abstract: This paper presents a study and a simulation to find the optimal design of a Hybrid Renewable Energy System (HRES) designed for the electrification of a house located in the village of El-Hadaïk near the city of Skikda northeast Algeria. The system consists of two renewable resources: a PV generator and a wind turbine. It also includes two back-up systems: a diesel generator and batteries. Homer software is used to dynamically analyze different combinations. It allows the determination of an optimal analysis based on the estimation of the Net Present Cost "NPC". The results are used to select the most economical hybrid system for the chosen site.

Keywords: Hybrid renewable energy systems, dynamic sizing, optimization, PV generator, wind turbine.

1. Introduction

At present, energy transition becomes a necessity because of depletion of fossil fuels, changes in their prices and the negative influence of greenhouse effect on the environment. Therefore, it is imperative to find alternative energy sources that can cover the continuous demand of energy and minimize the negative environmental impact, as well. Hybrid Renewable Energy Systems (HRES) are complex systems combining at least one renewable source with one or more conventional sources. The main advantage of HRES is that they offer some energy autonomy as they do not depend on a single source [1]. They also can solve at a very large part the problem of energy availability [1,2].

In the context of HRES and in many areas, hybrid solar and wind energy systems have become increasingly significant, attractive and cost-effective. Nevertheless, to ensure sufficient energy supply. backup energy systems and / or storage systems are required.

However, the choice of renewable energy sources and the design of such system is difficult because it depends on climatic conditions and must respond to the load profile as well.

This paper aims to determine the optimal design of a HRES including PV modules and wind turbines to supply a house. It includes also a diesel generator and some batteries used as a backup system.

2. Methodology

2.1. Problem Assessment

We intend to supply a house with electrical energy generated by a hybrid renewable energy system constituted of a PV generator and a wind turbine. The system involves some storage batteries and a diesel generator as a backup elements.

The problem to be solved is to find the optimal combination ensuring continuity of energy supply at minimum costs.

2.2. Potential resources

The city of El hadaeïk is located at about 3 km far from the city of Skikda, north-east of Algeria. The metrological data are presented in table 1. It presents the monthly mean value irradiance, temperature and wind speed.

Table 1: Synthesized, metrological data for el Hadaik city [4]

Month	Irradiance (kWh/m2/day)	Temperature (°C)	Wind speed (m/s)
January	2.27	7.82	5.35
February	3.15	8.93	5.45
March	4.26	11.7	5.48
April	5.22	14.9	5.42
May	6.20	20.2	4.61
June	6.91	25.3	4.32
July	7.08	28.4	4.38
August	6.12	28.2	4 .37
September	4.93	23.5	4.22
October	3.53	19.0	4.45
November	2.42	13.4	5.25
December	2.00	9.36	5.45

According to data from table 1, the solar irradiance is important during the period going from March to

September. Whereas, the average wind speed is particularly useful for power generation by wind turbines from January to April.

2.3 Components of the system

2.3.1 Load profile

The hybrid modeling in this study is performed to supply a house. The considered loads are shown in table 2.

Table 2: illustration of the load profile

Devices	Number	Power (W)
Lamps	5	75
Lap top	2	65
TV	1	140
Demo	1	30
Refrigerator	1	230
Air Conditioner	1	880/ cooling 870/ heating
Washing machine	1	360/ washing 160/spin
Hair dryer	1	2000
Iron	1	1200

Total energy consumed $Etot$ is the sum of all daily energy needs (E_i), it can be calculated as:

$$Etot = \sum E_i \qquad (1)$$
$$E_i(in\ Wh) = P_i.t \quad (2)$$

Where:

P_i: Power of unit i (in W).

t: Time (in hours)

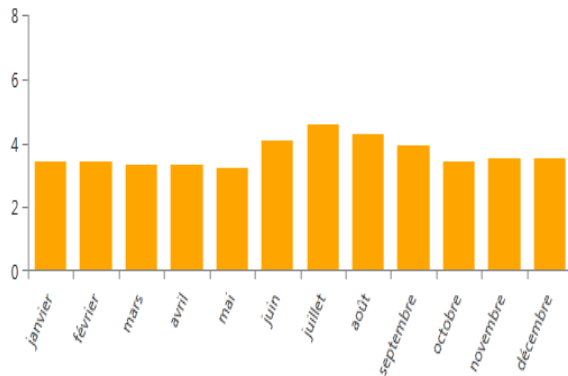Fig. 1 presents the average annual repartition of energy consumed each month.

Fig. 1. monthly average consumption

2.3.2 PV module

Solar energy is converted to electrical energy via PV modules based on the photovoltaic effect. Optimizing the performances of a module may be performed using a performance model [5]. Several models exist in the literature, one of them is given by [6-8]:

$$I = N_P I_{PH} - N_P I_S \left[exp\left(\frac{q}{K_1 T_C A} * \left(\frac{V}{N_S} + \frac{IR_S}{N_P} \right) \right) - 1 \right] - \frac{1}{R_{SH}} * \left(\frac{N_P V}{N_S} + IR_S \right) \dots\dots\dots \quad (3)$$

Where:

I_{PH}: Photocurrent

I_S: cell saturation current

q: Electron charge. q=1.6×10-19C

k: Boltzmann's Constant. k=1.38 × 10-23 J/K

Tc: cell operating temperature

R_{SH}: shunt resistance

R_S: Series resistance

IR_S: cell reverse saturation current

N_P: Number of parallel cells

N_S: Number of series cells

Energy produced by a PV panel can be estimated as [8-10]:

$$E_{ph} = P_r \times F_0 \times \frac{G_{eff}}{G_0} \times P_C \qquad (4)$$

Where:

P_r: performance index

F_0: factor that takes into account losses

G_{eff}: annual effective irradiance incident

G_0: Irradiance under standard conditions

P_C: Nominal power supplied by the manufacturer

The capital cost per kW of a PV module is about 360.04€, the replacement cost is assumed to be 360.04€ with a maintenance cost of 10 €. The lifetime of the PV system is considered to be of 25 years, the efficiency of the PV module is 13%, the derating factor is of 80% and ground reflectance is of 20% without tracker.

2.3.3 Wind turbine

The energy produced by a wind turbine depends on three main factors: wind speed, blade length and its height. It can be estimated using the following formula:

$$E_{eol} = \frac{1}{2} C_P \times \rho \times S_T \times V^3 \qquad (5)$$

Where:

C_P: wind turbine efficiency;

ρ : air density (=1.225 Kg/m3);

S_T: area swept by the rotor (= $\pi.R^2$ / R is the length off a blade)

V: is the wind speed (in m/s). It is dependent on its height and can be expressed by the following formula:

$$V = V_0 \times \left(\frac{H}{H_0} \right)^\alpha \qquad (6)$$

V_0: Is the wind speed (in m/s) at the reference length H_0 (10m)

In this study, we consider a "1KW AIGER" wind turbine with a capital cost of 1,690€, a replacement cost of 1,690 € and an O & M cost of 70 € / year.

2.3.4 Storage system

Lead-acid batteries are chosen as storage system. They have a deep cycling [11]. Fig. 2 present the ideal model of a battery.
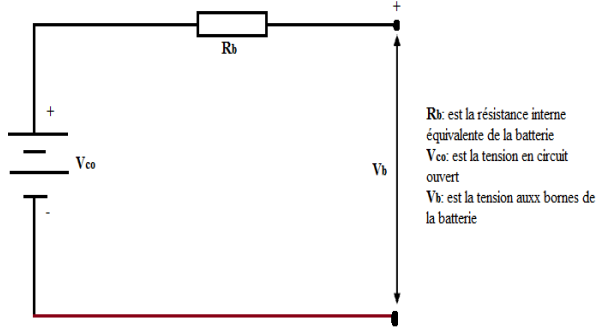

Rb: est la résistance interne équivalente de la batterie
Vco: est la tension en circuit ouvert
Vb: est la tension auxx bornes de la batterie

Fig. 2. Ideal model of a lead-acid battery

The state of charge of the battery is subject to the following constraint:

$$SOC_{max} \geq SOC(t) \geq SOC_{min} \qquad (7)$$

Where:

SOC_{max} : is the maximum allowable storage capacity. It corresponds to a nominal capacity of all accumulators (C_n), and is related to the total number N_b, the number of series connected batteries N_{bs} and the capacity of each battery C_b such as [12]:

$$C_n = C_b \left(\frac{N_b}{N_{bs}}\right) \qquad (8)$$

SOC_{min} : is the minimum allowable storage capacity, it is related to SOC_{max} as:

$$SOC_{min} = (1 - DOD) \cdot SOC_{max} \qquad (9)$$

DOD: is the depth of discharge of the battery.

The battery used is a "generic 1 Wh Lead Acid". This reference model has a nominal voltage of 12 volts and a nominal capacity of 83.4 Ah. The capital and the replacement costs are assumed to be 300€/unit, both, the Maintenance cost is supposed to be 10 €.

2.3.5 Converter

For this study the converter "Leonic S219CPH 8VDC 5K" is considered, with an expected lifetime of 15 years, an efficiency of 96% for the inversion process, and 94% for rectification

The inverter capital cost per kW, the replacement and maintenance costs are respectively: 600€, 600€ and 0€.

2.3.6 Diesel generator

The diesel generator is used as a backup system to provide the amount of energy not met by renewable energies, but also to charge the batteries.

The diesel generator used for this study with a power of 10Kw, the capital and replacement costs are estimated at 3000€ each.

3. Problem formulation

The primary concern in the design of the hybrid power system is to determine the size of each component, so that the load can be satisfied economically and reliably.

Considering the sources of renewable energy such as PV (E_{pv}), wind turbine (E_E) with the limits (L_{PV}) and (L_E) and the unit costs of electricity C_{PV}, C_E, generated by PV panels and wind turbine respectively.

The objective function is to minimize the cost of energy(COE) while meeting electricity demand (D) under certain constraints, it can be formulated as:

$$\begin{cases} \min COE = \sum Cu_i N_i E_i \\ \sum N_i E_i = D \\ E_i \leq L_i \\ E_i \geq 0 \\ N_i \geq 0 \end{cases}$$

$$\begin{cases} \min COE = 0.21 E_{PV} + 0.08 E_E \\ E_{PV} + E_E = 3000 \, (KW/AN) \\ E_{pv} \leq 1650 \\ E_E \leq 1700 \\ E_i \geq 0 \\ N_i \geq 0 \end{cases}$$

The optimal repartition of renewable energies and their percentage to participate to satisfy the global demand is presented in table 3

Table 3: Optimal energy repartition

Data			Results	
Energy resources	Unit costs	Capacity limit	Energy repartition	
Ei	€/kWh	kWh/year	kWh/year	%
EPV	0.21	1650	1300	43.3
EE	0.08	1700	1700	56.7
D = 3000 (kWh/year)			Minz = 526	

Knowing the characteristics of the energy and of the site, this technique enables to sizing the appropriate renewable energy system to be used.

4. Results and discussion

To determine the best mix of energy sources for the selected site, a number of possible combinations are simulated with the software Homer. Following assumptions are considered:

- Minimum fraction of renewable energy for all combinations is of 70% with an annual allowable shortage capacity equal to 5%.
- The time life of the simulated project is 25 years with an annual interest rate of 8%.

Table 4 shows an illustration of the different costs for different configurations.

The lowest net present cost (NPC) is for the mix containing (PV + Batteries) with 2930 €, this cost increases for other configurations to reach 7827€ for system containing (PV/DG/batteries). The cost of energy (COE) have a minimum value (0,179 €) for the (PV + batteries) system while it reaches a max value for the (PV/DG/batteries) system. The operation cost has its maximum value (144,76 €) for the (PV/ Wind Turbine/ batteries) but it has always the minimum value for the sensitive case (PV + batteries).

Table 4: composition of costs for different configurations of HRES

	COE (€)	NPC (€)	Operation Cost (€)	Initial Capital (€)	fuel Cost (€)	O&M (€)	ER Fraction (%)
PV/Batteries	0.179	2930	78.10	1920	0.00	26.67	100
Wind Turbine/Batteries	0.272	4718	141.43	2890	0.00	90.00	100
PV/ Wind Turbine/ batteries	0.296	5121	144.76	3250	00.00	93.33	100
Wind Turbine/ GD/ batteries	0.405	7018	87.23	5890	0.00	90.00	100
PV/ Wind Turbine/ G D/ batteries	0.429	7421	90.56	6250	0.00	93.33	100
PV/G D/ Batteries	0.452	7827	113.47	6360	19.99	5.10	71

Table 5: optimum sizing of different HERS configurations

	PV (kW)	N° des Eoliennes	D G (kW)	N° des Batteries	Converter (kW)
PV/Batteries	2.00			2	1.00
Eolienne/Batteries		1		2	1.00
PV/ wind turbine/ batteries	1.00	1		2	1.00
wind turbine/ GD/ batteries		1	1.00	2	1.00
PV/ wind turbine/ G D/ batteries	1.00	1	1.00	2	1.00
PV/G D/ Batteries	6.00		1.00	2	1.00

Table 5 illustrate the optimal sizing of the system, for different configurations. PV/Batteries is the sensitive case that require a configuration for 2 kW PV, 2 batteries and 1kw from the converter.

The NPC for this combination is spread over the three components, as shown in the histogram of the figure 5. In this histogram, we can observe that batteries consume 45% of the discounted cost of the system with a total of 1316,70€
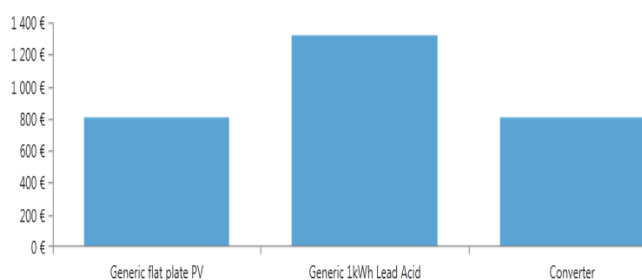

Fig. 3. repartition of the discounted cost on the components of the system

5. Conclusion

This paper presents a study on the feasibility of a hybrid renewable energy system, to supply a standalone habitation, using Homer software.

Several combinations were simulated, and the feasible configurations are ranked according to NPC & COE. Among these combinations, and according to COE, the (PV / Batteries) is the optimal system economically with 0,179 €/kWh, and environmentally with no greenhouse effects.

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