OPTIMAL SIZING OF A HYBRID RENEWABLE ENERGY SYSTEM TO FEED A CLINIC IN THE REGION OF TAMANRASSET

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ABSTRACT

This paper presents a techno-economical study for the optimal sizing of a hybrid renewable energy system dedicated for the electrification of a health care clinic, installed in the region of Tamanrasset, in the extreme south of Algeria.

The proposed hybrid system is constituted of PV arrays, wind turbine, storage batteries, inverters, regulators and a Liquefied Petroleum Gas (LPG) genset as a backup system.

The analysis of our hybrid system and its optimal sizing will be performed by means of HOMER software which has been developed for designing and analyzing hybrid power systems incorporating various type of energy sources.

Key Words: *Renewable energy, clinic, optimal sizing, Hybrid system, Homer.*

NOMENCLATURE

I_{PH}: Photocurrent	IS: Cell's saturation current
q: Charge of electron. q=1.6*10-19C	k: Boltzmann's constant k=1.38*10-23J/K
T_C: Cell effective temperature (°C)	A: Ideal factor dependent of the PV characteristic, A=1.3 for poly-crystalline solar cell
RSH: shunt resistance (Ω)	R_S: Series resistance
I_{SC}: Short circuit current at STC (A)	VOC: Open circuit Voltage (V)
K_1: Temperature coefficient of short circuit current	T_{ref}: Cell reference temperature
G: Solar irradiation (in Wh/m2)	IRS: Cell Inverse saturation current (A)
E_G: Gap energy (for crystalline silicium = 1.12 eV)	N_P: Number of parallel cells
NS: Number of series cells	η_r: Reference module efficiency

β: Temperature coefficient

$Tcref$: Reference cell temperature (in °C)

G(t): Solar irradiation (in Wh/m2)

S : Area swept by the turbine [m2] blades,

C_p: Rotor power coefficient

R_r: Rotor radius [m]

T_c: Cell effective temperature (in °C)

A: PV generator area (in m2)

ρ : Air density

V_w: Wind speed [m/s]

wr: Rotor angular speed [rad/s]

1. INTRODUCTION

One of the important challenges in Algeria is the provision of electricity for empowering health care services in isolated Saharan locations. Standalone hybrid renewable energy systems can play a strategic role in solving this issue and in providing sustainable development of the region.

In particular, Algeria has the highest solar potential in the world. Algeria has also quite windy. 78% of its surface is characterized by velocities exceeding 3 m/s with about 40% of these speeds are above 5 m/s [1].

Tamanrasset is a large province located at the south of Algeria (22.78 5.51 378m). It is characterized by an average annual global solar irradiation of 6300 Wh/m2 and an average sunshine hours of 9.32 h [2]. The LPG gas is cheap, environmentally friendly, and available in Algeria.

This paper focuses on the technico-economic study of a hybrid energy system constituted of three sources of energy: a photovoltaic generator, a wind turbine generator and an LPG generator, intended to feed a public clinical building such as a clinic to be installed in the region of Tamanrasset.

The analysis of the proposed hybrid system and its optimal sizing will be performed by means of HOMER software, which has been developed for designing and analyzing hybrid power systems, which contain a mix of conventional generators, cogeneration, wind turbines, solar photovoltaics, hydropower, batteries, fuel cells, hydropower, biomass and other inputs [3].

2. LOCATION AND RESSOURCES

The clinic is to be located in Tamanrasset, Algeria (22°47'19" N, 5°31'32" E). Figures 1 and 2 show the monthly average wind speed [4] and solar radiation [5], respectively, for this location.

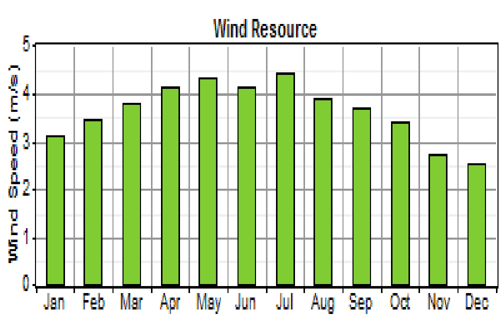

FIGURE 1. Monthly variation of mean wind speed at Tamanrasset

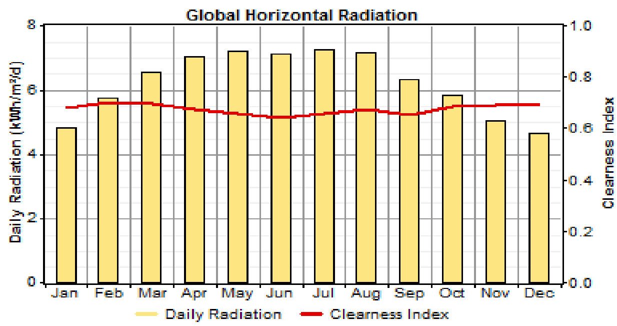

FIGURE 2. Average solar radiation at Tamanrasset

The studied location has a high solar irradiance and a considerable speed wind. The average radiation is 6.3 kW/m2/day, and the average wind speed is estimated at 3.63 m/s. These data are used as inputs for the software.

3. LOAD PROFILE

A typical clinic building consists of: a doctor room, nurses' room, two treatment rooms, an administration room, a small pharmacy, two restrooms and a waiting room. Medical equipment, lighting and other devices used in the clinic are summarized along with the required electric consumption in Table 1.

	Quantity	Power (Watts)	Time of use (h)	Energy required (W/h)
Lamps	13	20	12	3120
Lamps (out)	2	20	2	80
Refrigerator	1	80	14	1120
Freezer	1	80	14	1120
Vaporizer	1	50	3	150
Oxygen concentrator	1	300	2	600
Electric sterilizer	1	1500	3	4500
Water pump	1	100	6	600
TV set	1	150	12	1800
Ceiling fan	7	60	12	3840
Evaporative cooler	3	500	12	18000
Total AC average daily load = 34.93 KWh				

TABLE 1. Illustration of clinic load profile [6,7]

4. SYSTEM COMPONENTS

The proposed hybrid system is composed of the PV array, wind turbine, storage batteries, inverter, charge regulator and an LP gas genset as a backup system. The initial choice of component's size is based on a load profile. The architecture of the proposed hybrid system is shown below in Figure 3.

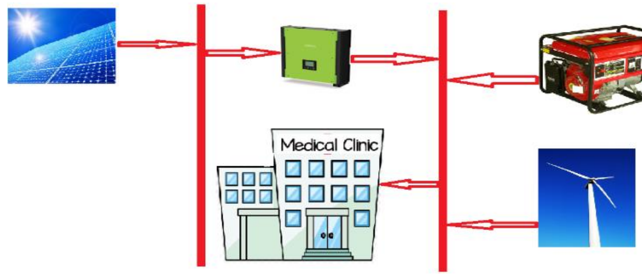

FIGURE 3. Architecture of the proposed system

Table 2 summarizes technical and economical data for different components of the proposed hybrid system as required by HOMER.

Parameters	Values	Parameters	Values
PV Array (CEM235-P 60 / polycrystalline)		Wind turbine (FD4.0-3000)	
Rated capacity	235 w	Rated power	3KW
Capital cost	30000 DA	Hub weight	3.8 m
Replacement cost	30000 DA	Capital cost	552812,86 DA
O & M cost	2332,36 DA	Replacement cost	552812,86 DA
Estimated life cycle	25 years	Estimated life cycle	25 years
GPL genset		O & M cost	4442,58DA
Rated Power	4,5 kW, 8 A	Power converter	
Capital cost	39000 DA	Rated Power	2kW
Replacement cost	39000 DA	Efficiency	90%
O & M cost	300 DA/hr	Capital cost	21000 DA/kW
Fuel cost (GPL)	9 DA/l	Replacement cost	21000 DA/kW
Operational life	15,000hrs	O&M cost	1200 DA/yr
		Operational lifetime	15 year

TABLE 2. Hybrid renewable energy system components details

Mathematical modeling of the different component is given in the following subsection.

4.1. PV ARRAY:

The mathematical model of the PV array is given in [8].
Equation (1) represents the characteristic I(V) of the PV panel

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

The photocurrent is given as:

$$I_{PH} = \left[I_{SC} + K_1 \left(T_C - T_{ref} \right) \right] * G \text{ ……….. (2)}$$

Equation (3)

$$I_S = I_{RS} \left(\frac{T_C}{T_{ref}} \right)^3 * exp\left[\frac{qE_G}{KA} \left(\frac{1}{T_{ref}} - \frac{1}{T_C} \right) \right] \text{ ……….. (3)}$$

The Cell's saturation and Inverse saturation currents are presented in (4) and (5) respectively.

$$I_{RS} = \frac{I_{SC}}{exp\left(\frac{qV_{OC}}{N_S k A T_C} \right) - 1} \text{ ……….. (4)}$$

$$T_C = T_{Air} + \frac{NOCT - 20}{800} A \text{ ……….. (5)}$$

The energy provided by solar panels is expressed by the following formula [9]:

$$P(t) = \eta_r * \left[1 - \beta * \left(T_c - T_{cref} \right) * A * G(t) \right] \text{ ……….. (6)}$$

4.2. WIND TURBINE:

Wind turbine converts kinetic wind energy into mechanical energy and then to electrical energy by means of an electrical generator.

The power produced by a wind turbine mainly depends on the interaction between its rotor and the wind. The available wind Power can be expressed by:

$$P_{wind} = \frac{1}{2} \rho S V_w^3 \text{ ……….. (7)}$$

The extractable power can be written as:

$$P_{Rotor} = \frac{1}{2} C_p \rho S V_w^3 \text{ ……….. (8)}$$

C_p: Rotor power coefficient, defined as the ratio of extractable power to available power. Betz [10] proved that C_p= 0.5926 under ideal conditions.

The ratio of the blade-tip linear speed to the wind speed, known as teep speed ratio and denoted λ can be expressed as [11]:

$$\lambda = \frac{w_r . R_r}{V_w} \text{ ……….. (9)}$$

4.3. LPG GENERATOR:

The choice of the proposed LPG genset is due to the availability of LPG in Algeria, its concurrent price and less ecological impact. The GPL gas current delivered by the generator is given by the formula (10), and the rated power is given by formula (11).

$$I_{DG}(t) = I_{DG\_max} * x_{DG}(t) \text{ ……….. (10)}$$

$$P_{DG}(t) = \sqrt{3} * I_{DG}(t) * U_{DG_{nom}.AC} * cos\varphi \text{ ……….. (11)}$$

4. RESULTS

This paper aims to determine the size of the hybrid system with the imposed following assumptions:

- Renewable energy penetration is at least 90% of the total energy produced.

- The annual loss of load probability value is 5% max.
- There is no loss of load probability.

The proposed system is simulated using Homer software. The provided economic inputs (capital, replacement and O&M costs, fuel cost… etc.), allow the software to evaluate the economics of the project.

The obtained optimal result by simulation is illustrated in Table 3. The proposed configuration requires 15 kW obtained from the PV system, 2 wind generators, 0.1 kW and 3 kW obtained respectively by LPG genset and the inverter.

The economics of the system are competitive, with a cost of 14.74 DA per kWh and an annual cost of fuel of 35576 DA, the total net present cost (NPC) is evaluated at 2200704

Environmentally, the renewable energy fraction of the proposed system is very close to 100%, and the quantities of different pollutant emissions are too low with a maximum of 60.6 kg/ year of the greenhouse effect, Nitrogen oxides emission is about 1.82 kg/year and the other emissions are under 1 kg/year.

Parameters

Architecture	PV (kW)	Wind generator (N°)	LPG Genset (kW)	Inverter (kW)		
	15	2	0.1	3		
Costs	Initial cost (DA)	Operating cost (DA/Year)	Total NPC (DA)	COE (DA/kWh)	Annual fuel cost (DA)	
	1545823	51202	2200704	14.74	35576	
Environmental (kg/year)	Carbon dioxide	Carbon monoxide	Unburned hydrocarbons	Particulate matter	Sulfur dioxide	Nitrogen oxides
	60.6	0.204	0.0226	0.0154	0.16	1.82

TABLE 3. Performance evaluation of the optimal solution

4. CONCLUSIONS

This paper has presented an analysis of the techno-economical feasibility for powering a Saharan health center with renewable energy options combined with LPG. The proposed solution is economic, and environmentally friendly, comprised 15 kW PV array, 2 wind generator units, 0.1 LPG generator and a 3kW inverter.

REFERENCES

[1] F. Chellali et al., A contribution in the actualization of wind map of Algeria, Renewable and Sustainable Energy Reviews, 15, 993–1002, 2011.

[2] M.R. Yaiche et al., Revised solar maps of Algeria based on sunshine duration, Energy Conversion and Management, 82, 114–123, 2014.

[3] www.homerenergy.com

[4] Algerian ONM

[5] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=africa#, (checked on 14/05/2015)

[6] Suresh Kumar and P.S. Manoharan, Optimization and Cost of Energy of Renewable Energy System in Health Clinic Building for a Coastal Area in Tamil Nadu, India Using Homer, Research Journal of Applied Sciences, Engineering and Technology 8(19): 2048-2056, 2014,

[7] Ali Al-Karaghouli, L.L. Kazmerski, "Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software", Solar Energy 84 710–714, 2010

[8] Sebbagh T. Abdelouahed A. "Etude de l'impact des facteurs climatique (Température, ensoleillement) sur la puissance des cellules Photovoltaïques", JSN02, Ecole Normale Supérieure d'Enseignement Technologique de Skikda, December 2014

[9] Acakpovi, A., Hagan, E. B., Michael M. B. Cost Benefit Analysis of Self-Optimized Hybrid SolarWind-Hydro Electrical Energy Supply as compared with HOMER Optimization, International Journal of Computer Applications (IJCA), 114(18), 32-38, 2015.

[10] A. Betz, "Wind Energy and its Exploitation by Windmills," Gottingen: Van-denhoeck und Ruprccht, p. 64, 1926

[11] J. Manwell and J. McGowan, Wind energy explained: theory, design and application. Wiley Chichester, 2003.