

# Optimal Sizing of a Hybrid Renewable Energy System Using Different Optimization Techniques

Abdel Djabar Bouchaala  
Electrotechnical Laboratory Skikda  
(LES), University 20 August 1955  
Department of Electrical Engineering,  
26 Road El Hadaiek 21000  
Skikda, Algeria.  
[a.bouchaala@univ-skikda.dz](mailto:a.bouchaala@univ-skikda.dz)

Ahcene Boukadoum  
Electrotechnical Laboratory Skikda  
(LES), University 20 August 1955  
Department of Electrical Engineering,  
26 Road El Hadaiek 21000  
Skikda, Algeria.  
[a.boukadoum@univ-skikda.dz](mailto:a.boukadoum@univ-skikda.dz)

Ahmed A. Zaki Diab  
Electrical Engineering Department  
, Faculty of Engineering, Minia  
University  
Minia 61111, Egypt.  
[a.diab@mu.edu.eg](mailto:a.diab@mu.edu.eg)

Asma Benhemine  
Smart grid and renewable energy  
University of bechar tahri mohamed  
Department of Electrical Engineering,  
Bechar, Algeria  
[asmameriem18@yahoo.com](mailto:asmameriem18@yahoo.com)

**Abstract**—Hybrid Renewable Energy Systems (HRES) offer a viable solution for meeting energy demand, particularly in remote locations such as deserts, the Sahara, and mountainous regions. This paper presents an HRES composed of photovoltaic (PV) panels, wind turbines (WT), battery banks (BB), and a diesel generator (DG) for a case study in the mountainous region of Stourat, Skikda, Algeria. The system design considers key climatic factors, including wind speed, temperature, and solar irradiance. To determine the optimal sizing of the system, four optimization techniques—Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA), Salp Swarm Algorithm (SSA), and Artificial Bee Colony (ABC)—were applied. The objective functions include minimizing the Cost of Energy (COE) and the Loss of Power Supply Probability (LPSP). The results show that the ABC algorithm achieved the best convergence, with a best objective function value of 0.10595, compared to 0.1071 for PSO, 0.10594 for SSA, and 0.11647 for WOA. Furthermore, after running the ABC algorithm, the optimized system resulted in a COE of 0.2579 \$/kWh, an LPSP of 0.0038, and a Total Annual Cost (TAC) of \$246,010. These findings demonstrate the effectiveness of optimization techniques in assisting designers in achieving optimal sizing and techno-economic feasibility for HRES.

**Keywords**—Hybrid Renewable Energy Systems (HRES)- Optimal Sizing- Optimization Techniques-Cost of Energy (COE)-Loss of Power Supply Probability (LPSP).

## I. INTRODUCTION

Despite the increasing diversity of energy sources to meet the daily energy needs of the population, there are drawbacks in the energy shortage, especially in remote desert areas and rugged mountainous regions that require

energy for their daily needs. Hybrid renewable energy systems are not based on being clean energy that does not produce gaseous emissions, but rather they are considered an ideal solution for achieving sustainable development by providing energy in areas far from the main electricity grid.

A Hybrid Renewable Energy System (HRES) is an integrated power system that combines two or more renewable energy sources—such as solar, wind, biomass, or hydro—with energy storage solutions (like batteries) and sometimes a backup conventional generator. This configuration ensures a more reliable and continuous power supply, particularly in remote or off-grid locations, by mitigating the intermittency associated with individual renewable sources [1-3]. The decreasing the HRES off grid in remot area needs the many software such as the

Many studies of optimal sizing the HRES off grid including the PV/WT/DG/BB using the optimization techniques such as in location case in Algeria in Djelfa [4] used the Multi objective salp swarm algorithm (MSSA) compared to author algorithm, In Biskra [5] used a the stochastic fractal search (SSA) and symbiotic organisms search (SOS) algorithms were compared to PSO. In Yobe State, Nigeria [6], used the grasshopper optimization algorithm (GOA) compared to PSO and Cuckoo search (CS) algorithm. In the El-Bahariya Oasis, Egypt [7], researchers applied the grey wolf optimizer (GWO) and its enhanced version, the improved grey wolf optimizer (IGWO), and SSA to achieve optimal configurations of HRES.

In this paper, we present the optimal sizing of a HRES using different optimization techniques, which includes photovoltaic panels (PV), wind turbines (WT), battery banks (BB), diesel generators (DG).. To achieve

this, we apply the optimization techniques representing The ABC and PSO and SSA ,WOA to minimize the Cost of Energy (COE), Loss of Power Supply Probability (LPSP).The study considers one year of climatic data, including wind speed, temperature, and solar irradiance, for the chosen case study location of Skikda, Algeria.

The organization of the paper is as follows: Section 2 describes the hybrid renewable energy system proposed. Section 3 formulates the optimization problem, detailing the objective function, constraints. Section 4 presents the results and discussion of the study. Finally, Section 5 provides the conclusion.

## II. DESCRIPTION OF THE HYBRID RENEWABLE ENERGY SYSTEM PROPOSED

Designed of the HRRS consists of renewable energies represented by photovoltaic units, wind turbines and conventional source represented by diesel generators and the energy storage represented by Battery bank , and the inverters. The configuration type is AC/DC. The photovoltaic units and batteries Banks are installed on the DC bus side, and on the other side, the wind turbine units and diesel generator units are installed, in addition to the load and the dummy load in the AC bus. The two-way inverter is located between the DC/AC buses. The load is represented by a group of residential units estimated at about one hundred residential homes under the influence of a single-phase voltage of 220 volts and a frequency of 50 Hz. Fig. 1 shows the most important details describing the proposed microgrid system

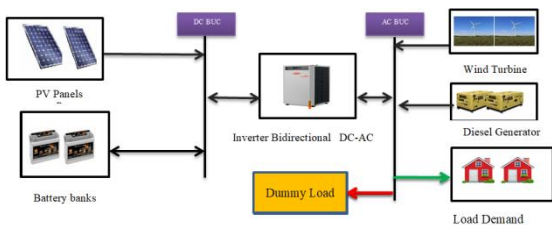


Fig .1. A schematic diagram describing the components of a HRES

## III. FORMULATION OF THE OPTIMIZATION PROBLEM

The objective function proposed for our system focuses on minimizing the loss of power supply probability (LPSP) , the cost of energy (COE) , It is expressed as:

$$Min_x(f) = Min_x(\omega_1 COE + \omega_2 LPSP) \quad (1)$$

Where ,the weighting factors  $\omega_1$ , and  $\omega_2$ , are determined through a trial-and-error process to achieve optimal results, with their sum constrained to equal 1. In this study, these factors are assigned values of  $\omega_1=0.4$ ,  $\omega_2=0.6$  .The vector X of decision variable is a four-dimensional representation of the optimization parameters, comprising: (i) the number of PV modules ( $N_{PV}$ ), (ii) the number of wind turbines ( $N_{WT}$ ), (iii) the number of battery storage banks ( $N_{BB}$ ), and (iv) the number of diesel generators ( $N_{DG}$ ).

$$Desing\ Variable = \begin{cases} N_{Min}^{PV} \leq N^{PV} \leq N_{Max}^{PV} \\ N_{Min}^{WT} \leq N^{WT} \leq N_{Max}^{WT} \\ N_{Min}^{DG} \leq N^{DG} \leq N_{Max}^{DG} \\ N_{Min}^{BB} \leq N^{BB} \leq N_{Max}^{BB} \end{cases} \quad (2)$$

### A. The cost of energy

The profitable economic of the HRES is based on the COE ,it is defined the cost o per unit electricity generated ,in( \$/KW).It can be calculated the follows as[8-9]:

$$COE = \frac{NPC}{\sum_{T=1}^{8760} P_L(h)} \times CRF \quad (3)$$

Where, NPC is the net present cost including the capital ,replacement, operation and maintenance costs . $P_L$  is the amount of energy consumed in hour, the capital recovery factor CRF is mentioned in [6][8] ,and CRF is given as:

$$CRF = \frac{i(1+i)^{Prj}}{(1+i)^{Prj}-1} \quad (4)$$

Where,i is the representing the real interest rate and Prj is the project life time in this( study consider 24 years).

The NPC is can be calculated the following equation as :

$$NPC = \frac{TAC}{CRF} \quad (5)$$

### B. Loss of power supply probability (LPSP)

The reliability of microgrid system based on LPSP which indicates the probability supply failure to meet energy demand .The LPSP can be calculated in year (8760) of the using the following equations[12-13]:

$$LPSP = \frac{\sum(P_L - P_{RE} + P_{B-Min} + P_{DG})}{P_L} \quad (6)$$

Where,  $P_L, P_{RE}, P_{B-Min}, P_{DG}$  are the power of the load demand, renewable energy ,minimum the battery storage ,diesel generator .The value of LPSP is generally between the range [0 1],if the LPSP equal 0 it mean the energy demand is fully satisfied .similarly, if the LPSP equals 1 it mean the energy demand is not satisfied.

Where, TAC is the representing the total annual cost of the microgrid system [8],[10].

## IV. LOCATION STUDY AND THE PARAMETERS OF HRES

The proposed system for a HRES off -grid is located high in the mountains of the Stora region in the state of Skikda in northern Algeria on the sea coast, which is located between the coordinates of latitude 36.9 and longitude 6.8, choosing Google Earth the study location on the map via satellite, as shown in (Fig .2.) The maximum and minimum values and their annual average, i.e. in 8760 hours. The results show measurements of temperature, solar radiation , and wind speed in Table.1, in addition to the proposed load values for a residential building containing about 100 residential units.Figs 3a, 3b, and 3c schow the environmental data—annual temperature, solar radiation, and wind speed, respectively—collected over 8,760 hours at the study location.

The technical and economic parameters of the microgrid components, which include solar panels, wind turbines, storage batteries and diesel generators, are shown in a table adopted from the following references[7],[11].



Fig .2.The location of the study the HRES off grid is on the map of Algeria

TABLE 1.THE MAXIMUM AND MINIMUM VALUES AND THEIR ANNUAL AVERAGE FOR TEMPERATURE, SOLAR RADIATION INTENSITY, WIND SPEED.

Location data	Max	Min	Mean(average)
Temperature in year(C°)	42.8	7.25	20
Irradiance in year (w/m2)	1018	0	242.76
Wind speed in year(m/s)	14.08	0.07	4.39

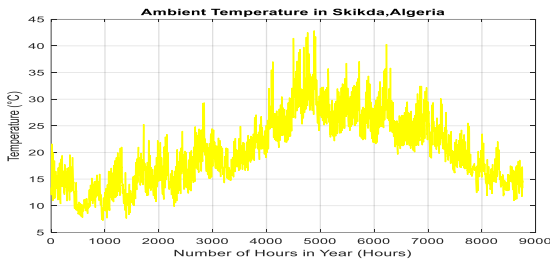


Fig.3a. Annual the Temperature of the location study

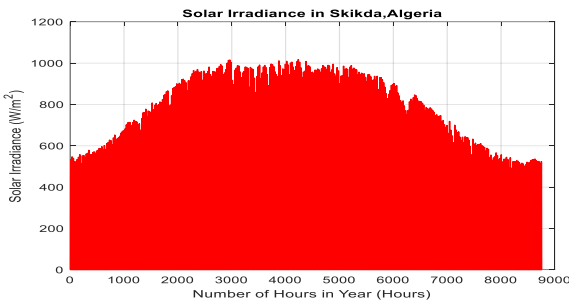


Fig.3b. Annual the Solar Irradiance of the location study

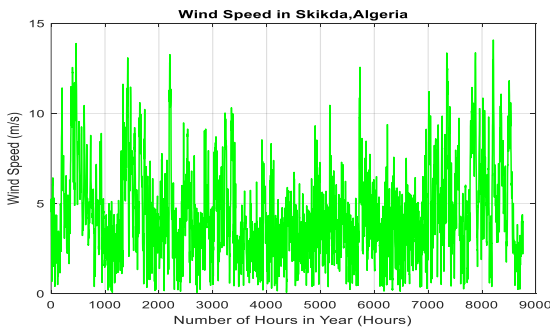


Fig.3c. Annual the wind speed of the location study

## V. RESULTS AND DISCUSSION

In this work use the different optimization in order to sizing the HRES in software Matlab in M-File interface .The optimization technique are employed the ABC and PSO,SSA,WOA .the results show the optimal sizing the components of the HRES.the ABC is best score objective 0.10595 and execution time 75.3511 seconds compare to other algorithm so that the number the PV panel is 385 and WT is 1 and DG is 1 and the BB is 32. And The COE is 0.2579( \$/KW) and LPSP is 0.0038 and the TAC is 2.4601e+05 and NPC 3.1449e+06 and The total Edummy load in year(T-Dummy ) 340.1667 Kw.this results and other algorithm details show in Table.1

The Figure show the convergence the algorithm with same iteration 100 and number of search agents 30.the results show the ABC best convergence with other algorithm limited to 0.10595 after the PSO and SSA than WOA but far and the best score 0.11647.

TABLE .2.THE OPTIMAL RESULTS OF THE HRES OBTAINED USING THE OPTIMIZATION TECHNIQUES ABC WOA PSO AND SSA

Algorithms	ABC	WOA	PSO	SSA
Best-Obj	0.10595	0.11647	0.1071	0.10594
Time(seconds)	75.3511	54.8534	58.7592	57.0526
N PV	385	402	432	392
N WT	1	2	1	1
N BB	32	40	100	40
NDG	1	1	1	1
COE (\$/KW)	0.2579	0.2518	0.2508	0.2498
TAC(\$)	2.4601e+05	2.4725e+05	2.4630e+05	2.4651e+05
LPSP	0.0038	0.0046	0.0038	0.0031
NPC (\$)	3.1449e+06	3.1607e+06	3.1485e+06	3.1364e+06
T-Dummy(kw)	340.1667	244.8800	319.2787	409.5286

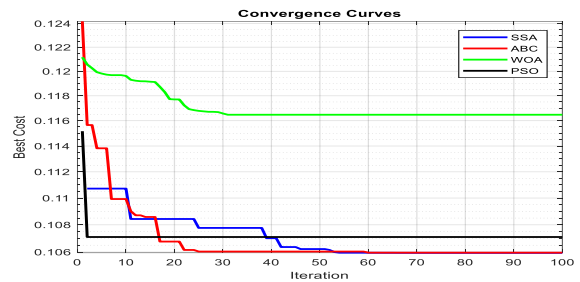


Fig.4 .the convergence fitness function using the Algorithms ABC PSO SSA WOA

## VI. CONCLUSION

This study presents a comprehensive analysis of the optimal sizing of a Hybrid Renewable Energy System (HRES) using advanced metaheuristic optimization techniques. Among the four optimization algorithms employed—ABC, PSO, SSA, and WOA—the ABC algorithm demonstrated superior performance, achieving the best trade-off between cost, reliability, and computational efficiency. The optimal system configuration using ABC consisted of 385 PV panels, one wind turbine, one diesel generator, and 32 battery banks, resulting in a Cost of Energy (COE) of 0.2579 \$/kWh and an LPSP of 0.0038. Additionally, SSA exhibited the lowest COE and NPC,

making it a viable alternative for cost-sensitive applications. The results emphasize the significance of optimization techniques in designing HRES that are both economically viable and technically efficient. The rapid convergence of ABC, along with its ability to minimize energy costs and ensure power reliability, makes it a promising approach for real-world renewable energy applications. Future work could explore hybrid optimization techniques that integrate multiple algorithms to further enhance system performance. Moreover, incorporating demand-side management strategies and real-time energy market data could improve the adaptability of HRES to dynamic energy requirements.

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