Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.52, p. 9-21. March. / April., 2025.
DOI: https://doi.org/10.5935/jetia. v11i52.1355.

RESEARCH ARTICLE OPEN ACCESS

OPTIMAL SIZING OF A HYBRID MICROGRID SYSTEM FOR A RURAL AREA OF ALGERIA

Badis Bacha[1], Hatem Ghodbane[2], Nadjiba Terki[3], Madina Hamiane[4], Omar Charrouf[5], Abir Betka[6], Aymene Bacha[7]

[1,2,3,5,7]Department of Electrical Engineering, Mohamed Khider University, Biskra, Algeria.
[4]College of Engineering, Royal University for Women, Riffa, Bahrain.
[6]Department of Electrical Engineering, Echahid Hamma Lakhdar University, El Oued, Algeria.

[1]http://orcid.org/ 0009-0002-1409-897X, [2]https://orcid.org/0009-0004-7809-8340, [3]http://orcid.org/0000-0003-0402-2322
[4]http://orcid.org/0000-0002-1921-9980, [5]http://orcid.org/0000-0003-4254-464X, [6]http://orcid.org/ 0000-0002-2142-1088
[7]http://orcid.org/0009-0004-2037-2378,

Email: badis.bacha@univ-biskra.dz, h.ghodbane@univ-biskra.dz, n.terki@univ-biskra.dz, mhamiane@hotmail.com, omar.charrouf@univ-biskra.dz, betkaabir@gmail.com, aymen98tech@gmail.com

ARTICLE INFO

Article History
Received: December 26, 2024
Revised: January 2, 2025
Accepted: February 15, 2025
Published: March 31, 2025

Keywords:
Hybrid microgrid,
Optimization,
Optimal Sizing,
Particle swarm optimization,
Weighted sum approach.

ABSTRACT

Renewable energy systems have replaced systems that use fossil fuels in many applications in different regions of the world. This is seen in the increasing use of solar and wind energy as the two most important sources for producing environment-friendly and economically convenient electrical energy. The fluctuating and unstable nature of renewable energy sources makes this type of energy complex to exploit, and related research has therefore mainly focused on Control and optimization. This work proposes an optimized configuration of two hybrid systems designed for a microgrid network with the aim to improve the power supply in isolated areas and provide a low cost, more reliable, and sustainable source of electricity for rural communities that may have limited access to traditional power grids. These hybrid setups consist of an initial system that caters for 10 houses which is then extended to serve 20 houses. Both setups utilize solar and wind energy sources, energy storage batteries, and a diesel generator. Real data collected in the Biskra region in the southeast of Algeria, is used. Particle Swarm Optimization algorithm is applied to achieve the optimal size of the hybrid system components through the weighted sum multi-objective approach, whereby three factors, namely, Cost of Electricity, Loss of Power Supply Probability, and Dummy Excess are combined into one objective function. Results of simulation show that the proposed approach achieves highly satisfactory values for the electricity prices in the 10- house and 20-house scenarios, with estimates of 0.15829 $/Kwh and 0.42112 $/Kwh, respectively.

I. INTRODUCTION

Future sustainability and respect for environmental standards are the two main biggest reasons that are motivating , on a daily basis, all countries of the world to exploit renewable resources of all kinds [1]. Despite this acceleration in the exploitation of renewable resources, the largest energy contributor in the world remains fossil and traditional sources. These sources are oil, gas and coal [2], [3] , and are the cause of the large emission of gasses and global warming that affects our planet [4].

Renewable energy sources are the best energy supply alternative for energy supply for sustainable development [5]. Many studies have shown that the electricity industry through renewable resources is low cost, more reliable, and environmentally friendly [5]. One of the most important energy systems in use today is microgrid (MG). They are small-sized systems for power generation and can operate independently or connect several networks with each other, and they also have the ability to be connected to the central network or separated according to the need. Supporting these systems, especially those installed in isolated places, with support systems such as generators, aims to increase their stability [6]. Microgrid systems include many renewable energy systems such as Photovoltaic (PV) cells. and Wind Turbine (WT) generators. Batteries and generators are also used to maintain the stability of the system, as well as the components of the loads and the control system. Small grids are characterized by the ability to provide energy for one consumer or a group of consumers according to the objectives of the system [7].

There are two types of direct and alternating current in small networks, due to the variety of sources available for these networks. The current generated by photovoltaic cells is direct current type (DC) while wind turbines generate alternating current (AC). Two areas that are very popular in research on Microgrid systems are design and control. The design of the system is a very important stage in which energy sources are selected and their sizes are determined taking account all restrictions, the most important of which is the environment at the lowest possible cost of investment [8],[9] . Optimal component size is the most significant element that is taken into account when designing renewable energy systems [10].

The methods of sizing, formations, storage methods, and control strategies are the most prominent issues addressed by research on renewable energy sources [11]. The most serious problem facing the exploitation of renewable energy sources is their intermittent nature . To overcome this problem, several sources are used together to form a hybrid system. The size of the system is either undersized or oversized. There are two methods for sizing, either through dedicated software programs or with traditional methods [12].

Figure. 1, illustrates this more clearly. Artificial intelligence (AI) is defined as enabling machines or software to perform types of functions that characterize human thought in [13]. The optimal sizing of hybrid renewable systems is done through the use of several methods, including classical methods, hybrid methods, and AI, as clearly depicted in Figure 2.

Several intelligence-based optimization techniques used in sizing of hybrid renewable energy systems have been presented in many studies and researches. Researchers in this field have used several smart algorithms to find the optimal size for hybrid systems, as reported in the study of Starke et al. [14], where a genetic algorithm is used to reduce operating and installation costs for a hybrid system consisting of photovoltaic solar panels (PV), and concentrated solar power systems (CSP) that concentrate solar energy. The Non-Dominated Sorting Genetic Algorithm II (NSGA II) was used by Kamjoo et al. [15] for the sizing of a hybrid system.

A Multi-Objective Self- adaptive Differential Evolution algorithm (MOSaDE) was used in the optimal sizing of a hybrid system in the Kingdom of Saudi Arabia, by Ramli et al. [16]. Optimal sizing using the Particle Swarm Optimization Algorithm (PSO) was applied to a hybrid system in order to improve the electrification of a rural area located in Kerman, Iran, by Askarzadeh et al. [17]. In [18], Fathy et al., implemented the Mine Blast Algorithm (MBA) in the sizing of a hybrid system for a remote site in Egypt.

The Ant Colony Optimization (ACO) algorithm was also used by Suhane et al. [19] for the optimal sizing of a hybrid system in an isolated site. In the same context, optimal sizing of a hybrid system in Taiwan was effectively solved by a multi-objective line-up competition algorithm (MLUCA) in Shi et al. [20]. Biogeography-based Optimization (BBO) algorithm was proposed by Gupta et al. [21] for the size optimization of a small autonomous hybrid power system. The optimal design of a hybrid system was also determined by solving a multi-objective problem using the Preference-Inspired Co-Evolutionary Approach (PICEA) in [22] by Shi et al. Moreover, Sanajaoba et al. [23], the Cuckoo Search algorithm (CSA) was the algorithm chosen to determine the optimal size of an isolated and hybrid system. The optimal size was found by Maleki et al. [24], taking into account the desired reliability of a hybrid system, by using the artificial bee swarm optimization algorithm (ABSO).

Zhao et al. [25] utilized the Improved Fruit Fly Algorithm (IFFA) to solve a multi-objective problem for sizing a hybrid system. On the other hand, some applications reported in the literature, where the PSO algorithm was used for the optimal design of hybrid renewable systems using objective functions in general formulation, the methods for solving them depend on the direct methods. Alternatively, in certain applications proposed in the literature, the Particle Swarm Optimization (PSO) algorithm has been employed for the optimal design of hybrid renewable systems. The suggested approaches involve formulating objective functions, and the methods utilized to solve them rely on regenerative or direct methods.

In [26], the Particle Swarm Optimization (PSO) algorithm was applied to determine the optimal sizing of a hybrid renewable energy system composed of PV (photovoltaic) panels, wind turbines, and a fuel cell. The primary objective of the study was to minimize the annual cost associated with the system. PSO was used as a computational tool to find the most cost-effective configuration for the hybrid system. Similarly, Kaviani et al. [27] relied on the PV-Wind-Fuel cell as components of a studied hybrid system. The objective function was solved through the PSO algorithm, with the aim to find the minimum cost. The PSO algorithm was also used by Khare et al. [28]to determine the optimal size of a hybrid system consisting of a PV–wind–diesel–battery system.

The objective function was formulated to minimize the system cost. Askarzadeh et al. [17] calculated the optimal size of a hybrid system consisting of PV/Wind/battery using a function aiming to minimize the life cycle cost (LCC) of the system. In the same context, The PSO algorithm was employed to size a hybrid system that incorporated PV, wind, fuel cell, battery, and diesel generator by Sharafi et al. [29], the study adopted a multi-objective function with the goal of minimizing three key parameters: the total cost, the total CO_2 emissions, and the energy deficit.

In general, multi-objective optimization problems are more common than single-objectives [30]. One of the problems that may affect the PSO algorithm when using multi-objective functions is the difficulty in controlling diversity, also called turbulence [31]. To overcome this difficulty and avoid running into other problems mentioned in [32], such as the possibility of entrapment into local optima and the inability to recover from these, we have adopted a new approach in solving the multi-objective problem proposed in this study.

This method is called the weighted sum (WS), or in more general terms the linear fitness combination technique. WS is a widely used method in dealing with multi-objective tasks. It is easy to implement and achieves computational efficiency in less time required for solution than other methods [31]. In this paper instead of employing three separate objective functions, we opted for the weighted sum method that combines them into a single objective function. This choice is made owing to the method's simplicity of use and proven effectiveness [33], as it gives satisfactory results with respect to all constraints, and enables us to achieve three goals at the same time.

To achieve the optimal configuration of a stand-alone HMS, this study aims to analyze the economic facets involved in designing a compact HMS that operates independently of the central grid. This system incorporates solar energy, wind energy, and a battery system for energy balancing, supplemented by a diesel generator as a backup power source. The agricultural region of Biskra, in Algeria,was the study area, where we obtained weather data through the meteorological station at the University of Biskra.

A novel approach to the PSO algorithm is adopted to address a multi-objective problem by associating it into a single objective function through a weighted combination of three factors: electricity cost (COE), loss of power supply probability (LPSP), and dummy excess. on a new line:

The following outline highlights the major contributions of our work.

• Our study goes beyond others by incorporating real-life data from the Biskra area in Algeria, encompassing sun radiation, wind speed, and temperature, rather than focusing on limited geographical regions.

• Unlike previous studies that relied on the PSO algorithm and one energy source, we have identified the most efficient microgrid system design with multiple sources.

• Our approach integrates a multi-objective function with a weighted sum, combining the cost of electricity (COE), the probability of power loss (LPSP), and the Dummy excess in a single fitness objective function. This is in contrast to previous studies that focused fitness function on single energy sources.

• To assess the performance of the developed approach under varying loads. Two models of microgrid systems are introduced, one consisting of 10 houses and the other consisting of 20 houses.

• Our results demonstrate that HMS have made significant improvements both in terms of efficiency and endurance. We offer comprehensive comparisons with previous studies to highlight advances in performance metrics such as COE and LPSP.

This paper is formulated as follows. Section II presents the components of the proposed HMS. Section III discusses the development of energy management strategy for the proposed system. Section IV gives the typical load assessment for the case under study. Section V presents the optimization problem which includes the cost analysis ,the reliability analysis ,the multi objective optimization, and the optimization strategy using Particle Swarm Optimization algorithm along with the optimization procedure Simulation results are discussed in Section VI, and finally, the conclusions are summarized in Section VII.

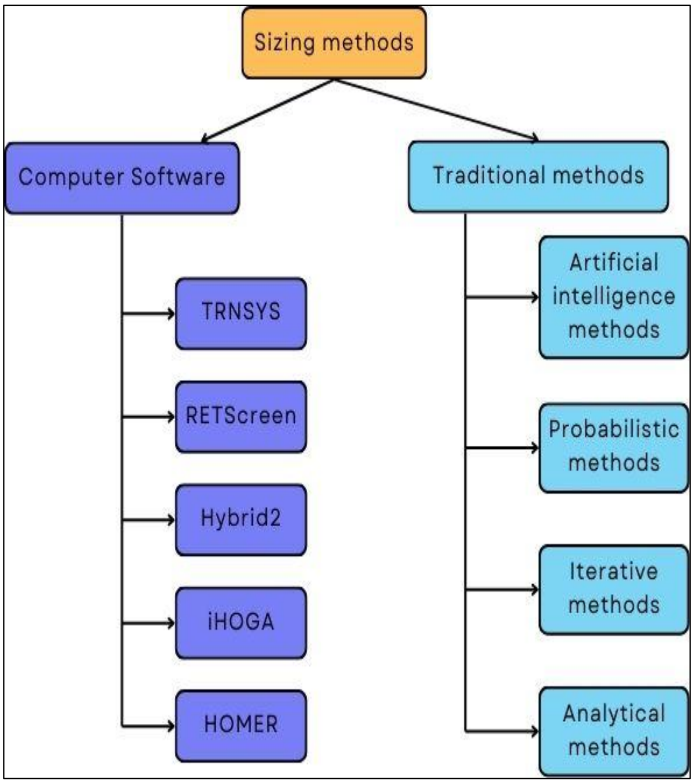


Figure 1: Sizing methods for hybrid system.
Source: Authors, (2025).

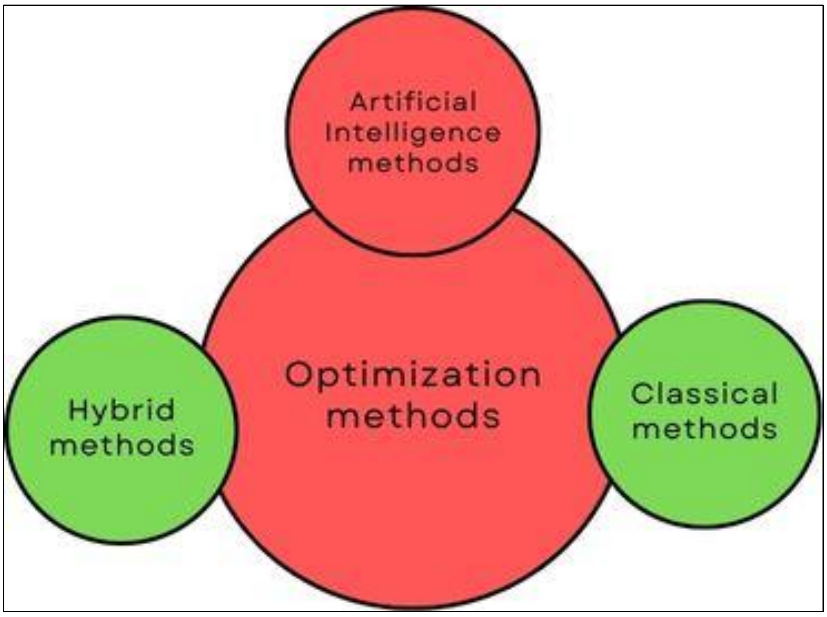


Figure 2: Optimization methods for hybrid systems.
Source: Authors, (2025).

II. HYBRID MICROGRID SYSTEM (HMS) DESCRIPTION

The Hybrid Microgrid System (HMS) examined in this study consists of five main system elements: a PV system, wind turbines (WT), diesel generators, an inverter, and a battery bank. Figure 3, shows the components of the hybrid system.

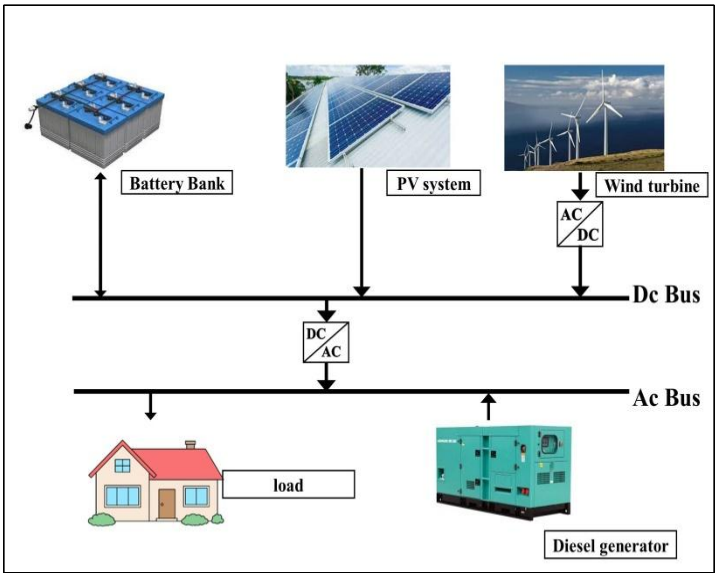


Figure 3: Components of a HMS.
Source: Authors, (2025).

II.1 PV SYSTEM

The following equation is used to compute the power output of PV panels [34, 35]:

$$P_{pv-out} = P_{rated} \times G/G_{ref} \; [1 + K_t \, ((T_{amb} + (0.0256 \times G)) - T_{ref})] \quad (1)$$

In which P_{rated} represents the PV rated power under standard test conditions (STC), G represents solar radiation (W/m^2), G_{ref} is 1 kW/m^2; K_t is a constant -3.7 × 10^{-3} (1/°C), T_{amb} represents ambient temperature, and T_{ref} represents the temperature in °C of PV cell at STC (25℃).

Table 1 provides specifics on PV parameters. Figure 4, and Figure 5, show data for the monthly average solar radiation and temperature for the city of Biskra in the southeast of Algeria in the year 2020.

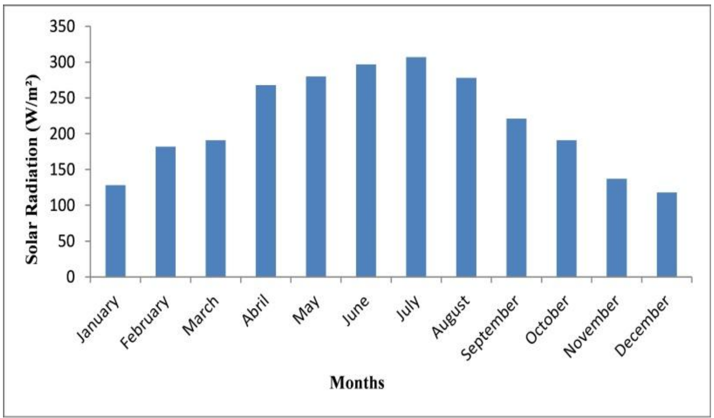


Figure 4: Monthly Averages of Solar Radiation in the year 2020
Source: Authors, (2025).

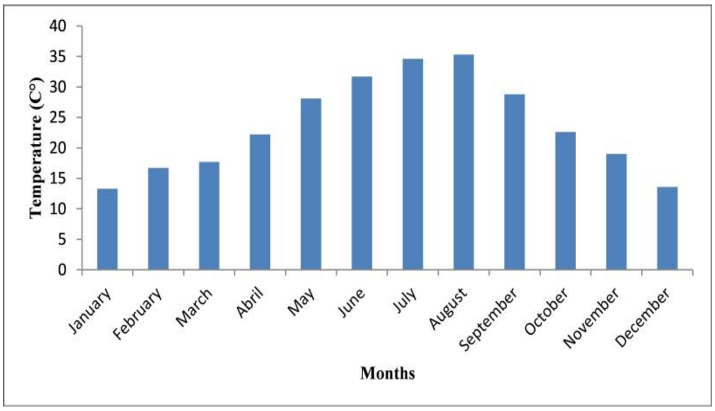


Figure 5: Monthly Averages of temperature in the year 2020.
Source: Authors, (2025).

II.2 WIND POWER SYSTEM

The wind turbine is composed of three primary components: the tower, the blades, and the generator, which transforms kinetic energy into electrical energy . The quantity of electrical energy produced by a WT is influenced by the wind speed and blade design [36].

$$P_{wind}(t) = \begin{cases} 0 & V(t) \le V_{cut-in} \text{ or } V(t) \ge V_{cut-out} \\ P_{rated} & V_{rated} \le V(t) \le V_{cut-out} \\ P_{rated} \dfrac{V(t)-V_{cut-in}}{V_{rated}-V_{cut-in}} & V_{cut-in} \le V(t) \le V_{rated} \end{cases} \quad (2)$$

where P_{rated} represents the rating power of a single wind turbine, V_{cut_in} is the cut in speed, V_{rated} the rated wind speed,

V_{cut_out} the Maximum speed and V(t) represents the wind speed at desired height. Wind speed differs significantly with height, and is given by:

$$V(t) = V_r(t) \times \left(\frac{h_2}{h_1}\right)^{\alpha} \quad (3)$$

where Vr(t) represents the speed at a reference height, h_1; V(t) is the speed at a hub height h_2 , and α is the coefficient of friction . The typical value for α is 1/7=0 .14 for a low roughness surface, and a well exposed site .

The characteristics of the wind turbine utilized in this optimization procedure are displayed in Table 1. Figure 6 shows the monthly average wind speed for the city of Biskra in the year 2020.

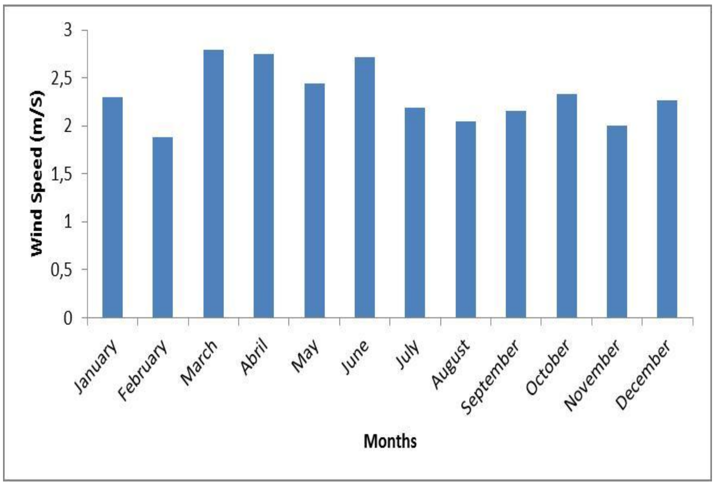


Figure 6: Monthly Averages of wind speed in the year 2020.
Source: Authors, (2025).

II.3 DIESEL GENERATOR

The diesel generator operates as a secondary power supply to the Microgrid systems. The characteristics of the loads that it aims to meet have a major role in choosing the rated capacity of the diesel generator. The diesel generator is used in the event that the hybrid system is unable to provide sufficient power to the loads. The fuel consumption Fuel(t) of the diesel generator is given by [37-39].

$$\mathrm{Fuel}(t) = 0.246 \times P_{diesel}(t) + 0.08415 \times P_{rat} \quad (4)$$

where $P_{diesel}(t)$ represents the generated power at time t, 0.246 and 0.08415 represent the approximated coefficients of the fuel consumption parameters, and P_{rat} is the rated power. Data for diesel generators used in microgrid optimization are presented in Table 1.

II.4 BATTERY

The fluctuating nature of the weather conditions between seasons and days of the year makes the energy produced from the hybrid system fluctuate as well, for this reason we had we had to use the storage system represented by the batteries in order to store the surplus energy and discharge it in case of need [40]. The battery state of charge SOC at time t can be calculated during the charging and discharging stages through the following equations:

$$SOC_{CH}(t) = SOC(t-1) \times (1-\sigma) + (P_{generation}(t) - (P_l(t)/\eta_{inv})) \times \eta_{ch} \quad (5)$$

$$SOC_{DISCH}(t) = SOC(t-1) \times (1-\sigma) + (P_l(t)/\eta_{inv}) - (P_{generation}(t)) \times \eta_{DISCH} \quad (6)$$

$$P_{generation}(t) = P_{PV-out}(t) + P_{wind}(t) \quad (7)$$

Where $SOC_{CH}(t)$ and $SOC_{DISCH}(t)$ represent the battery charging and discharging energy at time t, respectively. SOC(t-1) is the charge quantity of the battery bank at time (t-1), σ is the self-discharge rate, $P_{generation}(t)$ is the total power generated by the renewable energy system. Pl (t) is the hourly load demand at time t , η_{inv} is the inverter efficiency , η_{CH} is the battery charging efficiency, and η_{DISCH} is the battery discharging efficiency.

The battery is charged by the condition [41] :

$$SOC_{min} \leq SOC \leq SOC_{max} \quad (8)$$

Where SOC_{min} is the minimum charge quantity of the battery and SOC_{max} is its maximum charge quantity.

The extra energy can be exploited if the batteries reach the maximum charging limit to feed the dummy load, although it is an increased component in the system, it is nevertheless very important to maintain the energy balance within the system.

If SOC > SOC_{max} , P_{dummy} can be calculated through the following equation [42]:

$$P_{dummy}(t) = [(P_{PV-out}(t) \times \eta_{inv} + P_{wind}(t)) - P_l(t)] \quad (9)$$

III. HYNRID ENERGY SYSTEM

We chose one hour as a time interval in this study, and the energy management strategy was developed according to the load data, the intensity of solar radiation, the temperature, and the wind speed during a full year of 8760 hours. The principle of the energy management strategy in this study can be summarized as follows:

- If the energy produced from renewable sources exceeds the needs of the loads, the system stores the surplus in the batteries.
- If the batteries are charged to the maximum, the excess energy is directly discharged in the dump load.
- In the event that the system is unable to meet the needs of the loads through energy produced from renewable sources, the energy stored in the batteries is used to cover this deficit in meeting the demand for energy from the loads.
- In the event that the energy in the batteries reaches the minimum level, the diesel generator is started immediately and stopped after the system is able to produce enough energy to meet the demand from the loads.

IV. LOAD PROFILE

The load profile must be carefully studied in any area, especially the areas that are isolated from the central network . This is done before starting any design project for renewable energy systems, whereby, through an in-depth study of the load profile, all parts of the hybrid system are selected, and this is in order to design a system that is economically inexpensive and more reliable. Figure 7 shows the daily average load profile for the summer season for a rural house in the city of Biskra.

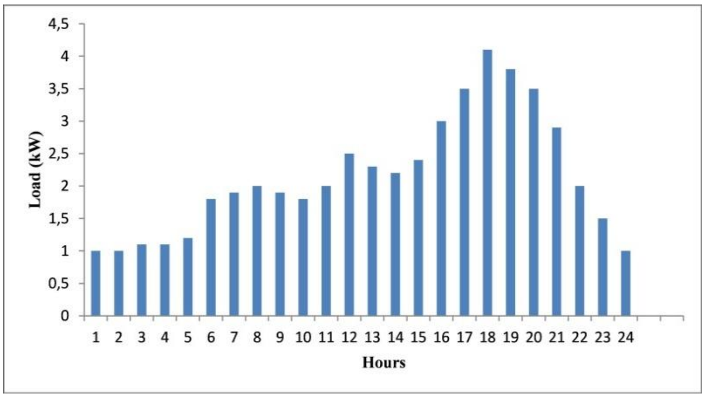


Figure 5: Typical rural house hourly load profile.
Source: Authors, (2025).

V. THE OPTIMIZATION PROBLEM

The most important element to be studied in the design projects of renewable systems is the optimal sizing of all components of the system, where designers try to reconcile the price of the components and their quality. This is in order to obtain an acceptable life span for all components of the system, which enables the consumer of electrical energy in isolated areas to obtain electricity at the lowest cost and with more reliability.

V.2 COST ANALYSIS

The cost of electricity (COE), is one of the most used indicators in design projects for renewable systems. It is defined as the constant price per unit of energy, and it includes all costs over the life of the project [43]. It can be calculated using the equation below.

$$COE = \frac{\text{Total Net Present cost}}{\sum_{t=1}^{8760} P_l(t)} \times CRF \quad (10)$$

with:

$$CRF = \frac{i_r \times (1+i_r)^R}{(1+i_r)^R - 1} \quad (11)$$

where CRF is a ratio used in calculating the present values of an annuity [44] , ir represents the real interest rate estimated in this study at 13% , and R is the life of the project under study and is estimated at 24 years.

We can define the total net present cost as the present value of the project cost throughout the life of the project and it includes the cost of installation, operation and maintenance .

V.3 RELIABILITY ANALYSIS

The reliability of the energy system is an important factor for the consumer, and this is to ensure the continuous supply without interruption of electrical energy. In this study, an important indicator is used, namely , the Loss of power supply probability (LPSP) , in order to study the possibility of failure of the power supply for any environmental or technical reason. LPSP can be calculated through Equation 12 below [45, 46].

$$LPSP = \sum_{1}^{8760} \frac{(P_l(t) - (P_{generation}(t) + SOC(t-1) - SOC_{min}) \times \eta_{inv} + P_{diesel}(t))}{P_l(t)} \quad (12)$$

Moreover, during our analysis of the reliability of the system, we have added the condition.

$$P_l(t) > P_{generation}(t)$$

V.4 MULTI OBJECTIVE OPTIMIZATION

The improvement strategy proposed in this study is to combine several elements into one objective function, which we call the weighted sum multi-objectives , and can be summarized in the following points :

- Reducing the cost of electricity COE.
- The increase in the desired reliability of the hybrid system through the reduction of potential energy losses LPSP.
- Reducing the energy spent on dummy load. We have used in the proposed objective function the ratio between dumpy load and load over a full year. This ratio is expressed in the equation below.

$$Dummy_{excess} = \sum_{1}^{8760} \frac{P_{dummy}(t)}{P_l(t)} \quad (13)$$

The Fitness Function FitnessFun used to obtain the optimal size for all components of a HMS can be expressed through Equation (14) below:

$$Fitness_{Fun}: F(X) = Minimum(COE + LPSP + Dummy_{excess}) \quad (14)$$

The decision variables vector X can be expressed as:

$$X = [N_{pv} \quad N_{wind} \quad N_{Battery} \quad N_{AD} \quad N_{diesel}] \quad (15)$$

where N_{PV} , N_{wind} , $N_{Battery}$, N_{AD} , and N_{diesel} , are the numbers of solar panels, wind turbines, batteries, autonomy days, and diesel generators, respectively .The proposed constraints are as follows:

$$1 \le N_{pv} \le 45 \quad (16)$$

$$0 \le N_{wind} \le 10 \quad (17)$$

$$1 \le N_{Battery} \le 45 \quad (18)$$

$$1 \le N_{diesel} \le 4 \quad (19)$$

$$1 \le N_{AD} \le 5 \quad (20)$$

V.5 OPTIMIZATIO STRATEGY USING PARTICLE SWARM OPTIMIZATIO ALGORITHM

The PSO algorithm simulates the movement of animal communities such as flocks of birds and fish, it exploits the intelligent social interactions of the flock and its ability to evolve and learn [47, 48]. PSO is a smart search algorithm, in which searching is carried out through the creation of a random set of solutions that are called a swarm, where each possible individual solution is called a particle [49]. PSO considers each particle moving through the problem hyperspace as a possible solution to the objective function . The steps of the PSO algorithm are summarized in three main steps as shown in Figure 8.

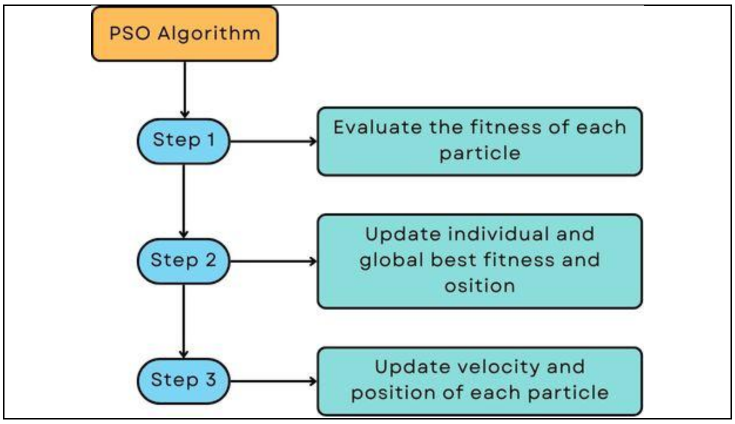


Figure 8: The three main steps of PSO algorithm

During the execution of the PSO algorithm, each particle remembers the best fitness it achieved, and compares it to the rest of the particles, which the algorithm calculates and updates in each iteration .The algorithm continues to repeat these operations according to pre-defined criteria and constraints until the optimal fitness function value is reached . Equation (21) the position of each particle at time step t is updated as follows:

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \quad (21)$$

where d = 1,2,..., D and i = 1, ...S. D and S are the dimensions of the search space and the swarm size respectively , $V_{id}(t+1)$ is the velocity of a particle at time step t+1 . The velocity is updated through Equation 22

$$V_{id}(t+1) = V_{id}(t) + C_1 \times random_1(P_{best}(t) - X_{id}(t)) + C_2 \times random_2(g_{best}(t) - X_{id}(t)) \quad (22)$$

Where ,$V_{id}(t)$ is the velocity at time t ,$C_1$and C_2 are constants ,$random_1$ and $random_2$ are random number between 1 and 2 ,P_{best} is the best individual position (cognitive learning) ,g_{best}

is the best global position (social learning). All steps of the particle swarm optimization algorithm are summarized in Figure 9.

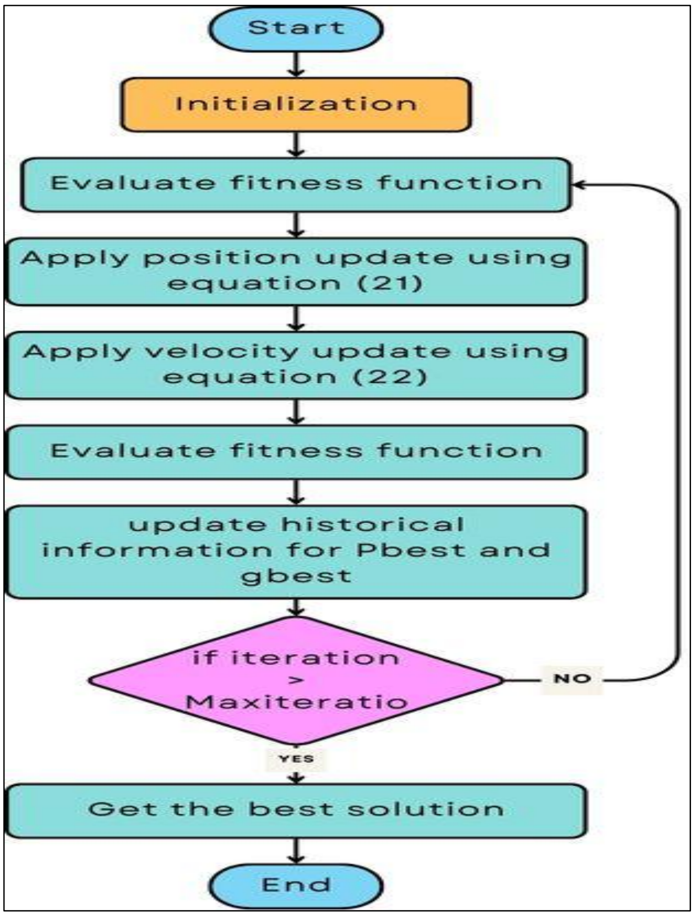


Figure 9: PSO algorithm flowchart.
Source: Authors, (2025).

The optimization problem can be expressed in general formulation as follows [50] :

$$\text{Minimize: } F_K(x) = [F_1(x), F_2(x), \dots, F_M(x)]^T \text{ ; } K = 1,2,3,\dots,M \quad X \quad (23)$$

$$\text{Subject to : } g_i(x) \leq 0 \text{ ; } i = 1,2,3,\dots,m$$

where $F_K(x)$ and $g_i(x)$ are functions of the design vector , M is the number of objective functions , **m** is the number of constraints , and **X** is a vector of design variables.

Optimization problems can be classified in two categories:

- Category 1 (single objective), when M=1 .
- Category 2 (Multiobjective), when M > 1 .

There has been a lot of research on category No. 2. This interest is due to the attractive features of this method, where it is possible to obtain one solution that achieves more than one objective at the same time [51, 52]. In this paper, we used and developed one of the methods used in solving multi-objective problems ,namely,the Weighted Sum Approach for Multiobjective Optimization(WSAFMO). This approach is often used in solving multi-objective problems, and consists of transforming a multi-function problem into a problem with one function that achieves all the objectives of its component functions. The weighting factors Wi Є [0,1] corresponding to the components functions are selected based on their relative importance[53]. We can mathematically express this method by:

$$\text{Minimize: } F_K(x) = [W_1 \times F_1(x) + W_2 \times F_2(x) + \cdots + W_M \times F_M(x)] \text{ ; } K = 1,2,3,\dots,M \quad X \quad (24)$$

$$\text{Subject to : } g_i(x) \leq 0 \text{ ; } i = 1,2,3,\dots,m$$

In this study , it is proposed that W1=W2 =W3=1 .

V.6 OPTIMIZATION PROCEDUR

In this study, we search for the optimal size of a HMS using the particle swarm optimization algorithm through the following steps:

A: The design of the HMS is carefully implemented through the conditions followed in the energy management strategy according to the following:

- Generation of the initial population.
- Implement the hybrid system design by evaluating equations (1) through (13).
- Evaluation of the fitness function through Equation (14) taking into consideration all the constraints in equations (16) through (20).

B: Run the optimization algorithm through the following operations.

- Update both position and velocity through Equation (21) and Equation (22), respectively, together with the sizing of all components of the proposed HMS.
- Implement the hybrid system design by evaluating equations (1) through (13).
- Evaluation of the fitness function through Equation 14 taking into consideration all the constraints in equations (16) through (20).
- Check whether the proposed system meets problem requirements and end criterion, or not. If so, the program will be stopped and will go to the next step, otherwise, the same procedure is repeated until the termination criterion is attained.
- Show the optimal size for all components of the proposed Microgrid system with the three optimal values for the fitness function parameters, which are COE, LPSP and Dummyexcess.

VI. RESULTS AND DISCUSSION

An isolated microgrid network system was designed to be applied in the region of Biskra, Algeria, which has many agricultural and pastoral sites that are very isolated and without electrical energy. We used real weather data captured from the weather station at the University of Biskra. The data showed that the highest average solar radiation occurred in July 2020, with an estimated value of 307.02 W/m2.

This peak is typical for the summer season when solar irradiation is generally at its maximum. In contrast, the average wind speed reached its highest in March 2020, estimated at 10.06 km/h (2 .79 m /s). This increase in wind speed during the spring can be attributed to seasonal climatic changes. Monthly average values of temperature, irradiation, and wind speed were analyzed, revealing seasonal patterns. Summer months exhibited the highest solar radiation, while spring months showed higher wind speeds. These seasonal variations are crucial for optimizing the hybrid energy system, as they influence the performance and reliability of both solar and wind energy sources.

All technical and economic specifications used for the components of the microgrid system consisting of solar panels, wind turbines, batteries and diesel generators, are shown in Table 1 , with the interest rate taken at 13%, and the project life estimated at 24 years.

Table 1: Technical and economic characteristics of the system components.

Component	Parameter	Value and Uint
Photovoltaic (PV	Life time	24 year
	Capital cost	3400 $/kW
	Rated power	7.3 kW
	PV regulator Cost Regulator efficiency	1500 $ 95 %
Wind turbine (WT)	Model	ZEYU FD-2KW
	Life time	24 year
	Capital cost	2000 $/kW
	Rated power	5 kW
	Rated speed	9.5 m/s
	Cut in speed	2.5 m/s
	Cut out speed	40 m/s
	Wind turbine regulator Cost	1000 $
	Efficiency	95 %
Diesel generator	Life time	24,000 hours
	Capital cost	1000 $/kW
	Rated power	4 kW
Battery	Life time	12 year
	Capital cost	280 $/kW
	Rated power	40 kWh
	Efficiency	85 %
Inverter	Life time	24 year
	Capital cost	2500 $
	Efficiency	92 %
Economic parameters	Life time of project	24 year
	Real interest	13 %
	Running cost +O&M cost	20 %
	Discount rate	8 %
	Fuel inflation rate	5 %

Source: Authors, (2025).

MATLAB programming and simulation platform was used in this work. The maximum number of iterations was set at 50 and the maximum number of search agents was set at 10. The main objective of our study was to search for the optimal size for all system components, that is, to search for the optimal numbers of solar panels, wind turbines, batteries and diesel generators.

Two cases were proposed for the study, the first case is a microgrid network consisting of 10 houses, and the second case is a microgrid network consisting of 20 houses. We have developed a new design approach through the proposed objective function. Table 2 shows the best value for the objective function and computing time.

Table 2: Optimization results using PSO.

Cases studied	Best fitness values	Time (sec)
Case 1	0,49993	52.67187
Case 2	0,43816	411.05354

Source: Authors, (2025).

Figure 10 illustrates the convergence of the technique for the two cases studied. The results indicate that the best value for the objective function in Case 1 is 0,49993, which is achieved in a time of 52.67187 seconds . As for Case 2, the best value of the objective function was 0,43816, achieved in 411.05354 seconds.

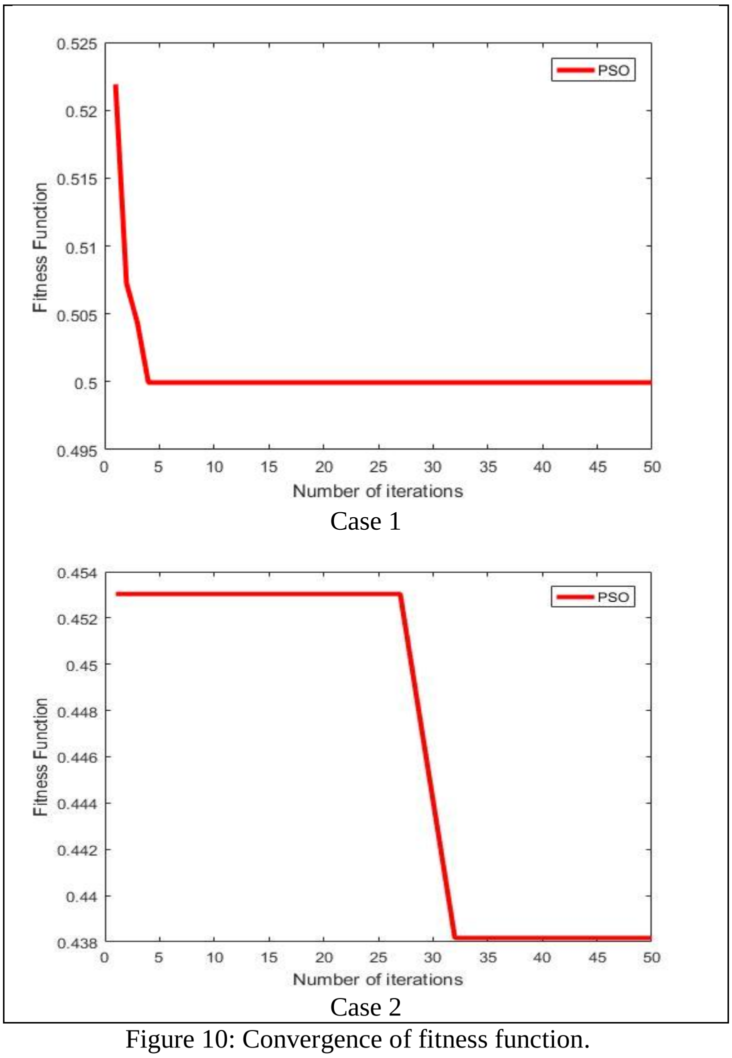


Figure 10: Convergence of fitness function.
Source: Authors, (2025).

Figure 11, illustrates the convergence curve for the cost of electricity, obtained for the two cases through the developed method of the PSO algorithm, algorithm. The figure indicates that the best cost of electricity obtained is estimated at 0,15829 $/Kwh and 0,42112 $/Kwh for Cases 1 and 2, respectively.

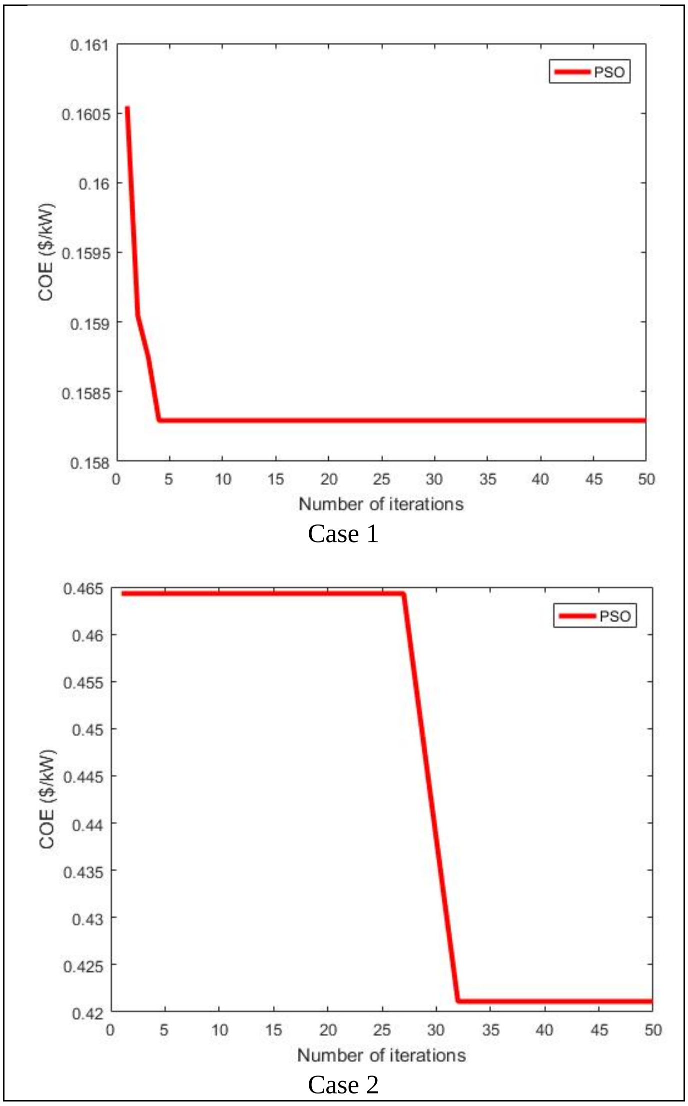
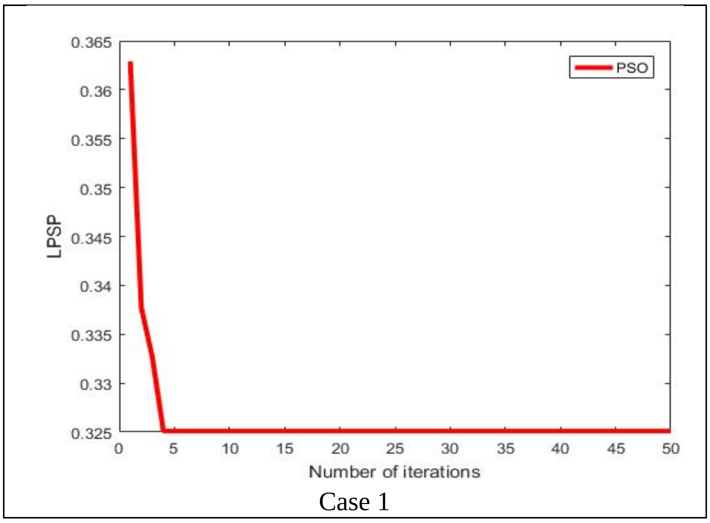


Figure 11: Convergence of cost of electricity (COE).

Figure 12, which displays the convergence curve for the Loss of power supply probability (LPSP), obtained for the two cases through the developed method of the PSO algorithm. The figure indicates that the best Loss of Power Supply Probability obtained is estimated at 0,32510 and 0,47711for Cases 1 and 2, respectively.



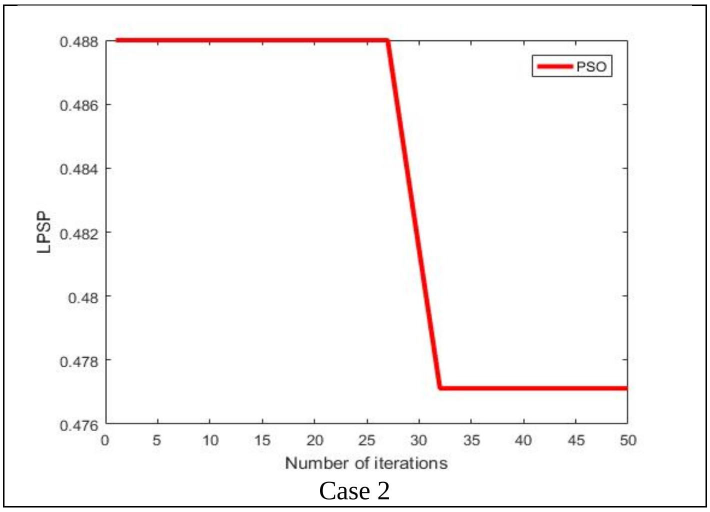


Figure 11: convergence curves for the Loss of power supply probability (LPSP)
Source: Authors, (2025).

Figure 13, which shows the convergence curve for Dummy excess, obtained for the two cases through the developed method of the PSO algorithm. The figure indicates that the best Dummy excess obtained is estimated at 0,55994 and 0,02145 for Cases 1 and 2, respectively.

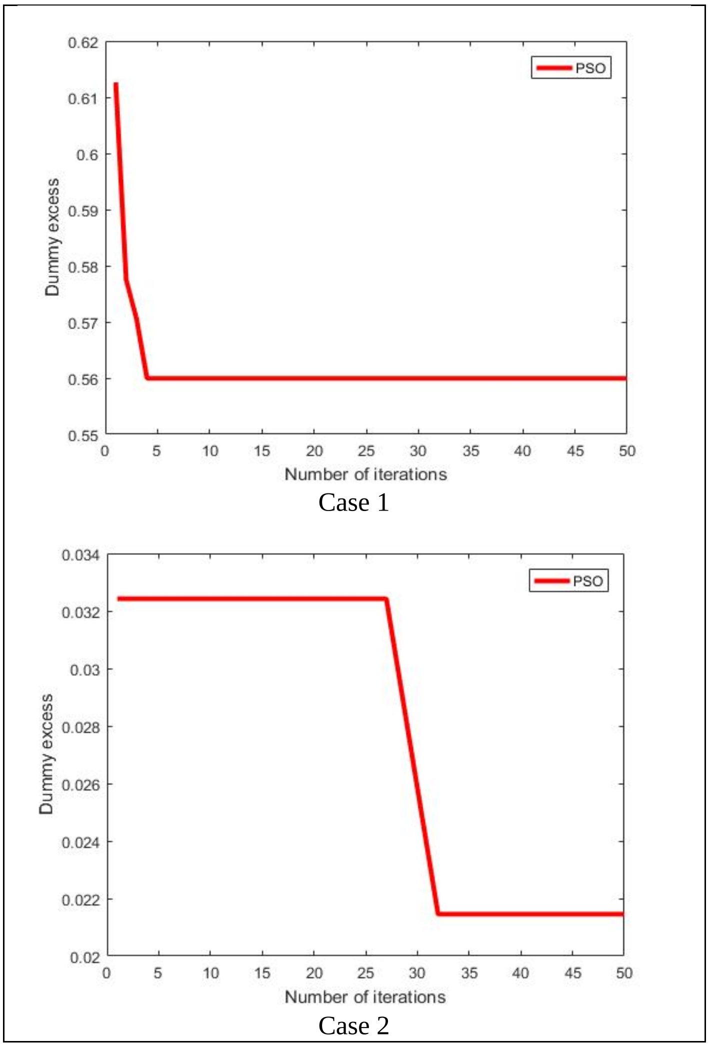


Figure 13: Convergence of Dummy excess.
Source: Authors, (2025).

Figure 14, presents a detailed comparison of the cost of energy (COE) for scenarios 1 and 2. The analysis demonstrates that Scenario 1 achieves the most favorable COE value of 0.15829 $/kWh, which reflects a more efficient cost structure compared to Scenario 2. This result highlights Scenario 1's advantage in minimizing energy expenses while maintaining overall system performance.

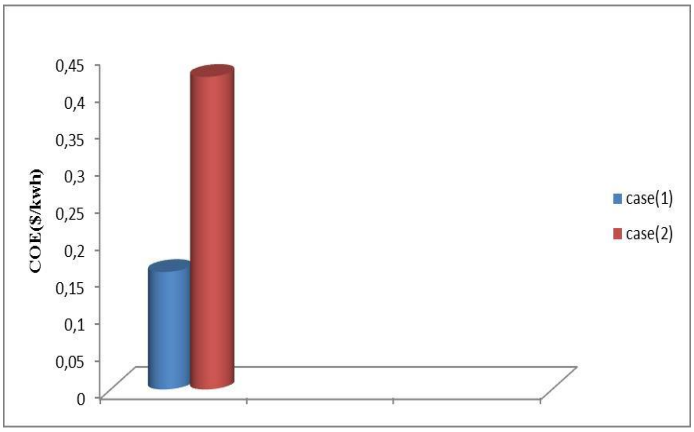


Figure 14: A comparison of the main optimization factors (COE)
Source: Authors, (2025).

Figure 15, illustrates the Loss of Power Supply Probability (LPSP) for scenarios 1 and 2. The data reveals that Scenario 1 not only performs better in terms of COE but also exhibits the lowest LPSP value of 0.32510. This indicates a lower likelihood of power supply disruptions, showcasing Scenario 1's robustness in ensuring a reliable energy supply. These findings underscore the effectiveness of Scenario 1 in optimizing both cost efficiency and reliability.

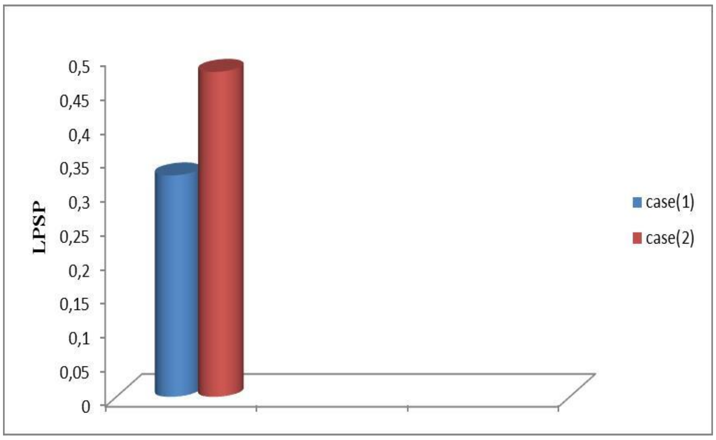


Figure 15: A comparison of the main optimization factors (LPSP).
Source: Authors, (2025).

Table 3 shows the optimal values obtained for three parameters that represent the objective function proposed in this study. Table 4 also gives the optimal number of each component type for the proposed HMS. In Case 1, the optimization method yields: 23 solar panels, 3 wind turbines, 10 batteries, 1 diesel generator, and 5 autonomy days.

In Case 2, we obtained 39 solar panels and 7 wind turbines, 11 batteries, 4 diesel generators, and 5 autonomy days. Table 5 gives the total energy generated over the course of a full year through all components of the proposed Microgrid system, where the energy production through solar energy is estimated at 269280 KW in Case 1 and 456602 KW in Case 2.

Table 3: Optimization results for COE , LPSP ,and Dummy excess using PSO

Cases studied	COE($/Kwh)	LPSP(%)	Dummy excess(%)
Case 1	0,15829	0,32510	0,55994
Case 2	0,42112	0,47711	0,02145

Source: Authors, (2025).

Table 4:Optimization results for the optimal number of system components using PSO.

Cases studied	N_{PV}	N_{wind}	$N_{Battery}$	N_{diesel}	N_{AD}
Case 1	23	3	10	1	5
Case 2	39	7	11	4	5

Source: Authors, (2025).

Table 5: The annual generated power of each component using PSO.

Cases studied	PV(KW)	Wind(KW)	Battery(KW)	Diesel(KW)
Case 1	2.6928e+05	4.4340e+03	1.4042e+05	1.1931e+04
Case 2	4.5660e+05	1.0346e+04	6.4405e+05	7.7986e+04

Source: Authors, (2025).

Figure 16 gives the percentage of energy provided by the solar panels, wind turbines, batteries and diesel generator for the proposed hybrid system in the two cases studied during a full year. As can be seen from these results, the Biskra region is a region very rich in renewable energy sources, especially solar energy. We have found that, in the first studied case, the percentage of solar energy reached 67% of the total energy, followed by batteries with 29%, diesel generator 3%, and wind energy 1%. In Case 2, the results indicate that the percentage of solar energy reached 64%, the percentage of battery reached 33%, diesel generator 2%, and wind turbines 1%.

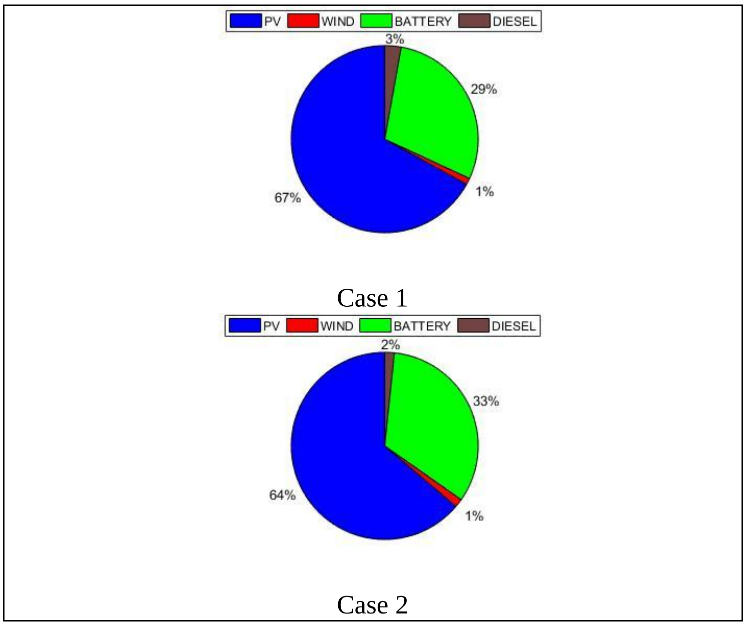


Figure 16: Percentage of annual energy contribution for all Microgrid's components system using PSO.
Source: Authors, (2025).

Figure 17, illustrates the energy generated in the microgrid system over a 72-hour period. The data show that during daylight hours, when the energy generated from renewable resources such as solar and wind exceeds the load demand, the hybrid system stores the excess energy in batteries until they are fully charged.

Once the batteries are at capacity, the system dissipates the surplus energy. Conversely, when renewable resources cannot meet the load demand, the stored energy in the batteries is utilized, resulting in a decrease in stored energy. If the energy in the batteries falls to the minimum allowable level, the diesel generator is activated to supplement the supply.

This behavior aligns with the findings reported by Abd El-Sattar et al. [54] in 2021, where similar storage and dissipation patterns were observed in HMS. Furthermore, the efficiency of energy storage and the role of the diesel generator in maintaining system reliability were consistent with the results of [55] in 2024, which highlighted the critical balance between renewable energy generation, storage capacity, and backup systems.

Our results underscore the importance of optimizing battery capacity and integrating robust backup solutions to ensure continuous power supply, particularly in scenarios where renewable energy generation is variable. This comprehensive analysis provides valuable insights into the operational dynamics of hybrid systems, contributing to the broader understanding of renewable energy integration and its practical implications for microgrid stability and efficiency.

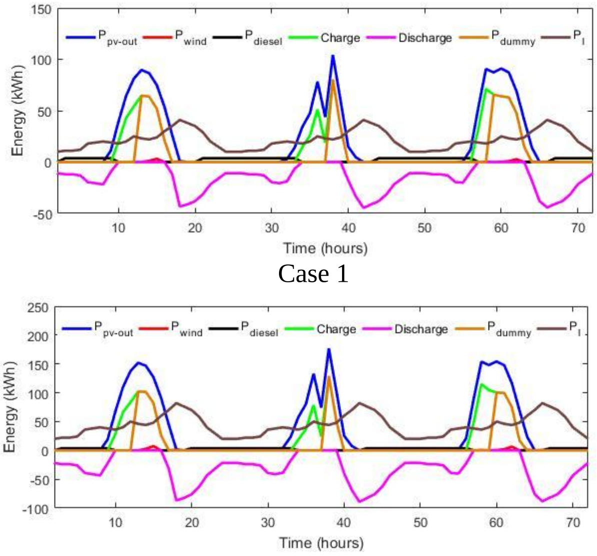


Figure 17: Microgrid system 's power over 72 hours using PSO
Source: Authors, (2025).

VII. CONCLUSIONS

In this paper , we have presented a study on the determination of the optimal size of the components of a microgrid system, consisting of solar panels, wind turbines, batteries, and diesel generators. In this study, it was suggested that two scenarios should be considered for a Microgrid system, one consisting of 10 houses, and the other one comprising 20 houses. We developed a new model of the particle swarm optimization algorithm and proposed an innovative way of using the weighted sum multi objective function by combining together the lowest price of electricity, more reliability, and less waste of dummy load energy.

We have chosen the agricultural and pastoral region of Biskra for our study, and we have reached the optimal size that enables us to guarantee the largest production of electricity at the lowest possible price and with greater reliability. All the results of the simulations that we have obtained confirmed that PSO is an effective optimization technique due to its ability to reach the optimal solution simply and with high efficiency. Also, the adopted multi-objective function was shown to alleviate the problem of sizing through the integration of the cost of electricity (COE), Loss of Power Supply Probability (LPSP), and Dummy excess into one objective function.

Furthermore, all the results obtained prove that the Biskra is rich in renewable energy sources, particularly solar energy. Therefore, this study can be seen as a promising incentive for prospective investors and decision makers to invest in this region and establish stations to supply all isolated areas and government facilities such as hospitals and schools with electrical energy.

VIII. AUTHOR'S CONTRIBUTION

Conceptualization: Badis Bacha.
Methodology: Badis Bacha and Abir Betka.
Investigation: Badis Bacha and Hatem Ghodbane.
Discussion of results: Badis Bacha, Abir Betka and Aymene Bacha.
Writing – Original Draft: Badis Bacha.
Writing – Review and Editing: Madina Hamiane and Nadjiba Terki.
Resources: Badis Bacha.
Supervision: Hatem Ghodbane and Nadjiba Terki.
Approval of the final text: Badis Bacha, Madina Hamiane and Omar Charrouf.

VX. REFERENCES

[1] Zhou, W., H. Yang, and Z.J.R.E. Fang, Battery behavior prediction and battery working states analysis of a hybrid solar–wind power generation system. Renewable Energy, 2008. 33(6): p. 1413-1423.

[2] Goedecke, M., S. Therdthianwong, and S.H.J.E.p. Gheewala, Life cycle cost analysis of alternative vehicles and fuels in Thailand. Energy policy, 2007. 35(6): p. 3236-3246.

[3] Straatman, P.J. and W.G.J.S.e. Van Sark, A new hybrid ocean thermal energy conversion–Offshore solar pond (OTEC–OSP) design: A cost optimization approach. Solar energy, 2008. 82(6): p. 520-527.

[4] Shaahid, S., M.J.R. Elhadidy, and s.e. reviews, Technical and economic assessment of grid-independent hybrid photovoltaic–diesel–battery power systems for commercial loads in desert environments. Renewable and sustainable energy reviews, 2007. 11(8): p. 1794-1810.

[5] Zhou, W., et al., Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. Applied energy, 2010. 87(2): p. 380-389.

[6] Farraj, W., A. Awad, and A. Qaroush. Optimal Sizing of Hybrid Microgrids. in 2020 6th IEEE International Energy Conference (ENERGYCon). 2020. IEEE.

[7] Shaffer, E., P. Roege, and T.J.U.A.R.L. Zheleva, Adelphi, MD, Tech Report ARL-TR-, Advanced microgrid concepts and technologies workshop. US Army Research Laboratory, Adelphi, MD, Tech Report ARL-TR-6407, 2013.

[8] Choi, S., et al. A microgrid energy management system for inducing optimal demand response. in 2011 IEEE international conference on smart grid communications (SmartGridComm). 2011. IEEE.

[9] Logenthiran, T., et al. Optimal sizing of distributed energy resources for integrated microgrids using evolutionary strategy. in 2012 IEEE Congress on Evolutionary Computation. 2012. IEEE.

[10] McPherson, M., et al., Planning for variable renewable energy and electric vehicle integration under varying degrees of decentralization: A case study in Lusaka, Zambia. Energy, 2018. 151: p. 332-346.

[11] Chauhan, A., R.J.R. Saini, and S.E. Reviews, A review on Integrated Renewable Energy System based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control. Renewable and Sustainable Energy Reviews, 2014. 38: p. 99-120.

[12] Ammari, C., et al., Sizing, optimization, control and energy management of hybrid renewable energy system—A review. Energy and Built, 2022. 3(4): p. 399-411.

[13] Upadhyay, S., M.J.R. Sharma, and S.E. Reviews, A review on configurations, control and sizing methodologies of hybrid energy systems. Renewable and Sustainable Energy Reviews, 2014. 38: p. 47-63.

[14] Starke, A.R., et al., Multi-objective optimization of hybrid CSP+ PV system using genetic algorithm. Energy, 2018. 147: p. 490-503.

[15] Kamjoo, A., et al., Multi-objective design under uncertainties of hybrid renewable energy system using NSGA-II and chance constrained programming. International journal of electrical power & energy systems, 2016. 74: p. 187-194.

[16] Ramli, M.A., H. Bouchekara, and A.S.J.R.e. Alghamdi, Optimal sizing of PV/wind/diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm. Renewable energy, 2018. 121: p. 400-411.

[17] Askarzadeh, A. and L.J.S.e. dos Santos Coelho, A novel framework for optimization of a grid independent hybrid renewable energy system: A case study of Iran. Solar energy, 2015. 112: p. 383-396.

[18] Fathy, A.J.R.e., A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt. Renewable energy, 2016. 95: p. 367-380.

[19] Suhane, P., et al., Sizing and performance analysis of standalone wind-photovoltaic based hybrid energy system using ant colony optimisation. IET Renewable Power Generation, 2016. 10(7): p. 964-972.

[20] Shi, B., W. Wu, and L.J.J.o.t.T.I.o.C.E. Yan, Size optimization of stand-alone PV/wind/diesel hybrid power generation systems. Journal of the Taiwan Institute of Chemical Engineers, 2017. 73: p. 93-101.

[21] Gupta, R., et al., BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting. Renewable and sustainable energy reviews, 2015. 41: p. 1366-1375.

[22] Shi, Z., R. Wang, and T.J.S.e. Zhang, Multi-objective optimal design of hybrid renewable energy systems using preference-inspired coevolutionary approach. Solar energy, 2015. 118: p. 96-106.

[23] Sanajaoba, S. and E.J.R.e. Fernandez, Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System. Renewable energy, 2016. 96: p. 1-10.

[24] Maleki, A. and A.J.S.E. Askarzadeh, Artificial bee swarm optimization for optimum sizing of a stand-alone PV/WT/FC hybrid system considering LPSP concept. Solar Energy, 2014. 107: p. 227-235.

[25] Zhao, J. and X.J.S.C. Yuan, Multi-objective optimization of stand-alone hybrid PV-wind-diesel-battery system using improved fruit fly optimization algorithm. Soft Computing, 2016. 20: p. 2841-2853.

[26] Sánchez, V., J.M. Ramirez, and G. Arriaga. Optimal sizing of a hybrid renewable system. in 2010 IEEE international conference on industrial technology. 2010. IEEE.

[27] Kaviani, A.K., G. Riahy, and S.M.J.R.e. Kouhsari, Optimal design of a reliable hydrogen-based stand-alone wind/PV generating system, considering component outages. Renewable energy, 2009. 34(11): p. 2380-2390.

[28] Khare, V., S. Nema, and P.J.I.J.o.S.E. Baredar, Optimisation of the hybrid renewable energy system by HOMER, PSO and CPSO for the study area. International Journal of Sustainable Energy, 2017. 36(4): p. 326-343.

[29] Sharafi, M. and T.Y.J.R.e. ELMekkawy, Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach. Renewable energy, 2014. 68: p. 67-79.

[30] Parsopoulos, K.E. and M.N. Vrahatis. Particle swarm optimization method in multiobjective problems. in Proceedings of the 2002 ACM symposium on Applied computing. 2002.

[31] Coello, C.A.C., Evolutionary algorithms for solving multi-objective problems. 2007: Springer.

[32] Ocłoń, P., et al., Multiobjective optimization of underground power cable systems. Energy, 2021. 215: p. 119089.

[33] Marler, R.T., J.S.J.S. Arora, and m. optimization, The weighted sum method for multi-objective optimization: new insights. Structural and multidisciplinary optimization, 2010. 41: p. 853-862.

[34] Daud, A.-K. and M.S.J.R.e. Ismail, Design of isolated hybrid systems minimizing costs and pollutant emissions. Renewable energy, 2012. 44: p. 215-224.

[35] Akter, H., et al., Optimal sizing and performance analysis of hybrid microgrid for remote island of developing country: Effect of sustainable parameters, benefits and installation barriers. Franklin Open, 2024: p. 100074.

[36] Porté-Agel, F., M. Bastankhah, and S.J.B.-l.m. Shamsoddin, Wind-turbine and wind-farm flows: A review. Boundary-layer meteorology, 2020. 174(1): p. 1-59.

[37] Shin, J., J.H. Lee, and M.J.J.A.e. Realff, Operational planning and optimal sizing of microgrid considering multi-scale wind uncertainty. Applied energy, 2017. 195: p. 616-633.

[38] Abeg, A.I., et al., Capacity and operation optimization of hybrid microgrid for economic zone using a novel meta-heuristic algorithm. Journal of Energy Storage, 2024. 94: p. 112314.

[39] Bukar, A.L., C.W. Tan, and K.Y.J.S.E. Lau, Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm. Solar Energy, 2019. 188: p. 685-696.

[40] Shang, C., et al., An improved particle swarm optimisation algorithm applied to battery sizing for stand-alone hybrid power systems. International Journal of Electrical Power & Energy Systems, 2016. 74: p. 104-117.

[41] Deshmukh, M.K., S.S.J.R. Deshmukh, and s.e. reviews, Modeling of hybrid renewable energy systems. Renewable and sustainable energy reviews, 2008. 12(1): p. 235-249.

[42] Mohamed, M.A., et al., A novel framework-based cuckoo search algorithm for sizing and optimization of grid-independent hybrid renewable energy systems. International journal of green energy, 2019. 16(1): p. 86-100.

[43] Luna-Rubio, R., et al., Optimal sizing of renewable hybrids energy systems: A review of methodologies. Solar energy, 2012. 86(4): p. 1077-1088.

[44] Dursun, B.J.R. and S.E. Reviews, Determination of the optimum hybrid renewable power generating systems for Kavakli campus of Kirklareli University, Turkey. Renewable and Sustainable Energy Reviews, 2012. 16(8): p. 6183-6190.

[45] Hosseini, S.J.a.-D., M. Moazzami, and H.J.M.J.o.E.E. Shahinzadeh, Optimal sizing of an isolated hybrid wind/PV/battery system with considering loss of power supply probability. Majlesi Journal of Electrical Engineering, 2017. 11(3): p. 63-69.

[46] Bacha, B., et al., Optimal sizing of a hybrid microgrid system using solar, wind, diesel, and battery energy storage to alleviate energy poverty in a rural area of Biskra, Algeria. Journal of Energy Storage, 2024. 84: p. 110651.

[47] Kennedy, J. and R. Eberhart. Particle swarm optimization. in Proceedings of ICNN'95-international conference on neural networks. 1995. IEEE.

[48] Chao, W., et al., Swarm intelligence: A survey of model classification and applications. Chinese Journal of Aeronautics, 2024.

[49] Bansal, J.C.J.E. and s.i. algorithms, Particle swarm optimization. Evolutionary and swarm intelligence algorithms, 2019: p. 11-23.

[50] Yang, X.-S., Engineering optimization: an introduction with metaheuristic applications. 2010: John Wiley & Sons.

[51] Atam, E., et al., A hybrid green energy-based system with a multi-objective optimization approach for optimal frost prevention in horticulture. Journal of Cleaner Production, 2021. 329: p. 129563.

[52] Wang, Z., Y. Pei, and J.J.A.S. Li, A survey on search strategy of evolutionary multi-objective optimization algorithms. Applied Sciences, 2023. 13(7): p. 4643.

[53] Zhang, H., et al., Modeling a hydrogen-based sustainable multi-carrier energy system using a multi-objective optimization considering embedded joint chance constraints. Energy, 2023. 278: p. 127643.

[54] Abd El-Sattar, H., et al., Optimal design of stand-alone hybrid PV/wind/biomass/battery energy storage system in Abu-Monqar, Egypt. Journal of Energy Storage, 2021. 44: p. 103336.

[55] Abdelsattar, M., et al., Optimal sizing of a proposed stand-alone hybrid energy system in a remote region of southwest Egypt applying different meta-heuristic algorithms. Neural Computing and Applications, 2024: p. 1-19.