

Design, simulation, sizing and optimization of hybrid renewable energy systems PV/Wind/Battery using PSO algorithm

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Abstract— In this paper, an optimization model is presented to determine the best size of a hybrid energy system (HES), which consists of photovoltaic (PV), wind turbine (WT) and battery. For distant regions and also the smart cities, this system enables a clean and stable power source. In this context, this study explores the application of a simple and efficient Particle Swarm Optimization (PSO) algorithm. This algorithm aims to determine the optimal configure of system components to minimize cost and meet load demand. For this objective, all the components are modeled (PV, WT and battery) and the leveled cost of energy is defined as an objective function. The concept of loss of power supply probability (LPSP) should be considered in hybrid energy systems in order to have a reliable system. The research presented in this paper was conducted in Constantine, Algeria and may be applied to any similar regions throughout the world.

Keywords - hybrid energy system (HES), photovoltaic (PV), wind turbine (WT), Particle Swarm Optimization (PSO).

I. INTRODUCTION

In recent years, the use of renewable energies has increased greatly due to the development of society and the economy and falling oil prices [1]. This development has led to more attention to environmental pollution. Renewable energy, as a clean energy source, can be used to replace fossil fuels, which pollute the environment and are a non-renewable resource, in order to provide enough electricity to meet people's daily needs and contribute to social development [2]. So it is clear that the future energy sustainability heavily depends on how the renewable energy problem is addressed to contribute in meeting the electrical power demand.

The most important challenge of the single renewable energy systems is their random environmental conditions (solar radiation and wind speed). As a solution, the combination of different energy sources such as wind and solar with battery storage improve the system efficiency and reliability [1]. However, due to the non-linear response of the system components and the dependence on environmental conditions and the random load profile, smart grid is used to tailor and incorporate these units so that electricity may be

moved across the system as efficiently and affordably as feasible [1].

The particle swarm optimization technique was used in this work to optimize an off-grid hybrid energy system (HES) and produce better results for matching renewable energy generation with home load using HES, utilizing MATLAB. In hybrid systems, optimal size is an important issue, it is defined by determining the number of system components to minimize cost and meet local load demand. An optimization approach can be used to do this work.

In previous studies, different methods have been presented for sizing, modeling and feasibility evaluation of such systems, utilizing a mix of renewable energy sources to deliver power for various applications. These methods are based on traditional methods, artificial intelligence methods and hybrid methods. This makes the selection of a suitable sizing methodology, much more important [1]. The reference [1] encompasses review in detail the different configurations, criteria selection, sizing methodologies and control & energy management of hybrid energy systems. Gupta et al. [3] employed C++-based analytical tools to efficiently construct a low-cost village electrification system while the diesel generator maintains a consistent output. Analytical approaches use less time to acquire the needed size for a specific demand than Monte Carlo simulation. An iterative optimization method was used by Yang et al. [4] to optimize a hybrid energy system size, they used LPSP and Leveled Cost of Energy model to optimize power reliability and system cost. Koutroulis et al. [5] presented an optimal sizing of HES based on a genetic algorithm to select the optimal number of units (PV modules, wind turbines and batteries) with a minimum cost, subject to the satisfaction of the load demand. Askarzadeh and dos Santos Coelho [6] proposed an optimized sizing of a hybrid solar, wind and battery system through PSO algorithm, their objectives are the minimization of life cycle cost (LCC) subject to reliable supply to meet load demand. Sharma et al. [7] developed hybrid method that combines a genetic algorithm (GA) with a particle swarm optimization algorithm to build and optimize an off-grid hybrid energy system's cost. The results show that the HGAPSO algorithm outperforms the GA and PSO algorithms in terms of cost savings.

In this paper, a particle swarm optimization algorithm has been introduced to size a hybrid energy system combined of PV/wind/battery taking into account seasonal variations in the load profile with the measured solar and wind energy resources, the cost of components and the cost of maintenance.

II. MODELING OF HYBRID ENERGY SYSTEM

Prior to any phase of optimal sizing, it is critical to model the hybrid system. This system is a configuration of two or more renewable and even non-renewable energy. Fig. 1 shows a schematic of the proposed hybrid energy system, as can be seen it consists of a photovoltaic, a wind turbine generator, inverter and a battery storage. All components are connected to the DC bus, except the load. Solar and wind energy are converted into electricity via PV modules and wind turbines. When the amount of energy produced exceeds the amount required to power the load, the excess energy is supplied to the battery bank until it is fully charged. When the energy produced is insufficient to meet the load, the batteries release energy to help the PV modules in covering the load, depending on the battery's level of charge.

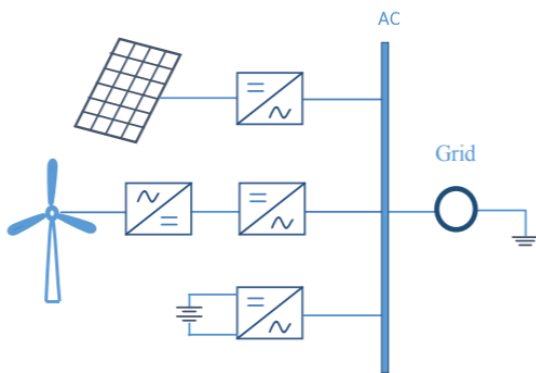


Fig. 1. Schematic drawing of the proposed system.

In the following subsections, a description of a general methodology for modeling a photovoltaic panel, wind turbine, and battery is described in detail.

A. Model of PV array

In order to present photovoltaic characteristics in operating conditions that differ from the standard test condition (1000W/m, 25C cell temperature), The solar radiation, the ambient temperature and manufacturer's data of the PV panels are used as model inputs to estimate the output energy generated for photovoltaic panel [8]. The output power of each PV system at time t, with respect to the solar radiation and the ambient temperature, can be obtained by the following formula [8]:

$$P_{pv}(t) = P_{rate_pv} \times \eta_{pv} \times \frac{S}{S_{ref}} \times [1 + K_t(T_c - T_{ref})] \quad (1)$$

Where:

- $P_{pv}(t)$ (kW) : the output power of PV arrays.

- P_{rate_pv} (kW) : the rated power of the photovoltaic module.
- η_{pv} : the photovoltaic derating factor.
- S (W/m^2): solar radiation intensity.
- S_{ref} (W/m^2) : the incident radiation at standard test conditions ($S_{ref} = 1000$ W/m^2).
- K_t ($1/C$): the temperature coefficient of power $K_t = -3.7 \times 10^{-3}$ ($1/C$).
- T_{ref} : the photovoltaic module temperature under standard test conditions.
- T_c (C): the photovoltaic panel temperature.

The PV cell temperature (T_c) can be estimated as follows [9]:

$$T_c = T_a + S \left(\frac{NOCT - 20}{800} \right) \quad (2)$$

Where:

- T_a (C): the ambient temperature.
- S (W/m^2): solar radiation intensity.
- $NOCT$: the nominal operating cell temperature.

If there are a number of photovoltaic panels then the total power is:

$$P_{Tpv}(t) = P_{pv}(t) \times N_{pv} \quad (3)$$

Where:

- $P_{pv}(t)$ (kW) : the output power of PV arrays.
- N_{pv} : the numbers of PV arrays.

B. Model of wind turbine

The electrical power generated by wind turbines does not behave in the same way as the wind in terms of variation [8]. There are currently many models for estimating the output power of wind turbines, such as linear, quadratic model [10], and model using the Weibull distribution [11]. In this study, a quadratic model based on rated power is used to present the wind turbine hourly output power. The power generated by a wind turbine is determined by three main factors: the power output curve, wind speed data from the chosen location, and tower height [25]. Following are descriptions of three operational levels [6], as illustrated in Fig. 2 [12]:

- The wind turbine will stop running when the wind speed is less than the cut-in value or exceeds the cut-off value (region 1, region 4).
- When the cut-in value is exceeded, the power delivered by the generator increase proportional to the wind speed until reaching the rated speed of the wind turbine (region 2).
- When the wind speed reaches the rated wind speed, the generator produces a constant output power (region 3).

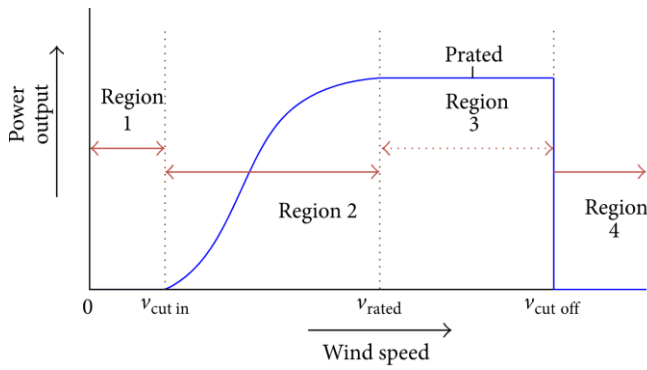


Fig. 2. Wind turbine output power characteristics [12].

The output power of wind turbine at time t is obtained as follows [13]:

$$P_{wt}(t) = \begin{cases} 0 & \text{if } v \leq V_i \text{ or } v \geq V_o \\ P_r \frac{v - V_i}{V_r - V_i} & \text{if } V_i < v < V_r \\ P_r & \text{if } V_r < v < V_o \end{cases} \quad (4)$$

Where:

- $P_{wt}(t)$: the output power of wind turbine.
- v (m/s^2): the wind speed.
- V_i, V_o, V_r (m/s^2): cut-in speed, cut-off speed and rated speed respectively.
- P_r (kW): rated power.

The wind speed is usually available for standard height, so the measured data of average hourly wind speed must be converted to the corresponding value at the hub height, which is calculated according to [14]:

$$v = v_o \times \left(\frac{H}{H_o}\right)^\alpha \quad (5)$$

Where:

- v (m/s^2): the wind speed at height H .
- v_o (m/s^2): the wind speed at height H_o .
- H (m): the desired height.
- H_o (m): the reference height.
- α : the roughness factor.

If there are a number of wind turbines then the total power is:

$$P_{Twt}(t) = P_{wt}(t) \times N_{wt} \quad (6)$$

Where:

- $P_{wt}(t)$: the output power of wind turbine.
- N_{wt} : the numbers of wind turbines.

C. Modeling of battery storage system

A battery bank system, which is usually of the lead-acid type [6], is a fundamental component in all renewable energy systems. It is used to store the excess electrical energy to regulate system voltage and to meet demand 24 hours a day, because the renewable energy systems provide irregular output power due to variable meteorological environments [15]. The state of charge (SOC) of the battery

depends on the output power of the PV panels, the wind turbines and the load and can be estimated as follows [16]:

1) Charging mode:

When the total output of the PV panels and wind turbine is more than the energy demand, the surplus power will be stored in the batteries. The battery energy can be described by [16]:

$$E_{BA}(t) = E_{BA}(t-1)(1-\sigma) + \left(E_{GA}(t) - \frac{E_L(t)}{\eta_{inv}}\right)\eta_{bc} \quad (7)$$

2) Discharging mode:

In this mode, the battery bank is used to supply the load. The energy will be extracted from the batteries, when power generation is insufficient to meet load demands. The battery energy can be obtained by [16]:

$$E_{BA}(t) = E_{BA}(t-1)(1-\sigma) - \left(\frac{E_L(t)}{\eta_{inv}} - E_{GA}(t)\right)/\eta_{bd} \quad (8)$$

Where:

- $E_{BA}(t)$: state of charge at time (t).
- $E_{BA}(t-1)$: state of charge at time ($t-1$).
- σ : hourly self-discharge rate.
- $E_{GA}(t)$ (kW): the total output power
- $E_L(t)$ (kW): the load demand.
- η_{bc} : the battery charging efficiency.
- η_{bd} : the battery discharging efficiency.
- η_{inv} : the inverter efficiency.

D. Model of inverter

The inverter converts the variable direct current output of a photovoltaic solar panel, the wind turbine and battery into alternating current. Because most electrical devices are supplied with AC power, an inverter is used before the load. The power that passes through the inverter to meet the demand is provided by [17]:

$$P_{in} = \frac{P_{ch}}{\eta_{inv}} \quad (9)$$

Where:

- P_{in} (kW): the power transiting the inverter.
- P_{ch} (kW): the hourly demand.
- η_{inv} (%): the inverter efficiency specified by the manufacturer.

III. FORMULATION OF THE OPTIMUM SIZING PROBLEM

The overall objective of this study is to show how to size system components to their optimal size. This is done by the minimization of the total annual cost (TAC) subject to some constraints.

A. Objective function

The purpose of the optimum design problem is the minimization of the total annual cost. The TAC can be divided into the annual capital cost (C_{Cap}) and the annual maintenance cost (C_{Man}). The optimization problem defined by [16]:

$$TAC = C_{Cap} + C_{Man} \quad (10)$$

The capital recovery factor (CRF), defined by Eq. (11), and is used to convert the initial capital cost to the annual capital cost [16].

$$CRF = \frac{j(1+j)^n}{(1+j)^n - 1} \quad (11)$$

Where:

- n : the lifetime of the system in years.
- j : the interest rate of the system.

Over the project's lifetime, some components need to be replaced several times. Only the batteries and inverter are assumed to be replaced in this study. Photovoltaic and wind turbine lifetimes are assumed to be 20 years. The battery bank is expected to be 5 years. Using the present worth factor for a single payment, we get [16]:

$$C_{Ba} = P_{Ba} \times \left(1 + \frac{1}{(1+i)^5} + \frac{1}{(1+i)^{10}} + \frac{1}{(1+i)^{15}} \right) \quad (12)$$

Where:

- C_{Ba} : the present worth of battery.
- P_{Ba} : the battery price.

Similarly, the lifetime of converter is expected to be 10 years. Using the present worth factor for a single payment, we get [16]:

$$C_{Conv/Inv} = P_{Conv/Inv} \times \left(1 + \frac{1}{(1+i)^{10}} \right) \quad (13)$$

Where:

- $C_{Conv/Inv}$: the present worth of converter/inverter components.
- $P_{Conv/Inv}$: the converter/inverter price.

Eq. (14) is obtained by dividing the capital cost into annual costs for the wind turbine, solar panels, converter/inverter, and battery [16].

$$C_{cap} = CRF \times \left[\frac{N_{wt} \times C_{wt} + N_{pv} \times C_{pv} + N_{Batt} \times C_{Batt}}{+ N_{Conv/Inv} \times C_{Conv/Inv}} \right] \quad (14)$$

Where:

- C_{wt} : the unit cost of wind turbine.
- C_{pv} : the unit cost of PV panels.
- $N_{Conv/Inv}$: the number of converter/inverter systems.

The annual maintenance cost of the system is obtained by [13]:

$$C_{Man} = N_{Wind} \times C_{Mnt}^{Wind} + N_{Pv} \times C_{Mnt}^{Pv} \quad (15)$$

Where:

- C_{Mnt}^{Wind} (kWh): the wind turbine's maintenance cost.
- C_{Mnt}^{Pv} (kWh): the PV panel's maintenance cost.

The cost of battery maintenance is overlooked.

The levelized cost of energy (LCOE) in \$/kWh is used to evaluate the economic performance of the hybrid system. The LCOE is calculated by the total annualized cost of the HES (TAC) and the total power load served ($E_L(t)$) [25].

$$LCOE = \frac{TAC}{\sum_{t=1}^{8760} E_L(t)} \quad (16)$$

B. Constraints

The above-mentioned objective function must be optimized in consideration of the constraints below.

1) Loss of power supply probability

The concept of loss of power supply probability (LPSP) should be considered in hybrid energy systems in order to have a reliable system. It is important to determine the combination PV/WT/Battery's minimum cost that yields the needed LPSP [18]. LPSP is defined by a value between 0 and 1 [19]. The load will never be satisfied if the LPSP is 1, and the load will always be satisfied if the LPSP is 0 [19]. LPSP is calculated in the following equation, for a specified period, T (1 year in this study) [19]:

$$LPSP = \frac{\sum_{t=1}^T LPS(t)}{\sum_{t=1}^T E_L(t)} \quad (17)$$

Where LPS is the loss of power supply can be obtained by [19]:

$$LPS(t) = E_L(t) - (E_{GA}(t) + E_{Batt}(t-1) - SOC_{min}) \eta_{inv} \quad (18)$$

Fig. 3 indicates the calculation of LPSP at each hour during the year.

2) State of charge

At any time, the battery charging and discharging operation is constrained by the minimum and the maximum permissible level, the following equation should be satisfied [14]:

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (19)$$

Where:

- SOC_{min} : the minimum permissible level.
- SOC_{max} : the maximum permissible level.

The maximum permissible level of battery bank is given by [17]:

$$SOC_{max} = C_{bat} \times N_{bat} \quad (20)$$

The minimum permissible level of battery bank is given by [17]:

$$SOC_{min} = C_{bat} \times N_{bat} (1 - DOD) \quad (21)$$

Where:

- C_{bat} : the nominal capacity of each battery.
- N_{bat} : the total number of batteries.
- DOD : the maximum depth of discharge in percentage.

3) The decision variables

The decision variables are the number of PV arrays, wind turbines and battery. So the following constraints should be satisfied [20]:

$$\begin{aligned} N_{pv} &= integer, 0 \leq N_{pv} \leq N_{pv}^{max} \\ N_{wt} &= integer, 0 \leq N_{wt} \leq N_{wt}^{max} \\ N_{Batt} &= integer, 0 \leq N_{Batt} \leq N_{Batt}^{max} \end{aligned} \quad (22)$$

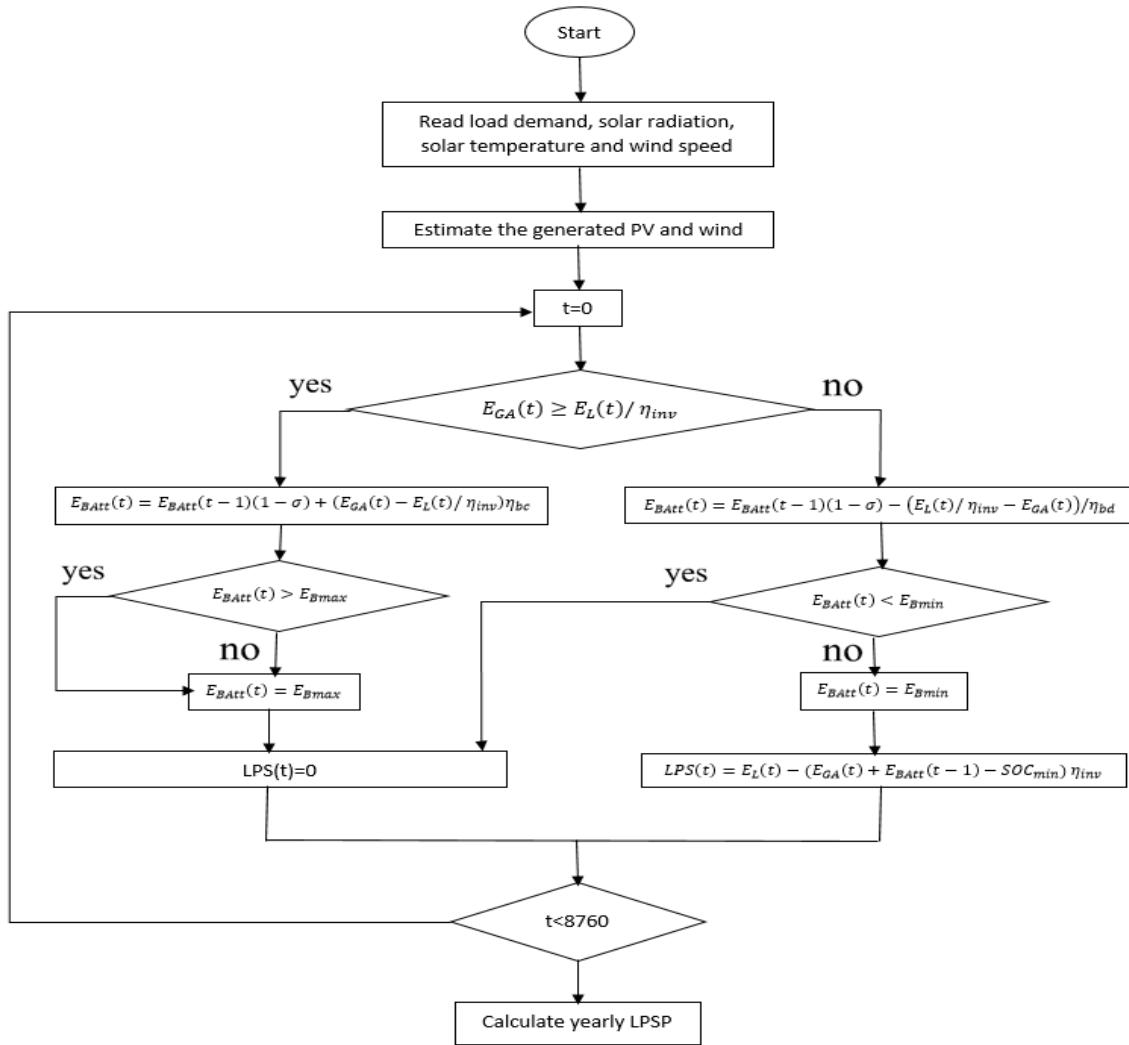


Fig. 3. The flowchart for the LPSP.

IV. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

The PSO algorithm is originally invented by Kennedy and Eberhart in 1995 [21]. It became one of the most used optimization algorithms because it has simple concept and can quickly find a reasonably good solution. This approach is based on the social behavior of birds, fish schools, and the swarm theory [22]. PSO is a metaheuristic algorithm which starts with a population of random solutions (particles) and attempt to discover the global solution of an optimization problem [6]. The algorithm of particle swarm optimization as used in this study is given in Fig. 4 [23].

In the PSO algorithm, each particle represents a possible solution, the optimization objective function evaluates these solutions to determine their fitness [24]. The number of solutions doubles in the next iteration until the best one is found. More particles in each iteration encourages the discovery of the best solution and reduces the number of optimization iterations. In PSO, each individual move around in the search space [24]. The local best values for each particle are obtained called p_{best} and the global best value among all particles is obtained

called g_{best} . Each particle tries to modify its position and velocity according to its own experience and the experience of neighboring particles. Position and velocity of each particle can be modified by the following equations [24]:

$$v_i^{k+1} = w^k \cdot v_i^k + c_1 \cdot r_1 \cdot (p_{best}^k - x_i^k) + r_2 \cdot (g_{best}^k - x_i^k) \quad (23)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (24)$$

Where:

- i : the particle.
- k : the iteration.
- v_i^k : the particle velocity.
- x_i^k : the current position of each particle.
- c_1, c_2 : positive acceleration constants.
- r_1, r_2 : uniform randomly generated numbers.
- p_{best}^k : The local best values for each particle.
- g_{best}^k : the global best value among all particles.
- w^k : the inertia weight factor.

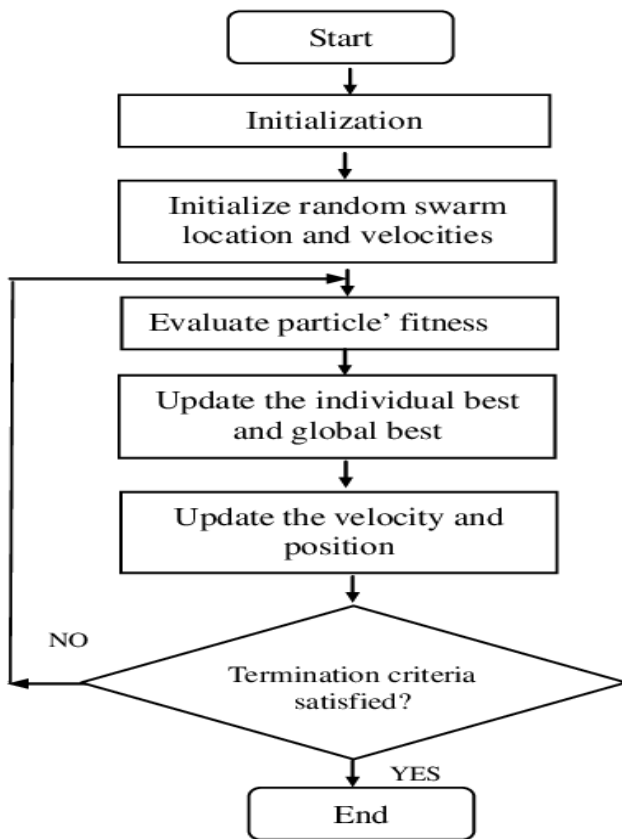


Fig. 4. Flow chart of PSO developed algorithm [23].

V. SIMULATION RESULTS AND DISCUSSION

In order to evaluate the performance of the heuristic techniques for optimum sizing of a real system, the meteorological data for the study area is obtained from Algeria, Constantine (latitude 36.3384, longitude 6.6199). This site represents the different climatic conditions considering seasonal variation. MATLAB software is used to code and execute the algorithm of optimization and run it on a PC with Intel I7-8550U CPU and 8 GB of RAM under Windows 7.

All the meteorological data has been taken from Nasa Power website during the year (8760 h). Fig. 5 shows a load profile well suited to the study area. It is considered the same for all days of the year. As shown in Fig. 6, the yearly solar irradiance, temperature and wind speed. According to the statistics, the solar radiation is highest in June and July and lowest in January. It can be seen that the change of temperature is most obvious in a year, with the maximum temperature in July and the lowest temperature in December. Wind speed data is also shown in Fig. 6, the average wind speed is 3.6 m/s, which can lead to generating electricity at night, unlike solar radiation.

The components of the studied system include the solar panel, the wind turbine, and a battery bank, the technical and economic specifications of which are detailed in Table 1.

Components	Description	
PV panel	Maximum power	270 W
	Cost	100 \$
	Maintenance cost	2\$
	Lifetime	25 years
Wind turbine	Nominal power	10000 W
	Cost	2500 \$
	Maintenance cost	25 \$
	Lifetime	20 years
	Cut in speed	2m/s
	Cut out speed	18m/s
Battery lead-acid	rated speed	10m/s
	Nominal capacity	200 Ah
	Maximum depth of discharge	50%
	Charge / discharge efficiency	80%
	Cost	350 \$
	Maintenance cost	3.5 \$
DC/AC converter	Lifetime	5 years
	Cost	900 \$
	Maintenance cost	10.8 \$
	Efficiency	92%
	Lifetime	10 years

Table 1: The parameters of the system components.

The parameters of the PSO algorithms are adjusted as follows:

Iteration max=100, number of particles=50, $c1=1.5$, $c2=1$, $r1=1$, $r2=1$, $\omega =1.5$.

The aim of this study is to create a hybrid energy system that can provide continuous and reliable power to a load. The PSO algorithm try to find the optimum number of solar panels, wind turbines and battery. The minimum and maximum numbers of each component are set to 0 and 200 for the number of photovoltaic modules, from 0 to 10 for the number of wind turbines and from 0 to 50 for the number of batteries.

Table 2 summarizes the results of the PSO algorithms on the sizing problem (the optimum number of the components and the COE value) with different values of LPSP (0%, 0.2% and 10%). These are different levels of reliability, it is known as the maximum LPSP that may be used, and it is set by the user. We can see that reliability improvement (LPSP) increases the cost of the system so by decreasing LPSP from 10% to 0%, COE surged about 1.9 times, because reliability is expensive.

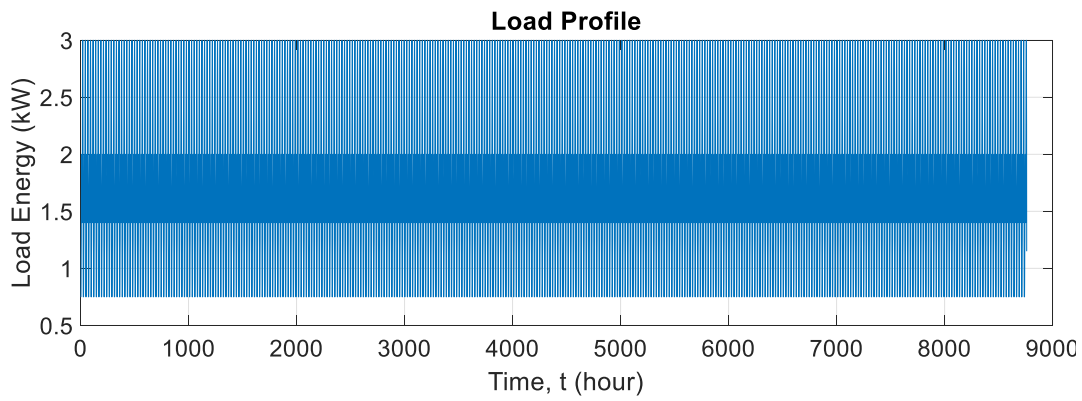


Fig. 5. Load profile of the study area during one year.

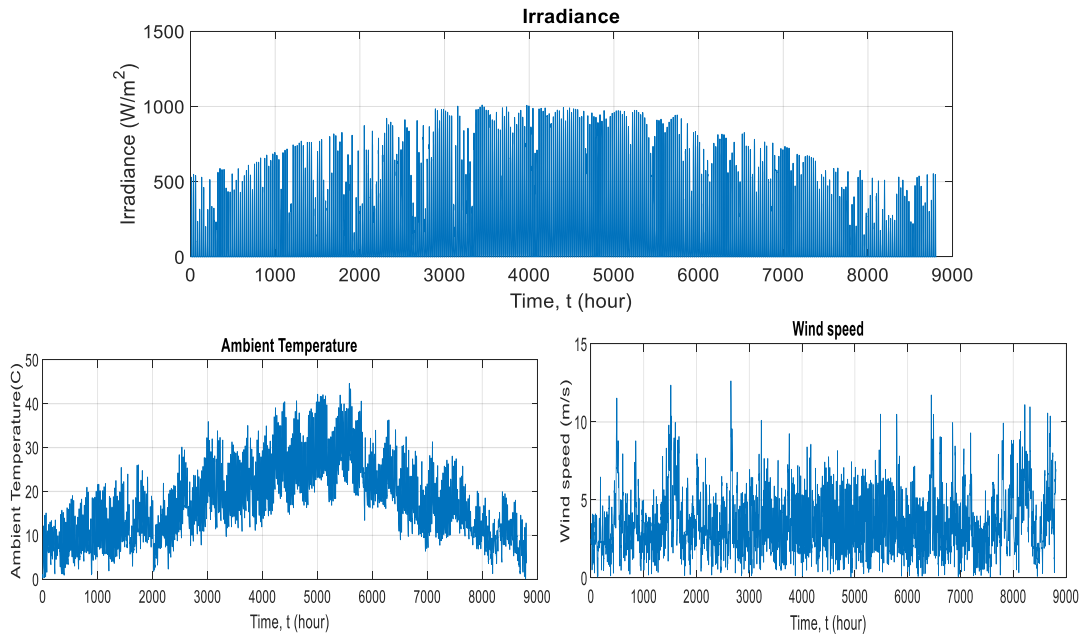


Fig. 6. The yearly meteorological data during one year.

LPSP (%)	N_{pv}	N_{wt}	N_{Batt}	COE (\$/kWh)
0	35	3	12	1.18
0.2	26	2	10	0.88
1	18	1	9	0.62

Table 2: Comparison of the results obtained by the PSO algorithm with different value of LPSP

Fig. 7 & 8. Show the power generated by the PV panels and wind turbines in LPSP=0. We noticed that the power of PV is high in summer and low in winter unlike the power of wind turbines which is balanced with different seasons. This is the benefit of wind turbines in HES which can lead to generating electricity in winter and at night to help PV panels to contribute in meeting the electrical power demand.

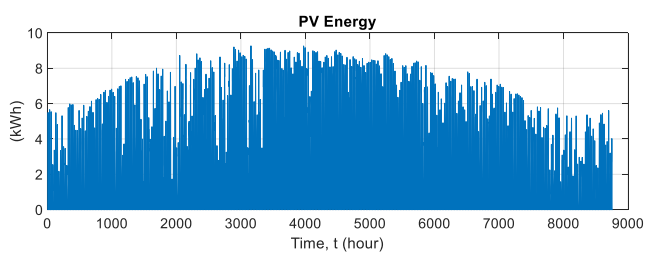


Fig. 7. Simulating intra-hourly PV energy fluctuations of the hybrid system in one year.

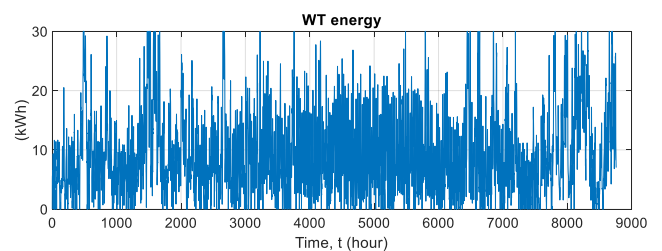


Fig. 8. Simulating intra-hourly WT energy fluctuations of the hybrid system in one year.

VI. CONCLUSION

This paper develops a methodology for optimum sizing of a hybrid renewable energy system consisting of PV, WT and battery utilizing PSO. The optimization objective was to minimize the system cost, subject to the satisfaction of the load demand. First, a description of a general methodology for modeling a photovoltaic panel,

wind turbine, and battery have been presented in detail. The proposed optimization technique was then exposed, along with the basic notion of PSO. Finally, a hybrid system was optimized using the PSO.

Simulation results reveal that the LCOE will decrease as the allowable LPSP increases from 0% to 2%. The lower LCOE indicates that if the LPSP is small and acceptable, the initial capital costs of a HES will be considerably reduced. Also the result show the value of wind turbines in HES which can lead to generating electricity in winter and at night to help PV panels to contribute in meeting the electrical power demand, this makes the number of batteries decrease. The techniques and analytical approaches utilized in this study can be applied to other hybrid systems as well.

VII. REFERENCES

- [1] S. Upadhyay and M. P. Sharma, "A review on configurations, control and sizing methodologies of hybrid energy systems," *Renew. Sustain. Energy Rev.*, vol. 38, pp. 47–63, 2014.
- [2] A. Makhsoos *et al.*, "Design, simulation and experimental evaluation of energy system for an unmanned surface vehicle," *Energy (Oxf.)*, vol. 148, pp. 362–372, 2018.
- [3] A. Gupta, R. P. Saini, and M. P. Sharma, "Steady-state modelling of hybrid energy system for off grid electrification of cluster of villages," *Renew. Energy*, vol. 35, no. 2, pp. 520–535, 2010.
- [4] H. Yang, L. Lu, and W. Zhou, "A novel optimization sizing model for hybrid solar-wind power generation system," *Sol. Energy*, vol. 81, no. 1, pp. 76–84, 2007.
- [5] E. Koutroulis, D. Kolokotsa, A. Potirakis, and K. Kalaitzakis, "Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms," *Sol. Energy*, vol. 80, no. 9, pp. 1072–1088, 2006.
- [6] A. Askarzadeh and L. dos Santos Coelho, "A novel framework for optimization of a grid independent hybrid renewable energy system: A case study of Iran," *Sol. Energy*, vol. 112, pp. 383–396, 2015.
- [7] D. Sharma, P. Gaur, and A. P. Mittal, "Comparative analysis of hybrid GAPSO optimization technique with GA and PSO methods for cost optimization of an off-grid hybrid energy system," *Energy Technol. Policy*, vol. 1, no. 1, pp. 106–114, 2014.
- [8] A. Ben Jemaa, N. Essounbouli, and A. Hamzaoui, "Optimum sizing of hybrid PV/Wind/battery installation using a fuzzy PSO," in *3rd International Symposium on Environmental Friendly Energies and Applications (EFEA)*, 2014, pp. 1–6.
- [9] A. Chauhan and V. K. Dwivedi, "Optimal sizing of a stand-alone PV/wind/MHP/biomass based hybrid energy system using PSO algorithm," in *2017 6th International Conference on Computer Applications In Electrical Engineering-Recent Advances (CERA)*, 2017, pp. 7–12.
- [10] R. Pallabazzer, "Evaluation of wind-generator potentiality," *Sol. Energy*, vol. 55, no. 1, pp. 49–59, 1995.
- [11] Johnson, G.L, *Wind energy systems*, USA: Pertinance Hall, 1985.
- [12] V. Sohoni, S. C. Gupta, and R. K. Nema, "A critical review on wind turbine power curve modelling techniques and their applications in wind based energy systems," *J. Energy*, vol. 2016, pp. 1–18, 2016.
- [13] A. Maleki and A. Askarzadeh, "Comparative study of artificial intelligence techniques for sizing of a hydrogen-based stand-alone photovoltaic/wind hybrid system," *Int. J. Hydrogen Energy*, vol. 39, no. 19, pp. 9973–9984, 2014.
- [14] F. A. Alturki, A. A. Al-Shamma'a, H. M. H. Farh, and K. AlSharabi, "Optimal sizing of autonomous hybrid energy system using supply-demand-based optimization algorithm," *Int. J. Energy Res.*, vol. 45, no. 1, pp. 605–625, 2021.
- [15] A. Redouane, P. Acouetey, A. E. Hasnaoui, and I. E. Harraki, "Feasibility study of energy hybrid systems for villages of the southern Moroccan coastline," in *2018 6th International Renewable and Sustainable Energy Conference (IRSEC)*, 2018, pp. 1–6.
- [16] A. Maleki, M. Ameri, and F. Keynia, "Scrutiny of multifarious particle swarm optimization for finding the optimal size of a PV/wind/battery hybrid system," *Renew. Energy*, vol. 80, pp. 552–563, 2015.
- [17] F. Fodhil, A. Hamidat, and O. Nadjemi, "Potential, optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electrification in Algeria," *Energy (Oxf.)*, vol. 169, pp. 613–624, 2019.
- [18] R. Ayop, N. M. Isa, and C. W. Tan, "Components sizing of photovoltaic stand-alone system based on loss of power supply probability," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 2731–2743, 2018.
- [19] A. Maleki and F. Pourfayaz, "Optimal sizing of autonomous hybrid photovoltaic/wind/battery power system with LPSP technology by using evolutionary algorithms," *Sol. Energy*, vol. 115, pp. 471–483, 2015.
- [20] S. Sanajaoba and E. Fernandez, "Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System," *Renew. Energy*, vol. 96, pp. 1–10, 2016.
- [21] KENNEDY and J., "Particle Swarm Optimization, Proceeding," *IEEE International Conference on Neural Networks, Piscataway, 1995*, pp. 1942–1948, 1995.
- [22] A. J. Ardakani, F. F. Ardakani, and S. H. Hosseinian, "A novel approach for optimal chiller loading using particle swarm optimization," *Energy Build.*, vol. 40, no. 12, pp. 2177–2187, 2008.
- [23] İ. B. Aydılek, "A hybrid firefly and particle swarm optimization algorithm for computationally expensive numerical problems," *Appl. Soft Comput.*, vol. 66, pp. 232–249, 2018.
- [24] M. A. Mohamed, A. M. Eltamaly, and A. I. Alolah, "PSO-based smart grid application for sizing and optimization of hybrid renewable energy systems," *PLoS One*, vol. 11, no. 8, p. e0159702, 2016.
- [25] X. Xu, W. Hu, D. Cao, Q. Huang, C. Chen, and Z. Chen, "Optimized sizing of a standalone PV-wind-hydropower station with pumped-storage installation hybrid energy system," *Renew. Energy*, vol. 147, pp. 1418–1431, 2020.