Smart Grid and Renewable Energy, 2022, 13, 249-267
https://www.scirp.org/journal/sgre
ISSN Online: 2151-4844
ISSN Print: 2151-481X

Allocation of Hybrid Distributed Generations and Energy Management in Radial Electrical Systems

Ngoussandou Bello Pierre[1*], Nicodem Nisso[2], Benjamin Diboma[3], Jean De Dieu Nguimfack Ndongmo[4], Sadam Alphonse[5]

[1]Department of Renewable Energy, National Advanced School of Engineering of Maroua, University of Maroua, Maroua, Cameroon
[2]Department of Computer Science and Telecommunications, National Advanced School of Engineering, University of Maroua, Maroua, Cameroon
[3]Department of Electrical Engineering, Advanced Technical Training School, University of Douala, Douala, Cameroon
[4]Department of Electrical and Power Engineering, Higher Technical Teacher Training College, University of Bamenda, Bamenda, Cameroon
[5]UFD PAI, Laboratoire d'Analyse de Simulation et Essais (LASE), IUT de Ngaoundéré, Ngaoundéré, Cameroun
Email: *nbellopierre@yahoo.fr, nnicodem2000@yahoo.fr, benjamin_diboma@yahoo.fr, nguimfack.jean@uniba.cm, ssadamalphonse@yahoo.fr

How to cite this paper: Pierre, N.B., Nisso, N., Diboma, B., De Dieu Nguimfack Ndongmo, J. and Alphonse, S. (2022) Allocation of Hybrid Distributed Generations and Energy Management in Radial Electrical Systems. *Smart Grid and Renewable Energy*, **13**, 249-267.
https://doi.org/10.4236/sgre.2022.1311016

Received: March 3, 2022
Accepted: November 22, 2022
Published: November 25, 2022

Abstract

This paper presents a method for optimal sizing of a Micro grid connected to a hybrid source to ensure the continuity and quality of energy in a locality with a stochastically changing population. The hybrid system is composed of a solar photovoltaic system, a wind turbine, and an energy storage system. The reliability of the system is evaluated based on the voltage level regulation on IEEE 33-bus and IEEE 69-bus standards. Power factor correction is performed, despite some reliability and robustness constraints. This work focuses on energy management in a hybrid system considering climatic disturbances on the one hand, and on the other hand, this work evaluates the energy quality and the cost of energy. A combination of genetic algorithms of particle swarm optimization (CGAPSO) shows high convergence speed, which illustrates the robustness of the proposed system. The study of this system shows its feasibility and compliance with standards. The results obtained show a significant reduction in the total cost of production of this proposed system.

Keywords

Power Losses, Hybrid System, Distributed Generations, Cost of Energy

1. Introduction

The search for optimal operation in production and distribution systems is increasingly a major issue with the advent of renewable energies in recent years. Thus, several optimization algorithms have been developed [1] [2] [3] [4] to control or reduce the cost of production, distribution, or transmission. Considering the fact that in some localities, solar or wind power plants are abandoned [5] before the amortization of the production cost. This is due to incorrect sizing. In addition, some constraints of use such as the increase in population, taking into account the variation of the mass density [6] [7], have an influence on the power output of the system. Among the optimization systems [8] [9], we have the optimization by particle Swarm optimization (PSO) and Genetic algorithms (GA) [10] [11] [12]. These Methods [13] are given to have a good speed of convergence and to minimize an objective function [2] [9] [14]. In addition, distributed generation methods also allow correcting the power factor at a common coupling point called a bus. The DG allows to reduce the power losses [15] and to have the power factor correction. However, the search for an optimum voltage encounters problems when the algorithm is wrongly chosen or when the complexity of the system is not considered by neglecting certain essential parameters. Moreover, the policy of decentralized production also allows to solve on the one hand the blackout problem and on the other hand to increase energy production.

The architecture of the electrical network is radial, most often the integration of battery bank and the consideration of the variability of the mass density of the air make the system complex to study. For this reason, the evaluation of the production cost of this system is made. The study of the quality of the energy by the correction of the power factor and the minimization of the power losses allow to take a decision on the behavior of the proposed system. In order to properly size multi-source energy systems, parameters [16] such as the number of batteries, the number of solar panels in series or in parallel, the number of wind generators, the number of inverters, as well as the power factor correction or the harmonic distortion rate, are parameters that must be taken into account in order to have a good optimization and a good performance [17]. In this work, all these elements will be taken into account and implemented using particle Swarm optimization (PSO) and Genetic algorithms (GA). The results of these algorithms will be evaluated based on the best scores with good convergence speed. The power losses will be tested on IEEE 33-bus and IEEE 69-bus standards [18]. The proposed grid-connected/PV/Wind/Battery system takes into consideration the climatic conditions of the site [9], such as the variation of irradiation [19] and the variation of wind speed, as well as the variation of the air mass density. The robustness and feasibility of this system will be evaluated based on a good voltage performance and a good power factor in front of the stochastic variation of the load, which is the energy demand of the site.

2. System Topology and Configuration

1) Hybrid System Grid Connected

Figure 1 shows the overall system consisting of a PV/Wind/Grid/battery plant with an energy storage system (ESS). A real-time visualization terminal and proposed to enable the necessary decision-making regarding the system. This system is managed through the combination of PSO + GA algorithms.

2) Loss Minimization in DG System

Minimal losses occur in the distribution network due to the optimal size and location of the DG. By applying the formula for nozzle losses, a reduction in power loss is achieved with the PSO + GA algorithms. The formula for minimizing these losses is given assuming a radial distribution network with N buses [20].

$$\text{Minimize } P_{Lij} = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\psi_{ij}\left(P_iP_j + Q_iQ_j\right) + \mu_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

For

$$\psi_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\phi_i - \phi_j\right) \quad (2)$$

$$\mu_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\phi_i - \phi_j\right) \quad (3)$$

Were

$$Z_{ij} = r_{ij} + jx_{ij} \quad (4)$$

✓ ***Contraints on DG placement:***

$$|V_i|^{\min} < V_i < |V_i|^{\max}$$

$I_{ij} \le |I_{ij}|^{\max}$, $|I_{ij}|^{\max}$, defined as the maximum limit of current in bus *i* and *j*. $|V_i|^{\min}$ and $|V_i|^{\max}$ are respectively the minimum and the maximum of voltage in bus *i*

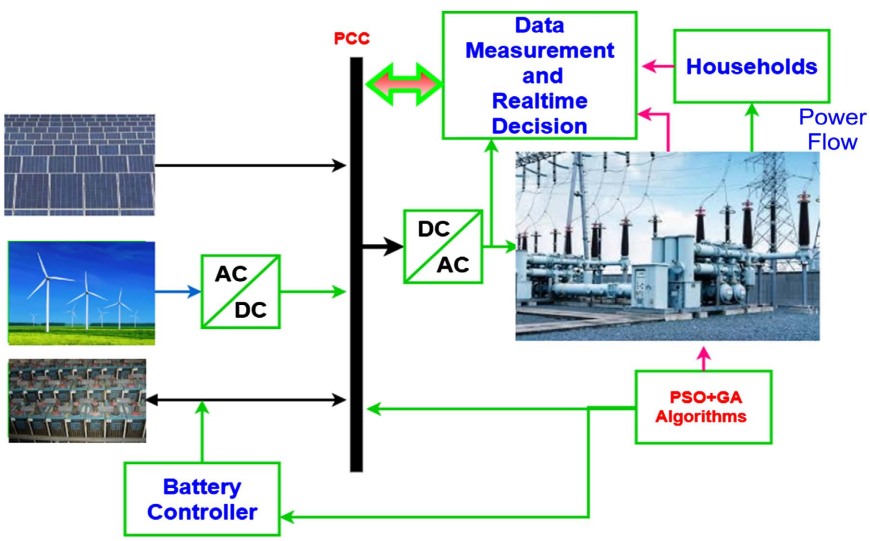

Figure 1. Proposed system configuration.

✓ ***IEEE 69-bus system Configuration***

The configuration of this system [21] is shown in **Figure 2**.

✓ **IEEE 69-bus system Configuration**

The configuration of this system [21] is shown in **Figure 3**.

3. The Photovoltaic System

Figure 4 shows an electrical diagram that governs the mathematical equations of a single diode photovoltaic system [3] [22]. This equation is implemented in a Simulink block considering the variations of climatic conditions [19].

From **Figure 4**, the output current of the solar cell can be given as follows:

$$I = I_L - I_{rs}\left[e^{\frac{q(v+R_S\cdot I)}{A\cdot k\cdot T}} - 1\right] - \frac{q(v+R_S I)}{R_{sh}} \tag{5}$$

where

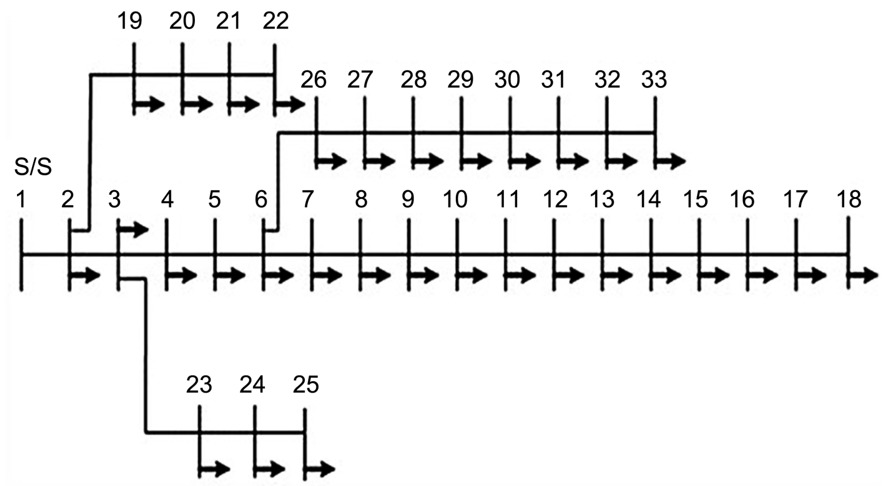

Figure 2. Single-line diagram of 33-bus system.

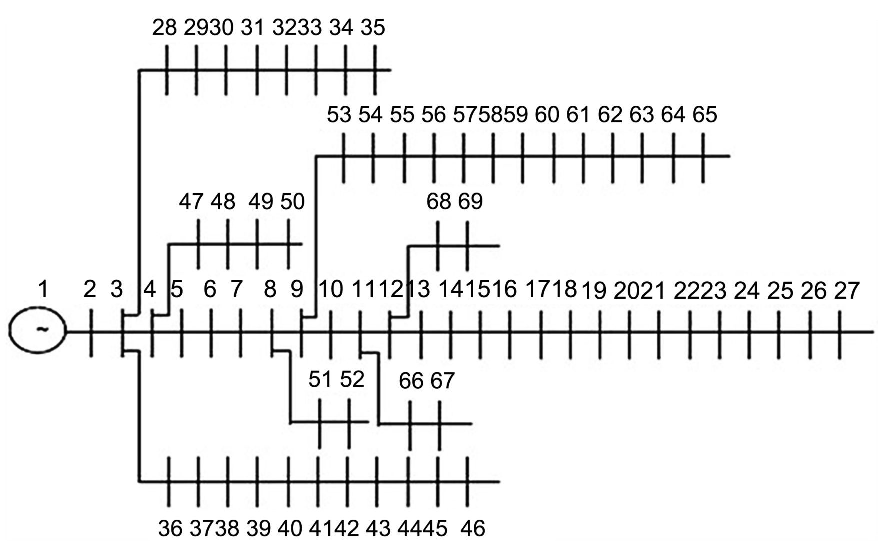

Figure 3. Single-line diagram of 69-bus system.

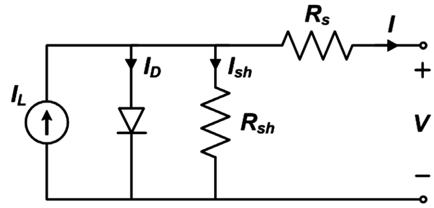

Figure 4. Equivalent model of one diode solar cell.

$$I = I_L - I_{rs}\left[e^{\frac{q(v+R_S\cdot I)}{A\cdot k\cdot T}} - 1\right] - \frac{q(v+R_S I)}{R_{sh}} \tag{6}$$

For PV cells connected together in series and parallel solar cell combinations to form a module the terminal equation of the PV module, it can be written as follows [2]:

$$I = N_p I_L - N_p I_{rs}\left[e^{\frac{q(v+R_S\cdot I)}{A\cdot k\cdot T\cdot N_S}} - 1\right] - N_p\left(\frac{q(v+R_S I)}{N_S\cdot R_{sh}}\right) \tag{7}$$

where: V is the cell output voltage; q is the electron charge (1.60217646 × 10^{-19} C); k is the Boltzmann's constant (1.3806503 × 10^{-23} J/K); T is the temperature in Kelvin; I_{rs} is the cell reverse saturation current; A is the diode ideality constant; N_p is the number of PV cells connected parallel; N_s is the number of PV cells connected in series.

The generated photocurrent I_L depends on solar irradiation and it's by the following equation:

$$I_L = \left[I_{sc} + k_i\left(T - T_s\right)\right]\frac{G}{1000} \tag{8}$$

where: k_i is the short-circuit current temperature coefficient; G is the solar irradiation in W/m^2; I_{sc} is the cells short-circuit current at reference temperature; T_s is the cell reference temperature.

When the cell's saturation current varies with temperature its equation is expressed as:

$$I_{rs} = I_{rs}\left[\frac{T}{T_s}\right]^3 \exp\left(\frac{q\cdot E_G}{k\cdot A}\left[\frac{1}{T_s} - \frac{1}{T}\right]\right) \tag{9}$$

where:

E_G is the band-gap energy of the semiconductor used in the cell, and I_{rs} is the reverse saturation at T_s.

4. Wind Turbine

4.1. Maximum Wind Power Recoverable

The available wind power per unit area [23] is given by the following equation:

$$\langle Ps\rangle = 1/2\,\rho\langle V^3\rangle \tag{10}$$

The wind speed of the site is transformed into mechanical energy and this speed is not totally recovered by the wind turbines. The maximum recoverable power of the site according to Betz' theory obtained from Equation (10)

$$\langle Pmax \rangle = 0.59 \langle Ps \rangle \tag{11}$$

By replacing the available power by its value, the power recovered per unit area becomes:

$$\langle Pr \rangle = 0.295 \rho \langle V^3 \rangle \tag{12}$$

4.2. Extrapolation of Wind Speed

At 10 m from the ground, the wind speed in Ngaoundéré is relatively slow. Equation (13) extrapolates to have a good wind speed [24].

$$V(h_2) = V(h_1)\left(\frac{h_2}{h_1}\right)^{\alpha} \tag{13}$$

$$\alpha = \frac{1}{\ln\left(\frac{\bar{h}}{zo}\right)} - \frac{0.0881}{1 - 0.00881 \times \ln\left(\frac{h_1}{h_0}\right)} \times \ln\left(\frac{V(h_1)}{6}\right) \tag{14}$$

$$\bar{h} = \sqrt{h_1 \times h_2} \tag{15}$$

$V(h)$ is the reference speed taking at Z meter at the ground; h_1 et h_2 are respectively reference variable high values. h_0 is the rigidity of ground. In Wouro Kessoum, extrapolation of the wind speed is given [6] by **Figure 5**.

4.3. Local Air Density Variation

Air density varies with altitude (Equation (16)) or with temperature, humidity and atmospheric pressure (Equation (9)). This parameter is also considered in the Wind speed Variation for having **Figure 5**.

$$\rho(P,T,H_r) = \frac{1}{287.06T}\left(P - 230.617 H_r \exp\left(\frac{17.5043\theta}{\theta + 241.2}\right)\right) \tag{16}$$

$$\rho = \rho_0 - 1.194 \times 10^{-4} h_m \tag{17}$$

with $\rho_0 = 1.196\ \text{kg/m}^3$.

4.4. The Output Power of the Wind Can Be Expressed as Follows (Powell, 1981)

The power Generated by the wind turbine is defined as follow:

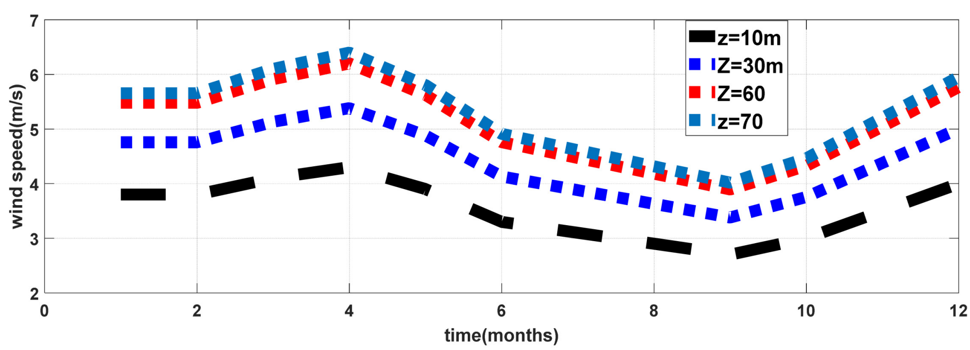

Figure 5. Wind speed for varying of the altitude.

$$P_{wt}=\begin{cases}0 \quad pour\ V<V_d \\ P_n\dfrac{V-V_c}{V_r-V_c} \quad V_d\le V\le Vn \\ P_n \quad Vn\le V\le Vm \\ O \quad V\ge Vm\end{cases} \tag{18}$$

With

$$P_n=C_p\eta\frac{1}{2}\rho A\frac{V_r^c-V_i^c}{V_d^{c-3}-Vi^c/V_d^3} \tag{19}$$

$$P_{wt}=\begin{cases}0 \quad pour\ V<V_d \\ aV^3-bP_n \quad V_d\le V\le Vn \\ P_n \quad Vn\le V\le Vm \\ O \quad V\ge Vm\end{cases} \tag{20}$$

where

$$a=\frac{P_n}{V_r^c-Vi^c} \text{ and } b=\frac{V_i^c}{V_r^c-Vi^c} \tag{21}$$

5. Modelling of the Battery

The available battery bank capacity [25] [26].

$$C_{bat}(t)=C_{bat}(t-1)(1-\sigma)+(surplus\ power)\eta_b \tag{22}$$

On the other hand, when the available energy generated is less than load demand, the battery bank is in discharging state.

$$C_{bat}(t)=C_{bat}(t-1)(1-\sigma)-(deficit\ power) \tag{23}$$

where $C_{bat}(t)$ and $C_{bat}(t-1)$ are the available battery bank capacity (Wh) at hour t and $t-1$, respectively; η_b is the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and during charging, the efficiency is 0.65 - 0.85 depending on the charging current [27]. the lifetime of the battery bank is 24 years. But in this proposed System, the battery bank is always in charging state.

5.1. Objective Functions

The present cost value (PVC) of PV generator is given in the following relationship, based on some parameters:

$$PVC_{PV_t}=I_{PV}+c_{omr,PV}\left(\frac{1+i}{r-i}\right)\left[1-\left(\frac{1+i}{1+r}\right)^n\right]-\left(\frac{1+i}{1+r}\right)^n \tag{24}$$

The present cost value (PVC) of wind turbine (WT) is given in the following relationship [28] [29]:

$$PVC_{WT}=I_{WT}+c_{omr,WT}\left(\frac{1+i}{r-i}\right)\left[1-\left(\frac{1+i}{1+r}\right)^n\right]-S_{WT}\left(\frac{1+i}{1+r}\right)^n \tag{25}$$

PVC_{Bat} of the battery bank can be calculated as:

$$PVC_{Bat} = I_{Bat} + c_{omr,bat}\left(\frac{1+i}{r-i}\right)\left[1-\left(\frac{1+i}{1+r}\right)^{n}\right] - S_{Bat}\left(\frac{1+i}{1+r}\right)^{n} \quad (26)$$

The functional objectives are presented in this section. The cost of energy (COE), and the present value cost (PVC) are used in this part. The lifetime of the solar PV system, wind turbine, and battery bank has been taken for 20 years. In the calculations, economic parameters of inflation (i), investment (I), and scrap value (s) are also considered to enhance the accuracy of the calculations.

5.2. Cost of Energy Production

The factors governing the cost of energy are [30]:

- Investment cost (including auxiliary fees for findings, connection to the network, etc.).
- Operating and maintenance cost.
- System energy production.
- The lifetime of the turbine.
- Discount rate during a time.
- The total energy produced.
- The factors governing the present cost value (PVC) are:
- The lifetime of the machine (n) was assumed to be 20 years.
- The interest rate (r) and inflation rate (i) were taken to be 15% and 12%, respectively.
- Operation maintenance and repair cost (Comr) were considered to be 25% of the annual cost of the machine (machine price/lifetime).
- Scrap value S was taken to be 10% of the machine price and civil work.
- Investment (I) includes the machine price plus its 20% for the civil work and other connections.

We have three functional objectives:

$$\text{Object } 1 = \min f\left(N_{pv}, N_{WT}, E_{ESS}\right) = N_{pv}\cdot C_{pv} + N_{WT}\cdot C_{WT} + C_{ESS}\cdot E_{ESS} \quad (27)$$

$$\text{Object } 2 = \min\left(COE\right) \quad (28)$$

$$\text{Object } 3 = \min\left(TNPC\right) = \min\left(\frac{PVC,tot}{CRF}\right) \quad (29)$$

where the COE can be evaluated by Equation (27)

$$COE = \frac{PVC,tot}{E_{served}} \quad (30)$$

with

$$E_{served} = E_{PV} + E_{WT} \quad (31)$$

$$PVC,tot = PVC_{PV} + PVC_{Bat} \quad (32)$$

$$CRF = \frac{i\left(1+i\right)^{n}}{\left(1+i\right)^{n}-1} \quad (31)$$

✓ *Contraints*:

- PV power limits:

$$P_{pvmin} \le P_{pv}(t) \le P_{pvmax}; \quad N_{PV} \ge 0 \tag{32}$$

- WT power limits:

$$P_{WTmin} \le P_{WT}(t) \le P_{WTmax}; \quad N_{WT} \ge 0 \tag{33}$$

- ESS stored energy and power limits:

$$E_{ESSmin} \le E_{ESS}(t) \le E_{ESSmax} \tag{34}$$

$$E_{ESSmin} = (1 - DOD) E_{ESSmax} \tag{35}$$

- Power balance

$$P_{pv}(t) + P_{WT}(t) \pm P_{ESS}(t) \ge P_{load}(t) \tag{36}$$

6. Hybrid Algorithm

6.1. Particle Swarm Optimization

Particle swarm optimization is an evolutionary algorithm that uses a population of candidate solutions to develop an optimal solution to the problem. This algorithm was proposed by Russel Eberhart and James Kennedy in 1995 [31]. He was originally inspired by the living world, more precisely by behavior of animal living in swarms, flights groups of birds. Indeed, we can observe in these animals' movement dynamics relatively complex, whereas individually each individual has "intelligence" limited, and has only local knowledge of her situation in the swarm. Local information and the memory of each individual are used to decide their shifting. Simple rules, such as "stay close to other people", "go in the same direction" or "going at the same speed", sufficient to maintain cohesion of the swarm, and allow the implementation of complex collective behaviors and adaptation. The particle swarm is a population of simple agents called particles. Each particle is considered as a solution of problem, where it has a position (the solution vector) and a speed. In addition, each particle has a memory allowing him to remember his best performance (in position and in value) and the best performance achieved by the "neighboring" particles (informants): each particle has in fact a group of informants, historically called its neighborhood. Each individual in PSO represents a possible solution assumed to have two properties: velocity and position. Each particle wanders through in the solution area and recalls the best functional objective value (position), which has already been discovered; the fitness value is saved and known Pbest. When a particle captures all the best population as its topological neighbors, the superior value is a global best and it is called Gbest. The particles flight with a certain velocity in the D-dimensional space to find the optimal solution. Let the variable (x_i) refers to the position of particle (i) in the study space and its speed is (v_i), so the (i^{th}) from the particle can be represented as [32]:

$$x_i = [x_{i1}, x_{i2}, x_{i3}, \cdots, x_{iD}] \tag{37}$$

The best past position of the i^{th} particle is saved under the name vector and calculated by:

$$P_i = \left(p_{i1}, p_{i2}, \cdots, p_{iD}\right)$$

where $i = 1,2,3,\cdots,N$ is the number of particles in a swarm.

$$v_i^{n+1} = w * v_i^n + C_1 * r_1 * \left(Pbest_i - x_i^n\right) + C_2 * r_2 * \left(Gbest - x_i^n\right) \tag{38}$$

$$x_i\left(j+1\right) = v_i\left(j+1\right) + x_i\left(j\right) \tag{39}$$

The r_1 and r_2 are random real numbers drawn from [0, 1], c_1 and c_2 are acceleration constants that pull each particle towards. Initialization of parameter: (population size (N_{Pop}) = 200, c_1 = 2, c_2 = 2, χ = 0.7, total number of iteration = 100).

The procedure for the implemented PSO is as the following:

6.2. Set PSO Parameters

Number of particule (*NP*) = 200; (population size (*NPop*) = 200, inertia weight (*w*) = 0.5, inertia weight damping ratio (*wdamp*) = 0.99, personal learning coefficient (c_1) = 2, global learning coefficient (c_2) = 2, total number of iterations = 100). Number of variable (*nvar*) = 4; for i = 1: *NP*.

1. Set dimension of the search variables: N_{PV}: number of PV; N_{WT}: number of wind turbines N_{Bat}: number of batteries; n: number of houshold

$N_{PV} \geq 0$; $N_{WT} \geq 0$; $N_{Bat} \geq 0$; $N \geq 0$.

2. Initialization

$X_i = [N_{PV}, N_{Bat}, N_{WT}, N_n]$, $V_i = 0$

3. Fitness of particle

$Pbest_{,i} = X_i$

End

4. $K = 0$; while $k \leq$ max of number of iterations

5. Update velocity and position of particles

$$v_i\left(t+1\right) = w\left(t\right)v_i\left(t\right) + c_1 r_1\left(P_i\left(t\right) - X_i\left(t\right)\right) + c_2 r_2\left(G\left(t\right) - X\left(t\right)\right) \tag{40}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{41}$$

6. Evaluate the fitness function

7. If $k <$ max iteration, then $k = k + 1$ and go to step 5 else go to step 7

6.3. Fraction of Power

This parameter varies with the variation of household numbers. This coefficient remains within the range prescribed by the standard.

The energy fraction makes it possible to harmonize the energy demand and the energy produced [33].

6.4. Energy Management

- If the total power produced by the solar PV panels and wind turbines is greater than the demand and the power supplied by the grid is less than the load. After satisfying the load, the excess power is still supplied to the grid and the battery.

- If the power produced by the wind turbines alone is sufficient to meet the load demand, the remaining power (solar and wind) can be supplied to the battery bank.
- If the battery bank power is greater than the power (solar & wind), the battery bank also supplies the load.

7. Results and Discussion

Table 1 groups the different values obtained by the PSO + GA algorithm. The variation of the number of households has been done. The number of PV modules, as well as the number of batteries, was determined for a fitness cost function that is estimated at $523764.00 for a locality of 250 habitants.

Figure 6 shows the voltage profile on IEEE 33-bus. It can be seen that at the common coupling point, the voltage is stabilized and regulated with a power factor correction.

Figure 7 shows the voltage profile on IEEE 69-bus. It can be also seen that, at the common coupling point, the voltage is stabilized and regulated with a power factor correction.

8. Optimization of the Hybrid System

Figure 8 shows an energy compensation without the battery integration. It occurs that in the absence of battery banks when the wind speed or irradiance

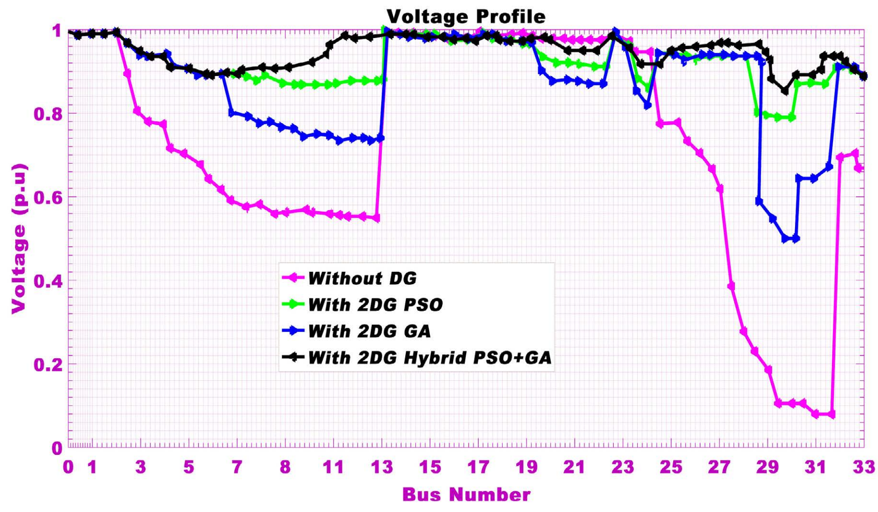

Figure 6. Voltage profile at IEEE 33-bus.

Table 1. Optimal hybrid combination system.

Number of PV module	45	50	64	59	85
Number of WT	6	10	12	15	17
Number of battery (kWh)	150	250	300	523	535
TNPC ($)	370253.99	480141.89	50375.40	38592.97	623764.00

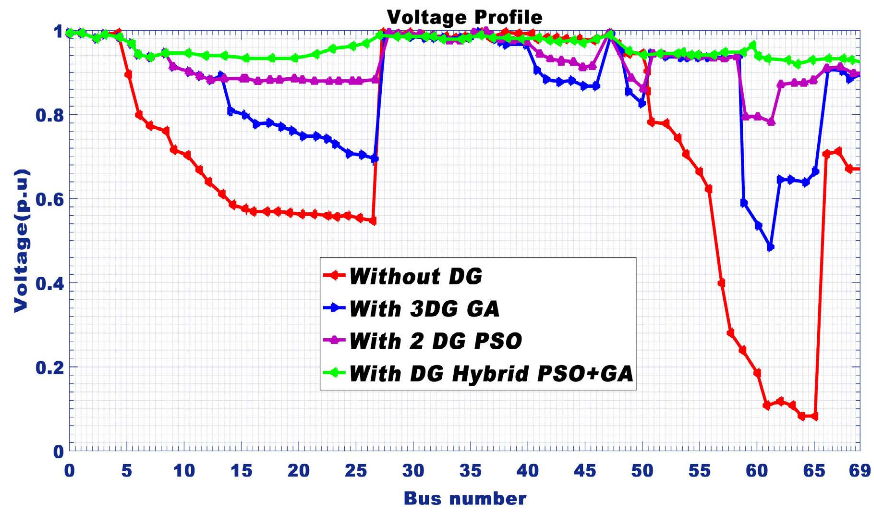

Figure 7. Voltage profile at IEEE 69-bus.

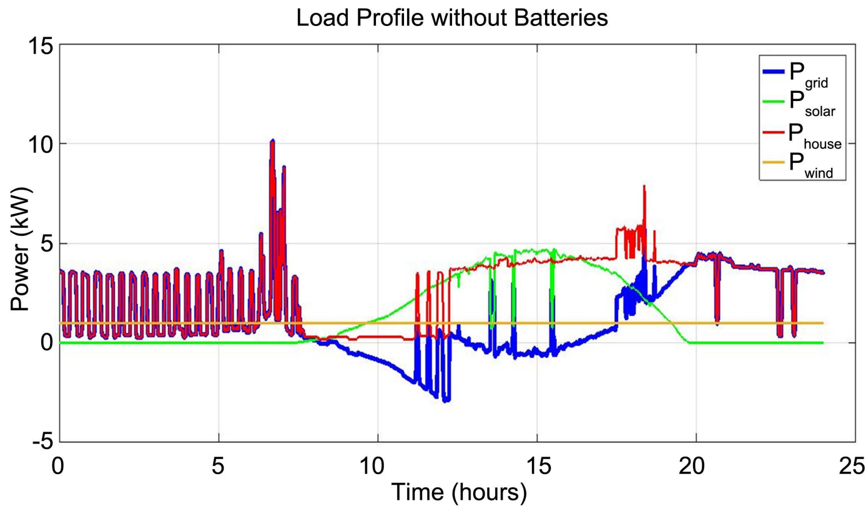

Figure 8. Load profile and power without battery.

varies in a decreasing way or is insufficient, a peak of the demand of the locality is entered. This creates a deficit or load shedding.

Figure 9 shows the state of charge of the energy storage system (ESS). This system consists of battery banks that keep the energy in a steady state or established. Even if there is no deficit on two of the three subsystems (PV, Wind, Grid), the batteries are still charging. Even if the energy produced by the PV is not sufficient, the energy from the system or the grid can charge the battery bank.

Figure 10, in contrast to Figure 8, shows a compensation in energy requested by the load. The energy compensation is done around 18 h. The importance of the integration of the battery bank and the reinforcement of the electrical network as in Figure 10. Because it can happen that the PV/Wind/Grid system does not provide the energy to satisfy the demand considerably. Therefore, the stored energy in the battery banks intervenes to compensate for the demand.

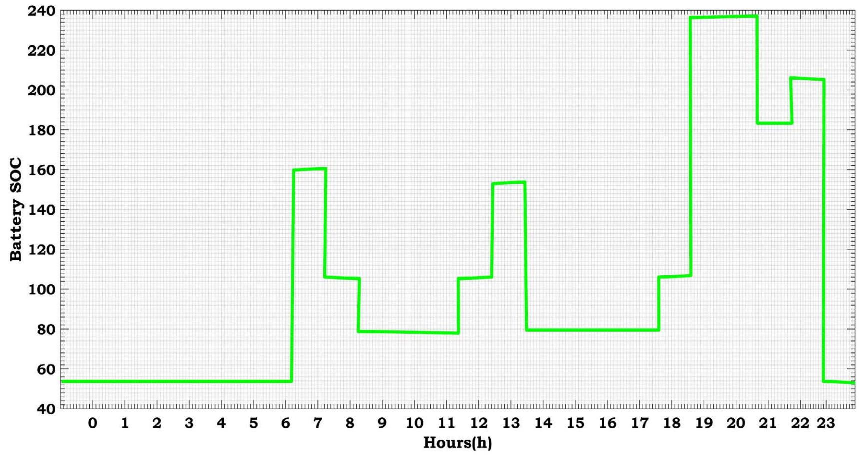

Figure 9. Battery bank state of charge during service.

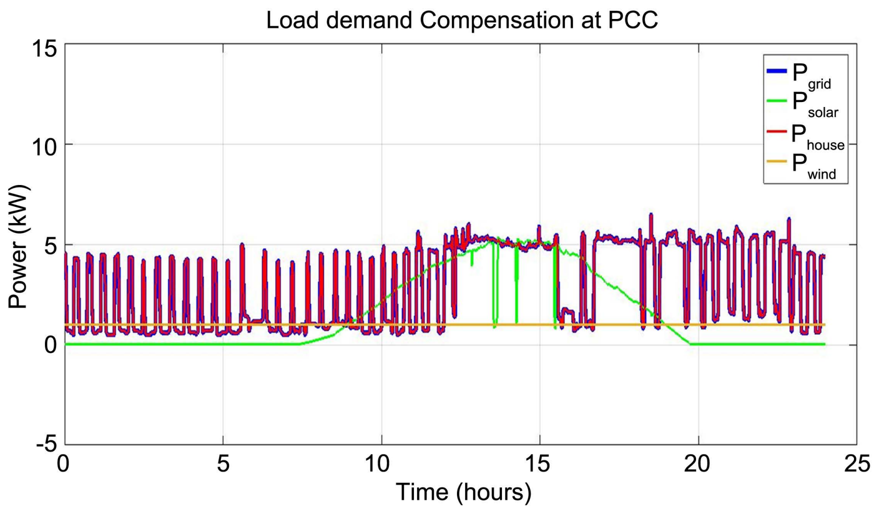

Figure 10. Load profile and power compensation with battery.

Figure 11 shows the convergence speed of three algorithms used: particle swarm optimization, genetic algorithm, hybrid PSO + GA algorithm. From this figure, the hybrid PSO + GA association has a good speed of convergence, that is to say, it increases the reduction and a better reduction of the cost function. It is clear that for the optimization of a hybrid0 multi-source system, PSO + GA is a better solution compared to GA and PSO. It appeared that the proposed method has given good optimization results. In the literature, methods are proposed such as [34] [35] which propose the cuckoo search method and the WOA method. However, in the literature, the integration of the battery bank is not considered too much, yet the proposed system compensates better the power in case of the deficit encountered in the three power plants (power grid, PV, Wind).

Table 2 summarizes the parameters of the wind power plant, as well as the price per unit of a component which is used in the PV plant.

Table 3 summarizes the parameters of the wind power plant, as well as the price per unit of a component which is used in the Wind plant.

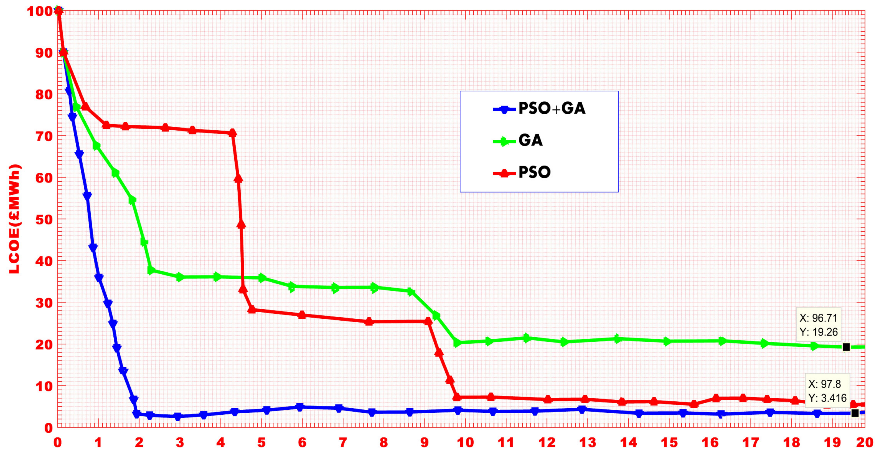

Figure 11. Graph of fitness function convergence.

Table 2. Photovoltaic parameters.

Parameters	values
The rated power	655 W
efficiency η	95%
The lifetime	20
Price/PV (30 kW)	$ (62,000)

Table 3. Parameters of wind turbine.

Parameters	Values
Cut-in, cut-out	2.5 m/s
wind speed	17 m/s
Rated of wind Speed	12 m/s
Hub height	65 m
Rotor diameter	44
The maximum power	650 kW
Price	$ (5700)

✓ *Power loss on distributed generation*

Table 4 shows the different minimum and maximum voltages obtained for optimal sizing at IEEE 69-bus. The power losses are also evaluated and determined with the PSO + GA algorithms.

Table 5 shows the different minimum and maximum voltages obtained for optimal sizing at IEEE 69-bus. The power losses are also evaluated and determined with the PSO + GA algorithms.

This Research is focused on the economical techniques of optimization. Functional objective base on minimization of the cost of energy production (COE), total net present cost (TNPC) and number of winds turbines, PV module and

Table 4. Proposed system on IEEE 33 bus radial distribution network.

Applied techniques	*V*in (p.u.)	*V*ax (p.u.)	(bus number)	(Reactive power)	Power loss	Loss reduction
Base case	0.905	0.9972	-	-	200.72	-
GA	0.9554	0.9976	8 28 27	522.7 544.2 541.6	139.5	58.02%
PSO	0.9689	0.9986	6 27 29	500.8 535.2 508.1	159.4	74.96%
PSO + GA	0.9701	0.9988	8 28 29	510.6 538.7 549.4	145.32	98.6%

Table 5. Proposed system on IEEE 69 bus radial distribution network.

Applied techniques	*V*in (p.u.)	*V*ax (p.u.)	location Bus	power (kVAR)	Loss (kW)	Loss reduction
Base case	0.9092	0.9999	-	-	241.92	-
GA	0.9754	0.999	62 47 63 53 64	382.4 157.5 346.7 289.3 498.1	165.65	75.08%
PSO	0.9728	0.999	46 66 58 61 63	380.0 156.5 142.2 420.6 425.2	154.02	88.33%
PSO + GA	0.9849	1.000	53 36 50 62 68	348.8 336.0 156.1 351.9 118.6	152.54	**98.95%**

batteries (N_{PV}, N_{WT}, N_B) taking account some constraints like the rising of the electrical demand, PV power limits, wind power limits and batteries power limits. The PSO algorithm was developed in MATLAB. The data of solar energy, wind energy temperature and air density were inserted. The TNPC increase with the increase in the number of households. With increase in the population of a locality, the algorithm allows the prediction of the TNPC and the components (N_{PV}, N_{WT}, E_{ESS}). For example, when n = 100; 150; 195, the TNPC are $310141.89; $45375.40; $48592.97. Figure 11 presents the Cost of Energy (COE) variation for this year. The average cost of energy per kWh for a year is $ 3.416/kWh.

The model and the system proposed in these work present better results. This demonstrates the feasibility and robustness of this system to climate hazards.

The hybrid PSO + GA algorithm compared to the methods proposed by [36] [37] in the literature, gives good performances. It has been shown that the addition of a battery bank is a guarantee for the continuity of service and the availability of energy over a day.

9. Conclusion

In this work, an optimal and economical sizing solution of a Grid-connected/PV/wind/battery system is proposed. The extrapolation of the energy demand has been done. Two scenarios have been studied: the case of insufficient energy and the case of sufficient energy delivered by the grid. The addition of a battery bank is done to correct at the same time the power factor which varies according to the population variation and to ensure the energy continuity in the system. Fractional power is studied to determine when the power produced is not sufficient. The life of the project was considered to be for 20 years of operation. Parameters such as temperature, pressure, sunshine, air mass density, were considered. This system is tested on IEEE 33-Bus and IEEE-69 standards and presents a good power factor correction. The various costs associated with the use of hybrid energy by evolutionary algorithms were evaluated, of which a minimum average cost per kWh of $3.536/kWh was obtained by the PSO; in a locality with a stochastically varying population.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Kitmo Tchaya, G.B., Djongyang, N. *et al.* (2022) Optimization of Hybrid Grid-Tie Wind Solar Power System for Large-Scale Energy Supply in Cameroon. *International Journal of Energy and Environmental Engineering*. https://doi.org/10.1007/s40095-022-00548-8

[2] Alphonse, S., Jacques, B., Kitmo, Djidimbele, R., Andre, P. and Cesar, K. (2021) Optimization PV/Batteries System: Application in Wouro Kessoum Village Ngaoundere Cameroon. *Journal of Power and Energy Engineering*, **9**, 50-59. https://doi.org/10.4236/jpee.2021.911003

[3] Kitmo, R., Djidimbélé, D., Kidmo, K., Tchaya, G.B. and Djongyang, N. (2021) Optimization of the Power Flow of Photovoltaic Generators in Electrical Networks by MPPT Algorithm and Parallel Active Filters. *Energy Reports*, **7**, 491-505. https://doi.org/10.1016/j.egyr.2021.07.103

[4] Giri, N.C., Mishra, S.P. and Mohanty, R.C. (2021) Performance Parameters, Optimization, and Recommendation in Large Scale On-Grid SPV Power Plant, Odisha, India. *International Journal of Modern Agriculture*, **9**, 159-167. http://modern-journals.com/index.php/ijma/article/view/196

[5] Altun, A.F. and Kilic, M. (2020) Design and Performance Evaluation Based on Economics and Environmental Impact of a PV-Wind-Diesel and Battery Standalone Power System for Various Climates in Turkey. *Renewable Energy*, **157**, 424-443.

https://doi.org/10.1016/j.renene.2020.05.042

[6] Alphonse, S., Bikai, J., Fokone, A.T. and Cesar, K. (2020) Potentiel énergétique éolien et profil de consommation d'énergie dans le village Wouro Kessoum Ngaoundéré Cameroun. *Journal of Renewable Energies*, **23**, 72-85.

[7] Alphonse, S., Jacques, B., Kitmo and César, K. (2021) Optimisation par la méthode essaim particulaire d'un parc éolien autonome dans la ville de Ngaoundéré Optimization by the Particle Swarm Method of an Autonomous Wind Farm in the City of Ngaoundere. *The 1st International Conference on Local Resource Exploitation*, Ngaoundéré, 20-23 April 2021, 857-867. https://www.researchgate.net/publication/356422689

[8] Giri, N.C. and Mohanty, R.C. (2022) Agrivoltaic System: Experimental Analysis for Enhancing Land Productivity and Revenue of Farmers. *Energy for Sustainable Development*, **70**, 54-61. https://doi.org/10.1016/j.esd.2022.07.003

[9] Kitmo, Tchaya, G.B., Kidmo, D.K., Alphonse, S. and Djongyang, N. (2021) Optimization of the Smart Grids Connected Using an Improved P&O MPPT Algorithm and Parallel Active Filters. *Journal of Solar Energy Research*, **6**, 814-828.

[10] Sandhya, Y.B., Rao, K.S., Rajesh, P.S., Giri, N.C., Das, S. and Bhadoria, V.S. (2022) Statistical Assessment of Sustainable Energy for the Lowest Feasible Levelized Cost of Electricity. 2022 *2nd International Conference on Advance Computing and Innovative Technologies in Engineering*, Greater Noida, 28-29 April 2022, 1106-1109. https://doi.org/10.1109/ICACITE53722.2022.9823748

[11] Giri, N.C. and Mohanty, R.C. (2022) Design of Agrivoltaic System to Optimize Land Use for Clean Energy-Food Production: A Socio-Economic and Environmental Assessment. *Clean Technologies and Environmental Policy*, **24**, 2595-2606. https://doi.org/10.1007/s10098-022-02337-7

[12] Mishra, S.P., Giri, N.C., Behera, D.D. and Nayak, S.R. (2020) Solar Trees: Shift from Grey to Green Sky for Future Fuel Pumps under Clean/Green Energy: India. *International Journal of Environment and Climate Change*, **10**, 68-86. https://doi.org/10.9734/ijecc/2020/v10i1130267 https://asianarchive.co.in/index.php/IJECC/article/view/4780

[13] Alphonse, S., Abraham, T.F., Raoul, O. and Marcel, E. (2019) Resolution of the Equation of Drying by the Finite Windows Methods: Preliminary Study. *International Journal of Engineering Science and Computing*, **9**, 19630-19633.

[14] Kitmo, Tchaya, G.B. and Djongyang, N. (2022) Optimization of the Photovoltaic Systems on the North Cameroon Interconnected Electrical Grid. *International Journal of Energy and Environmental Engineering*, **13**, 305-317. https://doi.org/10.1007/s40095-021-00427-8

[15] Djidimbélé, R., Ngoussandou, B.-P., Kidmo, D.K., Kitmo, Bajaj, M. and Raidandi, D. (2022) Optimal Sizing of Hybrid Systems for Power Loss Reduction and Voltage Improvement Using PSO Algorithm: Case Study of Guissia Rural Grid. *Energy Reports*, **8**, 86-95. https://doi.org/10.1016/j.egyr.2022.06.093

[16] Lin, X.-M., Kireeva, N., Timoshin, A.V., Naderipour, A., Abdul-Malek, Z. and Kamyab, H. (2021) A Multi-Criteria Framework for Designing of Stand-Alone and Grid-Connected Photovoltaic, Wind, Battery Clean Energy System Considering Reliability and Economic Assessment. *Energy*, **224**, Article ID: 120154. https://doi.org/10.1016/j.energy.2021.120154

[17] Lujano-Rojas, J.M., Dufo-López, R. and Bernal-Agustín, J.L. (2012) Optimal Sizing of Small Wind/Battery Systems Considering the DC Bus Voltage Stability Effect on Energy Capture, Wind Speed Variability, and Load Uncertainty. *Applied Energy*,

93, 404-412. https://doi.org/10.1016/j.apenergy.2011.12.035

[18] Prakash, D.B. and Lakshminarayana, C. (2016) Multiple DG Placements in Distribution System for Power Loss Reduction Using PSO Algorithm. *Procedia Technology*, **25**, 785-792. https://doi.org/10.1016/j.protcy.2016.08.173

[19] Yaouba, Bajaj, M., *et al.* (2022) An Experimental and Case Study on the Evaluation of the Partial Shading Impact on PV Module Performance Operating under the Sudano-Sahelian Climate of Cameroon. *Frontiers in Energy Research*, **10**, Article 924285. https://doi.org/10.3389/fenrg.2022.924285

[20] Das, C.K., Bass, O., Kothapalli, G., Mahmoud, T S. and Habibi, D. (2018) Overview of Energy Storage Systems in Distribution Networks: Placement, Sizing, Operation, and Power Quality. *Renewable and Sustainable Energy Reviews*, **91**, 1205-1230. https://doi.org/10.1016/j.rser.2018.03.068

[21] Baran, M.E. and Wu, F.F. (1989) Network Reconfiguration in Distribution Systems for Loss Reduction and Load Balancing. *IEEE Power Engineering Review*, **4**, 101-102. https://doi.org/10.37256/aecm.122020328

[22] Rasheed, M.S. and Shihab, S. (2020) Analysis of Mathematical Modeling of PV Cell with Numerical Algorithm. *Advanced Energy Conversion Materials*, **1**, 70-79. https://doi.org/10.37256/aecm.122020328

[23] Wang, J., Hu, J. and Ma, K. (2016) Wind Speed Probability Distribution Estimation and Wind Energy Assessment. *Renewable and Sustainable Energy Reviews*, **60**, 881-899. https://doi.org/10.1016/j.rser.2016.01.057

[24] Chaurasiya, P.K., Kumar, V. K., Warudkar, V. and Ahmed, S. (2019) Evaluation of Wind Energy Potential and Estimation of Wind Turbine Characteristics for Two Different Sites. *International Journal of Ambient Energy*, **42**, 1409-1419. https://doi.org/10.1080/01430750.2019.1611634

[25] Shoaib, M., Siddiqui, I., Rehman, S., Khan, S. and Alhems, L.M. (2019) Assessment of Wind Energy Potential Using Wind Energy Conversion System. *Journal of Cleaner Production*, **216**, 346-360. https://doi.org/10.1016/j.jclepro.2019.01.128

[26] Barakat, S., Ibrahim, H. and Elbaset, A.A. (2020) Multi-Objective Optimization of Grid-Connected PV-Wind Hybrid System Considering Reliability, Cost, and Environmental Aspects. *Sustainable Cities and Society*, **60**, Article ID: 102178. https://doi.org/10.1016/j.scs.2020.102178

[27] Belouda, M., Hajjaji, M., Sliti, H. and Mami, A. (2018) Bi-Objective Optimization of a Standalone Hybrid PV-Wind-Battery System Generation in a Remote Area in Tunisia. *Sustainable Energy, Grids and Networks*, **16**, 315-326. https://doi.org/10.1016/j.segan.2018.09.005

[28] Ohunakin, O.S., Oyewola, O.M. and Adaramola, M.S. (2013) Economic Analysis of Wind Energy Conversion Systems Using Levelized Cost of Electricity and Present Value Cost Methods in Nigeria. *International Journal of Energy and Environmental Engineering*, **4**, Article No. 2. https://doi.org/10.1186/2251-6832-4-2

[29] El Alimi, S., Maatallah, T., Dahmouni, A.W. and Nasrallah, S.B. (2012) Modeling and Investigation of the Wind Resource in the Gulf of Tunis, Tunisia. *Renewable and Sustainable Energy Reviews*, **16**, 5466-5478. https://doi.org/10.1016/j.rser.2012.05.004

[30] Gökçek, M. and Genç, M.S. (2009) Evaluation of Electricity Generation and Energy Cost of Wind Energy Conversion Systems (WECSs) in Central Turkey. *Applied Energy*, **86**, 2731-2739. https://doi.org/10.1016/j.apenergy.2009.03.025

[31] Eberhart, R.C. and Shi, Y. (1998) Comparison between Genetic Algorithms and Particle Swarm Optimization. In: Porto, V.W., Saravanan, N., Waagen, D. and Ei-

ben, A.E., Eds., *Evolutionary Programming VII. EP 1998*: *Lecture Notes in Computer Science*, Vol. 1447, Springer, Berlin, 611-616. https://doi.org/10.1007/BFb0040812

[32] Wang, L., *et al.* (2015) Particle Swarm Optimization Based Dictionary Learning for Remote Sensing Big Data. *Knowledge-Based Systems*, **79**, 43-50. https://doi.org/10.1016/j.knosys.2014.10.004

[33] Al-Ghussain, L., Ahmad, A.D., Abubaker, A.M., Abujubbeh, M., Almalaq, A. and Mohamed, M.A. (2021) A Demand-Supply Matching-Based Approach for Mapping Renewable Resources towards 100% Renewable Grids in 2050. *IEEE Access*, **9**, 58634-58651. https://doi.org/10.1109/ACCESS.2021.3072969

[34] Emad, D., El-Hameed, M.A. and El-Fergany, A.A. (2021) Optimal Techno-Economic Design of Hybrid PV/Wind System Comprising Battery Energy Storage: Case Study for a Remote Area. *Energy Conversion and Management*, **249**, Article ID: 114847. https://doi.org/10.1016/j.enconman.2021.114847

[35] Ahmadi, S. and Abdi, S. (2016) Application of the Hybrid Big Bang-Big Crunch Algorithm for Optimal Sizing of a Stand-Alone Hybrid PV/Wind/Battery System. *Solar Energy*, **134**, 366-374. https://doi.org/10.1016/j.solener.2016.05.019

[36] Mareli, M. and Twala, B. (2018) An Adaptive Cuckoo Search Algorithm for Optimisation. *Applied Computing and Informatics*, **14**, 107-115. https://doi.org/10.1016/j.aci.2017.09.001

[37] Trivedi, I.N., Jangir, P., Kumar, A., Jangir, N. and Totlani, R. (2018) A Novel Hybrid PSO-WOA Algorithm for Global Numerical Functions Optimization. In: Bhatia, S., Mishra, K., Tiwari, S. and Singh, V., Eds., *Advances in Computer and Computational Sciences*. *Advances in Intelligent Systems and Computing*, Vol. 554, Springer, Singapore, 53-60. https://doi.org/10.1007/978-981-10-3773-3_6