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Enhancing energy access in rural areas: Intelligent microgrid management for universal telecommunications and electricity

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ABSTRACT

In rural areas lacking an electricity grid, cell phone operators use generators to power their facilities. At the same time, however, the local population is finding it difficult to use the cell phones and other electronic devices for which these operators are deploying their efforts. This situation, due to the problem of access to energy, hinders universal access to telecommunications. The present study aims to solve this problem using microgrid techniques. A microgrid consisting of photovoltaic panels, a genset and storage batteries has been designed to meet the needs of cell phone operators' sites in Bapure, a rural locality in Togo. The focus is on managing energy flows between the various sources of the microgrid, and between the needs of the cell phone operators' site and those of the local population. To resolve the lack of solar irradiation data at Bapure, hourly solar irradiation was predicted using the Adaptive Neuro Fuzzy Inference System (ANFIS) algorithm to obtain a realistic result. Optimization studies were then carried out using the Particle Swarm Optimization (PSO) algorithm to determine the optimum system configuration to ensure continuity of service at the operator's site. The simulation results show that the proposed system has a surplus of energy production at all times, which can be used to supply electricity to the population at a cost equal to 0.0185 USD, with a solar energy utilization rate of 98,95 % and a generator that only needs to operate at 0.15 % throughout the year. The results obtained indicate that a renewable energy system can provide a more efficient solution for electrifying the rural mobile operator's sites and the local population, and can improve the quality of service for the telecommunications industries.

1. Introduction

Rural and remote areas in Sub-Saharan Africa generally suffer from a partial or complete lack of telecommunications and electricity services. To address this issue, several countries in Sub-Saharan Africa have in recent years introduced the notion of universal service into their regulations, in order to achieve the targets, set by MDG 7. Universal service establishes the right of every citizen to access certain essential services, particularly telecommunications and electricity, with affordable prices. Several authors have shown interest in the subject, including (Bastholm, 2019) who argues that universal access to electricity is high on the global agenda and is seen as essential for positive development in areas such as healthcare, education, poverty alleviation, food production and climate change. One specific micro-grid in Tanzania was used as a major case study.

According to the authors Kraft and Luh (2022), microgrids (MGs) using renewable energy sources play an important role in providing universal access to electricity in rural areas. The developed method is applied to a test case system on Idjwi Island, Democratic Republic of the Congo (DRC), with a micro hydropower plant (MHP) in combination with a photovoltaic (PV) system and a battery energy storage system (BESS).

Regarding the policy of universal access to electricity and telecommunications, although access to electricity is very low, with a very slow extension of the electricity network, telecommunications are progressing rapidly, reaching many rural areas with no electricity network. Indeed, in the absence of a power grid, mobile network operators power their sites with gensets. The choice of diesel generators is not without consequences for the environment, as they emit greenhouse gases (GHGs) and require very high maintenance costs. The presence of telecommunications services in these areas raises great interest among the population, who use this service massively despite their very low

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incomes and the difficulties they face in recharging their cell phones.

To meet the challenge of energy shortages, which affect not only telecommunications networks but also the population in rural areas, it's urgent to find alternative energy solutions that respect the environment. The use of Microgrids (MGs) is being extensively investigated as a feasible means of tackling the challenge of electrification, especially in rural and remote areas (Liu et al., 2018). The various methods and techniques that are currently in use and most viable to solve the rural electrification problem in Sub-Saharan Africa, through the use of Microgrid technology were discussed.

Recent studies suggest that hybrid power systems, such as those based on renewable energy sources, could support the development of a climate change adaption (Mudaheranwa et al., 2023). An extensive adoption of isolated microgrids is crucial to reach universal access to electricity by 2030, complying with the Sustainable Development Goals set by the United Nations (Petrelli, 2021). Decentralized off-grid electrification is seen as an important complement to the extension of the centralized grid, using renewable energy sources, solar technology for power generation, to minimize the environmental problems associated with energy use (Bastholm, 2019). The author presents a comprehensive model for rural microgrid planning, whose performances are tested on the case study of an isolated community in Uganda. According to Schnitzer et al. (2014), Governments, private developers, and NGOs throughout the world have been pursuing microgrids to electrify communities that are unlikely to be served in the near- or medium-term by extensions of traditional centralized, grid systems. As a result, the number of microgrids being developed is increasing rapidly. Rural hybrid microgrids, which manage solar and wind resources, constitute a valuable alternative to generate and distribute electricity sustainably using local resources (Canziani et al., 2021). For a remote area where extension of grid will become a very large investment, the study of Phurailatpam et al. (2018) reviled that autonomous microgrids can provide reliable supply of power at reasonable cost. For a more common situation in rural area with partial connectivity to grid, an integration of renewable generations shows that such a system can reliably provide continuous electricity at a cost of 0.163$ per unit in India. Author Nkado (2021) investigated the feasibility of integrating a photovoltaic-battery energy storage (PV-BES) system into the existing diesel generator system to reduce the community's total dependence on conventional energy while improving the reliability of the microgrid. The study also minimizes the levelized cost of energy (LCOE) and improves the reliability of the proposed microgrid system, reducing outage hours and the cost of loss of load (CLL). Solar photovoltaic energy was identified by Sackey et al. (2023) as the viable energy resource for achieving the desired power output for the MG. This study therefore proposes the development of a microgrid (MG) to supply electricity to Zipline's facilities in Sefwi-Wiawso, Ghana. Solar microgrid electrification offers rural Indian households social, economic and environmental benefits (Chakravarty and Roy, 2021).. Microgrid is gradually becoming an option for electricity access in non-electrified areas of developing countries (Longe et al., 2017). Authors showed that a Wind/Diesel Generator/Battery-powered microgrid has the lowest cost with a breakeven grid extension distance of −45.38 km. The proposed microgrid could supply electricity at \$0.320/kWh, with 0.0057 kg/kWh CO2 emissions and 90.5 % renewable fraction, which are lower than grid extension of the Eastern Cape. Hybrid microgrids are a promising solution for bridging the electricity access gap that currently exists in rural areas (Canziani et al., 2021). To prove this, the authors analyzed data obtained from the operation of a 9 kW hybrid microgrid in the fishermen's creek of Laguna Grande, Paracas, in the Ica region of Peru, which ran for 5 years, to have better understanding of hybrid rural microgrids. Microgrid is economically more beneficial to be developed in any rural area, as well as complying the minimum technical requirement of local grid code. So Khatun et al. (2023) reviewed microgrids from both a technical and financial standpoint in order to electrify rural places. Microgrids and off-grid solar projects represent a viable solution for rural electrification because of the constraints associated with grid expansion costs, limited access to reliable electricity, and priorities in addressing the climate agenda and Sustainable Development Goals in low-income countries (Tafula et al., 2023). The results of the methodology applied by the authors show that the selection of optimal locations for off-grid solar photovoltaic microgrid projects in Mozambique is significantly influenced by the following order of criteria: climatology, orography, technical and location, social, and institutional criteria. Solar-powered microgrids that provide electric service to two communities belonging to the Huichol indigenous group, which are both located in the mountains near Tepic, Nayarit, Mexico was described by Ortiz et al. (2013). Each microgrid consists of a photovoltaic power plant, a step-up transformer bank, and a radial medium-voltage distribution network. In their study, they carried out the solar-powered microgrids; their protection, control, and monitoring systems; and the operational experience accumulated thus far. Solar energy-based microgrids are the promising solution to terrain electrification particularly in rural, remote villages and for poor communities (Bhanja et al., 2021). The authors explored the challenges encountered in installing solar-based microgrids, especially in hilly terrains of rural India. The review highlighted the varied technical difficulties including the stability, reliability, power imbalance, control and operation. In order to meet with the energy requirements of the unelectrified rural communities, the author (Kurian, 2019) focused on a renewable hybrid solution for a village, located along the banks of a perennial river in Central India. The chosen system configuration consists of a low cost, highly efficient and easily installable micro-hydro vortex turbine combined with PV and energy storage since the area receives high annual solar energy.

The above-mentioned literature review is very useful and has covered aspects such as investments, rural electrification, climate change, solar technology for power generation, sustainable energy planning, minimization of environmental problems associated with energy use. However, these previous studies did not take into account the convergence between the telecommunications and electricity sectors. Indeed, the sites of mobile network operators exist in many rural areas and are potential points of production of electrical energy. But most of these sites are powered by diesel generators. The aim of this work is to prove that the use of microgrids on these sites can guarantee continuity of telecoms services in these areas and supply electricity to the local population. This study therefore proposes replacing generators only at these sites with microgrids made up of photovoltaic panels, generators and storage batteries.

To achieve this objective, which aims to enhance universal access to telecommunications and electrical energy, energy flows in the microgrid need to be managed using a robust management algorithm, due to the uncertainties associated with solar energy resources and the stochastic nature of electrical energy demand. Energy management system helps to maintain the balance between available generation and load demand, reduce peak load, greenhouse gas emissions and operational costs. Energy management can be achieved in many different ways, and is essential to realize smart grids (Meera and Lavanya, 2023). The most commonly used algorithms include Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization, Bat Algorithm, Cuckoo Search Algorithm, Artificial Bee Colony Algorithm etc. (Yazdanpanah, 2014) introduced a multi-objective function to optimize a microgrid based on wind and solar energy.

To evaluate the efficiency of a microgrid, several technico-economic measurement parameters are available in the literature, but those best suited to the objectives set in this work are: the probability of loss of power supply (LPSP); the levelized cost of electrical energy (LCOE) and the running time of the generator set (MRF).

In order to achieve the project's objective, the remainder of the study is divided into eight sections. The description of the microgrid configuration is given in Section 2. The study site is presented in Section 3. The Section 4 is focused on the study and modeling of the different components of the microgrids. The Section 5treated the choice of the intelligent energy management model. The Microgrid optimization method is investigated in Section 6. A discussion of the results obtained is developed in Section 7, and the conclusions drawn are presented in Section 8.

2. Characteristics of the microgrid

2.1. Description of the current energy system

The sites targeted in this study are the sites of telecommunications operators installed in rural areas whose main source of energy is the gensets. Fig. 1 shows the characteristics of a rural site.

These diesel generators have the advantage of being quick and easy to install, but have several disadvantages, particularly:

- greenhouse gas emissions;
- breakdowns or fuel shortages resulting in service interruptions sometimes lasting several days;
- difficulties in regularly refueling because of bad road conditions, especially during rainy periods;
- very high operating and maintenance costs;
- etc.

In addition, the local population suffers from a lack of access to electricity, which the generators are unable to provide because of the above-mentioned disadvantages. Thus, the population shows a lot of ingenuity by using several ways to recharge the devices either:

- using car batteries;
- waiting for market days, when individuals bring generators and recharging devices;
- taking batches of phones to nearby towns or to an operator's site, often several ten kilometers away, for recharging.

The Fig. 2 illustrates the recharging systems at the market and on the operators' sites

2.2. Proposed energy solution

To remedy the above-mentioned problems, it is proposed to supply the operators' sites in rural areas with microgrids composed of photovoltaic panels as the main source, combined with storage batteries and gensets. A case study was carried out on a site illustrated in Fig. 3

- The expected result are:
- the uninterrupted supply of electricity at the operator's site;
- the supply of electricity to the local population at lower cost via an electricity network illustrated in Fig. 4;
- a reduction in greenhouse gases and operating costs.

3. Selection of the study site

The site that is the subject of this study is located in Bapure, a village in the Bassar Prefecture in the Kara Region of north-western Togo. This site was served as part of a universal telecommunications service program and was initially powered by a genset. Fig. 5 shows the location of Bapure, which is situated at Latitude: 9.5259 N, Longitude: 0.6115E, altitude: 190 m on the map of Togo and 457.8 km from the capital Lomé.

One of the aims of this project is to promote renewable energies, particularly photovoltaics, and to increase the rate of access to electricity in rural areas. To this end, a microgrid has been installed on this site, including solar panels, storage batteries and genset.

4. Microgrid modeling

The futuristic vision of the project is to produce green energy locally to ensure uninterrupted power supply to telecoms installations in rural areas and to supply electricity to the local population. To achieve this, the proposed energy solution is a microgrid composed of solar panels, generators and storage batteries. Microgrid is defined as a cluster of interconnected distributed energy resources, energy storage systems, and loads which can operate in parallel with the grid or in an islanded mode (Farrokhabadi et al., 2017). Microgrid can be an DC (Dhaked and Birla, 2022), AC or hybrid AC-DC (Ortiz et al., 2019) grids depending on the elements constituting it, such as the sources of production and the loads to be supplied. The classification by scale of microgrids was done by Shahgholian (2021). The system proposed in this study is a hybrid DC-AC microgrid illustrated in Fig. 6.

4.1. Photovoltaic system modeling

Solar Cells of photovoltaic electrical characteristics differ very little from a diode. The output of the current source is directly proportional to the light falling on the cell. Several authors have proposed models for calculating the output power of the PV system, such as (Qiao et al., 2019), and (Song et al., 2020). For this research work, simplified model that considers the ambient temperature and solar irradiance, expressed by (Eq. (1)) (Dubois et al., 2018), is used.

Fig. 1. Operator's sites in areas without a power grid.

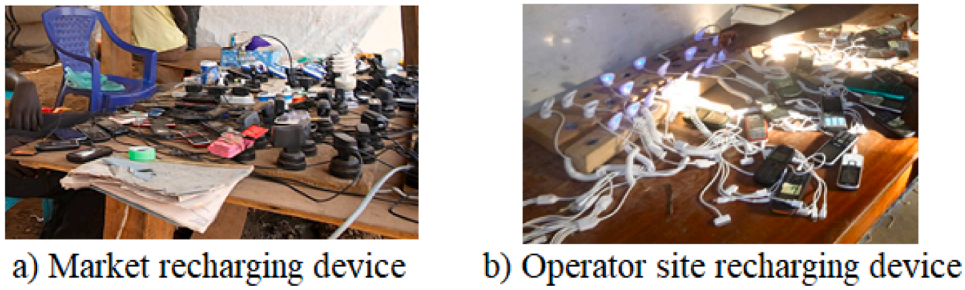


Fig. 2. Mobile phone recharging systems in rural areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Proposed hybrid energy system configuration. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

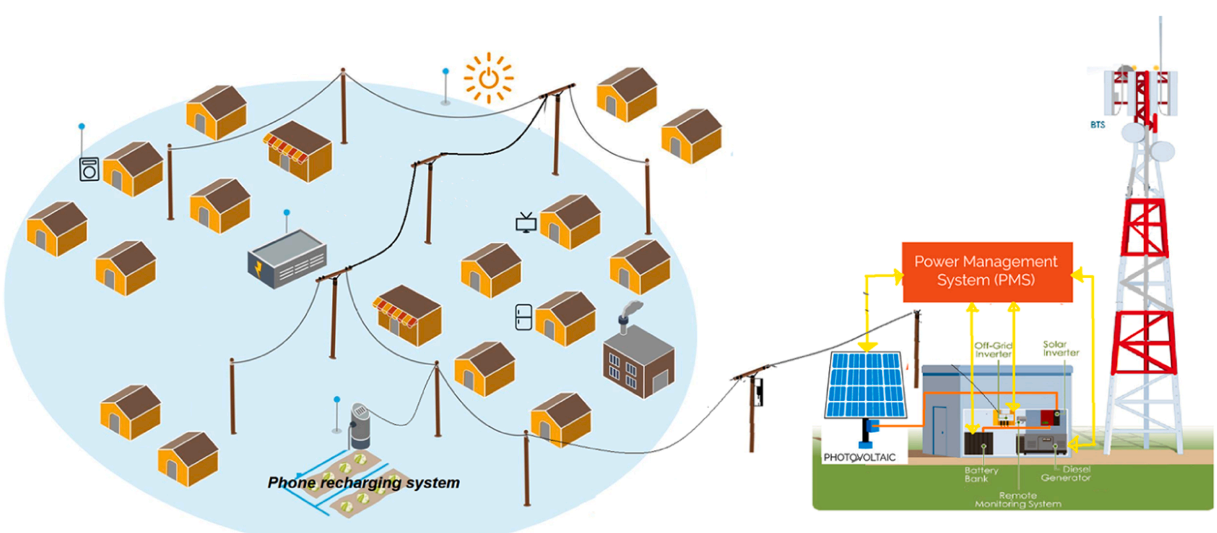


Fig. 4. Future vision of the project. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$P_{PV} = \frac{G}{G_{ref}}.P_r\left[1 + K\left(\left(T_{amb} + \left[\frac{(TNOCT - 20)}{800}\right].G\right) - T_{ref}\right)\right] \quad (1)$$

where: P_{PV} is output power of PV in watts (W), G is solar radiation in W/m^2, G_{ref} is solar radiation at standard test conditions (STC) (G_{ref} = 1000 W/m^2), P_r is Rated power in watts (W) at the STC, K is temperature coefficient estimated as $-3{,}7.\ 10^{-3}$ (1/°C), T_{amb} is ambient temperature in°C ($T_{amb} = 25$°C), $TNOCT$ is nominal operating temperature of the cell,

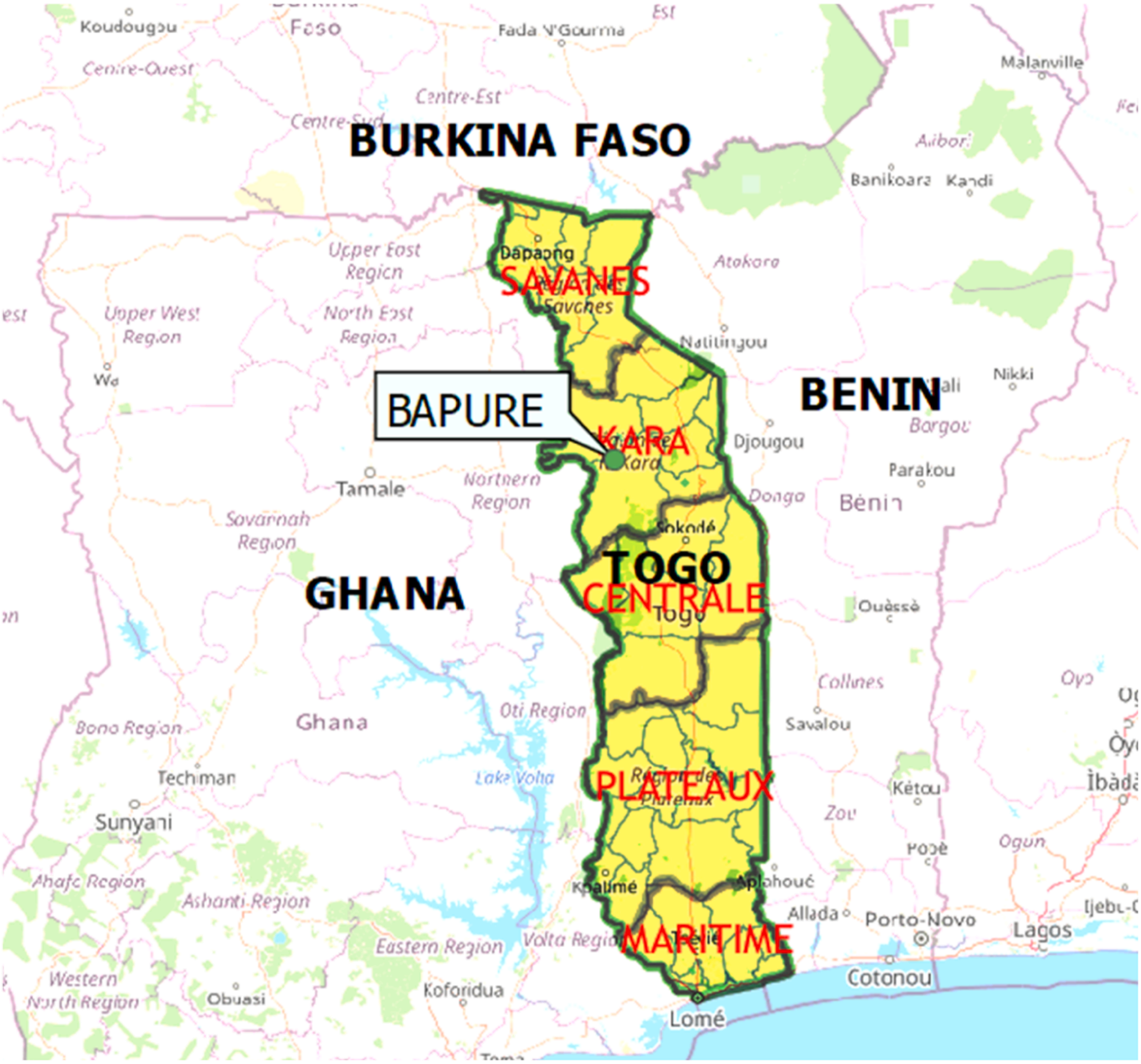


Fig. 5. Geographical location of Bapure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$T_{ref}$is cell temperature in$^{\circ}$C at STC.

4.2. Battery modeling

The role of the storage device is to enable the energy produced by the photovoltaic system to be stored during the day and used later when the sun is not shining or at peak consumption times. It is therefore characterized by Farrokhabadi et al. (2017):

- its total storage capacity measured in MWh;
- the power of storage system, measured in MW;
- a State Of Charge (SOC).

4.2.1. Battery capacity

The model for the battery capacity C_B of the system is expressed by (Eq. (2)).

$$C_B = \frac{P_{Load}.N_{DA}}{\eta_{Bat}.DOD.\eta_{Inv}} \tag{2}$$

Where: P_{Load}I the power of the load, DOD is the depth of discharge (20 %), η_{Inv} is the inverter efficiency (95 %), $\eta_{Bat}$is the battery efficiency (85 %), N_{DA} is the number of days of autonomy which can be up to 3 or 5 days.

The number of days of autonomy is determined to satisfy energy demand during periods of unavailability or absence of solar energy.

4.2.2. Battery power

The battery power $P_{Bat}(t)$ varies according to the production cycle of the photovoltaic panels and can have a positive or negative sign. When production exceeds demand, the sign of $P_{Bat}(t)$ is positive and represents the power stored by the storage system (Dhaked et al., 2019). When there is a shortfall in panel production, the battery supplies additional energy to meet the load demand; in this case, the sign of $P_{Bat}(t)$ is negative (Mouachi et al., 2020). The battery power $P_{Bat}(t)$ is expressed by (Eq. (3)).

$$P_{Bat}(t) = P_{PV}(t) - \frac{P_{Load}(t)}{\eta_{Inv}} \tag{3}$$

4.2.3. Battery state of charge (SOC)

The battery state of charge at a time t, SOC(t) in Wh, can take on three characteristic values, namely:

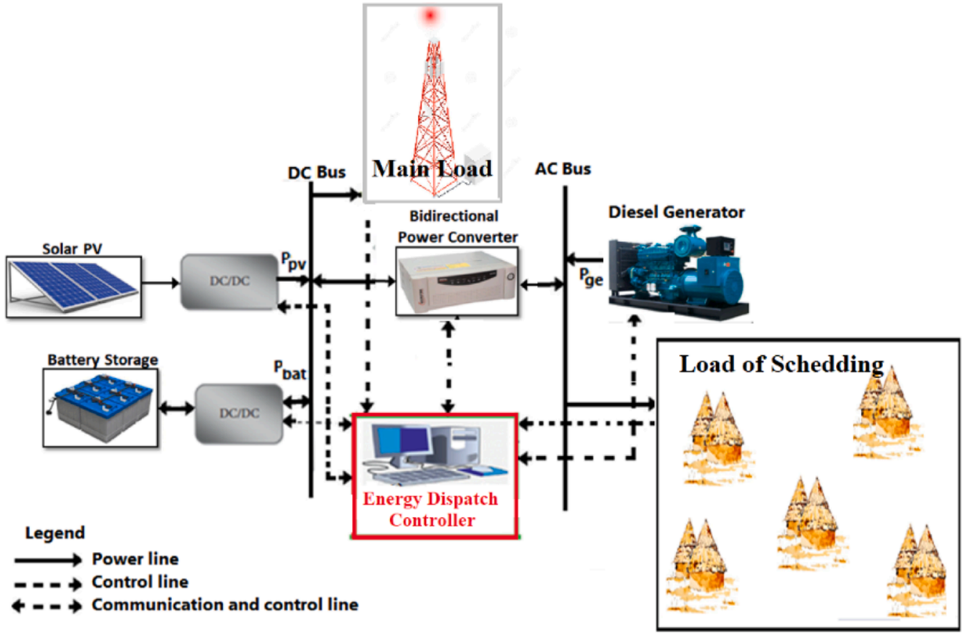


Fig. 6. Hybrid microgrid operating diagram. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

- the maximum capacity SOS(t) $= SOC_{max}$;
- the nominal capacity SOS(t) $= C_B$;
- the minimum capacity SOS(t) $=$ SOC_{min}which represents the maximum depth of discharge (MDD) of the battery.

Therefore, the SOC(t) can be expressed by (Eq. (4)) (Converters and Oeste, 2020).

$$SOC(t) = SOC(t-1)(1-\gamma) + P_{Bat}(t).\eta_{Inv} \quad (4)$$

where: γ is the battery self-discharge rate per hour rate, SOC (t $-$ 1) is the battery states of charge (Wh) at times (t $-$ 1), η_{Inv} is the inverter efficiency, and $P_{Bat}(t)$ is the power of the battery.

The storage device charges when the following two conditions expressed by (Eq. (5)) are met:

$$\begin{cases} SOC(t) < SOS_{max} \\ P_{PV}(t) > P_{Load}(t) \end{cases} \quad (5)$$

4.2.4. Battery constraints

To guarantee efficient operation and long life of batteries, they must charge and discharge within a minimum allowable discharge value $P_{Dmin}(t)$ and a maximum charge capacity $P_{Cmax}(t)$. This constraint is indicated by (Eq. (6)):

$$P_{Dmin}(t) \le P_{Bat}(t) \le P_{Cmax}(t) \quad (6)$$

4.3. Diesel generator modeling

Genset provides in microgrid, a rapid response to load variations and increases the efficiency of the whole system. Therefore, the genset is used when the following two conditions are met:

- no or insufficient photovoltaic power generation and;
- storage capacity below the minimum capacity (SOC(t) $< SOC_{min}$).

Apart from improving the reliability and efficiency of the system, the use of genset reduces the capacity of the storage device and the investment cost of a hybrid system. To be able to fulfill its role effectively in a microgrid, the following essential parameters need to be taken into account when designing the system (Manu et al., 2022):

- the quantity of diesel consumed per hour;
- its efficiency;
- the maximum power it can produce.

4.4. Diesel generator hourly consumption

The hourly consumption of genset is expressed by the following (Eq. (7)) (Moussa Kadri et al., 2022):

$$Q(t) = aP_{DG}(t) + bP_r \quad (7)$$

where: P_{DG} is the power generated by genset (kW), Q(t) is the hourly quantity of fuel consumed (L/hour), P_r is the nominal power (kW) of the genset, a and b are fuel consumption coefficients approximated at 0.246 L/kW and 0.08415 L/kW respectively (Alturki et al., 2020).

4.4.1. Genset efficiency

In nominal operation, the genset loses energy in the form of heat due to mechanical and electrical losses in the alternator and transmission. In general, the genset is characterized by its efficiency calculated by the following equation (Eq. (8)) is used (Azoumah et al., 2011):

$$\eta_g = \eta_{TF} * \eta_{DG} \quad (8)$$

Where: $\eta_g$is genset global efficiency and $\eta_{TF}$is genset Brake thermal efficiency.

4.5. Maximum power produced by genset

The use of a genset requires a number of precautions to be taken to optimize its operation. One of these precautions is to control the energy it produces. Therefore, (Eq. (9)) is used to restrict the energy produced by DG.

$$E_{DG} \le C_{DG} \times \Delta t \quad (9)$$

where: $E_{DG}$is the energy produced by the genset, C_{DG} is genset rate capacity and $\Delta t$is genset operating time.

4.6. Load modeling

At any time and in any condition, power produced by microgrid must be greater than or equal to site requirement. This constraint is expressed by (Eq. (10)).

$$P_{Load1}(t) \geq P_{PV}(t) + P_{DG}(t) \pm P_{Bat}(t) \tag{10}$$

where: P_{Load1} is the main load power, P_{PV} is PV generator power, P_{DG} is genset power, P_{Bat} is the batteries power.

The sign ("-" or "+") of battery's power depends on fact that battery can discharge (-) or charge (+).

4.7. Power constraints

Each generator is constrained by a maximum value $P_{max}(t)$ and a minimum value $P_{min}(t)$ which can fluctuate from one extreme to the other. This constraint is expressed by (Eq. (11)):

$$P_{min}(t) \leq P(t) \leq P_{max}(t) \tag{11}$$

5. Energy management system

Multi-source systems always require an intelligent energy management, which must be integrated into the power system. In the context of this project, the aim of intelligent energy management is to provide overall energy efficiency and flexibility of energy production in order to provide uninterrupted energy to the operator's site considered as the main load (P_{Load1}) and the use of excess production to provide low-cost electricity to the local population considered as load shedding (P_{Load2}). The system operates according to the following conditions:

- Condition 1: The PV generator's production exceeds the main load demand *($P_{PV} > P_{Load1}$)*, then:
  - if SOC(t) < SOC_{max}, the surplus ($P_S = P_{PV} - P_{Load1}$) is used to recharge the storage device;
  - if SOC(t) = SOC_{max}, the surplus ($P_S = P_{PV} - P_{Load1}$) is used to supply the shedding load ($P = P_{Load2}$);
- Condition 2: The PV generator's production less than the main load demand *($P_{PV} < P_{Load1}$)*, then:
  - if SOC(t) > SOC_{min}, the demand of the main load is satisfied by the contribution of PV production and the batteries energy *($P_{Load1} = P_{PV} + P_{Bat}$)*;
  - if SOC(t) ≤ SOC_{min}, the demand of the main load will be satisfied by the contribution of the generator DG and the energy produced by the solar panels *($P_{Load1} = P_{PV} + P_{DG}$)*;
- Condition 3: No producing of the PV generator *($P_{PV} = 0$)*, then:
  - if SOC(t) > SOC_{min}, the need of the main load will be satisfied by the contribution of the energy stored in the batteries ($P_{Load1} = P_{Bat}$);
  - if SOC(t) < SOC_{min}, then the main load will be provided by the genset only. The surplus production of the genset will be used to charge the batteries ($P_{DG} = P_{Load1} + P_{Bat}$). But, as soon as the PV generator production is resumed or SOC(t) = SOC_{max}, the DG is switched off.

This intelligent management of the different energy flows in the microgrid can be done with the algorithm shown in Fig. 7.

6. Microgrid optimization methods

There are several methods in the literature that are used to optimize microgrids, such as artificial intelligence (AI), the analytical method, the probabilistic approach and the software approach. These include, artificial neural networks (ANN) (Kang et al., 2021), fuzzy logic (Ameli et al., 2017), genetic algorithm (GA) (Sridevi et al., 2022), Dynamic Programming (Rüther et al., 2022), PSO (Particle Swarm Optimization)

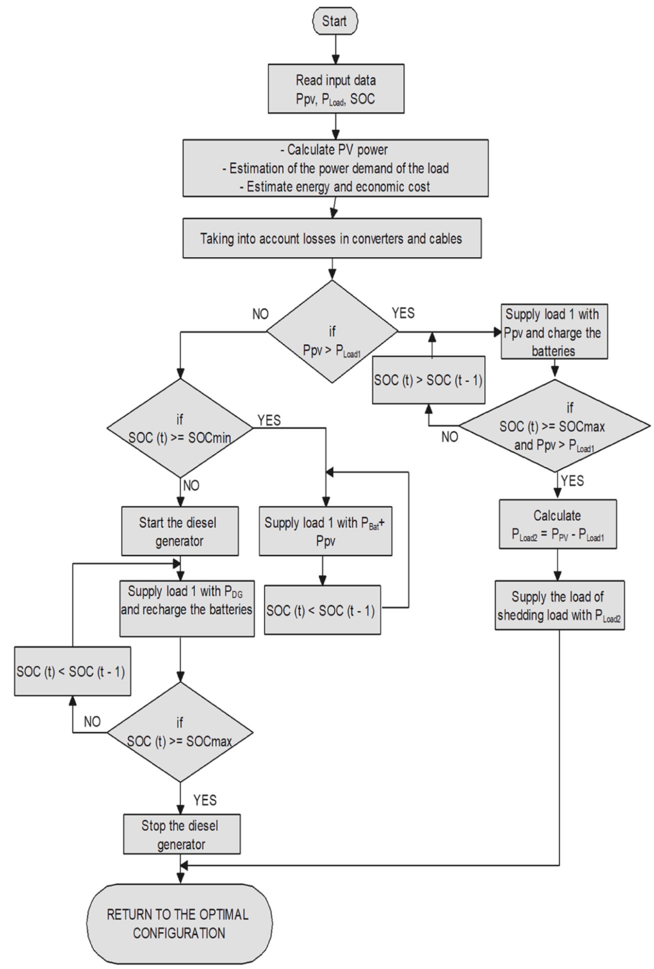


Fig. 7. Flowchart for intelligent energy management.

algorithm (Al-Saedi et al., 2017), etc. However, no one of these methods is considered to be ideal for all situations (Vukobratović et al., 2021), (Shami et al., 2022). Each one of the optimization approaches has its advantages and limitations. Thus, the choice of the best optimization approach depends on the problem to be analyzed to find the solution that maximizes or minimizes a function to be optimized (Duan and Liu, 2011). The algorithm to be used in this study should provide smart and optimal management of multiple sources microgrids in real-time, to always ensuring an uninterrupted supply of electricity to the operators' sites, and using the excess generation to provide electricity at a lower cost to the local population.

Several authors have made comparative studies of these smart algorithms. For example, the authors *Hossain* et al. *(2019)* used PSO algorithm in order to obtain optimal use of battery energy by controlling charging/discharging behaviours in the microgrid to facilitate the analysis of the cost functions. The authors *Kamoona* et al. *(2023)* provides an energy management system based on PSO to manage the power flow of a fuel cell hybrid electric vehicle that integrates three power sources FC, BAT and UC. Kerboua et al. (2020) applied the PSO algorithm to minimize the operating cost of the consumed energy in a smart city supplied by a micro-grid. *Al-Saedi* et al. *(2017)* implemented the PSO algorithm to improve the quality of the power supply in a microgrid to find the optimal controller parameters to satisfy the control objectives. The results show high performance of the applied PSO algorithm of regulating the microgrid voltage and frequency. According to the authors Hao et al. (2022), PSO algorithm is the most widely used optimization algorithm for microgrid management because of its robustness, flexibility and fast convergence. The authors Phan-Van et al. (2023)

evaluated and compared eight different metaheuristic approaches for optimizing the size of a hydrogen storage-based microgrid, with the aims of minimizing the microgrid's cost and ensuring the ability to regulate the energy flow within the system. The conventional PSO approach is proved to be superior compared to the remaining reviewed meta-heuristic when having the fastest conversion rate as well as the ability to obtain the best result. This study also proved that PSO is one of a best mathematical energy management strategy in microgrid which is able to achieve the lowest annual system cost. In addition, the PSO algorithm is proved to be one of the best algorithm to avoid being trapped in local optimum points, asthey have been observed to produce improved results in the final iterations, whereas the output of other algorithms remains constant. Compared to others evolutionary algorithms, PSO has much more profound intelligence background and could be performed more easily. Based on its advantages, the PSO is suitable for engineering applications, in the fields of evolutionary computing, optimization and many others (Li et al., 2019).

For the following reasons, PSO algorithm was chosen in this work to ensure the efficient management of energy production and the need in order to minimize the production and operation cost. Its practical implementation is done using the PySwarms python package (Moriwaki, 2022).

6.1. Particle swarm optimization (PSO)

The PSO algorithm is one of the most popular artificial intelligence (AI) technique used to find approximate solutions to extremely difficult or even impossible optimization problems. PSO is a swarm-based stochastic algorithm proposed originally in 1995 by Kennedy and Eberhart, which exploits the concepts of the social behavior of animals like fsh schooling and bird focking *(Gad, 2022)*. It is an optimization method that has been widely used in several fields governed by complex optimization problems. It is inspired by the social behavior of bees or birds that act together in a complex way, based on simple "rules", to find a solution to a specific optimization problem (Fan et al., 2022).

In the resolution of optimization problems, two characteristic values are important. The first value, called the best individual value, is the best recorded solution that each particle has taken until a given date. The second value, called the global best value, is the best-known solution of the whole swarm among the population (Song et al., 2020).

Each particle i in the swarm is characterized, at the given time t, by its position in the search space, which is updated by the equation (Eq. (12)), and a velocity that directs it to the best individual and global values, updated by the equation (Eq. (13)) (Jain et al., 2022).

$$x_i(k+1) = x_i(k) + V_i(k+1) \tag{12}$$

where: x_i is the position of the particle i, V_i is the velocity of the particle i in iteration k, k is the current iteration number.

$$V_i(k+1) = \omega V_i(k) + C_1 r_1 (P_{best}(k) - x_i(k)) + C_2 r_2 (G_{best}(k) - x_i(k)) \tag{13}$$

where: P_{best} is the best position of the individual particle, G_{best} is the best global position, ω is the inertia weight (denotes the coefficient of inertia), C_1 is Cognitive confidence coefficient, C_2 is social confidence coefficient, r_1, r_2 are random numbers between 0 and 1.

6.2. Optimal operation of the system

6.2.1. Fitness function

The fitness function expressed by equation Subject to $\begin{matrix} H(x) \le 0 \\ G(x) = 0 \end{matrix}$ (Eq. (14)) is the "objective function" used in this paper to find the optimal possible solution (Mouachi et al., 2020).

$$F_{Min}(x) = \begin{bmatrix} f_i(x) \\ \dots \\ f_n(x) \end{bmatrix} \text{ Subject to } \begin{cases} H(x) \le 0 \\ G(x) = 0 \end{cases} \tag{14}$$

where: $F_{Min}(x)$ is a vector representing the "objective functions", $f_i(x)$ is the individual goals to be achieved, X is a vector of the design search space, H(x) is equality constraints, G(x) is an inequality constraint.

6.2.2. Main indicators to estimate microgrid reliability

In general, there are many different methods for estimating the reliability of a hybrid microgrid system. Methods such as loss of power supply probability (LPSP), expected loss of energy (LOEE), loss of energy probability (LOEP), power supply failure probability (DPSP), expected loss of load (LOLE), loss of load risk (LOLR) and loss of load probability (LOLP) are the most widely used methods (Kiehbadroudinezhad et al., 2022). The authors Singh et al. (2020) used the LCOE method to optimize a sample hybrid renewable energy system (HRES) consisting of power sources such as solar photovoltaic, wind and diesel generators. Belmili et al. (2013) used the LPSP and DPSP method to determine the reliability of their hybrid system. Mouachi et al. (2020) used MRF method for low generator utilization rates to reduce greenhouse gases and operating costs.

The indicators that were used as objective functions to arrive at an optimized and reliable system in this project are:

- Economic efficiency indicator (LCOE: Levelized Cost Of Energy) which means the cost of electricity;
- Reliability indicator (LPSP: Loss of Power Supply Probability) which means the probability of loss of generated power;
- Maximum Renewable Factor (MRF), which means the operating time of the DG unit.

6.2.2.1. Levelized cost of electricity (LCOE).

Levelized cost of electricity (LCOE) is the total cost of the installation, replacement, fueling, and maintenance of an MG. It represents the price of electricity per ($USD/kWh) over the system's life (Phommixay et al., 2020). A low LCOE corresponds to a low electricity cost estimated by ((Eq. (15))), is often used.

$$LCOE\left(\frac{\$USD}{kWh}\right) = \frac{TC}{\sum_{t=1}^{8760} P_{Load}} \times CRF \tag{15}$$

Where: TC is a total system cost including the capital, spare parts, the exploitation, and the maintenance costs, $P_{Load}(t)$ is the hourly power consumed by the load, CRF is the Capital Recovery Factor, expressed by (Eq. (16)).

$$CRF(\beta, n) = \frac{\beta(1+\beta)^n}{(1+\beta)^n - 1} \tag{16}$$

where: n is a System lifetime (most of the time, equal to the lifetime of the PV panels (Mahmoud et al., 2022)), β is the economic evaluation rate of the system Discount.

6.2.2.2. Loss of power supply probability (LPSP).

LPSP is defined as the probability that an insufficient power supply results when the hybrid system (PV module, wind turbine and battery storage) is unable to satisfy the load demand (Tiwari and Dubey, 2015). The loss of power supply probability is used to assess the reliability of the system. It is expressed by (Eq. (17)) (Medina-Santana and Cárdenas-Barrón, 2022).

$$LPSP = \frac{\sum_{t=1}^{8760} \left(P_{Load}(t) - P_{PV}(t) + P_{DG}(t) + P_{Bat_{min}}(t)\right)}{\sum_{t=1}^{8760} (P_{Load}(t))} \tag{17}$$

where: $P_{PV}(t)$ is the power produced by the PV generator, $P_{DG}(t)$ is the power produced by the genset, $P_{Load}(t)$ is the power consumed by the load, $P_{Bat_{min}}(t)$ is the minimum allowable power of the batteries.

6.2.2.3. Maximum renewable factor (MRF). MRF is defined as a boundary to determine the amount of energy coming from a genset as compared to the PV generators. The objective is to minimize the genset usage, reducing the CO2 emissions and reducing the cost of operation. Hence, the MRF is expressed by, is bounded by 0 and 1 (Mouachi et al., 2020). If MRF is equal to:

- 0, then the renewable energy is not used;
- 1, then the energy is produced only by the genset

$$MRF(\%) = \left(1 - \frac{\sum_{t=1}^{8760}(P_{DG}(t))}{\sum_{t=1}^{8760}(P_{PV}(t))}\right) \times 100 \tag{18}$$

6.3. PSO optimization procedure

Particle Swarm Optimization (PSO) is a computational method used to find the optimal solution to a problem. It is an iterative optimization technique that was inspired by the behavior of social animals such as birds or fish. It involves a group of particles, or agents, that move through a search space and try to find the optimal solution to a given problem. Each particle is guided by its own experience and the experience of the other particles in the group, and the movement of the particles is determined by a set of rules that are based on the particle's current position, velocity, and the best position it has encountered so far (Zahraoui et al., 2021). The Fig. 8 shows the flowchart of the algorithm applied to the sized system.

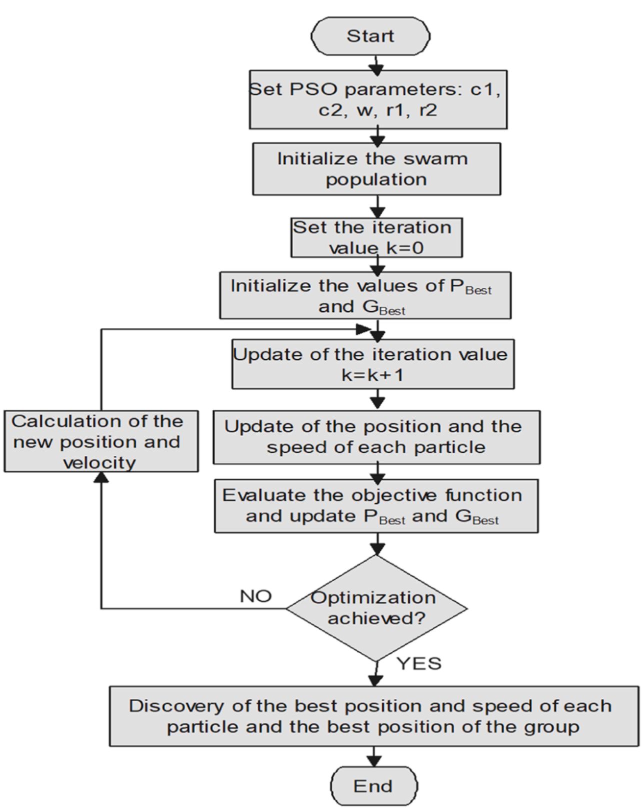


Fig. 8. Flowchart of PSO algorithm.

6.4. Algorithm aspects

The first step of the PSO algorithm is to initialize the swarm and control parameters. In the context of the basic PSO, the acceleration constants, c_1 and c_2, the initial velocities, particle positions, and personal best positions need to be specified. The last aspect of the PSO algorithm is the stopping condition. The stopping condition is to terminate the algorithm when a maximum number of iterations, or Function Evaluation, has been reached (Daggubati, 2012).

It is well known that the main parameters (inertia weight, two learning factors, velocity constraint and population size) have a critical effect on its performance that scale the contribution of the cognitive and social components. The acceleration coefficients, c_1 and c_2, together with the random vectors r_1 and r_2, control the stochastic influence of the cognitive and social components on the overall velocity of a particle which can ensure the convergence of PSO algorithm. In many cases, c_1 and c_2 are set to 2.0 which make the search to cover the region centered in P_{best} and G_{best}. Another common value is 1.49445 (Wang et al., 2018). The random values r1j(n), r2j(n) are in the range [0, 1], sampled from a uniform distribution and introduce a stochastic element to the algorithm (Daggubati, 2012).

The choice of population size is related to the complexity of the problem. As the complexity of the problem increases, the population size also grows. Common selection is 20–50. In some cases, larger population is used to meet the special needs (Wang et al., 2018). The inertia weight ω affects the particle's global and local search ability. The stochastic process theory in (Li et al., 2019) shows that the range of ω is [0, 1]. When ω is small, PSO algorithm hardly converges and the success rate is low. Along with the increase of ω, PSO algorithm has a better convergence and stability.

6.5. Pseudocode of PSO

The complete sequence of the algorithm applied to the technical-economic analysis of the hybrid system is shown below.

Step 1) Initialization phase (Input parameters).

Loading of the annual production data of the dimensioned photovoltaic system

Loading the annual load characteristics data;

Define the economical parameters of the system;

Define the constants:

Acceleration coefficients, C_1, C_2;

Coefficient of inertia ω;

Number of iteration k;

Randomly initialize the individual position P_{best} and the global position G_{best};

Step 2) Set the iteration variable;

Step 3) Set the positions and velocities of each particle in the swarm;

Step 4) Determine the initial value of the "objective function";

Step 5) Update the best individual position P_{best} and global position G_{best};

Step 6) Calculate the parameters LCOE, MRF and LPSP of the "objective function";

Step 7) Determination of G_{best}. The particle with LCOE and LPSP low, will be considered as the G_{best};

Step 8) Checking the stopping condition. If k = kmax, stop the algorithm and display the results. If $k \leq$ kmax, repeat step 2.

For each iteration, the individual objectives to be achieved: LPSP, MRF and the LCOE of the particles generated are calculated and if they meet the constraints, they will then be accepted as solutions to the objective function.

7. Results

To obtain the desired results, it is essential to have all the information and input parameters for the simulator. These include

- the solar energy potential of the area;
- the site's energy demand;
- the results of the techno-economic study;
- the design of the microgrid;
- the choice of the right equipment to optimize costs and efficiency;
- the intelligent management of the system using specific software.

7.1. Assessment of the solar resource in the locality

Efficient exploitation of the solar potential for photovoltaic energy production requires good knowledge of the variability of the solar resource in the geographical area concerned. Due to the fact that the meteorological data is not available everywhere, especially in rural areas, the authors Dadjiogou et al. (2022) used the Adaptive Neuro-Fuzzy Inference Systems (ANFIS) method to predict solar irradiation data from 394 Togo cantons in order to provide a national database of solar irradiation. The results of this study show that Togo has a favorable solar potential to the production of photovoltaic energy, and have made it possible to obtain the hourly solar irradiation for the Bapure locality. The irradiation data used cover a period of 1 year (1 January to 31 December 2023), i.e. a sample of 8760 measurements, which is illustrated in Fig. 9.

7.2. Site energy requirements

To estimate the site's electrical energy requirements, it was necessary to observe and measure the site's consumption for a period of one year. The results obtained from observation of the Bapure site during the year 2023 show that the site's energy requirement varies between 1.50 kW and 2.73 kW per hours. The Fig. 10, shows the variation in load demand.

7.3. Techno-economic parameters

Based on data relating to the site's energy requirements and the sunshine of the site, a technical and economic study was carried out to determine the characteristics and costs of the various project components. The results obtained are presented in Table 1. The currency is expressed in dollars, with 1 dollar = 612,50FCFA on 1 May 2024.

7.4. Design of the microgrid

The previous results were used to determine the different components of the system. These are as follows:

- Photovoltaic generators
- Genset
- Energy storage device
- power electronics converter

7.5. Control and communications within microgrids

Microgrids need an intelligent management to operate safely and effectively, thus needing to possess sophisticated microgrid control systems. Thus, PSO algorithm was used to manage the balance between production and demand. To achieve the set objectives, the system requires input data from all the components of the system

7.5.1. System input data

- The input data required for the simulator are as follows:
- Technical and economic parameters;
- Meteorological parameters:
  - annual hourly solar irradiation;
- Site electrical parameters:
  - annual power consumed by the load;
  - annual power produced by the PV generator;
  - annual level of variation of the battery.

The Techno-economic data, the site's energy requirements and the site's annual meteorological data are already known. To obtain the other parameters, the system was observed for a year to determine the power produced by the PV generator and the level of variation in charging and discharging the storage device. Fig. 11 shows an extract of the measured noise data.

7.5.2. Evolution of the level of charge and discharge of the storage device

Data of the level of charge and discharge of the batteries were recorded for one year and are shown in Fig. 12. It appears in this figure that the genset is not requested during the entire year 2023 because the level of charge of the battery varies between 60 % and 100 %.

7.5.3. Output power of the PV generator

The output power of the photovoltaic generator, produced in the year 2023 and recorded at one-hour intervals is shown in Fig. 13.

7.5.4. Simulation results

Apart from the input parameters, for simulations the algorithm needs other parameters to be set. After several tests, the parameters that enabled us to achieve satisfying results were as shown in Table 2.

The Fig. 14 shows the results obtained from the simulation of the optimization algorithm in Python.

The aim is to prove the effectiveness of the proposed strategy in

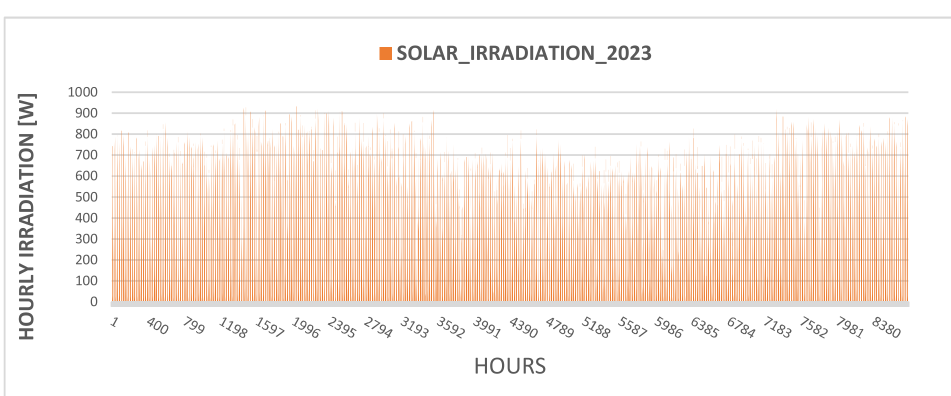


Fig. 9. Solar irradiation for the Bapure locality. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

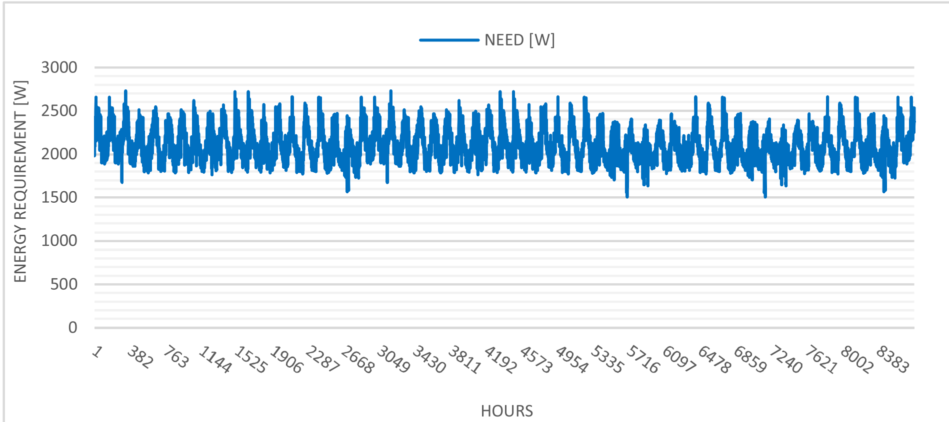


Fig. 10. Electrical energy requirement for the load. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Technical and economic data on the study electrical system.

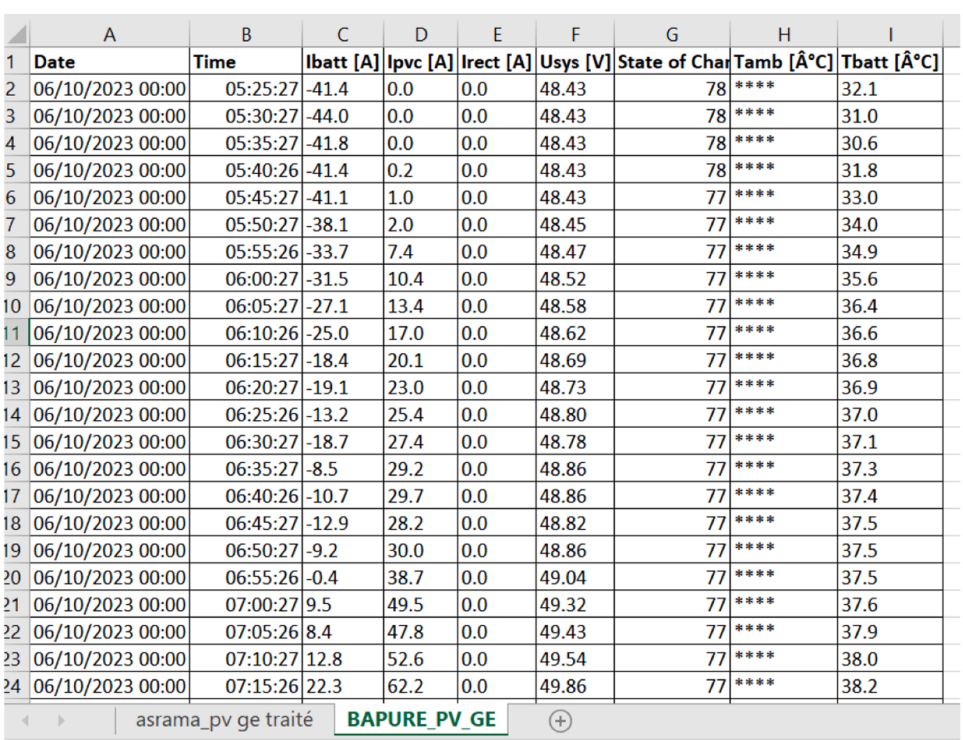
System elements	Economic parameters	Values
Photovoltaic generators	Energy workshop & panels (kWC)	15.00
	Lifetime (years)	25.00
	Initial cost [$USD/kW]	210.00
	DC/DC converter efficiency (%)	95.00
Genset	Lifetime (hours)	43,800.00
	Initial cost [$USD /kVA]	66.00
	Power rating (kVA)	15.00
Energy storage device	Capacity (Ah)	2000.00
	Efficiency (%)	85.00
	Lifetime (years)	5.00
	Initial cost ($USD /Ah)	11.00
	Number of days of autonomy	3.00
Economic parameters	Operating and maintenance cost (%)	4.73
	Lifetime of the project (years)	25.00

reducing operating costs, greenhouse gas emissions, production costs and service unavailability. To this end, the numerical values of the objective functions, namely LCOE, LPSP and MRF, have been determined and presented in Table 3.

7.6. Discussion

To appreciate the evolution of production and demand, a comparative analysis of the needs of the site with the power supplied by the PV generator and the battery was carried out and illustrated in Fig. 15. The black curve represents the evolution of the battery power. The negative part corresponds to the period when the battery is charging and the positive part corresponds to the period when the battery is supplying energy to the load.

The results of this comparative study show that between 4:00 p.m. and 7:00 a.m., the output power of PV generator is lower than the site's energy demand. During these times, the site's energy needs are provided



	A	B	C	D	E	F	G	H	I
1	Date	Time	Ibatt [A]	Ipvc [A]	Irect [A]	Usys [V]	State of Char	Tamb [Â°C]	Tbatt [Â°C]
2	06/10/2023 00:00	05:25:27	-41.4	0.0	0.0	48.43	78	****	32.1
3	06/10/2023 00:00	05:30:27	-44.0	0.0	0.0	48.43	78	****	31.0
4	06/10/2023 00:00	05:35:27	-41.8	0.0	0.0	48.43	78	****	30.6
5	06/10/2023 00:00	05:40:26	-41.4	0.2	0.0	48.43	78	****	31.8
6	06/10/2023 00:00	05:45:27	-41.1	1.0	0.0	48.43	77	****	33.0
7	06/10/2023 00:00	05:50:27	-38.1	2.0	0.0	48.45	77	****	34.0
8	06/10/2023 00:00	05:55:26	-33.7	7.4	0.0	48.47	77	****	34.9
9	06/10/2023 00:00	06:00:27	-31.5	10.4	0.0	48.52	77	****	35.6
10	06/10/2023 00:00	06:05:27	-27.1	13.4	0.0	48.58	77	****	36.4
11	06/10/2023 00:00	06:10:26	-25.0	17.0	0.0	48.62	77	****	36.6
12	06/10/2023 00:00	06:15:27	-18.4	20.1	0.0	48.69	77	****	36.8
13	06/10/2023 00:00	06:20:27	-19.1	23.0	0.0	48.73	77	****	36.9
14	06/10/2023 00:00	06:25:26	-13.2	25.4	0.0	48.80	77	****	37.0
15	06/10/2023 00:00	06:30:27	-18.7	27.4	0.0	48.78	77	****	37.1
16	06/10/2023 00:00	06:35:27	-8.5	29.2	0.0	48.86	77	****	37.3
17	06/10/2023 00:00	06:40:26	-10.7	29.7	0.0	48.86	77	****	37.4
18	06/10/2023 00:00	06:45:27	-12.9	28.2	0.0	48.82	77	****	37.5
19	06/10/2023 00:00	06:50:27	-9.2	30.0	0.0	48.86	77	****	37.5
20	06/10/2023 00:00	06:55:26	-0.4	38.7	0.0	49.04	77	****	37.5
21	06/10/2023 00:00	07:00:27	9.5	49.5	0.0	49.32	77	****	37.6
22	06/10/2023 00:00	07:05:26	8.4	47.8	0.0	49.43	77	****	37.9
23	06/10/2023 00:00	07:10:27	12.8	52.6	0.0	49.54	77	****	38.0
24	06/10/2023 00:00	07:15:26	22.3	62.2	0.0	49.86	77	****	38.2

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Fig. 11. Extract of energy parameters measured at the study site.

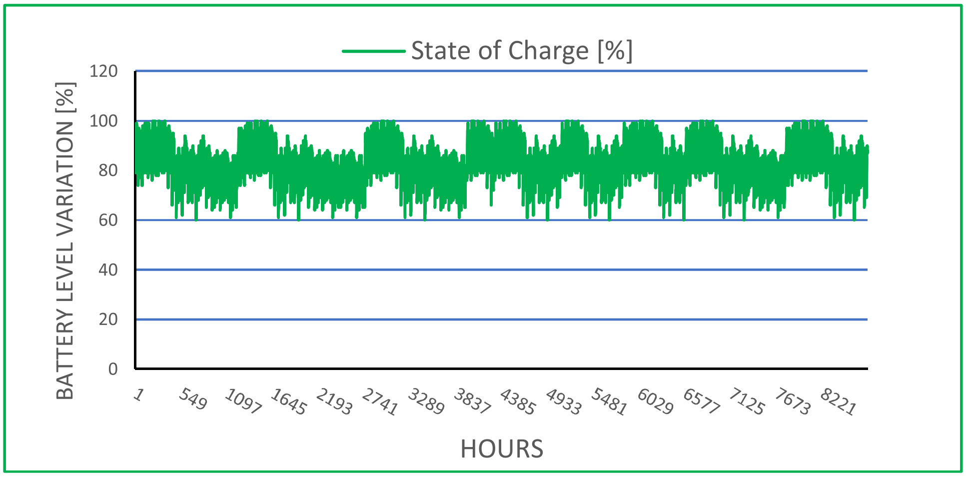

Fig. 12. Variation of charge and discharge of the batteries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

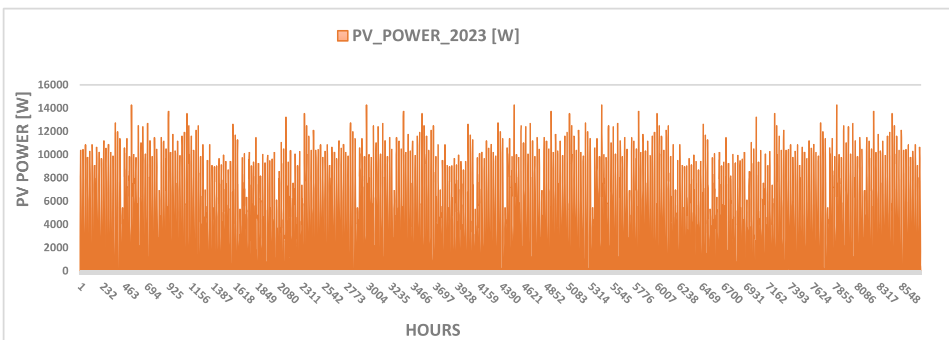

Fig. 13. Illustration of the power produced by the PV generator. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
PSO simulation parameters.

Parameters	Value
Number of iterations	100
Number of particles	100
Acceleration coefficients $c_1 = c_2$	1.495
Coefficient of inertia ω	0,729
Number of iterations k	100

by the batteries. During the daytime between 7:00 a.m. and 4:00 p.m., the production of the PV generator is greater than the site's energy needs. The excess energy produced by the PV generator is used to recharge the batteries.

Analysis of the battery charge/discharge level curve in Fig. 16. Battery power variation curve for 72 h Fig. 16 shows that the battery is underutilized. This indicates that there is surplus production on the site, which can be used to meet the energy needs of the local population.

Furthermore, the LCOE of US$0.0185 per kWh obtained proves that the proposed solution can supply electricity to the low-income population. A comparison with the cost of electricity currently charged in Togo by the national electricity company (CEET), which is US$0.14 for the social tranche, shows that this solution can help increase access to universal electricity service in rural areas.

In the study of Adetoro et al. (2023), Artificial bee colony (ABC), Genetic algorithm (GA) and PSO optimization techniques were adopted for the HRES sizing. The authors directly picked optimization approaches with the best performance and shortest operation time. It shows that PSO and GA converge to almost the same global minimum LCOE values. However, PSO performs better than GA in terms of convergence time.

The convergence curve of the proposed algorithm in this study to achieving the optimal result, illustrated in Fig. 17, compared with the results obtained in their study shows that the PSO algorithm is the best algorithm for the case study.

The proposed system is determined to reduce annual diesel usage by 98.95 %. This shows that the objective of reducing the running time of the genset and the operating costs has been achieved.

Moreover, the system guarantees a probability of loss (LPSP) of 0.15 %, demonstrating that service unavailability is virtually zero and that the solution meets the objective of guaranteeing continuity of service at telecoms operator sites.

In addition to the encouraging results obtained, the solution offers a number of advantages for both operators and the local population, which are summarized in Table 4.

8. Conclusions, limitations and outlook

In this study, a microgrid composed of a 14 kWC photovoltaic field, a 13 kVA generator and a 2000 Ah storage system was designed for a cell phone company facilities in Bapure, in the Togolese Republic. The designed microgrid is a stand-alone system whose aim is to supply uninterrupted electricity to operators' sites and electrify the low-income local community at very low cost. The daily energy demand of a typical site is calculated according to locality's solar irradiation data predicted by ANFIS, and the technical, economic, and environmental

```
Root simplex log...

Iteration    Objective       Primal Inf.    Dual Inf.     Time
    8956    2.3194028e+05   6.381239e+85   0.000000e+00   120s
    8957    2.3194028e+05   0.000000e+00   0.000000e+00   120s

Solved with barrier

Solved wiyh barrier
Solved in 8957 iterations and 120 seconds
Optima objective 2.3194028e+05
False
2024.04.29 20:41:00
F:\DOSSIER DKZ NOUVEAU\DOSSIER THESE\REDACTION MEMOIRE\PROGRAMME\Micro-Grids-master\MicroGrids_PSO_DADJIOGOU
non-concatenation axis is not aligned. a future version
of pandas will cahnge to not soort by default.
To accept the future behavior, pass sort=False.
To retain the current behavior and silence the worning, pass sort=True.
  sort=sort
Renewable nominal capacity is 15.0 kWC
Generator nominal capacity is 15 kVA
Batteery nominal capacity is 24.1 kWh
The LCOE is 0,0185  USD/kwh
The LPSP is 0,15 %
The MRF is 98,95 %
6.7 % Battery usage
The otimization took 120.0 seconds
Console IPython   Historique
```

Fig. 14. Results of simulation in Python.

Table 3
PSO results.

Parameters		Value
Output Results	LPSP (%)	0.15
	LCOE ($USD/kWh)	0.0185
	REF (%)	98.95

performances of the standalone system. The PSO algorithm was used to ensure a real-time intelligent management of the various sources constituting the microgrids and the two loads to be powered. Parameters including LPSP (Loss of power supply probability), LCOE (Levelized cost of electricity) and MRF (Maximum Renewable Factor) were calculated. The low cost of electricity (US$0.0185) obtained shows that this solution is a real opportunity to increase universal access to electricity for low-income populations in rural areas. Similarly, the MRF value 0,15 % reflects a significant reduction in operating costs associated with

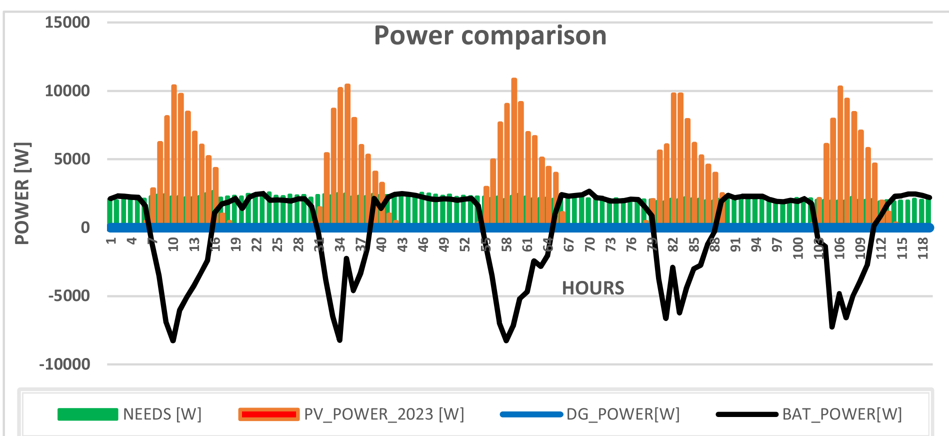

Fig. 15. Comparison of PV production and site energy requirements. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

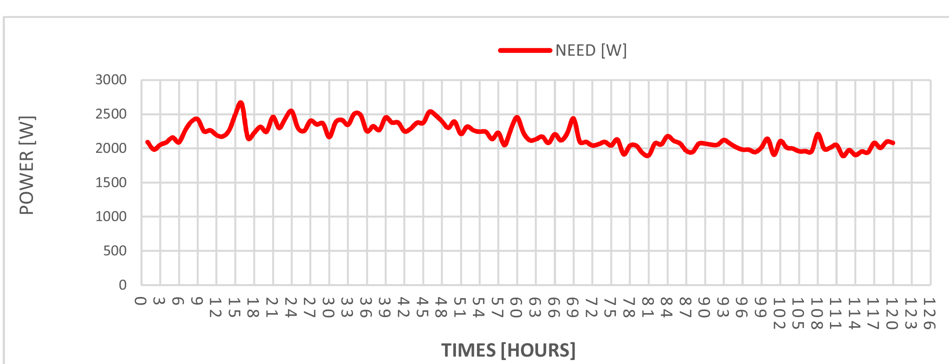

Fig. 16. Battery power variation curve for 72 h. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

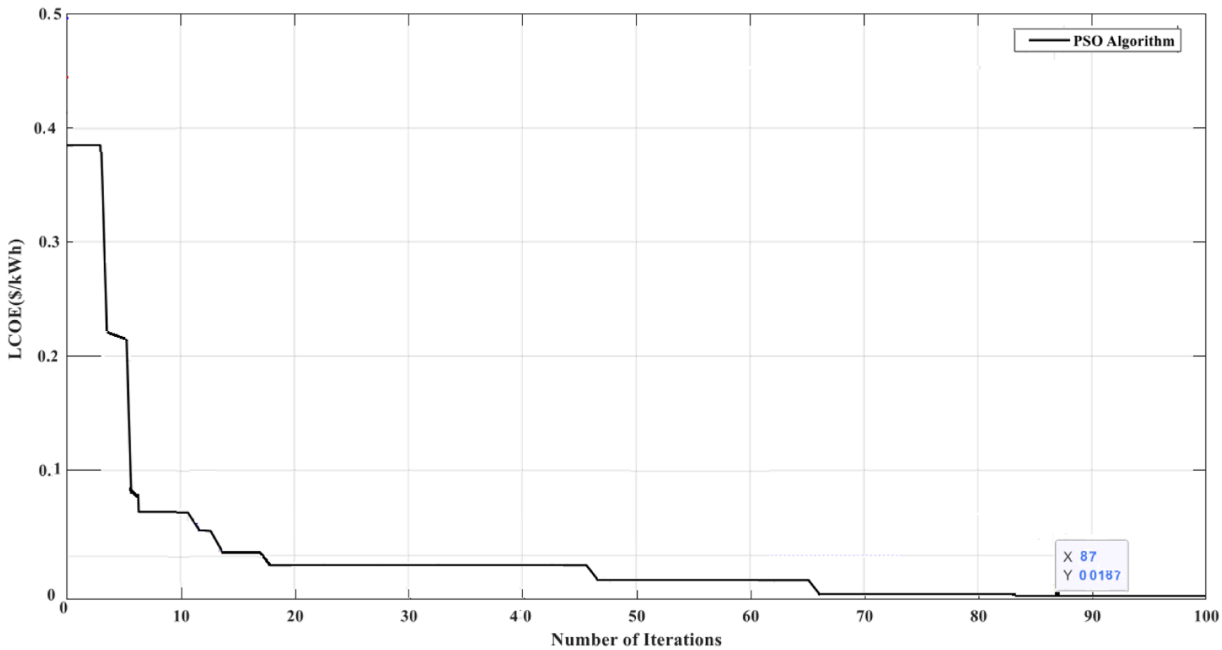

Fig. 17. Convergence rate of PSO algorithm.

Table 4
Advantages of the proposed solution.

Interested party	Advantages
Telecoms operators	• increased traffic; • provision of new service, particularly mobile money; • Increased the operator revenues through electricity billing; • reduction of system operating costs; • reduction of the service unavailability rate.
Local population	• construction of devices for recharging telephone batteries; • Possibility of household electrification through private subscriptions by the local population; • electrification of basic socio-community infrastructure (markets, health centers, boreholes, schools, etc.) located close to the grid; • public lighting.

generators and greenhouse gas emissions. In addition, it was proved that throughout the year, there is an overproduction of energy on the site which can be used to supply electricity to the local population. The power produced on the site can be easily increased depending on the demand from the local population. Extending this method to other sites can therefore significantly increase the share of renewable energies, in line with the target set by SDG 7.

This study provides the starting point of a real-time framework of energy trade between mobile operators and the local population in rural areas. Even though in this study, trade energy is not implemented pragmatically to analyze the behavior of consumer, the results show that microgrids could improve the quality of service for the telecommunications industries in rural areas. Also, to make effective this suggested solution, an agreement between the cell phone operators and the main distributors of electrical energy should be established. For e.g., in Togo, the regulation authorizes, through the Law N°2018–010 of August 8, 2018 and Decree No. 2019–021 of February 13, 2019, the production, distribution and marketing of renewable energy.

Future studies should focus on the transporting and distributing of the energy generated by microgrids from the operator's site to the local population. Research should also focus on implication of universal access to electrical energy on the revenues of mobile network operators, both in terms of the increase in the number of subscribers and traffic, and on the potential benefits from the sale of electricity.

CRediT authorship contribution statement

Kanlou Zandjina Dadjiogou: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ayité Sénah Akoda Ajavon:** Visualization, Validation, Supervision. **Yao Bokovi:** Visualization, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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