Resbee Publishers

Journal of Computational Mechanics, Power System and Control

Received 1 August, Revised 14 November, Accepted 3 December


# Optimizing Grid-Connected Photovoltaic (PV) Battery Energy Storage through Multi-Objective Ant-Lion Optimization (MOALO)

**Obi S. U.**

*Department of Electrical/Electronic Engineering*
*Faculty of Engineering*
*University of Port Harcourt*

**Uhunmwangho, R.**

*Department of Electrical/Electronic Engineering*
*Faculty of Engineering*
*University of Port Harcourt*

**Abstract:** As the demand for renewable energy continues to rise, it becomes crucial to discover effective ways to enhance grid-connected photovoltaic (PV) battery energy storage systems. The Institute of Petroleum Studies (IPS) complex at the University of Port Harcourt in Rivers State, Nigeria, embarked on a quest to determine the optimal approach for optimizing their PV battery energy storage system. This research aimed to fulfill this need by employing a diverse research methodology, incorporating the innovative MOALO theory. To begin with, the research gathered primary and secondary data to construct models for the power grid, solarPV, and battery. Furthermore, it meticulously analyzed the load profile of the IPS complex, at the University of Port Harcourt. Leveraging the power of the MOALO theory.The researchers accurately sized the system and evaluated the potential outcomes of simultaneously interconnecting all loads. To gauge the system's performance, there was a calculation of various parameters such as economics, random walk, boundary conditioning, entrapping ants, and ant trap development. Remarkably, the outcome showed that the fitness responses between the two trial runs, facilitated by the integration of MOALO, were strikingly similar, revealing a typical concave-connected shape, which is characteristic of a multi-objective solver. The optimal multi-objective cost implication of the system was estimated to be around 4,300 USD, with a power mismatch performance of approximately -1.7819e+09. Based on these compelling findings, the study concluded that MOALO serves as an impressive optimization tool capable of minimizing power mismatches and optimizing costs. Moreover, it recommended the generation of excess power as a means to achieve sustainability.

**Keywords:** Optimizing Grid-Connected Photovoltaic (PV), Battery Energy Storage, Solar Energy Systems, Multi-Objective Ant-Lion Optimization.

***Nomenclature***

| Abbreviations | Descriptions |
|---|---|
| PV | Photovoltaic |
| DER | Distributed Energy Resource |
| IPS | Institute of Petroleum Studies |
| MOALO | Multi-Objective Ant-Lion Optimization |
| BOS | Balance of System |
| GA | Genetic Algorithm |
| AC/DC | Alternating Current/Direct Current |
| RES | Renewable Energy Sources |
| DOD | Permissible Depth of Discharge |
| HMO-SAPSO | Hybrid Multi-Objective Simulated Annealing Particle Swarm Optimizer |
| PSO | Particle Swarm Optimization |
| USD | United States Dollars |
| AI | Artificial Intelligence |
| ALO | Artificial Lion Optimization |
| AVS | Automated Vehicle System |
| MPPT | Maximum Power Point Tracking |

# 1. Background to the Study

The increasing concerns about the environment have led to the popularity of PV solar energy systems[10], which are now considered DER. Among the different types of PV systems available, grid-connected PV battery energy storage systems have gained significant attention [4]due to their ability to store surplus energy from PV panels, which can be supplied back to the grid when needed. This technology is particularly important for public institutions that have high energy demands, such as the IPScomplex, University of Port Harcourt, Rivers State, Nigeria. Integrating solar energy into the grid poses a significant challenge due to its intermittent nature. Factors like seasonal changes and varying weather conditions can limit the performance of PV energy systems[18] [22], especially in regions with inconsistent and unreliable conditions. To address this issue, researchers have developed a metaheuristic algorithm called MOALO[8].

Inspired by the hunting behavior of antlions, this population-based approach strikes the perfect balance between multiple objectives to ensure optimal performance. By iteratively improving solutions, MOALO finds the optimal trade-off between objectives such as energy efficiency, cost, and environmental impact for grid-connected PV battery energy storage systems. The advantages of these systemsare eco-friendly, readily accessible, cost-effective, and noiseless. The optimization process involves determining the optimum capacity of PV panels, battery capacity, and control strategies that maximize energy efficiency, minimize costs, and reduce environmental impact.

## 1.1 Statement of the Problem

The scientific community worldwide has delved into the viability of solar energy systems, a prospect that has generated significant interest in the last few years. In Africa, stand-alone and grid-connected solar PV power systems have been the focus of research conducted on public higher educational institutions. Despite this, optimizing battery energy storage for grid-connected PV systems has proven a thorny issue, owing to myriad challenges such as erratic power supply from the national grid, financial implications, and environmental concerns from fossil fuel energy production. As a result, grid-connected solar PV has emerged as one of the most promising solutions to deal with these barriers. However, there have been unexpected failures, attributed to inconsistent natural phenomena, highlighting the need to strike a balance between electricity demand and supply while accepting solar energy's unpredictable nature. Determining the ideal size and configuration of battery storage systems remains crucial in enhancing their benefits and reducing operational costs in the IPS complex, University of Port Harcourt, Rivers State, Nigeria.

## 1.2 Aim and Objectives of the Study

This study was aimed at optimizing grid-connected PV battery energy storage through MOALOin the IPScomplex, University of Port Harcourt, Rivers State, Nigeria. Specifically, the objectives were to:

1. Ascertain the size of the panels and the BOS components required to measure the load demand for the IPS complex, University of Port Harcourt, Rivers State, Nigeria.
2. Determine the optimum size for the most demanding loading (peak-loading) condition(s) in the IPS complex, University of Port Harcourt.
3. Identify the "What-if" scenario if all loads are interconnected at the same time at the IPS complex, University of Port Harcourt.

## 1.3 Research Questions

1. What size of panels and BOS components are needed to measure load demand for the IPS complexat the University of Port Harcourt?
2. What size is ideal for peakloading under the most demanding conditions for the IPS complex atthe University of Port Harcourt?
3. What could be the potential consequences if all loads were interconnected simultaneously at the IPS complex, University of Port Harcourt?

# 2. Literature Review

Grid-connected PV systems, which are commonly known as grid-tied solar PVsystems[19], harness the sun's energy to generate electricity that can be linked to the utility grid. These systems contain multiple components such as solar panels, inverters, and efficient gadgets that join forces to translate gathered solar radiance into usable electricity[19]. Public institutions such as hospitals, government buildings, and schools have embraced the implementation of these systems to reduce their carbon footprint and achieve energy self-sufficiency[1]. In addition, battery energy storage makes use of excess electricity generated by the system, by storing it in a battery for later use. This offers a cost-effective and sustainable solution for managing energy surges and ensuring uninterrupted power supply.

Numerous studies have demonstrated that integrating battery storage with grid-connected solar-PV systems can result in significant cost savings[5], improved self-consumption rates[21],and reduced peak demand charges[6]. To maximize the efficiency and performance of this integrated system, optimization techniques like MOALO can be highly advantageous. For instance, a grid-connected PV system on a rooftop area was designed optimally using an analytical method in a study by [2]. The authors did not look at the grid-connected PV system life-cost analysis. Also, a grid-connected PV energy system optimal sizing for large-scale applications wascarried out. In the work conducted by [13], the GA was used to determine the optimal sizing of grid-connected solar systems to reduce the net present value. Howeverother goals were not taken into account during optimum sizing.[3] conducted a study that utilized MOALO to optimize the operation of a grid-connected PV system with battery energy storage in a public institution. The study yielded impressive results in terms of energy savings and self-consumption rate. In a similar vein, [14] explored the economic and environmental benefits of integrating battery energy storage with a grid-connected PV system in five climate zones. The researchers reported a significant reduction in dependence on fossil fuels and improved reliability and stability of the electrical grid infrastructure. Despite the growing attention towards the integration of battery storage with grid-connected solar-PV systems in recent years, more research is needed to address the gaps related to optimal sizing and the impact of various factors on system performance. Nonetheless, the integration of battery energy storage with grid-connected PV systems has tremendous potential to bolster the use of renewable energy sources across public institutions, reduce reliance on fossil fuels, and promote sustainability. In a nutshell, the MOALO approach and the integration of battery energy storage with grid-connected solar PV systems promise to revolutionize energy efficiency in public institutions and contribute to a more sustainable future.

## 2.1 Theoretical Framework

One theory for the theoretical framework foroptimizing grid-connected PV battery energy storage through MOALOwas proposed by[15].This theory averred that MOALO can be used to determine the optimal sizing of a grid-connected PV battery energy storage system by considering multiple objectives such as minimizing the cost, maximizing the reliability, and minimizing the environmental impact [15]. The theoretical application of this theory involves formulating a mathematical model that represents the PV battery energy storage system and its associated objectives. The MOALO algorithm is then applied to solve this multi-objective optimization problem, considering factors such as the size of the PV array, battery capacity, and inverter rating. By finding the Pareto-optimal solutions, which represent trade-offs between different objectives, this theory enables decision-makers to select the most suitable configuration for a grid-connected PV battery energy storage system.

## 2.2 Review Table

Table 1 portrays the objective, methodology, key findings, and contribution of the existing method. We considered eight papers that used a different methodology for the process. Each method has certain benefits and shortcomings that were explained in detail.

***Table 1:*** *Review Based on Existing Methods*

| Authors | Objective | Methodology | Key Findings | Contribution |
|---|---|---|---|---|
| **Belboul*et al.*, [3]** | Optimize hybrid energy systems with renewables, batteries, and generators. | Multiobjective optimization approach | The optimal configuration for the hybrid system included a combination of photovoltaic panels, wind turbines, batteries, and a diesel generator. | Provides insights into the optimal design and operation of hybrid PV/wind/battery/diesel generator systems integrated into microgrids. |
| **Nallolla*et al.*, [17]** | In-depth analysis of multi-objective optimization algorithms for hybrid AC/DC microgrids with RES. | Systematic literature review | Hybrid AC/DC microgrids optimized with successful multi-objective algorithms. | Enhancing AC/DC microgrid optimization with RES. |

| | | | | |
|---|---|---|---|---|
| **Shayeghi and Alilou [20]** | Develop a smart microgrid DSM approach balancing economy and environment. | Multi-objective optimization framework | Optimized load scheduling and demand response balanced trade-offs. | Optimizing microgrids with economic and environmental goals for sustainability and efficiency. |
| **Mohammad-Alikhani*et al.*, [16]** | Maximize AC mini-grid hybrid power efficiency through optimization. | Multiobjective genetic algorithm | The optimized approach found the best AC mini-grid hybrid power system. | AC mini-grid hybrid power system design with multiobjective optimization. |
| **Ghiasi [7]** | Efficiently analyze AC-DC smart microgrids with renewable energy resources. | A comprehensive methodology | Efficiently optimized AC-DC microgrid design with renewable energy. | Detailed study on multi-objective optimization for smart microgrids explained. |
| **Hafez*et al.*, [9]** | Determine the optimal sizing of an offline microgrid using anHMO-SAPSO. | Mixed research design | The HMO-SAPSO algorithm successfully optimized the sizing of an offline microgrid. | Introduced a hybrid optimization algorithm for sizing offline microgrids. |
| **Hemeida*et al.*, [11]** | Optimize a renewable energy sources-based microgrid system using a multi-objective multi-verse optimization algorithm. | Multi-verse optimization algorithm | The algorithm successfully optimized the design of a renewable energy sources-based microgrid system. | Established the concept of multiple universes for designing renewable energy-based microgrid systems. |
| **Hossain*et al.*, [12]** | Maximize home renewable power system size using multi-objective hybrid optimization. | Hybrid optimization approach | The hybrid optimization approach nailed the perfect sizing for home renewable power systems. | Introduced a hybrid optimization approach that combines GA and PSO techniques for sizing hybrid renewable power systems. |

### 2.3 Identified Research Gap

While there are existing studies on optimizing PV battery energy storage systems, the use of the MOALO algorithm for optimizing grid-connected PV battery energy storage systems hasnot been extensively explored in tertiary institutions in developing countries. By conducting research in this area, this study has contributed to the understanding of how the MOALO algorithm can be applied to optimize grid-connected PV battery energy storage systems in tertiary institutions in the developing world, potentially leading to improved performance, cost-effectiveness, and overall system efficiency.

## 3. Materials and Methodology

The successful evaluation of any renewable energy systemrequires that appropriate criteria of the chosen site be considered. Details are focused on power grid calculations, solar-PV calculations, battery model calculations, calculation of economics of the system and cost function presentation, random walk, boundary conditioning, sliding ants mimicking, entrapping the ants, ant trap development, ant capture and pit reconstruction, formulation and storage of elitist ants, finding the Pareto-optimal solution and archival storage (through improved distribution and decongesting of archives).

### 3.1 Power Grid Calculations

Generally, the power transferred to a given site may be expressed as [23]:

$$P_g(\tau)=\begin{cases} P_l(\tau)/\eta_r \;\; for\; V_{r,\min}\leq V_g\leq V_{r,\max} \\ 0, \qquad otherwise \end{cases} \tag{1}$$

Where,

$V_{r,\min}$ = minimum voltage of an interconnected AVS, V

$V_{r,\max}$ = maximum voltage of an interconnected AVS, V

$P_l$ = power demand load capacity response to sudden rise, kW

Vg = grid supply voltage, V

$\tau$ = hourly time within the year, 1, 2,…, 8760hr

$\eta_r$ = efficiency of the AVS

The energy drawn from the power grid can be computed as:

$$E_g(\tau) = P_g(\tau)\Delta\tau \tag{2}$$

$\Delta\tau$ = constant hourly time step.

## 3.2 Solar-PV Calculations

Solar energy is a highly intermittent source of energy and as such, the minimum and maximum possible power supply boundaries need to be identified for a given site. This can be achieved by considering primarily the solar irradiance at a given tilt angle and time of energy capture. The solar power obtainable for a given location can be expressed as [24]:

$$P_{pv} = N_s \times N_p \times V_{oc} \times I_{sc} \times FF \tag{3}$$

Where,

$P_{pv(rated)}$ = rated PV power, kW

$N_s$ = number of PV modules connected in series

$N_p$ = number of PV modules connected in parallel

$V_{oc}$ = open circuit voltage of single PV module at standard test conditions

$I_{sc}$ = short-circuit current of single PV module at standard test conditions

$FF$ = Fill factor of PV module

The parameters $V_{oc}$ and $I_{sc}$ may be computed as shown in Eqn8 and Eqn9 respectively:

$$V_{oc} = V_{oc(stc)} - K_v T_c \tag{4}$$

$$I_{sc} = \left(I_{sc(stc)} + K_i\left(T_c - 25\right)\right)G \tag{5}$$

$K_v$ = PV module open-circuit voltage temperature coefficient correction factor, V/oK

$K_i$ = PV module short-circuit current temperature coefficient correction factor, A/oK

$G$ = global solar irradiance, kW-hr/m2/day

$T_c$ = PV cell temperature, oK

The cell temperature $T_c$ , is influenced by ambient conditions and can be precisely estimated as:

$$T_c = T_{amb} + \left(0.0256 \times G\right) \tag{6}$$

$T_{amb}$ = ambient temperature, oK.

## 3.3 Battery Model Calculations

The battery model computations for the design of a storage bank are taken from the approach proposed in [25][26][27]. This model typically takes into account the energy demands for a given period (days of autonomy) without recourse to the use of a direct Solar-PV generation or the use of the Electric power grid:

$$C_{BAh} = \frac{E_{db} \times AD}{DOD \times \eta_{BAh} \times V_B} \tag{7}$$

Where,

$E_{db}$ = energy requirement from battery bank considering load demand, *kWh*
$AD$ = energy days of autonomy, *days*
$\eta_{BAh}$ = battery ampere-hour efficiency
$V_B$ = choice nominal voltage of battery block
$DOD$ = permissible depth of discharge of the battery.

## 3.4 Calculation of Economics of the System and Cost Function Presentation

The economics of the system borders on the cost in Naira or the equivalent dollar value to assure affordability investigations. As described in [28], the costing (capital cost) can be described as an objective (cost) function including the Solar-PV size costs, the Battery-bank size costs, and design installation costs as described below:

$$C = C_{pv} \cdot N_{pv} + C_{bat} \cdot N_{bat} + C_0 \quad (8)$$

Where,
$C_{PV}$ = unit cost of PV panel/module, USD
$C_{bat}$ = unit cost of a single battery, USD
$N_{pv}$ = number of series connected PV modules
$N_{bat}$ = number of batteries to form the bank
$C_0$ = total cost constant (design and installation costs), USD

Considering the model, it is expected that the AI optimizer evolves the parameters, $N_{pv}$ and $N_{bat}$ such that the total costs are minimized. The evolution process will involve randomly choosing the values within a set of upper and lower boundary constraints.

## 3.5 Random Walk

This is modeled as a cumulative sum of conditioned random numbers in an iterative loop at a time step, t as:

$$X(t) = \begin{bmatrix} 0, cumsum(2r(t_1)-1), cumsum(2r(t_2)-1), \ldots, \\ cumsum(2r(t_n)-1) \end{bmatrix}_{t=0:n} \quad (9)$$

Where,
$cumsum$ = a cumulative sum function
$n$ = maximum number of iterations of the ALO
$t$ = random number step (iteration step)
$r$ = a random number function

The stochastic function, $r$, can be obtained by the below stochastic function in rand, a random number function available in most programming languages:

$$r(t) = \begin{cases} 1, \; if \;\; rand > 0.5 \\ 0, \; otherwise \end{cases} \quad (10)$$

## 3.6 Boundary Conditioning

The ants may tend to overshoot their boundaries without control; however, they can avoid this situation by boundary control. To implement this feature, random walks are computed and normalized according to the formula below:

$$X_i^t = \frac{(X_i^t - a_i) \times (u_i^t - l_i^t)}{b_i - a_i} + l_i^t \quad (11)$$

Where,
$a_i$ = minimum (lower-bound) of random walk inith ant variable
$b_i$ = maximum (upper-bound) of random walk inith ant variable
$l_i^t$ = minimum of ith ant variable in t[th] iteration
$u_i^t$ = maximum of ith ant variable in t[th] iteration.

## 3.7 Sliding Ants Mimicking

Ants tend to slide into the ant-lions' pits and get trapped and hence eaten up by the ant-lions. To mimic this process, an adaptive decrease in the random walk boundaries should be performed. This is modeled as provided for the minimum and maximum ant variables respectively:

$$l^t = \frac{l^t}{I} \quad (12)$$

$$u^t = \frac{u^t}{I} \quad (13)$$

Where,

$I$ = a decrement ratio

The decrement ratio, I, is typically split into several sub-ratios to make the reduction process smoother. This process can be subsequently modeled using the equation below:

$$I = I + 10^w \frac{t}{T} \quad (14)$$

Where,

$T$ = maximum number of iterations

$w$ = an exploitation accuracy level adjustment factor

Typically, the parameter, w, is split into several uniform numeric values giving a set of uniform decrement ratios.

**Entrapping the Ants**

Ant-lions capture their prey (basically ants) by employing a mutation of random walks. This process can be modeled using the model equations for the minimum and maximum ant variables respectively:

$$l_i^t = Antlion_j^t + l_i^t \quad (15)$$

$$u_i^t = Antlion_j^t + u_i^t \quad (16)$$

Where,

$Antlion_j^t$ = position of the chosen j$^{th}$ ant-lion at t$^{th}$ iteration

## 3.8 Ant Trap Development

To ensure that the ants are captured effectively and with the highest possible accuracy, a fitness mechanism is necessary. In the ALO technique, this is achieved using a roulette wheel mechanism where the ant-lion(s) with the fittest values build bigger pits and hence attract more ants and are selected in the solution process

## 3.9 Ant Capture and Pit Reconstruction

To mimic the process of ant-lions catching and eating up their prey (mostly ants), it is normally assumed that when the ant(s) become fitter than the candidate ant-lion(s) i.e when they penetrate the sand in the antlion's pit, they can then be captured and eaten up by the corresponding ant-lion(s). The model describing this process is as shown in the equation below:

$$Antlion_j^t = Ant_i^t \qquad if\left(f\left(Ant_i^t\right) > f\left(Antlion_j^t\right)\right) \quad (17)$$

Where,

$Ant_i^t$ = position of the captured i$^{th}$ant at t$^{th}$ iteration

**Formulation and Storage of Elitist Ants**

Elitism plays a key role in evolutionary algorithms from which the ALO technique draws inspiration from. It occurs when best-fitted individuals are saved and carried over to subsequent generations.

In the ALO, this is modeled as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (18)$$

Where,

$R_A^t$ = Ant random walk selected by roulette wheel at t$^{th}$iteration

$R_E^t$ = Ant random walk around elite at t$^{th}$ iteration

### 3.10 Finding the Pareto-Optimal Solution and Archival Storage through Improving Distribution

Here, the ant-lions are selected from the archives solutions with the least populated neighborhood using the probability model:

$$p_i = \frac{c}{N_i} \tag{9}$$

Where,

$c$ = constant factor > 1

$N_i$ = number of solutions in the vicinity of the $i^{th}$ ant solution.

### 3.11 Finding the Pareto-Optimal Solution and Archival Storage through Decongesting Archives

Here, solutions are removed from the archive with the most populated neighborhood using the probability model:

$$p_i = \frac{N_i}{c} \tag{10}$$

In a constrained optimization problem, the decision (or solution) variable(s) are described as a finite position set with an upper bound (ub) and lower bound (lb) constrain i.e. their numerical values are strictly range-limited. These variables typically represent real-world or analytical parameters that form part of a model describing the process. In the multi-objective sense, it is necessary to have an Archive to keep track of best solution values as the iteration proceeds

### 3.12 Energy Data and Systems Specifications

The technical parameter specifications for the Solar-PV module and battery are as presented in Table 1 while that detailing the load appliances and their respective wattage, and the techno-economic evaluation of the Solar-PV grid-connected System, IPS complex, University of Port Harcourt are provided in subsequent Tables 2 in the results and discussions.

***Table 2:*** *Solar-PV and Battery Parameter ranges (Default Values)*

| Parameter | *Min. Value* | *Max. Value* | *Unit* |
|---|---|---|---|
| **Number of Parallel Connected PV Modules ($N_{pv}$)** | 1 | 196 | NA |
| **Global solar irradiance ( $G$ )** | 1 | *5* | *kW-hr/m²/day* |
| **Ambient Temperature ($T$)** | 24 | 27.3 | *°C* |
| **System Loading ($T_L$)** | 331.346 | 331.346 | KWh |
| **Autonomy Day ( $AD$ )** | 3 | *3* | *Days* |
| **Battery Ampere Hour Capacity, $C_{BAh}$** | 279 | *1156* | *A-h* |
| **Number of Parallel Connected Battery Units ( $N_{bat}$ )** | 1 | 438 | NA |

While other parameters in Table 1 are fixated, the parameters $N_{pv}$,$N_{bat}$, and $C_{BAh}$ are searched for by the MOALO algorithm. The parameter Npv is motivated by on-site hand (base) calculations of the Solar-PV system which amounted to a total of approximately 196 Solar-PV modules for a 24V, 350W, 14.58A unit Solar Panel/Module.

The parameter $N_{bat}$ is similarly motivated by on-site hand (base) calculations of the battery units in consideration, which amounted to 438 Battery units for a 24V Battery with a total ampere-hour capacity of 87656A-h.

## 4. Results and Discussions

### 4.1 Answers to Research Questions

**Research Question 1:** What size of panels and BOS components are needed to measure load demand for the IPScomplex, University of Port Harcourt?

The size of the panels and the BOS components such as solar charge controller, inverter, and battery that are deployed in the Solar-PV grid-connected system, IPScomplex, University of Port-Harcourt are determined by the following mathematical computations:

- **Solar Panel Sizing**

Recall:

Total power required for battery input = $\frac{\text{Total DC power required per day}}{\text{Battery efficiency}}$

But, the total DC power required for IPS Center, University of Port Harcourt = 331346Wh

Battery efficiency = 85%

∴ The total power required for battery input = $\frac{331346}{0.85}$

= 389818.8235

≅ 389819Wh

Required output power from panel per day = $\frac{\text{Total battery input power}}{\text{Controller efficiency}}$

Mostly, the controller has a higher efficiency of 95%.

∴ Panel output power = $\frac{389819}{0.95}$ = 410335.7895

≅ 410336Wh

Thus, solar panels should supply 410336Wh/day.

However, solar panel requirement = $\frac{\text{panel output power}}{\text{system voltage}}$

Since the panel output = 410336Wh/day and system voltage = 24V

Solar panel requirement = $\frac{410336}{24}$

= 17097.33333

≅ 17097Ah

But, sunlight available in the area = 6hrs

Amps required in panel = $^{\text{Ah}}/_{\text{h}}$

∴ Amps required in panel = $\frac{17097}{6}$

= 2849.5

≅ 2850A

In the market, we choose 24V, 350W, and 14.58A solar panels.

∴ No of panels required = $\frac{\text{Total Amps Required}}{\text{Panel Amps}} = \frac{2850}{14.58}$ = 195.473251

≅ 196

So, 196 Nos of 24V, 350Watts, 14.58A solar panels would be needed for the IPScomplex, University of Port Harcourt. The panels will be connected in parallel.

196 x 350W = 68600W or 68.6kW solar panels will be needed for the IPScomplex, University of Port Harcourt.

- **Solar Charge Controller Sizing**

Since 196nos of 24V, 350W, and 14.58A solar panels are required in the IPS complex, University of Port Harcourt.

∴ Total Watts = 350 X 196= 68600W

But system voltage = 24V

Since controller sizing = $\frac{\text{Total watt}}{\text{System voltage}} \times 1.25$

= $(\frac{68600}{24})$ x 1.25

= 2858.333333 x 1.25

= 3572.916666

≅ 3573Amps

So, 60 units of 60A MPPT controllers will be wired in parallel (i.e.$\frac{3573}{60}$ = 59.55) to be able to take care of 3573 Amps or 45 units of 80A MPPT controller will be wired in parallel (i.e. $\frac{3573}{80}$ = 44.6625) to be able to take care of the 3573 Amps.

- **Inverter Size**

Since the total wattage consumption = 200327W

The inverter value in VA = $\frac{200327}{0.8}$ (P.f. = 0.8)

= 250408.75 KVA

≅ 250KVA

Thus, the IPS complex, University of Port Harcourt needs an inverter unit of approximately 250KVA with a system voltage of 48V.

- **Battery size.**

Recall:

Total DC power required = $\frac{\text{Total watt-hou per day}}{\text{Inverter efficiency}}$

But, total watt-hour per day = 331346Wh

Inverter efficiency = 90%

= 0.9

∴ Total DC power needed = $\frac{331346}{0.9}$

= 368162.2222

≅ 368162Wh

Recall: Battery sizing (Ah) = $\frac{\text{DC power}}{\text{Battery voltage}}$

Battery sizing (Ah) = $\frac{368162}{24}$

= 15340.08333

≅ 15340Ah

Since battery DOD is 70% (lead acid) and 80% (lithium)

∴ Battery size = $\frac{15340}{0.7}$ = 21914.28571

≅ 21914Ah

Assuming the number of days the battery can supply without significant sun power (i.e. days of autonomy) = 3days

Since battery size with autonomy = days of autonomy x battery Ah/day

∴ Battery size with autonomy = 3 x 21914

= 65742Ah

Thus, the total battery size = battery size per day + battery size with autonomy

Required battery size = 21914 + 65742

= 87656Ah

Since the battery size available in the market = 24V, 200Ah lead acid battery, and the required battery size for IPS complex, University of Port Harcourt = 24V, 87656Ah.

∴ The number of batteries required = $\frac{87656}{200}$

= 438.28

≅ 438

Thus, the IPS complex, University of Port Harcourtwill require 438 Nos of 24V, 200Ah lead acid batteries, which are all connected in parallel.

- **Battery Size (without considering days of autonomy)**

Since the battery size available in the market = 24V, 200Ah lead acid battery.

Total DC power required/day = 368162Wh

∴ Battery size (Ah) = $\frac{368162}{24}$

= 15340.08333

≅ 15340

Since battery DOD = 70%

∴ The required battery Ah = $\frac{15340}{0.7}$

= 21914.28571

≅ 21914Ah

Thus, the number of batteries required = $21914/_{200}$

= 109.57

≅ 110

∴IPS complex, University of Port Harcourtwill require 110Nos of 24V, 200Ah batteries. And the connections are all in parallel.

**Research Question 2:** What is the optimal size using MOALO for peak-loading under challenging conditions for the IPS complex, University of Port Harcourt?

It can be observed that the maximum single loading occurred by the exterior security lighting at the IPS complex, University of Port Harcourtat a value of 16.6kWh. Also, the peak loading was due to combined appliances at a value of 305.358kWh.An approach considering primarily the peak demanding appliance for a particular duration of the day was applied to obtain an approximate load profile representation for the said site (IPS complex, University of Port Harcourt) as shown in Fig. 1.

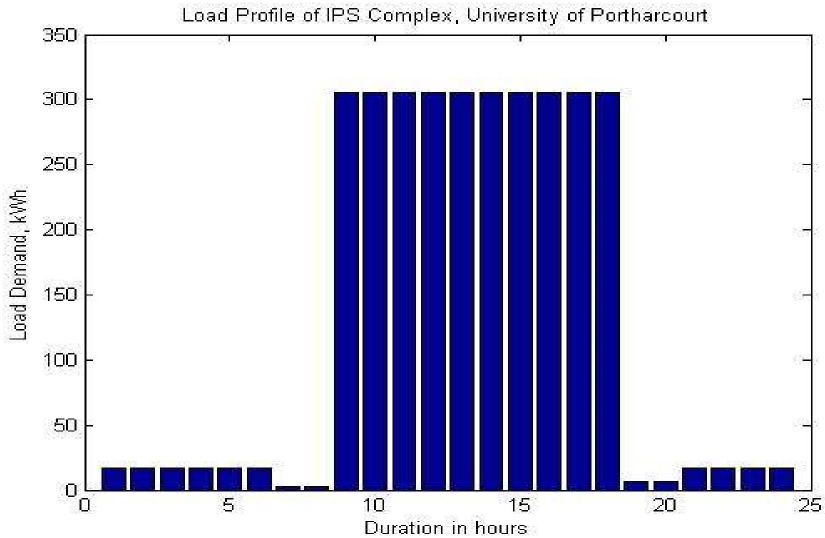


***Fig. 1.****Load profile of IPS complex, University of Port Harcourt*

In this part, the MOALO is used to obtain the key appropriate sizing – number of parallels connected Solar-PV modules, $N_{pv}$, number of parallel connected Solar Battery units, $N_{bat}$, and the estimate of the battery ampere-hour capacity, CBAh for the peak combined loading (Pdemand) of 305.358kWh as earlier defined. The boundary constraints are as earlier defined in the methodology.

Presented are the fitness responses considering the dual objectives f1 and f2, as shown in figures 2 and 3 for trial runs 1 and 2 respectively, at an irradiation level of 5000W/m2 and 100 iterations (100iters); these figures describe the property of competing objectives in a multi-objective optimization process; in the figures, f1 represents the mismatch in power demand-grid requirement for the Solar-PV and Battery power generation requirement while f2 represents the cost objective including the Solar-PV modules and Batteries. Sample numerical results are provided in Tables 3 and 4, while numerical results considering optimization parameters are presented in Table 5.In addition, fitness responses of the MOALO for the case of an irradiation level of 1000W/m2 are provided in Figures 5 and 6 for trial runs 2 and 3 respectively; the corresponding numerical values are presented in Tables 6 and 7, while the optimal parameter numerical results are as shown in Table 7.

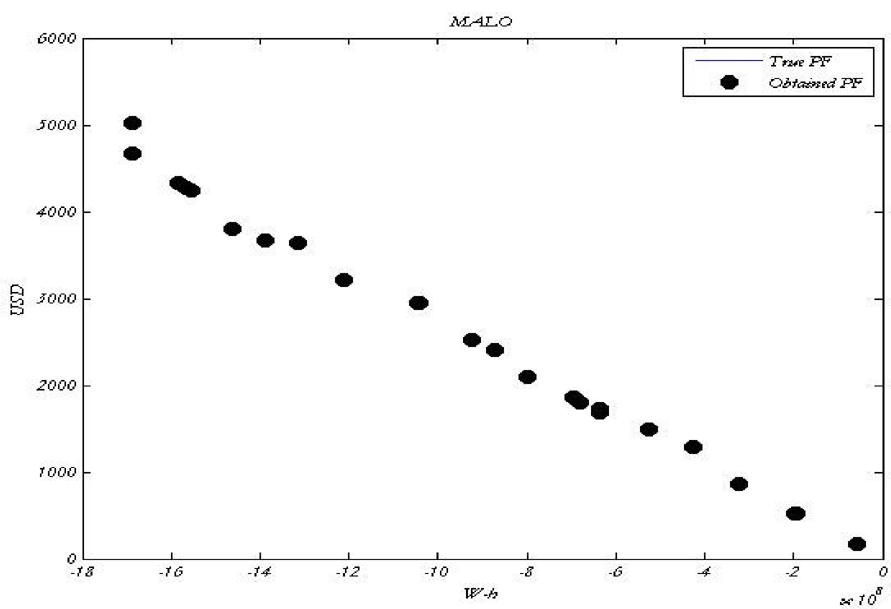


***Fig. 2.*** *Multi-objective solution of the first trial run, Irr = 5000W/m2,*

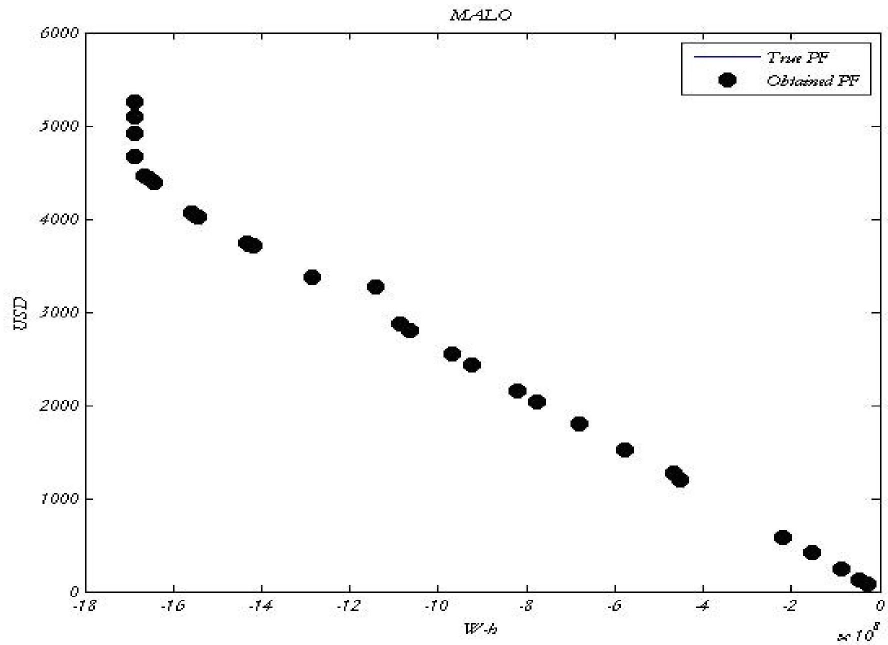


***Fig. 3.*** *Multi-objective solution of the second trial run, Irr = 5000W/m2*

***Table 3:*** *Sample Numerical of the first trial run, Irr = 5000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| **-1E+09** | 2946.92 |
| **-2E+09** | 4324.06 |
| **-1E+09** | 2946.40 |
| **-2E+09** | 4275.21 |
| **-2E+09** | 4241.64 |
| **-6E+08** | 1729.25 |
| **-3E+08** | 865.72 |
| **-3E+08** | 865.78 |
| **-3E+08** | 865.76 |
| **-3E+08** | 865.78 |
| **-3E+08** | 865.76 |
| **-9E+08** | 2403.20 |
| **-9E+08** | 2403.19 |
| **-9E+08** | 2403.19 |
| **-9E+08** | 2403.20 |
| **-9E+08** | 2403.20 |

***Table 4:*** *Sample Numerical of the second trial run, Irr = 5000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| **-3E+07** | 75.7226 |
| **-4E+07** | 123.243 |
| **-9E+07** | 236.838 |
| **-9E+08** | 2440.73 |
| **-1E+09** | 2547.95 |
| **-8E+08** | 2043.13 |
| **-8E+08** | 2043.17 |
| **-8E+08** | 2043.18 |
| **-8E+08** | 2159.5 |
| **-8E+08** | 2159.5 |
| **-3E+08** | 865.76 |
| **-2E+08** | 413.166 |
| **-2E+08** | 413.165 |
| **-2E+08** | 413.17 |
| **-2E+08** | 413.169 |
| **-2E+08** | 413.167 |

The data in Tables 2 and 3 reveal numerical information obtained from the first and second trial runs of power. This data was collected under specific conditions: Irr = 5000W/m2 (representing power per unit area) and 100iters (referring to the number of simulation steps). The Tables exhibit two columns, f1(W-h) and f2(USD). It seems that f1 denotes values in watt-hours (W-h), while f2 represents values in US dollars (USD). In the f1 column, watt-hours (W-h) measure the amount of electrical energy consumed or produced over time. Each row in the table represents a data point, with corresponding values in f1 and f2 columns. The f1 values range from -1E+09 to -9E+08, where the negative sign indicates negative energy values expressed in scientific notation (e.g., -1E+09 means -1 x 10^9). Conversely, the f2 values are positive and expressed in decimal notation.

***Table 5:*** *MOALO Optimization Results at, Irr = 5000W/m², $P_{demand}$ = 305.358kWh*

| Parameter | Optimized Value (Run1) | Optimized Value (Run2) | Unit |
|---|---|---|---|
| $N_{bat}$ | 209 | 371 | - |
| $N_{pv}$ | 1 | 1 | - |
| $C_{Bah}$ | **655** | **937** | **Ah** |

Results in Table 4 includetwo optimization runs, labeled Run1 and Run2, with optimized values for Nbat, Npv, and CBah. Nbat represents the battery count and remains at 209371 in both runs. Similarly, Npv, representing the PV panel count, remains constant. CBah, a cost-related metric, indicates better optimization with lower values. In Run1, CBah is 655937, with no change in Run2.

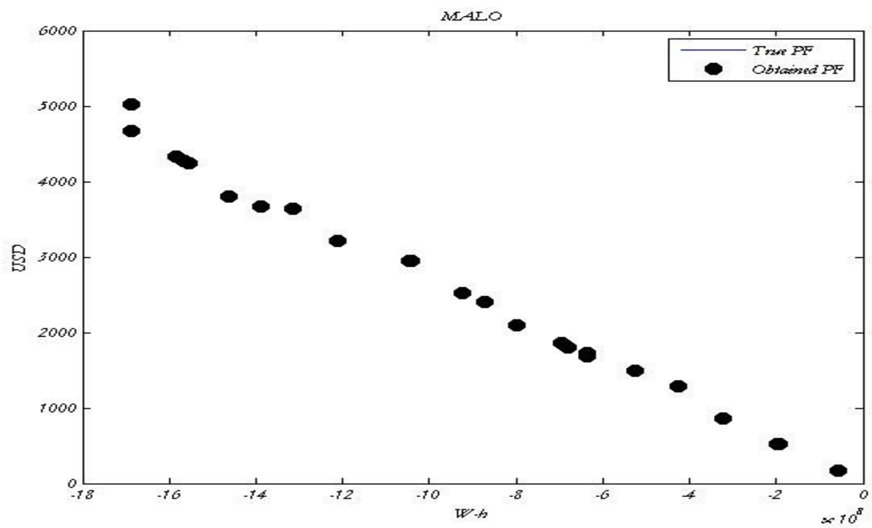


***Fig. 4.*** *Multi-objective solution of the first trial run, Irr = 1000W/m²*

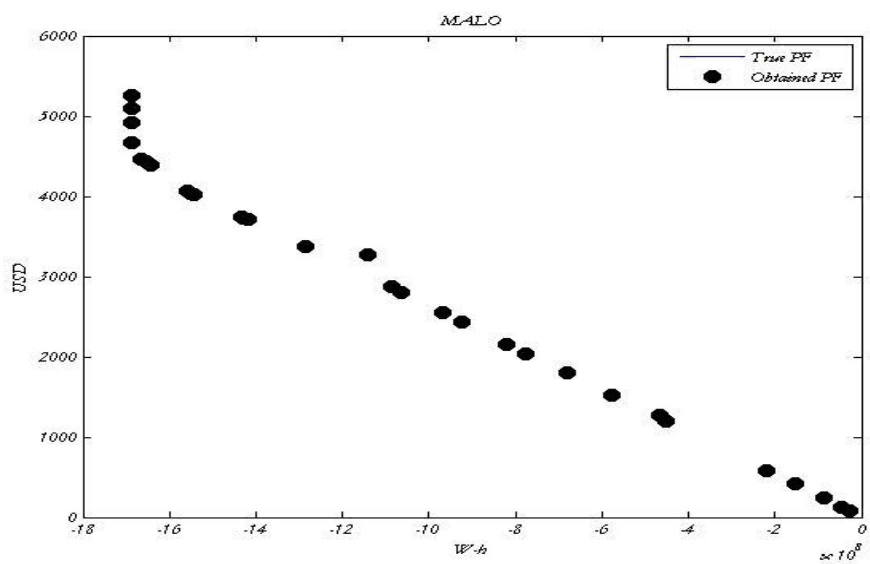


***Fig. 5***. *Multi-objective solution of the second trial run, Irr = 1000W/m²*

***Table 5:*** *Sample Numerical of the first trial run, Irr = 1000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| -1E+09 | 2946.92 |
| -2E+09 | 4324.06 |
| -1E+09 | 2946.40 |
| -2E+09 | 4275.21 |
| -2E+09 | 4241.64 |
| -6E+08 | 1729.25 |
| -3E+08 | 865.72 |
| -3E+08 | 865.78 |
| -3E+08 | 865.76 |
| -3E+08 | 865.78 |
| -3E+08 | 865.76 |
| -9E+08 | 2403.20 |
| -9E+08 | 2403.19 |
| -9E+08 | 2403.19 |
| -9E+08 | 2403.20 |
| -9E+08 | 2403.20 |

***Table 7:*** *Sample Numerical of the second trial run, Irr = 1000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| -3E+07 | 75.7226 |
| -4E+07 | 123.243 |
| -9E+07 | 236.838 |
| -9E+08 | 2440.73 |
| -1E+09 | 2547.95 |
| -8E+08 | 2043.13 |
| -8E+08 | 2043.17 |
| -8E+08 | 2043.18 |
| -8E+08 | 2159.5 |
| -8E+08 | 2159.5 |
| -3E+08 | 865.76 |
| -2E+08 | 413.166 |
| -2E+08 | 413.165 |
| -2E+08 | 413.17 |
| -2E+08 | 413.169 |
| -2E+08 | 413.167 |

***Table 8:*** *MOALO Optimization Results at, Irr = 1000W/m², $P_{demand}$ = 305.358kWh*

| Parameter | Optimized Value (Run1) | Optimized Value (Run2) | Unit |
|---|---|---|---|
| $N_{bat}$ | 209 | 371 | - |
| $N_{pv}$ | 1 | 1 | - |
| $C_{Bah}$ | **655** | **937** | **Ah** |

Table 8 presents the results of two optimization runs, referred to as Run1 and Run2. These runs focus on optimizing the values of Nbat, Npv, and CBah. Nbat represents the battery count, and it remains constant at 209371 in both runs. Similarly, Npv, which represents the PV panel count, also remains unchanged. The metric CBah, which is related to cost, indicates that lower values represent better optimization. In Run1, the CBah value is 655937, and there is no change in Run2.

**Research Question 3:** What are the possible outcomes of interconnecting all loads simultaneously using MOALO at IPS complex, University of Port Harcourt?

This part follows from the answer to research question 2, but with the loading increased to the total loading. The corresponding fitness responses considering an irradiation level of 5000W/m2 for the first and second trial runs are shown in Figures 6 and 7. The corresponding numerical sample values are shown in Tables 9 and 10, while the numerical optimization results are shown in Table 11.

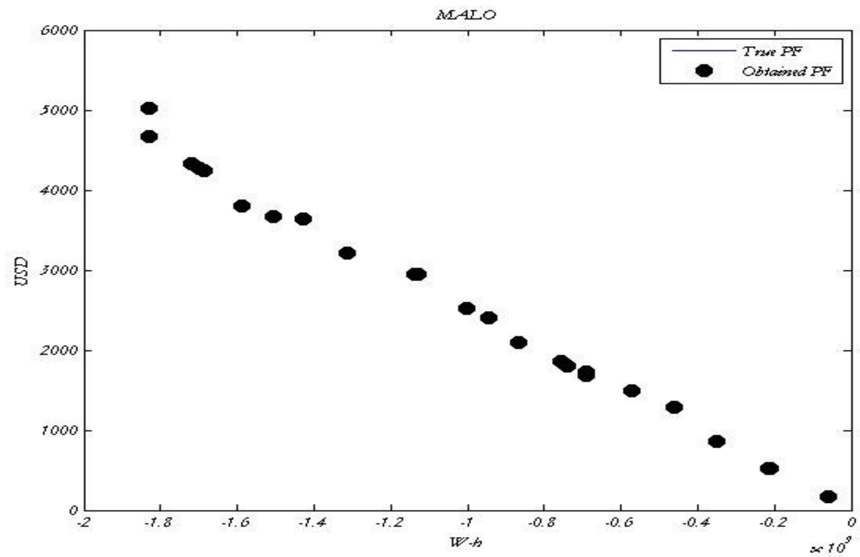


***Fig. 6.*** *Multi-objective solution of the first trial run, Irr = 5000W/m²*

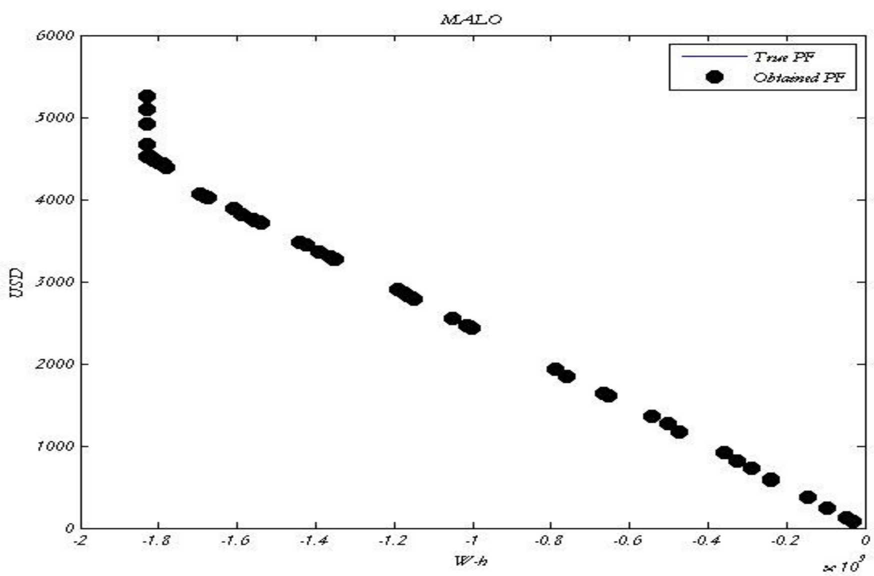


***Fig. 7.*** *Multi-objective solution of the second trial run, Irr = 5000W/m²*

***Table 9:*** *Sample Numerical of the first trial run, Irr = 5000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| **-1E+09** | 2946.92 |
| **-2E+09** | 4324.06 |
| **-1E+09** | 2946.40 |
| **-2E+09** | 4275.21 |
| **-2E+09** | 4241.64 |
| **-6E+08** | 1729.25 |
| **-3E+08** | 865.72 |
| **-3E+08** | 865.78 |
| **-3E+08** | 865.76 |
| **-3E+08** | 865.78 |
| **-3E+08** | 865.76 |
| **-9E+08** | 2403.20 |
| **-9E+08** | 2403.19 |
| **-9E+08** | 2403.19 |
| **-9E+08** | 2403.20 |
| **-9E+08** | 2403.20 |

***Table 10:*** *Sample Numerical of the second trial run, Irr = 5000W/m², 100iters*

| f1(W-h) | f2(USD) |
|---|---|
| **-3E+07** | 75.7226 |
| **-4E+07** | 123.243 |
| **-9E+07** | 236.838 |
| **-9E+08** | 2440.73 |
| **-1E+09** | 2547.95 |
| **-8E+08** | 2043.13 |
| **-8E+08** | 2043.17 |
| **-8E+08** | 2043.18 |
| **-8E+08** | 2159.5 |
| **-8E+08** | 2159.5 |
| **-3E+08** | 865.76 |
| **-2E+08** | 413.166 |
| **-2E+08** | 413.165 |
| **-2E+08** | 413.17 |
| **-2E+08** | 413.169 |
| **-2E+08** | 413.167 |

***Table 11:*** *MOALO Optimization Results at,Irr = 5000W/m², $P_{demand}$ = 331.346 kWh*

| Parameter | Optimized Value (Run1) | Optimized Value (Run2) | Unit |
|---|---|---|---|
| $N_{bat}$ | 209 | 159 | - |
| $N_p$ | 1 | 4 | - |
| $C_{Bah}$ | **655** | **554** | **Ah** |

The results of the MOALO optimization process are shown in the Table for possible outcomes of interconnecting all loads simultaneously using MOALO at the IPS complex, University of Port Harcourt. In this scenario, the solar irradiance is 5000W/m2, which means that the power received from the sun per unit area is 5000 watts per square meter. The power demand is 331.346 kWh. In Run 1, the optimization process used 209 batteries (Nbat), 1 photovoltaic (PV) panel (Np), and a battery bank capacity of 655 Ah (CBah). In Run 2, the optimized values for Nbat, Np, and CBah were 159, 4, and 554 Ah, respectively. Hence, achieving the goal of the optimization process to find the most efficient combination of batteries, PV panels, and battery bank capacity to meet power demand based on the extent of solar irradiance.

## 4.2 Discussion

Regarding the numerical results in Research Question 2 (Figures 2 and 3), it may be observed that the fitness responses between the two trial runs owing to MOALO's integration are roughly identical. They also exhibit a roughly linear Pareto-front with a concave-connected shape at the top; a typical characteristic of multi-objective problem solvers. Also, in Figures 4 and 5, a roughly linear profile is exhibited. The numerical results also differ in their estimation where for instance, with the irradiation and power demand parameter settings: Irr = 5000W/m2 and Pdemand = 305.358kWh, the estimated battery size is higher in trial 2 than in trial 1. Also, observed is the increase in the required battery ampere-hour capacity, CBAh for the second trial run when compared to the first. Similar patterns are also exhibited for the other parameter settings and in the second scenario. These variations in optimized parameters can be attributed to the stochastic nature of evolutionary computing algorithms making them a robust optimization tool. In particular, from the fitness responses of the various scenarios (Figures 4 to 7), it can be seen that the optimal multi-objective cost implication is around 4,300USD while the power mismatch performance is around -1.5846e+09 for Figure 4; -1.6422e+09 for figure 5 and -1.7000e+09 for Figure 6; -1.7819e+09for Figure 7 respectively. This implies the feasibility of providing excess power amounting to about 1.6GWh (Figures 4 and 5) and 1.7GWh (Figures 6 and 7) respectively to the power grid at reasonable cost per annum, which could be sold to the utility grid for profit.

## 4.3 Advantages and Disadvantages of Optimizing Grid-Connected PV Battery Energy Storage through MOALO

Optimizing Grid-Connected PV Battery Energy Storage through MOALO offers several advantages and disadvantages when compared to other multi-objective optimization techniques. Here are five of each:

i. **Enhanced convergence speed:** MOALO utilizes the concept of ant-lion optimization, which is inspired by the hunting behavior of ant-lion insects. This technique enables faster convergence towards optimal solutions compared to other optimization algorithms. The algorithm's ability to quickly identify promising regions in the search space can significantly reduce the computational time required for optimization.

ii. **Improved Economic Viability:** MOALO takes into account economic factors, such as the cost of PV panels, batteries, and energy storage systems. Optimizing these parameterscan help reduce the overall cost of grid-connected PV battery energy storage, making it more economically viable.

iii. **Optimal Battery Sizing:** MOALO considers multiple objectives, including battery capacity, to optimize the sizing of the battery in a grid-connected PV system. This ensures that the battery size is optimal for storing excess energy and minimizing energy wastage, leading to more efficient energy utilization.

iv. **Robustness and Reliability:** MOALO incorporates robustness and reliability factors into the optimization process. It can find solutions that are not only optimal under normal operating conditions but also resilient to uncertainties, such as changes in weather conditions or load demands. This enhances the grid-connected PV battery energy storage system's reliability and stability.

v. **Environmental Sustainability:** MOALO can consider environmental factors, such as reducing greenhouse gas emissions and minimizing the reliance on non-renewable energy sources. Optimizing the grid-connected PV battery energy storage systemcan contribute to a more sustainable and environmentally friendly energy solution.

### 4.4 Disadvantages of Optimizing Grid-Connected PV Battery Energy Storage through MOALO:

i. **Computational Complexity:** MOALO involves complex algorithms and calculations to evaluate multiple objectives simultaneously. As a result, it may require significant computational power and time to find optimal solutions. This can be a drawback, especially when dealing with large-scale grid-connected PV battery energy storage systems.

ii. **Sensitivity to Input Parameters:** The performance of MOALO can be sensitive to the selection of input parameters, such as the weightings assigned to different objectives. Suboptimal parameter settings may lead to suboptimal solutions. Thus, careful tuning and parameter selection are required to achieve the desired results.

iii. **Limited Real-World Application:** MOALO is a relatively new optimization technique, and its real-world application in grid-connected PV battery energy storage systems may be limited. Further research and validation are needed to establish its effectiveness and practicality in different scenarios.

iv. **Lack of Standardization:** Due to the novelty of MOALO, there may be a lack of standardized guidelines or benchmarks for evaluating its performance. This can make it challenging to compare the results obtained from MOALO with those obtained from other multi-objective optimization techniques.

**v.** **Expertise and Knowledge Requirements:** Implementing MOALO in grid-connected PV battery energy storage systems requires expertise and knowledge in both optimization techniques and renewable energy systems. The learning curve can be steep, and the availability of skilled personnel may be limited, posing a challenge for widespread adoption.

## 5. Conclusions and Recommendations

The investigation into optimizing grid-connected photovoltaic battery energy storage systems through MOALO has yielded a successful examination of severalobjectives. These include determining the required size for panels and BOS components, identifying the optimal size for peak-loading conditions, and testing various "What-if" scenarios. The numerical results indicate a linear response between trial runs, demonstrating the stochastic nature of evolutionary computing algorithms. Consequently, MOALO is a robust optimization tool capable of optimizing multi-objective cost implications and reducing power mismatch performance. The study also revealed that by generating an excess of 1.6-1.7 GWh of power per annum, organizations can offset their carbon footprint while earning a profit. Overall, this study serves as a foundation for large organizations aiming to create more sustainable operations while reducing reliance on non-renewable energy sources.

## Compliance with Ethical Standards

**Conflicts of interest:** Authors declared that they have no conflict of interest.

**Human participants:** The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

## References


[1] Y. M. E. Abdelsalam, “Development of a mobile application for grid-tied solar photovoltaic (PV) system design for residential buildings”, Journal of Mechanical, Civil and Industrial Engineering, Vol. 4, no. 2, pp.18-24, 2023.

[2] E. Y. Alhaddad and A. Alsaad, “Grid-connected photovoltaic power systems: domestic simulation and design in Kuwait (a case study of the public authority applied for education and training (PAAET))”, 2016.

[3] Z. Belboul, B. Toual, A. Kouzou, L. Mokrani, A. Bensalem, R. Kennel and M. Abdelrahem, “Multiobjective optimization of a hybrid PV/wind/battery/diesel generator system integrated in microgrid: A case study in Djelfa, Algeria”, *Energies*, Vol. 15, no. 10, pp. 3579, 2022.

[4] N. Debdouche, L. Zarour, H. Benbouhenni, F. Mehazzem and B. Deffaf, “Robust integral backstepping control microgrid connected photovoltaic System with battery energy storage through multi-functional voltage source inverter using direct power control SVM strategies”, Energy Reports, Vol. 10, pp. 565-580, 2023.

[5] M. R. Elkadeem and M. A. Abido, “Optimal planning and operation of grid-connected PV/CHP/battery energy system considering demand response and electric vehicles for a multi-residential complex building”, Journal of Energy Storage, Vol. 72, pp. 108198, 2023.

[6] B. rdenebat, D.Buyankhishig, S. Byambaa and N. Urasaki, “A study of grid-connected residential PV-battery systems in Mongolia”, Energies, Vol. 16, no. 10, pp. 4176, 2023.

[7] M. Ghiasi, “Detailed study, multi-objective optimization, and design of an AC-DC smart microgrid with hybrid renewable energy resources”, Energy, M. Vol. 169, pp. 496-507, 2019.

[8] A. Goli, A. Ala and M. Hajiaghaei-Keshteli, “Efficient multi-objective meta-heuristic algorithms for energy-aware non-permutation flow-shop scheduling problem”, Expert Systems with Applications, Vol. 213, pp. 119077, 2023.

[9] A. A.Hafez, A. Y. Abdelaziz, M. A. Hendy and A. F. Ali, “Optimal sizing of off-line microgrid via hybrid multi-objective simulated annealing particle swarm optimizer”, Computers & Electrical Engineering, Vol. 94, pp. 107294, 2021.

[10] B. Hamidinasab, H. Javadikia, F. Hosseini-Fashami, H. Kouchaki-Penchah and A. Nabavi-Pelesaraei, “Illuminating sustainability: A comprehensive review of the environmental life cycle and exergetic impacts of solar systems on the agri-food sector”, Solar Energy, Vol. 262, pp. 111830, 2023.

[11] A. M. Hemeida, A. S. Omer, A. M. Bahaa-Eldin, S. Alkhalaf, M. Ahmed, T. SenjyuandG. El-Saady, “Multi-objective multi-verse optimization of renewable energy sources-based micro-grid system: Real case”, Ain Shams Engineering Journal, Vol. 13, no. 1, pp. 101543, 2022.

[12] M. A. Hossain, A. Ahmed, S. R. Tito, R. Ahshan, T. H. Sakib and S. H. Nengroo, “Multi-Objective Hybrid Optimization for Optimal Sizing of a Hybrid Renewable Power System for Home Applications”, Energies, Vol. 16, no. 1, pp. 96, 2022.

[13] N. I. Ibrahim, F. A. Al-Sulaiman and F. N. Ani, “A detailed parametric study of a solar driven double-effect absorption chiller under various solar radiation data”, Journal of Cleaner Production, Vol. 251, pp. 119750, 2020.

[14] C. Li, D. Zhou and Y. Zheng, “Techno-economic comparative study of grid-connected PV power systems in five climate zones”, China. Energy, Vol. 165, pp. 1352-1369, 2018.

[15] S. Mirjalili, P. Jangir and S. Saremi, “Multi-objective ant lion optimizer: a multi-objective optimization algorithm for solving engineering problems”, Applied Intelligence, Vol. 46, pp. 79-95, 2017.

[16] A. Mohammad-Alikhani, A. Mahmoudi, R. Khezri and S. Kahourzade, “Multiobjective Optimization of System Configuration and Component Capacity in an AC Minigrid Hybrid Power System”, IEEE Transactions on Industry Applications, Vol. 58, no. 3, pp. 4158-4170, 2022.

[17] C. A. P. V. Nallolla, D. Chittathuru and S. Padmanaban, “Multi-Objective Optimization Algorithms for a Hybrid AC/DC Microgrid Using RES: A Comprehensive Review”, Electronics, Vol. 12, no. 4, pp. 1062, 2023.

[18] J. D. Osorio, S. Zea, A. Rivera-Alvarez, G. A. Patiño-Jaramillo, R. Hovsapian and J. C.Ordonez, “Low-temperature solar thermal-power systems for residential electricity supply under various seasonal and climate conditions”, Applied Thermal Engineering, pp. 120905, 2023.

[19] H. Samanta, A. Bhattacharjee, T. K. Barui, C. Bandyopadhyay, K. D. Bhattacharya, S. Sengupta and H. Saha, “A novel low-cost solution for mitigating the loss of power supply probability in grid-tied Solar PV systems during daytime grid-outage scenario”, International Journal of Renewable Energy Research, Vol. 13, no. 1, pp. 104-116, 2023.

[20] H. Shayeghi and M. Alilou, “Multi-Objective demand side management to improve economic and environmental issues of a smart microgrid”, Journal of Operation and Automation in Power Engineering, Vol. 9, no. 3, pp. 182-192, 2021.

[21] Z. Wang, M. B. Luther, P. Horan, J. Matthews, and C. Liu, “On-site solar PV generation and use: Self-consumption and self-sufficiency”, In Building Simulation, Tsinghua University Press,pp. 1-15, Apr. 2023.

[22] V. K. Yadav, J. Sarkar and P. Ghosh, “Thermodynamic, economic and environmental assessments of a novel solar-driven combined cooling and power system”, Journal of Cleaner Production, Vol. 402, pp. 136791, 2023.

[23] M. S. Okundamiya, J. O. Emagbetere and E. A. Ogujor, "Evaluation of various global solar radiation models for Nigeria", International Journal of Green Energy, Vol. 13, no. 5, pp.505-512, 2016.
[24] T. R. Ayodele, A. S. O. Ogunjuyigbe, K. O. Akpeji and O. O. Akinola, "Prioritized rule based load management technique for residential building powered by PV/battery system", Engineering science and technology, an international journal, Vol. 20, no. 3, pp. 859-873, 2017.
[25] M. A. Omar and M. M Mahmoud, "Design and simulation of a PV system operating in grid-connected and stand-alone modes for areas of daily grid blackouts", International Journal of Photoenergy, 2019.
[26] L. Olatomiwa, "Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities", Energy Reports, Vol. 2, pp. 141-146, 2016.
[27] M. S. Ismail, M. Moghavvemi and T. M. I. Mahlia, "Design of an optimized photovoltaic and microturbine hybrid power system for a remote small community: Case study of Palestine", Energy conversion and management, Vol. 75, pp. 271-281, 2013.
[28] R. Ayop, N. M. Isa and C. W. Tan, "Components sizing of photovoltaic stand-alone system based on loss of power supply probability", Renewable and Sustainable Energy Reviews, Vol. 81, pp.2731-2743, 2018.