Using Grey Wolf Optimization Algorithm and Whale Optimization Algorithm for Optimal Sizing of Grid-Connected Bifacial PV Systems

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Abstract*—The shift towards renewable energies is driven by the shortage of fossil fuels for electricity generation and the associated harmful impacts. Grid-connected PV systems are a reliable and effective choice for power production across different uses, making them a key player in the global renewable energy landscape. Consequently, the careful selection of components for these systems is a crucial and widely studied aspect in this area of research. This paper introduced using gray wolf optimization algorithm GWO & whale optimization algorithm WOA for determining the optimal number of grid - connected bifacial photovoltaic PV systems in Babylon Hilla. The considered factors included available space, desired energy production, radiation, dihedral factor, budget constraints, and grid connectivity requirements. The mathematical formulation of the problem and implementation details of the algorithms are presented. In addition, two cases studied are performed one for a residential area, and the other for a single house. The results demonstrated the efficiency and effectiveness of both algorithms in identifying optimal solutions for determining the size of systems in the area under study. However, the WOA surpassed the GWO in meeting the optimization criteria. The proper selection of these systems resulted in higher power generation, lower costs, improved energy management, and the advancement of sustainable solar energy solutions.

***Keywords*—Grid-Connected PV System; Bifacial PV Panels; Grey Wolf Optimization GWO; Whale Optimization Algorithm WOA; Net PRESESNT Value NPV.**

I. Introduction

The global demand for clean and sustainable energy has led to a rapid increase in the adoption of PV systems. Among these, bifacial PV technology has gained prominence for its unique ability to harness sunlight from both sides of the solar panel. Bifacial PV systems, shown in Fig. 1, are among the innovative and efficient technologies in PV production. Grid-connected bifacial photovoltaic (PV) systems have emerged as a promising solution for harnessing solar energy with higher energy yield compared to traditional PV systems. However, determining the optimal sizing for these systems is a complex task that requires many factors and variables to ensure optimal efficiency and performance. In this context, the use of nature-inspired optimization algorithms comes into play in improving the process of determining the optimal size of PV systems. Bifacial PV systems stand apart from conventional mono-facial systems due to their capacity to capture sunlight from both the front and back of the solar panels. The extra irradiance from the rear side can substantially enhance the power output of a PV system, underscoring the importance of accurately sizing the system to optimize energy yield. Designing a bifacial PV system necessitates considering various factors, including the ideal tilt angle, albedo, and shading effects [1].

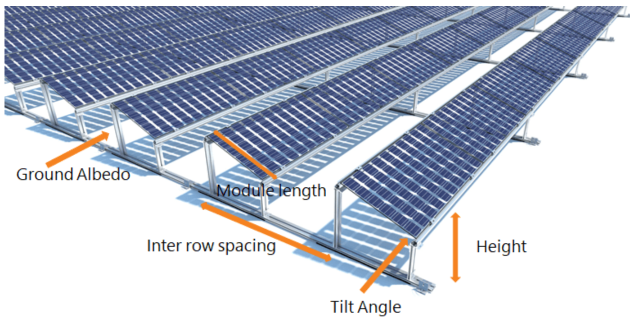

Fig. 1. Bi-facial power plant

Bifacial PV systems technology is recognized as a cutting-edge innovation in the PV power industry. Recent advancements include improved installation methods, enhanced productivity, and the utilization of graphic analysis and artificial intelligence to optimize performance and sizing. This technology is continuously evolving, solidifying its position as a reliable solution for sustainable power generation. When working with bifacial PV systems, the most crucial factors to consider are the bifacial factor and back side radiation. The bifacial factor indicates how well PV cells can capture solar radiation from both the front and back. Essentially, bifacial solar cells can harness energy from both sides of the sun, boosting their efficiency and output. Back-side radiation refers to the sunlight that reaches the back of bifacial solar modules. This radiation is utilized to enhance the productivity of bifacial photovoltaic systems, as it is converted into electrical energy by solar cells on both sides. Leveraging back-side radiation increases system throughput and efficiency, making it a compelling choice for sustainable energy generation.

To size a bifacial PV system optimally, one must consider both the front and rear-side irradiance. It should analyze site-specific conditions, such as latitude, climate, terrain, and shading, to estimate annual irradiance values accurately. Additionally, adopting appropriate tilt angles and albedo levels can further optimize the energy gain from both the front and rear side of the panels, leading to increased output and system efficiency [1], [2].

To optimize the performance of the grid-connected PV systems and ensure efficient energy utilization, it is crucial to determine the optimal sizing of PV systems. This literature review aims to explore the existing research on the optimal sizing of grid-connected PV systems, focusing on key aspects such as system capacity, inverter sizing, and energy storage solutions. By analyzing the insights gained from previous studies, this review aims to contribute to the informed decision-making process regarding PV system sizing [3], [4].

The capacity of a grid-connected PV system is primarily influenced by factors like household electricity usage, solar irradiation levels in a specific location, and the available roof area for PV panel installation. Various studies have suggested mathematical models and optimization algorithms to determine the most suitable system capacity. In [5] a research is conducted by using a hybrid algorithm that combines genetic algorithm and the Big Bang-Big Crunch algorithm to optimize the PV system capacity in terms of energy yield and return on investment. These studies provide valuable information for accurately sizing PV systems to maximize energy generation.

A novel approach is introduced in [6] to optimize the dimensions of grid-connected bifacial PV systems. Their method utilizes a hybrid meta-heuristic algorithm and takes into account a range of technical and economic considerations, such as system efficiency, energy generation, and cost. The study offers valuable insights on how to effectively size key components like PV panels, inverters, and cables in order to enhance overall system performance and economic feasibility.

The inverter has a vital role in grid-connected PV systems as it converts the DC output from PV panels into AC suitable for the grid. It is crucial to size the inverter optimally to ensure efficiency and prevent power losses. Different approaches have been proposed, including maximum power point tracking, dynamic voltage regulation, and grid voltage stability. An intelligent algorithm based on particle swarm optimization is introduced in [7] to determine the optimal inverter size and minimize grid voltage fluctuations. Understanding these techniques can aid in accurately sizing inverters and enhancing the reliability and performance of grid-connected PV systems.

An optimal inverter sizing method for bifacial PV systems considering environmental factors, system temperature, and solar radiation, resulting in enhanced system performance and reliability is proposed in [8]. Integrating energy storage systems (ESS) with bifacial PV systems can boost overall system efficiency and address the intermittent nature of solar energy generation. Properly sizing batteries in grid-connected bifacial PV systems ensures dependable storage capacity and improved system stability. In addition, a study is conducted in [9] to examined the combined approach of sizing bifacial PV arrays and lithium-ion batteries to maximize financial gains while minimizing energy losses.

Additionally, another solution is proposed in [10], this solution utilized a hybrid optimization algorithm, that combines particle swarm optimization and adaptive simulated annealing. This research highlights the importance of accurately sizing energy storage in grid-connected PV systems to enhance load management and promote greater energy self-sufficiency.

Ensuring the maximum power generation potential of a bifacial PV array relies heavily on its optimal sizing. Numerous studies have investigated the influence of different factors on system performance, such as tilt angle, azimuth angle, and module spacing. According to [11], an optimized tilt angle can greatly enhance the energy yield of a bifacial PV array, leading to an overall output increase of up to 27.5% through effective utilization of the rear side. A comprehensive examination of the ideal dimensions and design factors for grid-connected bifacial PV systems is conducted, the study delves into the different elements at play, encompassing PV panels, inverters, mounting systems, and balance of system components. Additionally, the paper emphasizes the significance of incorporating shading, rear-side irradiance, and bifacially factor into the sizing procedure.

The study presented in [12], that specifically addresses the optimal sizing of grid-connected bifacial PV systems, taking into account the distinctive features of bifacial modules. Their proposed mathematical model incorporates the rear-side irradiance and bi-faciality factor to determine the most suitable sizing for PV panels and inverters. Additionally, the study also examines the impact of different tilt angles and shading on the overall performance of the system [12].

The ideal dimensions for bifacial PV systems in residential settings is explored in [13]. Various factors are examined including energy requirements, roof space availability, and cost analysis, to provide a comprehensive approach. The researchers introduce a methodology that considers the unique attributes of bifacial modules, such as rear-side irradiance and bi-faciality factor.

In addition to the technical factors, the sizing of components in grid-connected bifacial PV systems also takes into account economic optimization. Numerous research studies have concentrated on maximizing return on investment (ROI) and minimizing the payback period. These studies consider factors such as installation costs, maintenance expenses, and feed-in tariffs [15].

Furthermore, apart from these studies, numerous research papers delve into the ideal dimensions of separate elements like PV panels, inverters, and mounting systems in traditional PV systems. Although these studies may not directly focus on bifacial PV systems, they offer valuable perspectives on the factors that should be taken into account while determining the size of these components. Maximizing energy yield, optimizing system performance, and achieving economic viability are all dependent on the optimal sizing of grid-connected bifacial PV system components [16].

Extensive literature on this subject highlight the significant impact of factors such as array configuration, inverter sizing, energy storage integration, and economic optimization on overall system efficiency. However, further research is needed to create comprehensive sizing models that consider local conditions and objectives, providing guidance for decision-making during the design and implementation of bifacial PV systems.

Bifacial PV systems are among the innovative and efficient technologies in PV production. However, determining the optimal sizing for these systems is a complex task that requires many factors and variables to ensure optimal efficiency and performance. In this context, the use of nature-inspired optimization algorithms such as the Gray Wolf Optimization Algorithm (GWO) and the Whale Optimization Algorithm (WOA) comes into play in improving the process of determining the optimal size of PV systems. Based on the above, the research delves into the impact, benefits, and efficacy of utilizing both GWO and WOA on the efficiency and cost of operating photovoltaic energy systems.

The study seeks to introduce a contemporary and efficient method utilizing GWO and WOA to enhance the efficiency of photovoltaic energy systems, with a focus on bifacial systems. It offers a novel framework for determining the ideal size of these systems through nature-inspired optimization algorithms. Two case studies will be conducted using these algorithms: one for powering a residential area and another for supplying electricity to a home in Babylon Governorate, Iraq.

The contributions of the paper are summarized as follow:

- Highlighting the requirements and steps for determining the optimal size of grid-connected PV systems.
- Using both GWO & WOA algorithm to determine the optimal size of PV system components by minimizing NPV and maximizing LPSP.
- Applying the proposed algorithms to two case studies, the first a residential neighborhood in the city of Babylon, and the second a single house.

The rest of this paper is organized as follows: section 2 presents an optimal sizing of grid-connected bifacial PV systems requirements. Section 3 shows the basic components required for optimal sizing. Section 4 presents the basic components required for optimal sizing. Section 5 presents the techno-economic analysis of sizing grid-connected PV systems. Section 6 presents the studied system. Finally, section 7 concludes the paper.

II. Optimal Sizing of Grid-Connected Bifacial PV Systems Requirements

The optimal sizing of grid-connected bifacial PV systems requires careful consideration of various components including PV panels, inverters, mounting systems, DC/AC cables, and balance of system components. Factors such as available space, desired energy output, budget, rear-side irradiance, bi-faciality factor, maximum power output, grid connection requirements, wind load, tilt angle, shading, current carrying capacity, voltage drop, distance between components, and system design and requirements should all be taken into account [17], [18].

To determine the optimal sizing, it is recommended to perform a detailed techno-economic analysis using software tools or seek assistance from solar energy professionals. When determining the optimal sizing of these components, several factors must be considered. These factors include the available space for installation, which will determine the number and size of PV panels that can be used. The desired energy output of the system will also play a role in determining the number and size of PV panels needed. Additionally, the available budget will influence the selection of components and their sizes. The amount of irradiance received by the rear side of the bifacial PV panels will affect their performance and should be taken into account when sizing the system [19].

Lastly, the bifaciality factor, which measures how effectively the rear side of the bifacial PV panels converts sunlight into electricity, should also be considered in the sizing process. Consideration should be given to shading, as it can decrease the energy output of the PV system. The sizing of the system should take this into account. Ensure that the current carrying capacity of the DC/AC cables is adequate to handle the generated current from the PV panels and its delivery to the grid [20].

Efficient power transmission requires minimizing the voltage drop in the DC/AC cables. To optimize system performance and minimize power losses, the distance between PV panels, inverters, and other components should be taken into consideration. Consider the distance between PV panels, inverters, and other components to minimize power losses and optimize system performance. Take into account the overall system design and specific requirements, such as backup power or energy storage, when sizing the components [21].

III. Basic Components Required for Optimal Sizing

To optimize the size of grid-connected bifacial PV systems, it is crucial to determine the appropriate sizing for different components in order to maximize performance and energy generation. The following factors should be taken into account [22], [23]:

1. PV Panels: The size of PV panels should be determined based on available roof or ground space, desired energy output, and budget. Since bifacial PV panels can generate electricity from both sides, their sizing should also consider the expected rear-side irradiance and the bifaciality factor.

2. Inverter: The inverter plays a crucial role in converting the DC power generated by the PV panels into AC power for grid connection. The sizing of the inverter depends on factors such as the maximum power output of the PV panels and the specific requirements of the grid connection.
3. The mounting system is responsible for securing the PV panels in place. It is crucial to take into account factors such as wind load, tilt angle, and shading when determining the appropriate size for the mounting system.
4. When selecting the size of the DC and AC cables, it is important to consider the current carrying capacity, voltage drop, and the distance between the PV array and the inverter.
5. Balance of System (BOS) Components encompass various electrical components, including fuses, breakers, combiner boxes, monitoring systems, and other necessary components for the safe and efficient operation of the PV system. The sizing of these components is dependent on the specific design and requirements of the system.

In order to find the best size for these components, it is recommended to conduct a thorough techno-economic evaluation that takes into account factors like energy needs, solar resources, efficiency losses, and financial considerations. This evaluation can be carried out using specialized software or by seeking guidance from solar energy experts who can offer precise simulations and suggestions tailored to your project's needs.

IV. Basic Components Required for Optimal Sizing

Sizing a grid-connected bifacial PV system involves several crucial steps which are [24], [25], [26]:

- The assessment of available space is necessary to determine the number and size of PV panels that can be accommodated.
- The identification of the desired energy output helps in determining the required number and size of PV panels.
- Budget considerations play a significant role in selecting components and their sizes.
- Evaluating the amount of irradiance received by the rear side of bifacial PV panels is essential as it impacts their performance.
- The bifaciality factor, which measures the effectiveness of the rear side in converting sunlight into electricity, should also be taken into account.
- The maximum power output of the panels and inverters should be assessed to ensure compatibility and the ability to deliver the desired energy output.
- Grid connection requirements, such as voltage and frequency, should also be taken into consideration.
- Wind load in the installation area should be evaluated to select appropriate mounting systems.
- The optimal tilt angle for the PV panels should be determined to maximize energy output.
- Shading from nearby objects or structures should be considered, as it can reduce the energy output.
- The current carrying capacity of the cables should be assessed to handle the generated current.
- Minimizing voltage drop in the cables is also important for efficient power transmission.
- The distance between components should be considered to minimize power losses.
- System design and specific requirements, such as backup power or energy storage, should be taken into account.

By following these steps, a properly sized grid-connected bifacial PV system can be achieved, considering various factors and optimizing its performance. An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

PV load is the amount of electrical power consumed by a photovoltaic system, typically measured in kilowatts (kW) or megawatts (MW). Monitoring and managing this parameter are crucial for optimizing system performance and efficiency. Factors such as solar panel size and orientation, weather conditions, and connected appliances can influence PV load. Accurately defining PV load is essential for designing, installing, and operating photovoltaic systems efficiently and sustainably.

Energy storage is an essential element in the shift towards a sustainable and dependable energy system. It involves the methods and technologies used to capture and retain energy for future use. This enables the effective management of renewable energy sources like solar and wind, which can be inconsistent. Energy storage systems are crucial for balancing supply and demand, optimizing energy usage, and enhancing grid efficiency. By storing surplus energy during low-demand periods and releasing it during peak times, energy storage helps stabilize the grid and decrease dependence on fossil fuels.

V. Techno-Economic Analysis of Sizing Grid-Connected PV Systems

The analysis of sizing grid-connected PV systems is crucial for sustainable energy development. It is necessary to assess the cost-efficiency and performance of PV systems as renewable energy sources become more prominent. This essay explores the factors involved in this analysis and its significance in the broader context of energy transition. By examining the technical and economic aspects of sizing, this essay aims to provide a comprehensive understanding of the topic [28]. PV system sizing is vital in determining its performance and electricity generation capacity for meeting energy demands. The size of a grid-connected PV system directly influences the amount of electricity generated and its potential for meeting the energy demands of a particular location [29].

To begin with, PV system sizing plays a pivotal role in determining its overall performance. The size of a grid-connected PV system directly influences the amount of electricity generated and its potential for meeting the energy demands of a particular location. Accurate sizing is crucial to ensure optimal utilization of available resources and maximize the system's output. Various factors, such as solar irradiation, location, and system efficiency, need to be considered while determining the appropriate system size [30]. Moreover, sizing also involves selecting the optimal number and arrangement of PV modules, which must align with the requirements of the end-user [29], [30].

In addition to technical considerations, an economic analysis must be conducted to determine the feasibility of grid-connected PV systems. The cost of PV modules, inverters, balance of systems, installation, and maintenance all factor into the techno-economic analysis. By evaluating the upfront costs, operating expenses, and potential revenues generated by the system, an accurate financial assessment can be made [31]. This analysis also includes estimating the system's return on investment (ROI), payback period, and net present value (NPV). These financial indicators provide valuable insights into the long-term viability and profitability of the PV system [32].

The examination of the techno-economic factors also takes into account the various incentives and regulations associated with grid-connected PV systems. Many nations have introduced feed-in tariffs, tax credits, and other forms of support to encourage the use of renewable energy. These incentives can greatly impact investment choices and the overall economic viability of the system [33]. Hence, it is crucial to possess a thorough comprehension of the present policies and regulations in order to conduct a precise techno-economic analysis. This analysis can aid policymakers in evaluating the effectiveness of current incentives and identifying possibilities for improvement or alteration [34].

Moreover, properly analyzing the technology and economics of grid-connected PV systems is essential for driving the global energy transition. PV systems are crucial in reducing reliance on fossil fuels and decarbonizing the electricity industry [35]. By accurately sizing these systems, policymakers can seamlessly integrate them into the current grid infrastructure while maintaining stability and avoiding excessive expenses [36]. Furthermore, the economic analysis offers valuable insights into the competitiveness of PV systems compared to traditional energy sources. This analysis assists governments and businesses in making well-informed choices regarding future investments in renewable energy [36], [37].

VI. The Studied System

A. The Main Goal of Studied System

The primary objective of this system is to propose an optimization method that not only identifies the ideal configuration and size of a grid connected PV system, but also determines the most efficient power flow management. This is aimed at improving the profitability, reliability, and feasibility of the system over a 20-year research period. The sizing decisions involve determining the number of PV panels, batteries, and inverters, as well as the amount of energy purchased from the electrical network, energy injected into the grid, and electricity tariffs for a 24-hour duration. The key goals of this study are to minimize the net present value of the cost PW and the loss of power supply probability LPSP. PW and the loss of power supply probability LPSP.

The aim of developing a power flow management optimization is to improve the system's feasibility and reliability in meeting load demands at any given time. Previous studies on sizing optimization have not adequately addressed the improvement of system feasibility, and this aspect is often overlooked [38].

In Hilla - Babil, Iraq, a study was conducted on a residential area comprising 96 houses with an average capacity of 141 kwh/day. The area is powered by a photovoltaic farm connected to the network. Fig. 2 illustrates a simplified diagram of this photovoltaic system connected to the network. The capacity of the system supplying this residential area is 2.5 MW. 141kwh/day.

Fig. 3 displays the load curve of the residential area that is being powered by the photovoltaic farm.

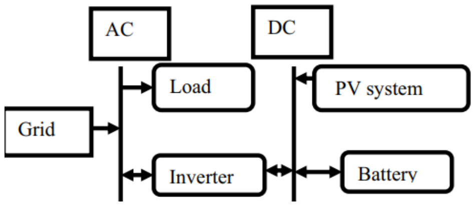

Fig. 2. A farm PV system connected to the power grid

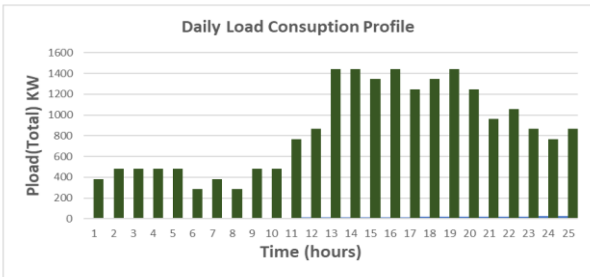

Fig. 3. The load curve of the residential area

The research also encompassed an analysis of a solitary residential load, specifically a single house, to fulfill the daily needs of the dwelling according to the preferred components. These discoveries will be showcased in a sequential manner. The load pattern for a single day is depicted in Fig. 4.

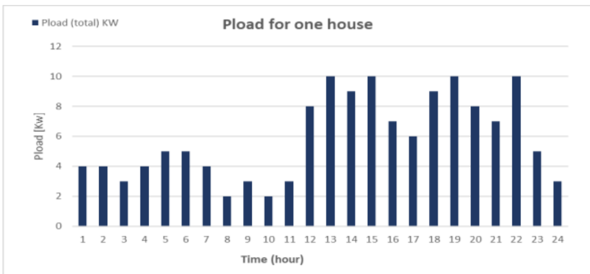

Fig. 4. The load curve for one house

B. Selection of the Studied System Component

The average house demand:

$$5\ Kw * 24 = 120\ \frac{Kwh}{day} \quad (1)$$

The average demand of studied residential area:

$$5\ \text{Kw} * 96 = 480\ \text{Kw} \quad (2)$$

$$120 * 96 = 11520\ \frac{Kwh}{day} \quad (3)$$

$$N_{PV} = \frac{P_{PV-MAX}}{P_{one-pv}} = \frac{480\ Kw}{0.55\ Kw} = 874\ module \quad (4)$$

The minimum and maximum limits for the number of bifacial photovoltaic panels used in the photovoltaic farm were determined based on the values in the (1), (2), (3), & (4).

1) *Bifacial PV Modules Characteristics:* Series Bifacial PV Modules P-Type Half-cut offer improved resistance to microcracking and evenly distributed internal stress. They achieve an impressive 600 Wp with a 15% increase in bifocality and a bifocality factor of up to 70 ± 5%. These modules have a minimal degradation rate of only 0.45 year over year and come with a 30-year power warranty for extended lifespan and performance. They also exhibit minimal degradation for LID e, LeTID modules. Manufactured using Ga doped wafer, Smart soldering, and 10BB technology, these modules provide exceptional PID resistance. Fig. 5 demonstrates the higher generation form of bifacial solar panel due to bifacial technology [39], [40].

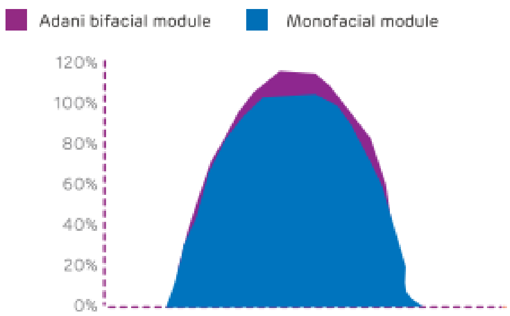

Fig. 5. The comparison between bifacial and monoracial modules

The voltage and current values of the cell at various levels of solar radiation intensity are depicted in the Fig. 6.

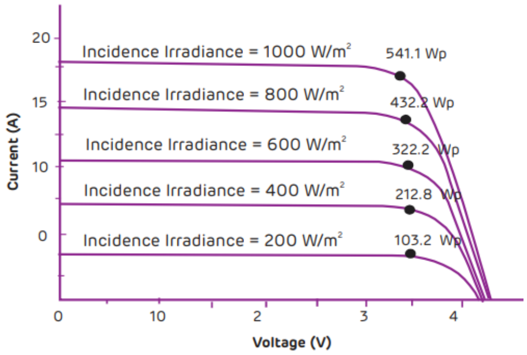

Fig. 6. Values of voltages and currents at different values of solar radiation intensity

2) *PV Inverter Characteristics:* The system has a capacity of 25 MW, which is then multiplied by the loss and reliability factor. Therefore, MPPT 100 KW inverters must be used. As a result, the required range of inverters is between 4 and 6 inverters.

3) *PV Battery Characteristics:* The formula is used to determine the battery capacity based on a discharge level of 40%, a voltage of 96 volts, and a battery life of 5 years, resulting in a total energy consumption of 21312 kilowatt-hours per day.

C. The Objective Function of Studied System

The main goal of this research is to introduce a novel method for identifying the best parameters of a grid-connected solar power system that includes storage elements. This approach integrates economic and technical evaluations spanning two decades to improve the profitability, reliability, and viability of the systems. The main objective of this study is to optimize the present cost element, PW, in order to enhance profitability, while simultaneously reducing LPSP to minimize load power losses and ensure a consistent power supply for the loads.

1) *The First Objective Function:* The P_w parameter assesses the investment status of the entire system over a specific time frame. It represents the disparity between the present value of cash flows and the present value of cash outflows during the investment analysis period.

$$P_w = F_{C1} + (R_{C1} + R_{c3}).\frac{(1+i)^{20}-1}{(1+i)^{20}*i} + R_{C2}.(1+i)^{-5} + R_{C2}.(1+i)^{-10} + R_{C2}.(1+i)^{-15} + F_{C2}.(1+i)^{-15} - A_R.\frac{(1+i)^{20}-1}{(1+i)^{20}*i} - S_O.(1+i)^{-20} \quad (5)$$

The cost function is to minimize the P_w Where:

$$F_{C1} = C_{PV} * N_{PV} + C_{INVERTER} * N_{INVERTER} + C_{BATTERY} * N_{BATTERY} \quad (6)$$

Where: P_w is Present cost element. F_{C1} is Construction cost. C_{PV} is PV module cost. N_{PV} is PV module number. $C_{INVERTER}$ is PV inverter cost. $N_{INVERTER}$ is PV inverter number. $C_{BATTERY}$ is PV battery cost. $N_{BATTERY}$ is PV battery number.

$$R_{C1} = C_{o-PV} * N_{PV} + C_{o-INVERTER} * N_{INVERTER} + C_{o-BATTERY} * N_{BATTERY} \quad (7)$$

Where: R_{C1} is Annual maintenance cost of the system components. C_{o-PV} is PV maintenance cost. $C_{o-INVERTER}$ is inverter maintenance cost. $C_{o-BATTERY}$ is Battery maintenance cost.

The total cost of inverters replacing, and the total cost of batteries replacing is giving as (8) and (9):

$$F_{C2} = C_{rep-INVERTER} * N_{INVERTER} \quad (8)$$

$$R_{C2} = C_{rep-BATTERY} * N_{BATTERY} \quad (9)$$

Where: $C_{rep-INVERTER}$ is the cost of one inverter replacing. $C_{rep-BATTERY}$ is the cost of one battery replacing. F_{C2} is the total cost of inverters replacing. R_{C2} is the total cost of batteries replacing.

The annual cost of power withdrawn from the network, the annual revenue, and the rescue package are given in the (10), (11), and (12) respectively.

$$R_{C3} = C_g * P_g \quad (10)$$

$$A_R = C_{E-SELL} * P_S \quad (11)$$

$$S_O = 0.2 * F_{C1} \quad (12)$$

Where: R_{C3} is the annual cost of power withdrawn from the network. C_g is the price of 1 Kw taken from the grid. P_g is Power taken from the grid. A_R: Annual revenue. C_{E-SELL} is the price of 1 Kw selling to the grid. P_S is Power injected to the grid. S_O: Rescue package.

The working status of the system has been clarified by documenting these relationships, which help determine whether the system is selling the network or renting from it.

$if \quad (P_{PV} + P_{BATTERY}) - P_{load} < 0$ then $the\ result\ is\ P_g$

$$P_g = |(P_{PV} + P_{BATTERY}) - P_{load}|$$

$if \quad (P_{PV} + P_{BATTERY}) - P_{load} > 0$ then $the\ result\ is\ P_s$

$$P_s = |(P_{PV} + P_{BATTERY}) - P_{load}|$$

Where: P_{PV} is Power taken from the batteries. $P_{BATTERY}$ is Power taken from the batteries. P_{load} is Load power demand.

2) *The Second Objective Function:* During the study period, LPSP, given in (13), represents the ratio of the load that cannot be fulfilled by the system to the total load.

$$LPSP = \frac{\sum_{i=1}^{N}(P_{load}(ti) - (P_{PV}(ti) + P_{BATTERY}(ti)))}{\sum_{i=1}^{N} P_{load}(ti)} \quad (13)$$

Where i is the hour, and N is the number of hours working.

If LPSP equals zero, it indicates complete satisfaction of the load. Conversely, if LPSP equals one, it indicates dissatisfaction of the load.

D. The Optimization Constraints

The economic sizing optimization process of the system under study must adhere to the following constraints.

- PV module number:

$$N_{PV-min} \leq N_{PV} \leq N_{PV-max} \quad (14)$$

- Battery number:

$$N_{BATTERY-min} \leq N_{BATTERY} \leq N_{BATTERY-max} \quad (15)$$

- Inverter number:

$$N_{INV-min} \leq N_{INV} \leq N_{INV-max} \quad (16)$$

- LPSP:

$$0 \leq \text{LPSP} \leq 1 \quad (17)$$

E. The Optimization Algorithms

1) Grey Wolf Optimization GWO: The Grey Wolf Optimization (GWO) algorithm is a nature-inspired optimization technique that mimics the hunting behavior of grey wolves. As a popular metaheuristic algorithm, GWO aims to find the optimal solution to complex optimization problems by simulating the social hierarchy and hunting strategies of a wolf pack. This algorithm follows the principles of dominance and cooperation among the alpha, beta, and delta wolves to explore the solution space efficiently. By leveraging communication and coordination mechanisms, the GWO algorithm intelligently balances exploration and exploitation to improve the search efficiency and convergence rate. This nature-inspired approach demonstrates promising potential for solving real-world problems in engineering, economics, and other fields. Fig. 7 shows the GWO steps, and the flow chart of this algorithm is shown in Fig. 8 [41].

Fig. 7. The hunting behaviour of grey wolves involves (A) chasing, approaching, and tracking prey, as well as (B-D) pursuing, harassing, and encircling, and finally, (E) a stationary situation and attack

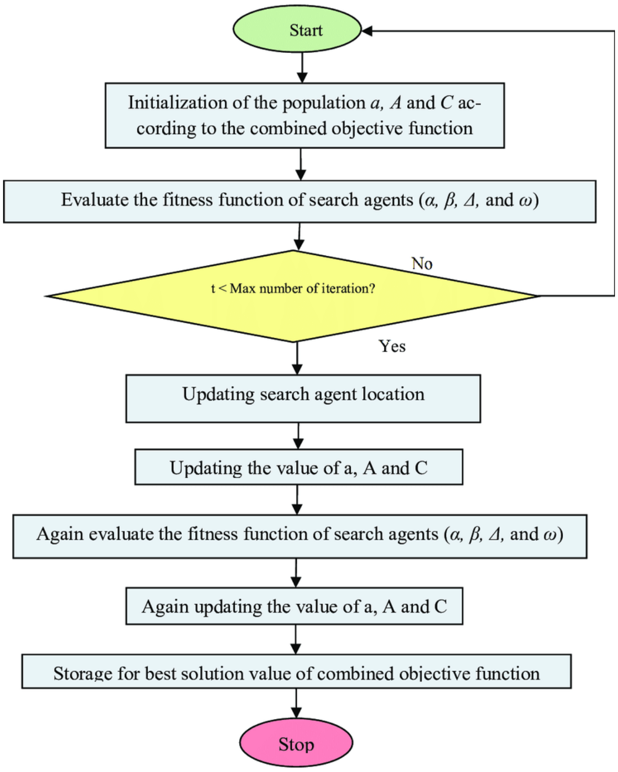

Fig. 8. The flow chart of GWO

The GWO algorithm draws inspiration from the social structure and hunting tactics of gray wolves in nature. By replicating the leadership dynamics of wolf packs, this algorithm effectively navigates complex optimization challenges like sizing grid-connected PV systems [43]. Its ability to strike a balance between exploration and exploitation enables it to efficiently search for solutions while refining its approach towards the optimal solution. This equilibrium is key in optimizing PV system sizes, and GWO has demonstrated strong convergence capabilities across different optimization tasks.

The rapid convergence towards a global optimum exhibited by GWO can be advantageous in determining the best sizing configurations for grid-connected bifacial PV systems in a timely manner. GWO has proven to be effective in various engineering and optimization challenges, showcasing its ability to find optimal solutions. Consequently, the strengths of GWO have made it a popular choice for optimizing the sizing of grid-connected bifacial PV systems [42]. These strengths include its nature-inspired optimization strategy, ability to balance exploration and exploitation, efficient convergence, scalability, adaptability, and successful track record in solving intricate optimization problems. The GWO& WOA used in both systems, for one house and for residential area, is adjusted as listed in Table I and Table II.

TABLE I. OPTIMIZATION PARAMETERS

GWO & WOA	Values
Number of hunting agents (population)	1000
Number of unknown variables	3
Maximum number of iterations	200

TABLE II. THE WEIGHTS USED IN THE OBJECTIVES OF THE ALGORITHMS

The objectives weight in both cases			
Case study 1	The Residential area weights	w_1	w_2
		0.0000003	0.7
Case study 2	The one house weights	w_1	w_2
		0.00001	0.5

2) The Whale Optimization Algorithm WOA: WOA is a nature-inspired search algorithm that mimics the behavior of hunting whales to solve optimization problems. The WOA employs a population-based framework to iteratively update candidate solutions, with each individual in the population representing a potential solution. These individuals, referred to as whales, explore the search space by adjusting their positions and velocities according to specific equations. The algorithm further employs three main mechanisms, namely searching, encircling, and attacking, which mirror the hunting behaviour of whales. By simulating these mechanisms, the WOA strikes a balance between exploration and exploitation, exhibiting competitive performance in solving a wide range of complex optimization problems. Despite its simplicity, the WOA outperforms many existing algorithms, showcasing its potential as a promising optimization technique. Fig. 9 shows the working principles of WOA, and the Fig. 10 shows the flow chart of WOA [44].

The WOA is a compelling choice for optimizing the size of bifacial PV systems due to its proven effectiveness in solving optimization problems across various fields. Its unique ability to efficiently navigate the research space and rapidly converge on optimal solutions makes it a reliable option for determining PV system sizes. Furthermore, the algorithm's diverse methods can inspire innovative approaches to finding the best size for these systems.

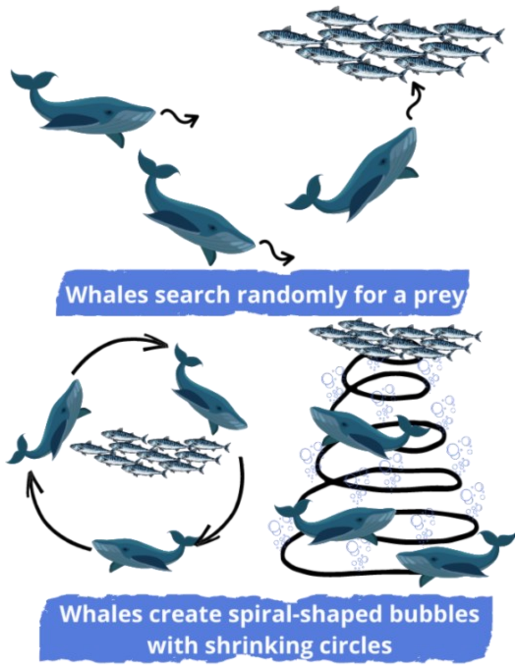

Fig. 9. The Whale Optimization Algorithm WOA

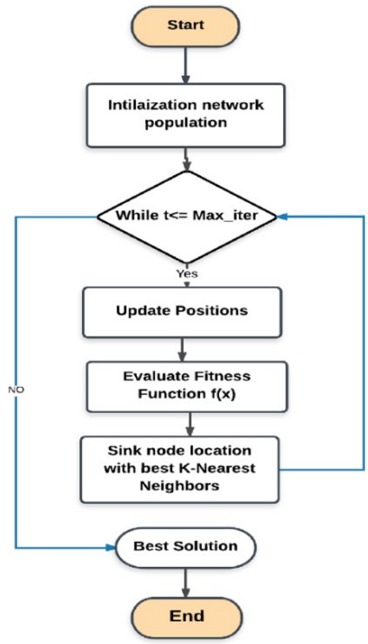

Fig. 10. The flow chart of whale optimization algorithm

WOA is user-friendly and straightforward, making it ideal for research and analysis studies. Its foundation in biological principles allows for easy application and comprehension of its functionality [45]. With both exploratory and convergent strengths, WOA excels in finding diverse and precise solutions to intricate problems, particularly in sizing solar energy systems efficiently and accurately. Given these strengths, utilizing the WOA in this study is a compelling choice, as it offers a range of benefits and capabilities that can enhance the effectiveness and precision of determining the optimal size of bifacial solar energy systems [46].

Using both the WOA and the GWO to determine the optimal size of bifacial PV systems offers a chance to discover innovative optimization techniques, conduct a comparative study of various algorithms, assess their effectiveness, and potentially achieve better outcomes [47].

F. The System Parameters

The different elements used in this work are presented in the Table III and Table IV shows the cost value for each component in the system.

The constraints limits for both residential area and one house case are listed in the Table V and Table VI respectively.

TABLE III. SYSTEM PARAMETERS

System parameters				
Parameter	**N(years)**	**Cg**	**Ce-sell**	***i***
Value	20	0.14	0.16	14%

TABLE IV. SYSTEM COST PARAMETERS

System cost parameters				
Component	**Cost**	**Maintenance cost**	**Replacement cost**	**Lifetime (year)**
Bifacial PV module	C_{PV}	C_{o-PV}	------	20
	217.63	2.66	------	
Battery	$C_{BATTERY}$	$C_{o-BATTERY}$	$C_{rep-BATTERY}$	5
	250	3	250	
Inverter	$C_{INVERTER}$	$C_{o-INVERTER}$	$C_{rep-INVERTER}$	15
	1942	17	1942	

TABLE V. THE CONSTRAINTS LIMITS IN CASE OF RESIDENTIAL AREA

N_{min}	N	N_{max}
N_{PV-min}	N_{PV}	N_{PV-max}
750		900
$N_{BATTERY-min}$	$N_{BATTERY}$	$N_{BATTERY-max}$
100		400
$N_{INV-min}$	N_{INV}	$N_{INV-max}$
4		6

TABLE VI. THE CONSTRAINTS LIMITS IN CASE OF ONE HOUSE

N_{min}	N	N_{max}
N_{PV-min}	N_{PV}	N_{PV-max}
10		15
$N_{BATTERY-min}$	$N_{BATTERY}$	$N_{BATTERY-max}$
1		4
$N_{INV-min}$	N_{INV}	$N_{INV-max}$
3		7

G. The System Results

1) Residential Area Results: The objective function variations in the residential zone using the GWO technique are depicted in Fig. 11. The initial objective function had a desired minimum value of 735,000, while the second objective function aimed for a value of 0.32. Notably, the desired value achieved stability after 100 iterations, with a slight deviation, but it reached its ultimate form from the fifth iteration onwards. As Fig. 12 shows, the GWO achieved a fitness of 0.450 for the residential area after the fifth iteration.

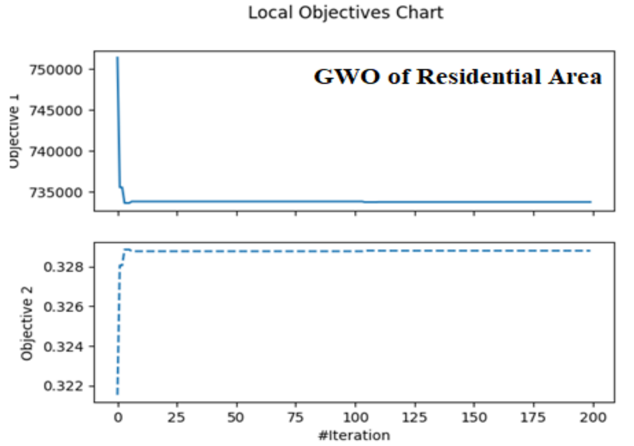

Fig. 11. The local objective chart for residential area using GWO algorithm

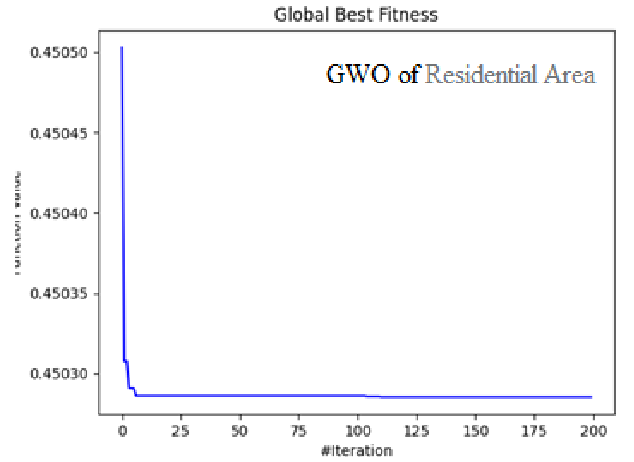

Fig. 12. The global objective fitness for residential area using GWO algorithm

The whale algorithm demonstrated its superiority over the GWO in the residential area by assigning a marginally lower value to the initial target, as Fig. 13 shows. It maintained stability without requiring any adjustments, thus emphasizing the exceptional performance of the whale optimization algorithm.

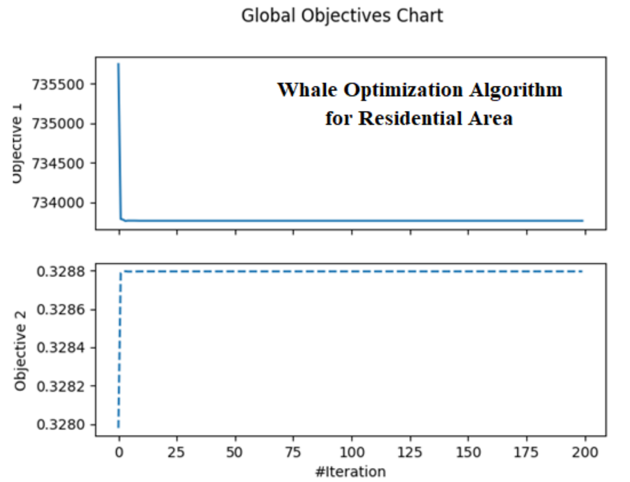

Fig. 13. The global objective chart for Whale Optimization Algorithm for Residential Area

From Fig. 14 conclude that no significant changes in the fitness dimension for the residential area were observed from the implementation of the whale algorithm.

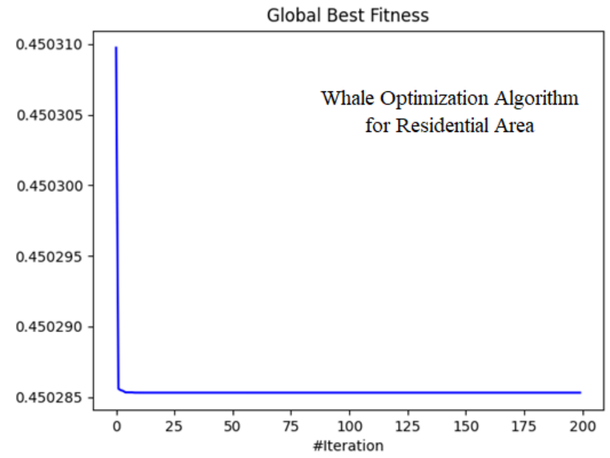

Fig. 14. The global best fitness for Whale Optimization Algorithm for Residential Area

TABLE VII. THE BEST SOLUTION FROM GWO ALGORITHM FOR RESIDENTIAL AREA

The best solution					
for Residential Area	N_{PV}	$N_{BATTERY}$	N_{INV}	P_W	*LPSP*
	800	212	4	733762.95	0.3279

The load curve, PV curve, and battery curve within 24 hours for a residential area are depicted in Fig. 15. The figure highlights the enhancement in energy and load management achieved by efficiently controlling the system components.

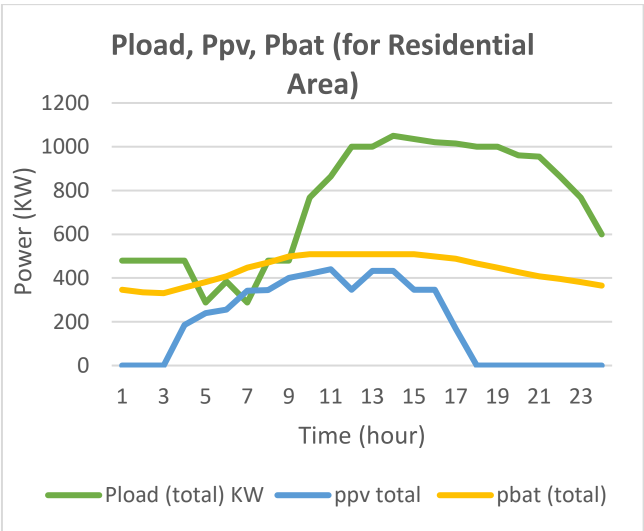

Fig. 15. load, PV, battery curves for residential area

2) One House Results: The GWO algorithm assigned a value of 56400 to the first objective function for a one house, while the second objective function received a value of -0.710. The negative sign signifies that the generation exceeds consumption, which is advantageous as homeowners can sell excess energy to the public network by connecting their system with it. Fig. 16 shows the global objective chart for one area using GWO algorithm.

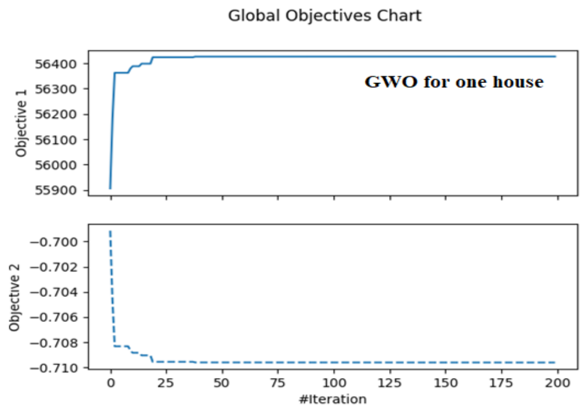

Fig. 16. Global objective chart for one area using GWO algorithm

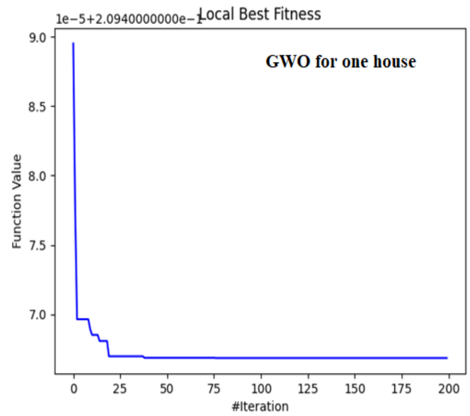

Fig. 17. local objective chart for residential area using GWO algorithm

The WOA and GWO were compared for a residential area, as Fig. 18 shows. It was observed that the WOA had a quicker response, while the GWO yielded a lower objective function value.

GWO excels in its simplicity and ease of use, its rapid generation of innovative solutions, and its versatility in tackling various research challenges. However, it may underperform in certain scenarios compared to alternative algorithms and requires precise parameter adjustments for optimal results. The WOA algorithm stands out for its effective exploration and exploitation of research spaces, its adaptability to various problems, and its ability to maintain a balance between exploration and exploitation. However, it can be complex in certain situations, requiring extra effort to implement, and may be sensitive to parameter settings, necessitating careful tuning. In general, The GWO algorithm has the potential to surpass WOA in certain scenarios because of its simplicity and quick attainment of optimal solutions, whereas WOA excels in thorough exploration of research spaces and achieving a harmonious blend of exploration and exploitation.

The best solution obtained from the algorithms for one house case is given in Table VIII.

TABLE VIII. THE BEST SOLUTION FROM ALGORITHMS FOR BOTH CASE STUDIES

The best solution					
for One House	N_{PV}	$N_{BATTERY}$	N_{INV}	P_W	*LPSP*
	10	4	4	56426.94	-0.7096

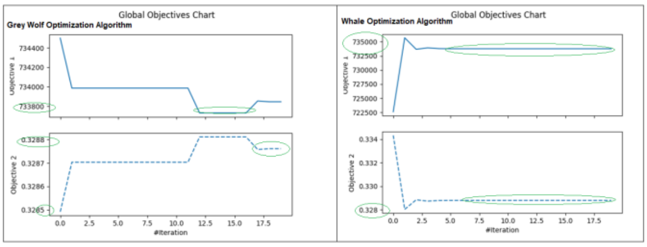

Fig. 18. global objective chart comparison for residential area using GWO & WOA algorithms

Fig. 19 shows the improvement achieved in energy management and load management through optimal adjustment of the number of components of a single house feeding system.

From Fig. 15 and Fig. 19, the illustration demonstrates the importance of carefully selecting components for grid-connected PV systems in enhancing energy management, load management, and system performance. Optimal selection of components, such as photovoltaic cells, inverters, and batteries, that are efficient and compatible with each other is key to improving energy generation and use. By choosing high-efficiency components, energy generation can be maximized, while effective energy storage with batteries can minimize waste and improve overall energy management.

Efficient load management is a key benefit of selecting the right PV systems, allowing for power to be directed to different loads and adjusting consumption based on system needs. Additionally, this optimal selection helps distribute energy effectively among various loads, preventing overload. Ultimately, the focus should be on enhancing system performance and stability by improving adaptability to changing conditions. Overall, choosing the right components for a grid-connected PV system can enhance energy and load management, as well as overall system performance, offering sustainable solutions for energy generation and utilization.

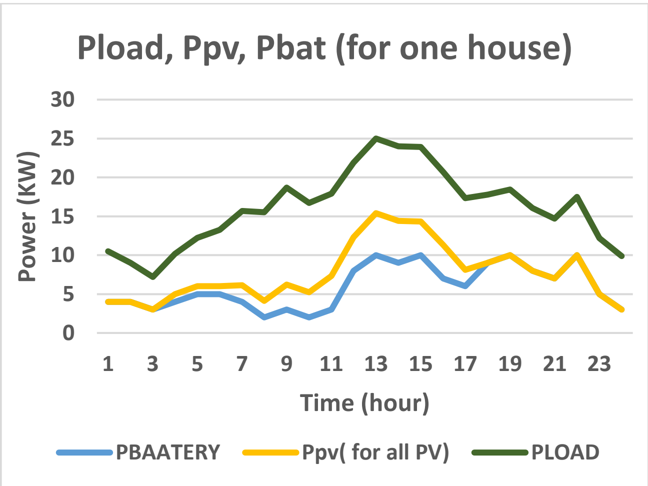

Fig. 19. load, PV, battery curves for residential area

VII. Conclusions and Recommendations

This paper proposes utilizing GWO and WOA for optimizing the size of grid-connected bifacial PV systems. By considering factors such as available space, desired energy output, irradiance, bifaciality factor, budget constraints, and grid connection requirements. Two objective functions are employed, which are minimizing NPV and maximizing LPSP. The results of the optimization process highlight the effectiveness and efficiency of both GWO and WOA algorithms in finding optimal solutions that address multiple objectives, including maximizing energy production, minimizing costs, and adhering to system constraints. Two case studies are conducted to demonstrate the methodology's effectiveness, one for a single house and another for a residential area, confirming the increased energy efficiency and cost-effectiveness of the optimized systems. The economic benefits of the whale optimization algorithm were notable, but the gray wolf algorithm excelled in energy management. Finally, the renewable energy sector can further support sustainable development and tackle current global energy challenges by adopting these innovative optimization techniques. Further research should focus on integrating real-time data and dynamic factors like weather and grid demand fluctuations to improve optimization accuracy and effectiveness.

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