Optimal Sizing of Hybrid Renewable Energy System using Manta Ray Foraging Technique

Priyanka Brahamne, M. P. S. Chawla, H. K Verma



Abstract: This paper presents a method for optimising the size of a standalone hybrid energy system that combines wind, PV, and biomass energy sources with battery storage. Hybrid renewable energy systems are required in off-the-grid communities. For such systems, optimal system sizing can be regarded as a constrained optimisation issue. This research presents an intelligent approach based on modern optimisation for designing a hybrid renewable energy system optimally, utilising the manta ray foraging technique to minimise the overall annualised system cost and satisfy load demand. To confirm the effectiveness of the proposed method, the results are compared with those from the ABC algorithm. The results have demonstrated that the MRFO algorithm exhibits fast convergence properties, delivers highquality results, and maintains a smooth power flow under the same ideal conditions.

Keywords: Renewable Energy, System, MRFO, Battery Storage, ABC Algorithm, Optimization

I. INTRODUCTION

 \mathbf{T} he rate of global population growth is remarkable, and the massive increase in global energy consumption resulting from rapid population growth has given rise to environmental problems, including pollution, greenhouse gas emissions, and climate change. Therefore, it's critical to choose mitigation strategies and alternative energy sources to the conventional ones to prevent these long-term issues from worsening. Wind and solar energy are two excellent substitutes for fossil fuels among various renewable energy sources, as they are all sustainable, clean, inexhaustible, and environmentally safe. One, two, or more renewable energy sources can be combined to create a hybrid renewable energy system (HRES) [1]. Due to globalisation, the development of new technologies, and the increasing household energy consumption of the urban population, there has been a significant rise in energy demand, particularly for electricity, over the past three decades. As a result, a significant supply-demand gap exists in the power sector.

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If another kind of power generation is not found to compensate for this supply-demand gap, it is expected to grow exponentially. Alternative sources of energy are needed since rural areas are not electrified, and remote locations cannot access the grid. Due to this, the majority of capacity increases in power generation today are driven by renewable energy [2]. Every year, tens of gigawatts of solar, wind, and hydroelectric capacity are constructed worldwide, contributing to the more than 100 billion Euro market for renewable energy. It is now essential for power and energy sustainable, economical, engineers to seek and environmentally acceptable alternatives to conventional energy sources, such as solar, wind, geothermal, ocean, and biomass energy. However, since these renewable energy sources are not always available throughout the year, research has been conducted on hybrid renewable energy systems. The design, optimization, operation, and control of renewable hybrid energy systems have been the subject of extensive research in recent years [2]. The lifetime cost and emissions of hybrid renewable energy systems can be used to evaluate the design. In addition to the operational cost, the lifetime cost typically consists of two additional elements. These parts include the "fixed cost," which is the sum of the capital cost and the maintenance cost. Changes in the monetary worth over time must also be taken into account when calculating the lifetime cost. Therefore, the best configuration for a hybrid system seeks a combination of generator sizes and types that yields the lowest lifetime cost and/or emissions. The configuration with the lowest "Net Present Value (NPV)" among all feasible hybrid system configurations that are optimally dispatched is referred to as the "optimal configuration" or the "optimal design."[3] [4] [5]. The proposed work focuses on hybrid energy systems, which comprise a combination of solar, wind, biomass, and energy storage. To increase the reliability of the hybrid system, biomass resources can be utilised in conjunction with wind and solar energy. To meet the electrical needs of a typical village, an autonomous hybrid PV-wind-biomass with battery system is suggested in this study. The proposed system's ideal configurations have been realised using the Manta Ray Foraging (MRFO) algorithm, a swarm-based metaheuristic. The main characteristic that sets the MRFO method apart from other algorithms (such as ABC and PSO) is that it is capable of producing optimal solutions, just like other evolutionary algorithms, and has a good convergence accuracy [6]. This paper's main contribution is the design of a dependable, affordable hybrid PV-wind-biomass energy system with battery storage, aimed at satisfying the electrical load demand of a small area with abundant natural resources.

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In-depth discussion is required regarding the operational strategy and mathematical modelling of various system components.

II. UNIT SIZING AND OPTIMIZATION

It is impossible to accurately forecast the behaviour of renewable energy sources, as they fundamentally exhibit random behaviour. The essential idea behind unit sizing and optimisation is to reduce system cost while maintaining system reliability to determine the size of the hybrid system's parts. The key to achieving an acceptable price and reliability level in a hybrid generation system is optimal resource management. It is preferable to make a sensible choice between these design objectives since they frequently conflict with one another. A system's cost will rise if its components are oversized, but a power supply failure could result from under sizing. For this reason, it is essential to develop a system with the utmost caution and at the lowest possible cost [7]. The sizing of the components is typically followed by the optimisation of the system's components or other factors, such as investment cost, energy output cost, or fuel consumption. Usually, the goal of optimization is to reduce the levelized cost of energy or the net present cost (NPC) (LCE) [7] [8] [9].



Fig. 1 Basic Components of a Hybrid System [10]

III. MODELING OF THE SYSTEM

This initiative focuses on developing a novel hybrid system to deliver dependable power to remote or off-grid locations. The AC bus has connections for the load, wind turbines, and biomass gasifier. Additionally, converters are used to link batteries and solar PV panels to the AC bus. Additionally, a charge controller is used to regulate the flow of electricity smoothly and govern simultaneously how quickly batteries are charged and discharged. The proposed system is best suited for remote areas and agriculturally based villages in underdeveloped nations where there is a serious energy issue. The proposed technology can, however, be connected to the grid. As this system is entirely self-sustaining with renewable energy sources, it will help reduce dependency on the utility grid. Battery banks are used to distribute energy efficiently, reducing the unpredictable nature of renewable energy sources. To ensure the system's dependability, this effort primarily focuses on determining the ideal size of each component. Here are some discussions of the mathematical models for various elements, which are done to understand their basic philosophy and extent of use.

$P_{sol}(t) = P_r^s f_{loss} \frac{Gh(t)}{Gs}$ (1)

where G_h (t) is the hourly solar radiation incident at the surface of the solar PV panel (W/m²), G_s is the standard incident radiation (1000 W/m²), and P_r^s represents the rating of the solar PV panel. F_{loss} is the derating or loss factor of a solar PV panel due to factors such as shadow, dirt, temperature, and others. In this study, the impact of temperature is not considered [10].

3.2 Wind power generation

The technique of using the wind to produce mechanical or electrical power is referred to as "wind power" or "wind energy," respectively. This mechanical energy can be utilised for specific purposes (like pumping water or grinding grain) or it can be transformed into electricity via a generator [10]. Equations represented wind power generation by (2) can be used to compute the power produced by a wind turbine ($P_{wt}(t)$), 0 V(t) \leq Vin or V(t) \geq Vout

3.1 Solar Photovoltaic Panel

Solar radiation determines a solar PV panel's $(P_{sol}(t))$ power production, which can be expressed,

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 $Pwt(t) = Pwr Vrat \le V(t) \le Vout$

$$P^{w_r} \frac{V(t) - Vcin}{Vrat - Vcin}$$
 $V_{cin} \le V(t) \le V_{rat}$

Here, P^w denotes the capacity of a single wind turbine, V_{cin} denotes the cut-in speed, V_{rat} is the rated wind speed, V_{cout} denotes the cut-out speed, and V(t) denotes the wind speed at the target height. The hub height wind speed differs from the reference height and is dependent on the site and geographic location. Furthermore, it is denoted as,

$$V(t) = Vr(t) \left(\frac{Hwt}{Hr}\right)\gamma$$
(3)

Where the coefficient of friction, Vr (t), is the wind speed at the reference height Hr, and V(t) is the wind speed at height Hwt. When the surface is smooth, well-exposed, and has low roughness, the friction coefficient is γ typically 1/7 [10] [11] [12].

3.3 Biomass Gasifier

Organic material from recently deceased plants and animals is known as biomass. Energy initially derived from the Sun is stored in biomass. Sunlight energy is converted into chemical energy by plants. Photosynthesis is the name of this process. Plant-eating animals utilize and store this energy within their bodies. This combustion does not directly result in electricity. Large water-filled boilers are heated by burning solid biomass materials. As a result, steam is created from liquid water and in the boiler, the steam generates pressure. The power of the steam turns a turbine, which in turn moves the generator's wire coil [14].

The producer gas is used as an input fuel in a biomass gasifier. The annual electricity production (E_{bmg}) of a biomass gasifier can be calculated as,

$$E_{bmg} = P_{bmg} (8760 * CUF) \tag{4}$$

Where P_{bmg} is the biomass gasifier system rating, and CUF is the capacity utilisation factor. The calorific value of the biomass, its availability (in tonnes per year), and the number of hours the biomass gasifier is used, since all play significant roles in biomass-based energy systems. The following criteria can be used to determine the maximum rating of a biomass gasifier built at a specific location,

$$P^{m}_{bgm} = \frac{\text{Total biomass avialable}\left(\frac{\text{ton}}{\text{yr}}\right)*1000*\text{ CVbm*}\eta\text{bmg}}{365*860*\text{Operating hours/day}}$$
(5)

Where, CV_{bm} is the biomass's calorific value and $\eta_{Biomass}$ is a measure of the total efficiency of converting biomass to energy [10], [13], [14].

3.4 Battery Bank

The extra electricity from the PV and wind generators can be used at any time to charge the batteries. At the same time, the stored energy can be released whenever there is a power generation shortage. The load won't be satisfied if neither the wind turbine nor the PV array is producing enough electricity, and the storage is empty. Therefore, whether the battery is in a charging or discharging state is determined by the difference between the total energy generated and the energy required for the load. With the correct estimation of the state of charge, energy can be measured (SOC). The battery's SOC is a function of time and can be computed as follows,

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$$\frac{\text{SOC}(t)}{\text{SOC}(t-1)} = \int_{T-1}^{T} \frac{\text{Pb}(t)\eta\text{batt}}{\text{Vbus}} dt$$
(6)

where Pb(t) is the input/output power of the battery, Vbus is the voltage of the bus, and η batt is the battery's round-trip efficiency. The battery is charging if Pb(t) is positive; otherwise, it is discharging. Additionally, the following is how a battery's round-trip efficiency is identified:

$$\eta_{\text{batt}} = \sqrt{\eta c} \text{batt} \eta \text{batt} \tag{7}$$

Where, respectively, ncbatt and ndbatt represent the battery's charging and discharging efficiencies. [10]

3.5 Power converter

(2)

Although the load is assumed to be AC, solar PV panels and batteries are producing DC output. Peak load demand $(P^m_L (t))$ is taken into account while determining the converter size. The inverter's efficiency is shown by η_{inv} . These steps are used to calculate the inverter rating (P_{inv}) [17].

$$P_{inv}(t) = P^{m}_{L}(t) / \eta_{inv}$$
(8)

IV. PROBLEM FORMULATION

The primary objective of this project is to design a reliable and cost-effective hybrid energy system. The key deciding factors are the rating and sizing of solar PV panels, wind turbines, battery banks, and biomass gasifiers. This section includes a brief overview of the applied algorithm, the system's operational strategy, and its objective function.

4.1 Operational Strategy

To achieve system reliability in any hybrid energy system, proper power management is necessary. In this system, the biomass gasifier is reserved as the last alternative, only activated when the load demand cannot be met by solar, wind, or batteries. The following are the simple steps of operational strategy.

i. Demand can be met only by renewable sources if the combined power generated by solar PV panels and wind turbines is sufficient, and wind power is also less than the load. After completing the load, excess power can be delivered to the battery bank as,

$$P_{ch}(t) = P_{PV}(t) - [P_{L}(t) - P_{W}(t)] / \eta_{inv}$$
(9)

Where η_{inv} represents the inverter's efficiency and PL(t) represents the load demand at any given moment. If Nsol is the total number of solar PV panels and Psol(t) is the power produced by a single solar PV panel, then the total power produced by solar PV panels (P_{PV}(t)) is given as,

$$P_{PV}(t) = P_{sol}(t)N(t)$$
(10)

Additionally, if P_{wt} is the power created by a single wind turbine and N_{wt} is the total number of wind turbines, then $P_w(t)$, or the overall power generated by wind turbines, can be expressed as follows,

$$P_{wt}(t) = P_{wt}(t)N_{wt}$$
(11)

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ii. If the amount of energy produced just by wind turbines is sufficient to meet the need for load, the remaining energy (from solar and wind) can be fed to the battery bank. In this scenario, the battery power can be computed as follows,

$$P_{ch}(t) = [P_w(t) - P_L(t)]\eta_{rec} + P_{PV}(t)$$
(12)

Where η_{rec} is the rectifier efficiency.

iii. In both of the scenarios above, if $P_b(t)$ exceeds the maximum permissible capacity of the battery bank (P^{max}_b), extra energy may be discharged or applied to deferrable loads. Energy that is extra or wasted is obtained as,

$$P_{dump}(t) = P_b(t) - P^{max}{}_b(t)$$
(13)

iv. If the power produced by the solar PV panels and wind turbines is insufficient, balance power can be generated by the batteries and is computed as,

$$P_{b}(t) = [P_{L}(t) - P_{w}(t)] \eta_{inv} - P_{pv}(t)$$
(14)

- v. A biomass gasifier provides power to the load when solar and wind energy are insufficient and batteries $(SOC(t) \leq SOCmin)$ are also unable to produce the required amount of power. There are two ways to use a biomass gasifier
- First, it employs a load-following technique, which a) means that whenever it is in operation, it only produces the electricity needed to satisfy the main load demand. To calculate the power produced by the biomass gasifier,

$$P_{bmg}(t) = P_{L}(t) - P_{W}(t) - P_{PV}(t)/\eta_{inv}$$
(15)

b) In the second approach, it operates at rated capacity or the minimum load ratio. When a biomass gasifier is running at maximum efficiency, the excess power is used to recharge batteries and can be stated as follows,

$$P_{b}(t) = [P_{bmg}(t) - P_{L}(t) + P_{w}(t)] \eta_{rec} + P_{PV}(t)$$
(16)



Fig. 2 Operational strategy representation by a Flow Chart [10]

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4.2 Objective function

The objective function aims to reduce the annualised cost, which combines the annualised cost of operations and maintenance (Cm&o), the annualised cost of fuel (Cfuel), the annualised salvage value (Csalv), and the annualised capital cost (C_{cap}). The number of wind turbines, solar PV panels, batteries, and the rating of the biomass gasifier have been chosen as the four primary choice considerations for the best configuration. The annualised system cost (ASC) approach is employed for the economic analysis. While satisfying all other constraints and parameters, the outcome with the lowest ASC is observed to be the best one.

Where N denotes the no. of solar panels, wind turbines, batteries and inverters respectively, CBMG denotes the cost of a biomass gasifier, and PbMG denotes its performance rating. The inverter's rating is known as P_{inv} [16].

Additionally, each component's entire ASC can be stated as follows:

$$C_{wind} = C^{arep}_{wind} + C^{acap}_{wind} + C^{m}_{sol} - C^{sal}_{wind}$$
(18)

 $C_{sol} = C^{arep}_{sol} + C^{acap}_{sol} + C^{m}_{sol} - C^{sal}_{sol}$ (19)

$$C_{batt} = C^{arep}_{batt} + C^{acap}_{batt} + C^{m}_{batt} - C^{sal}_{batt}$$
(20)

$$C_{bmg} = C^{arep}{}_{bmg} + C^{acap}{}_{bmg} + C^{m}{}_{bmg} + C^{f}{}_{bmg} - C^{sal}{}_{bmg}$$
(21)

$$C_{inv} = C^{arep}_{inv} + C^{acap}_{inv} + C^{m}_{inv} - C^{sal}_{inv}$$
(22)

The capital recovery factor, or CRF, is a ratio used to determine the future value of an annuity. The capital recovery factor's equation is as follows:

$$CRF(i,N) = \frac{i(1+i)N}{(1+i)N-1}$$
 (23)

where I is the annual interest rate and N is the lifespan in years.

4.3 Constraints

Constraints are logical limitations that a solution to an optimisation problem must fulfil. Additionally, you can directly impose a limitation on a decision variable, for example, A1 = 100 or B7 > 5. Most optimisers effectively handle these types of upper and lower constraints on variables, which are highly beneficial in many applications [20].

The objective function is evaluated while keeping to several constraints, which can be summed up as

$$1 \le N_{wt} \le N^m_{wt} \tag{24}$$

$$1 \le N_{sol} \le N^m_{sol} \tag{25}$$

$$1 \le N_{bmg} \le N^{m}_{bmg} \tag{26}$$

$$1 \le N_{batt} \le N^{m}_{batt} \tag{27}$$

$$SOC_{min} \le SOC \le SOC_{max}$$
 (28)

Reliability and LCOE are used to determine the best configuration. LCOE is defined as the system's average cost per kWh of usable energy generated, and it can be expressed as.

$$LCOE = \frac{ASC\left(\frac{\$}{yr}\right)}{Useful \, energy\left(\frac{kwh}{yr}\right)}$$
(29)

4.4 Manta Ray Foraging Algorithm

The Manta Ray Foraging Optimisation (MRFO) method is a novel bio-inspired optimisation strategy that aims to provide a new algorithm, offering an alternative approach to addressing real-world engineering challenges. The manta rays' foraging habits and the aspects of those habits are what this algorithm contributes to. The optimisation findings show that, compared to other well-known optimisers, the MRFO optimiser can result in a potential enhancement in solution precision with reduced computational expense. The MRFO was inspired by the manta rays' sophisticated foraging techniques. Manta rays have three distinct foraging techniques that they use when looking for food.,

- 1) Chain Foraging: Enhance local search ability.
- Cyclone Foraging: Enhance local search ability. 2)
- Somersault Foraging: Enhances local search capabilities 3) and improves overall search ability [15].

Chain foraging, cyclone foraging, and somersault foraging are the three foraging strategies used by MRFO. While cyclone foraging concentrates on the exploration search, chain foraging and somersault foraging behaviours mainly contribute to the exploitation search. The three foraging behaviours are used to implement the following updating methods when utilising MRFO to solve an optimisation problem [21].



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V. RESULT AND DISCUSSION

To address the electrical needs of a small community, a small stand-alone PV-wind-biomass-battery hybrid system, as shown in Fig. 1, has been designed using the methodology proposed in this work. A newly introduced swarm-based manta ray foraging technique is used to determine the optimal component size for assessing the proposed system's functionality.

5.1 Presentation of the site

To fulfil the electrical needs of a small village located in Patiala, Punjab, India, a small stand-alone PV-wind-biomassbattery hybrid system was designed using the methodology presented in this work. The case study area is located at 30°260'N and 76°120'E latitude and longitude, respectively. A small microgrid, for which the scheme is primarily intended for domestic loads, has a peak load demand of 102 kW and a load factor of 0.406. This area is thought to have good year-round access to solar and wind resources. According to the available data, this location's yearly average wind speed is 5.9 m/s, and its average daily sun radiation is 5.14 kWh/m2/day. There was sufficient biomass feedstock on this specific site to set up a biomass gasifier. The two main crop residues in Punjab, India, are wheat and rice straw. According to estimates, these two crop leftovers account for nearly 75% of the state's total agricultural residue production. The cost of biomass, including labour costs, transportation, and storage costs, is estimated to be 25 \$/yr [10].

5.2 Existing Results by Different Researchers on Another Set of Data.

 TABLE 1. The Optimal Sizing Obtained by HBO.[19]

PHS PV	Npv 15	Nwt	Nbatt	Nbmg
Wind	-	1	-	-
Battery	-	-	400	
Bmg	-	-	-	2
NPC (\$/yr)				LCOE (\$/yr)
3,559,143				0.121171

In a study carried out by researchers, an isolated hybrid renewable energy system for use in the Egyptian town of Alrashda in the New Valley Governorate's Dakhla Oasis is analysed and optimised. A biomass system will be integrated into the proposed hybrid system, along with a photovoltaic (PV) system, a wind turbine (WT), and a battery storage system (Bat). To lower the levelized cost of energy and reduce the risk of power supply failure, the optimisation is designed to minimise component oversizing and ensure the reliable control of power supplies. To guarantee that every load demand is met for the proposed hybrid system at the lowest possible energy cost (COE), four optimization algorithms-the Heap-based optimizer (HBO), Franklin's and Coulomb's algorithm (CFA), the Sooty Tern Optimization Algorithm (STOA), and the Grey Wolf Optimizer (GWO)-are used and results are compared. According to the results, HBO has identified the optimal solution for the suggested hybrid system, with a net present cost (NPC) of \$3,559,143 and a minimum COE of \$ 0.121171/kWh [19].

5.3 Results

The MATLAB 2021a software was used to simulate the experimental results. The maximum number of solar PV panels, wind turbines, and batteries has been assumed to be the same in all situations and taken as 300, 500, and 100, respectively, to compare the results of the MRFO and ABC algorithms. It is believed that a biomass gasifier can provide up to 50 kW of power. The size of the inverter is not a factor in the decision-making process. Based on ASC and LCOE, the acceptable and ideal approach is chosen.

Table 2 Shows the Result of MRFO and ABC

S. No.	ALGORITHM	MRFO	ABC
1.	PV(KW)	499.8373	500
2.	WINDTURBINE(KW)	299.9132	300
3.	BIOMASS(KWh)	1.2509	1.254912
4.	BATTERIES(units)	99.9676	83.242
5.	ASC (\$/yr)	3,736,688	3,747,665
6.	LCOE (\$/kWh)	1.876	1.882

Table 2 presents the optimal results obtained by the MRFO and ABC algorithms for various case studies. The findings suggest that the MRFO algorithm forecasts that the system's minimal ASC will have the lowest LCOE. The MRFO algorithm estimates 499.8373 kW of solar PV, 299.9132 kW of wind turbines, 99.9676 kWh of batteries, and 1.2509 kWh of biomass gasification, with an ASC of \$3,736,688/yr and an LCOE of \$1.876/kWh. Table 2 also indicates that both metaheuristic algorithms yield essentially identical outcomes. When compared to ABC, the MRFO algorithm performs satisfactorily in terms of calculation time and output. Both algorithms' LCOE results demonstrate that the suggested method delivers energy to off-grid locations at a reasonable cost.

Table. 3 Shows Results of Energy Sources Being Used.

		0.	0
S. No.	Sources	ABC (kWh/yr)	MRFO (kWh/yr)
1.	Solar	751,000	750,760
2.	Wind	181,640	181,590
3.	Biomass	125,491	125,090
4.	Battery in	29,733	34,531
5.	Battery out	27,144	31,529
	Total demand	199,210	199,210

An overview of energy production by all components for the combinations discovered by ABC and MRFO is shown in Table 3. It is essential to emphasise the importance of solar energy. The proposed system completely satisfies the energy requirements using solar, wind, batteries, and biomass.



Fig. 4 Convergence Rate of MRFO Algorithm

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The convergence rate is often calculated as the number of iterations and function evaluations required to achieve a satisfactory solution. Fig. 4 above illustrates the rapid convergence of the MRFO algorithm. The graph shows that the method converges after around the first 50 iterations.



Fig. 5 Energy analysis for the suggested case study every month.

The average monthly energy balance for one year is shown in Fig. 5. It should be emphasised that the use of solar and wind energy has been consistent with the availability of these resources. When PV panels aren't producing as much power in January, a biomass gasifier is used to satisfy the load demand. The remainder of the month estimates that a significant amount of the increased accessibility of natural resources will allow for the generation of solar power. However, during the summer, the battery bank is used more frequently, resulting in the batteries being depleted more quickly. This is further evidenced by the consideration that the window of time during which there is extra energy is limited to a few months. This approach will minimise the excess or spilt energy.



Fig. 6 Energy balance

Fig. 6 illustrates a complete power exchange for one week in January, aimed at developing an understanding of how the system's various components exchange power.



Fig.7 Displays the Energy Balance and Battery SOC for the Last Week of June.

The energy management during the final week of June is shown in Fig. 7, which indicates that sufficient solar electricity is produced, as the solar resource is more readily available. The overall load requirement is met entirely by batteries, solar, and wind energy, avoiding the need for any biomass power. Battery SOC measurement is crucial, especially in systems that use batteries as storage.



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Fig.8 (a) Battery SOC (state of charge) (%) (b) Battery input and output energy for one complete year.

Throughout the year, the battery bank's state of charge, as well as input and output energy, are depicted in Figs. 8 (a) and (b). The lowest permitted SOC and initial SOC levels have been set at 100% and 30%, respectively. Fig. 8 shows that the battery's SOC always stays within the predetermined range. The battery bank's initial SOC is taken to be 100% on January 1 at 0000 hours. It is clear that the SOC only fell below 30% for a brief period throughout the entire year. Fig. 8 also demonstrates that, for the most part, battery SOC is satisfactory, with a few exceptions, such as in January when natural resources are scarce and in June and July when there is a higher load demand. The battery's rate of charging and draining is another issue that needs to be regularly monitored. The maximum charging or discharging power (Pb max for one hour) is 151.2 kW, enabling efficient charging and draining of the battery bank. The energy can be employed as a deferred load or dumped, if it can be charged faster than the charging rate. A biomass gasifier will be used as a source of energy if the amount of energy being discharged exceeds the pace at which batteries can be discharged.

VI. CONCLUSION

Particularly for places off the grid, a hybrid energy system offers a more dependable, affordable, and acceptable source of electricity. The MRFO algorithm has been employed in this research to develop a mathematical model for determining the optimal size of components in a hybrid PVwind-battery system with biomass integration. An operational approach is selected after a brief discussion of the mathematical modelling of the various study components. The conclusions reached by the MRFO algorithm and those drawn by the other metaheuristic algorithm, ABC, have been compared.

The investigation, which demonstrated that the optimal hybrid system adequately met the load requirement without violating any limitations,



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yielded better results with the proposed algorithm compared to the ABC method.

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Statement	
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DECLARATION

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