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

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Abstract: ***In this paper, a method for optimizing the size of a standalone hybrid that consists of a wind, PV, and biomass energy system with battery storage is discussed. Hybrid renewable energy systems are required in off-the-grid communities. For such systems, the optimal system sizing can be regarded as one of the constrained optimization issues. This research presents an intelligent approach based on modern optimization for designing the hybrid renewable energy system optimally using the manta ray foraging technique, minimizing overall annualized system cost and satisfying load demand. In order to confirm the effectiveness of the proposed method, results are compared against findings from the ABC algorithm. The results have proven that the MRFO algorithm has fast convergence properties, the ability to deliver high-quality results, and the capacity to manage a smooth power flow under the same ideal conditions.***

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

I. INTRODUCTION

The rate of global population growth is remarkable and massive increase in global energy consumption caused by the rapid population growth gives rise to environmental problems such as pollution, greenhouse gas emissions, and climate change. Therefore, it's critical that to make a choice for mitigation strategies and alternative energy sources to the conventional ones in order to stop these long-term issues from getting worse. Wind and solar energy are two excellent substitutes for fossil fuels among the various sources of renewable energy as they are both 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 globalization, the development of new technologies, and the rising household energy consumption of the urban population, there has been an enormous rise in the demand for energy, particularly electricity, over the past three decades. As a result, there is a significant supply-demand gap in the power sector.

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 generating today are driven by renewable energy [2]. Every year, tens of gigawatts of solar, wind, and hydroelectric capacity are constructed throughout the world, contributing to the more than 100 billion Euro market for renewable energy. It is now essential for power and energy engineers to keep an eye out for sustainable, economical, and environmentally acceptable alternatives to conventional energy sources, such as the sun, wind, geothermal, ocean, and biomass. However, due to the fact that these renewable energy sources are not always available throughout the year, research has been done 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 emission 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 looks for a combination of generator sizes and types that gives the lowest lifetime cost and/or emission. 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 are made up of a combination of solar, wind, biomass, and energy storage. In order to increase the reliability of the hybrid system, biomass resources can be utilized alongside 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 suggested system's ideal configurations has been realized using the Manta Ray Foraging (MRFO) algorithm, a swarm-based metaheuristic. The main characteristic that sets the MRFO method apart from other algorithms (such 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 to satisfy 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 forecast the behavior of renewable energy sources as they fundamentally exhibit random behavior. The essential idea behind unit sizing and optimization is to reduce system cost, while maintaining system reliability in order to determine the size of the hybrid system's component parts. The key to achieving an acceptable cost 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 important 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 optimization of the system's components or other factors, such as investment cost, output energy 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].

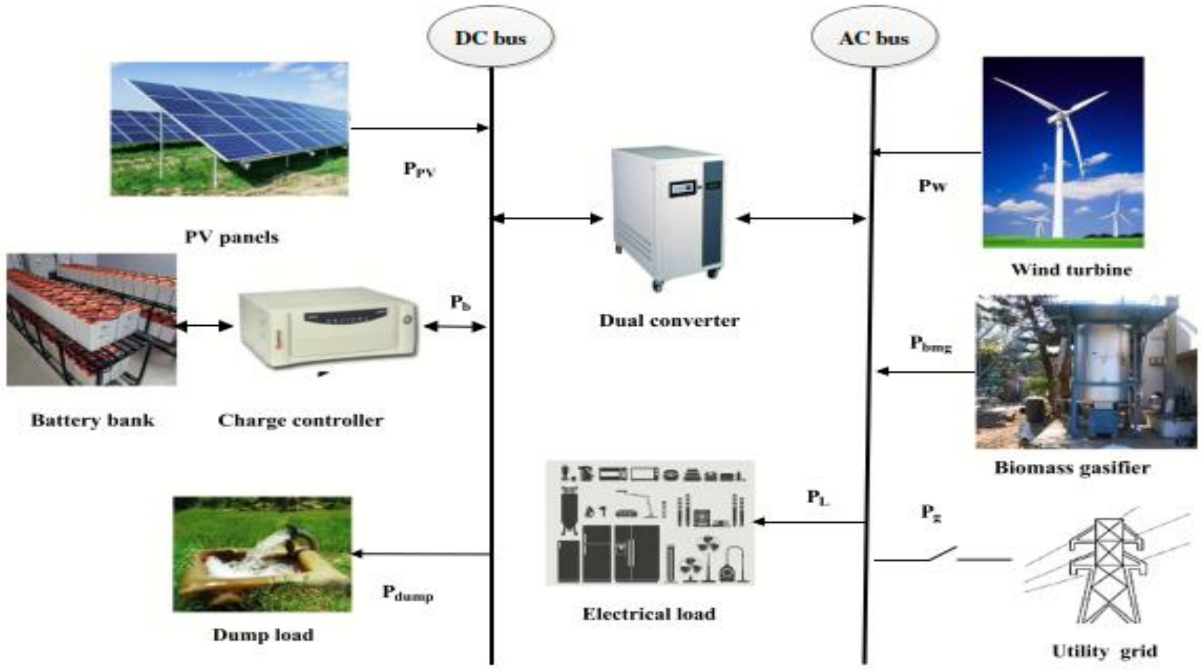

Fig. 1 Basic Components of a Hybrid System [10]

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 keep the electricity flowing 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 assist in reducing dependency on the utility grid. Battery banks are used to distribute energy efficiently, reducing the unpredictable nature of renewable energy sources. In order to ensure the system's dependability, this effort focuses mostly on the ideal size of each component. Here are some discussions of the mathematical models for various components is done to understand their basic philosophy and extent of use.

3.1 Solar Photovoltaic Panel

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

$$P_{sol}(t)= P^{s}_{r}\, f_{loss} \frac{Gh(t)}{Gs} \quad (1)$$

where G_h (t) is the hourly solar radiation incident at the surface of the solar PV panel (W/m^2), G_s is the standard incident radiation (1000 W/m^2), and P^s_r represents the rating of the solar PV panel. F_{loss} is the derating or loss factor of the solar PV panel due to shadow, dirt, temperature, and other factors. In this study, the impact of temperature is not taken into account. [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 certain 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 $V(t) \geq Vout$

$$\mathrm{Pwt}\,(t) = \begin{cases} \mathrm{Pwr} & \mathrm{Vrat} \leq V(t) \leq \mathrm{Vout} \\ P^{w}{}_{r}\frac{V(t)-\mathrm{Vcin}}{\mathrm{Vrat}-\mathrm{Vcin}} & V_{cin} \leq V(t) \leq V_{rat} \end{cases} \quad (2)$$

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 furlong speed, and V(t) denotes the wind speed at the target height. The hub height wind speed is different from reference height and is dependent on the site and geographic area. Furthermore, it is denoted as,

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

Where, γ is 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 that originally came from the Sun is found 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 own 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. A turbine is turned by the power of the steam and generator's wire coil is moved by the turbine.[14]

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

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

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,

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

Where, CV_{bm} is the biomass's calorific value and η_{bmg} 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, while the stored energy can be released anytime, wherever there is a shortage of power generation. The load won't be satisfied if neither the wind turbine nor the PV array are 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 load required. 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,

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

where Pb(t) is the input/output power of the battery, Vbus is the voltage of the bus, and ηbatt is the battery's round-trip efficiency. 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,

$$\eta_{batt} = \sqrt{\eta cbatt \eta batt} \quad (7)$$

where, respectively, ηcbatt and ηdbatt represent the battery's charging and discharging efficiencies. [10]

3.5 Power converter

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]

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

IV. PROBLEM FORMULATION

The major goal of this project is to design a dependable and affordable 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 preserved as the last alternative, only turning on 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,

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

Where η_{inv} stands for the inverter's efficiency and $P_{L}(t)$ stands for load demand at any 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,

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

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 follow,

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

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,

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

Where, η_{rec} is the rectifier efficiency.

iii. In both of the aforementioned scenarios, 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,

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

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,

$$P_b(t) = [P_L(t) - P_w(t)]\,\eta_{inv} - P_{pv}(t) \tag{14}$$

v. A biomass gasifier gives power to the load if solar and wind energy are insufficient and batteries ($SOC(t) \le SOC_{min}$) are also unable to produce the required amount of power. There are two ways to use a biomass gasifier

a) First, it employs a load-following technique, which means that whenever it is in operation, it only produces the electricity needed to satisfy the main load demand. In order to calculate the power produced by the biomass gasifier,

$$P_{bmg}(t) = P_L(t) - P_W(t) - P_{PV}(t)/\eta_{inv} \tag{15}$$

b) In the second approach, it runs at rated capacity or 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,

$$P_b(t) = [P_{bmg}(t) - P_L(t) + P_w(t)]\ \eta_{rec} + P_{PV}(t) \tag{16}$$

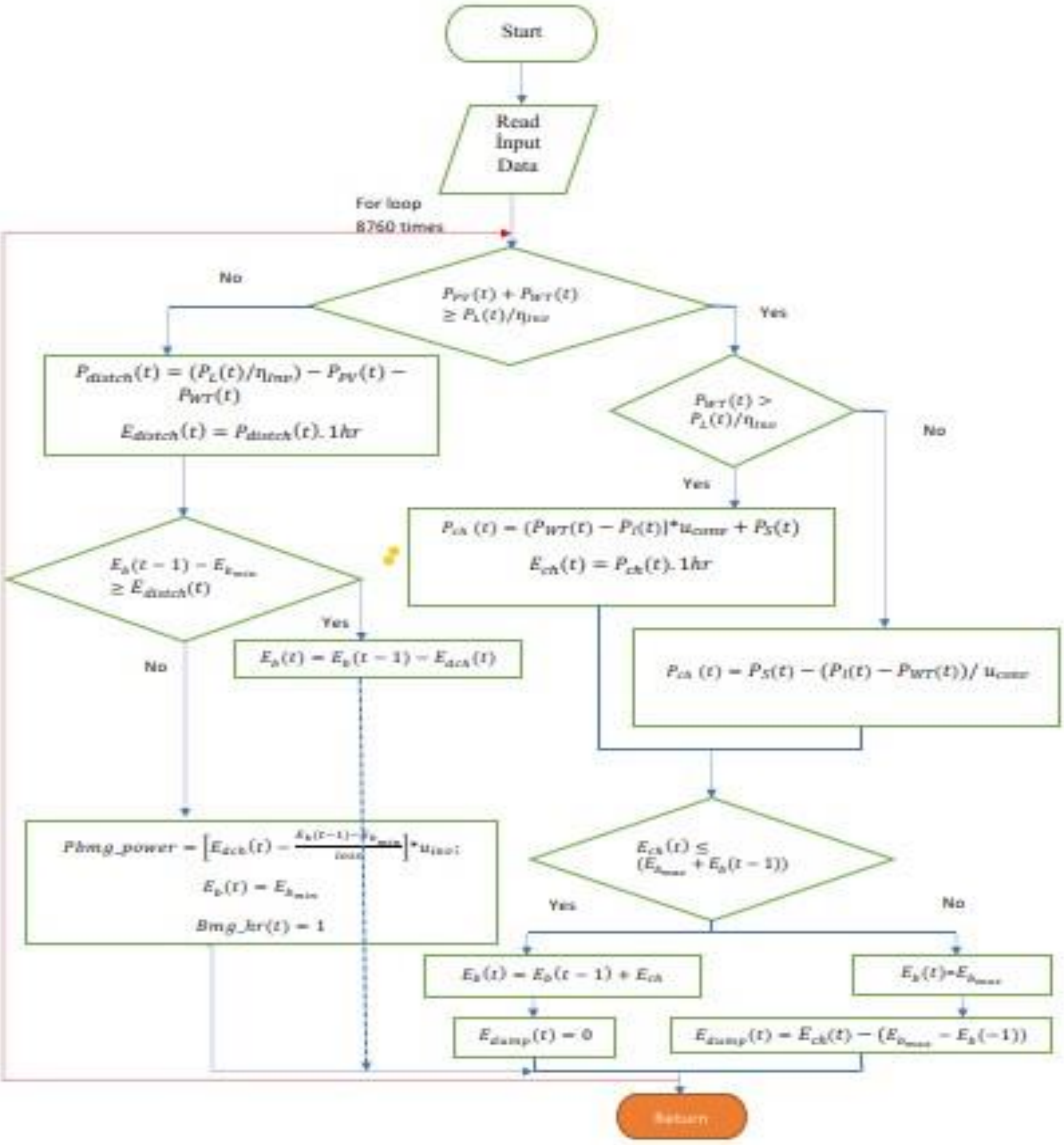

Fig. 2 Operational strategy representation by a Flow Chart [10]

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4.2 Objective function

The objective function aims to reduce the annualized cost, which combines the annualized cost of operations and maintenance ($C_{m\&o}$) and annualized cost of fuel (C_{fuel}), annualised salvage value (C_{salv}), and annualized 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.

$$\text{Min ASC} = F\,(N_{sol}\,C_{sol} + N_{wt}\,C_{wt} + N_{batt}\,C_{batt} + P_{inv}\,C_{inv} + P_{bmg}\,C_{bmg}) \tag{17}$$

Where, N denotes the no. of solar panel, wind turbine, battery and inverter respectively. The cost of a biomass gasifier is denoted by C_{bmg}, and its performance rating is denoted by P_{bmg}. The inverter's rating is known as P_{inv}. [16]
Additionally, each component's entire ASC can be stated as follows:

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

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

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

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

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

The capital recovery factor, or CRF, is a ratio used to determine how much an annuities will be worth in the future. The capital recovery factor's equation is as follows:

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

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

4.3 Constraints

Constraints are logical limitations that an optimization problem's solution must fulfill. Additionally, you can directly impose a limitation on a decision variable, for example, A1 = 100 or B7>=5. Most optimizers handle these types of upper and lower constraints on the variables effectively, and they are highly helpful in many issues. [20]
The objective function is evaluated while keeping to a number of constraints, which can be summed up as

$$1 \leq N_{wt} \leq N^{m}{}_{wt} \tag{24}$$

$$1 \leq N_{sol} \leq N^{m}{}_{sol} \tag{25}$$

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

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

$$SOC_{min} \leq SOC \leq SOC_{max} \tag{28}$$

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,

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

4.4 Manta Ray Foraging Algorithm

Manta Ray Foraging Optimization (MRFO) method is a new bio-inspired optimization strategy that aims to give a novel algorithm, that provides an alternative optimization approach for dealing with real-world engineering difficulties. The manta rays' foraging habits and the aspects of those habits are what this algorithm contributes to. The optimization findings show that, in comparison to other well-known optimizers, the MRFO optimizer 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 that is,

1) Chain Foraging: Enhance local search ability.
2) Cyclone Foraging: Enhance local search ability.
3) Somersault Foraging: Enhance local search ability and rises 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 behaviors mostly contribute to the exploitation search. The three foraging behaviors are used to implement the following updating methods when utilizing MRFO to solve an optimization problem. [21]

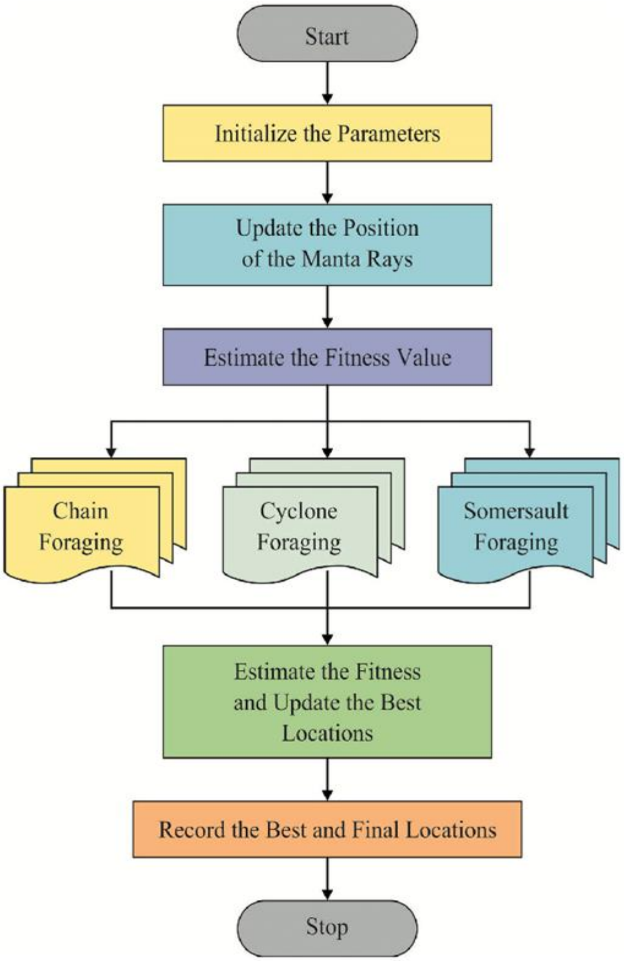

Fig. 3 Flow Chart of MRFO [18]

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 freshly introduced swarm-based manta ray foraging technique is used to determine the best component size to assess 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-biomass-battery 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. 102 kW of peak load demand and a load factor of 0.406 are the peak load demand and load factor for a small micro grid, respectively, for which the scheme is primarily intended for domestic loads. 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 Result by Different Researcher on Another Sets of Data.

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

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

In this study carried out by some researchers an isolated hybrid renewable energy system for use in the Egyptian town of Alrashda in the Dakhla Oasis's New Valley Governorate is analyzed and optimized. A biomass system will be integrated into the proposed hybrid system along with a photovoltaic (PV), wind turbine (WT), and battery storage system (Bat). With the goal of lowering the levelized cost of energy and the chance of a power supply failure, the optimization is built to minimize component oversizing and assure 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 come up with the best optimal solution for the suggested hybrid system, with a net present cost (NPC) of $3,559,143 and a minimal 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 have been assumed to be the same in all situations and taken as 300, 500, and 100 respectively for the purposes of comparing 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 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 displays all of the optimum results that the MRFO and ABC algorithms were able to obtain for various case studies. The findings suggest that the MRFO algorithm forecasts 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 batteries, and 1.2509 kWh of biomass gasification with an ASC of 3,736,688 $/yr and an LCOE of 1.876 $/kWh. The table.2 also indicates that both metaheuristic algorithms yield outcomes that are essentially identical. 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.

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 should be emphasized that solar energy is important. The proposed system completely satisfies the energy requirement using solar, wind, and batteries and biomass.

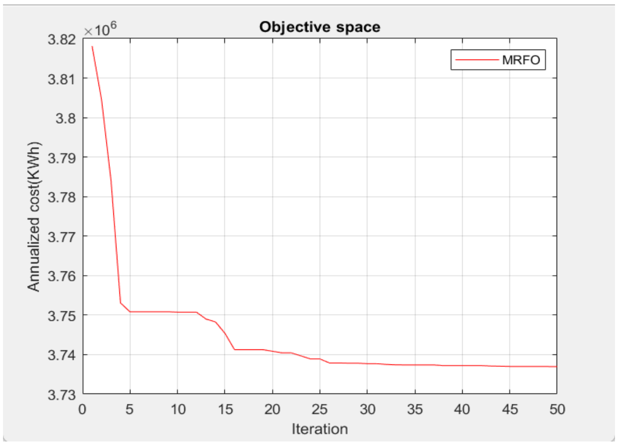

Fig. 4 Convergence Rate of MRFO Algorithm

Convergence rate is often calculated as the number of iterations and function evaluations required to arrive at a satisfactory solution. Fig.4 above shows how quickly the MRFO algorithm converges. The graph shows that the method converges after around the first 50 iterations.

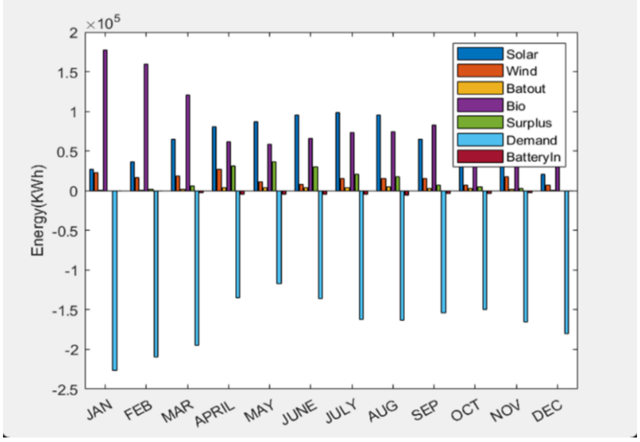

Fig. 5 Energy analysis for the suggested case study on monthly basis.

The average monthly energy balance for one year is shown in Fig.5. It should be emphasized that the use of solar and wind energy has been consistent with the supply of those resources. When PV panels aren't producing as much power in January, a biomass gasifier is used to satisfying the load demand. The remainder of the month estimates a significant amount of the increased accessibility of natural resources allows for the generation of solar power. However, during the summer, the battery bank is used more frequently, i.e. the batteries are being used up more quickly. It is further evidenced by the Consider that the window of time when there is extra energy is limited to a few months. The excess or spilled energy will be reduced to a minimum by this approach.

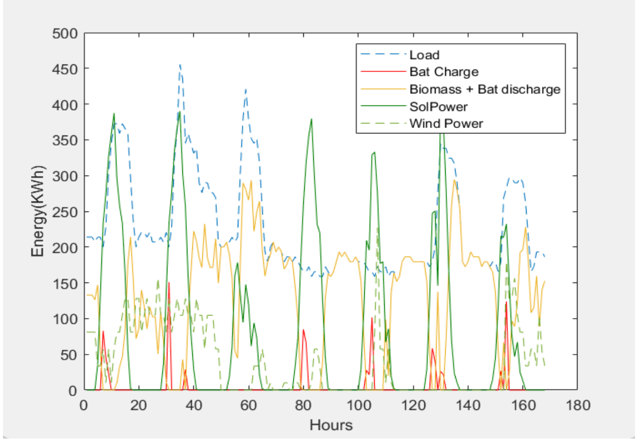

Fig. 6 Energy balance

Fig.6 depicts a complete power exchange for one week in the month of January to develop an understanding that how the system's many components exchange power.

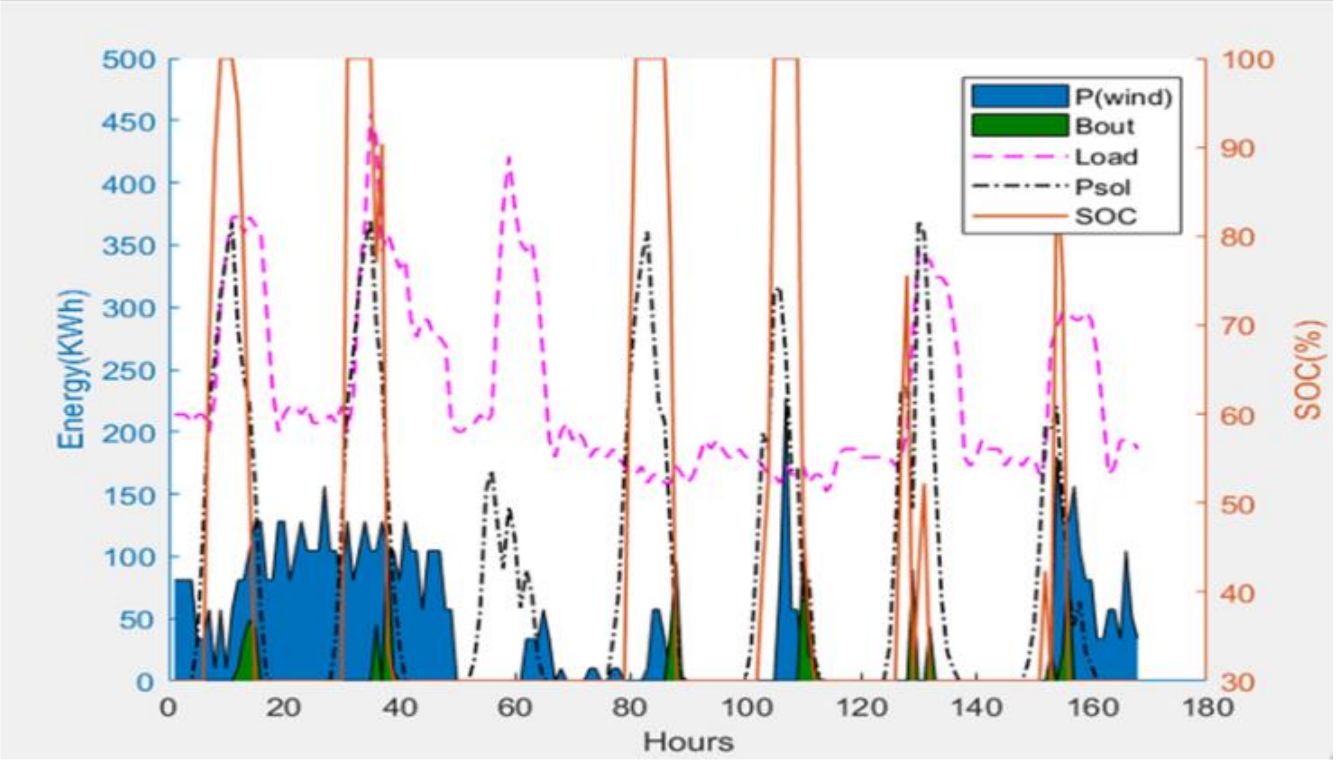

Fig.7 Displays the Energy Balance and Battery SOC for the Last Week of June.

The energy management during the final week of June is shown in the fig.7 which indicates that sufficient solar electricity is produced, since 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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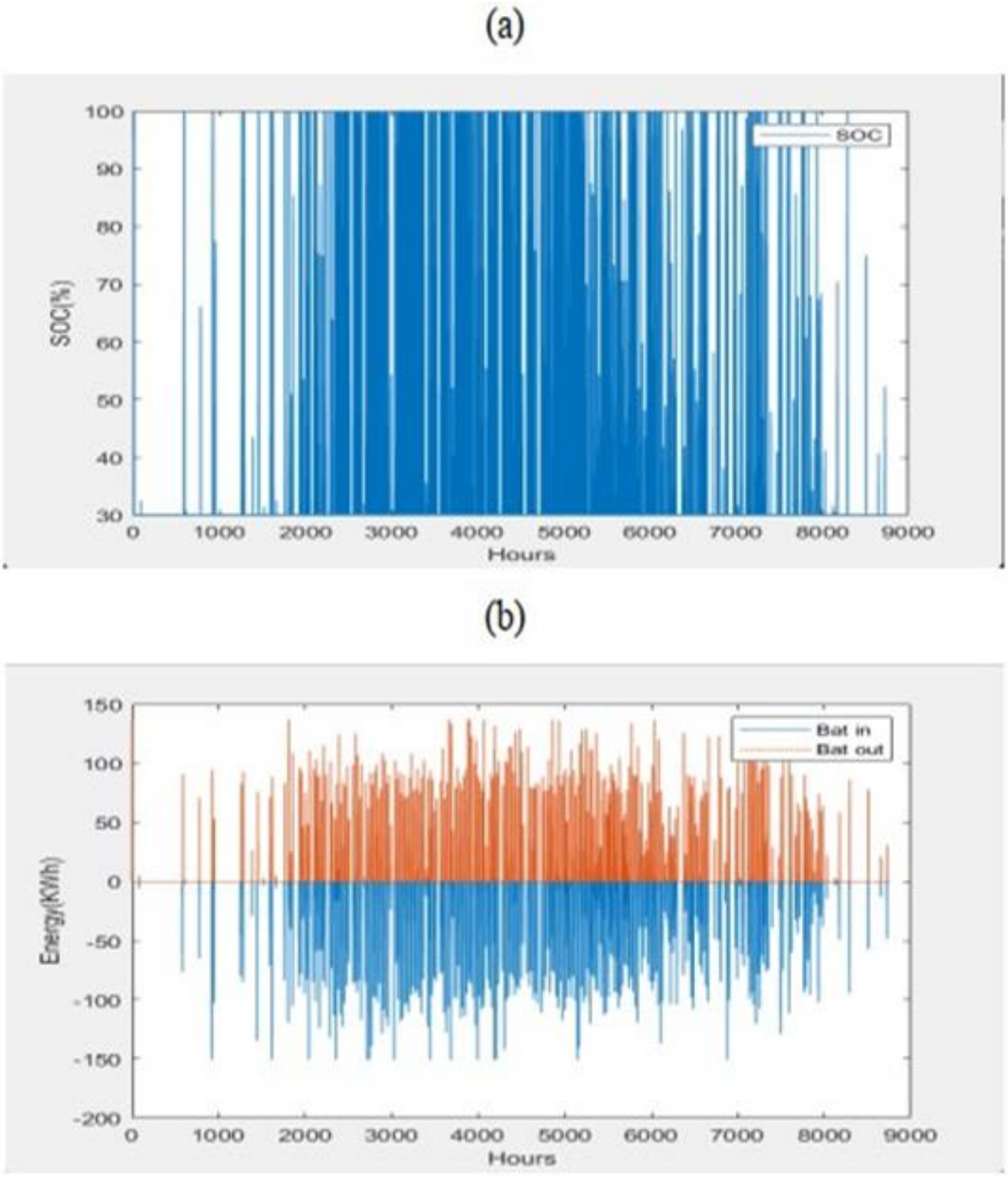

Fig.8 (a) Battery SOC (state of charge) (%) (b) Battery input and output energy for one complete year.

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 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 from that SOC only fell below 30% for a brief period of time throughout the entire year. Fig.8 also demonstrates that, for the most part, battery SOC is good, with a few exceptions, such as in January when natural resources are low 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. Maximum charging or discharging power (Pb max for one hour period) is 151.2 kW for 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 used in this research to construct a mathematical model for determining the ideal size of components in a hybrid PV-wind-battery with biomass. 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 the drawn by the other metaheuristic algorithm ABC have been compared.

The investigation that showed the optimal hybrid system adequately satisfied the load requirement without violating any limitations showed better results with the proposed algorithm when compared to ABC.

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Authors Contributions	All authors have equal participation in this article.

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