Published in AJSE, Vol:23, Issue: 3
Received on 8th May 2024
Revised on 28th October 2024
Published on 31st December 2024

AIUB JOURNAL OF SCIENCE AND ENGINEERING
ISSN: 1608 – 3679 (print) 2520 – 4890 (Online)

Optimal Sizing for an Islanded Microgrid using Grey Wolf Optimization: A Case Study of Manpura Island, Bangladesh

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Abstract— **Renewable energy sources (RESs) perform a crucial role in addressing energy crisis in remote rural areas where it is uneconomical to expand electrical distribution systems. RESs, like solar power, are able to power microgrids, which might be one way to address this problem. In order to guarantee that the system meets the essential performance requirements while reducing the overall cost, the microgrid must be sized optimally. This study proposed an approach of optimal sizing of an islanded microgrid at Manpura Island, Bangladesh, consisting of several configurations including photovoltaic (PV) systems, diesel generator (DG), and three distinct battery technologies, LA, Li-ion, and Ni-Fe are intended to meet the island's load demand. Grey wolf optimization (GWO) is used to reduce the LCC and COE by taking operational constraints into account. Further, indicators of the LPSP assess the reliability and effectiveness of the island microgrid system. The results demonstrate that the GWO outperforms both the genetic algorithm (GA) and particle swarm optimization (PSO) method in term of optimal systems performance with LPSP of 0%, LCC of $202748 and COE of 0.3048$/KWh.**

Index Terms—**Optimal sizing, Island microgrid, life cycle cost, grey wolf optimization, Manpura Island, Bangladesh.**

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I. Introduction

BANGLADESH has had a significant increase in its power requirements over the past decade as a result of rapid economic growth, improved living conditions, and major population growth. It was expected that by 2019, the population would number 165 million [1]. However, around 83% of the nation's population can connect to the electrical grid [2]. In rural areas, especially, the remaining population still needs greater access to electricity. Renewable energy sources (RESs) were especially pivotal in isolated rural areas whereas the extension of power grids was impracticable and uneconomical to solve these crises [3]. A practical solution to this problem involves the advancement of microgrids that utilize sustainable energy sources including wind, solar, and battery banks. Microgrids may be grid-connected to the conventional utility grid or run as autonomous power grids dependent on local sources.

Regardless of the specific configuration of microgrids, they have effectively reduced CO_2 emissions and energy costs. Nevertheless, the fluctuation and irregularity of RESs like wind turbine (WT) and photovoltaic (PV) units have contributed to the use of storage banks that are important in microgrids [4]. Evaluating all feasible configurations might be time-consuming for complicated challenges in today's modern world.

Achieving the required performance standards while reducing the overall cost of the microgrid system necessitates the optimal system size [5]. Microgrid optimal sizing aims at achieving the required levels of resilience, cost-effectiveness, and reliability via the greatest feasible mix of component size and number [6]. Isolated microgrids lack a main grid; hence, in order to provide a steady power supply, optimum sizing is very important [7]. The best sizing of microgrid systems has been the subject of many studies have used different techno-economic analyses, traditional techniques, software available for purchase, and optimization algorithms. Classical methods have many drawbacks, including inflexibility, difficulty finding a global optimum, and difficulty adjusting to changing conditions. The ability of commercial software programs to manage multiple goals is limited, and they lack sophisticated optimization features. Techniques for optimization algorithms provide a rapidly converging globally optimum solution, therefore overcoming the drawbacks of classical methods and commercial software. Algorithms result in more efficient solution to complex problems [8, 9].

The literature is filled with discussions regarding the optimal configuration of microgrid systems. For instance, the moth-flame optimization algorithm (MFOA) was employed by Bandopadhyay, J., et al. [10] to size a grid-connected microgrid system that included a PV, WT, and BESS. The primary objective of the research was to lower the price of electrical energy. Geleta, D.K., et al. [11] used the artificial bee colony (ABC) technique to calculate the ideal microgrid sizing for PV, WT, and BESS. The objective function takes into account the total annual cost. Utilizing the firefly optimization method (FOA), Sanajaoba, S., et al. [12] were able to determine the optimal microgrid size, which included WT, PV, and BESS. The study's objective is to reduce energy costs. A Harris Hawks Optimization (HHO) method was used by Çetinbaş, İ., et al. [13] to calculate the sizes of microgrids that included PV, WT, DG, and BESS, and lowering the cost of electricity was the investigation's goal. The grasshopper optimization algorithm (GOA) was utilized by Jasim, A.M., et al. [14] to determine the best configuration for a microgrid that included a WT, PV, biogasifier, DG, and BESS. The primary objective is to reduce the annual net cost in its entirety. The optimal size for the microgrid system, which comprised pump storage units, biogas, PV, and superconducting magnetic energy storage (SMES), was determined by Agaije, T.F., et al. [15] using the whale optimization approach. The investigation's goal was to minimize capital costs. Salp Swarm Algorithm (SSA) was used by Kumar, P.P., et al. [16] to calculate the optimal size of a microgrid system comprising a PV, biomass generator (BMG), and BESS. Reducing the levelized cost of energy and the yearly levelized cost was the study's main goal. El Boujdaini, L., et al. [16] used Particle Swarm Optimization (PSO) to calculate the ideal PV, WT, and BESS microgrid system configuration size. Lowering energy costs is the primary objective. Lazaar, N.F., et al. [17] optimized a battery, PV, and hydrogen energy storage system configuration using the genetic algorithm (GA). The study's objective was to lower the net present cost.

TABLE I
DIFFERENT METHOD USED TO OFF-GRID MICROGRID IN BANGLADESH

Ref.	Sources used in microgrid	Optimization Technique	Objective Function	Study area
[17]	PV, WT, BESS, Biogas	Genetic Algorithm (GA) & International Data encryption algorithm	Cost of energy (COE), Life cycle emission (LCE)	St. Martin's Island
[18]	PV, PHS, DG	GA & HOMER	Net present cost (NPC), COE, CO_2 emissions	Sitakunda
[19]	WT, PV, biomass, DG	GA & HOMER	NPC, Levelized cost of energy (LCOE)	Bhola
[20]	WT, PV, DG, BESS	HOMER	NPC, COE, CO_2 emissions	Cox's Bazar
[21]	PV, Tidal, DG, BESS	HOMER	NPC, COE, CO_2 emissions	Patuakhali
[22]	WT, PV, BESS, DG	HOMER	NPC, COE, LCE	Rajshahi
[23]	WT, PV, BESS, Biogas, DG	HOMER	NPC, COE, CO_2 emissions	Satkhira
[24]	PV, Biomass, DG, BESS	HOMER	NPC, COE, CO_2 emissions	Panchagarhh
[25]	WT, PV, DG, BESS	Mixed-integer linear programming (MILP) & HOMER	NPC, COE, CO_2 emissions	Hatiya Island
This Study	PV, DG, BESS	GA, PSO & GWO	LCC, COE	Manpura Island

In comparison to prior research and the present study, several off-grid microgrid systems were designed specifically for Bangladesh and were used to assess the performance of various power systems in different places are presented in Table I. Most of the studies have limitations in ignoring the life cycle cost (LCC). Adding LCC during computation time improves the analysis of the planning and operation of microgrid systems [9]. The microgrid system's LCC comprises capital, replacement, resale, and operation and maintenance costs [11]. Nevertheless, the error in planning is essential due to the need for more consideration for the microgrid component lifetime and uptime [12]. In addition, the microgrid sizing problem is solved in this study through the use of a recent metaheuristic optimization method, the grey wolf optimization algorithm (GWO). It is of crucial significance in the case study area to select a sustainable microgrid structure that is appropriate for Manpura Island. The microgrid is composed of PV, DG, and BESS. The following are the study's contributions:

- The main contribution consists of identifying an optimal configuration that reduces life cycle costs (LCC) and cost of energy (COE), meets demand, and maintains a loss of power supply probability (LPSP).
- Determine whether energy-storage technologies—

photovoltaic (PV), diesel generator (DG), and batteries - particularly lead acid (LA), lithium-ion (Li-ion), and nickel-iron (Ni-Fe) - are the most cost-effective and environmentally friendly.

- Implementation of GWO serves as a novel AI technique aimed at improving the size of island microgrids. The obtained outcomes are evaluated about accuracy and convergence, and compared to the findings of GA and PSO.

The organization of the following sections is: The case study area is described in depth in Section II. In Section III, the methodology is explained in detail. Section IV provides illustrations of the results and discussions. Section V presents the conclusion.

II. CASE STUDY: MANPURA ISLAND, BANGLADESH

Manpura Island is located in Bangladesh's northern Bay of Bengal, specifically at the Meghna River mouth. It is divided into Manpura Upazila and Bhola District. The island spans 373 km^2 and has a population of approximately 1,25,000. The coordinates of Manpura are 22.2369°N 90.9542°E. A satellite picture of the site is shown in Fig. 1, source of Google Maps.

Fig. 1. The map shows the location of the study area.. (Source: Google Maps).

The connected load for Manpura Island consists of twenty-four residences, four shops, a mosque, a madrasa, and a power plant office. A television, two fans, and three lights are present in each house, along with a wall outlet. Every shop is set up with both a light and a fan. There are six lamps, six fans, and a computer installed in the madrasa. There are four lamps, four fans, and a pump within the mosque. There is a computer, a lamp, a charging station, and a fan within the workspace. Two distinct seasons are indicated by the expected load: winter, which covers from November to February, and summer, which covers from March to October. Fig. 2 shows a daily load curve for two seasons based on the primary data that was supplied. The curve illustrates the daily total capacity consumed per hour. During the winter, people do not use fans due to the cold weather. Because of this, demand is consistently very low after midnight. In both seasons, peak consumed power occurred at 9 p.m. on the 21st hour, with values of 9580 W during the summer and 5380 W during the winter. The locality's total daily consumption is 140060 W for summer and 74600 W for winter [27].

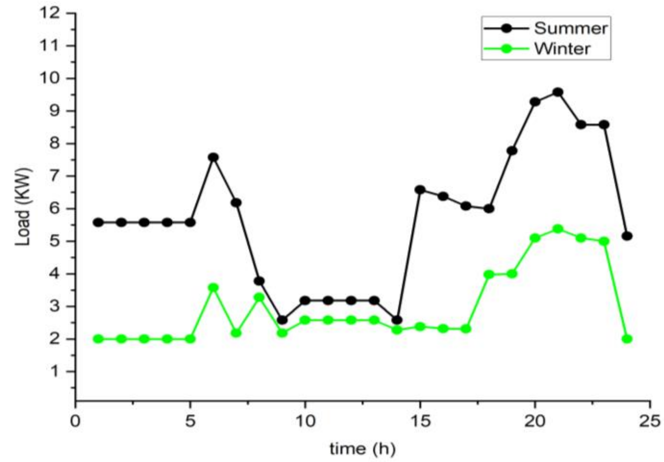

Fig. 2. Daily load profile.

III. METHODOLOGY

In the process of determining the optimal size for a microgrid, accurate mathematical representations of its components are vital. The study presented a microgrid that combines backup diesel generation and a BESS with a PV energy source. Fig. 3 displays the microgrid's schematic diagram under investigation, and the ensuing subsections provide in-depth explanation of each component model. As shown in Fig. 4, the proposed microgrid employs an operational energy management strategy (EMS). When PV is unable to fulfill load needs, the energy management strategy uses batteries; when the BESS runs low, 50% of the nominal power of the DG system is used. PV is the primary energy source for the EMS.

A. PV Power Generation

The mathematical expression for photovoltaics power output (P_{PV}) is as follows [28]:

$$P_{PV}(t) = PV_{rated} \times \left(\frac{G_t}{G_{ref}}\right) \times [1 + K_T \times (T_c - T_{ref})] \quad (1)$$

The equation provided calculates the cell temperature (T_c):

$$T_c = T_{amb}(t) + (0.0256 \times G(t)) \quad (2)$$

Energy generation of a PV panel (E_{PV}) is as follows:

$$E_{PV}(t) = N_{PV} \times P_{PV}(t) \times \Delta t \quad (3)$$

B. Battery Energy Storage System (BESS)

The mathematical expression presented in reference [28] is employed to calculate the store energy in the battery bank (E_{Batt}) at a given hour t.

$$E_{Batt}(t) = (1-\sigma) \times E_{Batt}(t-1) + \left(E_G(t) - \frac{E_L(t)}{\eta_{Conv}}\right) \times \eta_{CC} \times \eta_{rbatt} \quad (4)$$

The following equations are utilized in the generation of electrical energy (E_G):

$$E_G(t) = [E_{DC}(t)] \times \eta_{Conv} \quad (5)$$

$$E_{DC}(t) = E_{PV}(t) \quad (6)$$

When renewable energy sources (RESs) fail to generate enough electrical power to meet demand, the battery energy system supplies the necessary capacity, which is calculated as follows:

$$E_{Batt}(t) = (1-\sigma) \times E_{Batt}(t-1) + \frac{\left(\frac{E_L(t)}{\eta_{Conv}} - E_G(t)\right)}{\eta_{rbatt}} \quad (7)$$

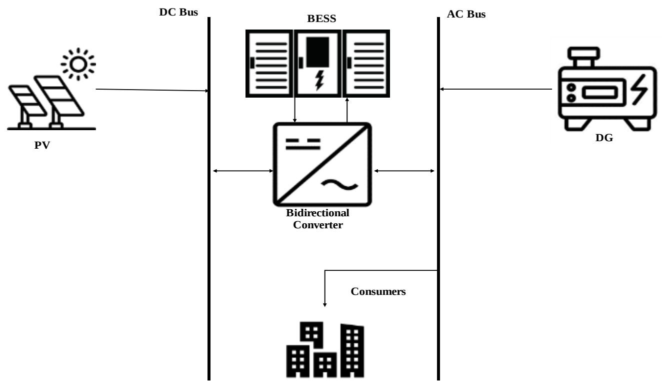

Fig. 3. Proposed Microgrid

C. Diesel Generator (DG)

The quantity required to meet demand determines the hourly fuel consumption of DG, which is governed by the linear rule and is calculated as follows [28]:

$$F_{DG}(t) = \left(a_{DG} \times P_{DG,gen}(t) + b_{DG} \times P_{DG,rat}\right) l/h \quad (8)$$

To calculate the TAFCIL for the DG, use the equation that follows:

$$TAFCIL = \sum_{t=1}^{8760} F_{DG}(t) \quad (9)$$

D. CO_2 emission

The anticipated CO_2 emissions are calculated based on the following is the expected fuel usage per hour [28]:

$$CO_2 = SE_{CO_2}(kg/l) \times F_{DG}(t)\left(\frac{l}{h}\right) \quad (10)$$

To calculate the total annual CO_2 emissions from the DG, apply the following equation:

$$TA_{CO_2} = \sum_{t=1}^{8760} CO_2 \quad (11)$$

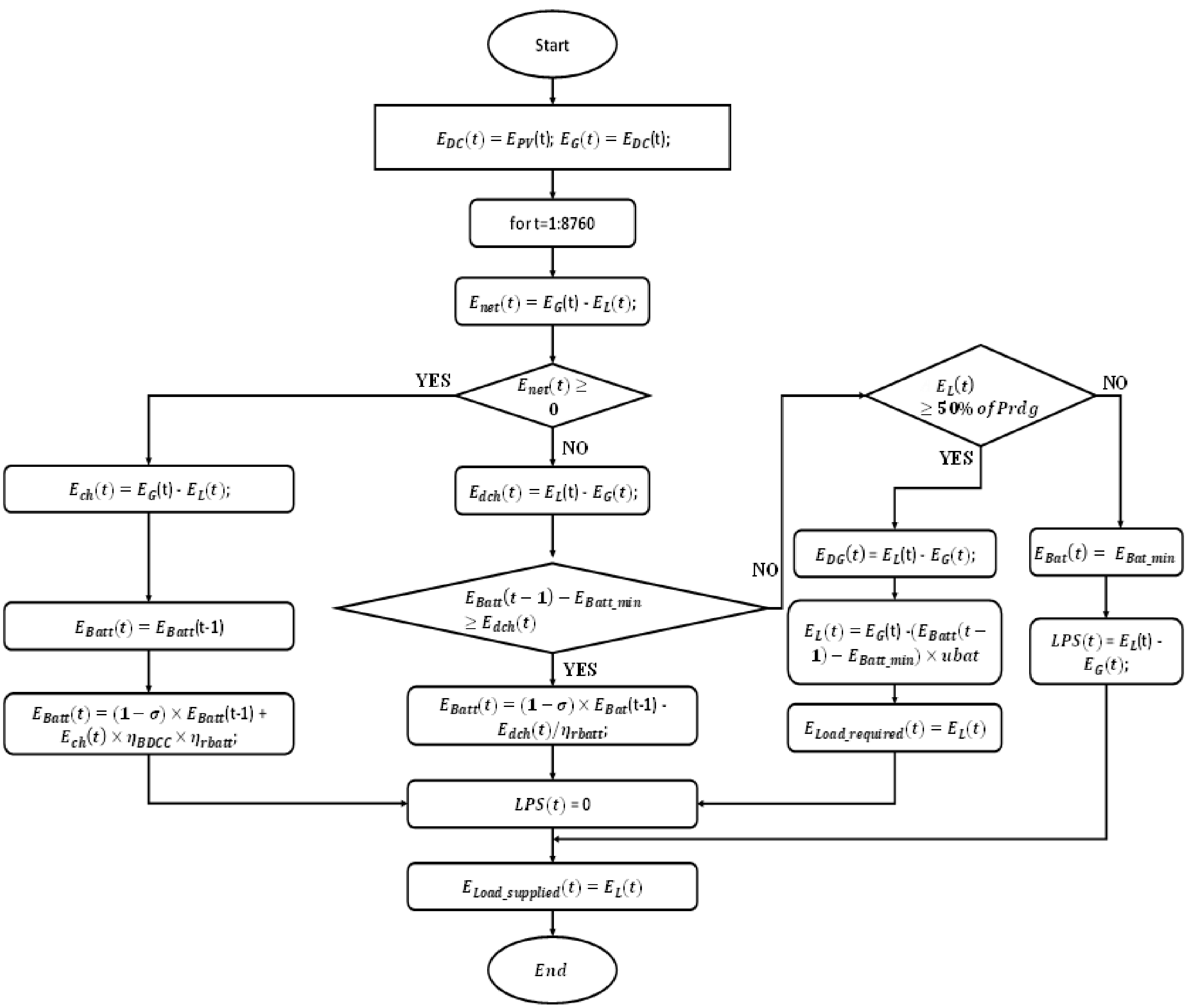

Fig. 4. Energy management strategy (EMS) of the proposed microgrid

E. Bi-Directional Converter with a Charge Controller

During electrical energy conversion, the BDC-CC acts as both a rectifier and an inverter. Inverter mode converts DC back into AC while rectifier mode converts AC into DC. The battery bank benefits from the charge controller's efficient prevention of overcharging or discharging. The BDC-CC power rating ($P_{BD\text{-}CC}$) is determined using the following equation [3]:

$$P_{\mathrm{BDC-CC}} = E_{T,max} \times 1.1 \quad (12)$$

The converter's multiplication factor of 1.1 indicates that is capable of accommodating an extra 10% of its full capacity.

F. Economic Analysis

The life cycle cost of the total system is calculated by combining the ICC, EREC, $P_{V,O\&M}$ costs, $P_{V,REP}$ costs, and $P_{V,FUEL}$ prices [29].

$$\mathrm{LCC} = \mathrm{ICC} + \mathrm{EREC} + \mathrm{P_{V,O\&M}} + \mathrm{P_{V,REP}} + \mathrm{P_{V,FUEL}} \quad (13)$$

To find the microgrid component's ICC, use the following formula:

$$ICC = \left[\left(N_{PV} \times C_{PV,cap}\right) + \left(N_{BATT} \times C_{BATT,cap}\right) + \left(C_{BDC-CC,cap}\right) + \left(C_{DG,cap}\right)\right] \quad (14)$$

To calculate microgrid component EREC costs, the subsequent equation is applied:

$$EREC = \left(N_{PV} \times C_{PV,erec}\right) + \left(N_{BATT} \times C_{BATT,erec}\right) \times \sum_{b=1}^{N_r} \frac{(1+x)^{bN_c-1}}{(1+y)^{bN_c}}) + \left(C_{BDC-CC,erec} \times \sum_{b=1}^{N_r} \frac{(1+x)^{bN_c-1}}{(1+y)^{bN_c}})\right) + \left(C_{DG,erec} \times \sum_{b=1}^{N_r} \frac{(1+x)^{bN_c-1}}{(1+y)^{bN_c}})\right) \quad (15)$$

The following formula is used to determine the microgrid components' present value of their yearly operation and maintenance costs:

$$P_{V,O\&M} = \left[\left(N_{PV} \times C_{PV,O\&M}\right) + \left(N_{BATT} \times C_{BATT,O\&M}\right) + \left(C_{BDC-CC,O\&M}\right) + \left(C_{DG,O\&M}\right)\right] \times \sum_{i=1}^{N} \frac{(1+x)^{i-1}}{(1+y)^{i}}] \quad (16)$$

$$y = \frac{I_{nom} - x}{1+x} \quad (17)$$

The following formula is used to determine the present value of yearly replacement costs for microgrid components:

$$P_{V,REP} = \left(N_{BATT} \times C_{BATT,REP}\right) \times \sum_{b=1}^{N_r} \frac{(1+x)^{bN_c-1}}{(1+y)^{bN_c}}) + \left(C_{DG,REP} \times \sum_{b=1}^{N_r} \frac{(1+x)^{bN_c-1}}{(1+y)^{bN_c}})\right) \quad (18)$$

$$N_r = int\left(\frac{N - N_C}{N_C}\right) \quad (19)$$

The present value of the yearly fuel price for the microgrid component is shown in the following equation.

$$P_{V,FUEL} = TAFCIL_{DG} \times \sum_{i=1}^{N} \frac{(1+x)^{i-1}}{(1+y)^{i}} \quad (20)$$

G. Optimization techniques

The study addressed technical and economic constraints when optimizing the sizing of island microgrids with different configurations using the grey wolf optimization (GWO) algorithm. GWO is known for its simplicity, flexibility, and efficiency. The study entails determining the cost of energy (COE) and life cycle cost (LCC) of an objective function. Particle swarm optimization (PSO) and genetic algorithms (GA) are used to verify the proposed approach.

1) Grey Wolf Optimization (GWO)

GWO is an intelligent optimization technique that mimics the hunting and leadership styles of grey wolves in natural form. User-friendly, the GWO algorithm is distinguished by its simplicity in theory, high search accuracy, efficiency in search, and simplicity of study. Alphas, betas, deltas, and omegas are the four groups into which the wolves are divided in the GWO algorithm. The strength of these groupings is ascertained by the use of a fitness function. The pack leaders and highest-ranking members are the alpha wolves. The second most dominant wolves are beta wolves. It helps the dominating wolves and keeps the wolf pack organized and orderly. Below the beta wolves, the delta wolves are distinguished by their ferocity but absence of leadership traits. At the bottom of the hierarchy are produced less strong omega wolves [29]. Fig. 5 shows the GWO flowchart applied to the proposed microgrid system.

2) Genetic Algorithm (GA)

GA are evolutionary techniques based on computational optimization. Three fundamental GA operators are Mutation, Crossover, and Selection. Working together, these operators evolve the population to raise mean fitness. While mutation and crossover promote genetic variety, selection ensures that better population members are procreated. Because GA is iterative, the next generations pick up knowledge from the ones before them. The approach promotes the replication of fitter individuals, hence disseminating "excellent DNA" or superior solutions. The method converges to the best or almost best solution through this natural selection process. GAs can converge to global optimal solutions with appropriate algorithm settings. Because GAs is flexible and able to investigate a wide range of solutions, they help address challenging optimization problems in many fields. Depending on the encoding method, the chromosomes—parameters of the different solutions—are kept in a binary integer or real value data structure. A fitness function particular to the problem measures the chromosomal solution [31].

3) Particle Swarm Optimization (PSO)

The PSO algorithm is a stochastic optimization method that is based on the concept of swarm intelligence. Individual PSO particles make up this "swarm," and the algorithm explores and takes advantage of a search space by using their combined activity. Every swarm particle moves through the search space with a particular velocity and direction. PSO is special in that way particles move. The primary factors influencing them are the most well-established location of the particle and the overall most well-established location of the swarm. Within the search area, these positions stand for viable solutions. Particles move constantly assessing and changing their places in line with the quality of these known solutions. A particle that improves its position during exploration helps the swarm as well as itself. As particles exchange information to guide the swarm collectively towards areas of the search space that are more likely to hold better solutions, this cooperative behavior defines PSO. PSO mimics, essentially, the social behavior of particles in a swarm, where the group's general movement is informed and influenced by the findings of individual particles, helping to optimize a particular problem [31].

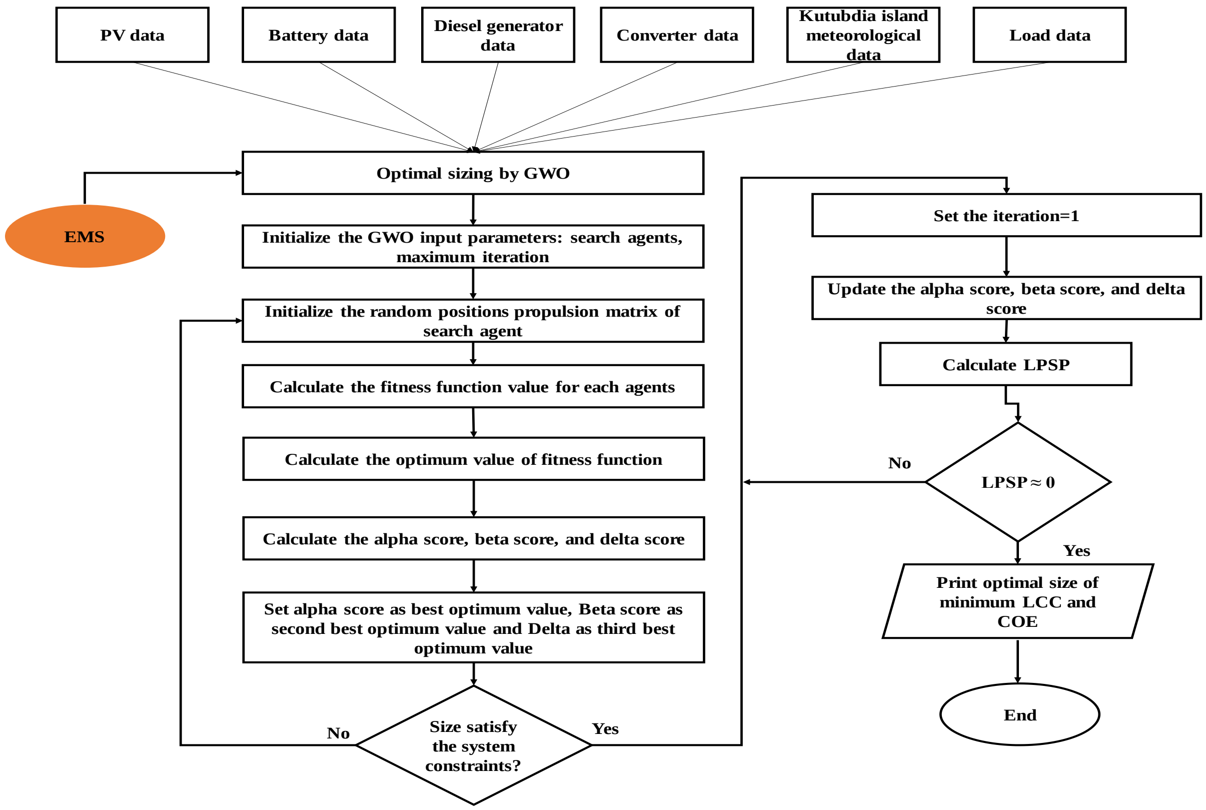

Fig. 5. GWO flowchart of the proposed microgrid.

H. Problem Formulation

LCC, COE, and constraints related to PV, battery, and DG are taken into account when formulating the function's purpose. The following factors in more detail now:

1) Objective Function

Life Cycle Cost (LCC):
Minimize the system's LCC while satisfying the requirement of LPSP. Three factors affect the LCC: the number of PV panels (N_{PV}), batteries (N_{BATT}) and diesel generator (N_{DG}).

$$min\ LCC(N_{PV}, N_{BATT}, N_{DG}) = \sum_{C=PV,BATT,DG}^{min}(LCC)_C \quad (21)$$

Cost of Energy (COE):
An essential factor in evaluating the economic analysis of the microgrid is the cost of energy (COE). Then, to find it, the following equation is used:

$$COE = \left(\frac{LCC}{\sum_{t=1}^{8760} E_L(t)}\right) \times CRF \quad (22)$$

2) Constraints

Upper and Lower bounds:
The study's upper bound is the largest amount possible after limiting the use of the remaining sources, which include diesel, solar, and batteries, while its lower bound is zero.

$$0 \le N_{PV} \le N_{PVmax} \quad (23)$$
$$0 \le N_{BATT} \le N_{BATTmax} \quad (24)$$
$$0 \le N_{DG} \le N_{DGmax} \quad (25)$$

Battery Energy Storage limits:
The following limitation will determine how much energy the battery bank can store or release [33]:

$$E_{BATTmin} \le E_{BATT}(t) \le E_{BATTmax} \quad (26)$$
$$E_{BATTmax} = \left(\frac{N_{BATT} \times V_{BATT} \times S_{BATT}}{1000}\right) \times SOC_{max-bat} \quad (27)$$
$$E_{BATTmin} = \left(\frac{N_{BATT} \times V_{BATT} \times S_{BATT}}{1000}\right) \times SOC_{min-bat} \quad (28)$$
$$SOC_{min-bat} = 1 - DOD \quad (29)$$
$$SOC_{max-bat} = SOC_{min-bat} + DOD \quad (30)$$

Diesel Generator Limit:
According to the study, DG operating requires a minimum load equal to 50% of its rated capacity. Therefore, once the DG satisfies the requirements provided below [27], it will operate in a simulated environment:

$$\frac{E_L(t)}{\eta_{conv}} \ge P_{DG,rat \times \Delta t} \quad (31)$$

Power Reliability Index:
Energy reliability index indicates its dependable capacity to supply the reliable power supply in specific circumstances. The microgrid power reliability index involves calculating the LPSP, which represents the possibility of power supply failure. The computation [32] is derived using the hourly energy consumption and loss of power supply (LPS).

$$LPS(t) = \frac{E_L(t)}{\eta_{conv}} - E_G(t) - [(1-\sigma) \times E_{BATT}(t-1) - E_{Batt-min}] \times \eta_{rbatt} \quad (32)$$
$$LPSP = \frac{\sum_{t=1}^{T} LPS(t)}{\sum_{t=1}^{T} E_L(t)} \quad (33)$$

IV. Results and Discussion

The research incorporates the optimal sizing of the microgrid system using MATLAB, taking GA, PSO, and GWO algorithms into consideration. PV, DG, and BESS constitute the microgrid system. Manpura Island in Bangladesh serves as the case study area. It is situated at 22.2369°N and 90.9542°E. At first, input data were gathered, such as load demand, solar irradiation, and ambient temperature. The historical data was collected by NASA. The hourly capacity requirement of the island microgrid fluctuates, ranging from 2 to 10 kW. Fig. 6 depicts the typical year's annual load demand. The annual ambient temperature and solar irradiance are depicted in Fig. 7-8. The components of the island microgrid are susceptible to the impact of disasters. Components with an appropriate rated capacity are required to prevent equipment failure outages and guarantee the reliability of the system. Table II presents the economic and technical specifications of the system.

TABLE II
MICROGRID COMPONENT ECONOMIC AND TECHNICAL SPECIFICATIONS

Parameters	**Value**	**Parameters**	**Value**
Project lifetime	25 years	Nominal voltage (VBAT) [40]	12.8V
Nominal interest rate [33]	8%	Round trip efficiency (ηrbat)	92%
Inflation rate [33]	3%	Lifespan	800 cycles @70% DOD
Rated power of PV Panel [34]	0.25kWp	Self-discharge rate (%/day) (σ)	0.20%
Lifetime of PV Panel	25 years	Capital cost (CC)	$3,317
Capital cost of PV Panel	$250.00	Annual O&M cost	No maintenance
AO&M cost of PV Panel	$6.25	Operating temperature	−20 °C to +50 °C
DG (Company: Hyundai, Model No: DHY8600SE-T) [38]	12 KVA	Cycle life	3000 cycles @70% DOD
C&R of DG	$2058	Battery (Type: Nickel Iron, Company: Iron Edison, Model no: TN 1000 [41]	
Diesel Price [14]	$0.97	Nominal capacity (SBAT)	1000Ah
Battery (Type: Lead Acid, Company: Trojan, Model no: SSIG 06 490 [39]		Nominal voltage (VBAT)	1.2V
Nominal capacity (SBAT)	490Ah	Round trip efficiency (ηrbat)	80%
Nominal voltage (VBAT)	6V	Lifespan	30 years @70% DOD
Round trip efficiency (ηrbat)	85%	Self-discharge rate (%/day) (σ)	1.00%
Lifespan	3 years @70% DOD	Capital cost (CC)	$1057
Self-discharge rate (%/day) (σ)	0.30%	Annual O&M cost	2% of CC
Capital cost (CC)	$410	Cycle life	11000 cycles @70% DOD
Annual O&M cost	2.5% of CC	Rated power of BDC-CC	10kW
Cycle life	800 cycles @70% DOD	Lifetime of converter [28]	10 years
Operating temperature	-20°C to +45 °C	Capital cost of converter [28]	$1080
Battery (Type: Lithium Iron Phosphate, Company: Victron, Model no: LFP-12.8/200-a [39]		AO&M cost of converter [28]	2.5% of CC
Nominal capacity (SBAT)	300Ah	Erection cost of converter [28]	$129.6
Erection cost of PV [28]	$25.6	Erection cost of battery [28]	3% of CC of battery

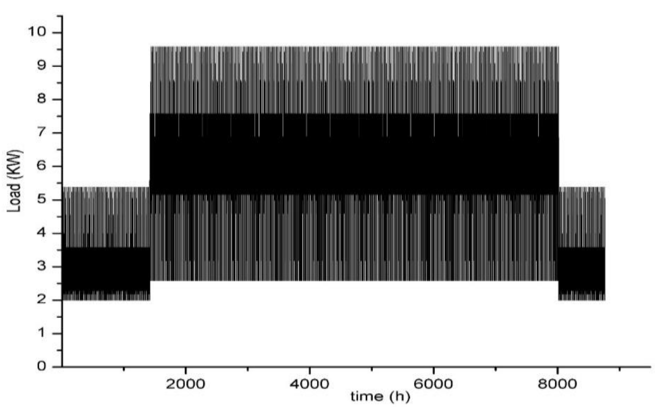

Fig. 6. Annual load demand

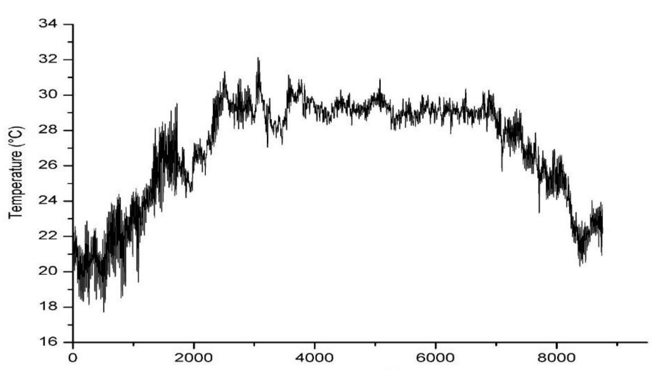

Fig. 7. Annual ambient temperature.

TABLE III
OPTIMIZATION RESULTS OBTAINED VIA GA, PSO AND GWO METHODS

Configuration	Quantity and Cost	GA	PSO	**GWO**
PV/LA/DG	N_{PV}	292	285	**292**
	N_{BATT}	145	120	**114**
	TAFCIL	0	235	**197**
	$TACO_2$ (kgs)	0	564	**474**
	COE ($/kWh)	0.3237	0.3194	**0.3048**
	LCC ($)	220106	212520	**202748**
PV/Li-ion/DG	NPV	690	647	**654**
	NB	47	50	**45**
	TAFCIL	50	1904	**1313**
	$TACO_2$ (kgs)	121	4570	**3150**
	COE ($/kWh)	0.8920	0.8631	**0.8512**
	LCC ($)	593574	574295	**566430**
PV/Ni-Fe/DG	NPV	361	375	**292**
	NB	106	99	**114**
	TAFCIL	3.25	115	**198**
	$TACO_2$ (kgs)	7.8	277	**474**
	COE ($/kWh)	0.4785	0.4717	**0.4552**
	LCC ($)	318410	313906	**302811**

A. *Optimal Size of different configuration and methods*

The optimal size for the three configurations produced by the three methods is shown in Table II. Every solution has an LPSP value of 0%. Based on the findings, the PV/LA/DG combination has been identified as the most efficient option for the case study, as assessed by the use of the GWO technique. This combination results in a system with a minimum life cycle cost (LCC) of $202748 and a COE of 0.3048 $/KWh. As well as the annual energy production from PV and DG, Fig. 9 shows how the LA battery bank is charged and discharged in response to load demand. Fig. 10 depicts the comparison between the proposed approach and other methodologies in evaluating the variability of LCC and COE. The proposed methodology has the lowest LCC and COE compared to GA and PSO methods. The PSO approach demonstrates a 4.5% increase, while the GA method exhibits a 7% rise.

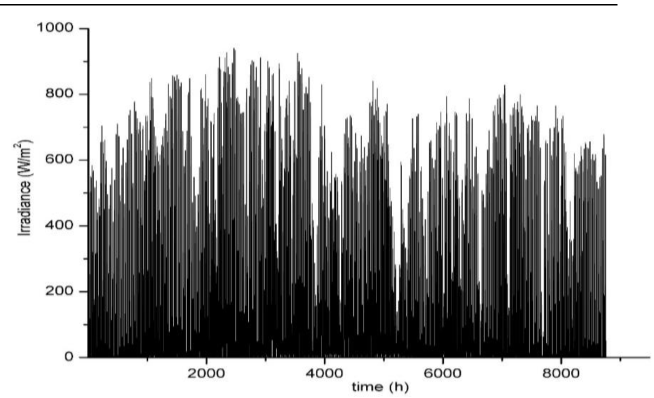

Fig. 8. Annual solar irradiance.

B. *Optimal Size of different configuration and methods*

The optimal size for the three configurations produced by the three methods is shown in Table II. Every solution has an LPSP value of 0%. Based on the findings, the PV/LA/DG combination has been identified as the most efficient option for the case study, as assessed by the use of the GWO technique. This combination results in a system with a minimum life cycle cost (LCC) of $202748 and a cost of energy (COE) of 0.3048 $/KWh. As well as the annual energy production from PV and DG, Fig. 9 shows how the LA battery bank is charged and discharged in response to load demand. Fig. 10 depicts the comparison between the proposed approach and other methodologies in evaluating the variability of LCC and COE. The proposed methodology has the lowest LCC and COE compared to GA and PSO methods. The PSO approach demonstrates a 4.5% increase, while the GA method exhibits a 7% rise.

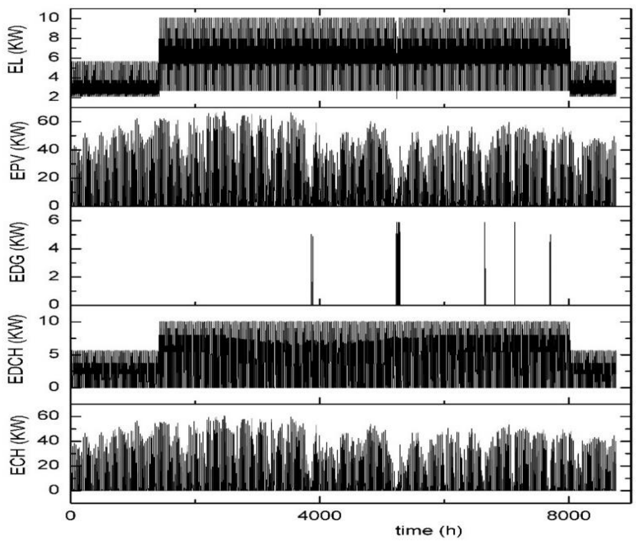

Fig. 9. Annual electricity generation of microgrid.

C. Impact of LA/Li-ion/Ni-Fe Battery Technology

The microgrid in LA, which relies on battery technology, provides the most economical LCC and COE, which are $202748 and 0.3048$/KWh, respectively, as illustrated in Table II. In comparison to various configurations of battery-based microgrids, the base case of this analysis offers an optimal value. The Li-ion-powered microgrid has an LCC and COE of $566430 and 0.8512$/KWh, respectively, costs approximately 180% higher than the base. The microgrid powered by Ni-Fe battery has a LCC of $302811 and a COE of 0.4552 $/kWh, which is approximately 49% higher than the base.

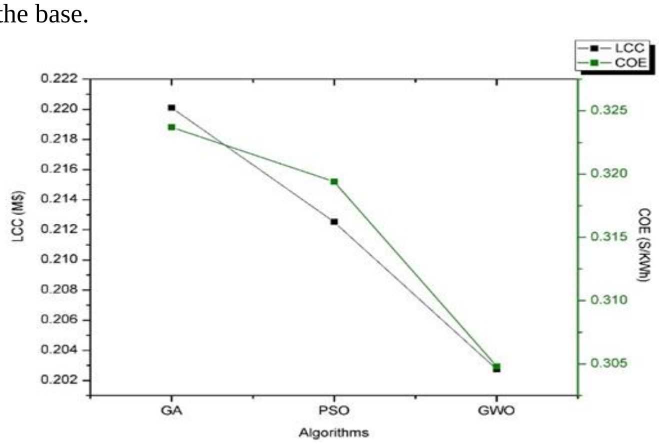

Fig. 10 LCC and COE variation for different algorithm

D. Convergence Speed

Figure 11 shows the convergence curve for each algorithm for the LA-based microgrid. Using the convergence of GA, PSO, and GWO algorithms to the optimal value of LCC, the suggested method attained the lowest LCC at the 23rd, 21st, and 18th iterations, respectively.

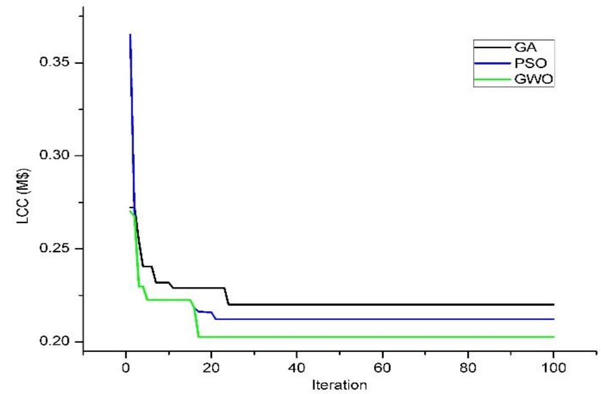

Fig. 11 Convergence curve of the LA battery based microgrid for different algorithms.

E. Comparison Analysis

A comparative analysis highlighting the effectiveness of the proposed approach on Manpura Island in earlier efforts is presented in Table IV. A number of studies on the design of a microgrid for Manpura Island have been carried out by RESs. For the most part, LCC disregarded this research. The proposed approach's COE is 0.3048$/kWh, which is lower than previous works.

TABLE IV
COMPARISON STUDY WITH PREVIOUS WORKS AT MANPURA ISLAND

Ref.	Sources used in microgrid	Techniques	LCC	COE ($/KWh)
[27]	PV/BESS	PVGIS	×	×
[36]	PV/Hydrokinetic energy/Biogas/WT/BESS	HOMER	×	0.5515
[37]	PV/Biogas/WT	HOMER	×	0.691
[38]	PV/WT/BESS	HOMER	×	0.315
Proposed work	**PV/DG/BESS**	**GWO**	**√**	**0.3048**

V. CONCLUSION

In this study for Manpura Island Bangladesh, finding the optimal microgrid component size using GWO is suggested in situations when expanding the distribution network is impractical to achieve low LCC and COE. Further research has been carried out on the choice of three battery technologies: Li-ion, Ni-Fe, and LA, for a steady supply of power. The GWO technique offers fast convergence speed and the best islanded microgrid design with optimum LCC and COE values in comparison to GA and PSO. Results obtained showed that the lowest LCC and COE, $202748 and 0.3048$/KWh, respectively, were obtained with an LA battery-based microgrid design. With an LCC of $566430 and a COE of 0.8512 $/KWh, the Li-ion-powered microgrid performs around 180% better than the base value. LCC and COE of the Ni-Fe battery-powered microgrid are $302811 and 0.4552 $/kWh, which is 49% more than the base value. In the end, a comparison analysis was conducted between LCC and COE, in relation to previous studies conducted at Manpura Island. The findings of this study conclusively demonstrate that the proposed work yields superior outcomes when compared to previous works. Island microgrids have policy implications that improve resilience by integrating clean energy, expanding access to electricity, and reducing total costs. By identifying particular sustainable indicators, it will undoubtedly be beneficial for policymakers to find appropriate microgrid designs, especially in any remote area of a developing country.

The future scope entails developing an algorithm that solves continuous multi-objective functions. In addition, the implementation of managing energy savings and rescheduling times when demand is at its lowest can reduce peak load demands through an effective planning process. By putting this concept into practice, investment costs might be significantly decreased.

NOMENCLATURE

Symbols	Description
MG	Microgrid
RES	Renewable energy sources
PV	Photovoltaic
WT	Wind turbine
PHS	Pump hydro system
DG	Diesel generator
BESS	Battery energy storage system
LA	Lead acid
Li-ion	Lithium-ion
Ni-Fe	Nickel - iron
LCC	Life cycle cost
COE	Cost of energy
ICC	Initial capital cost
NPC	Net present cost
LCE	Life cycle emission
LCOE	Levelized cost of energy
LPSP	Loss of power supply probability
TAFCIL	Total annual fuel consumption in liters
N_{PV}	Number of photovoltaic panels
N_{BATT}	Number of batteries
SoC	State of charge
HOMER	Hybrid Optimization of Multiple Energy Resources
GA	Genetic Algorithm
PSO	Particle swarm optimization
GWO	Grey wolf optimization
AO&M	Annual operation and maintenance
DOD	Depth of discharge
LPS	Loss of power supply
P_{PV}, P_{DG}	Power out of photovoltaics panels, and diesel generator
T_c, T_{ref}, T_{amb}	Temperature of cell, reference, and ambient
G	Solar irradiation
K_T	Maximum power transfer coefficient
E_G, E_{PV}, E_{Batt}, E_{DC}	Generation of electrical energy, photovoltaics panels, batteries, DC
E_L	Electrical load demand
η_{conv}, η_{rbatt}	Efficiency of converter and round-trip efficiency
σ	Battery's self-discharge rate
F_{DG}	Diesel generator fuel consumption
a_{DG} , b_{DG}	Diesel generator of consumption curve coefficients
l	liters
h	hours
SE_{CO_2}	Per liters diesel specific emission of carbon dioxide
$E_{T,max}$	Maximum energy transferable by the converter
$P_{V,O\&M}$, $P_{V,REP}$, $P_{V,FUEL}$	Present value of operation and maintenance costs, replacements costs, and fuel costs
$C_{PV,cap}$, $C_{BATT,cap}$, $C_{BDC-CC,cap}$, $C_{DG,cap}$	Capital cost of photovoltaics panels, batteries, bi-directional converter, and diesel generator
$C_{PV,erec}$, $C_{BATT,erec}$, $C_{BDC-CC,erec}$, $C_{DG,erec}$	Erection cost of photovoltaics panels, batteries, bi-directional converter, and diesel generator
$C_{PV,O\&M}$, $C_{BATT,O\&M}$, $C_{BDC-CC,O\&M}$ $C_{DG,O\&M}$	Operation and maintenance cost of photovoltaics panels, batteries, bi-directional converter, and diesel generator
$C_{BATT,REP}$, $C_{DG,REP}$	Replacement cost of batteries, and diesel generator
y	Discount rate
I_{nom}	Nominal interest rate
x	Inflation rate
N	Life span
N_C	Life duration of each component
N_r	Number of component replacements required
CRF	Capital recovery factor
V_{BATT}, S_{BATT}	Voltage and rated capacity of the battery

REFERENCES

[1] B. K. Das, and F. Zaman, "Performance analysis of a PV/Diesel hybrid system for a remote area in Bangladesh: Effects of dispatch

strategies, batteries, and generator selection," *Energy*, vol. 169, pp. 263-276, Feb. 2019.

[2] J. Farfan, and C. Breyer, "Structural changes of global power generation capacity towards sustainability and the risk of stranded investments supported by a sustainability indicator," *J. of Clean. Prod.*, vol. 141, pp. 370-384, Jan. 2017.

[3] A.M. Patel, and S. K. Singal, "Optimal component selection of integrated renewable energy system for power generation in stand-alone applications," *Energy*, vol.175, pp. 481-504, May 2019.

[4] B. Bahmani-Firouzi, and R. Azizipanah-Abarghooee, "Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm," *Int. J. of Elec. P. & Energy Systems*, vol. 56, pp. 42-54, Mar. 2014.

[5] J. Bandopadhyay, and P. K. Roy, "Application of hybrid multi-objective moth flame optimization technique for optimal performance of hybrid micro-grid system," *App. Soft Comp.*, vol. 95, 106487, Oct. 2020.

[6] D.K. Geleta, and M. S. Manshahia, "Artificial bee colony-based optimization of hybrid wind and solar renewable energy system," In Handbook of research on energy-saving technologies for environmentally-friendly agricultural development, pp. 429-453, IGI Global, 2020.

[7] S. Sanajaoba, "Optimal sizing of off-grid hybrid energy system based on minimum cost of energy and reliability criteria using firefly algorithm," *Solar Energy*, vol. 188, pp. 655-666, Aug. 2019.

[8] I. Çetinbaş, B. Tamyürek, and M. Demirtaş, "Sizing optimization and design of an autonomous AC microgrid for commercial loads using Harris Hawks Optimization algorithm," *Energy Conv. and Manage.*, vol. 245, 114562, Oct. 2021.

[9] A.R. Sagor, M.R. Hazari, S. Ahmad, E. Ogliari, C.A. Hossain, E. Jahan, & M.A. Mannan, "Optimal sizing of islanded microgrid using pelican optimization algorithm for Kutubdia Island of Bangladesh," Electric Power Systems Research, 238, 111088, 2025.

[10] V.V. Thang, and T. Ha, "Optimal siting and sizing of renewable sources in distribution system planning based on life cycle cost and considering uncertainties," *AIMS Energy*, vol. 7, no. 2, pp. 211-226, Apr. 2019.

[11] D.A. Konneh, H.O.R. Howlader, R. Shigenobu, T. Senjyu, S. Chakraborty, and N. Krishna, "A multi-criteria decision maker for grid-connected hybrid renewable energy systems selection using multi-objective particle swarm optimization," *Sustainability*, vol. 11, no. 4, 1188, Feb. 2019.

[12] S. Hosseini, and M.D. Sarder, "Development of a Bayesian network model for optimal site selection of electric vehicle charging station," *Int. J. of Elec. P. & Energy Systems*, vol. 105, pp. 110-122, Feb. 2019.

[13] A.M. Jasim, B.H. Jasim, F.C. Baiceanu, and B.C. Neagu, "Optimized sizing of energy management system for off-grid hybrid solar/wind/battery/biogasifier/diesel microgrid system," *Mathematics*, vol. 11, no. 5, 1248, Mar. 2023.

[14] T.F. Agajie, A. Fopah-Lele, I. Amoussou, A. Ali, B. Khan, O. P. Mahela, R.S.S. Nuvvula, D. K. Ngwashi, E. S. Flores, and E. Tanyi, "Techno-Economic Analysis and Optimization of Hybrid Renewable Energy System with Energy Storage under Two Operational Modes," *Sustainability*, vol. 15, no. 15, 11735, Jul. 2023.

[15] P.P. Kumar, and R. P. Saini. "Optimization of an off-grid integrated hybrid renewable energy system with different battery technologies for rural electrification in India," *J. of energy storage*, vol. 32, 101912, Dec. 2020.

[16] L.E. Boujdaini, A. Mezrhab, M. A. Moussaoui, F. Jurado, and D. Vera, "Sizing of a stand-alone PV–wind–battery–diesel hybrid energy system and optimal combination using a particle swarm optimization algorithm," *Elec. Engi.*, vol. 104, no. 5, pp. 3339-3359, Apr. 2022.

[17] N. Lazaar, E. Fakhri, M. Barakat, J. Sabor, and H. Gualous. "A genetic algorithm based optimal sizing strategy for PV/battery/hydrogen hybrid system." in *A.I. and Ind. Appl.: AI Tech. for Cyber-Physical, Digital Twin Systems and Engi. Appl.*, pp. 247-259, Springer International Publishing, Jul. 2020.

[18] B.K. Das, R. Hassan, M.S.H.K. Tushar, F. Zaman, M. Hasan, and P. Das. "Techno-economic and environmental assessment of a hybrid renewable energy system using multi-objective genetic algorithm: A case study for remote Island in Bangladesh," *Energy Conversion and Management*, vol. 230, 113823, Feb. 2021.

[19] B.K. Das, M. Hasan, and F. Rashid, "Optimal sizing of a grid-independent PV/diesel/pump-hydro hybrid system: A case study in Bangladesh," *Sustain. Energy Tech. and Assess.*, vol. 44, 100997, Apr. 2021.

[20] F. Rashid, M.E. Hoque, M. Aziz, T.N. Sakib, M.T. Islam, and R. M. Robin, "Investigation of optimal hybrid energy systems using available energy sources in a rural area of Bangladesh," *Energies*, vol. 14, no. 18, 5794, Sept. 2021.

[21] T. Chowdhury,H. Chowdhury, M.I. Miskat, P. Chowdhury, S. M. Sait, M. Thirugnanasambandam, and R. Saidur. "Developing and evaluating a stand-alone hybrid energy system for Rohingya refugee community in Bangladesh," *Energy*, vol. 191, 116568, Jan. 2020.

[22] H.S. Das, A.H.M. Yatim, C.W. Tan, and K. Y. Lau. "Proposition of a PV/tidal powered micro-hydro and diesel hybrid system: A southern Bangladesh focus," *Renew. and Sustain. Energy Reviews*, vol. 53, pp. 1137-1148, Jan. 2016.

[23] S. Mandal, B.K. Das, and N. Hoque, "Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh," *J. of Clean. Prod.*, vol. 200, pp. 12-27, Nov. 2018.

[24] B.K. Das, N. Hoque, S. Mandal, T. K. Pal, and M. A. Raihan. "A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh," *Energy*, vol. 134, pp. 775-788, Sept. 2017.

[25] M.S. Islam, R. Akhter, and M.A. Rahman, "A thorough investigation on hybrid application of biomass gasifier and PV resources to meet energy needs for a northern rural off-grid region of Bangladesh: A potential solution to replicate in rural off-grid areas or not?," *Energy*, vol. 145, pp. 338-355, Feb. 2018.

[26] H. Akter, H.O.R. Howlader, F. Mamud, A.Y. Saber, A. Yona, and T. Senjyu, "Optimal sizing and performance analysis of hybrid microgrid for remote island of developing country: Effect of sustainable parameters, benefits and installation barriers," *Franklin Open*, vol. 6, 100074, Feb. 2024.

[27] F.Akter, K.A. Ekram, M.A. Hoque, and M.J. Abedin, "An Assessment of Solar Micro-Grid System in the Islands of Bangladesh for Sustainable Energy Access," *Malaysian J. on Composites Sci. and Manufacturing*, vol. 12, no. 1, pp. 31-42, Nov. 2023.

[28] A.L. Bukar, C. W. Tan, and K. Y. Lau, "Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm," *Sol. Energy*, vol. 188, pp. 685-696, Aug. 2019.

[29] K.F. Man, K.S. Tang, and S. Kwong, "Genetic algorithms: concepts and applications [in engineering design]," *IEEE trans. on Ind. Electro.*, vol. 43, no. 5, pp. 519-534, Oct. 1996.

[30] S. Sharma, S. Bhattacharjee, and A. Bhattacharya, "Grey wolf optimisation for optimal sizing of battery energy storage device to minimise operation cost of microgrid," *IET Gen. Transmi. & Distri.*, vol. 10, no. 3, pp. 625-637, Feb 2016.

[31] N. Ghorbani, A. Kasaeian, A. Toopshekan, L. Bahrami, and A. Maghami. "Optimizing a hybrid wind-PV-battery system using GA-PSO and MOPSO for reducing cost and increasing reliability," *Energy*, vol.154, pp. 581-591, Jul. 2018.

[32] F.A. Alturki, A.A. Al-Shamma'a, H.M.H Farh, and K. AlSharabi, "Optimal sizing of autonomous hybrid energy system using supply-demand-based optimization algorithm," *Int. J. of Energy Res.*, vol. 45, no. 1, pp. 605-625, Aug. 2020.

[33] H. Qari, S. Khosrogorji, and H. Torkaman, "Optimal sizing of hybrid WT/PV/diesel generator/battery system using MINLP method for a region in Kerman," *Scientia Iranica*, vol. 27, no. 6. pp. 3066-3074, Dec. 2020.

[34] M.A.Zaman, and M.A. Razzak, "Sustainable microgrid analysis for Kutubdia Island of Bangladesh," *IEEE Access*, vol. 10, pp. 37533-37556, Apr. 2022.

[35] A. Bhatt, M. P. Sharma, and R. P. Saini, "Feasibility and sensitivity analysis of an off-grid micro hydro–photovoltaic–biomass and biogas–diesel–battery hybrid energy system for a remote area in Uttarakhand state, India," *Renew. and Sustain. Energy Reviews*, vol. 61, pp. 53-69, Aug. 2016.

[36] R. Ahmmed, M.S. Rahman, M.A. Sarker, M.H. Ali, and M.S. Shadik, "Optimizing Hybrid Power for Manpura Island: A Case Study in Bangladesh," *J. of Energy Engi. and Thermo*., vol. 3, no. 01, pp. 20-30, Jan 2023.

[37] T. Chowdhury, S. Hasan, H. Chowdhury, A. Hasnat, A. Rashedi, M. R.M. Asyraf, M.Z. Hassan, and S.M. Sait. "Sizing of an island standalone hybrid system considering economic and environmental parameters: a case study," *Energies*, vol. 15, no. 16, 5940, Aug. 2022.

[38] F. Rabbi, M. Sarker, M.H. Ali, M.O. Rahman, S. Zaman, and K.H. Suvo, "Techno-Economic Feasibility Analysis of Solar Wind-Based Hybrid Power System on the Islands of the Northern Bay of Bengal," *in 4th International Conference for Emerging Technology (INCET)*, Belgaum, India, 2023, pp. 1-5.
[39] “Hyundai Power Products,” hyundaipower-de.com. [Online] Available: https://www.hyundaipower-de.com/. [Accessed on 20 December, 2023]
[40] “Trojan Battery Company,” trojanbattery.com. [Online] Available: https://www.trojanbattery.com/. [Accessed on 20 December, 2023].
[41] “Victron Energy Blue Power,” victronenergy.com. [Online] Available: https://www.victronenergy.com/batteries. [Accessed on 21 December 2023].
[42] “Iron Edison,” ironedison.com. [Online] Available: https://ironedison.com/store. [Accessed on 21 December 2023].

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