Optimal Cost and Component Configuration Analysis of Micro-grid using GWO Algorithm

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***Abstract*—Economic analysis is used to assess the ideal size of a micro-grid and its efficiency. In order to maintain and grow a micro-grid economically, optimization is essential. A variety of equality and inequality requirements may be met to reduce the entire production cost, which includes subsidies for things like capital, operations, pollution, and renewable energy. Grey wolf optimization (GWO) is a powerful and adaptable cost-cutting strategy. GWO is used in tandem with other AI-based optimization methods in particular situations. Here, we provide a model for evaluating the viability, expense, and societal and environmental effects of energy systems that operate independently from the grid. Harmonization of micro-grids. It's possible that the micro-mathematical grid's role is to recycle power output hour by hour in accordance with available resources and to store any excess energy in a battery. In this work, we simulate and optimize a PV-Wind-WtE-battery hybrid system in the halishahar thana of Chattogram, Bangladesh. Design concerns include renewable energy sources including solar panels, wind turbines, batteries, and diesel engines. By our estimates, the thana uses around 107,150 MWh of power annually. We use a Grey wolf optimization approach to find the optimal design parameters to minimize the overall yearly cost. This micro-grid can easily provide 1,40,423.8 MWh, more than enough to power Halishahar for a whole year. A low levelized cost of energy (LCOE) of 0.221 $/kWh is achieved with this setup. It reduces carbon dioxide emissions by a larger margin than traditional power.**

***Keywords*—Micro-grid, Grey wolf optimization, Waste to energy, Energy management, Sustainable energy, Generation.**

I. Introduction

Electricity is one of man's basic need since it is used in almost every area of modern life. Because of this, having a reliable source of electricity is crucial. While the economy of Bangladesh has grown over the previous decade, many residents of rural areas and islands still lack access to grid-connected electricity [1]. Most of the energy used in Bangladesh comes from coal, oil, and gas, all of which are major contributors to greenhouse gas emissions and other air pollution problems. Power plants nowadays use renewable energy sources like solar and wind since they are better for the environment [2]. Generation sources for renewable energy in a hybrid system may include the sun, the wind, biomass, hydrogen, and even fossil fuels. The issue with solar and wind power is its unpredictability [3]. A hybrid renewable energy system integrates renewable energy sources with traditional sources of energy and/or energy storage. In light of the increasing demand for energy and the increasing emissions of greenhouse gases, people have been searching for greener ways to store and utilise that energy. We looked at how the configuration of micro-grids and the availability of energy storage systems affected the total cost of ownership. Depending on the circumstances, a variety of energy storage systems may be considered cheap. Become familiar with the procedure.

Uncertainties and volatility in renewable energy sources may be mitigated with this design. Building a hybrid PV/Wind/WtE/Battery system is evaluated in many research, both from a technological and financial perspective [4]. Energy from renewable sources is stored in the hybrid system's battery. The goal of current studies is to determine the best ways to optimize micro-grid components to meet load requirements at the lowest possible cost with the greatest possible dependability. Optimal improvement strategies are required for the micro-grid because of its intricacy. Since it employs the global optimum to find the optimal solution, grey wolf optimization

(GWO) is a good and practical method for enhancing the micro-grid [5]. Renewable energy is in high demand because of people's growing awareness of environmental issues. The initial investment for a micro-grid system is high. A renewable energy system's technical and financial efficiency may both benefit from optimization. Cutting down on the micro-components grid's might save money on both installation and running expenses. To save costs and maximize the efficiency of the system's components, GWO is used in the planning and design of an off-grid micro-grid for Halishahar, Chattogram.

Unlike other similar calculations, GWO is rather straightforward. In contrast to traditional optimization methods, GWO eliminates complex steps like calculating overlaps and mutations. Grey wolf optimization use a performance measure or goal function to guide search over the problem space. Functions without a need for distinction benefit from GWO's utilization. It doesn't have to rely on the assumptions and approximations of other optimization techniques. The result of GWO is encoded as a real number, depending on the response. With the constant answer, we may determine the number of dimensions [6]. Since renewable energy sources are difficult to anticipate and plan for, hybrid renewable systems often include a controllable energy source, such as diesel, to increase the system's reliability [7]. In this paper our main goal is to construct a micro-grid that operates independently from the larger grid by using WtE, PV, Wind, Diesel, and a battery system. Our contribution is to determine the best setup for a micro-parts grid's with the help of grey wolf optimization to save down installation and operation expenses, and also in an effort to lessen production of greenhouse gases and other environmental damage.

II. Micro-grid System Modeling

The method for constructing the micro-grid system diagram is shown in Fig. 1, where the mathematical significance and function of each component are elaborated. Solar photovoltaic (PV) panels, wind turbines, a waste-to-energy plant, a diesel generator, batteries, and AC-to-DC converters are all part of the system.

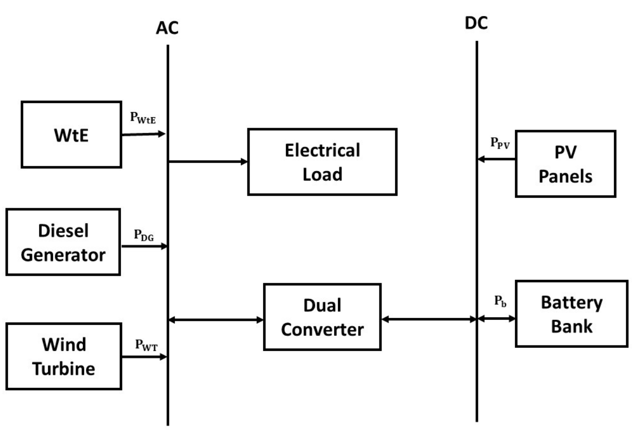


Fig. 1: Hybrid Power Generation System

LCOE and CO_2 gas emission is minimized by using an energy management strategy and the GWO optimization model. Wind turbines and solar panels, seen in Fig. 1, are two examples of renewable energy sources. WtE is able to create energy from waste. The microgrid system now has a load linked to it. Extra power can be stored in the energy storage and the Diesel Generator can be used as backup during peak output periods.

A. Waste to Energy Technology (WtE) Modeling

The Waste-to-Energy (WtE) method is a kind of energy conversion that uses a technology to transform waste materials into usable heat and power. The schematic representation of WtE is shown in Fig. 2. This design makes use of garbage as a feed-stock and supplements it with oxygen from an air separation unit. FastOx gasification describes this process.

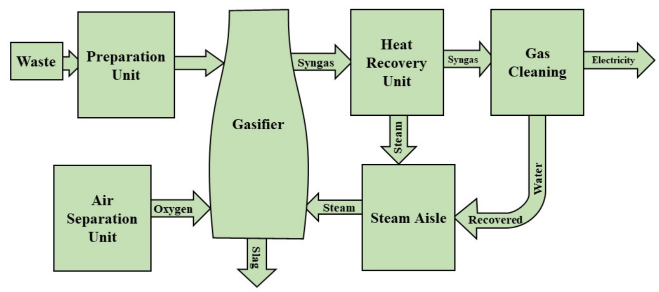


Fig. 2: Schematic Diagram of WtE [7]

Fig. 2 demonstrates how waste is loaded into the gasifier via the top opening. Steam and air enter the building. At 2,150 degrees Celsius, the mixture changed into gas. Garbage reacts as it sinks to the gasifier's hottest section. Distinct types of particles are released from each zone's cannon. Carbon char, inorganic chemicals, and metals are the end products of the transformation of trash from the base layer. Adding oxygen and heat to carbon char may produce synthesis gas. Much heat is produced by this exothermic reaction. The waste is heated by the gasifier as it reacts with the synthesis gas and becomes hotter. Synthetic gas is sent upwards via the gasifier vessel and into the heat recovery and gas purification systems. At the bottom of the gasifier, molten minerals and metals accumulate.

The energy potential recovery from municipal solid waste is denoted by the symbol P_{WtE}, and can be calculated using the equation (1).

$$P_{WtE} = LHV_{msw} \times W_{msw} \times \frac{1000}{3.6} \tag{1}$$

Potential energy from municipal solid waste is denoted by P_{WtE}, the weight of MSW is denoted by W_{msw} in tons, and the net low heating value of the MSW is denoted by LHV_{msw} (MJ/kg), together with the conversion ratio (1 kWh = 3.6 MJ) [8].

B. Diesel Generator Modeling

The diesel generator serves as an emergency power supply for the system. Limiting diesel production to acceptable levels is essential. The generator's efficiency drops at low loading rates. To maximize energy efficiency and provide a sufficient buffer for power variations such as sudden spikes in load demand, diesel production has to stay within the usual range.

Diesel generator fuel consumption, represented by the symbol $q(t)$ in the context of micro-grid architecture [9], may be written as

$$q(t) = aP_{DG}(t) + bP_{rated} \quad (2)$$

The rated power is denoted by P_{rated}, the generated power by $P_{DG}(t)$, and the fuel consumption characteristics by a and b as coefficients in the equation (2). The ideal values of *a* and *b* in this study are *0.2461* and *0.08415* [9].

C. Wind Turbine Modeling

The quadratic model is used for the wind turbines. The output power of the wind turbine may be calculated using the following formula (3).

$$P_{wt}(t) = \begin{cases} 0 & V(t) \leqslant V_{cin} \text{ or } V(t) \geqslant V_{cout} \\ P_r^w & V_{rat} \leqslant V(t) \leqslant V_{cout} \\ P_r^w \Big(\dfrac{V(t) - V_{cin}}{V_{rat} - V_{cin}} \Big) & V_{cin} \leqslant V(t) \leqslant V_{rat} \end{cases} \quad (3)$$

The power output of a single wind turbine is represented by the following equation, where P_r^w is the turbine's rating and the four variables represent four different wind speeds: V_{cin} (the cut-in speed), V_{cout} (the furlong speed), V_{rat} (the rated wind speed), and V_t (the wind speed at the target height) [10].

D. PV Panel Modeling

The amount of energy generated by a solar PV panel may be determined by solving the equation (4).

$$P_{sol}(t) = P_r^s \tfrac{G_h(t)}{G_S} \Big[1 + k_t \Big(T_{amb}(t) + 0.0256 G_h(t) - T_S \Big) \Big] \quad (4)$$

In this formula, P_r^s represents the solar PV panel's power rating, and $G_h(t)$ represents the hourly solar radiation incident on the panel's surface (W/m^2). Standard incident radiation (1000 W/m^2) is denoted by G_S, and the value of k_t is $-3.7 \times 10^{-3}(1/°C)$. Hourly ambient temperature is denoted by $T_{amb}(t)$, whereas T_S corresponds to the standard temperature of 25 $°C$ [11].

E. Battery Bank Modeling

During times of high renewable energy production, excess energy may be stored in a micro-grid and then used to power homes and businesses during times of low production. To accurately estimate energy, charge assessment is required. Battery state-of-charge (SOC) may be calculated over time using the formula (5).

$$\frac{SOC(t)}{SOC(t-1)} = \int_T^{T-1} \frac{P_b(t)\eta_{batt}}{V_{bus}} dt \quad (5)$$

The variables in this equation are the battery's input/output power ($P_b(t)$), the bus voltage (V_{bus}), and the battery's round trip efficiency (η_{batt}). The battery is being charged if $P_b(t)$ is positive; otherwise, it is being discharged [10].

F. Dual Converter Model

DC-to-AC power conversion is required for every DC-based technology. It is necessary to convert the DC power produced by solar PV panels and batteries to AC. Peak load, designated by $P_L^m(t)$ determines the required size of the converter [12]. To get the converter's power output, represented by P_{inv}, the following formula is used.

$$P_{inv}(t) = P_L^m(t)/\eta_{inv} \quad (6)$$

In equation (6), η_{inv} represents the efficiency of the converter.

III. Energy Management System

All of the generating units that make up the micro-grid system optimized in this research are located in close proximity to the area of electrical consumption; as a result, no electrical losses due to distribution are considered in finding the best design for this system. Energy management must be a key focus throughout the design and development phases of the system's architecture to guarantee that all of the components of the micro-grid function together properly. The battery bank is recharged anytime the system generates more power than is required; the diesel generator is employed as a backup or dispatchable source. Excess power from renewable sources is sent to a dump load, and if the power produced is not enough to meet the demands of the load and the battery bank, the battery bank is used to make up the difference. Diesel generator is started to satisfy load needs and charge battery bank when renewable energy source and battery bank are unable to do so.

IV. Grey Wolf Optimization

The Grey Wolf optimization method is used to get the optimal value for the micro-grid's total net present cost. The optimization's one and only goal is to lower the system's running costs. In comparison to conventional optimization methods, the Grey Wolf Optimizer can quickly and reliably sustain research and exploitation of optimum value. GWO's algorithm flowchart is shown in Fig. 3.

To begin, we use the random function in MATLAB to create random samples of wolf populations. Each wolf's integer value represents the system's carrying capacity. In the end, the optimal solution will be determined by selecting the wolf that best fits the conditions. Each wolf is first scored on the objective function and placed into one of three categories: $alpha$, $beta$, or $gamma$. The $alpha$ wolf is the best-adapted of the young wolves today. The $beta$ function is the second best fit, while the $gamma$ function is the third best match. After that, the micro-individual grid's sets of generation are put through their paces. Sets of wolves advance to the next iteration if their fitness values are high enough to fulfill the optimization criteria; otherwise, they are penalized severely and eliminated early on in the reduction process. Each iteration, only the best-fitting wolf advances to the next iteration, when both their location and the coefficient vector inside them are updated. The fitness of the whole wolf pack is assessed once again, and the packs are divided into $alpha$, $beta$, and $gamma$ wolf packs based on the results. This process of assessing fitness and updating position will continue until the maximum number of iterations is reached or the termination criterion is fulfilled. This allows for the achievement of the ideal variable and the desired values.

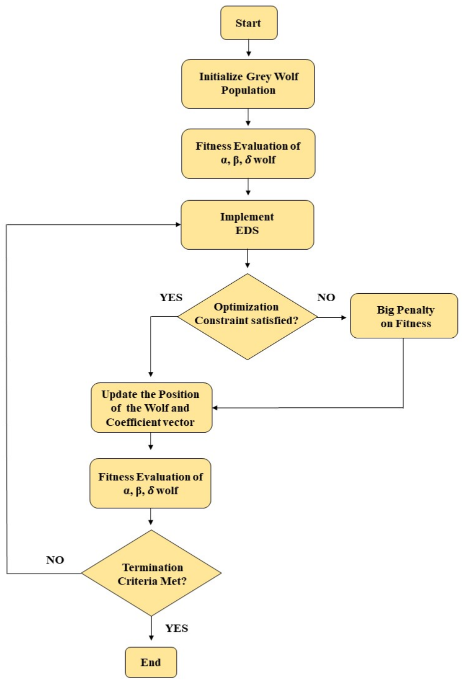


Fig. 3: Grey wolf optimization flowchart

V. Mathematical Model for Optimization

The study's ultimate goal is to create a hybrid energy system that is both cost-effective and low-maintenance. The quantity and size of WtE, solar panels, wind turbines, batteries, and other energy storage devices are critical.

A. Objective Function and Constraints

This study is intended to determine the lowest feasible NPC value for the hybrid system, without compromising performance. The amount of wind turbines, solar PV panels, batteries, and WtE rating all go into the optimal setup. The cost-benefit analysis is made possible by annualized system cost (ASC). All needs may be met by the lowest ASC option. Capital expenditures, replacement expenses, and O&M expenses are all included into the objective function. Expenditures on infrastructure and installation are examples of capital expenditures. The function F that follows is the primary function of the objective that has to be reduced.

$$ASC_{min} = F(P_{sol}C_{sol} + N_{wt}C_{wt} + P_{wte}C_{wte} + N_{batt}C_{batt} + P_{inv}C_{inv}) \quad (7)$$

In equation (7) the costs of solar PV panels (per kW), wind turbines (per kW), batteries (per unit), and inverters (per kW) are denoted by C_{sol}, C_{wt}, C_{batt}, and C_{inv}, respectively. The rating of WtE is denoted by P_{wte}, whereas the cost of WtE is denoted by C_{wte}. The rating of the inverter is denoted by the symbol P_{inv}, the number of batteries is denoted by N_{batt} and the number of wind turbines is denoted by N_{wt} [13].

The objective function is made as small as possible by strictly adhering to a number of constraints, which may be summed up as

$$C_{sol} = (C_{acp} + C_{arep} + C_m - C_{sal})_{sol} \quad (8)$$

$$C_{wt} = (C_{acp} + C_{arep} + C_m - C_{sal})_{wt} \quad (9)$$

$$C_{wte} = (C_{acp} + C_{arep} + C_m + C_f - C_{sal})_{wte} \quad (10)$$

$$C_{batt} = (C_{acp} + C_{arep} + C_m - C_{sal})_{batt} \quad (11)$$

$$C_{inv} = (C_{acp} + C_{arep} + C_m - C_{sal})_{inv} \quad (12)$$

The annual capital cost, annual replacement cost, maintenance cost, operation cost and salvage cost are denoted by C_{acp}, C_{arep}, C_m, C_f and C_{sal}, respectively. [14].

The optimal setup is decided upon by balancing the levelized cost of energy (LCOE) with the need for the greatest possible degree of reliability. The levelized cost of energy (LCOE) is the average cost of powering a facility per usable kilowatt-hour of energy [13]. You may write it down as the equation (13).

$$LCOE = \frac{\text{ASC (\$/year)}}{\text{Total useful energy served (kWh/year)}} \quad (13)$$

TABLE I: Components Parameters of optimization [15], [16]

Component Name	Per Unit Capacity	Capital Cost ($)	Replacement Cost ($)	O&M Cost ($/yr)
PV Panel	1 kW	1500	-	50
Wind Turbine	1 kW	1300	1200	200
WtE (Waste to Energy)	1 kW	4000	-	150
Diesel Generator	1 kW	1200	1000	0.050
Battery	7 kWh 6V, 1156Ah)	1250	1100	20

B. GHG Emission Estimation

We estimated the GHG emissions ($kg\ CO_2\ equivalent$) on the basis of life cycle assessment (LCA) of power generation using the equation (14).

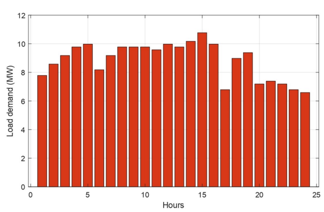
$$Emission_{total} = C_{wte}\sum_{1}^{8760} P_{wte} + C_{dg}\sum_{1}^{8760} P_{dg} \quad (14)$$

Here, C_{wte} & C_{dg} represent the CO_2 emission factor of WtE plant and Diesel generator respectively. P_{wte} & P_{dg} were the generation by WtE plant and Diesel generator respectively [17].

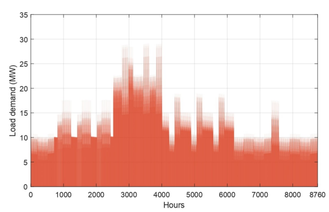
VI. Analysis Condition

A. Load Model

Halishahar's Wards 11, 25, and 26 are the primary areas of emphasis for the annualized basic load consumption model estimate. The coordinates *22°19'* and *22°20'* north latitude and *91°45'* and *91°48'* east longitude that make up Halishahar Thana. We gathered information on the country's daily electricity consumption pattern from the Power Grid Company of Bangladesh (PGCB), whose data we utilized to arrive at our conclusions [18]. The substation at Halishahar, North Patenga, is where the Power Grid Company of Bangladesh Ltd. collects information about the demand for electricity. Based on the load calculation, the thana consumes an estimated 107,150 MWh of energy each year. Halishahar's hourly load demand is shown in Fig. 4a, while the city's yearly load demand is depicted in Fig. 4b.



(a) 24 Hours Load

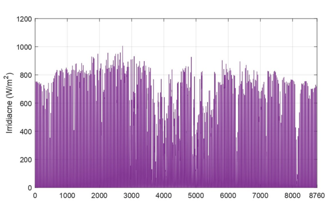


(b) Annual Load

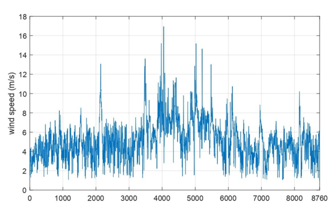
Fig. 4: Electrical Load Demand (Hourly)

B. Renewable resource data

It is required to collect data on Halishahar's renewable resources on an hourly basis before proceeding. The information on local resources is gathered from the NASA Power database [19].



(a) Solar Irradiance



(b) Wind Speed

Fig. 5: Annual Solar and Wind Data (Hourly)

Statistical data for solar irradiance and wind speed at Halishahar are shown graphically in Fig. 5a and Fig. 5b, respectively for each hour.

VII. Results & Discussions

The GWO algorithm approach to system modeling simulates all feasible adjustment based on the available parameters in order to meet the load demand. In the event that the system is unable to supply the necessary load, a diesel generator will be put into service as a backup.

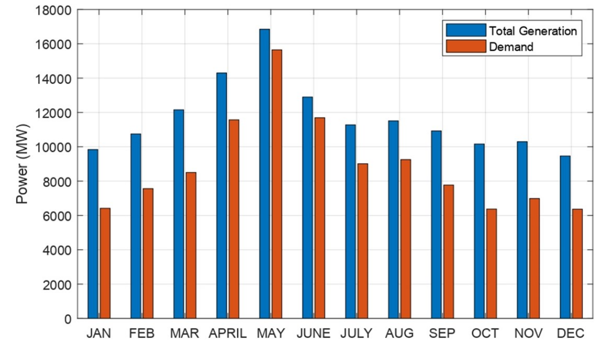


Fig. 6: Comparison between total generation and load demand

Fig. 6 represents a comparison of the annual total generation with the annual load demand. From this figure, we can compute the overall amount of Renewable energy derived through photovoltaic, wind, and WtE conversion.

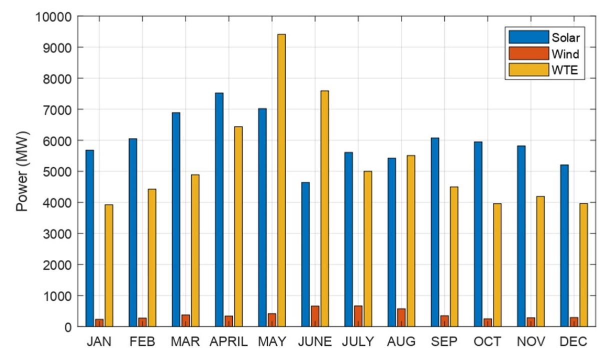


Fig. 7: Energy Generation Comparison

Fig. 7 compares renewable energy generation. Solar energy now provides most of our electricity. The wind farm has the lowest production of any of our power source. Beside, WtE generation makes a great impact on this power system.

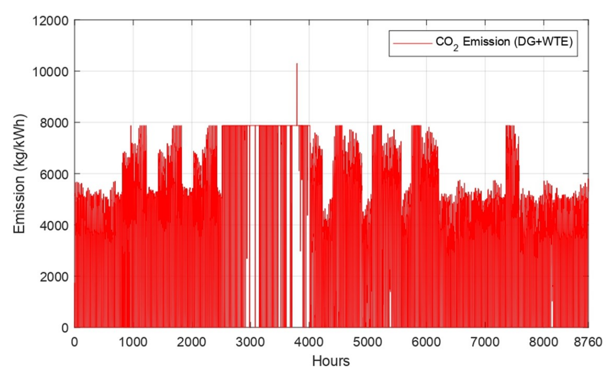


Fig. 8: Annual CO_2 Emission

From optimization result, we get to know this micro-grid system for halishahar is generating highest 33502 *ton/kWh*

CO_2 which is from WtE plant though the diesel generator not needed to be activated to satisfy the load demand. The CO_2 emission of our micro-grid over the course of one year (8760 hours) is shown in Fig. 8.

The NPC and LCOE of the system are decreased and the results of each model are optimized by the GWO algorithm. To maximizing each model's results, GWO makes sure that the system's NPC (Net Present Cost) and LCOE (Levelized Cost of Energy) are as little as possible.

TABLE II: Final Design of Micro-grid

Component Name	Quantity (kW)	Annual Generation (MW)	Annual Cost Cost ($)
Solar	43648	71888	100.9M
Wind turbine	2325	4724	12.43M
WtE	25000	63807	188.5M
Battery Unit	31203	-	77.11M
Diesel Generator	1000	4.795	4.91M
Total		**1,40,423.8**	**383.9M**

The GWO algorithm generated the micro-grid with annual generation from renewable sources and a WtE plant. Table II gives a high-level overview of annual generation and costs, which total to 1,40,423.8 MW and $383.9M, respectively. The levelized cost of energy for this micro-grid is $0.221.

VIII. Conclusions

In this study, the sizing of an off-grid hybrid renewable energy system is examined. This system provides electricity to a particular area and uses an energy management system to control the operation of its components. The components of the analyzed system are PV, Wind, WtE, and battery. It has been established that the micro-grid production system's output is adequate to meet the load requirement in the designated area. The facility's initial investment and overall operating costs would be greatly reduced by utilizing the optimum microgrid components. Additionally, it is discovered that annual CO_2 emissions are less than those typically associated with energy production. This technology might be improved upon and used in new contexts as the need for energy increases in the coming years. As a result, this hybrid system is appropriate for such a setting because it has a minimal influence on the environment and the GWO algorithm performs well to solve issues of this form.

The project's annual generation and cost are calculated. The model is additionally subject to a number of restrictions in a real-world or simulated setting. A WtE main generating unit is also present. While waste as an energy source holds considerable promise, the cost is high. The majority of the time, trash is burned directly to create combustion gas, which is then used to create energy. The LCOE of the system is 0.221$ KWh, which is a fair price for renewable energy. The method also significantly cut down on harmful CO_2 emissions. Using GWO algorithm we got these data for our proposed micro-grid, we can take some other algorithms like ant-colony optimization,PSO algorithm, genetic algorithm etc as our future work to compare with our optimized result which is done by GWO.

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