Economic Analysis and Optimal Design of Micro-grid using PSO Algorithm

Md. Arafat Bin Zafar
Dept. of Electrical and Electronic Engineering
International Islamic University Chittagong
Chattogram 4314, Bangladesh
arafatbzafar@gmail.com

Md. Rashidul Islam
Dept. of Electrical and Electronic Engineering
International Islamic University Chittagong
Chattogram 4314, Bangladesh
rashidul05eee@yahoo.com

Md. Sajjad-Ul Islam
Dept. of Electrical and Electronic Engineering
International Islamic University Chittagong
Chattogram 4314, Bangladesh
sajjadulislam714@gmail.com

Md Shafiullah
Interdisciplinary Research Center for Renewable Energy and Power Systems
King Fahad University of Petroleum & Minerals
Dhahran 31261, Saudi Arabia
shafiullah@kfupm.edu.sa

Arafat Ibne Ikram
Dept. of Electrical and Electronic Engineering
International Islamic University Chittagong
Chattogram 4314, Bangladesh
arafatibne.ikram@gmail.com

***Abstract*—The efficiency of a micro-grid and its optimal size are both determined through economic analysis. Optimization is necessary for running and expanding a micro-grid economically. Fulfilling equity and inequality standards may reduce total production costs including capital, operations, pollution, and renewable energy subsidies. A cost-optimization method called particle swarm optimization (PSO) is effective and flexible. Here, a framework for assessing the practicality, cost, and impact of off-grid energy systems on people and the planet is presented. A mathematical function of the micro-grid component might recycle power production by the hour based on available resources and store any surplus energy in a battery. Here, a model of a PV-Wind-WtE-battery hybrid system is proposed for the halishahar area of Chattogram, Bangladesh. Design considerations include solar panels, wind turbines, batteries, and diesel engine power. To determine the best parameters for the design in terms of total annual cost, particle swarm optimization algorithm is employed. This micro-grid has no trouble providing Halishahar with sufficient power for a whole year. The LCOE of this system is 0.22 $/kWh. Compared to conventional electricity, it results in lower carbon dioxide emissions.**

***Keywords*—Cost optimization, Greenhouse gas emission, Micro-grid, Particle swarm optimization, Renewable energy, Waste to energy.**

I. Introduction

Electricity is a critical requirement because it's everywhere. In Bangladesh, not having reliable electricity makes life hard. Bangladesh's GDP grew 6% annually over the past decade, however many rural and island populations lack grid-connected power. Bangladesh relies mostly on coal, oil, and gas, which emit CO_2 and other pollutants. People are seeking for alternate energy sources and eco-friendly ways to store energy as fossil fuels decrease and greenhouse gas emissions grow. We studied how micro-grid structure and energy storage capacity impacted LCOE. Many energy storage methods are cost-effective, depending on needs.

Several studies give a practical and techno-economic evaluation of establishing a hybrid PV/Wind/WtE/Battery system [1]. Phommixay et al. contributed in review on the cost optimization of micro-grids via particle swarm optimization brief details about PSO algorithm, Optimum micro-grid sizing, optimal cost [2]. In this review, There is no discussion about CO_2 and it is considered one of limitation. Modern research focuses on optimizing micro-grid components to fulfill load needs at the lowest cost and highest reliability. Due to the complexity of improving the micro-grid, effective optimization approaches were needed. Particle swarm optimization (PSO) is a good and practical technique to improve the micro-grid since it uses the worldwide optimum to discover the ideal solution [3]. Environmental concerns drive demand for renewable energy. Optimizing a renewable energy system can enhance its technological and economical performance. Reducing the number of micro-grid pieces reduces startup and energy costs. We designed an off-grid micro-grid for Halishahar, Chattogram, using PSO.

This paper aims to build an off-grid micro-grid system with core generating units like WtE, PV, Wind, Diesel, and an energy storage system, to minimize the total cost of installation and levelized cost of energy by finding the optimal component configuration using Particle swarm Optimization algorithm, and to reduce greenhouse gas emissions and environmental damage.

II. Modeling the Hybrid System

Fig. 1 shows the approach to the micro-grid system diagram, explaining each part's mathematical meaning and purpose. It has PV panels, wind turbines, a waste-to-energy plant, a diesel generator, batteries, and AC/DC converters.

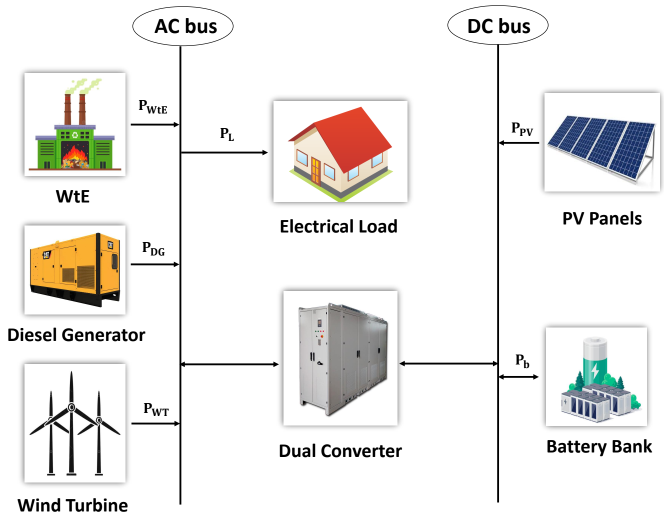


Fig. 1: Hybrid Power Generation System

LCOE and GHG emissions are reduced using an Energy Management Strategy and PSO. WtE turns waste into electricity. In times of high production, extra energy can be stored in Battery Bank. Besides, Diesel Generator used as backup.

A. PV Panel Model

In order to calculate the amount of energy produced by a solar PV panel, the equation (1) is used.

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

In this equation, P_r^s stands for the solar PV panel's rating, $G_h(t)$ stands for the hourly solar radiation incident at the surface of the solar PV panel (W/m^2), G_S stands for the standard incident radiation (1000 W/m^2), k_t is $-3.7 \times 10^{-3}(1/°C)$, $T_{amb}(t)$ stands for the hourly ambient temperature, and T_S stands for the standard temperature 25 $°C$ [4].

B. Wind Turbine Model

The wind turbine model in the proposed design employed was quadratic. To determine the wind turbine's output power, the equation (2) is used.

$$P_{wt}(t) = \begin{cases} 0 & V(t) \leqslant V_{cin} \text{ or } V(t) \geqslant V_{cout} \\ P_r^w & V_{rat} \leqslant V(t) \leqslant V_{cout} \\ P_r^w\left(\dfrac{V(t) - V_{cin}}{V_{rat} - V_{cin}}\right) & V_{cin} \leqslant V(t) \leqslant V_{rat} \end{cases} \quad (2)$$

This equation represents the power output of a single wind turbine, with the rating of the turbine denoted by P_r^w, and with 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) [5].

C. Modeling of Waste to Energy Technology (WtE)

The MSW fractions' high heating values (HHV) were calculated using a bomb calorimeter. The relatively low thermal energy output from the waste fractions used for power generation is shown in (3).

$$LHV_{msw} = \sum_{1}^{9} W \times HV \quad (3)$$

In this equation, LHV_{msw} represents the low heating value, HV represents the average heating values of MSW and W represents the percentage by weight [6]. Equation (4) is used to get the energy potential recovery from MSW, P_{WtE}.

$$P_{WtE} = LHV_{msw} \times W_{msw} \times \frac{1000}{3.6} \quad (4)$$

In this equation, P_{WtE} represents the energy potential from MSW, W_{msw} in tons represents the weight of MSW, LHV_{msw} represents the net low heating value of the MSW (MJ/kg) and converting ratio (1 kWh = 3.6 MJ) [6].

D. Diesel Generator Model

In the process of designing a micro-grid, the amount of fuel that a diesel generator uses, denoted by the symbol $q(t)$ [7], can be expressed as

$$q(t) = aP_{DG}(t) + bP_{rated} \quad (5)$$

Equation (5) represents the rated power as P_{rated}, the produced power as $P_{DG}(t)$, and the fuel consumption characteristics as a and b as coefficients [7].

E. Battery Bank Model

Micro-grids store surplus energy during periods of plentiful renewable energy production and deliver power during times of little or no output. Assessing charge is needed to measure energy effectively. The battery's SOC can be determined over a period of time using the formula (6)

$$\frac{SOC(t)}{SOC(t-1)} = \int_{T}^{T-1} \frac{P_b(t)\eta_{batt}}{V_{bus}} dt \quad (6)$$

In this equation V_{bus} represents the bus voltage, $P_b(t)$ represents the input/output power of the battery, and η_{batt} represents the battery's round trip efficiency. If $P_b(t)$ is positive, the battery is being charged; otherwise, it is being discharged [5].

F. Dual Converter Model

A system using DC components needs DC-to-AC power conversion. Solar PV panels and batteries generate DC electricity, which must be converted to AC. The size of the converter is set by the peak load, denoted by $P_L^m(t)$ [5]. The power output of the converter, denoted by P_{inv}, may be calculated as follows:

$$P_{inv}(t) = P_L^m(t)/\eta_{inv} \quad (7)$$

In equation (7), η_{inv} represents the efficiency of the converter.

III. Particle Swarm Optimization

Micro-grid components, installation costs, LCOE and GHG emissions are reduced using PSO. MATLAB's random function generated random particle swarms. Then, objective function is used to evaluate each population cluster. If any of the conditions weren't met, the technique would penalize the optimal value. The PSO was able to minimize the objective function while ensuring the micro-grid could supply the load for the energy penetration scenario. By using this method, the best particle from a swarm can be selected. Individual and overall top scores were recorded in separate variables. At this stage, the program checks if the border exceeded the minimum or maximum particle count and weight and velocity will be updated.

IV. Energy Management Strategy

All of the generating units in the micro-grid system optimized in this study are near the region of electrical demand, hence no distribution losses are evaluated.

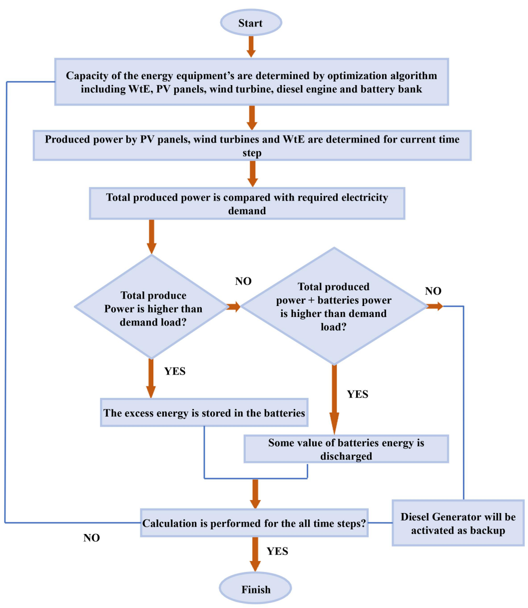


Fig. 2: Flowchart of Energy Management Strategy of Micro-grid System

Energy management must be a priority in micro-grid planning and development for seamless operation. "Fig. 2" displays the analysis's energy management method [8].

V. Optimization Problem Formulation

This research sought the hybrid system's minimal NPC value without sacrificing efficiency. Wind turbines, solar PV panels, batteries, and WtE rating determine best configuration. ASC analyzes cost-benefit and its lowest solution meets all needs. The goal function includes capital, replacement, and O&M. Installation and civil works are capital expenditures. The following function is the key aim function that must be lowered.

$$ASC_{min} = F(P_{sol}C_{sol} + N_{wt}C_{wt} + P_{wte}C_{wte} + N_{batt}C_{batt} + P_{inv}C_{inv}) \tag{8}$$

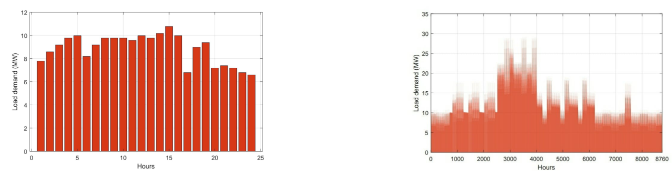
In equation (8) the costs of solar PV panels (per kW), wind turbines (per kW), batteries (per unit), and inverters (per kW) are denoted by C_{sol}, C_{wt}, C_{batt}, and C_{inv}, respectively. The rating of WtE is denoted by P_{wte}, whereas the cost of WtE is denoted by C_{wte}. The rating of the inverter is denoted by the symbol P_{inv} [9].

Best configuration is determined by LCOE and dependability. LCOE is the system's average usable kwh price [9]. It can be presented in equation (9).

$$LCOE = \frac{\text{ASC (\$/year)}}{\text{Total useful energy served (kWh/year)}} \tag{9}$$

VI. Analysis Condition

The estimation of annualized basic load consumption model focused on Halishahar area covering *22°19'* and *22°20'* north latitude and *91°45'* and *91°48'* east longitude. Electrical load demand data is obtained from the Power Grid Company of Bangladesh Ltd [10]. The area's annual energy demand is estimated to be 107,150 MWh based on load calculation.



(a) 24 Hours Load (b) Annual Load

Fig. 3: Electrical Load Demand (Hourly)

Hourly and annual load demand of Halishahar are shown in Fig. 3a and Fig. 3b, respectively. Besides, hourly solar irradiance and hourly wind speed statistics for Halishahar are collected from NASA website [11].

VII. Results & Discussions

In system modeling, the PSO method simulates every conceivable modification to meet load requirements. If the system can't meet demand, a diesel generator will be used.

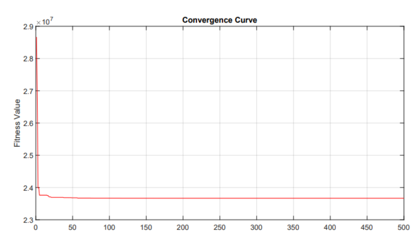


Fig. 4: Convergence Curve of PSO

PSO obtains the optimum value of 2.38×10^7 after 50 iterations of 500 under operational limitations as shown in Fig. 4. Here, renewable sources can meet the load without a diesel generator. PSO optimizes each model's outcomes and reduces the system's NPC and LCOE.

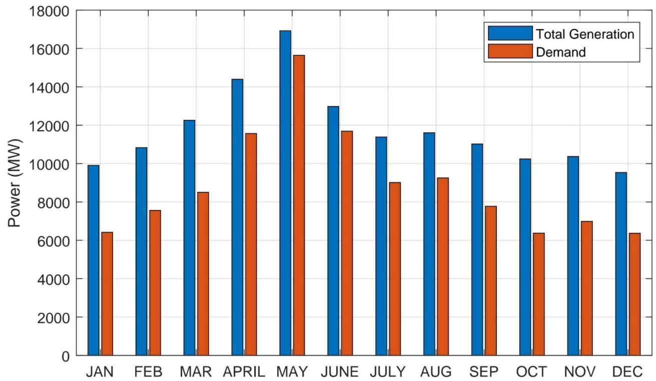


Fig. 5: Comparison between total generation and load demand

Fig. 5 compares annual generation and load demand. From this figure, photovoltaic, wind, and WtE conversion of renewable energy can be analysed.

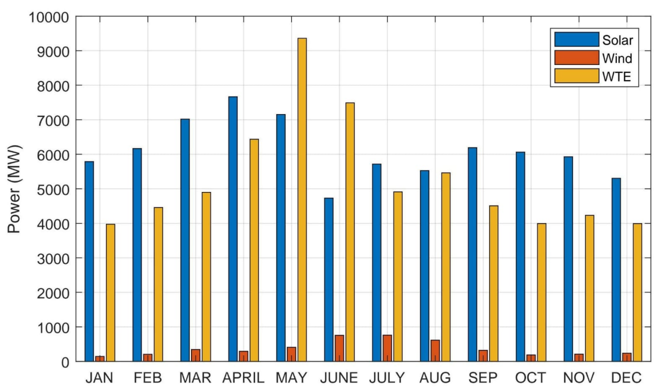


Fig. 6: Energy Generation Comparison

Fig. 6 compares renewable energy production. Solar provides most of the electricity. The wind turbine produces the least power. Also, WtE generation affects this power system.

TABLE I: Final Design of Micro-grid

Component Name	Quantity (kW)	Annual Generation (MW)	Annual Cost Cost ($)
Solar	44478	73256	1.0284×10^8
Wind turbine	2925	4482.7	1.5631×10^7
WtE	25000	63714	1.8832×10^8
Battery Unit	31379	-	7.7539×10^7
Converter Unit	37900	-	4.1373×10^4
Total		**141452.7**	$\mathbf{3.8437\times10^8}$

Annual generation from renewable sources and WtE plant for the micro-grid were provided by the PSO algorithm. Table I helps us get a bird's-eye view of the annual generation and costs, which come out to 141452.7 MW and $3.8437\times\mathbf{10}^8$ \$, respectively. This micro-grid had an LCOE of 0.22$.

VIII. Conclusions

This paper constructed an off-grid hybrid renewable energy system that supplies electricity to a small community and uses an energy management system to control its equipment. The evaluated system is comprised of PV-Wind-WtE-Battery. The micro-grid's final output meets the area's electrical demand. Using micro-grid components would reduce the initial cost and operating costs. In addition, it was found that the average yearly CO_2 emission was lower than usual. This technology may be refined and applied in new ways as energy demand rises. Therefore, this hybrid system is suitable for such an environment because it reduces environmental impact and uses the PSO algorithm to solve problems.

The annual generation and cost of this project is computed. In a real or simulated context, the model is subject to several additional limitations. More so, there's a WtE main generating unit. Waste as an energy source has great promise but a hefty price. Primarily, garbage is burned to create combustion gas, which is used to generate electricity. Boilers use biomass fuel to create high-pressure steam. The yearly LCOE of the system's CO_2 emissions may be computed, and Biomass can be included into the electricity supply. All of these are future work for the micro-grid.

References

[1] M. A. B. Zafar, M. S.-U. Islam, M. R. Islam, and M. Shafiullah, "Optimized waste to energy technology combined with pv-wind-diesel for halishahar in chattogram," in *2022 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*. IEEE, 2022, pp. 1–5.

[2] S. Phommixay, M. L. Doumbia, and D. Lupien St-Pierre, "Review on the cost optimization of microgrids via particle swarm optimization," *International Journal of Energy and Environmental Engineering*, vol. 11, no. 1, pp. 73–89, 2020.

[3] M. Fadaee and M. Radzi, "Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: A review," *Renewable and sustainable energy reviews*, vol. 16, no. 5, pp. 3364–3369, 2012.

[4] S. Singh, A. Slowik, N. Kanwar, and N. K. Meena, "Techno-economic feasibility analysis of grid-connected microgrid design by using a modified multi-strategy fusion artificial bee colony algorithm," *Energies*, vol. 14, no. 1, p. 190, 2021.

[5] S. Singh, M. Singh, and S. C. Kaushik, "Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system," *Energy Conversion and Management*, vol. 128, pp. 178–190, 2016.

[6] R. Ibikunle, I. Titiladunayo, B. Akinnuli, A. Lukman, P. Ikubanni, and O. Agboola, "Modelling the energy content of municipal solid waste and determination of its physico-chemical correlation using multiple regression analysis," *International journal of mechanical engineering and technology*, vol. 9, no. 11, pp. 220–232, 2018.

[7] M. A. Ramli, H. Bouchekara, and A. S. Alghamdi, "Optimal sizing of PV/wind/diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm," *Renewable energy*, vol. 121, pp. 400–411, 2018.

[8] H. Borhanazad, S. Mekhilef, V. G. Ganapathy, M. Modiri-Delshad, and A. Mirtaheri, "Optimization of micro-grid system using MOPSO," *Renewable energy*, vol. 71, pp. 295–306, 2014.

[9] A. Lorestani and M. Ardehali, "Optimal integration of renewable energy sources for autonomous tri-generation combined cooling, heating and power system based on evolutionary particle swarm optimization algorithm," *Energy*, vol. 145, pp. 839–855, 2018.

[10] "Power Grid Company of Bangladesh Ltd." Accessed April 20, 2021. [Online]. Available: http://www.pgcb.gov.bd/

[11] "NASA POWER — Data Access Viewer, Prediction Of Worldwide Energy Resource," Accessed July 15, 2022. [Online]. Available: https://power.larc.nasa.gov/data-access-viewer/