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Optimization a Hybrid Wind and Solar System in Off-Grid and Grid-Connect to Supply Load

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Abstract— *A micro-grid consists of loads, power generation, and energy storage. There are residential and commercial micro-grids. Active is the distributed micro-network. The production resources of micro-grids are either based on fossil fuels or renewable energy. Micro-grids can be independent or connected to the grid. This study investigates the viability and optimal design of a micro-grid based on renewable energy sources, taking pollution control into account, for the iron and steel production project of Mass Group Holdings (MGH) in Sulaymaniyah, Bazian, Iraq. After modeling the considered micro-grid in two modes, grid-connected and grid-independent, and entering the required data, such as weather data, Net Pure Cost (NPC) and pollution are used to calculate the consumption load of the superior plans. Multi-objective optimization utilizing the proposed optimization model yields an objective function value of 0.5237, whereas the PSO algorithm yields 0.5279, demonstrating that the proposed grid-connected method is superior. For off-grid mode, however, the objective functions in the proposed model and PSO optimization are 0.7241 and 0.7282, respectively. In the event that a battery is connected to the network, the diesel generator works for 620 hours less, saving fuel and making the diesel generator more economical from an economic standpoint. In this regard, the network-connected mode produced superior results to the mode that was not connected to the network.*

Keywords—Micro-grid, renewable energy source, energy cost, pollution, optimization.

1. INTRODUCTION

The term "micro-grid" refers to a section of the electricity distribution network that, in addition to electrical loads, consists of power generation sources and electrical storage facilities [1], [2]. Micro-grids can be found in both residential and commercial settings. In fact, the micro-network functions as a distribution network that is active [3], [4]. In micro-grids, production resources can be broken down into two broad categories: those that rely on fossil fuels and those that rely on renewable energies [5], [6]. These micro-grids can either be connected to the grid or operate independently from it.

In both the current and future configurations of the power system, smart grids are going to play a significant role [7], [8]. The most recent and cutting-edge power grids not only have the capability to connect a large number of renewable energy sources to the power system, but they also provide real-time information regarding the power grid itself [9], [10]. Because of the rapid expansion of global industry and business, there has been a significant decrease in the amount of energy that is readily available as a consequence of the excessive consumption of fossil fuels [11], [12]. In addition, there is the problem of energy security and environmental concerns, which has led to investments in technology that generates electricity with low levels of carbon dioxide [13]. The generation of electricity from renewable energy sources is a workable solution that will not only meet the rising demand for energy but will also take into account concerns about the environment [14], [15]. This has become one of the priorities in all countries around the world. In recent years, Turkey has reduced its reliance on energy sources from outside the country, which has coincided with an increase in the country's use of power plants that are fueled by renewable energy sources. Although the contribution of renewable energy production to total electricity generation in Turkey in 2015 was equivalent to six percent, the Turkish government has set a goal of contributing at least thirty percent of total energy production from renewable sources by the year 2023 [16], [17].

Because renewable energy source are intermittent and connected (intermittent), and their locations are geographically spread, the connection of renewable energy source has imposed more uncertainties and challenges on electricity systems [18], [19]. The growing electricity output from renewable energy source necessitates many research to study the consequences of renewable energy source connection on the electrical system [20], [21]. Various forms of system instability and security have appeared in the past, as power systems evolve through the constant addition of new units to the power systems and incremental operation under high pressure conditions [22], [23].

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Numerous studies have been undertaken to examine the impact of renewable energy and explore the ramifications of wind power on the electricity market [24], [25]. Significant network disruptions were observed in cases where wind power generation forecasts were not conducted with precision [26]. Shafiullah et al [27] conducted a simulation of a power system model specifically designed for the Australian power grid. The primary objective of their investigation was to examine the impact of integrating large-scale renewable energy sources on the power transmission system. Molina et al. [28] examined the effects of renewable energy on various aspects of the Chilean electricity system, including costs, technological diversity, CO_2 emissions, and energy injection. Duan et al. [29] introduced a methodology for examining the impact of wind energy on the transmission system by employing the Weibull distribution function. Moreover, the outcomes of this approach were utilized to assess the transmission capability of the lines. Syafawati et al. [30] undertook a case study to assess the viability of solar energy in the context of Malaysia. Furthermore, an examination of solar radiation and the geometric correlation of its inherent resources was conducted to ascertain its prospective viability.

Particle Swarm Optimization (PSO) and Bat Algorithm (BA) are two well-known metaheuristic optimization techniques utilized for complex optimization problems [31]. PSO is inspired by the social behavior of bird flocks and fish schools [32]. It involves a group of potential solutions (particles) moving through the search space, adjusting their positions based on their individual experiences and the knowledge of the best-performing particles. The simplicity of implementation and fast convergence to optimal solutions are some of its notable advantages, especially for large-scale optimization challenges. BA takes cues from the echolocation behavior of microbats. It incorporates frequency-tuning and loudness adjustment mechanisms to explore and exploit the search space effectively [33]. By balancing exploration and exploitation, BA demonstrates adaptability to dynamic environments and various types of optimization problems. Both PSO and BA provide valuable tools for solving complex optimization problems, each with its own strengths. While PSO stands out for its simplicity and efficiency in handling large-scale problems, BA offers a strong adaptability to dynamic environments and a good balance between exploration and exploitation. Their implementation can offer valuable insights into the performance and applicability of these algorithms in various real-world optimization challenges.

Jahangir and Cheraghi [34] have been suggested to ascertain the most advantageous dimensions of system components, taking into account different objectives. Liu et al. [35] introduced a modeling framework that utilizes game theory to optimize the design of a multi-energy system and renewable resources. It also proposes a solution strategy for this optimization problem. Ghaffari and Askarzadeh [36] proposed a highly efficient and successful approach for optimizing the dimensions of a hybrid system comprising of photovoltaic panels, diesel generators, and solar cells. Within the context of the measurement, the objective is to minimize the overall net current cost, taking into account two primary constraints: the potential loss of power source and the proportion of renewable energy. Mamaghani et al. [37] examines the utilization of photovoltaic panels, wind turbines, and diesel generators in an autonomous hybrid power generation system for providing electricity to three off-grid villages in Columbus with varying climate conditions. Sanajaoba and Fernandez [38] focused on utilizing the Cuckoo search methodology to determine the optimal sizing of three distinct system designs: photovoltaic-battery, wind-battery, and photovoltaic-wind-battery. These designs are specifically applicable in remote areas in India, with the objective of minimizing system cost and accounting for seasonal changes.

The utilization of multiple renewable sources has proven to be a feasible solution for generating electricity in different scenarios, considering the intermittent and discontinuous nature of the energy produced by these sources. By effectively combining these resources, it is feasible to establish a dependable, economically efficient, and ecologically sustainable production system. This article introduces a design that can be implemented in two modes: one that is connected to the grid and another that is independent of the grid. The goal is to determine the superior design in terms of both economic and environmental factors. To achieve this, the BA optimization and numerical simulation are employed. This study examines the viability and optimal configuration of a micro-grid powered by renewable energy sources, while considering pollution mitigation, for the steel production operations of Mass Group Holding (MGH) in Sulaymaniyah, Bazian, Iraq. Upon simulating the micro-grid in both grid-connected and grid-independent modes, and inputting the required data, including weather data, the power consumption of the higher-level systems is determined using the Net Pure Cost (NPC) and pollution as factors.

2. MATERIALS AND MEHODS

The geographical location of Mass Group Holding (MGH) established a project to produce iron and steel in Sulaymaniyah, Bazian, Iraq is located at $45.04°$ longitude and $35.66°$ latitude and at an altitude of $924\ meters$ above sea level indicating its relatively high altitude within the region (Fig. 1). MGH is a prominent conglomerate operating in the region of Kurdistan, Iraq. The company has strategically established a project for the production of iron and steel in Sulaymaniyah, Bazian. This geographical positioning not only reflects the company's regional presence but also underscores its role in the development and industrialization of the local economy.

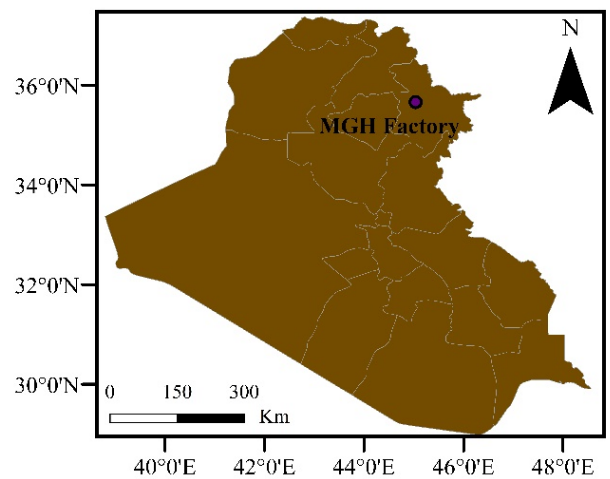

Fig. 1. MGH steel factory location.

2.1. Load consumption data

According to its energy unit, the study factory has prepared information regarding its consumption load. An annual average consumption load is $298.52\ kW$. As a result of simplifying the implementation of the numerical model, we have reduced the load scale. Random changes in load are assumed to occur both on an hourly and daily basis. According to Table 1, power consumption is represented by a graph for each month of the year. October is the month in which the most power is consumed.

2.2. Environmental data

Fig. 2 depicts the climate data required for numerical modeling. Environmental information pertaining to the plant is collected from the National Solar Radiation Database (NSRDB). The extracted

Table 1. Power demand data in the MGH steel factory.

Month	Min (kW)	Max (kW)	Mean (kW)
Jan.	230.26	411.84	321.05
Feb.	202.63	332.89	267.76
Mar.	214.47	427.63	321.05
Apr.	246.05	332.89	289.47
May	230.26	356.58	293.42
Jun.	214.47	313.16	263.82
Jul.	167.11	384.21	275.66
Aug.	190.79	340.79	265.79
Sep.	159.21	376.32	267.76
Oct.	285.53	542.11	413.82
Nov.	202.63	415.79	309.21
Dec.	222.37	364.47	293.42

data Temporal Resolution is 60 min and Spatial Resolution is 4 km. Fig. 2-(a) shows the Global Horizontal Irradiation (GHI). It can been seen that GHI reach its maximum value in July. The average annual wind speed is 1.65 m/s. The highest wind speed is in November and the equivalent of 8.2 m/s and the lowest wind speed is in July with 0.1 m/s. In Fig. 2-(b) the wind speed profile is shown in the 2019. Fig. 2-(c) and Fig. 2-(d) show the relative humidity, and temperature respectively for this region.

2.3. Hybrid system

Fig. 3 displays a comprehensive framework of the integrated energy production system that relies on renewable resources. This system comprises solar cells, a wind turbine, a diesel generator, a converter, and a battery. It has the capability to function in two distinct modes: connected to the grid and operating autonomously from the grid. As a consequence of these sources, there is a rise in the dependability of providing the factory's consumption load. The newly integrated combined system is designed to supply either a portion or all of the energy needed by the manufacturing facility. The project is expected to have a duration of 25 years.

In the following, the details of the elements of this system are introduced.

Wind energy is considered as a renewable energy that can be used in all areas, even areas far from the grid, due to its widespread use. Due to the intermittent nature of the wind and the non-continuous nature of the wind, the energy produced by the wind turbine depends on the speed of the wind and finally the rotation speed of the wind turbine [11]. We use Equation (1) to calculate the speed of the wind hitting the turbine blades [39].

$$V(t) = V_r(t) \left(\frac{h}{h_r}\right)^{\tau} \quad (1)$$

where, τ is the power coefficient of the wind turbine, $V_r(t)$ is the wind speed at the height h. The selected turbine in this study is PGE 45/10. The rated power of the turbine is 40 kW and its lifespan is 25 years. The number of turbines considered is $0, 3, 6, ..., 12$. Fig. 4 The output power of the wind turbine is given according to the wind speed.

Electricity is completely covered. Photovoltaic cells have an appropriate potential to supply electric energy in a grid-independent mode. One of the advantages of this technology is the lack of need for wide transmission lines. The output power of solar panels is affected by the amount of sunlight, which is calculated using Equation (2) [40]. The size of the solar arrays is equal to $0, 100, 200, ..., 600$ kW, and the lifespan of this equipment is considered to be 25 years.

$$\mathrm{p_{spv}(t)} = \mathrm{G}_B(\mathrm{t}) \times \eta_{\mathrm{pv}}(\mathrm{t}) \times \mathrm{AN_{SPV}} \times \eta_{\mathrm{C-SPV}} \quad (2)$$

where, $_{pv}(t)$ is the efficiency of solar panels, $G_B(t)$ is the amount of sunlight radiation on the surface of photovoltaic panels,

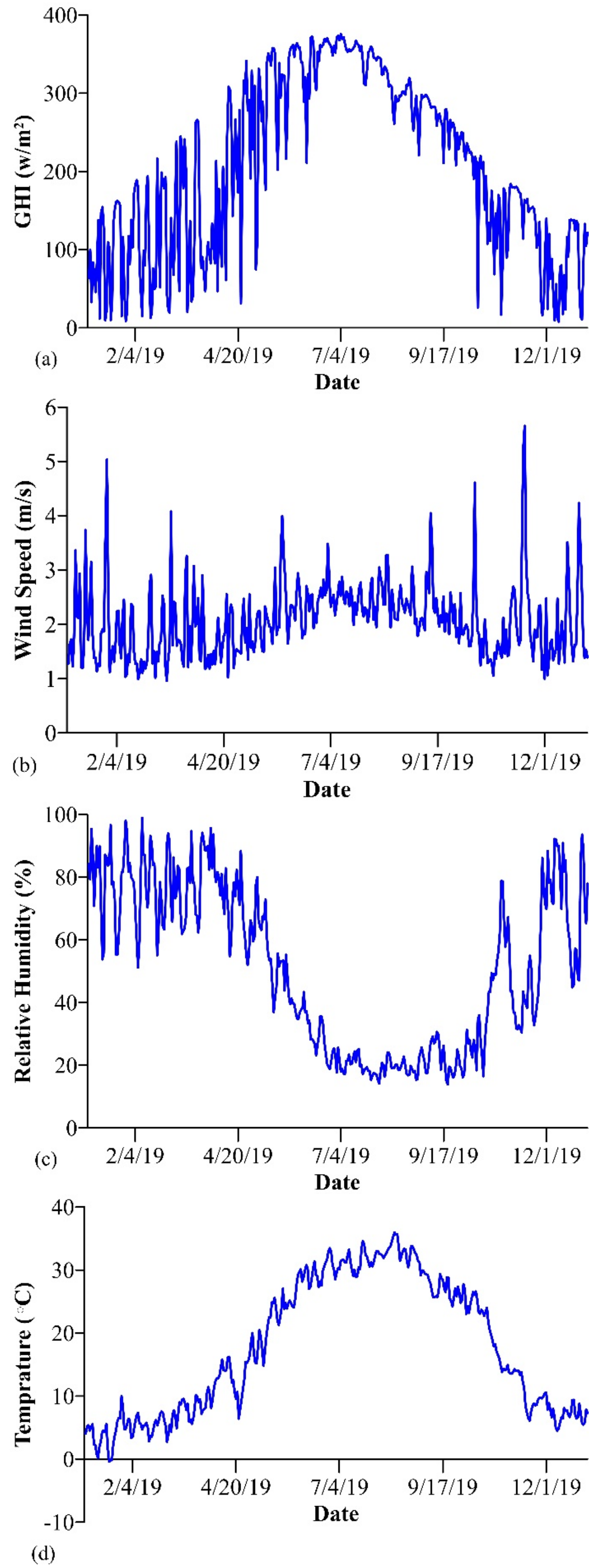

Fig. 2. Climate data for numerical modeling a) GHI, b) wind speed data, c) relative humidity, and d) temperature.

$\eta_{\mathrm{C-SPV}}$ is the amount of losses of solar panels due to dust, and

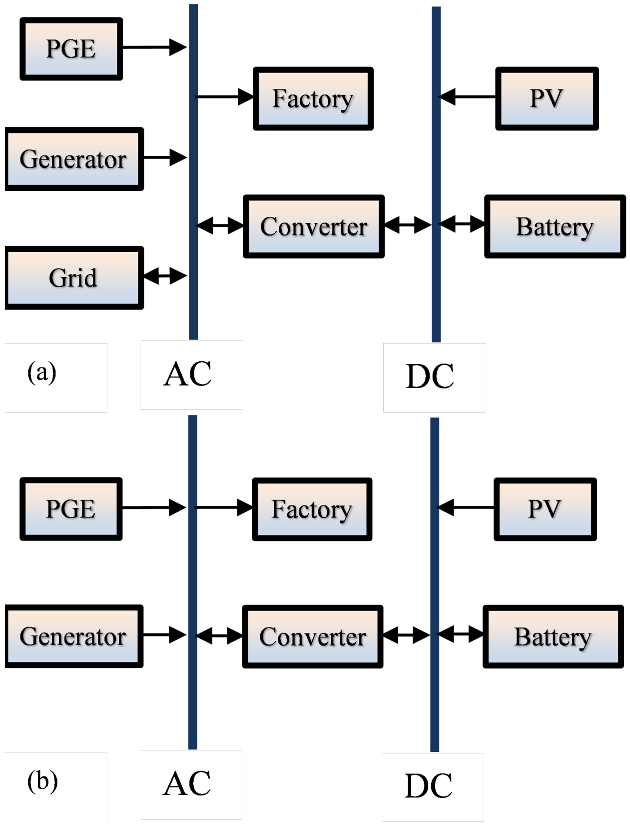

Fig. 3. General frame of the combined system of energy production based on renewable resources a) connected to the grid and b) independent from the grid.

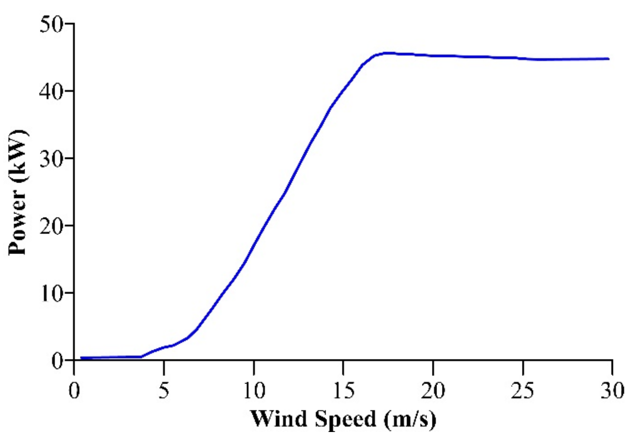

Fig. 4. Wind turbine power generation features.

AN_{SPV} snow and rain on the surface of photovoltaic panels and the number of solar panels [41].

Intermittency of power generation using renewable energies such as wind and solar challenges the grid. Therefore, a storage system should be installed in the micro-grid that can charge additional energy with renewable sources during the peak of power generation and discharge it when the power generation falls. In this micro grid, a battery bank is installed for storage. The battery used in this design's battery bank includes 0, 24, 48, 72, 96 batteries.

An internal combustion generator with natural gas fuel has been used for the back of the wind turbine and photovoltaic panels. Also, the sizes considered for the diesel generator are 0, 100, 200,..., 500.

The converter installed in this design is for converting AC power to DC and vice versa. The sizes considered for this equipment are $0, 50, 100, ...,\ 300\ kW$ respectively.

2.4. Bat optimization algorithm

Bats are the sole group of mammals capable of flight, and a significant number of them possess the sophisticated capability of echolocation for navigation. The majority of bats employ acoustic signals within a specific frequency range to ascertain their spatial orientation. Within the realm of bat species, small bats serve as prominent illustrations of organisms that employ sound as a mechanism for spatial orientation. Micro chiropteran bats possess the ability to emit high-intensity sound pulses and subsequently analyze the resulting echoes produced upon interacting with their immediate environment.

The BA optimization, initially introduced by Yang [42] in 2010, draws inspiration from the foraging behavior of bats as they search for prey. The algorithm incorporates two overarching principles: 1) Bats possess the ability to perceive distance through echolocation, utilizing chirping sounds. Furthermore, they demonstrate the capacity to distinguish between the acoustic signals produced by potential food sources and other objects in their surroundings. 2) According to the second law, bats exhibit random behavior as they pursue their prey. They do so by moving at a velocity v_i and occupying a specific location x_i. This pursuit occurs at a constant frequency f_{min}, and involves the emission of sound waves with varying wavelengths and sound volumes denoted by R. Additionally; bats possess the ability to autonomously modify both the wavelength and rate of the emitted pulses. Ensure that you prioritize self-care and attend to your well-being. Coordinate a hunting expedition in close proximity to their location. Fig. 5 shows the flowchart of BA optimization.

Based on this the mathematical modeling of the BA optimization is describe in Equation (1). The positional value (p_i) and velocity (v_i) of each virtual bat (i) within the subsequent search space (d) can be obtained using the following relationships during each iteration of the algorithm.

$$\begin{aligned} f_i &= f_{\min} + \left(f_{\max} - f_{\min}\right)\beta \\ v_i^{\tau+1} &= v_i^{\tau} + \left(p_i^{\tau} - p_*\right) f_i, \\ p_i^{\tau+1} &= p_i^{\tau} + v_i^{\tau} \end{aligned} \tag{3}$$

where τ is the repetition counter of the algorithm and β is a random number with uniform distribution between zero and one. p_* is the best current position which is selected in each iteration after comparing with new positions of virtual bats. On the other hand, in each iteration, a local search is performed based on a random walk around the location of the best bat as $p_{new} = p_{old} + \varepsilon R^{\tau}$ where $\varepsilon \in [0, 1]$. It will be In the above relationship, $p^{\tau} = \langle p^{\tau} \rangle$ is defined as the average loudness of all bats in the repetition of τ. In terms of the volume of the sound R_i and the rate i of the sending pulse r in each repetition of the algorithm, it should be updated according to Equation (2).

$$\begin{aligned} R_i^{\tau+1} &= \alpha R_i^{\tau} & \forall 0 \le \alpha \le 1 \\ r_i &= \left[1 - \exp\left(-\gamma\tau\right)\right] & \forall \gamma \ge 0, 0 \le r_i \le 1 \\ p^{\tau} &= \langle p^{\tau} \rangle \end{aligned} \tag{4}$$

3. RESULTS AND DISCUSSION

The optimization problem was solved using BA optimization in two distinct instances, and the results were compared to those of the particle swarm optimization algorithm.

The first scenario involves the multi-objective optimization of the hybrid system using nominal parameters.

The second scenario: load-dependent multi-objective optimization of the hybrid system.

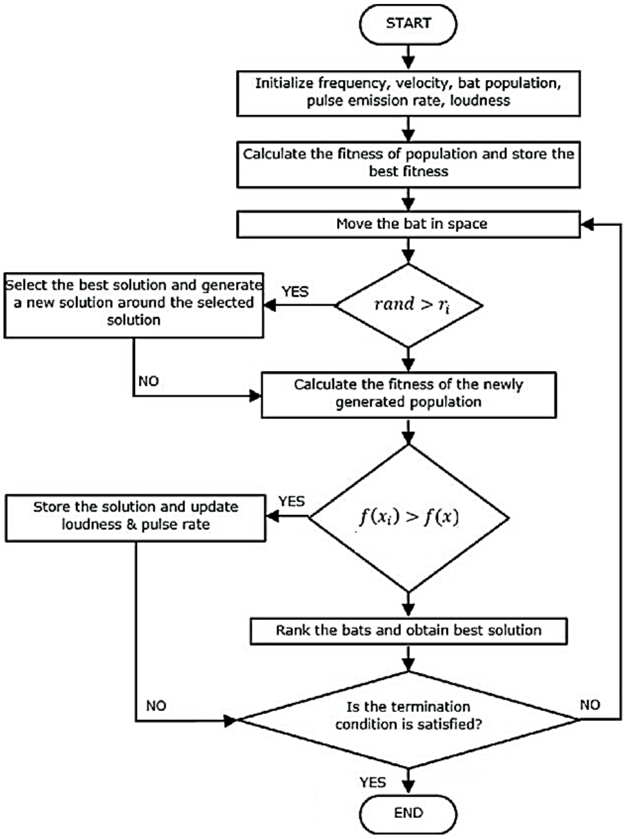

Fig. 5. BA optimization framework.

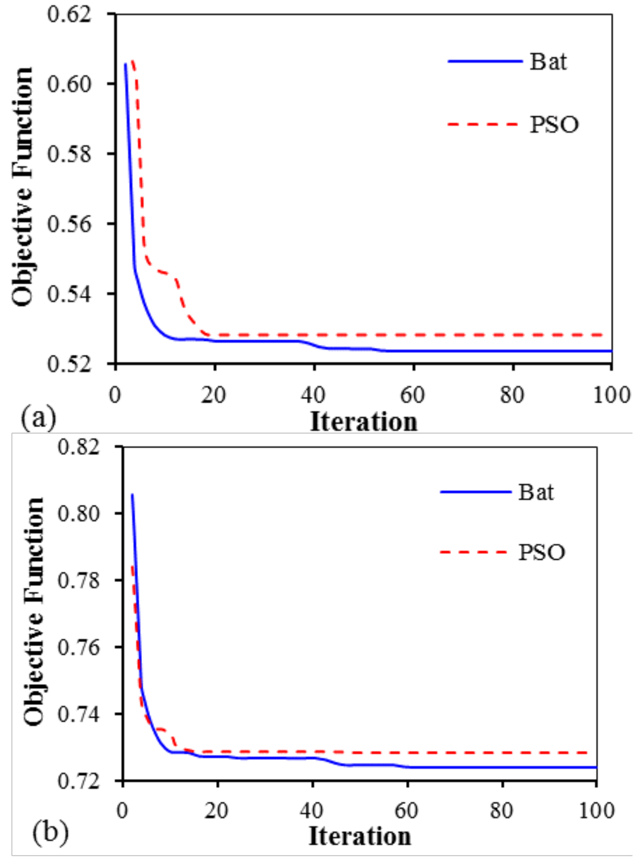

Fig. 6. The convergence curve of the BA optimization in the first scenario a) connected b) off-grid in scenario 1.

3.1. Scenario 1

The results of the multi-objective optimization that was performed on the hybrid system have been presented for the standard parameters of the system. Experimentation and subsequent refinement were necessary steps in order to arrive at the final parameter settings for each algorithm. The convergence curve of multi-objective optimization using the BA and PSO is depicted in Fig. 5. According to this figure, the BA optimization method results in a lower value for the objective function and a lower annual cost than the particle crowding method. In multi-objective optimization, the BA algorithm obtains a value for the objective function of 0.5237, while the PSO algorithm obtains a value of 0.5279. This demonstrates that the method that was proposed is superior, as can be seen in Fig. 6-(a). In a similar vein, the objective function values for BA and PSO optimization in off-grid mode are 0.7241 and 0.7283, respectively.

3.2. Scenario 2

In the second scenario, Fig. 7-(a) and 7-(b), respectively, show the multi-objective optimization results of the hybrid B system for 10% changes in load demand using the bat optimization algorithm and PSO for connected and off-grid mode. This graph demonstrates the superior performance of the proposed algorithm versus the PSO algorithm.

Following the compilation of the essential information, the simulation of the hybrid system is carried out, and the superior designs are put into action. After that, these designs are analyzed in terms of their NPC as well as the amount of carbon dioxide gas that they emit. This accomplishment was accomplished by utilizing the network in order to acquire the design that is most advantageous, not only economically, but also in terms of its impact on the environment. In order to conduct additional research into the superior designs that have been presented in the past, the numerical model is utilized in both the network-connected and non-network-connected scenarios. The results of optimization and simulation are presented in Table 2, which takes into account both interconnected and separate power grids as well as both possible outcomes. The results that are presented in Table 2 are the optimal outcomes of the numerical simulation. These outcomes were selected from the results of all of the simulations and optimizations.

In the state that is connected to the network, the network supplies the factory with some of the necessary quantity of the energy that it consumes. In the first strategy that was presented, the network, a diesel generator, a battery, and a converter were arranged in such a way that the diesel generator would produce 5 percent of the energy needed by the university, while the network would produce 90 percent of the necessary energy. This strategy is the most cost-effective strategy. In the second and third designs, a grid, diesel generator, wind turbine with battery, and battery pack are all combined into one system. The diesel generator works for 620 hours less when there is a battery, which results in the diesel generator saving fuel and becoming more economically sound from an economic point of view. When a battery is present, as opposed to when there is no battery, there is a decrease in the amount of nitrogen oxides produced as well as the release of pollutants into the environment.

It is a combination of a diesel generator, a battery, a converter with a wind turbine and a converter without a wind turbine when it is operating in the independent grid mode. The performance of the diesel generator is decreased by four percent as a result of the installation of a wind turbine; however, when one takes into account the reduction in the cost of diesel fuel, the NPC is decreased. In the scenario, where there is a wind turbine, there is also a reduction in pollution because there is a reduction in the

Table 2. Simulation results for connected to the network off-grid from the network.

Connected								
Scenario	Analysis	PV (kW)	PGE45	DG (kW)	Battery	Converter (kW)	NPC ($)	CO_2 (m^3)
1	Bat	100		300		50	2971.87	56.19
	PSO	200	3	200		50	2995.3	52.90
	Numerical	200	6	100	36		2996.44	56.75
2	Bat	200	6	100	36		2998.55	53.53
	PSO	200	6	200	24	50	3050.80	53.93
	Numerical	200	6	200	36	50	3059.80	54.01
Off-Grid								
Scenario	Analysis	PV (kW)	PGE45	Diesel (kW)	Battery	Converter (kW)	NPC ($)	CO_2 (m^3)
1	Bat		9	400	24	50	7415.9	995.80
	PSO		12	500	48	100	7425.7	1036.78
	Numerical	100	12	400	48	150	7506.9	922.94
2	Bat	100	8	300			7643.4	1046.63
	PSO	100		400	36	100	7675.5	1015.64
	Numerical	100		500	12	150	7957.1	1053.63

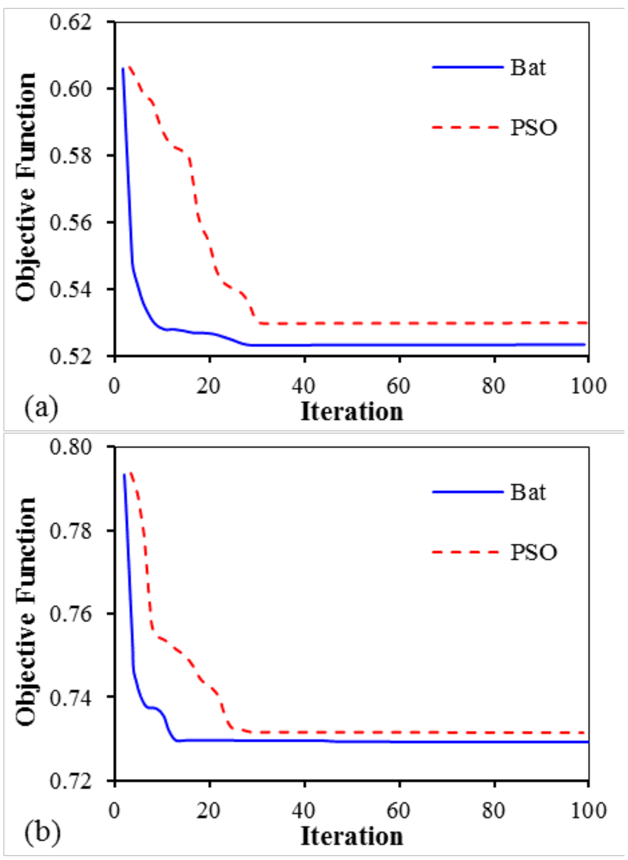

Fig. 7. The convergence curve of the BA optimization in the first scenario a) connected b) off-grid in scenario 2.

consumption of fossil fuels. In the third plan, the incorporation of photovoltaic cells results in a decrease in pollution, while there is an increase in NPC.

Because of the exchange of power with the grid, a state that is connected to the grid reaps benefits not only economically but also environmentally. The degree to which these benefits are realized is contingent on the degree to which the micro-grid's internal production and consumption compare to that of the upstream grid. The findings that were derived from the simulation indicate that being connected to the grid offers advantages in terms of both the economy and the environment when compared to operating independently.

4. CONCLUSIONS

In hybrid energy systems, power generation is fueled by multiple energy sources that work in tandem, resulting in greater reliability compared to systems that generate energy from a single source. The solar and the wind are two of the most common and simple ways to get energy into your home. Both can be discovered in virtually any location. It is necessary to conduct feasibility studies for each region separately because each region requires a distinctive composite system and a specific number of components based on weather conditions and load. These requirements make it necessary to conduct feasibility studies for each region individually. In addition to this, it is necessary to conduct feasibility studies on a regional basis for each region individually because it is necessary. As a result of this, it is essential to carry out studies of feasibility on an individual basis for each region. The optimal plan that has the least detrimental impact on the environment and the cost should be chosen as the course of action in order to satisfy the load's requirements for energy. This will allow the load to be satisfied.

A numerical model of the steel factory's combined grid-connected and grid-independent system had to be developed in order to meet the load requirements. The alternative that was found to be the most beneficial for both the economy and the environment was the one that was taken into consideration The PSO algorithm produces an objective function value of 0.5279, whereas the proposed grid-connected method produces an objective function value of 0.5237 when performing multi-objective optimization with the proposed optimization model. This demonstrates that the proposed grid-connected method is superior. However, the objective functions for the proposed model and the PSO optimization are 0.7241 and 0.7282, respectively, for the off-grid mode. If a battery is connected to the network, the diesel generator will work for 620 fewer hours, which will save fuel and make the diesel generator more cost-effective from an economic point of view. In this regard, the mode that was connected to the network was able to produce results that were superior to those produced by the mode that was not connected to the network.

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