Journal of Operation and Automation in Power Engineering

vol. XX, no. XX, Dec. 2022, Pages: XXXX (Proofed)

http://joape.uma.ac.ir

1978
University of Mohaghegh Ardabili

Hybrid Energy Systems Optimization Using Firefly Algorithm: Integration of Various Resources for Enhanced Stability and Flexibility

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Abstract— *The concept of hybrid energy systems has emerged as a distinct alternative in the past few decades, with the aim of enhancing the resilience and adaptability of energy systems to fluctuations and diverse energy sources. One of the principal objectives of hybrid energy systems is to mitigate the environmental repercussions associated with the generation and utilization of energy. Using more than one energy source at the same time, like solar panels, wind turbines, and combined heat and power (CHP) systems, has many benefits, such as higher efficiency, less reliance on fossil fuels, and lower greenhouse gas emissions. This study presents an optimal approach for the design of hybrid energy systems utilizing the Firefly algorithm within the given paradigm. Incorporated into the structure are vital components like wind turbines, solar panels, combined heat and power (CHP) systems, battery storage, and converters. Furthermore, it considers the various uncertainties pertaining to production capacity, demand, and costs. The firefly optimization technique is being employed to effectively identify the most optimal solutions within a context characterized by several uncertainties. The optimization results of this framework are demonstrated to be superior in effectiveness and efficiency when compared to those obtained from other optimization algorithms. This finding provides confirmation of the algorithm's effectiveness and efficiency in enhancing the performance and stability of hybrid energy systems.*

Keywords—Hybrid energy systems, firefly algorithm, optimization, renewable energy, wind turbines, solar panels, combined heat and power (CHP) systems.

1. INTRODUCTION

Global energy challenges have sparked the search for ideal energy usage solutions. Hybrid energy systems, which have become more common in recent years, provide new opportunities for improving energy efficiency [1]. These systems efficiently handle several types of loads, such as thermal and electrical (both AC and DC), inspiring academics to envision prospective energy models [2, 3]. These systems are hard to understand because they use solar, wind, combined heat and power, and energy storage technologies. It's especially hard to figure out how to predict and improve things like wind turbines, solar panels, battery storage, converters, and combined heat and power systems [4].

However, in order to properly design complex systems, it is essential to use strong optimization techniques that can identify the best solutions even in the presence of non-convex, non-linear, and discrete choice factors [5]. The design process for such systems entails the application of optimization techniques to guarantee superior efficiency, optimal usage of resources, and a reduction in costs [6–8]. To tackle various optimization problems in this field, one must comprehend the intricate interplay between system components, handle non-convex and discrete decision variables, and adapt to dynamic conditions [9, 10].

Recent studies have presented optimization models that specifically target dependability in the integration of multi-energy systems, with a particular emphasis on electricity and natural gas [11, 12]. These models strive to enhance performance and dependability in interconnected energy systems that integrate various sources and carriers. By considering uncertainties, network restrictions, demand patterns, and various decision factors, these approaches aim to optimize the design, operation, and integration of different energy systems [13, 14].

To successfully integrate many energy carriers and sources, it

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Received: 11 Dec. 2023
Revised: 02 May 2024
Accepted: 03 May 2024
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DOI: 10.22098/joape.2024.14214.2090
Research Paper

is necessary to utilize optimization frameworks that are skilled in handling complex linkages between various systems. Recent efforts have focused on developing sophisticated optimization models that utilize mathematical programming and algorithmic approaches. These models aim to create robust and dependable solutions for multi-energy systems [15, 16]. The main objective of this research is to guarantee the dependability and durability of interconnected energy networks while improving their functioning. It is essential to effectively handle uncertainties associated with swings in demand, changes in prices, and disruptions in supply. Successful integration of multi-energy systems necessitates careful consideration of reliability measures, network restrictions, and the interplay between electricity and gas networks [17–19]. Studies have focused on conducting optimization analyses to discover the specific types and capacities of equipment needed for planning hybrid energy systems [20]. The main focus of this research is to analyze the limitations of natural gas and electrical networks and develop a hybrid energy system that combines various renewable resources, such as wind turbines, solar panels, and diesel engines.

Furthermore, studies have investigated the possible utilization of storage systems to improve the economic and technological effectiveness of autonomous hybrid energy systems that depend on renewable sources [21]. These studies concentrate on reducing the operational expenses of autonomous hybrid energy systems by optimizing their objective function [22, 23]. The integration of various energy sources in a hybrid configuration, together with the use of storage devices, seeks to address issues pertaining to the reliability, consistency, and cost-effectiveness of energy delivery [24]. The objective of these studies is to enhance power use, optimize the efficiency of resources, and assess the economic viability by taking into account the original investment expenses, operational costs, and possible revenue generated from surplus energy production [25, 26].

Examining the implementation of storage system deployment, strategies for managing load, and economic modeling in hybrid energy systems is a crucial milestone in the pursuit of sustainable and resilient energy solutions [27, 28]. This method not only addresses current energy requirements but also strategically anticipates future energy obstacles, promoting a more environmentally friendly and sustainable energy landscape [29, 30]. The focus of research has mostly been around enhancing the efficiency of multi-resource energy systems through the integration of renewable and conventional energy sources, including wind turbines, solar panels, energy storage, and gas turbines. The primary obstacle revolves around resolving uncertainty in the availability of renewable energy sources, specifically solar panels and wind turbines, in autonomous hybrid energy systems [31–33]. Scientists have developed advanced operational models that utilize probability to reduce operational expenses in virtual power plants that consist of several energy sources. Concurrently, research has examined hybrid energy systems that prioritize diesel generators, solar panels, and biomass energy. These studies have analyzed the expenses associated with energy across various load profiles [34, 35].

Furthermore, thorough cost assessments have compared hybrid energy systems that are connected to independent upstream networks. A notable study was conducted to enhance the efficiency of a self-sustaining hybrid energy system that includes combined heat and power (CHP), solar panels, wind turbines, and electric vehicles. The main objective was to minimize operational expenses while also addressing environmental concerns [36–40]. Nevertheless, this research has revealed significant constraints in modeling, such as insufficient efficacy of objective functions, neglect of technology and economic limitations, and restrictions within evolutionary optimization methodologies. To improve the accuracy, convergence, and flexibility of energy system modeling, it is crucial to address these limitations [41, 42].

Mr. Javed *et al* [43] conducted a study on an operational strategy and optimization problem for a hybrid, off-grid solar-wind system. The research concentrated on a pumped hydraulic battery storage system. Additionally, a nonlinear optimization problem for the system was described. The results demonstrated that FA exhibited superior performance.

The aforementioned studies highlight several shortcomings in modeling, including ineffective and inadequate objective functions, neglect of technical and economic limitations, and limitations within evolutionary optimization techniques, such as inadequate accuracy, premature convergence, and inflexibility. This article introduces a methodology for maximizing the efficiency of hybrid energy systems by employing the Firefly Algorithm optimization algorithm. The framework includes wind turbines, solar panels, and battery storage technologies. The integration of the suggested hybrid energy system with the existing network also takes into account limitations on power exchange. The target functions encompass the expenses associated with installation elements, including capital investment, maintenance costs, CHP fuel prices, projected load shedding costs, and power exchange charges. Moreover, this framework includes a full range of limitations associated with hybrid energy systems.

Within the domain of scholarly research, it is apparent that there are numerous deficiencies in energy system modelling, namely in the field of optimization. This requires the creation and implementation of more effective and resilient optimization approaches. Therefore, this study presents a new approach to enhance the efficiency of hybrid energy systems by utilizing the Firefly Algorithm optimization tool.

The primary contribution of this study is the development of an optimized framework for hybrid energy system design, aimed at addressing critical deficiencies identified in earlier modeling approaches. Hybrid energy systems offer a promising approach to enhancing energy resilience and sustainability by leveraging multiple renewable and conventional energy sources. However, the design and optimization of these systems pose significant challenges due to complex interactions between various components and operational uncertainties. In this work, we propose an integrated approach that incorporates essential components such as solar panels, wind turbines, battery storage devices, combined heat and power (CHP) systems, and converters. By optimizing the configuration and operation of these components using the Firefly algorithm, we aim to achieve enhanced stability, flexibility, and efficiency in hybrid energy systems. Key aspects considered include the dynamic interactions between the recommended hybrid energy system and the broader network, along with constraints related to power exchange and operational parameters. To assess cost-effectiveness, the framework integrates diverse cost components as objective functions, encompassing installation costs, maintenance expenses, CHP fuel costs, predicted load-shedding costs, and power transactions. Through the application of advanced optimization techniques, this framework not only improves the effectiveness of hybrid energy system design but also provides insights into achieving optimal system performance under various operational scenarios and uncertainties. The proposed approach represents a significant advancement in the optimization of energy systems, offering practical solutions to improve efficiency, sustainability, and resilience in power engineering applications. The findings from this study contribute to the growing body of knowledge on hybrid energy systems optimization, providing valuable guidance for engineers, researchers, and policymakers seeking to implement more sustainable and robust energy solutions in practice.

2. OPTIMAL MODELLING OF INTEGRATED ENERGY SYSTEMS AND EQUIPMENTS

The integrated energy system discussed in this article encompasses wind turbines, solar panels, combined heat and power (CHP), battery storage, as well as direct current (DC), alternating current (AC), and thermal loads. To enhance the efficiency of this system, it is important to thoroughly elaborate on the equipment model employed, as outlined below.

The power generated by solar panels is contingent upon weather conditions, radiation levels, and panel temperature. Eqs. (1) and (2) are used to model the output power of solar panels [44].

$$P_{sp}(t) = N_{sp} \cdot \left\{ \tilde{p}_{sp} \cdot \left(\frac{v}{v_{ref}} \right) \cdot [1 + \vartheta \cdot (T_c - T_{ref})] \right\} \\ \forall t \in \mathrm{T} \tag{1}$$

$$T_c = T_{\text{air}} + [((T_{\text{nomm}} - 20)/800) \cdot v] \tag{2}$$

The aforementioned equations involve the variables N_{sp} (representing the quantity of solar panels), $\tilde{p}_{sp}$ (representing the nominal power of each solar panel), solar radiation, and ϑ the temperature coefficient of the solar panel. The temperature of the solar panel cell is denoted as 1/C, while T_{air} represents the air temperature, and Tnorm refers to the operational temperature of the solar panel.

Wind turbines are divided into four distinct zones based on the wind speed. The wind turbine has 0% production power in both the first and fourth zones. In the second functional zone, the turbine's output power is directly proportional to the wind speed raised to the third power. The third region, referred to as the constant power region, maintains a consistent and equivalent value. The Eqs. (3) and (4) are used to model the output power of wind turbines [45].

$$P_{ut}(t) = N_{wt} \\ \left\{ \begin{array}{cc} 0 & ; \forall v(t) \leq v_{\text{cut-in}} \\ a \times v(t)^3 + b \times \tilde{p}_{\text{wt}} & ; \forall v_{\text{cut-in}} < v(t) < \tilde{v} \\ \tilde{p}_{\text{ut}} & ; \forall \tilde{v} < v(t) < v_{\text{cut-out}} \\ 0 & ; \forall v(t) \geq v_{\text{cut-out}} \end{array} \right. ; \forall t \in T \tag{3}$$

$$a = \frac{\tilde{p}_{\text{wt}}}{\tilde{v}^3 - v_{\text{cut-in}}^3}, \; b = \frac{v_{\text{cut-in}}^3}{\tilde{v}^3 - v_{\text{cut-in}}^3} \tag{4}$$

In these equations, N_{wt} denotes the quantity of wind turbines, $\tilde{p}_{\text{wt}}$ signifies the rated power of the wind turbine, $v(t)$ represents the wind turbine's speed, $v_{\text{cut-in}}$ indicates the lower cut-off speed of the wind turbine, $v_{\text{cut-out}}$ corresponds to the upper cut-off speed of the wind turbine, and $\tilde{v}$ stands for the rated speed of the wind turbine.

The integrated electricity and heat system cogeneration system generates electricity and heat by utilizing natural gas as fuel. In order to meet the thermal demands, the heating network generates thermal energy, and in order to meet the electrical demands of the integrated energy system, it generates electric power. Eq. (5) is used to model the CHP system.

$$P_{\text{chp}}(t) = \alpha_{\text{chp}} \cdot H_{\text{chp}} + \beta_{\text{chp}} \cdot T_{\text{chp}} + \gamma_{\text{chp}} \tag{5}$$

The gas consumption of the CHP system is determined using Eq. (6).

$$f_{\text{chp}}(t) = \frac{3.412}{GHV} \left(\frac{P_{\text{chp}}(t) + H_{\text{chp}}(t)}{\eta_{\text{chp}}} \right) \tag{6}$$

The relationships can be defined as follows: $P_{\text{chp}}(t)$ represents the electrical power produced by the system, $H_{\text{chp}}(t)$ represents the thermal power produced by the system. T_{chp} represents the output temperature of the cap system, while GHV represents the gross calorific value. η_{chp} represents the system efficiency. α_{chp}, β_{chp}, and γ_{chp} are the coefficients of the fuel consumption curve of the CHP system.

Storage generators function as a backup in the self-sustaining hybrid energy system. When the power produced by wind turbines, combined heat and power (CHP) solar panels, and power exchanged with the upstream network matches the power required by consumers, the capacity of the battery storage remains constant, regardless of power transmission limitations. However, if the production capacity of these devices and the power exchanged with the upstream network, taking into account power transmission limits, exceeds the power demanded by customers, the surplus power is utilized for battery charging. Eqs. (7) to (9) are used to simulate the battery charging process [46].

$$E_{bs}(t) = E_{bs}(t-1) \cdot (1-\tau) + \\ P_{chbs}(t) \cdot \eta_{chbs}; \forall t \in \mathrm{T} \tag{7}$$

$$P_{ch-bs}(t) = \left\{ \begin{array}{cc} dP_{ch-bs}(t) & dP_{ch-bs}(t) \leq N_{c-bs} \cdot \tilde{P}_c \\ N_{c-bs} \cdot \tilde{P}_c & dP_{ch-bs}(t) > N_{c-bs} \cdot \tilde{P}_c \end{array} \right. \\ \forall t \in \mathrm{T} \tag{8}$$

$$P_{ch-bs}(t) = [p_{chp}(t) + p_{bury}(t) + p_{sp}(t) .\eta_{inv} + ... \\ ...p_{up}(t) .\eta_{con}^2] - (p_{load}(t) + p_{sell}(t)); \forall t \in T \tag{9}$$

The equations represent the charge quantity of the battery storage at time t, denoted as E_{bs}, and the hourly self-discharge rate of the battery storage, denoted as τ. The charging power of the battery storage at time t is denoted as P_{ch-bs}, while the charging efficiency of the storage is represented by η_{chbs}. Additionally, dP_{ch-bs} refers to the charging power of the battery at time t. The efficiency of a converter η_{con} . p_{bury} refers to the electricity acquired from the network supplier, whereas P_{sell} represents the electricity sold back to the network supplier. The variables in question are as follows: P_{load} represents the power demand of consumers, $\tilde{P}_c$ represents the nominal power of the converter, and N_{c-bs} represents the number of converters in the battery storage system.

If the production capacity of this equipment, along with the power exchanged with the upstream network, is insufficient to meet the power demand of consumers due to transmission limits, any excess power shortfall is compensated for by batteries. Eqs. (10) to (12) are used to represent the battery discharge process [47].

$$E_{bs}(t) = E_{bs}(t-1) \cdot (1-\tau) - P_{dch-bs}(t) \cdot \eta_{deh-bs} \\ \forall t \in T \tag{10}$$

$$P_{\text{dch-bs}}(t) = \left\{ \begin{array}{cc} dP_{\text{dch-bs}}(t) & dP_{\text{deh-bs}}(t) \leq N_{c-bs} \tilde{P}_c \\ N_{c-bs} \cdot \tilde{P}_c & dP_{\text{dch-bs}}(t) > N_{c-bs} \tilde{P}_c \end{array} \right. \\ \forall t \in T \tag{11}$$

$$dP_{\text{dch-bs}}(t) = (P_{\text{load}}(t) + P_{\text{sell}}(t)) - [p_{\text{chp}}(t) + \ldots \\ \ldots P_{\text{buy}}(t) + P_{sp}(t) \cdot \eta_{con} + P_{ut}(t) \cdot \eta_{con}^2]; \; \forall t \in \mathrm{T} \tag{12}$$

In the above equations, η_{deh-bs} represents the efficiency of the battery storage during discharge, whereas $dP_{\text{dch-bs}}$ represents the power output of the battery storage at a specific time t.

2.1. Formulating the optimal problem through mathematical modeling

The suggested approach for addressing the optimal configuration of hybrid energy systems poses an intricate optimization challenge. This problem exhibits non-linearity, non-convexity, mixed-integer nature, and substantial magnitude. It involves a wide range of technological, security, economic, and logical limitations.

The main goal of developing the integrated energy system is to identify the optimal mix and capacity of equipment to efficiently handle demand while minimizing total costs. Eq. (13) takes into account many objective functions, such as investment charges, maintenance costs, fuel expenditures, and expected load relief costs, in order to optimize the design of this comprehensive energy setup.

$$\begin{aligned} Min\ C_T = W_I \cdot C_I + W_M \cdot C_M + \\ W_F \cdot C_F + W_L \cdot C_L + W_C \cdot C_C \end{aligned} \tag{13}$$

In the above relation, W_I, W_M, W_F, W_L, and W_C represent the weighting coefficients associated with investment cost, repair and maintenance cost, fuel cost, load shedding cost, and power exchange cost with the upstream network, respectively. Furthermore, C_I, C_M, C_F, C_L, and C_C represent the expenses associated with investment, repair and maintenance, fuel consumption, load shedding, and power exchanges with the upstream network, respectively. Additionally, the weighting coefficients for various objective functions might range from zero to one. In this study, the weighting factor associated with the investment cost, W_I, is assumed to be equal to one. The coefficients are deemed to be equivalent to 0.8 for other goal functions. The rationale behind this is the significance of investment costs in relation to other objective functions. The investment cost associated with the equipment of an independent combined energy system is determined using Eqs. (14) and (15).

$$\begin{aligned} C_I = CRC \cdot [N_{sp} \cdot C_{I,\,sp} + N_{wt} \cdot C_{I,\,wt} + \\ N_{bs} \cdot C_{I,bs} \ldots\ldots + N_{\mathrm{con}}\ .C_{I,\,\mathrm{con}}\ + C_{I,\,chp}] \end{aligned} \tag{14}$$

$$CRC = m \cdot (1+m)^k / \left[(1+m)^k - 1 \right] \tag{15}$$

In the given equations, CRC represents the coefficient of return on investment, m denotes the interest rate, and k signifies the lifetime of the integrated energy system. $C_{I,sp}$, $C_{I,wt}$, $C_{I,bs}$ and $C_{I,chp}$ are associated with the investment cost of solar panels and wind turbines. The components include storage, battery, converter, and CHP system.

3. OPTIMIZATION OF THE PROBLEM WITH THE ALGORITHM; SIMULATION

The firefly algorithm (FA) is a meta-heuristic optimization algorithm. This is a result of the fascinating light emission patterns that certain firefly species' bioluminescent activity produces. Firefly species utilize various rhythmic light flash patterns to communicate for mating and lure potential prey. As a general principle, only one firefly is attracted to other fireflies regardless of their sex because fireflies are considered unisexual. (ii) The brilliance of a firefly is directly proportional to its attractiveness. Dim fireflies will gravitate towards brighter fireflies when observing the movement of two flashing fireflies. If there is no firefly that is brighter or if all fireflies have the same brightness, their movement in the search space is random. (iii) The topography of the objective function governs the luminosity of the firefly. The light intensity at a distance r is represented by the formula $I = I_0 e^{-\gamma r}$, which is a combination of light absorption $I = I_0 e^{-\gamma r}$ and light attenuation $I = I_0 / r^2$ formulas, resulting in Eq. (16). The attractiveness of a firefly (β) is calculated using similar formulas and Eq. (17).

$$I = I_0 e^{-\gamma r^2} \approx \frac{I_0}{1 + \gamma r^2} \tag{16}$$

$$\beta = \beta_0 e^{-\gamma r^m} \approx \frac{\beta_0}{1 + \gamma r^m} \tag{17}$$

The Firefly algorithm utilizes a parameter called m to quantify the level of attractiveness of a Firefly. This parameter is a non-negative value. When the value of m is zero, the attractiveness of the firefly remains consistent, regardless of its distance. The allure of the firefly diminishes significantly as the value of m increases and the distance grows. Put simply, the firefly's attraction never diminishes to zero, and it's worth consistently remains above one. The parameter γ is utilized in the light intensity formula to determine the functions of spatial position and the reciprocal of the square of the distance. To eliminate the reliance on spatial position, it is recommended to utilize the distance-based parameter $\Gamma = 1/\sqrt{\gamma}$. The previous and current position of the object is being attracted towards the firefly's position using a lighter. This attraction is computed using Eq. (18), which represents a random vector with a uniform or Gaussian distribution. The mutation coefficient is denoted by α, whereas the light absorption coefficient is represented by γ. During the algorithm's convergence process, the value of can be adjusted by either increasing or decreasing it, with the change occurring in a linear or exponential manner [48–52]. Fig. 1 shows the optimization procedure. The optimization algorithm was developed in MATLAB R2016b.

Table 1. The optimal values achieved for the goal function of the hybrid energy system design issue under various scenarios.

Algorithm	FA	BA	GA
Scenario 1	21140.7	23312.3	23778.7
Scenario 2	19642.3	22154.7	22651.21
Scenario 3	17551.7	19378.4	19774.4

$$x_i' = x_i + \beta_0 e^{-\gamma r^m} (x_j - x_i) + \alpha \varepsilon_i \tag{18}$$

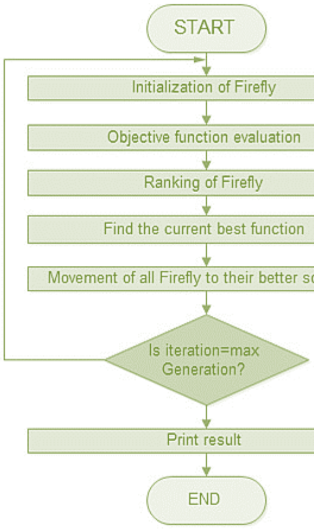

Fig. 1. The firefly algorithm flowchart.

Fig. 2-(a) presents the recorded wind speed data, Fig. 2-(b) exhibits the measured solar radiation data across a span of one year, and Fig. 2-(c) demonstrates the annual load curve in a comparable fashion.

The electric load curve and thermal load curve for a 24-hour period are displayed in Fig. 3. It is evident that there is a consistent demand for both electric and thermal power throughout these hours.

A comprehensive methodology has been suggested to analyse the structure of hybrid energy systems in three separate scenarios. Scenario 1 involves a system that consists exclusively of solar panels, battery storage devices, and combined heat and power (CHP). Scenario 2 centres around a hybrid energy system that exclusively combines wind turbines, battery storage devices, and combined heat and power (CHP). Scenario 3 encompasses a sophisticated hybrid energy system that combines solar panels, wind turbines, battery storage units, and combined heat and power (CHP). These scenarios present a variety of arrangements

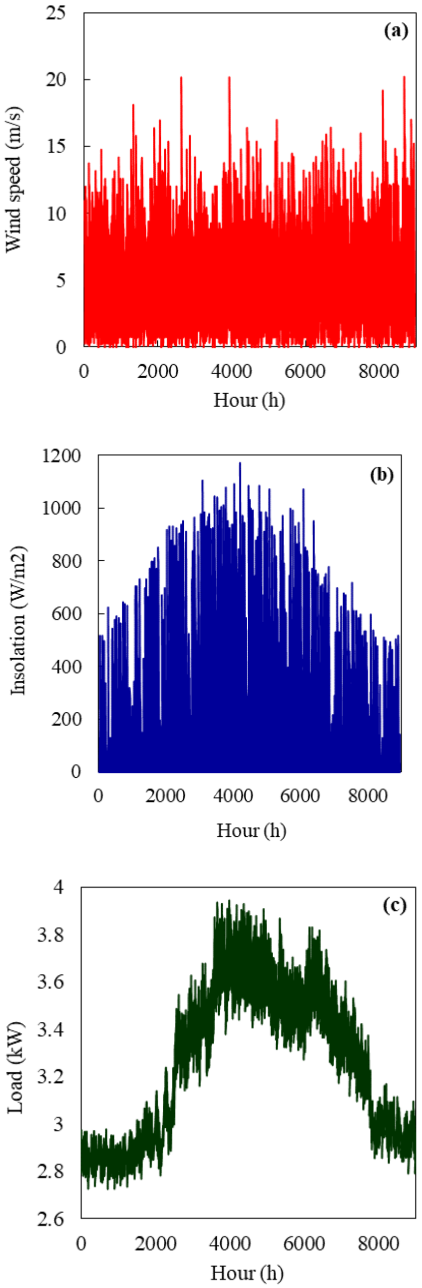

Fig. 2. (a) Wind speed data, (b) Solar radiation data and (c) Load curve.

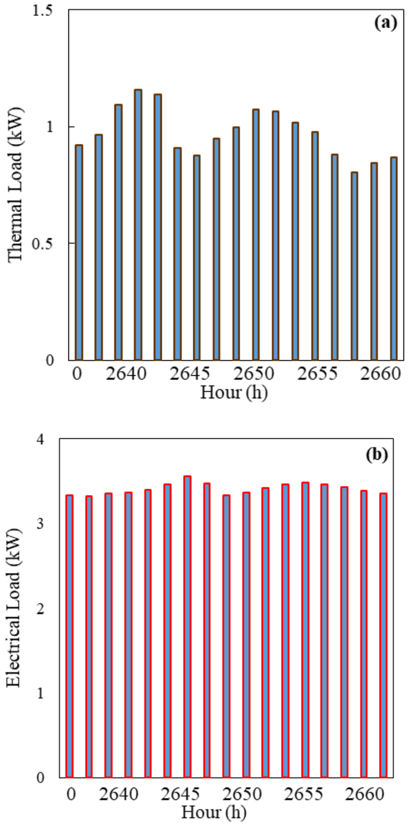

Fig. 3. (a) Thermal power, (b) Electrical power.

Table 2. Optimal results related to the amount of equipment under different scenarios in the design of the combined energy system.

Scenario	Algorithm	Average number of solar panels	Average number of wind turbines	Average number of battery savers	Average number of converters
Scenario 1	FA	73	0	22	17
	BA	80	0	24	20
	GA	86	0	26	22
Scenario 2	FA	0	15	21	12
	BA	0	17	25	14
	GA	0	18	26	15
Scenario 3	FA	36	10	18	8
	BA	40	11	21	11
	GA	42	12	23	12

involving renewable energy sources, storage mechanisms, and CHP technology. This allows for a thorough examination of the most effective designs for hybrid energy systems.

In this study, the objective function is the predicted load removal cost index, which is different from other studies that often model the energy system dependability index as an adverb. Therefore, the optimization algorithm takes this into account. The objective is to minimize investment costs, maintenance expenses, power exchanges with the upstream network, and fuel consumption of the CHP system. Additionally, it aims to reduce the cost associated with eliminating the projected load, which is similar to reducing the ENS (projected net Savings). Thus, in the third scenario, a reduced value for the ENS index and consequently a lower cost for reducing the predicted load have been achieved as compared to the first and second scenarios. Nevertheless, the execution time in the third scenario is 13.35 and 24.50 percent greater than that of the second and first scenarios, respectively. This can be attributed to the rise in the quantity of design possibilities. Furthermore, based on the findings shown in Tables 2 and 3, it is evident that the firefly algorithm has consistently outperformed both the genetic and bee community algorithms in all scenarios examined in this work.

Table 1 presents the optimal values achieved for the objective function of the combined energy system design problem. This objective function encompasses the sum of investment costs, maintenance expenses, power exchanges with the upstream network, supplied energy, and CHP system fuel. The values were obtained through the utilization of various optimization algorithms and were obtained under different scenarios.

The results in Table 1 demonstrate that the design cost of the combined energy system in the third scenario, utilizing the firefly algorithm, is lower compared to the first and second scenarios. This is attributed to the improved selection of equipment. The optimal design results for the first and second scenarios are presented in Tables 2 and 3, with cost reductions of 18.30% and

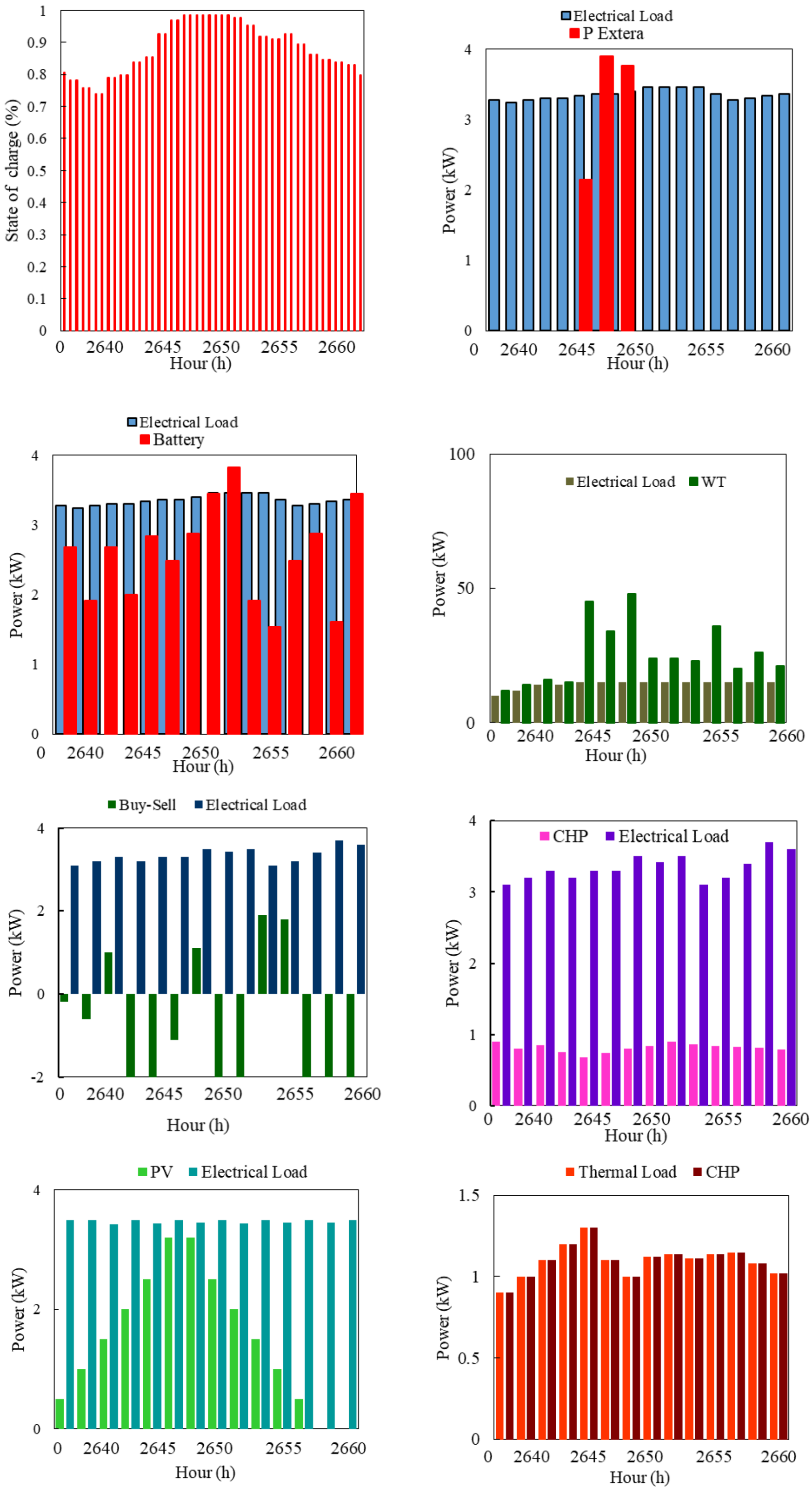

Fig. 4. The state of the elements of the combined energy system for a period of time.

13.6%, respectively. The third scenario offers a greater range of design alternatives, allowing the optimization algorithm to have more freedom and flexibility in selecting these options. In this scenario, a more economically efficient combination of equipment is being examined for the design of the integrated energy system as compared to the first and second possibilities. Furthermore, the design expenditure of the integrated energy system in the second scenario amounts to 5.68% of the similar expenditure in the first

Table 3. Optimal results related to the amount of equipment under different scenarios in the design of the combined energy system.

Scenario	Algorithm	Average ENS (kWh)	Average execution time(s)	Average total cost ($)
Scenario 1	FA	0.213	106.15	21439.1
	BA	0.410	126.12	23744.7
	GA	0.508	138.75	24455.2
Scenario 2	FA	0.115	117.11	20256.15
	BA	0.276	140.74	22562.10
	GA	0.297	151.52	23361.3
Scenario 3	FA	0.63	130.41	17975.4
	BA	0.113	157.6	19778.16
	GA	0.121	163.45	20076.18

scenario.

During a period of twenty-four hours in which demand was low, the components of the integrated energy system are depicted in Fig. 4, which shows their current status. In light of the diagram, the following are the conclusions that can be drawn: It is the responsibility of the battery storage system to maintain a continuous, ideal charging status at all times, acting as a reliable backup to address power requirements whenever they are required. In addition, the combined heat and power system operates without any interruptions, thereby satisfying the complete requirement for thermal load and supplying a portion of the essential electric load in the integrated energy system. Furthermore, for a duration of 15 hours, the system acts as a seller of power to the upstream network, and for a duration of 7 hours, it functions as a buyer of power from the upstream network. There has been a significant absence of power transfer between the upstream and downstream networks for a period of two hours. This represents a significant problem. As an additional point of interest, the solar panels are operational for around half of the day and night, whereas the wind turbines are operating for the majority of the day. Additionally, the transmission lines' limitations prevent the integrated energy system from sending the increased power it produces to the upstream network.

4. CONCLUSION

The purpose of this study is to propose a novel approach to the design of hybrid energy systems that are connected to the upstream grid. This approach makes use of the Firefly algorithm. A number of components are included in these systems. These components include wind turbines, solar panels, combined heat and power (CHP) units, battery storage units, and thermal loads, in addition to direct and alternating electric loads. A number of objective functions, including investment cost, maintenance cost, power exchange costs with the upstream network, unsupplied energy prices, and fuel expenses for the combined heat and power system, were calculated and evaluated using the framework. In addition, a thorough investigation was carried out in order to take into account the numerous technical, logical, economic, and security constraints that were pertinent to the scenario.

The implemented framework underwent testing in several situations, which varied based on the permissible elements throughout the design phase. The data clearly showed that, with the exception of wind turbines, the third scenario performed significantly better than the first scenario. Furthermore, the outcomes of the second scenario were significantly more favorable in comparison to the previous scenario. The firefly algorithm's exceptional performance in all three circumstances highlights its better optimization skills in this context, making it a fascinating discovery. The results highlight the capability and effectiveness of the Firefly algorithm in optimizing the designs of hybrid energy systems, providing significant opportunities for future energy planning and system improvement.

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