International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 3
ISSN: 2088-5334

Reduction of Electricity Cost of Residential Home Using PSO and WOA Optimization Method

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***Abstract*— Recently, the reduction of electricity costs in residential areas has become one of the major research fields. A comprehensive power management system is required to lower the cost of both power generation and consumption. Moreover, the world's energy consumption is continuously increasing. This rise is the consequence of perpetual birth rates and the expansion of factories, which have both significantly increased carbon dioxide emissions and global warming. In order to address these difficulties, hybrid renewable energy systems have evolved in an important way since the development of renewable energy sources. Two meta-heuristic approaches are applied in this paper: the first one is the particle swarm optimization (PSO), which is inspired by the social behavior of bird swarms, and the second one is the whale optimization algorithm (WOA) which is inspired by humpback whale hunting behavior, to tackle the main issue in this work which is decreasing the overall electricity cost of a residential home. The residential home considered in this work consists of two renewable energy sources: a solar panel and the wind turbine, and a power storage system based on battery. This residential home is connected to the main grid through a bidirectional inverter. Furthermore, a comparative optimization study was suggested where we propose two different residential load demands. The results showed the best decrease in the total electricity cost and the best optimal solution by employing the whale optimization approach in both proposed cases.**

***Keywords*—Reduction of electricity cost; residential home; particle swarm optimization; whale optimization algorithm.**

Manuscript received 27 Oct. 2022; revised 27 Nov. 2022; accepted 29 Dec. 2022. Date of publication 30 Jun. 2023.

I. Introduction

The utilization of different renewable energy sources has grown significantly since the early 1970s fuel crisis. Renewable energy sources have such an immense opportunity in the hybrid energy system, considering that they are non-exhaustible and contain no contamination [1]. During the last decades, the power produced from renewable sources has expanded dramatically. Furthermore, because of worldwide and regional restrictions, by 2020, major developed nations are projected to produce at least 15% of their electricity from renewable energy sources [2].

Several nations have lately utilized wind turbines after they depend on countless photovoltaic systems to reduce their reliance on non-renewable sources such as oil and coil. Considering the necessity and requirement for renewable energy sources, the main disadvantage of such power throughout many situations is its reliance on uncontrollable environmental circumstances. Due to the uncertainty of seasonal changes, individual renewable may not ensure uninterrupted electricity supply to microgrids [3], [4]. Therefore, combining two or more renewable sources in the same multi-source system is better.

Considering the numerous conceivable mixes of resource power, hybrid energy systems may provide very efficient energy-generating options. The goals of employing hybrid energy systems are to enhance overall efficiency and fuel adaptability, as well as to boost dependability and handle variable renewable energy sources. Furthermore, these technologies cut expenses, consumption of fossil fuels, primary energy, and dioxide emissions. In remote locations without an established power infrastructure, hybrid power systems can be connected to the main grid or isolated systems [5].

In recent years, the challenge of optimizing and managing power in a hybrid system has become a strategic concern. This process determines the most appropriate minimum or maximum of arithmetic operations among several viable options, where feasible answers meet all the requirements [6].

The investigators have applied and developed diverse optimization techniques to handle the various hybrid power system issues. Nsafon et al. [7] used a sustainability strategy to discover the best design for a feasible photovoltaic, wind turbine, and diesel hybrid combination, where many hybrid system designs were developed to provide the load demand by modifying the photovoltaic slope and wind turbine hub height under various dispatch techniques. The power system has been optimized for each design to get the most electrical output at the lowest cost.

To develop an efficient financial structure that is most appropriate to deliver the necessary power while reducing the net present cost and the cost of desalinated water for a remote farm situated in Noubarya, Egypt, hybrid optimization software based on a genetic algorithm was suggested by Tawfik et al. [8]. Abualigah et al. [9] study aimed to offer research for different kinds of deep learning and machine learning algorithms used in solar and wind energy supply. Lahlou et al. [10] suggested a more effective management technique for a patented transformable photovoltaic-wind system, which mainly uses two flexible photovoltaic panels for the ecological production of green energy. Gholami and Dehnavi [11] presented a modified particle swarm optimization algorithm to optimize the sharing power across many renewable energy sources such as photovoltaic, wind turbines, power plants, and combined heat. Certain benchmark functions are used to validate the proposed approach, and the suggested technique is compared to several metaheuristic algorithms. Danoune et al. [12] devised and used a whale optimization method to identify optimal features of different proton exchange membrane fuel cells and compared the results with previous metaheuristic optimization results. Azaroual et al. [13] presented a method for reducing grid utilization for electricity use in the load while increasing sales of renewable energy. Moreover, battery storage is allowed to sell extra electricity during high-price times.

The model incorporates time-of-use and step-rate tariffs to govern the performance of the grid system while also taking into account the volatility of the power cost. To address the load frequency control issue of three region hybrid electric power systems, a straightforward dual-mode fractional order controller was developed and successfully applied by Srivishnupriya et al. [14]. The above controller has been compared to others, including the conventional proportional-integral controller, the sine cosine algorithm tuned fractional proportional-integral controller, and the sine cosine optimization algorithm tuned dual mode, proportional-integral controller. In order to lower the overall cost of the microgrid in a home grid, Zakaria et al. [15] focus on microgrid power management control.

Additionally, the effect of distributed generator emissions and the depreciation of energy storage systems on the overall operating costs of microgrids were investigated. Numerous techniques, like the particle swarm optimization, gravitational search algorithm, hybrid population-based algorithm, and the suggested capuchin search algorithm, have been applied, and the outcomes have been compared. The study by Pramono et al. [16] used a wireless device with a wireless sensor network design to evaluate environmental factors in a space, such as humidity and temperature. Vu et al. [17] presented an optimization search for a typical non-fired brick factory in Quang Binh province, Vietnam, where they proposed two scenarios, the grid-tied wind, and solar hybrid power system scenario, which achieved the greater ecologic, financial, and technical efficiency than the grid-tied solar power system scenario. Ismail et al. [18] analyzed and demonstrated an enhanced approach for optimizing the generation of biochemical systems that integrates the particle swarm optimization algorithm and the Newton method.

For the architecture of a hybrid renewable power system combination incorporating solar, wind, and marine energy for a prototypical coastal community, Ang et al. [19] presented a multifunctional, multi-objective optimization approach. The findings imply that while various combinations of renewable power sources may be economically feasible, optimizing for cost, energy use, and power shortfall may become more difficult as yearly demand rises. The techno-economic feasibility of installing a solar-driven cogeneration facility for electricity and hydrogen in the Farakhi village is examined by Dadak [20], where the system's effectiveness is determined and tracked using financial methodology. Cheng and Yao [21] introduced a revolutionary U-type Darrieus wind turbine and developed it by utilizing a machine learning approach based on back propagation neural network and three optimization techniques: the genetic algorithm, particle swarm optimization, and simulated annealing.

In order to create an effective single-axis solar tracking system, Abdel-hamed et al. [22] suggested the proposed Harris Hawks optimization - PID controller, and this approach had been compared employing various personal goals using specified performance indices. A multi-objective whale optimization algorithm approach has been described and implemented to manage three major goals for a stand-balancing humanoid robot: less jerk, less orbit power, and less phase portrait error by Sanprasit and Artrit [23]. Idris et al. [24] proposed a moth-flame optimization technique to enhance wind farm power production and to find the best controller and compared the results to a dynamic spiral algorithm and safe experimentation dynamics-based techniques. Padmini and Shankar [25] created two improved photos from a single hazy photo utilizing the particle swarm optimization and fuzzy intensification operators. Then, these two resulting pictures were combined by utilizing the multi-scale fusion approach. A study presented by Loy et al. [26] utilized a thermo gravimetric analyzer combined with a mass spectrometer to explore the catalytic air gasification of rice husks in order to optimize the syngas and hydrogen composition. Al-khazarji et al. [27] proposed a robust technique for optimum position control for DC motors in a robotic arm system, as well as a comparative study had been presented by utilizing a regular PID controller and an optimal controller.

In order to improve a balanced load and a current photovoltaic power generation, Vai et al. [28] created an ideal low voltage distribution topology with the inclusion of photovoltaic and three distinct proposed solutions, including reverse power relay, solar hybrid inverter, and battery energy storage and to reduce power loss and imbalanced demand in the three-phase distribution network, the repeated phase ABC has been used. An auto robot system was constructed in Arduino and Python to better detect and collect plastic floating rubbish by applying a fast approximate nearest neighbor search by Nuanmeesri [29]. This new technique found the quickest one-way route and reduced time and energy usage.

The primary goal of this study is to reduce the overall electricity cost of a residential home system consisting of two renewable energy sources (photovoltaic and wind turbine) and a battery storage system to completely fulfill load demand while consuming less energy from the grid. A bidirectional link connects this hybrid system to the main grid. There were two meta-heuristic methods offered, and the results were compared.

This paper is organized as follows. The proposed residential power management system and the two meta-heuristic optimization algorithms, particle swarm optimization and whale optimization algorithms, are described in section II. Simulation results are presented and discussed in section III. Finally, section IV concludes the paper.

II. Materials and Method

A. Residential Power Management

1) Residential Power System Model: To meet a load requirement, the residential system studied in this paper is connected to the main grid by a bidirectional link. The system comprises a battery storage system, wind turbine, and photovoltaic Fig. 1. The connection with the main grid allowed a bidirectional power exchange in the sense that when the power generated by renewable sources is insufficient, the load consumed power by discharging the battery storage system or from the main grid, depending on the battery's state of charge and power. Furthermore, the excess power generated by renewable energy sources is transported to the battery or sold to the main grid. The wind turbine and the photovoltaic systems are unstable and intermittent, so they complement each other. Generally, the wind systems' highest working hours are at night, while the solar systems rated maximum times are during the day and at seasonal times. Moreover, the hybrid system must contain a storage device, such as a battery; if the overall power output of the production exceeds the energy required, the battery can charge and then deliver power during the discharge phase.

The two different daily predicted data power, the solar-produced power and the wind turbine-generated power of the residential system illustrated in Fig. 2 with a sampling interval of one hour. Otherwise, Fig. 3 displays the cost of grid-supplied or sold electricity. The 3.5KW photovoltaic equipped system has an efficiency of 18.6% and a total area of 25 m^2. The microturbine wind of 2.4 KW has a nominal speed of 14 m/s, a cutout speed of 25 m/s, and a rated power of 2.1 KW. With a starting nominal battery capacity of 6 KWh and a minimum state of charge of 15%, a battery storage capacity of 10 KWh is chosen.

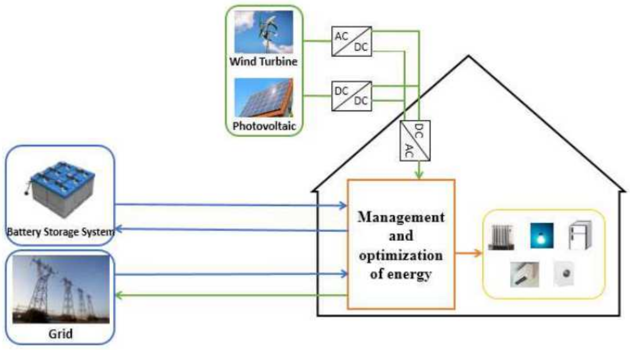

Fig. 1 Grid-connected residential energy system

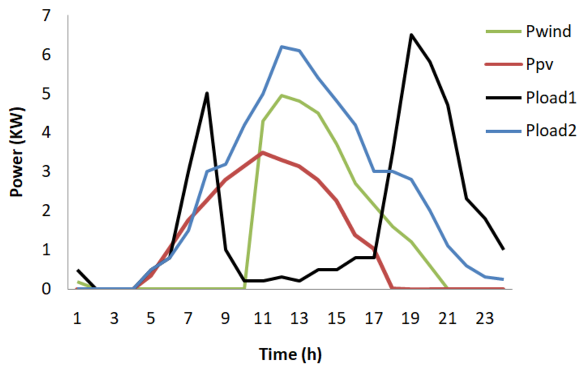

Fig. 2 Load demand, photovoltaic and wind turbine power in 24h

2) Mathematical Formulation of Model: The problem goal is to reduce the energy bought from the grid while lowering the total cost of the electricity bill. The cost function is defined as follows:

$$\min f=\sum_{t=1}^{24}\begin{bmatrix}C_{grid}(t)*P_{grid}(t)*dt+C_{bat}(t)*P_{bat}(t)*dt+\\ C_{pv}*P_{pv}(t)*dt+C_{wind}*P_{wind}(t)*dt\end{bmatrix} \quad (1)$$

Where C_{grid} [€/kWh] is the electricity cost, P_{grid} [kW] is the bought and sold power from the main grid, C_{bat} [€/kWh] is the maintenance price of battery storage system, P_{bat} [kW] is the charging and discharging power of battery storage system , C_{wind} [€/kWh] and C_{pv} [€/kWh] are the maintenance and production cost of wind turbine and photovoltaic systems respectively, P_{pv} [kW] is the photovoltaic power, P_{wind}[kW] is the wind turbine power and dt is the step time which is equal to one hour.

The problem function is dependent on constraints to create a viable optimal solution, which are described as equalities and inequalities equations that put a boundary on the parameters of the issue. The power load demand is provided by a mix of battery storage power, renewable energy production power, and electricity network power. The power balance is represented by (2), which is to maintain the equivalence of supply power and load needed power under any limitations and at all times.

$$P_{grid}(t) - P_{bat}(t) + P_{PV}(t) + P_{wind}(t)= P_{load}(t) \quad (2)$$

Where P_{grid}[kW] is the power injected or consumed from the main grid, P_{pv}[kW] is photovoltaic power, P_{WT} [kW] is wind turbine power, P_{bat}[kW] is the battery storage system charging or discharging power, while P_{load}[kW] is the power demand of hybrid system.

The power imported from/to the grid, the charging/discharging power of the battery storage system, the photovoltaic power, and the wind turbine power are represented by the following inequality equations:

$$P_{grid}^{min} \leq P_{grid}(t) \leq P_{grid}^{max} \quad (3)$$

$$P_{bat}^{min} \leq P_{bat}(t) \leq P_{bat}^{mac} \quad (4)$$

$$P_{pv} \geq 0 \quad (5)$$

$$P_{wind} \geq 0 \quad (6)$$

Where P_{grid}[kW] is the injected or consumed grid power, P_{grid}^{max}[kW] is the maximum power consumed by the grid, P_{grid}^{min}[kW] is the maximum power injected to the grid, P_{PV}[kW] photovoltaic power, and P_{WT}[kW] wind turbine power.

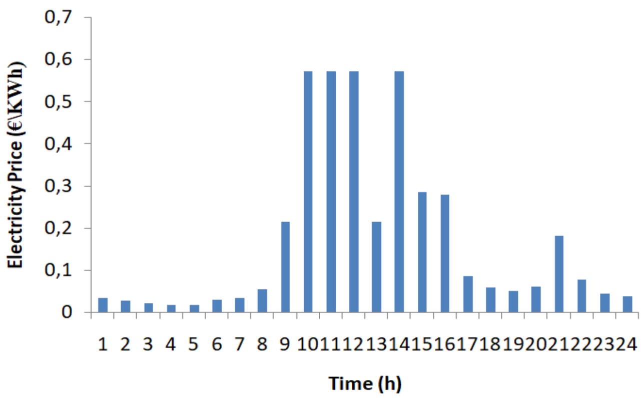

Fig. 3 Hourly electricity price

B. *Meta-Heuristic Optimization Algorithm*

A comparative study was suggested in this paper, where we used two meta-heuristic optimization algorithms: the particle swarm optimization and the whale optimization algorithm.

1) Particle Swarm Optimization: The particle swarm optimization (PSO) method, invented by Kennedy and Eberhart, is a meta-heuristic optimization approach. It is a simple approach that seems to be effective for optimizing a wide range of functions. Social optimization occurs within the context of daily life. In regard to its connections with living, particle swarm optimization has clear links with evolutionary computing. Theoretically, it looks to be between genetic algorithms and evolutionary programming. It is heavily reliant on stochastic processes, such as evolutionary programming [30]. It is inspired by the social behavior of bird swarms, which is based on the activity of the swarm's particles in a multidimensional space. Using the velocity and position equation, the PSO particles are changed at random in each iteration [31], [32]. At each iteration, the position and velocity of every swarm particle are updated based on the best current position, using the given equations:

$$V_i(k+1) = w * V_i(k) + C1 * r1 * (X_{i,best}(k) - X_i(k) + c2 * r2 * (X_{g,best}(k) - X_i(k)) \quad (7)$$

$$X_i(k+1) = X_i(k) + V_i(k+1) \quad (8)$$

Where X_i is the particle position, $X_{i,best}$ is the best particle position in the current iteration , $X_{g,best}$ is the global best position of the particles which represents the optimal solution in the current iteration, V_i is the velocity, w is the inertia weight coefficient for particles, c1 and c2 are the personal and social acceleration coefficients and r1 and r2 are random numbers from [0, 1].

2) Whale Optimization Algorithm: This optimization strategy, inspired by humpback whale hunting behavior, is a population and probabilistic research approach proposed in 2016 by Mirjalili and Lewis [33]. In this developed approach three steps were followed which are: encircling prey, bubble net attacking and seeking for the prey. Equation (9) calculates the distance between agent and best agent. The other particles must now pursue the goal, as shown in (10). It is important to note here that the best agent should be modified at each iteration if a better option exists.

$$\vec{D} = \left|\vec{C} * \overrightarrow{X^*} - \overrightarrow{X(i)}\right| \quad (9)$$

$$\vec{X}(i+1) = \overrightarrow{X^*} - \vec{A} * \vec{D} \quad (10)$$

Where $\vec{D}$ is the distance vector between the best position and the agents. We can calculate the constant vectors $\vec{C}$ and $\vec{A}$ with (11) and (12).

$$\vec{C} = 2 * \vec{r} \quad (11)$$

$$\vec{A} = 2 * \vec{a} * \vec{r} - \vec{a} \quad (12)$$

Where $\vec{r}$ is a random value from [0,1] and $\vec{a}$ take a linear decreasing value from 2 to 0.

Equation (13) might be used to replicate a unique fishing strategy used by humpback whales which is bubble net feeding behavior.

$$\vec{X}(i+1) = \begin{cases} \overrightarrow{X^*}\vec{A} * \vec{D} & if\ p < 0.5 \\ \overrightarrow{D'} * e^{b*l} * \cos(2*\pi*l) + \overrightarrow{X^*} & if\ p \geq 0.5 \end{cases} \quad (13)$$

Where p is a random variable from 0 to 1, b is equal to 1 and l is a random value that lies in $-1 \leq l \leq 1$.

To ensure that a global exploration is done in all areas, the particles are compelled to go far away from the reference whale, as mathematically indicated in (14) and (15).

$$\vec{D} = \left|\vec{C} * \overrightarrow{X_{rand}}(i) - \vec{X}(i)\right| \quad (14)$$

$$\vec{X}(i+1) = \overrightarrow{X_{rand}}(i) - \vec{A} * \vec{D} \quad (15)$$

Where $\overrightarrow{X_{rand}}(i)$ is the position, which is randomly taken from the current particle.

III. Results and Discussion

A comparative study was created in this paper by using photovoltaic-produced power data, wind turbine-produced power data from Melhem et al. [34], and two different residential load demands to handle the optimization issue, which is minimizing the total electricity cost of a residential load. MATLAB was used to simulate the suggested power management system using two different meta-heuristic optimization methods. Throughout 400 iterations, the created code was performed several times separately, and the lowest of the possible solutions was chosen as the required answer. In addition, the number of particles in both meta-heuristic methods were adjusted to 10 agents. Fig. 2 depicts the expected daily data of residential power needs, solar-generated power, and wind turbine-generated power with a step duration of one hour. Meanwhile, Fig. 3 displays the cost of grid electricity.

The convergence results of the electricity total cost of the first residential load demand by applying the particle swarm optimization and whale optimization algorithm are presented in Fig. 4, where we notice that the optimum results were found by utilizing the WOA. Even from the beginning of the simulation, the electricity cost of using PSO was higher than using WOA.

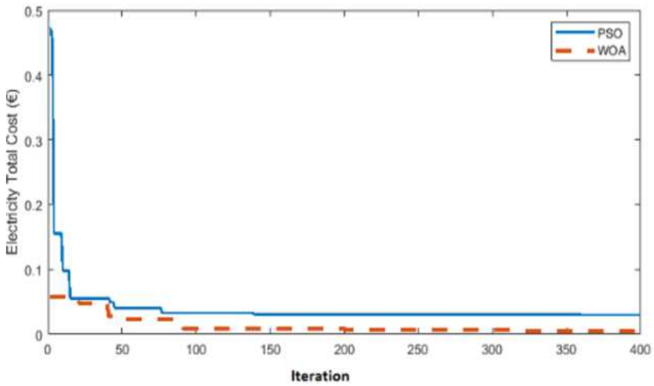

Fig. 4 Electricity total cost convergence of Load1 using PSO and WOA

Furthermore, the convergence speed findings in Fig. 4 demonstrate that the WOA strategy converged quickly when compared to the PSO optimization method, where the minimum convergence cost was 0,0053807€ in iteration number 377, and the minimum cost by using PSO was 0,029374€ in the iteration number 390.

Fig. 5 and Fig. 6 represent the grid power and battery storage system power results of the first residential optimization to supply the required power load by using the PSO and WOA methods, where the positive power is the consumed power from the main grid, and the charged power to the battery storage system and the negative power is the injected power to the main grid and the discharged power from a battery storage system. The highest purchased power from the grid was from the first hours of the day and at night, going from 1 a.m. to 8 a.m. and from 6 p.m. to 12 p.m. in the result of PSO optimization and from 6 a.m. to 8 a.m. and 6 p.m. to 11 p.m. in the results of WOA, where the power generated by the renewable energy sources was not sufficient to meet the residential demand and the tariff of electric power was at its lowest rate. Furthermore, the more power injected into the grid from 9 a.m. to 5 p.m., where we had more power produced by renewable energy sources, and at the same time, the tariff of electric power was at its highest rate, which minimized the cost of the electric bill of the hybrid system too. In addition, the battery storage system when we used the PSO is charged from 10 a.m. to 5 p.m. and with slight charging from 1 a.m. to 6 a.m. by the excess power of the renewable energy sources and discharged to meet the load demand when the generated power from renewable energy sources is not enough which is from 7 a.m. to 9 a.m. and from 6 p.m. to 11 p.m. However, it was observed that the charging and discharging power of the battery storage system using the WOA optimization method was volatile between charging and discharging all day.

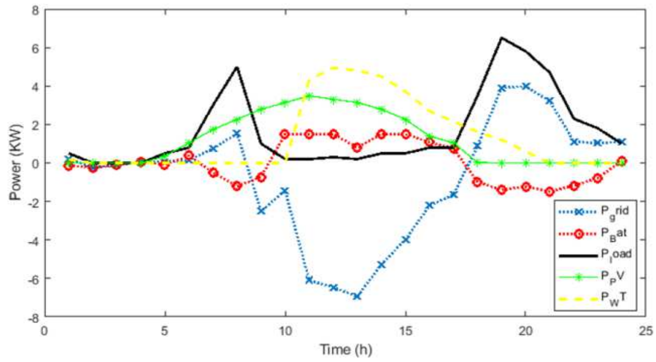

Fig. 5 Grid and Battery Power for the Load1 by using PSO

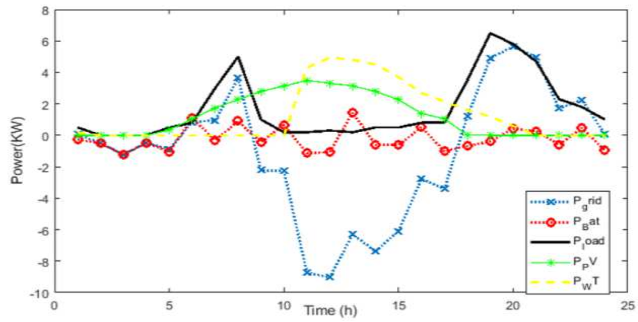

Fig. 6 Grid and Battery Power for Load1 by using WOA.

Fig. 7 depicts the convergence results of the total electricity cost of the second residential load demand by utilizing particle swarm optimization and whale optimization techniques. From the comparison of the convergence results of the two meta-heuristic methods used, we obtained that the WOA produced the best minimum outcomes. Furthermore, the convergence speed results in Fig. 7 show that the WOA strategy converged faster than the PSO optimization approach, where the low convergence cost was 0,0034066 € in iteration number 361, and the minimum cost by utilizing PSO was 0,039904 € in iteration number 388.

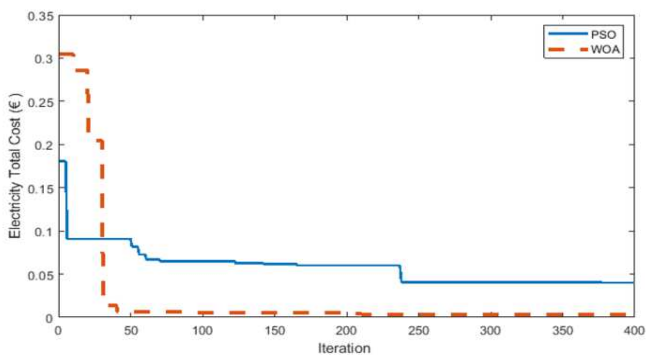

Fig. 7 Electricity total cost convergence of Load2 using PSO and WOA

The consumed/sold grid power and the charging/discharging battery storage system power by using the two meta-heuristic optimization methods for the second case are illustrated in Fig. 8 and Fig. 9. The most power was injected into the grid between 11 a.m. and 3 p.m., when we had the most power produced by renewable energy sources and the electric power tariff was at its highest, and this is lowering the cost of the residential electric bill. On the other hand, the consumed power from the grid was from 6 p.m. to 11 p.m. when we applied PSO and from 6 p.m. to 12 p.m. when we applied the WOA method. From 1 a.m. to 10 a.m., the grid power was volatile between consuming and selling power using the PSO and WOA optimization methods.

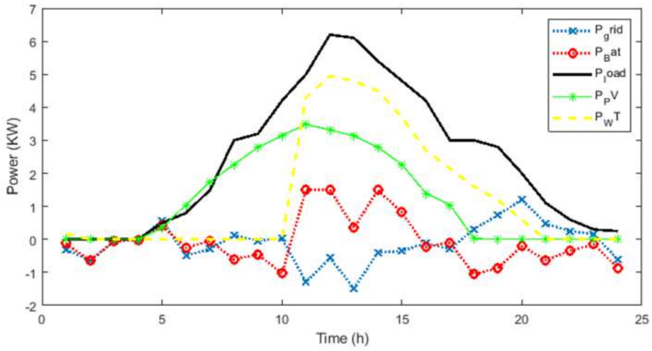

Fig. 8 Grid and Battery Power for the Load2 by using PSO

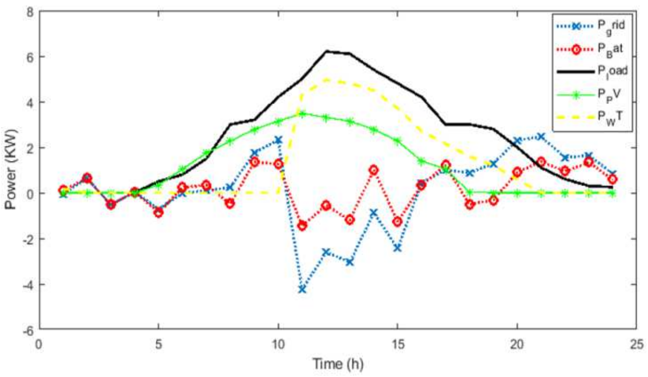

Fig. 9 Grid and Battery Power for Load2 by using WOA.

Finally, based on the outcomes of the two different optimization approaches employed in this work, we determined that using the WOA instead of the PSO resulted in the greatest decrease in the overall power cost of residential electricity.

IV. Conclusion

In this research, two meta-heuristic methods are employed: particle swarm optimization and whale optimization algorithm, to meet the required load by optimizing and managing the power of a residential home that is equipped with two renewable energy sources and a battery storage system that is connected to the main grid through a bidirectional inverter. Two different daily power demands of a residential home were proposed to confirm which meta-heuristic optimization method can afford the optimum result and the best minimum electricity total cost. From the optimization results, the lowest daily cost was given by using the whale optimization algorithm in the two proposed cases. Finally, continual loading and unloading throughout the day affects battery life. As a result, we will address this issue in the future to ensure a long lifespan.

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