Optimal Rooftop Photovoltaic System Placement To Minimize Monthly Used Energy Costs For Households In Vietnam's Cities And Towns

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Abstract. *This study presents a strategy to stop paying monthly used energy costs for households in Vietnam's cities and towns. To get there, the total energy cost acquired from the utility grid must equal the total extra energy supplied to the grid. In addition to the power consumption reduction from the grid for household customers, the extra energy produced by the rooftop photovoltaic system (RPV) is sold back to the grid. This mechanism has effectively freed up the monthly energy bill for individual customers. However, the optimal rated power of the rooftop photovoltaic system (RPV) must first be determined. Two meta-heuristic algorithms, including the Coati optimization algorithm (COA) and the Osprey optimization algorithm (OOA), are implemented to solve the problem. The results obtained by the two algorithms are compared using different criteria. Through these comparisons, OOA completely outperforms COA regarding solution quality and stabilization. For instance, OOA is the only method to reach the best optimal rated power of the RPV. Moreover, OOA is also more effective than COA with 50.17% on mean cost, 11.49% on maximum cost, and 17.06% on standard deviation. By using the solution found by OOA, RPV not only fulfills the household's needs but also reduces the electric energy cost to zero. While evaluating a five-year operation period, the household can get the benefit of $3,635.64. So, using the RPV is very effective for reaching both economic and environmental benefits.*

Keywords

Energy costs, rooftop photovoltaic system, Coati optimization algorithm, Osprey optimization algorithm, power grid.

1. Introduction

Nowadays, the rapid growth of electricity load demand puts more pressure on electricity-generating sources such as thermal power plants (TPPs) and hydroelectric plants (HPTs) [1]. The operation processes of these generating sources have caused serious problems for the environment and have accelerated the negative effects of the global warming phenomenon [2–4]. On top of that, HPTs also brings different negative effects that directly affect human life and other high-alert environmental problem besides their substantial contribution [5–7]. In this circumstance, the need for clean, safe, and sustainable energy sources is really urgent, and renewable energy sources such as wind and solar energy are considered the perfect solution for mitigating the negative effects of global warming and climate change [8]. Besides the large-scale wind and solar power plants connected to the transmission network, the RPV are also encouraged to be installed by governments at the family scale in many countries with huge potential for solar energy [9–11]. Vietnam is considered to be one of the nations with considerable potential for developing and exploiting the benefits of using renewable energy sources, especially solar energy [12–14]. By acknowledging natural advantages, the Vietnamese government has issued a series of legal documents to create favorable conditions for the development, investment, and expansion of the exploitation and use of solar energy at various levels and scales [15–17]. Notably, in [15], the Vietnamese government intends to increase the total energy supplied by all renewable energy sources (RESs) from 58 billion kWh in 2015 to 101 billion kWh in 2020, 186 billion kWh in 2030, and 452 billion kWh in 2050, respectively. In [16], detailed policies and particular decisions have been granted regarding different considerations, such as financial support, investment, and incentives for any individual or group installing RPV systems on various scales. Besides, all the taxes related to the execution of the RPV project are also supported by the government and other state agencies. Afterward, Decision No. 13/2020/QD-TTg [17] issued in 2020 is the other encouragement from the government based on what is addressed in [16], aiming at expanding the scale and total power output of RESs to meet the target set in [15].

Moreover, the RPVs are also connected to the utility grid to pump back the extra energy in hours when the amount of energy produced by the RPV is higher than the load demand. This implementation helps lower consumers' monthly energy bills [18–21], so RPVs are widely accepted and installed by family-scale consumers. The model of an RPV connected to a utility grid is briefly depicted in Figure 1. In the figure, the presence of the inverter plays an important role. For instance, the inverter is in charge of converting the DC produced by RPVs to AC, which is the house's main type of electrical device. Moreover, the inverter also allows for optimizing the amount of power output produced by the RPVs at a particular period using all data of power consumption from all the devices in the house. In addition to that, the presence of an inverter enhances the safety degree of the RPV operation while dealing with different conditions of power demand. Due to the vital role of the inverter in an RPV system, the rated power of the inverter must be determined based on the following criteria:

- The converting ratio: This criterion is the power ratio converted from direct current (DC) to alternative current (AC). The inverter power ratio is selected for civil applications between 1.15 and 1.25.

- Total power output of the RPV system: This criterion means that the inverter's rated power output must be large enough to handle the amount of power produced by the RPV system at any given time. However, the rated power of RPV must be an affordable value that balances both economic and financial aspects.

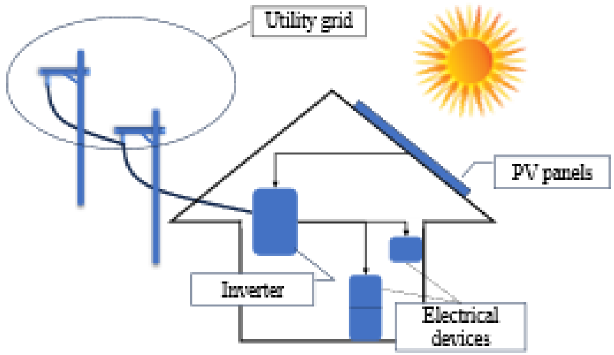

Fig. 1: The illustration of RPV connect with utility grid.

- The real efficiency of the inverter: A high-efficiency inverter will improve the usability of DC power while transforming AC power.

- Reliability: This criterion is mainly about maintaining all the operational specifications for long-term use under different conditions.

Normally, the installation of RPV systems will be accompanied by a battery energy storage system (BESS). BESS is utilized for two main purposes: 1) to store the extra energy at a given time when the power produced by the RPV system is higher than the actual demand and 2) to supply energy for use at night when the RPV system cannot directly produce energy. However, the absence of BESS in Figure 1 served the initial purpose that instead of storing extra energy in the BESS, this amount of energy is immediately sold back to the grid. Therefore, the electrical customers still use the grid's energy at nighttime. On top of that, while the BESS is not installed, the initial investment in the RPV is also partly reduced. Based on that, the operational and maintenance costs of the whole system will be reduced as well.

In summary, this study only focuses on determining the optimal value of the RPV system's rated power so that the consumer's energy bill is minimal. To reach the target, suppose that the following terms are already satisfied:

- All the criteria for selecting the inverter's rated power have been fulfilled.

- The grid can handle any extra energy injected by the RPV system at any time.

- The government has granted all the policies related to injecting and selling extra energy from the RPV system into the utility grid.

Many researchers have previously considered the problem of reducing energy costs while installing the RPV. For instance, the author in [22] applied meta-heuristic algorithms called genetic algorithms (GA) to optimize the energy management strategy so that the consumer could reduce the energy cost considering the time of use tax. For the same purpose, the study [23] applied a hybrid method, which is genetic-wind-driven optimization (GWDO), to reduce the energy cost in different case studies with the consideration of an energy storage system (ESS). The authors in [24, 25] proposed a different strategy to minimize the energy cost by optimizing the control and schedule of all the household appliances with RPV using a Grey Wolf Optimization (GWO). In [26], the authors applied a power optimization tool called the Earthworm optimization algorithm to optimize the electricity cost for residential houses with the installation of RPV and a battery energy storage system (BESS). The results indicate that EWA can reduce 45% of the energy cost compared to the unoptimized value and 7% less than the similar values given by the cuckoo search algorithm (CSA). Next, the authors in [27] focused on reaching zero energy consumption for buildings by optimizing the design of the energy management system, which includes RPV, BESS, and diesel generators. To achieve the target, the proposed harmonic search algorithm (PHSA) has been applied to determine the optimal rated parameters for the whole configuration. Reducing the energy cost for consumers with an RPV system with consideration of load demand variation and the dynamic power output from the RPV is a complex optimization problem. As observed from previous studies, meta-heuristic algorithms play a crucial role in reaching the optimal solution.

In Vietnam, Vietnam electricity (EVN) has encouraged the placement of RPV for households in towns and cities to cut the energy use from conventional power sources, such as thermal power plants and hydropower plants. The wholesale electric tariff for the household use [28] is applied to determine money for used energy every month. For hours with zero or low solar radiation, the households use total energy or apart of energy from the distribution power gird (DPG) of EVN. For other hours with high solar radiation, the generation of RPV is greater than the use of the household, the extra generation from the RPV will be transmitted to the DPG of EVN. EVN will pay money to the household for the extra generation with the price of 1920 Vietnam dong (VND) per kWh [29]. Finally, the total used energy cost will be calculated by using the wholesale electricity tariff for the household use, and the revenue of the extra generation is determined at the end of each month. If the used energy costs are greater than the revenue, EVN must pay money for the household. Otherwise, the household must pay the money to the EVN.

As mentioned above, the presence of the RPV system returns a lot of positive effects on both utility operation and consumer perspectives, such as reducing the pressure on the transmission process, alleviating environmental damage, and lowering the energy bill for energy customers. However, the integration of RPV with different scales into the grid also causes some adverse effects as follows:

- Voltage fluctuation may occur at a given time and affect other loads operating in their design specifications. If the voltage fluctuation lasts long enough, it could lead to the voltage collapse phenomenon [30], interrupting the power supply to many customers.
- Harmonic and frequency distortion can highly reduce the efficiency of electrical devices, especially in the transformers [31]
- Reverse power flow phenomena in the grid [32] damage the crucial elements in the grid, such as transformers, generators, and protection devices.
- Reduce the grid's reliability, stability, and safety due to unexpected changes compared to the design configuration.

In this paper, the optimal placement of the RPV for households in towns and cities of Vietnam is considered for minimizing the monthly used energy cost for the households. And we suppose the minimum cost is zero VND. Two novel meta-heuristic algorithms, including the Coati optimization algorithm (COA) [33] and the Osprey optimization algorithm (OOA) [34], are applied to determine the optimal rated power of a RPV to eliminate the energy cost in each month for a medium-sized consumer. Both COA and OOA were recently proposed in 2023, and they are nature-inspired meta-heuristic algorithms. Specifically, while COA is developed by mimicking the hunting method of the Coati species, OOA is built by simulating the hunting movements of the osprey in nature.

The novelties of the study are summarized as follows:

- Successfully propose a new strategy to eliminate the energy bill of the energy consumer each month.
- Apply two novel meta-heuristic algorithms, including COA and OOA, to solve the considered problem.
- Indicate the most capable method, OOA while dealing with the considered problem using different comparison criteria.
- Propose a new model that both solves the environmental problem and decreases the pressure on the utility grid due to less energy consumption each month.

The contributions of the study are as follows:

- Use the electric energy from rooftop solar photovoltaic systems to minimize the energy cost for electric customer.
- Reduce the conventional power from thermal power plants to minimize the emission of fossil fuel burnt process.
- Reach benefit for electric customers in using rooftop solar photovoltaic systems.
- Indicate an effective search method for dealing with the proposed problem in the study.

2. Problem description

2.1. The main objective function

As mentioned in the introduction section, the study aims at eliminating the deviation between total energy consumption cost and total revenue of selling the extra energy to the utility to a medium-scale electrical consumer within a month. That also means that the consumer will not pay any monthly energy bill cost. The mathematical expression of the main objective function is given below:

$$MinimizeDev_c = C_{grid}^{month} - C_{RPV}^{month}, \tag{1}$$

Where Dev_c is the cost that customer must pay for electric sale company after considering the energy supplied by solar photovoltaic system on rooftop of the house. C_{RPV}^{month} is the total revenue of selling the energy to the utility for one month with 30 days (VND). C_{grid}^{month} is the total energy consumption cost for hours without solar radiation and hours with low power from RPV. C_{grid}^{month} and C_{RPV}^{month} are calculated by:

$$C_{RPV}^{month} = A_{RPV}^{month} \times Pr_{RPV}, \tag{2}$$

and

$$C_{grid}^{month} = A_{grid}^{month} \times Pr_{6lev}, \tag{3}$$

where A_{RPV}^{month} is total extra energy of one month that the RPV generate electricity to the power grid (in kWh); Pr_{RPV} is the price for each energy unit supplied by RPV to the power grid, and Pr_{sel} is constantly 1920 (VND/kWh); A_{grid}^{month} is the total energy that the customer used from utility for one month at hours without solar radiation and with low generation from RPV (in kWh). Pr_{6lev} is the six-level price according to the wholesale electricity tariff for household use in cities and towns of Vietnam [28]. The illustration of the six-level price is presented in Figure 2.

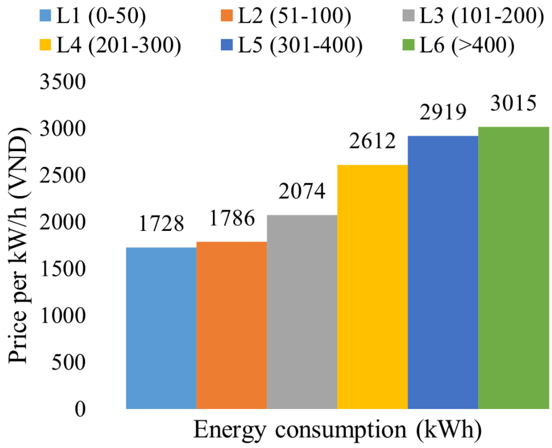

Fig. 2: The six-level price for calculating the energy consumption within a month.

2.2. The involved constraints

1) The equivalent constraints

The constraint of total extra energy from the RPV system: This constraint is about the difference between the power supplied by RPV system and the amount of power required by load at each hour when RPV system is available. We suppose the solar radiations for electric generation occurs from hour 6 to hour 17 in which the power generated by RPV is higher than the load demand at the hour i. So, A_{RPV}^{month} Equation (2) is calculated as follows:

$$A_{RPV}^{month} = 30 \times \sum_{i=6}^{17} \Delta P_i^{ex}, \quad \forall \Delta P_i^{ex} > 0, \tag{4}$$

With

$$\Delta P_i^{ex} = P_i^{PV} - P_i^{load}, \tag{5}$$

and

$$P_i^{PV} = KPV_i \times P_{rt}^{PV}, \tag{6}$$

Where ΔP_i^{ex} is the power that RPV supplies to power grid after meeting the load demand at the ith hour; P_i^{load} (kW) is the power demand of the load at the hour i (kW); P_i^{PV} is the power generated by the RPV at the hour i (kW); KPV_i the energy exchange coefficient of the RPV at the hour i; and P_{rt}^{PV}, is the rated power of the RPV (kW).

The constraints of total energy acquired from utility grid: This constraint is determined by the amount of energy acquired from utility grid at hours while the RPV is not available and the hours while the energy supplied by RPV system is smaller than the demand. The expression of this constraints is given as follows:

$$A_{grid}^{month} = 30 \times \left(\sum_{\substack{i=0 \\ i \neq 6 \div 7}}^{24} P_i^{load} + \sum_{i=6}^{17} |\Delta P_i^{ex}| \right), \forall \Delta P_i^{ex} < 0. \quad (7)$$

2) The inequivalent constraint.

The constraints of RPV rated capacity. This constraint means that, the amount of energy supplied by the RPV at each hour must located within its operational limits as presented by the following expression:

$$P^{PV,lst} \leqslant P_i^{PV} \leqslant P^{PV,hst}, \quad (8)$$

Where, $P^{PV,lst}$ and $P^{PV,hst}$ are the lowest and highest generation limits of the RPVs.

3. The applied methods

In this section, two novel meta-heuristic algorithms are implemented to solve the considered problem, as described in the previous section. As mentioned earlier, both the Coati optimization algorithm (COA) and the Osprey optimization algorithm (OOA) are nature-inspired meta-heuristic algorithms. The two algorithms share the same structure, and the only difference between them is their update procedure for the new solution, which will be described in the next subsections:

3.1. The Coati optimization algorithm

The update procedure to produce the new solution of COA is structured by two stages and the mathematical model for each stage is given as follows:

Stage 1: The new solutions are updated using the following implementation:

$$M_k^{new,st1} = \begin{cases} M_k + MT_1(IP - MT_2 M_k), & if: k < \dfrac{Pop}{2} \\ M_k + MT_1(IP^G - MT_2 M_k), & \\ \quad if: Fit_{IP^G} < F_{M_k}, k > \dfrac{Pop}{2} & \\ M_k + MT_1(M_k - IP^G), & otherwise \end{cases}, \quad (9)$$

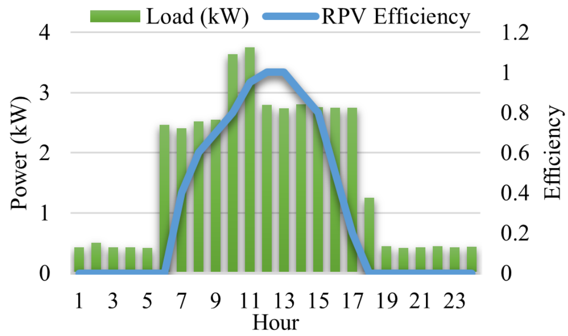

Fig. 3: Load demand and RPV efficiency at each hour within a day.

Where, $M_k^{new,st1}$ is the new location of the Coati k; MT_1 is the first multiplying term and its values is randomized between 0 and 1; IP is the prey location on the tree and IP^G is the prey location on the ground; MT_2 is the second multiplying term and its value is randomly picked up between 1 and 2; and Pop is the population number; Fit_{IP^g} and F_{M_k} are the fitness value of the prey on the ground and the fitness value of the current coati

Stage 2: The update for new solutions is executed using the following model:

$$M_k^{new,st2} = M_k + (1 - 2 \times MT_1) \times (B_k^{lst} + MT_1 \times (B_k^h st - B_k^{lst})), \quad with \quad k = 1, 2, \ldots, Pop \quad , \quad (10)$$

Where, $M_k^{new,st1}$ is the new location of the Coati k; B_k^{lst} and B_k^{hst} are the lowest and highest limits of the solution space.

3.2. Osprey Optimization Algorithm

Like the COA, the update procedure of OOA for new solutions is also executed by two stages and the expressions of each stage will be described as below:

Stage 1: The new solution is produced using the following expression:

$$X_p^{new,st1} = X_p + AF_1(X_{SL} - AF_2 X_p), \quad with \quad p = 1, 2, \ldots, Pop \quad , \quad (11)$$

Where, $X_p^{new,st1}$ is the new solution p in Stage 1; X_k is the current solution p in stage 1; AF_1 and AF_2 are the random factors with the range of $[0, 1]$ for AF_1 and $[1, 2]$ for AF_2; X_{SL} is a random solution that is randomly selected from the population.

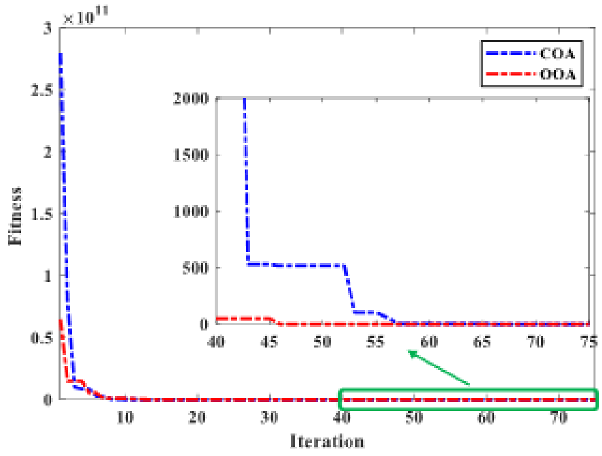

Fig. 4: The best convergence curves given by the two applied methods

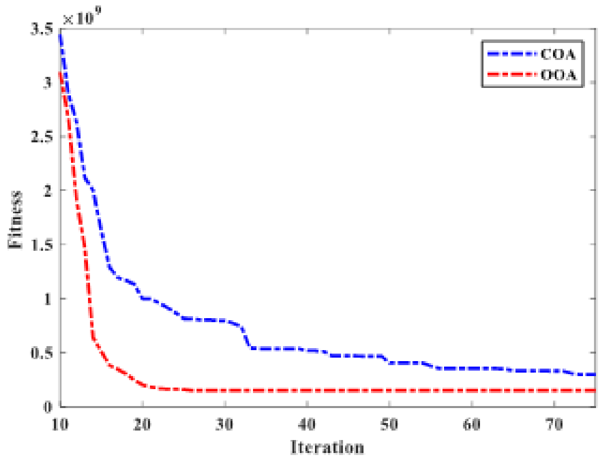

Fig. 5: The average convergence curves given by the two applied methods.

Stage 2: The new solution is updated using the expression below:

$$X_p^{new,st2} = X_p + \frac{B_p^{lst} + AF_1(B_p^{hst} - B_p^{lst})}{IT}, \quad with \quad p = 1, 2, \ldots, Pop \quad , \tag{12}$$

Where, $X_p^{new,st2}$ is the new solution p in Stage 2; B_p^{lst} and B_p^{hst} is the lowest and highest limits of the solution p; and IT is the current countered value of iteration.

4. The results and discussions

4.1. Input data

In this section, the two algorithms, including COA and OOA, will be applied to find out the optimal rated power of the RPV so that the energy bill monthly consumer must pay is zero. Suppose that the consumer in the study is a medium-sized restaurant that acquires 1200 kWh of electricity per month from the utility grid. In addition, the load demand, the RPV efficiency, and the power supplied by RPV at each hour of the day, are illustrated in Figure 3. Moreover, presuming that RPV can only supply power from 7 a.m. to 5 p.m. in the day, and the rated power of the considered RPV is varied from 2 to 15kW. The variation range of the inverter's rated power is selected based on the following terms:

- These rated power values can be found easily in the market while deciding to install the RPV system for household use.
- The interval between 2 to 15 kW also creates a solution space large enough to cover all the local and global optimization while judging the actual performance of the two applied methods.

For having a fair comparison between the two applied methods, their initial control parameters in terms of population (Pop) and Maximum index of iteration (MI) are fairly set by 15 and 75, respectively. Moreover, both methods are operated with 50 independent runs for the best results. The whole study is performed on a personal computer with the main specifications: CPU intel Core i7 with 2.6 GHz for the base clock speed; 8GB of Random accessing memories. Other coding and simulations are implemented in MATLAB programing language version 2018a.

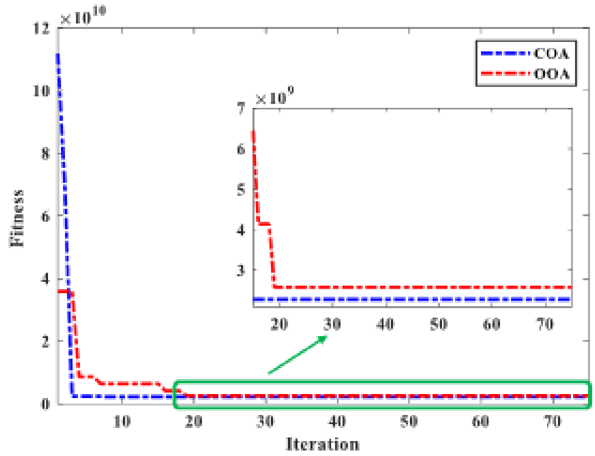

Fig. 6: The max convergence curves given by the two applied methods.

4.2. Obtained results

Figure 4 presents the best convergence curves found by the two applied methods after 50 independent runs. The blue curve belongs to COA, while OOA gives the red one. It is easy to observe that OOA only requires

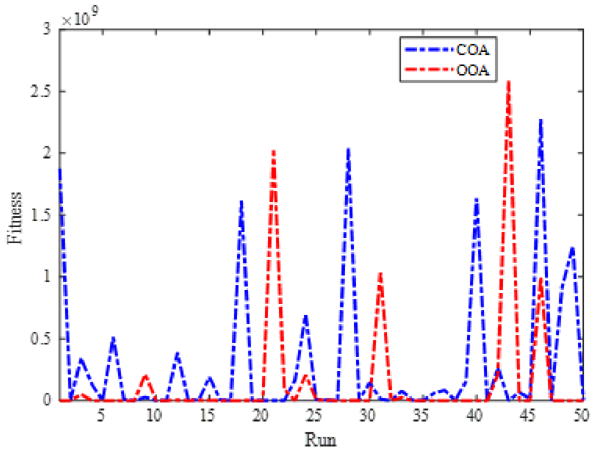

Fig. 7: The summary of 50 independent run given by the two applied methods.

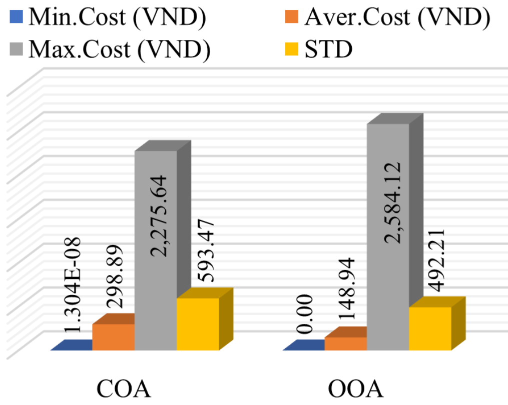

Fig. 8: The summary results obtained by the two applied methods.

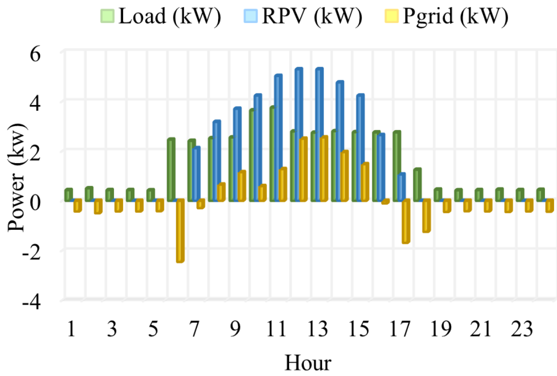

Fig. 9: Power demand, power supplied by RPVs, and power generated to grid.

approximately 50 iterations to reach the best fitness value, but the COA cannot perform the same even when the last iteration is used. Figure 5 shows the average convergence of fifty runs to indicate the stability of the applied algorithms. OOA almost reached the best average solution after 45 iterations, and the search process still needed to be improved further for the remaining iterations. Unlike OOA, COA still improved the quality of found solutions from the 45th iteration to the last iteration; however, the average solution of COA at the last iteration was worse than that of OOA at the 45th iteration.

Figure 6 describes the worst convergence curve; meanwhile, Figure 7 presents the fitness of 50 obtained solutions to indicate the highest fluctuations of the two applied algorithms. In Figure 7, OOA only reaches one worse solution than COA, and the solution's fitness is found at the 43^{rd} run for OOA and at the 47^{th} run for COA. So, the worst solution of OOA has lower quality than that of COA, and the worst convergence of OOA is poorer than that of COA, as shown in Figure 6. In conclusion, OOA is still a higher performance algorithm than COA in reaching the best solution and stable search performance.

Figure 8 provides a detailed comparison between the two applied methods in different criteria, including the minimum energy cost value (Min.Cost), average energy cost values (Aver.Cost), maximum energy cost value (Max.Cost), and standard deviation (STD). As stated, Min.Cost is the most important criterion to conclude the effectiveness of algorithms [35] meanwhile Aver.Cost and STD are two criteria for evaluating the stabilization of algorithms [36]. The method with better effectiveness and stabilization will be more suitable for considered problems [37]. Based on the first criterion, OOA is completely superior to COA. OOA is the only method for reaching the optimal value, while COA cannot achieve the same value. On the Aver.Cost, the result obtained by OOA is 148.94 (VND), while the corresponding value obtained by COA is up to 298.89 (VND). By doing a simple calculation, OOA is 50.17% better than COA on this criterion. In terms of the Max.Cost criterion, COA reaches better values than OOA, approximately 11.94%. Lastly, the observation of the STD indicates that OOA is more stable than COA by 17.06% on second criterion.

4.3. Discussions

Tab. 1: The optimal solution found by the two applied methods.

Methods	Limit boundaries of RPV (kW)	The optimal rated power of RPV (W)
COA	[2–15]	5,288.5251
OOA	[2–15]	5,288.5252

Table 1 shows the optimal rated power of the RPV obtained by COA and OOA. The two rated power values have a very tiny deviation, 0.0001 W, which is very small compared to the rated power of 5,288.5 W. However, OOA can reach the target of not paying money for buying electricity from electric sale company. COA must pay money, $1.304.10^{-8}$, which is approximately zero VND. However, about the solution ability to the problem, COA cannot satisfy the requirement. To clarify the issue, the fitness function is expressed in Equation (13). In the equation, F_{pen} is a penalty factor to make the violation bigger, and it is set to 10^6 by experiment.

$$Fitness = Dev_c + |Dev_c| \times F_{pen}. \tag{13}$$

Using the above analyses, with the results from Table 1 and Equation (13), judgments about the performance of COA and OOA are as follows: OOA is the better method for dealing with the proposed problem. Only OOA reaches the global solution by reaching zero (VND) of the energy bill. At the same time, COA is trapped in local optima and cannot determine the value of the energy bill, which is similar to OOA.

Figure 9 shows the power of load, power generated by the RPVs, and the power supplied to the grid after meeting the demand ($Pgrid$). Here, $Pgrid$ in yellow bars has two directions, up and down, in which the up direction has positive values, but the down direction has negative values. The positive values mean that the installed RPV fully supply the load, and the extra power is supplied to the power grid. In Equation (4), $\Delta P_i^{ex} > 0$ is the up direction of the yellow bars. On the contrary, the negative values mean the generation from the installed RPV is smaller than load demand, or the generation from the installed RPV is zero. The generation from RPV is zero from the 1st to 6th hours and from the 18^{th} to 24^{th} hours, so the $Pgrid$ is negative, and its absolute value equals the load demand. At hours 7, 16, and 17, the generation of RPV is smaller than the load demand, so the load demand must use power from the RPV and power grid. From hours 8 to 15, the generation from RPV is greater than the lower demand, so the yellow bars are up. Here, the target is not to pay money for using electric energy, and the rated power of 5,288.5251W can reach the target. If we install a higher power than 5,288.5251W, the height of the up yellow bars will be higher and yellow bars with the down direction at hours 7, 16, and 17 will change into the up direction.

If we do not install RPVs, we must pay the cost of 1,200 kWh per month. The energy cost for each month is calculated for the energy by using Figure 2, and it is 3,348,200 VND. As shown in the study [38], the capital cost of the photovoltaic system is 770 \$/kW, and the operating and maintenance (O&M) costs are 10\$/MWh. From Figure 9, we calculate that the total energy produced by RPV is 41.51 kWh per day, and the energy for one year (365 days) is 15,152.95 kWh. The capital cost for the rated power of 5,288.5251 W is about \$4,072.5, and the O&M costs are \$150.2 per year. If the operating year number is five years, the sum of the capital and O&M costs are (\$4,072.5 + 5 × \$150.2)=\$4,823.50. The energy cost for the five years without the installed RPV is (3,348,200×12×5)= 200,892,000 VND. Using the currency converter website [39], the money in VND is equal to \$8,459.14. So, the customer can get a benefit (\$8459.14-\$4,823.50)=\$3,635.64.

In summary, a small electric load using 1,200 kWh with an energy cost of \$150.2 per month can benefit \$3,635.64 for five years, corresponding to \$60.6 per month. Using rooftop photovoltaic systems can cut the high energy demand from conventional power plants such as thermal and hydropower plants. That can reduce negative impacts on the earth.

5. Conclusion

In this study, two novel meta-heuristic algorithms, including the Coati optimizer algorithm and the Osprey optimizer algorithm, were successfully applied to determine the rooftop photovoltaic systems' optimal rated power so that the monthly energy cost equaled zero. The results obtained by both methods could satisfy all the constraints with zero penalty values. However, OOA offered better solutions than COA for approximately fifty runs reflected via the minimum and average fitness values. Therefore, OOA deserved an affordable search method, and dealing with such a considered problem was highly recommended. Besides that, the study also remained some downsides that need to be improved for better overall quality, as follows:

- The real radiation data was not considered.
- The actual energy consumption of particular electrical devices was just supposed for the considered problem.
- Battery energy storage systems (BESSs) were not considered a complete configuration of RPV in practice.

Due to the shortcomings above, the following research will solve the problem by considering accurate data from solar radiation, RPV efficiency, and load demand at each hour. Besides that, BESS has to be considered to store energies in low-demand hours and supply back to the load at high-demand hours. The combination of BESS and actual data on solar radiation and wind speed can tackle the shortcomings of the study.

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