# Optimization of Photovoltaic System on Distribution Network for Maximizing Annual Profits

Huu Truong Trinh[1] and Thuan Thanh Nguyen[1,*]

ARTICLE INFO

*Article history:*
Received: 3 March 2025
Revised: 16 June 2025
Accepted: 5 September 2025
Online: 20 July 2026

*Keywords*:
Photovoltaic
Wild Horse Optimizer
Distribution network
Annual cost

ABSTRACT

Distributed generation is increasingly used in distribution networks due to its economic and technical benefits. Photovoltaic (PV) generation system accounts for a large proportion of installed DG. However, PV and load consumption are unstable. The wild horse optimizer algorithm (WHO) is used to find the optimal location and area of PV. The goal of the problem is to optimize the annual cost after PV installation including PV installation and maintenance costs as well as costs of power loss of the system and electricity of PV. The proposed algorithm is run on a 33-node distribution network. The problem considers the voltage limit constraints and the load carrying capacity of the line. After running the program, the payback period is 3.85 years, the power loss is reduced by 21.13% compared to the original, and the voltage profile is improved. The effectiveness of WHO is demonstrated when compared with three algorithms PSO, Coot and GWO. The results show that WHO responds well to the PV installation problem.

## 1. INTRODUCTION

Due to the development of science, technology, economy and society, the demand for electricity is increasing [1]. Therefore, it is necessary to connect additional power sources to the system. However, fossil fuels are becoming increasingly scarce. Fossil fuel power plants emit greenhouse gases that negatively affect the environment [2]. Nowadays, renewable energy sources are used more and more. Renewable energy sources are endless and do not pollute the environment [3]. Among renewable energy sources, photovoltaic generation system is widely used. PV installation can bring many economic and technical benefits such as reduced losses, improved reliability. However, improper PV installation will cause negative impacts such as high losses, unsatisfactory voltage characteristics, and frequency fluctuations [4]. Therefore, the PV installation problem needs to be carefully considered.

There are many DG installation problems that consider DG capacity and load to be constant over time [5, 6]. For PV installation problem, there are many different cases. In ref. [7], a multi-objective problem is proposed including minimizing power loss and maximizing voltage profile, this study does not consider the time variation of PV and load. In ref. [8], GA algorithm is used to find the minimum power loss, this paper considers the change of PV power. PV power depends on solar radiation, which changes throughout the day. The four seasons have different levels of solar radiation. Similarly, load consumption depends on demand. Therefore, this study considers the variability of PV and load consumption.

PV installation problem with many input parameters and large amount of calculations. These are nonlinear problems, so appropriate methods are required to solve them. Current meta-heuristic algorithms can solve nonlinear problems. For power systems, algorithms can be used to solve problems such as optimal power flow problem [9]-[13], capacitor installation problem [14]-[18], network reconfiguration problem [19]-[21], battery energy storage system installation problem [22]-[26]. PV installation problem also applies many different algorithms. Archimedes optimization algorithm (AOA) is used in ref. [27], AOA outperforms the compared algorithms. In [28], dynamic harmony search algorithm (DHSA) is applied to determine the size and location of PV, this study did not compare DHSA with other algorithms. In [29], particle swarm optimization (PSO) is used for the problem with three objectives, the results are compared with those of another studies, which demonstrate the effectiveness of PSO. Ref. [30] used Adaptive inertia weight particle swarm optimization (AIW-PSO), this study did not compare AIW-PSO with other algorithms. Multi-objective grey wolf optimizer (MOGWO) is used in ref. [31] for the PV placement problem wherein the comparison results with three other algorithms show the effectiveness of MOGWO. In [32], pathfinder Algorithm (PFA) gained the best, mean and standard deviation of PFA are all less than those of PSO, TLBO, CSA, GOA for the PV placement. New algorithms are introduced every year and researchers

[1]*Faculty of Electrical Engineering Technology, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam.*
**Corresponding author:* Thuan Thanh Nguyen; Phone: +84-916-664-414; Email: nguyenthanhthuan@iuh.edu.vn.

are always looking to improve them to achieve higher efficiency. However, there is no single algorithm that is completely superior. Therefore, it is necessary to apply new method. In this study, the wild horse optimizer (WHO) algorithm [33] is applied. WHO relies on the behavior of wild horses. WHO was introduced in 2021 and it has been successfully applied in several recent studies. In [34], WHO is used to construct the equivalent circuit of triple-junction solar panel. WHO has succeeded in extracting the maximum power with 99.93% efficiency. In [35], WHO is used for engineering analysis and capital cost design for hybrid electric power system. The results are compared with the HOMER application, which shows that the method applying the WHO algorithm is better.

The PV installation problem includes two component variables: PV location and PV area. The objective of the problem is to minimize costs and maximize profits. Payback period is considered to check the efficiency of the project. Constraints include voltage constraint and load carrying capacity of the line. The problem considers the variability of PV power and load. Solar illuminance data collected in Ho Chi Minh City. The historical solar irradiation series consists of four days representing the four seasons. The proposed algorithm is applied to a 33-node distribution network. The performance of WHO is compared with three algorithms including PSO, Coot and GWO. The novelties and contributions of the study include:

i) Determine PV location and area to optimize costs;

ii) Consider installing PV under the conditions of solar radiation and electricity tariff in Ho Chi Minh City, Vietnam.

iii) WHO is proposed to solve the PV installation optimization problem;

iv) WHO performance demonstrated on a 33-node distribution network;

v) Properly installed PV reduces power loss and improves voltage profile.

## 2. PROBLEM FORMULATION

### *2.1 Objective function*

The objective of the problem is to reduce PV installation and maintenance costs, reduce power losses and increase profits after installing PV into the distribution network. Installation costs are shown in the following formula:

$$CI_{PV} = F_{PV} \times price_{PV} \tag{1}$$

where, $CI_{PV}$ is the cost of installing the solar panel system, $F_{PV}$ is the installation area, $price_{PV}$ is the cost of installing the solar panel system per 1 $m^2$.

In addition to the cost of installing a solar panel system, there are also system maintenance costs. The total costs are shown below:

$$C_T = CI_{PV} + M_{PV} \tag{2}$$

where, $C_T$ is the cost of installation and maintenance of the system, $M_{PV}$ is the cost of maintenance of PV.

After optimizing PV installation, the power loss will change, usually this power loss will be smaller than the original. Therefore, the difference in the power loss after PV installation and the initial loss is also the profit earned.

$$\Delta P_L^T = \sum_{i=1}^{96} (P_{L0}^i - P_{LPV}^i) \tag{3}$$

with, $\Delta P_L^T$ is the total power loss reduction, $P_{L0}^i$ is the initial power loss of the ith hour, $P_{LPV}^i$ is the power loss after PV installation of the ith hour. The 96 hours is equivalent to 24 hours of 4 typical days of four seasons in a year.

PV capacity determines the amount of electricity produced, and this electricity can be sold to the grid. PV capacity is calculated by the following formula:

$$P_{PV} = \eta \times F_{PV} \times \sum_{i=1}^{96} R_i \tag{4}$$

with, $P_{PV}$ is the total PV power, $\eta$ is the solar panel system efficiency, $R_i$ is the solar radiation of the ith hour.

Assuming the lifetime of the PV system is 20 years. The objective function of the problem is to minimize costs and maximize profits over a year:

$$F_{obj} = Min\left(c_1 \frac{C_T}{20} - c_2 \times \frac{365}{4}\left(\Delta P_L^T + \sum_{k=1}^{N_{PV}} P_{PV}^k\right) \times p_e\right) \tag{5}$$

where, $c_1$, $c_2$ are constants added to find the best solution to the minimization problem, $P_{PV}^k$ is the capacity of the kth PV, $N_{PV}$ is the total number of PVs installed in the system, $p_e$ is the electricity tariff paid per kWh.

### *2.2 Constraints*

The problem includes the following constraints:

- Voltage constraints:

$$U_{min}^{lim} \le U_h \le U_{max}^{lim} \tag{6}$$

with, $U_h$ is the voltage at node $h$, $[U_{min}^{lim}, U_{max}^{lim}]$ is the allowable voltage limit, $U_{min}^{lim} = 0.95\, p.u$ , $U_{max}^{lim} = 1.05\, p.u.$

- Limits on the carrying capacity of transmission lines:

$$I_m \le I_{rate,m} \tag{7}$$

with, $I_m$ is the current on branch $m$, $I_{rate,m}$ is the allowable rated current on branch $m$.

## 3. WHO ALGORITHM FOR THE PROBLEM

### *3.1 WHO algorithm*

WHO based on the unique movements and mating patterns of wild horses along with the influence of leaders. The WHO algorithm starts with an initial randomly generated population $(\vec{x}) = \{\vec{x}_1, \vec{x}_2, \dots, \vec{x}_n\}$. If the total horse population is $P$, then the number of groups is calculated as $N_S = PS \times P$ , where $PS$ represents the percentage of stallions. The number of leaders is $N_S$ the remaining horses ($N_F = P - N_S$) are distributed equally to the groups.

The position of the horse is updated according to the foraging behavior, the mating behavior of the horse in the herd and the position of the leader horse.

First, the horse's position is based on its foraging behavior. With $rand > PC$ ($rand$ is a random number in the range [0, 1], $PC$ is a parameter of the proposed algorithm), the new position of the horse in the herd according to the foraging behavior is updated according to formula (8):

$$H_{k+1}^l = 2Kcos(2\pi RK) \times \left(L^l - H_k^l\right) + L^l \tag{8}$$

where $H_k^l$, $H_{k+1}^l$ are the current and new positions of the horses; $L^l$ is the position of the leader in the l[th] group. $R$ is a random number in the range [-2, 2]. $K$ is the adaptation mechanism (9).

$$P = \overrightarrow{R_1} < TD;\ ID = (P == 0);\ K = R_2 \Theta ID + \overrightarrow{R_3}\Theta(\sim ID) \tag{9}$$

where, $P$ is is a binary vector (containing 0 and 1) with dimensions matching those of the problem, $\overrightarrow{\mathrm{R}_1}$ and $\overrightarrow{\mathrm{R}_3}$ are random vectors with values in the range [0, 1], $\mathrm{R}_2$ is a random scalar within [0, 1], ID represents the indices in the random vector $\overrightarrow{\mathrm{R}_1}$ that satisfy the condition $(\mathrm{P} == 0)$. TD is an adaptive parameter (10).

$$TD = 1 - iter \times \frac{1}{MaxIter} \tag{10}$$

where, $iter$ represents the current iteration, $MaxIter$ denotes the maximum number of iterations.

When a foal reaches maturity, it leaves its parent group to join a new group. To simulate this, suppose a male horse leaves group $k$, a female horse leaves group l to join the same group, after the two mate and the foal joins group d. With $rand \leq PC$, the position of the horse is updated according to (11):

$$H_d^p = Mean(H_k^e + H_l^f) \text{ with } k \neq l \neq d, p = e = f \tag{11}$$

where, $H_d^p$ is the position of horse p from group d leaving the group with parents who left groups $k$ and $l$. $H_k^e$ and $H_l^f$ are the foals $e$ and $f$ that left groups $k$ and $l$ when they reached adulthood, joined a group and mated with each other.

The leader takes the group to the target area. The leader is updated as follows:

$$L_{k+1} = \begin{cases} 2Kcos(2\pi R_4 K) \times (G - L_k) + G & if\ \ R_5 > 0.5 \\ 2Kcos(2\pi R_4 K) \times (G - L_k) - G & if\ \ R_5 \leq 0.5 \end{cases} \tag{12}$$

where, $L_k$ , $L_{k+1}$ are the current and new positions of the leader, $R_4$ is a random number in the range [-2, 2], G is the target, $R_5$ is a random number with uniform distribution in the range [0, 1].

***Details of WHO application to the problem***

The steps for applying WHO to the problem are presented as follows:

- Step 1: Input the parameters of WHO.
- Step 2: The initial population of horses is represented as $H_i = [L_m, F_m]$ with $m = 1, \ldots, N_{PV}$ ( $N_{PV}$ is the number of PVs). $Lo_m$, $F_m$ are the location and area of the mth PV, initialized as:

$$L_{i,m} = round[L_{L,m} + r.(L_{U,m} - L_{L,m})] \tag{13}$$

$$F_{i,m} = F_{L,m} + r.(F_{U,m} - F_{L,m}) \tag{14}$$

  where, $L_{U,m}$ and $L_{L,m}$ are the upper and lower limits of the position PV. The reference node is node 1 so the lower limit of the PV position is 2, the upper limit is the maximum node of the network. $F_{U,m}$ and $F_{L,m}$ are the limits of PV area, $F_{U,m}$ and $F_{L,m}$ are the limits of PV area, $F_{U,m} = 25000\ m^2$, $F_{L,m} = 500\ m^2$, $r$ is a random number in [0,1].
- Step 3: The initialized population is evaluated based on a fitness function:

$$fit = F_{obj} + K_p \times [max\left(U_{lim}^{min} - U_{min}, 0\right) + max(U_{max} - U_{max}^{lim}, 0) + max(I_{max} - I_{rate}, 0)] \tag{15}$$

  where, $K_p = 1000$ is a penalty factor, $U_{min}$ and $U_{max}$ are the minimun and maximum voltages, $I_{max}$ is the maximum current.
- Step 4: Update the new position of the individual by Eq. 8 and Eq. 11.
- Step 5: Evaluate the objective function for the new position by Eq. 15.
- Step 6: Update the new position of the leader by Eq. 12.
- Step 7: Evaluate the objective function of the new leadership position by Eq. 15.
- Step 8: Compare the objective function in step 7 and step 5 to select the best individuals as leaders.
- Step 9: Repeat step 4 until the iteration increases to reach its maximum value to find the best solution.

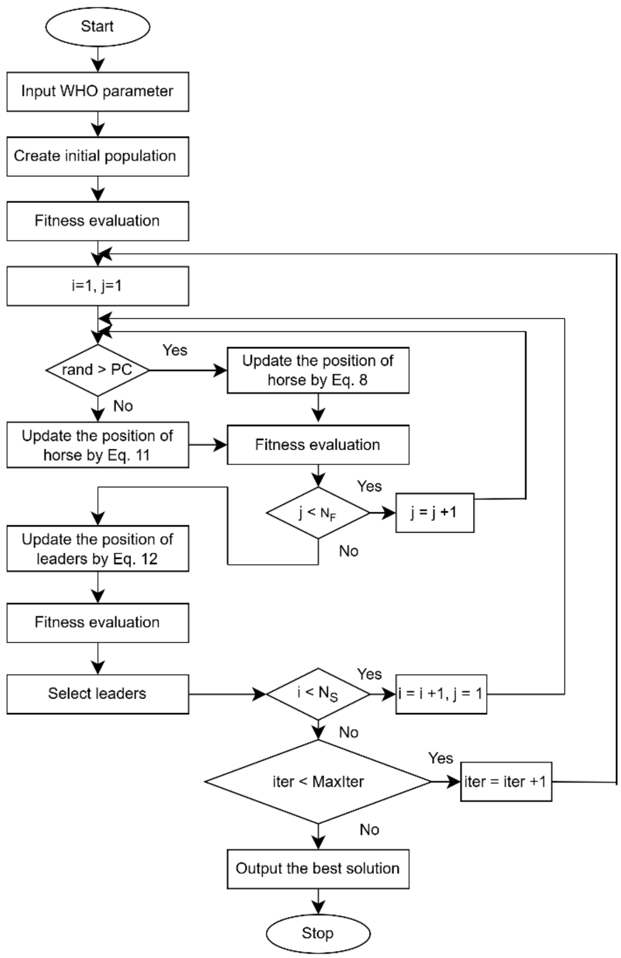


**Fig. 1. The flowchart of the proposed method.**

## 4. RESULTS AND DISCUSSION

The WHO algorithm is used to find the location and area of PV on the 33-node grid shown in Fig. 2. The number of PV installed in the problem is 3. The control parameters including population and maximum number of iterations are set to 30 and 100. The PS and PC indexes are respectively chosen to 0.2 and 0.13, respectively. The parameters c1 and c2 of the objective function eed to be carefully determined. If the parameter c1 is small, the investment cost will be high; conversely, if c1 is large, the investment cost will be low. The parameters c1 and c2 that are determined from various tests are 4.25 and 1, respectively. The results are compared with three other algorithms, Coot, PSO and GWO. The algorithms are run in Matlab software with 20 independent runs on a personal computer with Intel(R) Core (TM) i5-8250U CPU @ 1.80 GHz, 12GB RAM configuration. The PV installation location is in Ho Chi Minh City area with radiation data collected on the website globalsolaratlas.info. Ho Chi Minh City has a Direct Normal Irradiation (DNI) of 1233 kWh/m²/year with a high number of sunshine hours throughout the year. This creates ideal conditions for solar power development. The 4-season radiation is shown in Fig. 3. Radiation data for four seasons are aggregated over 12 months of the year. Seasonal radiation is the average radiation over a 3-month period. Hourly load curve of the test system is shown in Fig. 4.

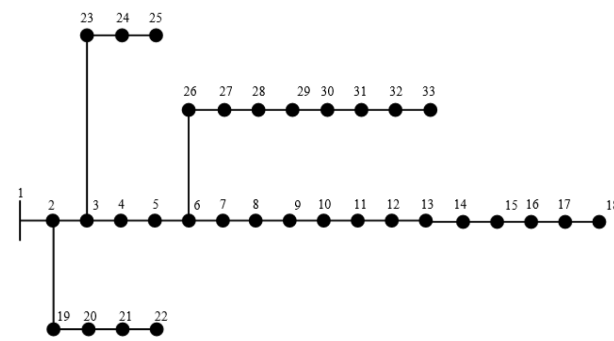


**Fig. 2. The 33-node system.**

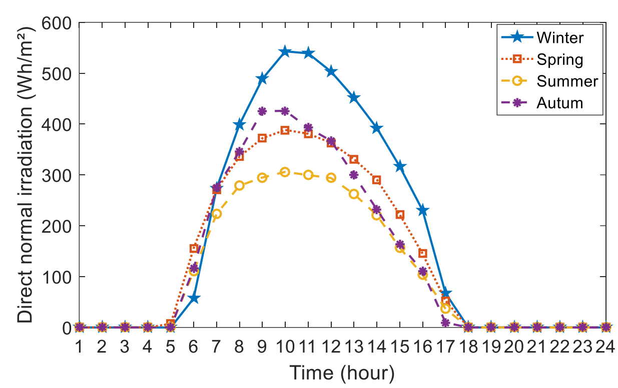


**Fig. 3. Historical series of solar irradiation in 96 hourly intervals**

After running the proposed algorithm, the objective function result of the problem is -1259.394; 3 PVs are installed at nodes 32, 14, 17 with corresponding areas of 7122.90, 4127.88, 2858.06 ($m^2$). Fig. 5 shows the voltage profile at 10 a.m. in winter, the voltage after PV installation is improved and within the appropriate range. Fig. 6 shows the annual voltage profile of node 15, voltage is improved with solar radiation. However, when there is no radiation, the PV power is zero then the voltage profile is not improved.

The annual power loss before PV installation was 1189000 kW, after PV installation the loss decreased to 937825 kW. The total annual power loss after PV installation was reduced by 21.13% compared to the original value. In which, winter has the lowest power loss of 225402 kW, while summer has the highest power loss of 242747 kW. The profile of power loss is shown in Fig. 7. The power loss reduction depends largely on the radiation intensity at each time.

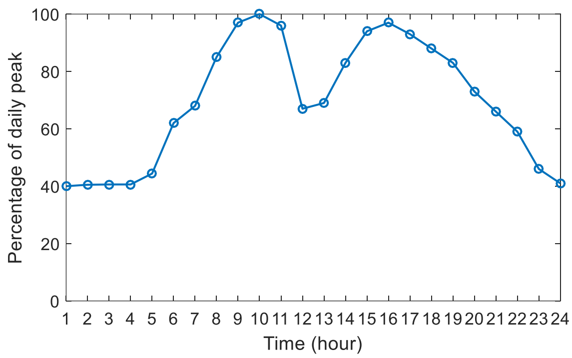


**Fig. 4. Hourly load curve of the test system**

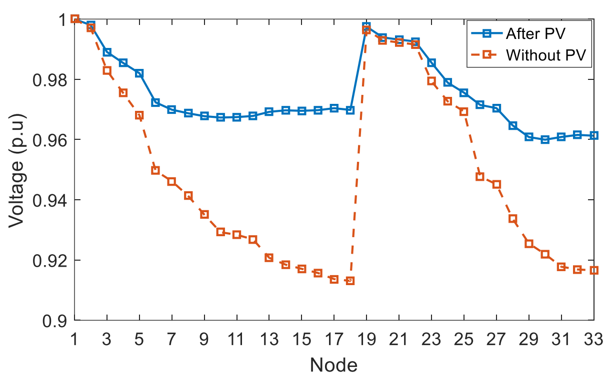


**Fig. 5. Voltage profile on the 33-node system at 10 a.m in the winter.**

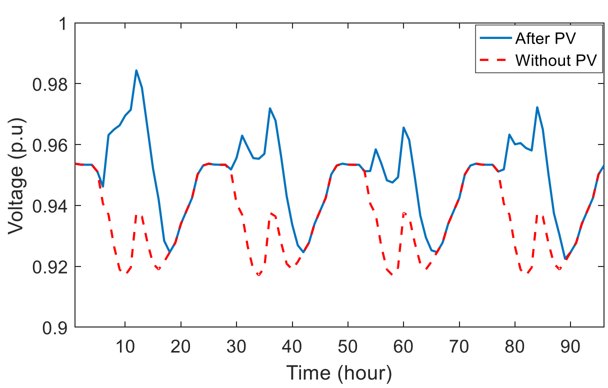


**Fig. 6. Annual voltage profile of node 15.**

The effectiveness of the WHO algorithm is demonstrated when compared with three algorithms, Coot, PSO and GWO. The algorithms are compared with WHO to demonstrate the effectiveness of WHO. Table 1 compares the results of the four algorithms. The annual power loss after PV installation is reduced, for WHO and PSO the annual power loss is similar, while for Coot and GWO this value is larger. Minimum voltage amplitude is improved from 0.9131 to 0.9188.

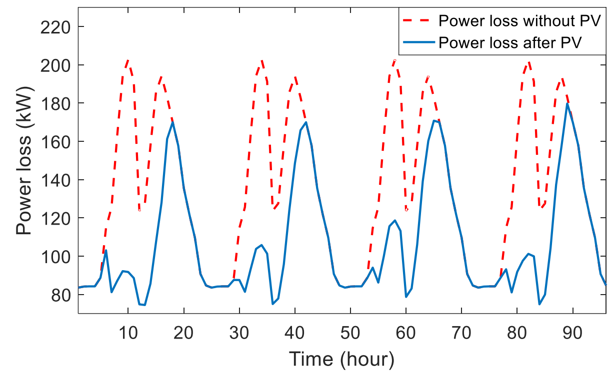


**Fig. 7. Profile of power loss in 33-node system.**

**Table 1. Optimal PV location and area for 33-node network**

| Method | PV area in m$^2$ (node) | Total PV area (m$^2$) | Annual power Loss (kW) | $V_{min}$ (pu) |
|---|---|---|---|---|
| Initial | - | - | 1189000 | 0.9131 |
| WHO | 7122.90 (32)<br>4127.88 (14)<br>2858.06 (17) | 14108.84 | 937825 | 0.9188 |
| Coot | 2902.41 (17)<br>4068.06 (14)<br>7134.86 (32) | 14105.33 | 937866 | 0.9188 |
| PSO | 2858.06 (17)<br>4127.88 (14)<br>7122.90 (32) | 14108.84 | 937825 | 0.9188 |
| GWO | 4124.25 (14)<br>2859.63 (17)<br>7120.37 (32) | 14104.25 | 937868 | 0.9188 |

Table 2 analyzes the payback period. The total investment of the project is 1354449 USD, the annual maintenance cost is 16931 USD, the annual profit is 368336 USD and the payback period is 3.85 years.

**Table 2. Analysis of the payback period**

| Invest ($) | Maintenance ($/year) | Annual profit ($) | Payback period |
|---|---|---|---|
| 1354449 | 16931 | 368336 | 3.85 |

According to Table 3, the minimum objective function value (Min.) of WHO is equivalent to PSO, GWO and smaller than Coot, the maximum value (Max.) is not much larger than Coot, GWO and much smaller than PSO, the average value (Ave.) is smaller than PSO, Coot and GWO, the standard deviation (Std) is larger than Coot and smaller than PSO and GWO, the calculation time is faster than Coot and slower than PSO and GWO.

**Table 3. Comparison of effectiveness of WHO with Coot, PSO and GWO**

| Item | Max. | Min. | Ave. | Std | Time (s) |
|---|---|---|---|---|---|
| WHO | -1039.4 | -1259.4 | -1202.6 | 77.6 | 20537 |
| Coot | -1082.3 | -1259.3 | -1182.9 | 70.5 | 23224 |
| PSO | -327.1 | -1259.4 | -1091.7 | 205.9 | 18860 |
| GWO | -1073.0 | -1259.4 | -1199.2 | 79.4 | 20337 |

Fig. 8 shows the convergence characteristic curve, the WHO characteristic curve converges earlier than Coot, PSO and GWO. Fig. 9 shows that the fluctuation level of WHO is almost equivalent to Coot and GWO, while PSO fluctuates strongly. The above analysis has demonstrated the effectiveness of WHO for the problem of PV location and area determination.

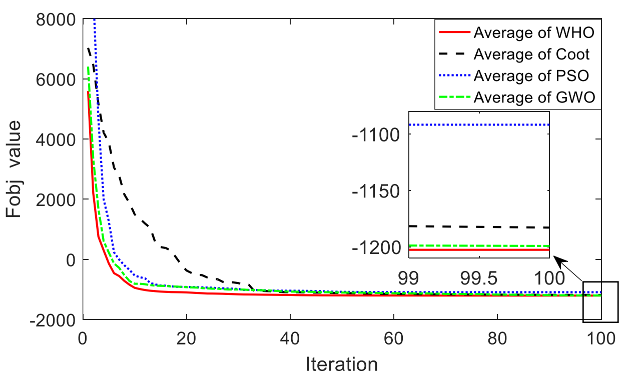


**Fig. 8. Convergence characters of WHO, Coot, PSO and GWO.**

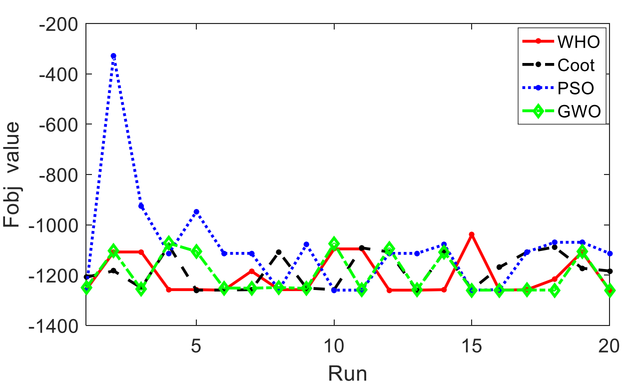


**Fig. 9. Optimal value per run.**

## 5. CONCLUSIONS

This paper applies the WHO algorithm to the PV installation cost optimization problem. The variability of PV and the load consumption are considered. The problem is run on a 33-node test system. The results show that the payback period is less than 4 years, which is considered quite satisfactory. The power loss is significantly reduced, and the voltage profile is also improved. When comparing WHO with PSO, Coot and GWO, the results show that WHO has the majority of superior parameters. This proves that the proposed method responds well to the PV installation problem. In the future, the problem can be applied to real systems and PV can be combined with other power sources or devices such as wind turbine and capacitors. The PV areas in this study is large, subsequent research will study smaller areas suitable for large cities.

## REFERENCES

[1] W. Tang, K. Huang, Y. Zhang, and T. Qian. 2023. Optimal allocation of photovoltaic generations in buildings-to-distribution-network integration system using improved backtracking search optimization algorithm. IET Generation, Transmission and Distribution 17(18): 4086–4106.

[2] M. Khalid, M. AlMuhaini, R. P. Aguilera, and A. V. Savkin. 2018. Method for planning a wind-solar-battery hybrid power plant with optimal generationdemand matching. IET Renewable Power Generation 12(15): 1800–1806.

[3] R. O. Bawazir and N. S. Cetin. 2020. Comprehensive overview of optimizing PV-DG allocation in power system and solar energy resource potential assessments. Energy Reports 6: 173–208.

[4] I. Khenissi, R. Sellami, M. A. Fakhfakh, and R. Neji. 2021. Power Loss Minimization Using Optimal Placement and Sizing of Photovoltaic Distributed Generation Under Daily Load Consumption Profile with PSO and GA Algorithms. Journal of Control, Automation and Electrical Systems 32(5): 1317–1331.

[5] D. B. Prakash and C. Lakshminarayana. 2016. Multiple DG Placements in Distribution System for Power Loss Reduction Using PSO Algorithm. Procedia Technology 25(Raerest): 785–792.

[6] R. SELLAMI, F. SHER, and R. NEJI. 2022. An improved MOPSO algorithm for optimal sizing & placement of distributed generation: A case study of the Tunisian offshore distribution network (ASHTART). Energy Reports 8: 6960–6975.

[7] E. M. Getie, B. B. Gessesse, and T. G. Workneh. 2020 Photovoltaic Generation Integration with Radial Feeders Using GA and GIS. International Journal of Photoenergy 2020.

[8] M. Ahmadi, M. E. Lotfy, R. Shigenobu, A. Yona, and T. Senjyu. 2018. Optimal sizing and placement of rooftop solar photovoltaic at Kabul city real distribution network. IET Generation, Transmission and Distribution 12(2): 303–309

[9] K. Teeparthi and D. M. Vinod Kumar. 2017. Multi-objective hybrid PSO-APO algorithm-based security constrained optimal power flow with wind and thermal generators. Engineering Science and Technology, an International Journal 20(2): 411–426.

[10] S. Li, W. Gong, C. Hu, X. Yan, L. Wang, and Q. Gu. 2021. Adaptive constraint differential evolution for optimal power flow. Energy 235: 121362.

[11] V. Roberge, M. Tarbouchi, and F. Okou. 2016. Optimal power flow based on parallel metaheuristics for graphics processing units. Electric Power Systems Research 140: 344–353.

[12] P. P. Biswas, P. N. Suganthan, R. Mallipeddi, and G. A. J.

Amaratunga. 2018. Optimal power flow solutions using differential evolution algorithm integrated with effective constraint handling techniques. Engineering Applications of Artificial Intelligence 68(October 2017): 81–100.

[13] M. P. Duong, D. N. Vo, T. T. Nguyen, and V. D. Phan. 2021. Optimal Power Flow in Power System Considering Wind Power Integrated into Grid. GMSARN International Journal 15(4): 287–300.

[14] A. Arief, M. B. Nappu, S. Mustafa, Erwin, and S. Thaha. 2022. Optimal capacitor placement in a dominant induction motor loads power system. Energy Reports 8: 592–597.

[15] C. Karri, Sudhakar AVV. 2017. Invasive Weed Optimization for Optimal Capacitor Placement on a Radial Distribution System. International Journal of Electrical Engineering & Technology 8(5): 9-19.

[16] A. A. Augusto, J. C. S. de Souza, M. B. Do Coutto Filho, H. R. de Oliveira Rocha, and J. E. V. Tafur. 2020. Optimized Capacitor Placement Considering Load and Network Variability. Journal of Control, Automation and Electrical Systems 31(6): 1489-1498.

[17] M. R. Babu, C. V. Kumar, and S. Anitha. 2021. Simultaneous Reconfiguration and Optimal Capacitor Placement Using Adaptive Whale Optimization Algorithm for Radial Distribution System. Journal of Electrical Engineering and Technology 16(1): 181-190.

[18] S. Auchariyamet and S. Sirisumrannukul. 2009. Optimal Capacitor Placement in Unbalanced Loading Distribution System with Nonlinear Loads by Adaptive Particle Swarm Technique. GMSARN International Journal 3 3: 91–100.

[19] A. M. Othman, A. A. El-Fergany, and A. Y. Abdelaziz. 2015. Optimal Reconfiguration Comprising Voltage Stability Aspect Using Enhanced Binary Particle Swarm Optimization Algorithm. Electric Power Components and Systems 43(14): 1656–1666,

[20] M. V. dos Santos, G. A. Brigatto, and L. P. Garcés. 2020. Methodology of solution for the distribution network reconfiguration problem based on improved harmony search algorithm. IET Generation, Transmission and Distribution 14(26): 6526–6533.

[21] T. T. Tran, D. N. Vo, and P. Vasant. 2016. Distribution Network Reconfiguration Using One Rank Cuckoo Search Algorithm. GMSARN International Journal 10: 33–39.

[22] T. Kerdphol, Y. Qudaih, and Y. Mitani. 2015. Battery energy storage system size optimization in microgrid using particle swarm optimization. IEEE PES Innovative Smart Grid Technologies Conference Europe. Istanbul, Turkey, 12-15 October. Publisher: IEEE

[23] T. T. Nguyen, H. P. Nguyen, and T. L. Duong. 2023. Optimal placement of battery energy storage system considering penetration of distributed generations. International Journal of Electrical and Computer Engineering 13(6): 6068–6078.

[24] Z. Yuan, W. Wang, H. Wang, and A. Yildizbasi. 2020. A new methodology for optimal location and sizing of battery energy storage system in distribution networks for loss reduction. Journal of Energy Storage 29(January): 101368.

[25] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi. 2018. Optimal placement of distributed energy storage systems in distribution networks using artificial bee colony algorithm. Applied Energy 232(July): 212–228.

[26] M. R. Nayak, D. Behura, and K. Kasturi. 2021. Optimal allocation of energy storage system and its benefit analysis for unbalanced distribution network with wind generation. Journal of Computational Science 51(February): 101319.

[27] V. Janamala and K. R. Rani. 2022. Optimal allocation of solar photovoltaic distributed generation in electrical distribution networks using Archimedes optimization algorithm. Clean Energy 6(2): 1036–52.

[28] K. Dhayalini and R. Mukesh. 2019. Optimal setting and sizing of distributed solar photovoltaic generation in an electrical distribution system. 2019 Innovations in Power and Advanced Computing Technologies, i-PACT 2019: 1–5.

[29] M. F. N. Khan and T. N. Malik. 2017. Probablistic generation model for optimal allocation of PV DG in distribution system with time-varying load models. Journal of Renewable and Sustainable Energy 9(6).

[30] A. Lasmari, M. Zellagui, H. A. Hassan, S. Settoul, A. Y. Abdelaziz, and R. Chenni. 2020. Optimal Energy-Efficient Integration of Photovoltaic DG in Radial Distribution Systems for Various Load Models. 11th International Renewable Energy Congress, IREC 2020 (Irec): 2–7.

[31] A. Lasmari, S. Settoul, M. Zellagui, and R. Chenni. 2020. Optimal Hourly Scheduling of PV Sources in EDS Considering the Power Variability of Load Demand and DG Using MOGWO Algorithm. Proceedings - 2020 6th International Conference on Electric Power and Energy Conversion Systems, EPECS. Istanbul, Turkey, 05-07 October. Publisher: IEEE

[32] V. Janamala. 2021. A new meta-heuristic pathfinder algorithm for solving optimal allocation of solar photovoltaic system in multi-lateral distribution system for improving resilience. SN Applied Sciences 3(1): 1–17.

[33] I. Naruei and F. Keynia. 2022. Wild horse optimizer: a new meta-heuristic algorithm for solving engineering optimization problems. Springer London.

[34] A. Fathy, H. Rezk, D. Yousri, and H. H. Alhelou. 2023. Recent approach of wild horse optimizer for identifying the optimal parameters of high efficiency triple-junction solar system. IET Renewable Power Generation 17(4): 856–872.

[35] Marliani, A. Arief, and I. C. Gunadin. 2023. Implementation of wild horse optimization (WHO) method for optimal hybrid renewable energy designs. 2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE). Jakarta, Indonesia, 16-16 February. Publisher: IEEE.