OPTIMIZING THE EFFICIENCY OF PHOTOVOLTAIC DISTRIBUTED GENERATION IN THE DISTRIBUTION SYSTEM

Ly Huu Pham[1], *Tai Thanh Phan*[2,*], *Van Thanh Ngoc Nguyen*[2], *Khoa Dang Tran Phan*[2], *Phung Hai Nguyen*[3]

[1]Power System Optimization Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[2]Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[3]Lin Ka Services Co. Ltd, Level 5, Songdo Building, 62A Pham Ngoc Thach Street, Vo Thi Sau Ward, Dist.3, Ho Chi Minh City, Vietnam

*Corresponding Author: Tai Thanh Phan (Email:phanthanhtai@tdtu.edu.vn)
(Received: 06-November-2023; accepted: 06-March-2024; published: 31-March-2024)
http://dx.doi.org/10.55579/jaec.202481.440

Abstract. *This article studies the influence of distributed generation (DG), specifically the influence of photovoltaic (PV) in the distribution system. The particle swarm optimization algorithm (PSO) will be applied to determine the best capacity and location of PV on a test system of EEE 33 nodes so that active power loss is minimized, and the voltage profile is improved. The performance of the applied method is evaluated by comparing its results to those from some previous methods, including the Genetic Algorithm (GA), the Bacterial Foraging Optimization Algorithm (BFOA), and the Backtracking Search Optimization Algorithm (BSOA). As a result, it proved that the proposed method is better than others in terms of processing time, voltage profile, and minimization system capacity loss. In addition, the main contribution of the study is to give detailed solutions for operators in installing how many PVs in the power system can satisfy economic and technical aspects.*

Keywords: Distributed generation, PSO, Optimal location, Power loss

1. Introduction

Currently, the power grid of most countries in the world consists of many interconnected grids to form a sprawling network, called a centralized power grid system [1]. The mission of the system is to meet load demand such as residential and industrial loads. Therefore, the more the country develops, the more the power transmission grid system develops [2]. However, many limitations of the power grid system in terms of non-ferrous metal costs and geographical location make it difficult to meet high demands as well as power supply reliability. Namely, some mountainous and remote areas often encounter power outages. This forces engineers and scientists to find new solutions to optimize electricity generation costs as well as reduce power loss on the line as possible level and ensure electricity quality for customers [3, 4].

In recent years, fossil energy sources have decreased significantly and customers' demand for electricity is increasing. Therefore, the application of renewable energy sources (RES) to produce electricity and connect to the traditional power system is gradually becoming popular [5]. RES is one of the clean energy sources that has been used and researched for many years. From the advantages of this renewable energy source like no use of fuel, DGs are exploited due to many benefits to the power system [6, 7].

Electrical machines, robot control, power systems, facial recognition, and other renewable energy sources are only a few of the electrical engineering domains where optimization algorithms have been used [8–13]. Namely, authors in [14] used an algorithm to optimally control the speed of a synchronous motor by controlling the direction of the magnetic field while authors in [15] have applied algorithms to optimally integrate electric vehicle charging stations and photovoltaic systems into the existing power grid. And, finding optimal solutions and solving the problem of optimizing DG sources in distribution systems has been researched and implemented in [16, 17].

Studies in [18,19] are suggested to search benefits to the power system such as reducing power loss and improving power quality, voltage profile, voltage wave, and standard frequency. To avoid economic losses, the improvement of voltage stability is very important in the operation of power systems. Therefore, the solution of using solar batteries in the power network is recommended in [20].

In this paper, we recommend PSO to determine the optimal location and the best power of DG on a test system with the aim of improving voltage stability and reducing power loss. PSO is one population-based optimization method that draws inspiration from the social dynamics of flying flocks of birds in searching food. PSO is often used to solve optimization problems in which a set of candidate solutions represented as particles to reach the optimal solution by iteratively adjusting their position in the search space. PSO has been used in a number of fields since it was first introduced by James Kennedy and Russell C. Eberhart in 1995, including robotics [21], financial forecasting [22], healthcare [23], and civil engineering [24]. PSO has fewer parameters to implement, less computational effort for parameter optimization. This method is very effective because it uses the concept of swarm intelligence, in which particles in the search space share information and move collectively to promising areas, leading to the optimal results achieved tend to converge faster than the algorithms.

2. Problem Formulation

2.1. Objective function

The main function of the problem is to minimize the total active power loss of the distribution system and it can be calculated by [25]:

$$F = \min \sum P_{\text{loss}} \tag{1}$$

Where: P_{loss} is the total active power loss, which is calculated by the resistance of the branch multiplied by the square of the current flowing on its branch.

2.2. Constraints

In addition to the main objective function, there are several constraints as follows: Voltages at nodes and currents on branches must not exceed their limits:

$$0.95 \leq V_j \leq 1.05 \tag{2}$$

$$|I_{branch}| \leq I_{branch}^{\max} \tag{3}$$

Where: V_j is the voltage at the jth node, I_{branch} is the current that flows through each system branch, and $I_{branch}^{\max}$ is the maximum current of the branch.

The power of the generating source (P_{gs}) and the power of the PV (P_{PV}) must be ensured to balance with the load power (P_{load}) and the total active power loss on the line [19]:

$$P_{gs} + \sum_{k=1}^{N_{PV}} P_{PV_k} = \sum_{j=1}^{n} P_{load_j} + P_{loss} \tag{4}$$

The minimum $\left(P_{PV}^{\min}\right)$ and maximum $\left(P_{PV}^{max}\right)$ limits of PV are given by [25]:

$$P_{PV}^{\min} \leq P_{PV_k} \leq P_{PV}^{max} \tag{5}$$

3. Applying the Backward/ Forward Sweep method and Particle Swarm Optimization algorithm to find the best capacity and location of the PV

3.1. Applying the Backward/ Forward Sweep method to calculate power flow distribution

The study of power flow or load flow distribution has been carried out to find the optimal parameters of devices for the stable operating conditions of the power system. It is considered one of the most frequently performed studies because of the benefits of electricity to help operators plan, operate, optimize, and control electrical systems.

Load flow analysis is performed in the power system design phase to determine whether the voltage profile is within the power grid's tolerances. During the operation phase, load flow analysis is used to determine, maintain the required voltage magnitude, select the active and reactive power flows in different branches and minimize power loss of the electrical system.

Some basic power flow distribution algorithms have been researched and applied such as Newton Raphson, and Gauss-Seidel. These methods may not be effective because of their unique characteristics of distribution grids such as radial structure, high R/X ratio, unbalanced load, etc. [26]. Other methods, the ladder network theory and the Backward/ Forward Sweep (BW/ FW) method, are often used due to the efficiency and accuracy of their solution. In this study, the author used the BW/ FW method to analyze power flow in the distribution power system.

There are two steps in the BW/FW method: Forward sweep and Backward sweep. Kirchhoff's first and second laws are used to calculate the current during the backward sweep operation, going from the farthest node to the source node. Calculating the voltage in a forward sweep involves going from the source node to the farthest node. This algorithm's input data is given in [26, 27]. **Step** 1. Calculate and convert data from basic unit (SI) to per unit system (pu):

$$Z_{SI} = \frac{V_{SI}^2}{S_{SI}} \quad (6)$$

$$Z_{pu} = \frac{R_i + jX_i}{Z_{SI}} \quad (7)$$

$$S_{pu} = \frac{P_i + jQ_i}{S_{SI}} \quad (8)$$

Whereas:

Z_{SI} is the impedance of the line.

$V_{SI}$is the voltage of the system.

S_{SI}, S_{pu} is the apparent power at nodes.

Z_{pu}: is the impedance of the line.

R_i and X_i are the resistance and reactance of the line.

P_i and Q_i are active power and reactive power at the ith-node.

Step 2. Calculate the current through the branches using the BW method:

The current through the ith branch is calculated by:

$$I_i = \frac{S_i}{V_i} \quad (9)$$

Where:

I_i is the current through the ith branch.

S_i is the apparent power of the ith branch.

V_i is the voltage at the ith node.

Step 3. Calculate the voltage at nodes using the FW method:

$$V_{i+1} = V_i - I_{i,i+1} \times Z_{i,i+1} \quad (10)$$

where:

V_{i+1} is the voltage at node i+1.

$I_{i,i+1}$, $Z_{i,i+1}$ are the current and the impedance from node i to node $i+1$.

Step 4 . Calculate the active power loss:

$$P_{i,i+1} = R_{i,i+1} \times I_{i,i+1}^2 \quad (11)$$

The total active power loss of the system is calculated as follows:

$$P_{\text{loss}} = \sum_{i=1}^{n-1} P_{i,i+1} \times S_{SI} \quad (12)$$

with $P_{i,i+1}$ is active power loss from node i to node $i+1$.

3.2. Applying Particle Swarm Optimization algorithm to the problem

In 1995, two scientists, James Kennedy, and Russell C. Eberhart, researched and invented an optimal algorithm, called PSO algorithm [28]. This method was based on birds' principles, biological characteristics, and intelligence in moving in search of food. The mechanism of updating new solutions of PSO method is given in Eqs. (13-16) and its flow chart is presented in Figure 1.

$$X_j = X_{j,\min} + rand(X_{j,max} - X_{j,\min}) \quad (13)$$

$$V_j = V_{j,\min} + rand(V_{j,\max} - V_{j,\min}) \quad (14)$$

$$V_{j,new} = V_j + c_1 r_1 (P_{best,j} - X_j) + c_2 r_2 (G_{best} - X_j) \quad (15)$$

$$X_{j,new} = X_j + V_{j,new} \quad (16)$$

where: X_j, $X_{j,min}$ and $X_{j,max}$ are the positions of entity j, the limit constrains the smallest and largest positions of entity j, respectively. V_j, $V_{j,min}$ and $V_{j,max}$ are the velocities of entity j, the limit constrains the smallest and largest velocity of entity j, respectively. $V_{j,new}$ is the new velocity of j-particle at the new loop. $r1$, $r2$ are random coefficients between 0 and 1. $c1$, $c2$ are weight coefficients. $X_{i,new}$ is the new position of j-particle at the new loop.

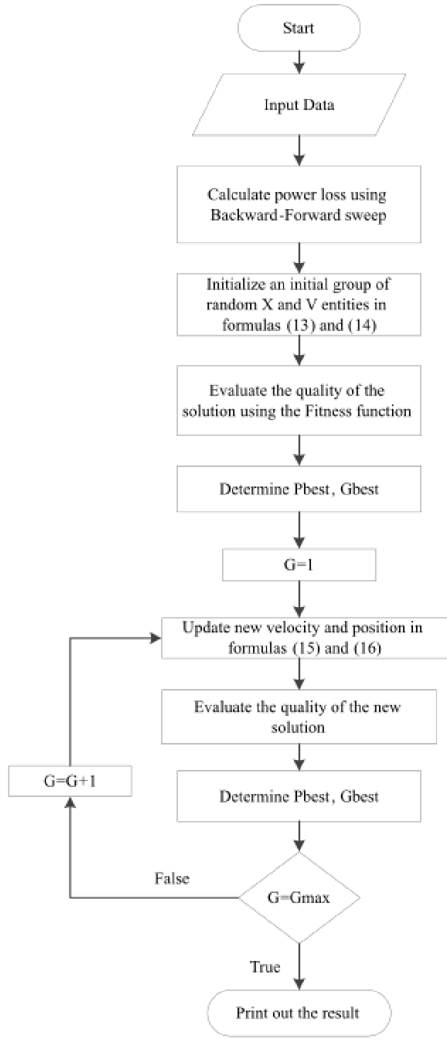

Fig. 1: The flowchart of the PSO algorithm.

4. Simulation Results

The IEEE 33-node distribution system [29] shown in Figure 2 is used to simulate and demonstrate the effectiveness of PSO algorithm. The load parameters include a total active power of 3715 (kW) and a total reactive power is 2300 (kVAR), respectively. The detailed load data is listed in Table 1 and the single-line diagram of the IEEE 33-node system is shown in Figure 2. The system voltage of 12.66 kV is used for calculation. In this study, the number of PV is considered in three cases with case 1 of 1 PV, case 2 of 2 PV, and case 3 of 3 PV. The results of three cases found by PSO are reported in different tables below. For finding the best solutions found by PSO, two control variables such as population size and maximum iterations are investigated for the case 3 with 3 PV. In addition, fifty trial runs are selected for this case. Pa-

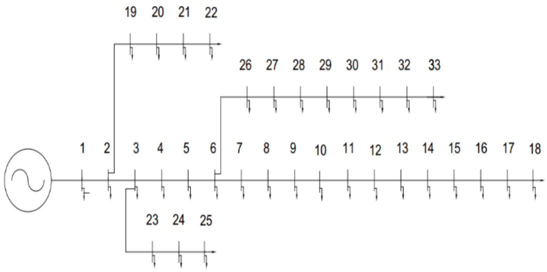

Fig. 2: IEEE 33-node distribution system diagram.

Tab. 1: Data of an IEEE 33-node distribution system.

Branch name	From node	To node	R (mΩ)	X (mΩ)	P (MW)	Q (MVar)
Line 1	Node 1	Node 2	92.2	47	0.1	0.06
Line 2	Node 2	Node 3	493	251.1	0.09	0.04
Line 3	Node 2	Node 19	164	156.5	0.09	0.04
Line 4	Node 3	Node 4	366	186.4	0.12	0.08
Line 5	Node 3	Node 23	451.2	308.3	0.09	0.05
Line 6	Node 4	Node 5	381.1	194.1	0.06	0.03
Line 7	Node 5	Node 6	819	707	0.06	0.02
Line 8	Node 6	Node 7	187.2	618.8	0.2	0.1
Line 9	Node 6	Node 26	203	103.4	0.06	0.025
Line 10	Node 7	Node 8	1711.4	1235.1	0.2	0.1
Line 11	Node 8	Node 9	1030	740	0.06	0.02
Line 12	Node 9	Node 10	1044	740	0.06	0.02
Line 13	Node 10	Node 11	196.6	65	0.045	0.03
Line 14	Node 11	Node 12	374.4	123.8	0.06	0.035
Line 15	Node 12	Node 13	1468	1155	0.06	0.035
Line 16	Node 13	Node 14	541.6	712.9	0.12	0.08
Line 17	Node 14	Node 15	591	526	0.06	0.01
Line 18	Node 15	Node 16	746.3	545	0.06	0.02
Line 19	Node 16	Node 17	1289	1721	0.06	0.02
Line 20	Node 17	Node 18	732	574	0.09	0.04
Line 21	Node 19	Node 20	1504.2	1355.4	0.09	0.04
Line 22	Node 20	Node 21	409.5	478.4	0.09	0.04
Line 23	Node 21	Node 22	708.9	937.3	0.09	0.04
Line 24	Node 23	Node 24	898	709.1	0.42	0.2
Line 25	Node 24	Node 25	896	701.1	0.42	0.2
Line 26	Node 26	Node 27	284.2	144.7	0.06	0.025
Line 27	Node 27	Node 28	1059	933.7	0.06	0.02
Line 28	Node 28	Node 29	804.2	700.6	0.12	0.07
Line 29	Node 29	Node 30	507.5	258.5	0.2	0.6
Line 30	Node 30	Node 31	974.4	963	0.15	0.07
Line 31	Node 31	Node 32	310.5	361.9	0.21	0.1
Line 32	Node 32	Node 33	341	530.2	0.06	0.04

rameters and the surveyed results are reported in Table 2, Table 3, and Figure 3. With each

Tab. 2: Different sets of parameters of PSO algorithm for Case 3.

Case	Runs	Population size	Maximum Iterations
1	50	50	50
2	50	70	70
3	50	85	85
4	50	100	100
5	50	100	150
6	50	100	200

Tab. 3: Surveyed results obtained by PSO algorithm for Case 3.

Case	Total size of PV (kW)	Min P_{loss} (kW)	Mean P_{loss} (kW)	Max P_{loss} (kW)	Standard deviation
1	3270.14	77.79	82.84	91.33	0.97
2	2841.59	75.95	81.14	86.17	2.26
3	2719.06	73.85	79.74	83.96	2.23
4	2824.4	74.41	78.8094	83.01	2.01
5	2818.14	73.76	77.71	80.86	1.43
6	2637.16	73.7	77.24	81.14	1.5

pair of population size and maximum iterations in Table 2, we can determine total size of PV, Minimum Ploss, Mean Ploss, Maximum Ploss, and standard deviation as reported in Table 3. Clearly, when we increase the value of population size and maximum iterations, the obtained results will be changed. As a results, the best solution with best ploss of 73.70 kW is corresponding to population size of 100 and maximum iterations of 200. If we continue increasing these values, the results are unchanged. Fifty Ploss values with fifty trial runs are displayed in Figure 3. Besides, the convergence characteristic of PSO among 50 runs with population size of 100 and maximum iterations of 200 is plotted in Figure 4.

From Table 4, we can see that the number of PVs has a very clear impact on the distribution grid system. In the case of the system without PV, the total active power loss is 211.00 (kW). This value is reduced to 111.03 (kW) for the case of 1 PV at node 6, to 87.17 (kW) for the case of 2 PV nodes 13 and 30, and to 73.70 (kW) for the case of 3 PV at nodes 14, 24, and 30 respectively. In addition to reducing the total power loss, the voltage at the nodes of the system has also been improved as compared to the case without PV penetration as shown in Figure 5, Figure 6, and Figure 7 respectively. In the case of not considering PV penetration, the minimum voltage and maximum voltage are 0.904 (pu) and 0.997 (pu), respectively. The minimum voltage with PV is 0.942 (pu) for case 1, 0.965 (pu) for case 2 and 0.968 (pu) for case 3, respectively. The maximum voltage at the nodes has been improved up to 0.998 (pu) and 0.999 (pu) in the cases of 1 PV, 2 PV, and 3 PV respectively.

In addition, the results of applying the PSO algorithm are compared with the GA [30],

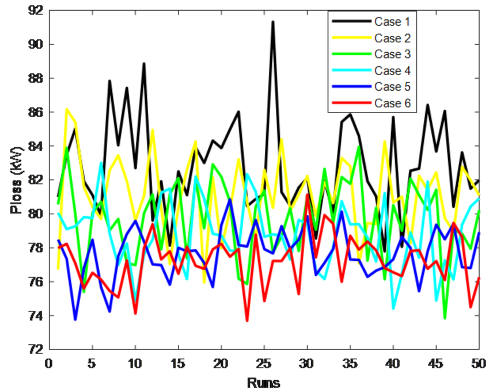

Fig. 3: Surveyed results obtained by PSO algorithm for Case 3

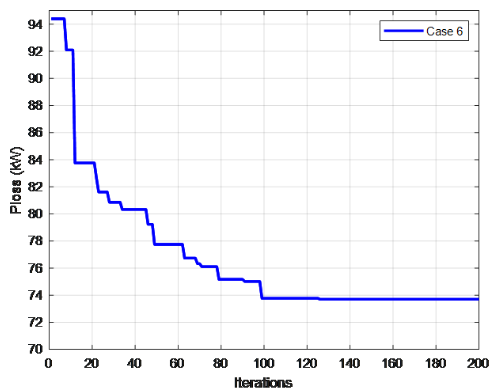

Fig. 4: Convergence characteristics of the PSO algorithm for case 3

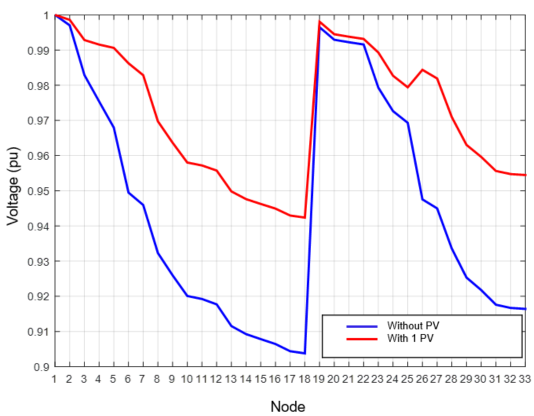

Fig. 5: The voltage of the IEEE 33-node distribution system before and after 1 PV installation

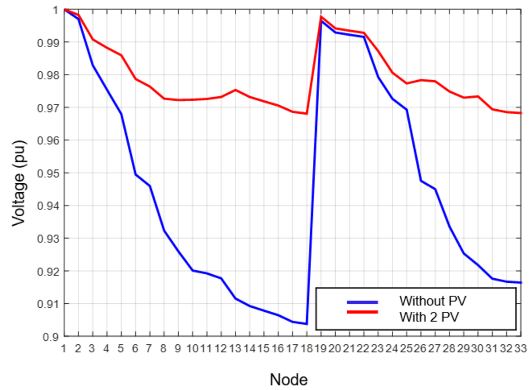

Fig. 6: The voltage of the IEEE 33-node distribution system before and after 2 PV installation

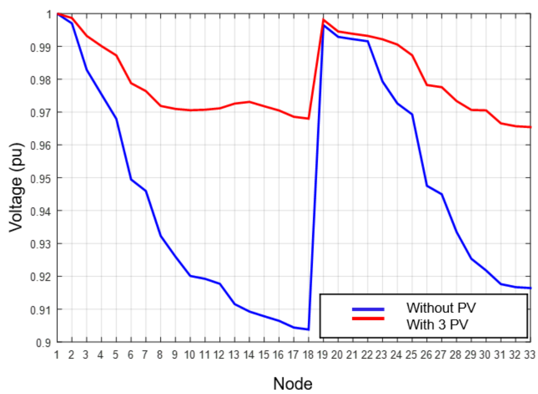

Fig. 7: The voltage of the IEEE 33-node distribution system before and after 3 PV installation

Tab. 4: Results of IEEE 33-node system with PV.

	Without PV	1 PV	2 PV	3 PV
Capacity (kW) and location of PV	-	2590.23 (6)	1154.34 (30) 843.01 (13)	992.32 (30) 876.93 (24) 767.92 (14)
P_{loss} (kW)	211.00	111.03	87.17	73.70
Reduce power loss (%)	-	47.38	58.69	65.07
V_{min} (pu)	0.904	0.942	0.965	0.968
V_{max} (pu)	0.997	0.998	0.999	0.999

BFOA [31] and BSOA [32] in terms of power loss and voltage stability and detailed results are presented in Table 5. In the case of installing three PVs on the distribution system, the GA algorithm finds nodes 11, 29, and 30 for placing

PVs, the total PV capacity is 2994.2 (kW) and the power loss decreases to 106.30 (kW). The locations found by the BFOA algorithm are nodes 17, 18, and 33, respectively, with a total capacity of 2488.9 (kW) and a total power loss of 98.30 (kW). The total PV capacity found by the BSOA algorithm is 1669 (kW) installed at nodes 13, 28, and 31 respectively. While these positions for installing PVs suggested by PSO method stand at nodes 30, 24, and 14 respectively. The reduction of active power loss is 73.70 and the total capacity of PV is 2637.1 (kW). From the mentioned discussion, it can be concluded that the PSO algorithm has produced relatively more effective results than others.

Tab. 5: Results of PSO algorithm compared to GA, BFOA and BSOA algorithms.

		GA [30]	BFOA [31]	BSOA [32]	Proposed method (PSO)
Without PV	P_{loss} (kW)	211			
	V_{min} (pu)	0.9038 (18)			
3 PV	P_{loss} (kW)	106.30	98.30	89.05	73.70
	Reduce power loss (%)	49.61	53.41	57.79	65.07
	V_{min} (pu)	0.9809	0.9645	0.9554	0.9654
	Capacity (kW) and location of PV	1500 (11) 422.8 (29) 1071.4 (30)	633.5 (17) 908.2 (18) 947.2 (33)	632 (13) 487 (28) 550 (31)	992.3 (30) 876.9 (24) 767.9 (14)
	Total size of PV (kW)	2994.2	2488.9	1669	2637.1

5. Conclusions

In this paper, the application of PSO algorithm in determining the location and capacity of the PV source on the distribution grid system has big contributions in minimizing the system's power loss and increasing the system's voltage stability compared to that from other methods. As a result, the PSO algorithm is highly effective in solving optimization problems. In addition, it has also proven the effectiveness of renewable energy sources on the traditional power grid in minimizing economic losses and improving the system's power quality. However, PV is an uncertain energy source, and the research in this article does not consider these uncertain conditions. Installing the number of PVs on the system depends on the economics of being able to install solar panels. Besides, depending on the geographical location, the amount of solar radiation received during the day, and depending on the electricity supply needs, customers can choose options to install the appropriate number of PV. The results also show that the PSO algorithm is highly effective in solving optimization problems in power systems.

References

[1] Wandhare, R. & Agarwal, V. (2014). Novel stability enhancing control strategy for centralized PV-grid systems for smart grid applications. *IEEE Transactions on Smart Grid*, *5(3)*, 1389–1396.

[2] Guo, S., Zhao, H., & Zhao, H. (2017). The most economical mode of power supply for remote and less developed areas in China: power grid extension or micro-grid. *Sustainability*, *9(6)*, 910.

[3] Abas, N., Dilshad, S., Khalid, A., Saleem, M., & Kha, N. (2020). Power quality improvement using dynamic voltage restorer. *IEEE Access*, *8*, 164325–164339.

[4] Chourasiya, S. & Agarwal, S. (2015). A review: control techniques for shunt active power filter for power quality improvement from non-linear loads. *International Electrical Engineering Journal*, *6(10)*, 2028–2032.

[5] Maradin, D. (2021). Advantages and disadvantages of renewable energy sources utilization. *International Journal of Energy Economics and Policy*, *11*, 3.

[6] Pandey, R. & Arora, M. (2016). Distributed generation system: A review and its impact on India. *International Research Journal of Engineering and Technology*, *3*, 04.

[7] Walt, H., Bansal, R., & Naidoo, R. (2018). PV based distributed generation power system protection: A review. *Renewable Energy Focus*, *24*, 33–40.

[8] Tran, C., Lai, G., Ca, T., Nguyen, T., & Nguyen, P. (2023). A sensor fault-tolerant control solution based on current observers applied to three phase induction motor drive. *Journal of Advanced Engineering and Computation*, *7(3)*,, 154–163.

[9] Nguyen, T., Nguyen, M., & Tran, C. (2022). Sensor fault diagnosis technique applied to three-phase induction motor drive. *Bulletin of Electrical Engineering and Informatics*, *11(6)*, 3127–3135.

[10] Tran, C., Nguyen, T., & Nguyen, P. (2021). A field-oriented control method using the virtual currents for the induction motor drive. *International Journal of Power Electronics and Drive Systems*, *12*, 2095–2102.

[11] Tran, A. & Vu, T. (2023). A study on general state model of differential drive wheeled mobile robots. *Journal of Advanced Engineering and Computation*, *7(3)*, 174–186.

[12] Ahamed, M., Reza, M., & Al-Amin, M. (2020). Electricity generation from speed breaker by air compression method using wells turbine. *Journal of Advanced Engineering and Computation*, *4(2)*, 140–148.

[13] Ali, M. & D.Kumar (2022). The Impact of Optimization Algorithms on The Performance of Face Recognition Neural Networks. *Journal of Advanced Engineering and Computation*, *6(4)*, 248–259.

[14] Vo, H. (2023). Sliding mode speed controller design for field oriented controlled PMSM drive of an electric vehicle. *Journal of Advanced Engineering and Computation*, *7(3)*, 164–173.

[15] Fokui, W., Ngoo, L., & Saulo, M. (2022). Optimal Integration of Electric Vehicle Charging Stations and Compensating Photovoltaic Systems in a Distribution Network Segregated into Communities. *Journal of Advanced Engineering and Computation*, *6(4)*, 260–275.

[16] Phan, V., Duong, M., Doan, M., & Nguyen, .T. (2021). Optimal Distributed Photovoltaic Units Placement in Radial Distribution System Considering Harmonic Distortion Limitation. *International Journal on Electrical Engineering & Informatics*, *13(2)*.

[17] Pham, T., Nguyen, T., & Dinh, B. (2021). Find optimal capacity and location of distributed generation units in radial distribution networks by using enhanced coyote optimization algorithm. *Neural Computing and Applications*, *33*, 4343–4371.

[18] Nguyen, T., Ngoc, T., Nguyen, T., Nguyen, T., & Nguyen, N. (2021). Optimization of location and size of distributed generations for maximizing their capacity and minimizing power loss of distribution system based on cuckoo search algorithm. *Bulletin of Electrical Engineering and Informatics*, *10(4)*, 1769–1776.

[19] Nguyen, T. & Nguyen, T. (2023). Power Loss Minimization by Optimal Placement of Distributed Generation Considering the Distribution Network Configuration Based on Artificial Ecosystem Optimization. *Advances in Electrical and Electronic Engineering*, *20(4)*, 418–431.

[20] Tamoor, M., Tahir, M., Zaka, M., & Iqtidar, E. (2022). Photovoltaic distributed generation integrated electrical distribution system for development of sustainable energy using reliability assessment indices and levelized cost of electricity. *Environmental Progress & Sustainable Energy*, *41(4)*, e13815.

[21] Zhang, L., Zhang, Y., & Li, Y. (2020). Mobile robot path planning based on improved localized particle swarm optimization. *IEEE Sensors Journal*, *21(5)*, 6962–6972.

[22] Qiao, G. & Du, L. (2019). CEnterprise financial risk early warning method based on hybrid PSO-SVM model. *Journal of Applied Science and Engineering*, *22(1)*, 171–178.

[23] Liu, W. (2020). Novel particle swarm optimization algorithms with applications to healthcare data analysis (Doctoral dissertation. *Brunel University London.*

[24] Kashani, A., Gandomi, M., Camp, C., Rostamian, M., & Gandomi, A.H. (2020). Metaheuristics in civil engineering: a review. *Techno-Press*, *1*, 019–42.

[25] Reddy, D., Reddy, V., & Manohar, T. (2018). Optimal Distributed Photovoltaic Units Placement in Radial Distribution System Considering Harmonic Distortion Limitation. *Journal of Electrical Systems and Information Technology*, *5(2)*.

[26] Rana, A., Darji, J., & Pandya, M. (2014). Backward/forward sweep load flow algorithm for radial distribution system. *International journal for scientific research and development*, *2(1)*, 398–400.

[27] Dharageshwari, K. & Nayanatara, C. (2015). Multiobjective optimal placement of multiple distributed generations in IEEE 33 bus radial system using simulated annealing. *International conference on circuits, power and computing technologies, IEEE*, 1–7.

[28] Kennedy, J. & Eberhart, R. (1995). Particle swarm optimization. *In Proceedings of ICNN'95-international conference on neural networks*, *4*, 1942–1948.

[29] Wu, H., Wang, M., Xu, Z., & Jia, Y. (2022). Graph attention enabled convolutional network for distribution system probabilistic power flow. *IEEE Transactions on Industry Applications*, *58(6)*, 7068–7078.

[30] Moradi, M. & Abedini, M. (2012). A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *International Journal of Electrical Power & Energy Systems*, *34(1)*, 66–74.

[31] Mohamed, I. & Kowsalya, M. (2014). Optimal distributed generation and capacitor placement in power distribution networks for power loss minimization. *International Conference on Advances in Electrical Engineering (ICAEE)*, 1–6.

[32] El-Fergany, A. (2015). Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm. *International Journal of Electrical Power & Energy Systems*, *64*, 1197–1205.

About Authors

Ly Huu PHAM received the B.E. (2004), M.E. (2009) degrees in electrical engineering from Ho Chi Minh City University of Technology, Vietnam. His research interests include optimization algorithms, power system optimization, and renewable energy. He can be contacted at email: phamhuuly@tdtu.edu.vn.

Tai Thanh PHAN received a Master degree in Electrical Engineering from Ton Duc Thang University, Ho Chi Minh City, Vietnam, in 2020. Now, he is a lecturer at the Faculty of Electrical and Electronics Engineering at Ton Duc Thang University, Ho Chi Minh City, Vietnam. His research areas are the application of optimization algorithms in the power system, renewable energy, and control engineering.

Van Thanh Ngoc NGUYEN was born in Vietnam in 2002. Now, she is a student at the Faculty of Electrical and Electronics Engineering at Ton Duc Thang University, Ho Chi Minh City, Vietnam. Her research interests are the application of optimization algorithms in the power system and renewable energy.

Khoa Dang Tran PHAN was born in Vietnam in 2001. Now, he is a student at the Faculty of Electrical and Electronics Engineering at Ton Duc Thang University, Ho Chi Minh City, Vietnam. His research interests are the application of optimization algorithms in the power system and renewable energy.

Phung Hai NGUYEN is the Director of Lin Ka Services Co. Ltd, Level 5, Songdo Building, 62A Pham Ngoc Thach Street, Vo Thi Sau Ward, Dist.3, HCM City, Vietnam.