Artificial Intelligence Technique for Optimal Allocation of Renewable Energy Based DGs in Distribution Networks

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Abstract. This paper proposes the artificial intelligence technique based on hybrid optimization phasor particle swarm optimization and a gravitational search algorithm, called PPSO-GSA for optimal allocation of renewable energy-based distributed generators (OA-RE-DGs), particularly wind and solar power generators, in distribution networks. The main objective is to maximize the techno-economic benefits in the distribution system by optimal allocation and integration of RE-DGs into distribution system. The proposed PPSO-GSA is implemented and validated on 94-bus practical distribution system located in Portuguese considering single and multiple scenarios of RE-DGs installation. The results reveal that optimizing the location and size of RE-DGs results in a substantial reduction in active power loss and yearly economic loss as well as improving system voltage profile and stability. Moreover, the convergence characteristics, computational efficiency and applicability of the proposed artificial intelligence technique is evaluated by comparative analysis and comparison with other optimization techniques.

Keywords: Artificial intelligence technique · Renewable energy · Distributed generators · Phasor particle swarm optimization · Gravitational search algorithm

1 Introduction

Worldwide, increasing electricity demands enabled a significant escalation in electric power production and such a load expansion that causes to influence the economies of developed countries to be motivated towards optimal planning of electric power generation sources and its utilization. Recently, a major part around 75% of electrical power is producing via fossil fuel-based energy sources [1] and it is directly related to natural reserves which is expected to be reduced day by day [2] also increase in the prices [3]. The production of electricity using conventional methods are causes to produce carbon emission [4]. Moreover, the large power plants are commonly located at long distance from the load centers which lost about 15% of power in transmission lines which affect the system performance and customers appliances [5].

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Hence, it is worth mentioning that the optimal planning and utilization of renewable energy sources (RE-DGs) such as wind turbine, solar photovoltaic has been considered globally to tackle and meet the high electricity demands at reasonable price [6]. The integration of RE-DGs units in distribution system plays an important role in term of active loss minimization, but still it has a challenge of optimal planning that needs to be addressed thoroughly [7, 8]. The optimal planning and integration of RE-DGs assist to maximize the technical and economic benefits of the power system. Generally, the objectives of optimal planning and integration of RE-DGs in distribution networks include power loss minimization, improving voltage profile, system stability, and operational cost minimization [9–14].

Recently, optimal planning and integration of RES-DGs in distribution networks are addressed and proposed the solution by using different optimization techniques that have been reviewed in [15–18], where different distribution systems are considered along with objective functions. Furthermore the objective functions are formulated for optimal allocation and sizing of RE-DG units and the work done is focused on strengthening the technical and economic implications in the distribution networks in terms of key objectives; power loss minimization, voltage profile improvement, energy loss, and smoothing buses voltages.

In this paper, a novel artificial intelligence technique namely PPSO-GSA is developed to solve the problem of OA-RE-DGs in distribution networks. The PPSO-GSA algorithm is employed to enhance the techno-economic benefits in distribution system by employing RE-DGs integration into the distribution system. Techno-economic benefits include, minimizing active power loss, improving buses voltage, voltage stability and yearly economic loss. Different scenarios of PV and WT integration, considering single and multiple DG units are examined on practical Portuguese RDS and results are compared with the existing literature.

The rest of the paper is organized as follows: Sect. 2 defines the problem formulation of the OA-RE-DGs. Proposed PPSO-GSA approach, and its implementation procedure is described in Sect. 3. Section 4 presents the simulation results and comparison with literature; finally, the conclusions are given in Sect. 5.

2 Problem Formulation

The problem of optimal placement and sizing of renewable energy based DG units (OA-RE-DGs) can be considered as a constrained, non-linear, discrete optimization problem [19]. The problem is formulated as an optimal power flow model [20], which has a single or multi-objective optimization function. The considered objectives should be properly optimized while satisfying the system operational constraints.

2.1 Objective Function

The key objective of this study is to maximize the techno-economic benefits in the distribution system by integration of RE-DG units into distribution networks. Several performance indicators should be taken into account while solving the problem of OA-RE-DGs. Therefore, minimizing active power losses, optimizing the annual profit as well as improving voltage and voltage stability index of system buses are considered as objectives of this study. This multi-objective function can be expressed using a weighted sum method [5, 21, 22].

$$ObjF = \min\left(\omega_1 \times P_{loss} + \omega_2 \times VD_T + \omega_3 \times (1/OVSI) + \omega_4 \times TAES\right) \quad (1)$$

where, P_{loss}, VD_T, *OVSI, and TAES* represents the reduction of the total active power losses, improvement of buses voltage, strengthening of buses stability, and saving in yearly economic loss, respectively. In addition, $\omega_1, \omega_2, \omega_3$ and ω_4 are weighting factors, in which the total sum of absolute values of the weights associated with each objective should equal to 1.0.

The four objectives studied in this work can be expressed mathematically as:

$$P_{loss} = \sum_{b=1}^{NBR} P_{loss,b} \quad (2)$$

$$P_{loss,b} = g_{ij,b} \times [V_i^2 + V_j^2 - 2 \times V_i \times V_j \times \cos(\theta_i - \theta_j)] \quad (3)$$

where, $P_{loss,b}$ is the active power loss of branch bth, $g_{ij,b}$ is the conductance of branch b connecting the ith and jth buses, V_i, V_j, θ_i, and θ_j are the voltage magnitudes and voltage angles at bus i and j, respectively.

$$VD_T = \sum_{i=1}^{NB} \left| V_i - V_i^{ref} \right| \quad (4)$$

where, V_i is the magnitude of the voltage of the bus number i, while v_i^{ref} denoting the magnitude of the reference voltage at the same bus, which is usually equal to 1 p.u.

$$OVSI = \sum_{i=2}^{NB} |VSI(j)| \quad (5)$$

$$VSI(j) = |V(i)|^4 - 4 \times [P_{ij,b} \times x_{ij,b} - Q_{ij,b} \times r_{ij,b}]^2 - 4 \times [P_{ij,b} \times r_{ij,b} + Q_{ij,b} \times x_{ij,b}] \times |V(i)|^2 \quad (6)$$

where, *OVSI* is the overall voltage stability index of the whole power network, while *VSI(j)* is the stability index of *jth* bus connected with the *ith* bus through a branch *bth* of a resistance $r_{ij,b}$ and reactance $x_{ij,b}$. Also, $P_{ij,b}$ and $Q_{ij,b}$ respectively are the active and reactive power flow from ith bus to *jth* bus. Where the bus with least VSI, corresponds to the most sensitive bus.

$$TAES = AEL_{T,noDG} - AEL_{T,DG} \quad (7)$$

where, *TAES* is the total annual economic saving gained when RES is integrated into the power network. $AEL_{T,noDG}$ and $AEL_{T,DG}$ are the total annual economic loss without and with DG and can be expressed as follows:

$$AEL_{T,noDG} = Ploss_{noDG} \times C_E \times 8760 \quad (8)$$

$$AEL_{T,DG} = Ploss_{DG} \times C_E \times 8760 + \left(C_{DG} \times \sum_{m=1}^{NDG} P_{DG,m} \right) / T_{DG} \quad (9)$$

where, C_E is the average cost of energy loss per kWh. C_{DG} and T_{DG} are the cost of injected power via DGs per kW and the total DG lifetime in years, respectively.

2.2 Equality Constraints

The power balance in the distribution network has considered as equality constraints.

$$P_{slak} + \sum_{m=1}^{NDG} P_{DG,m} = \sum_{i=1}^{NB} P_{DG,i} + \sum_{b=1}^{NBR} P_{Loss,b} \quad (10)$$

$$Q_{slak} + \sum_{m=1}^{NDG} Q_{DG,m} = \sum_{i=1}^{NB} Q_{DG,i} + \sum_{b=1}^{NBR} Q_{Loss,b} \quad (11)$$

where, P_{slak}, Q_{slak}, $P_{DG,i}$, and $Q_{DG,i}$ are the active and reactive power injected by the slack (i.e. swing) bus and *ith* DG, respectively. $P_{DG,m}$ and $Q_{DG,m}$ are the active and reactive power demand, where $P_{Loss,b}$ and $Q_{Loss,b}$ are the active and reactive power loss of *bth* branch.

2.3 Inequality Constraints

- The voltage limits must be as follow:

$$V\min \leq Vi \leq \max \quad i \forall NB \quad (12)$$

- The apparent power flow limits need to be as below:

$$S_b \leq S_b^{\max} \quad b \forall NBR \quad (13)$$

- The DG capacity constraints; i.e. DG penetration level (μ) and the maximum size of individual units. Also, the DG power factor ($PF_{DG,m}$) should be within safe limits as expressed below:

$$\sum_{m=1}^{NDG} S_{DG,m} \leq \mu \sum_{i=1}^{NB} S_{D,i} \quad (14)$$

$$S_{DG,m} \leq S_{DG,m}^{\max} \quad m \forall NDG \tag{15}$$

$$PF_{DG,m}^{\min} \leq PF_{DG,m} \leq PF_{DG,m}^{\max} \tag{16}$$

$$S_{DG,m} = \sqrt{P_{DG,m}^2 - Q_{DG,m}^2} \tag{17}$$

$$S_{D,i} = \sqrt{P_{D,i}^2 - Q_{D,i}^2} \tag{18}$$

3 Proposed Method

In this study the artificial intelligence technique based on combined metaheuristic optimization approach PPSO and GSA algorithm, namely PPSO-GSA algorithm is proposed [23]. The proposed model is able to optimally allocate the RES-DG units in distribution networks which has extensive properties of PPSO [24] and GSA [25]. In particular the PPSO-GSA considering the phase angle (θ) and being represented by trigonometric functions (i.e., sine and cosine) associated with phase angle θ [26]. Furthermore, it uses the stochastic search method and search agents are considered as vectors with control variables ($\mathbf{x}_i$) in n dimension. Utilizing stochastic search operators on the current population, the proposed AI technique create a new population using a successive iterative correction scheme [27]. The following equations have been considered while program problem optimization.

$$\mathbf{v}_i(iter+1) = r_1 \times \mathbf{v}_i(iter) + r_2 \times C_1(iter) \times \mathbf{a}_i(iter) + r_3 \times C_2(iter) \\ \times (\mathbf{gbest}(iter) - \mathbf{x}_i(iter)) \tag{19}$$

$$C_1(iter) = |\cos\theta_i(iter)|^{2\times\sin\theta_i(iter)} \tag{20}$$

$$C_2(iter) = |\sin\theta_i(iter)|^{2\times\cos\theta_i(iter)} \tag{21}$$

$$\mathbf{x}_i(iter+1) = \mathbf{x}_i(iter) + \mathbf{v}_i(iter+1) \tag{22}$$

where, the acceleration of agent $\mathbf{a}_i$, being modified utilizing the equations given in [25] and r_1, r_2, and r_3 are random numbers in the range of [0, 1].

$$\theta_i(iter+1) = \theta_i(iter) + |\cos\theta_i(iter) + \sin\theta_i(iter)| \times 2\pi \tag{23}$$

The program execution of the proposed PPSO-GSA technique follows many steps and procedures as per given flow chart illustrated in Fig. 1.

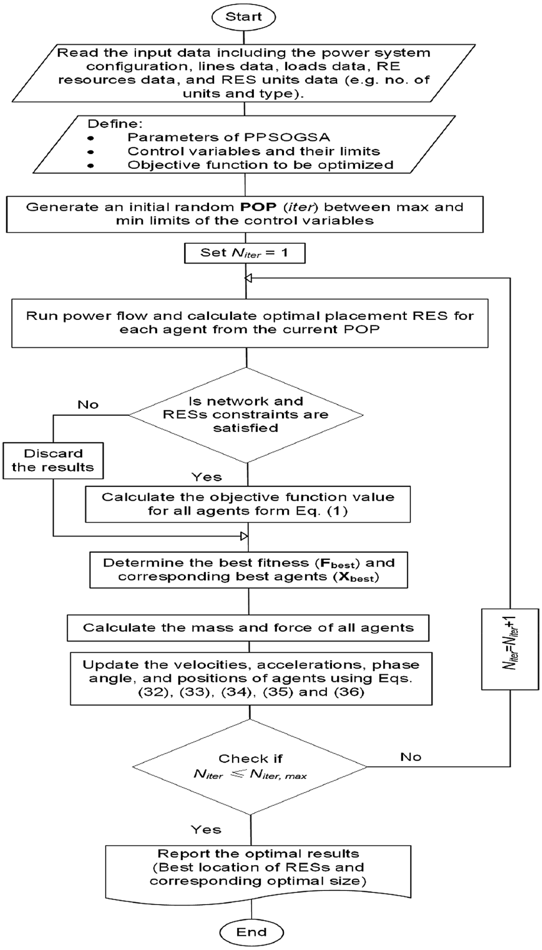

Fig. 1. Flow diagram of PPSO-GSA implementation for OA-RE-DGs

4 Simulation Results and Discussion

4.1 Simulation Strategies

In this paper, PPSO-GSA is implemented on practical distribution system of 94 bus located in Portuguese, the proposed model considering the allocation of renewable energy sources particularly, PV and WT, with different generation capacities. The input data and study parameters are shown in Table 1. Moreover, two cases, including single and multiple installation of PV and WT units are examined to evaluate the performance of the proposed methodology and its positive impacts on system indices.

Table 1. Input parameters for simulation

Description	Set value(s)
PPSO-GSA parameters:	
$N_{iter,max}$	100
N_{pop}	50
N_{runs}	50
System inequality constraints:	
Bus voltage limits (p.u.)	±10%
RE-DG size limits (MVA)	$0 \leq S_{DG} \leq 5$
RE-DG PF limits [28]	$1 \leq PF_{PV} \leq 1$ & $0.65 \leq PF_{WT} \leq 1$
Max. No of RE-DG units/bus	2
Cost data [21]:	
C_{DG} ($/kW)	30
T_{DG} (years)	10
C_E ($/kWh)	0.05
*PV inject active power only	
*WT inject active and reactive power	
*Each bus can integrate one DG only	

4.2 Practical Portuguese 94-Bus RDS

In order to evaluate the effectiveness of the artificial intelligence technique the proposed PPSO-GSA has implemented on Practical 94-bus shown in Fig. 2. The line and load data of considered system has obtained from [29], and the load model of the distribution system is assumed as a constant power load [30]. Using the base case without DGs integration and 100% loading conditions the results are presented in the Table 2. It interprets the system specifications and initial power flow results without any RE-DG unit contribution. Moreover, employing the proposed model considering RE-DG units integration along with different scenarios (i.e. single and multiple RE-DG units) the results obtained are shown in Table 3. It can be seen that integrating the PV and WT generators into the system at optimal locations, the voltage profile has significantly improved and the stability index increased dramatically as compared to the base case without RE-DGs as presented in Figs. 3 and 4, respectively.

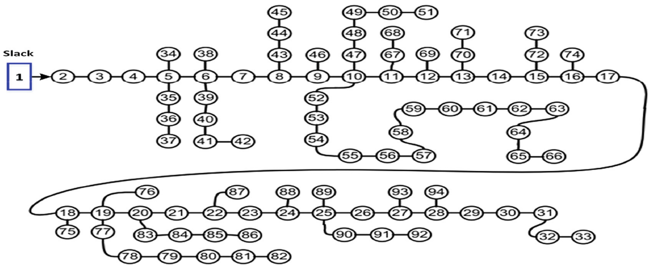

Fig. 2. Single line diagram of practical 94-bus distribution system located in Portuguese

Table 2. Test System results without RE-DGs

Description	Portuguese 94-bus system
System specifications:	
NB	94
Nbr	93
Vsys (kV)	15
Base MVA	100
Initial power flow results:	
S_{load} (MVA)	4.797 + j 2.323
P_{loss} (kW)	362.86
Q_{loss} (kVAr)	504.04
V_{min},bus (p.u.)	0.5183,92
V_{max},bus (p.u.) (without slack bus)	0.9804,2
VD_T (p.u)*	9.126
OVSI	62.265
$AEL_{T,noDG}$ (\$)	158932.68
CPU time (s)	6.831223

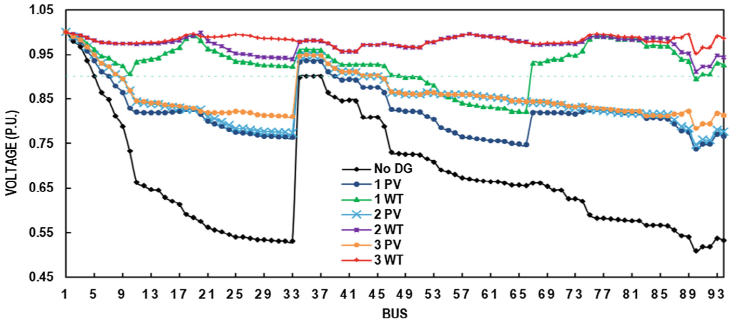

Fig. 3. Voltage profile without and with RE-DG unit's integration

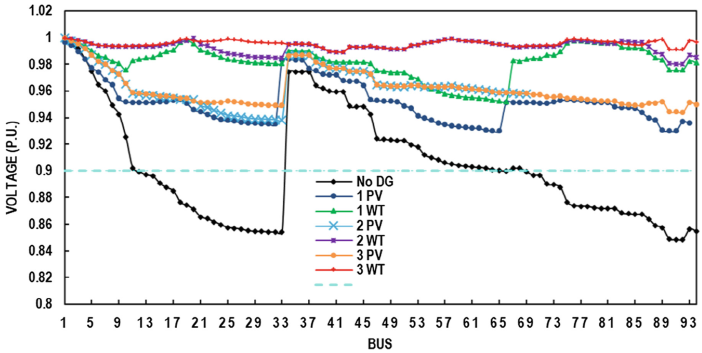

Fig. 4. Bus VSI profile without and with RE-DG unit's integration.

Table 3. Results obtained by proposed PPSO-GSA for optimal allocation of RE-DGs

Description	Single RE-DG (DGs No/Type)		Multiple RE-DGs (DGs No/Type)			
	1/PV	1/WT	2/PV	2/WT	3/PV	3/WT
P_{loss} (kW)	132.395	81.269	79.255	21.719	72.932	14.856
V_{min}/bus (p.u.)	0.9301/66	0.9522/66	0.9332/92	0.9802/92	0.9442/92	0.9892/42
V_{max}/bus (p.u.)	0.9968/2	0.9981/19	0.9974/2	0.9997/20	0.9974/2	0.9993/19
DG_MVA/PF, Bus No	2.636/1,19	2.9683/0.893,19	1.978/1,20 1.726/1,58	2.189/0.898,20 1.905/0.898,58	1.467/1,19 0.557/1,25 1.6987/1,58	1.62/0.899,19 0.61/0.899,25 1.87/0.895,58
OVSI	76.384	86.372	78.814	90.445	79.558	91.286
VD_T (p.u)	4.491	1.712	3.790	0.636	3.570	0.420
$AEL_{T,DG}$ *($)*	57996.939	35603.76	34719.53	9519.01	31949.47	6508.49
TAES ($)	34412.301	56805.48	57689.70	82890.22	60459.76	85900.74
CPU time (s)	13.96653	13.906	20.25375	16.241	23.038	17.982

In the first scenario, considering single RE-DG unit integration, the optimal location has identified as bus number 6 for PV and WT installation. Also optimized the sizes of PV and WT at power factor of 0.8239. The proposed optimization reduces the high power loss to 132.95 kW and 81.269 kW by suggesting the PV and WT, respectively. Moreover, Fig. 5 shows the branch power loss variation with and base case without the integration of PV and WT units, where the current flow and power loss in branches 1 to 19 is decreased drastically after PV or WT unit's penetration. This optimal planning reduces the yearly economic loss to 57996.939 $ and 35603.761 $ from 158932.68 $ for the base case without RESs.

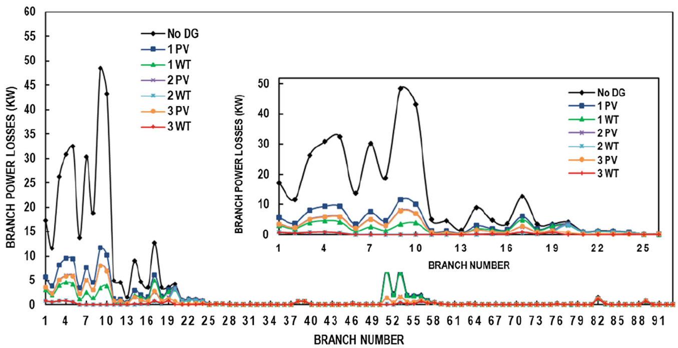

Fig. 5. Branch active power loss without and with RE-DG units

Furthermore, the minimum voltage magnitude has improved to 0.9301 p.u and 0.9522 p.u using PV and WT respectively, together with increasing the VSI of all system buses. Thus, strengthening system power quality and stability. It should be mentioned that the optimal planning of RE-DGs in active distribution network has off-line implementation nature; thus, the time of processing is not considered a concern [30]. Nevertheless, the PPSO-GSA consumes a small value of 13.966 s and 13.906 s of CPU time with PV and WT, respectively.

In the second scenario, the integration of multiple RE-DG units (i.e., two and three units) is considered, and its implications are investigated. For the case of two PVs, buses 20 and 58 are selected as optimal locations for PV unit integration with a capacity of 1.9785 MW and 1.7267 MW, respectively. On the other hand, the optimal locations for three PV units are the buses 19, 25 and 58 and the PVs capacities are 1.4679, 0.5571 and 1.6987 MW, respectively. It is worth mentioning that the active power loss has significantly reduced to 79.255 kW and 72.932 kW by two PV and three PV units, respectively. On the same line, the yearly savings enhanced to 57689.709 $ and 60459.762 $ are achieved with two PV and three PV units, respectively.

Furthermore, while optimal planning of two WT units, buses 20 and 58 are also designated as optimal locations with optimal WTs power capacities of 2.1898 MVA, 1.9054 MVA with power factors equals 0.8985 and 0.8983, respectively. As a result, the network losses are minified to 21.719 kW. Also, the optimal integration of three WT units at buses 19, 25 and 58 intensively decreased the power loss to only 14.856 kW. Moreover, the obtained results also show that the annual economic savings are increased to 82890.229 $ and 85900.741 $, respectively.

In general, due to the capability of WTs to supply reactive power, it gives better voltage profile and noticeably enhances system stability compared to PV (realize Figs. 5 and 6), where the minimum voltage magnitudes are achieved 0.9802 p.u. at bus 20 and 0.9892 p.u at bus 42, together with a considerable increase in the OVSI of 90.445 and 91.286 by the contribution of 2 and 3 WTs, respectively.

Clearly, it can be seen from Table 3 that whenever the number of PVs and WTs (i.e., the penetration level of RESs) is increased, a considerable improvement in the techno-economic performance is achieved, which is presented by the bar graph given in Fig. 6.

Table 4 arranges the numerical results of the proposed PPSO-GSA method and comparison with other existing techniques reported in the literature for 94-bus RDS. The fair comparison shows that the proposed algorithm provides global optimal solutions and better results than other methods and verify the capability of PPSO-GSA to solve the planning problem and improve the system performance.

Table 4. Comparison of PPSO-GSA results with other methodologies

DGs No/Type	Methodology	P_{loss} (kW)	V_{min} (p.u.)	V_{max} (p.u.)	RE-DG data (kVA/PF, bus)	CPU time (s)
1/PV	BSOA [28]	153.56	0.9276	0.9967	2398.5/1,21	118.00
	KHA [31]	132.3957	0.9301	0.9968	2636.0175/1,19	22.570
	SKHA [31]	132.3957	0.9301	0.9968	2636.018/1,19	21.170
	PPSO-GSA	132.395	0.9301	0.9968	2636/1,19	13.966
1/WT	BSOA [28]	85.13	0.9519	0.998	2398.5/0.532,18	234.01
	PPSO-GSA	81.269	0.9522	0.9981	2968.3/0.894,19	13.906
2/PV	KHA [31]	86.6475	0.9284	0.9974	1.940/1,56 1.752/1,83	20.626
	SKHA [31]	79.2549	0.9301	0.9968	1.7260/1,58 1.978/1,20	20.298
	PPSO-GSA	79.25	0.9332	0.9974	1978.5/1,20 1726.7/1,58	20.253
3/PV	KHA [31]	74.4907	0.934	0.9976	0.955/1,10 1.833/1,20 1.285/1,58	19.249
	SKHA [31]	73.1022	0.9437	0.9974	0.498/1,25 1.575/1,19 1.638/1,58	19.046
	PPSO-GSA	72.932	0.9442	0.9974	1.4679/1,19 0.5571/1,25 1.6987/1,58	23.038

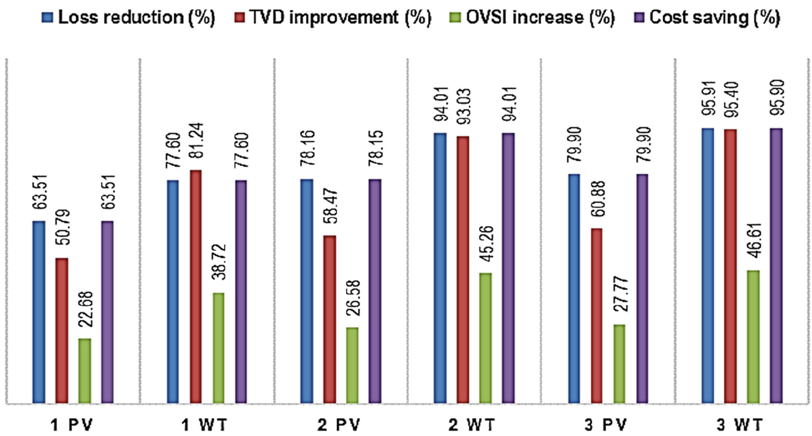

Fig. 6. Techno-economic indices achieved by RE-DG units integration in 94-bus RDS

4.3 Performance Evaluation of the Proposed Algorithm

In general, the meta-heuristic algorithms are characterized by its randomness. Therefore, many trials have been made to prove the robustness of the proposed PPSO-GSA with 20 independent runs. Samples of the optimization objective convergences of the *Ploss* is given in Fig. 7. The results elucidate that the PPSO-GSA accelerates to the near-optimal solution smoothly, robust, and having steady convergence characteristics.

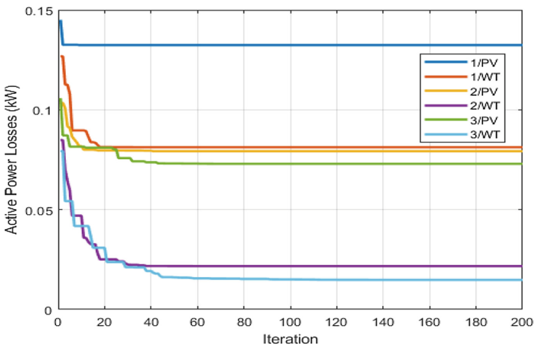

Fig. 7. Convergence rate of PPSO-GSA algorithm

5 Conclusions

In this paper, the artificial intelligence technique based on PPSO and GSA, namely PPSO-GSA has utilized for the RE-DG unit's allocation in the distribution system. The developed model optimizes the sizing and locations of RE-DG units with the main objective of techno-economic binifit maximation in distribution system, The key highlights from the obtained results are:

- The PPSO-GSA provides better solution to the planning problem of RE-DGs either in single or multiple scenarios of DGs integration.
- The contribution of PV and WT power generators in the distribution system and its optimal allocation enhances the system performance and power quality in term of power loss reduction and voltage profile improvement.
- The more increase in the penetration of RE-DGs, the more melioration in technical and financial indices of the distribution system, especially with the case of WTs.
- In comparison with the literature, thank to the artificial intelligence technique that provides better results and high-quality solutions in all cases.

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References

1. IRENA. Global Energy, a Roadmap to 2050 by Irena 2018. http://www.irena.org
2. Dawoud, S.M., Lin, X., Okba, M.I.: Hybrid renewable microgrid optimization techniques: a review. Renew. Sustain. Energy Rev. **82**, 2039–2052 (2018)
3. Djelailia, O., Kelaiaia, M.S., Labar, H., Necaibia, S., Merad, F.: Energy hybridization photovoltaic/diesel generator/pump storage hydroelectric management based on online optimal fuel consumption per kWh. Sustain. Cities Soc. **44**, 1–15 (2019)
4. Quek, T.Y.A., Ee, W.L.A., Chen, W., Ng, T.S.A.: Environmental impacts of transitioning to renewable electricity for Singapore and the surrounding region: a life cycle assessment. J. Clean. Prod. **214**, 1–11 (2019)
5. Poornazaryan, B., Karimyan, P., Gharehpetian, G.B., Abedi, M.: Optimal allocation and sizing of DG units considering voltage stability, losses and load variations. Int. J. Electr. Power Energy Syst. **79**, 42–52 (2016)
6. Kosai, S.: Dynamic vulnerability in standalone hybrid renewable energy system. Energy Convers. Manag. **180**, 258–268 (2019)
7. Xia, S., Bu, S., Wan, C., Lu, X., Chan, K.W., Zhou, B.: A fully distributed hierarchical control framework for coordinated operation of DERs in active distribution power networks. IEEE Trans. Power Syst. **8950** (2018)
8. Wang, L., Yuan, M., Zhang, F., Wang, X., Dai, L., Zhao, F.: Risk assessment of distribution networks integrating large-scale distributed photovoltaics. IEEE Access **7**, 59653–59664 (2019)
9. Xiang, Y., et al.: Optimal active distribution network planning: a review. Electr. Power Compon. Syst. **44**(10), 1075–1094 (2016)
10. Qazi, A., Hussain, F., Rahim, N.A.B.D., Member, S.: Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions. IEEE Access **7**, 63837–63851 (2019)
11. Razavi, S.E., et al.: Impact of distributed generation on protection and voltage regulation of distribution systems: a review. Renew. Sustain. Energy Rev. **105**, 157–167 (2019)
12. Mararakanye, N., Bekker, B.: Renewable energy integration impacts within the context of generator type, penetration level and grid characteristics. Renew. Sustain. Energy Rev. **108**, 441–451 (2019)
13. Ghadi, M.J., Ghavidel, S., Rajabi, A., Azizivahed, A., Li, L., Zhang, J.: A review on economic and technical operation of active distribution systems. Renew. Sustain. Energy **104**, 38–53 (2019)
14. Carvalho, P.C.M., Costa, R.M.: Implementation and evaluation of the first renewable energy systems technical course in Brazil. IEEE Access **7**, 46538–46549 (2019)
15. Mahmoud, P.H.A., Huy, P.D., Ramachandaramurthy, V.K.: A review of the optimal allocation of distributed generation: objectives, constraints, methods, and algorithms. Renew. Sustain. Energy Rev. **75**, 293–312 (2017)
16. Nduka, O.S., Pal, B.C.: Quantitative evaluation of actual loss reduction benefits of a renewable heavy DG distribution network. IEEE Trans. Sustain. Energy **9**(3), 1384–1396 (2018)
17. Sultana, U., Khairuddin, A.B., Aman, M.M., Mokhtar, A.S., Zareen, N.: A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system. Renew. Sustain. Energy Rev. **63**, 363–378 (2016)
18. Ehsan, A., Yang, Q.: Optimal integration and planning of renewable distributed generation in the power distribution networks: a review of analytical techniques. Appl. Energy **210**, 44–59 (2018)

19. Mithulananthan, N.: Optimal allocation of distributed generation using hybrid grey wolf optimizer. IEEE Access **5**, 14807–14818 (2017)
20. El-Fergany, A.: Multi-objective allocation of multi-type distributed generators along distribution networks using backtracking search algorithm and fuzzy expert rules. Electr. Power Compon. Syst. **44**(3), 252–267 (2016)
21. Kumar, S., Mandal, K.K., Chakraborty, N.: Optimal DG placement by multi-objective opposition based chaotic differential evolution for techno-economic analysis. Appl. Soft Comput. J. **78**, 70–83 (2019)
22. Ullah, Z., Wang, S., Radosavljevic, J., Lai, J.: A solution to the optimal power flow problem considering WT and PV generation. IEEE Access **7**, 46763–46772 (2019)
23. Mirjalili, S., Zaiton, S., Hashim, M.: A new hybrid PSOGSA algorithm for function optimization, no. 1, pp. 374–377 (2010)
24. Ghasemi, M., Akbari, E., Rahimnejad, A., Ehsan, S., Sahand, R., Li, G.: Phasor particle swarm optimization: a simple and efficient variant of PSO (2018)
25. Rashedi, E., Nezamabadi-pour, H., Saryazdi, S.: GSA: a gravitational search algorithm. Inf. Sci. (NY) **179**(13), 2232–2248 (2009)
26. Maleki, A., Khajeh, M.G., Ameri, M.: Optimal sizing of a grid independent hybrid renewable energy system incorporating resource uncertainty, and load uncertainty. Int. J. Electr. Power Energy Syst. **83**, 514–524 (2016)
27. Radosavljevic, J.: Metaheuristic optimization in power engineering. Institution of Engineering and Technology (2018)
28. El-Fergany, A.: Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm. Int. J. Electr. Power Energy Syst. **64**, 1197–1205 (2015)
29. Pires, D.F., Antunes, C.H., Martins, A.G.: NSGA-II with local search for a multi-objective reactive power compensation problem. Int. J. Electr. Power Energy Syst. **43**(1), 313–324 (2012)
30. El-Fergany, A.: Study impact of various load models on DG placement and sizing using backtracking search algorithm. Appl. Soft Comput. J. **30**, 803–811 (2015)
31. ChithraDevi, S.A., Lakshminarasimman, L., Balamurugan, R.: Stud Krill herd algorithm for multiple DG placement and sizing in a radial distribution system. Eng. Sci. Technol. Int. J. **20**(2), 748–759 (2017)