Transactions on Machine Intelligence 8(2) (2025) 101–108

ISSN Online: 2821-1693

Transactions on Machine Intelligence

Journal Homepage: https://tmachineintelligence.ir/

# Application of the Harmony Search Metaheuristic Algorithm in Distribution Network Optimization with Focus on Reconfiguration and Simultaneous Installation of Distributed Generation Units

A. Abdi Farzani[1], R. Roshanfekr[2,*]

[1] Master's Student, Department of Electrical Engineering, Hakim Sabzevari University, Sabzevar, Iran
[2] Assistant Professor, Department of Electrical Engineering, Hakim Sabzevari University, Sabzevar, Iran

**ARTICLE INFO**

Article History:
Received 11 January 2025
Received in revised form 3 March 2025
Accepted 29 April 2025
Available online 7 June 2025

Keywords:
Distributed Generation, Distribution Network Reconfiguration, Distribution Network Optimization, Loss Reduction, Harmony Search Algorithm

**ABSTRACT**

Distribution network reconfiguration and the optimal utilization of distributed generation (DG) resources are effective methods for reducing losses and improving power quality in electrical distribution systems. In recent years, the use of DG has attracted significant attention due to its notable advantages. Integrating DG can reduce network losses and enhance voltage stability. Furthermore, the use of DG resources contributes to increasing the reliability of the system. Therefore, optimal placement of these resources, combined with appropriate distribution network reconfiguration, can have a substantial impact on overall system performance. In this study, a novel approach for reconstructing the distribution network structure in the presence of DG units is proposed. The primary objective of this approach is to minimize power losses and bus voltage deviations while improving the voltage profile in the distribution system. To achieve these objectives, the Harmony Search Algorithm (HSA), a metaheuristic optimization method, is employed for network reconfiguration and simultaneous identification of optimal DG placement. Additionally, sensitivity analysis is used to determine the most suitable locations for DG installation. The proposed method is tested on a 33-bus radial distribution system to demonstrate its efficiency and effectiveness. The results obtained from this study are satisfactory.

## 1. INTRODUCTION

Power losses and energy dissipation in electrical networks impose substantial financial costs on utility companies. The highest losses occur in distribution networks, where a significant portion of power generation is wasted in our country. To reduce losses and improve voltage stability, various solutions such as capacitor installation, utilization of distributed generation (DG) resources, peak-load management, and distribution feeder reconfiguration have proven effective. Implementing these measures can significantly enhance the performance and efficiency of distribution networks while minimizing energy losses [1].

* Corresponding Author: roshanfekr@hsu.ac.ir
Assistant Professor, Department of Electrical Engineering, Hakim Sabzevari University, Sabzevar, Iran



http://dx.doi.org/10.22034/TMI.2025.244843

The integration of distributed generation can provide considerable benefits for power systems, including improved power quality, enhanced voltage profiles, reduced losses, and increased system reliability. By supplying active power locally at load points and reducing transmission losses, voltage stability and network reliability are improved. However, the proper placement of these resources is crucial, as incorrect installation can increase costs and reduce system efficiency [2]. Reference [3] reviews the types of distributed generation resources that can be used to compensate active and reactive power and reduce losses in distribution networks.

The objective of this study, in addition to the aforementioned goals, is to optimize the bus voltage profile using a metaheuristic algorithm, specifically the Harmony Search Algorithm (HSA).

### 1.1. Review of Previous Studies

Distribution network reconfiguration is considered a simple and cost-effective approach to reduce losses in power distribution systems [2]. Minimizing losses and improving voltage stability in a distribution network with distributed generation requires an effective optimization method to propose the optimal network configuration. In recent years, metaheuristic algorithms have been introduced to overcome these limitations. A review of the literature shows that various evolutionary optimization algorithms have been applied to address the problem of distribution network reconfiguration.

In [4], the Runner Root algorithm was applied to the distribution network reconfiguration problem. This algorithm is inspired by the growth and propagation mechanisms of plant roots in nature. The study aimed to optimize the distribution network by minimizing active power losses, balancing loads among network branches, and balancing loads across feeders. Results indicated that the proposed algorithm can efficiently reconfigure the network considering one or multiple objectives.

In [5], a method for simultaneous DG placement and network reconfiguration using the Teaching-Learning-Based Optimization (TLBO) algorithm was investigated. The main objective was to reduce losses and improve the voltage profile of the system. The proposed approach was tested on a standard 33-bus system, demonstrating good performance in achieving optimal solutions.

In [6], to address the challenge of reconfiguring a distribution network with optimal DG units aimed at loss minimization, the Parallel Slime Mould Algorithm was evaluated.

Article [7] applied Differential Evolution (DE) and Salp Swarm Algorithm (SSA) to optimize the allocation of photovoltaic panels and wind turbines while solving the radial distribution network reconfiguration problem to reduce costs and improve reliability.

In [8], an improved Binary Particle Swarm Optimization (BPSO) algorithm was used to minimize losses and maintain bus voltages during network reconfiguration and capacitor placement.

### 1.2. Overview of the Harmony Search Algorithm (HSA)

The Harmony Search Algorithm (HSA), proposed by Green et al. [9], is a metaheuristic inspired by the process of musical improvisation by musicians. HSA is simple, computationally efficient, and easy to implement, and it has been successfully applied to a variety of real-world problems, including the Traveling Salesman Problem [10].

The main steps of HSA, as outlined in [9], are:

1. Problem definition and initialization of parameters
2. Initialization of the Harmony Memory
3. Generation of a new harmony
4. Updating the Harmony Memory
5. Checking the termination criteria

## 2. PROBLEM DEFINITION AND FRAMEWORK

The objective of this study is to simultaneously perform distribution network reconfiguration and optimal capacitor allocation. The optimization variables for the distribution system reconfiguration problem include:

- The open/closed status of tie switches,
- The selected bus numbers for capacitor installation, and
- The size of capacitors installed at each bus.

These variables can be represented in a bit-array format as follows:

$$x = [\ \mathrm{Tie}_1\ ,\mathrm{Tie}_2\ ,\dots\ ,\mathrm{Tie}_{\mathrm{N_{Tie}}}\ ,\mathrm{SW}_1\ ,\mathrm{SW}_2\ ,\dots,\mathrm{SW}_{\mathrm{N_{Tie}}}\ ,\ \mathrm{P}_{DG1}\ ,\mathrm{P}_{DG2}\ ,\dots\ ,\mathrm{P}_{\mathrm{DG}N_{DG}}\ ] \tag{1}$$

In this array, $\mathrm{Tie}_i$ represents the status (open or closed) of the tie switches, $\mathrm{SW}_i$ indicates the bus number of the corresponding tie switch, $N_{tie}$ denotes the total number of tie switches, and $P_{\mathrm{DG1}}$ represents the power rating of the $i$-th distributed generation (DG) unit.

### 2.1. Objective Functions of the Optimization Problem

In this study, the objective functions include minimizing the active power losses of the network and the voltage deviation at the network buses.

*2.1.1. Active Power Losses of the Network:*

Considering that distribution system lines are modeled as short lines, the current in each branch is first calculated. Then, the total system losses are computed using the corresponding loss equation

$$F_1(x) = \sum_{i=1}^{Nb} R_i |I_i|^2 \tag{2}$$

In this equation, $N_b$represents the total number of lines in the network, while $R_i$and $|\ I_i\ |$denote the resistance and the RMS value of the current in the $i$-th line, respectively [11].

*2.1.2. Voltage Deviation of Network Buses:*

The second objective function is related to the voltage deviation at the distribution network buses and is calculated using the following relation:

$$F_2(x) = \ Max_i |V_i - V_{rate}| \tag{3}$$

In this equation, $V_{\mathrm{rate}}$and $V_i$represent the nominal voltage of the bus and the actual voltage at the $i$-th bus, respectively [12].

### 2.2. Optimization Problem Constraints

*2.2.1. Bus Isolation Constraint*

After performing the reconfiguration of the distribution network, ensuring that all buses and nodes remain energized and properly supplied is of critical importance. This is essential to provide reliable power to all connected loads without voltage drops and to maintain system stability. In other words, the network reconfiguration must be carried out in a way that prevents any load from being disconnected or forming a separate island. To guarantee the radial structure of the network after reconfiguration, the following constraint can be applied:

$$N_{branch} = \ N_{bus} - \ N_{source} \tag{4}$$

In this equation, $N_{\text{bus}}$ and $N_{\text{source}}$ represent the number of buses and network substations, respectively.

*2.2.2. Bus Voltage Constraint*

After reconfiguring the network, the voltage at all buses must remain within a specified range of the nominal voltage (for example, ±5%) [11-12]. The following limiting constraint should be applied to the voltage of all buses in the network:

$$V_{i\,min} < V_i < V_{i\,max} \tag{5}$$

*2.2.3. Feeder Current Constraint*

After network reconfiguration, the current flowing through each feeder section must remain within a specified range. The following limiting constraint should be applied to the current of all network feeders:

$$I_{ij(min)} < I_{ij} < I_{ij(max)} \tag{6}$$

represents the current flowing through the feeder connecting buses $i$ and $j$ [11-12].

*2.2.4. Active Power Constraint of Distributed Generation Units*

If $P_{DG,i}^{\min}$ and $P_{DG,i}^{\max}$ denote the lower and upper bounds of the active power output of the $i$-th distributed generation (DG) unit, respectively, then the following condition must be satisfied for each DG unit in the distribution network:

$$P_{DG.i}^{min} \leq P_{DG.i} \leq P_{DG.i}^{max} \tag{7}$$

## 3. LOAD FLOW EQUATIONS

Simple recursive equations can be used to calculate the load distribution in the power distribution system [13].

$$\mathrm{P_{k+1}} = \mathrm{P_k} - \mathrm{P_{Loss.k}} - \mathrm{P_{Lk+1}} = \mathrm{P_k} - \frac{\mathrm{R_k}}{|\mathrm{V_k}|^2}\{\mathrm{P_k}^2 + (\mathrm{Q_k} + \mathrm{Y_k}|\mathrm{V_k}|^2)^2\} - \mathrm{P_{Lk+1}} \tag{8}$$

$$\mathrm{Q_{k+1}} = \mathrm{Q_k} - \mathrm{Q_{Loss.k}} - \mathrm{Q_{Lk+1}} = \mathrm{Q_k} - \frac{\mathrm{X_k}}{|\mathrm{V_k}|^2}\{\mathrm{P_k}^2 + (\mathrm{Q_k} + \mathrm{Y_{k1}}|\mathrm{V_k}|^2)^2\} - \mathrm{Y_{k1}}|\mathrm{V_k}|^2 - \mathrm{Y_{k2}}|\mathrm{V_{k+1}}|^2 - \mathrm{Q_{Lk+1}} \tag{9}$$

$$|\mathrm{V_{k+1}}|^2 = |\mathrm{V_k}|^2 + \frac{\mathrm{R_k}^2+\mathrm{X_k}^2}{|V_k|^2}\left(P_k{}^2 + Q_k{}'^2\right) - 2(R_kP_k + X_kQ_k) = |\mathrm{V_k}|^2 + \frac{\mathrm{R_k}^2+\mathrm{X_k}^2}{|V_k|^2}\left(P_k{}^2 + (Q_k + Y_k|V_k|^2)^2\right) - 2\left(R_kP_k + X_k(Q_k + Y_k|V_k|^2)\right) \tag{10}$$

The line power losses between two buses $k$ and $k+1$ are calculated as follows:

$$P_{Loss}(k.k+1) = R_k\frac{\mathrm{P_k}^2+\mathrm{Q_k}^2}{|V_k|^2} \tag{11}$$

The total feeder losses, representing the sum of losses across all feeder lines, are calculated as follows:

$$\mathrm{P_{T.Loss}} = \sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{P_k}(\mathrm{k.k+1}) \tag{12}$$

### 3.1. Sensitivity Analysis for DG Placement

To calculate sensitivity factors [14], candidate bus locations for the installation of DG units are determined using sensitivity analysis.

The active power losses are calculated as follows:

$$P_{lineloss} = \frac{(P_{Lk.eff}^2 + Q_{Lk.eff}^2)R_k}{V_k^2} \tag{13}$$

The loss sensitivity factor is calculated using the following relationship:

$$\frac{\partial P_{lineloss}}{\partial P_{Lk.eff}} = \frac{2 * P_{Lk.eff} * R_k}{V_k^2} \tag{14}$$

The loss sensitivity factor [9] in the system is calculated using load flow analysis, and the values for all buses are sorted in descending order. The required size of the DG unit for each candidate bus is determined using the Harmony Search Algorithm (HSA).

## 4. SIMULATION RESULT

In this section, the results obtained from the simulation and implementation of the Harmony Search metaheuristic algorithm for distribution network reconfiguration in the presence of Distributed Generation (DG) units are presented. The main objectives of this algorithm are to reduce network losses, minimize voltage deviations, and improve the voltage profile in the distribution system.

To achieve these goals, the Harmony Search Algorithm is applied to simultaneously optimize the network configuration and determine the optimal locations for installing DG units in the distribution network. In this study, a 33-bus radial test distribution system [15] is considered, which includes 5 main switches and 32 sectionalizing switches. The network load and line data are extracted from [16]. Based on these data, the total active and reactive loads of the network are 3715 kW and 2300 kVAr, respectively.

The Harmony Search Algorithm, with tuned parameters (population size, maximum number of generations, and total number of runs), is employed to identify the optimal DG installation locations. The final selection of the DG locations is performed using sensitivity analysis [14]. Three optimal positions in the network are selected for DG installation, and the results are presented in Table 1. Table 2 presents the results of distribution network reconfiguration in the presence of DG units, and Figure 2 illustrates the optimized voltage profile.

**Table 1.** Optimal Locations for DG Installation

| Bus 33 | Bus 32 | Bus 31 | Ideal DG Location |
|---|---|---|---|
| **557.25** | 536.81 | 576.60 | (kW) DG Capacity |

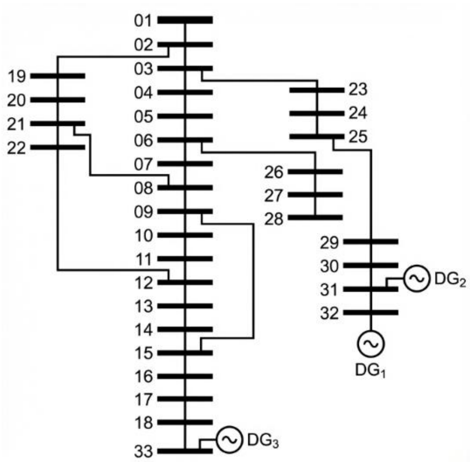


**Fig. 1.** Optimized network structure after reconfiguration and DG installation

**Table 2.** Distribution Network Reconfiguration Results in the Presence of DG Units

| Opened Switches | Voltage Deviation (pu) | Power Loss (kW) | Condition |
|---|---|---|---|
| 37-36-35-34-33 | 0.0695 | 202.6771 | Before Reconfiguration |
| 37-31-14-11-3 | 0.0425 | 41.5524 | After Reconfiguration |

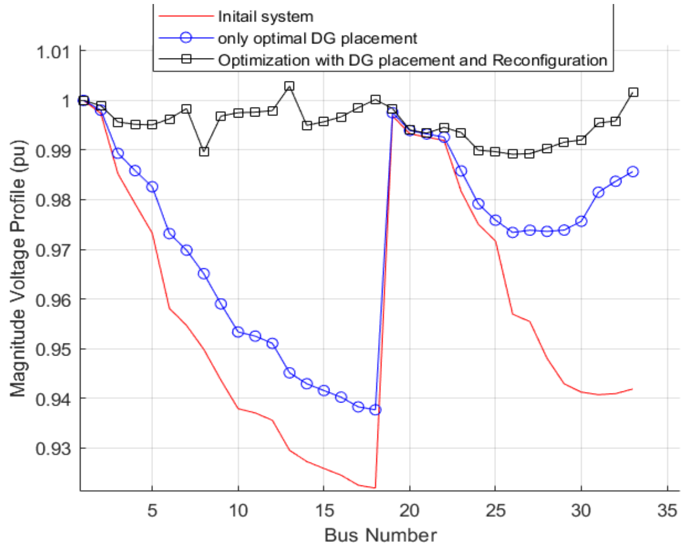


**Fig. 2.** Voltage Profile of the 33-Bus Test Network

## 5. CONCLUSION

The primary goal of this study was to reduce power losses and voltage deviation in a radial distribution network through network reconfiguration. To achieve this objective, the Harmony Search Algorithm (HSA), a metaheuristic optimization technique, was employed. Network reconfiguration is a complex, large-scale, nonlinear optimization problem with both discrete and continuous variables. As the system size increases, the number of local optima and scenarios to be analyzed grows significantly, making classical methods incapable of finding the global optimum efficiently.

In this research, a 33-bus test system was utilized to demonstrate loss reduction. The reconfiguration of the network in the presence of Distributed Generation (DG) units further reduced losses and improved the voltage profile. The HSA method was applied for both single-objective and multi-objective optimization of the network, providing solutions that are close to optimal efficiently.

Therefore, it can be concluded that distribution network reconfiguration is an effective strategy for enhancing network performance in terms of reducing losses, minimizing voltage deviations, and improving the voltage profile, and that the Harmony Search Algorithm is a powerful and efficient approach for solving such multi-objective optimization problems.

### Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

### Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

**Acknowledgments**

We would like to express our gratitude to all individuals who contributed to this project.

**Declaration of Interest**

The authors declare that they have no competing interests.

**Funding**

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

**REFERENCES**

[1] Duan, D.-L., Ling, X.-D., Wu, X.-Y., & Zhong, B. (2015). Reconfiguration of distribution network for loss reduction and reliability improvement based on an enhanced genetic algorithm. *International Journal of Electrical Power & Energy Systems*, 64, 88-95. https://doi.org/10.1016/j.ijepes.2014.07.036

[2] Amini, S., Ghasemi, S., & Moshtagh, J. (2021). Distribution feeder reconfiguration using PSOGSA algorithm in presence of distribution generation based on a fuzzy approach. *Computational Intelligence in Electrical Engineering*, 12(3), 73-86.

[3] Kansal, S., Kumar, V., & Tyagi, B. (2013). Optimal placement of different type of DG sources in distribution networks. *International Journal of Electrical Power & Energy Systems*, 53, 752-760. https://doi.org/10.1016/j.ijepes.2013.05.040

[4] Nguyen, T. T., Nguyen, T. T., Truong, V. A., Nguyen, Q. T., & Phung, T. A. (2017). Multi-objective electric distribution network reconfiguration solution using runner-root algorithm. *Applied Soft Computing*, 52, 93-108. https://doi.org/10.1016/j.asoc.2016.12.018

[5] Kanwar, N., Gupta, N., Niazi, K. R., & Swarnkar, A. (2016). An integrated approach for distributed resource allocation and network reconfiguration considering load diversity among customers. *Sustainable Energy, Grids and Networks*, 7, 37-46. https://doi.org/10.1016/j.segan.2016.05.002

[6] Wang, H.-J., Pan, J.-S., Nguyen, T.-T., & Weng, S. (2022). Distribution network reconfiguration with distributed generation based on parallel slime mould algorithm. *Energy*, 244, 123011. https://doi.org/10.1016/j.energy.2021.123011

[7] Fathi, R., Tousi, B., & Galvani, S. (2023). Allocation of renewable resources with radial distribution network reconfiguration using improved salp swarm algorithm. *Applied Soft Computing*, 132, 109828. https://doi.org/10.1016/j.asoc.2022.109828

[8] Niknam, T., Kavousifard, A., & Aghaei, J. (2012). Scenario-based multiobjective distribution feeder reconfiguration considering wind power using adaptive modified particle swarm optimisation. *IET Renewable Power Generation*, 6(4), 236-247. https://doi.org/10.1049/iet-rpg.2011.0256

[9] Geem, Z. W., Kim, J. H., & Loganathan, G. V. (2001). A new heuristic optimization algorithm: Harmony search. *Simulation*, 76(2), 60-68. https://doi.org/10.1177/003754970107600201

[10] Geem, Z. W., Tseng, C.-L., & Park, Y. (2005). Harmony search for generalized orienteering problem: Best touring in China. In L. Wang, K. Chen, & Y. S. Ong (Eds.), *Advances in Natural Computation* (LNCS vol. 3612, pp. 741-750). Springer. https://doi.org/10.1007/11539902_91

[11] Siahbalaee, J., Rezanejad, N., & Gharehpetian, G. B. (2019). Reconfiguration and DG sizing and placement using improved shuffled frog leaping algorithm. *Electric Power Components and Systems*, 47(16-17), 1475-1488. https://doi.org/10.1080/15325008.2019.1689449

[12] Lotfi, H., Azizivahed, A., Shojaei, A. A., Seyedi, S., & Othman, M. F. B. (2021). Multi-objective distribution feeder reconfiguration along with optimal sizing of capacitors and distributed generators regarding network voltage security. *Electric Power Components and Systems*, 49(6-7), 652-668. https://doi.org/10.1080/15325008.2021.2011486

[13] Ghosh, S., & Sherpa, K. S. (2008). An efficient method for load-flow solution of radial distribution networks. *International Journal of Electrical Power & Energy Systems Engineering*, 1(2), 108-115.

[14] Prakash, K., & Sydulu, M. (2007). Particle swarm optimization based capacitor placement on radial distribution systems. In *2007 IEEE Power Engineering Society General Meeting* (pp. 1-5). IEEE. https://doi.org/10.1109/PES.2007.386149

[15] Baran, M. E., & Wu, F. F. (1989). Network reconfiguration in distribution systems for loss reduction and load balancing. *IEEE Transactions on Power Delivery*, 4(2), 1401-1407. https://doi.org/10.1109/61.25627

[16] Srinivasa Rao, R., Narasimham, S. V. L., Ramalinga Raju, M., & Srinivasa Rao, A. (2011). Optimal network reconfiguration of large-scale distribution system using harmony search algorithm. *IEEE Transactions on Power Systems*, 26(3), 1080-1088. https://doi.org/10.1109/TPWRS.2010.2076839