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Enhancing voltage stability and Minimizing Power Losses via Reconfiguration and Sizing of Distributed Generators

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ABSTRACT

This paper provides an alternative approach for improving voltage stability and minimizing power losses through distribution system reconfiguration and adjusting the capacities of the Distributed Generators (DGs). The problem is formulated as multi-objective functions. Multi-objective genetic algorithm is utilized to evaluate the highest system loadability and minimum power losses by optimally sizing the distributed generators along with optimal network reconfiguration. The proposed technique is applied to IEEE 69-bus radial distribution system. The results showed the effectiveness of the proposed approach in improving the voltage profile and reducing in the power losses of the system.

KEYWORDS: Network reconfiguration; Distributed generators; Line loadability index; Multi-objective optimization; Genetic algorithm

1 INTRODUCTION

Concerns over global climate change, the greenhouse effect, and the quality of living environment have created attention to renewable energy resources for power generation. Today, several renewable energy technologies become cost-competitive with conventional technologies [1]. Because of the emergence of renewable energy resources, the distribution network has evolved from a radial network to a meshed network. Increasing the number of Distribution Generators (DGs) in the network made it more complex and the optimal utilization of the network becomes urgent [2, 3].

The installation of DGs in optimal distribution system sites provides numerous advantages. Some of these advantages are reducing power losses, enhancing voltage profile, peak demand shaving, relieving distribution line overload, lowering environmental impacts, increasing overall energy efficiency, and deferring expenditures to replace existing generating, and distribution systems [4].

A rise in the demand for electricity and operation close to stability limits makes improving system stability and security crucial for modern power networks [5]. Introducing voltage stability indices has been a critical challenge in many voltage stability investigations. These indices offer adequate information for monitoring the voltage stability in a power system.

An efficient method that has been utilized to boost the performance of distribution networks is network reconfiguration, which involves closing and opening sectionalizing and tie switches [6]. By reconfiguration, power losses reduction, an improvement of the voltage profile and increasing the system stability and reliability can be achieved [7].

In the literature, various approaches have been applied for reconfiguration of radial distribution system. These approaches can be classified into two groups: the conventional approaches and the artificial based approaches.

Merlin and Back [8] proposed a distribution system reconfiguration to reduce the losses. Here, all branches are closed (a full graph) and a strategy was used to open the branches that carry the minimum current. The approach is a greedy algorithm, which does not ensure the feasibility of the final result. In the past two decades, a number of modern heuristic tools have been developed to solve optimization problems that were previously challenging or difficult to solve. Some of these tools are simulated annealing, tabu search, particle swarm, and evolutionary computation [9, 10].

Ching-Tzong Su et al.[11] presented the Ant Colony Search Algorithm (ACSA) technique to solve the network reconfiguration problems.

For large distribution systems, the selection of the branches to be opened is a difficult issue, due to the huge number of possible radial configurations. Graph theory-based fuzzy adaptive evolutionary algorithm-based multi-objective reconfiguration technique was introduced by N. Gupta et al. [9, 12]. The study demonstrated that fundamental losses as well as losses from harmonic components were minimized with satisfying current and voltage deviation limits.

M.H. Moradi and M. Abedini [13] described a unique technique for allocating and sizing the DGs in distribution networks in order to minimize network loss. The technique combines the Genetic Algorithm (GA) and particle swarm optimization. Antonio José Gil Mena [14] proposed an approach to find the distributed generators location and capacity for a distribution system that consists of multiple distributed generation sources. In the approach, minimizing power losses and generation costs were considered. S. Jazebi et al. [15] proposed a fuzzy genetic algorithm-based network reconfiguration technique to improve the voltage stability in radial distribution networks. R. Kyomugisha et al. [16] proposed a multi objective GA to minimize the generation cost, transmission power loss, and a line voltage stability index.

In this paper, a new approach is proposed for improving the voltage stability and minimizing power losses of distribution systems via network reconfiguration and sizing of distributed generators. The problem is formulated as a multi-objective optimization problem. The pareto front based multi-objective GA is applied to determine the solution for the problem.

2 PROBLEM FORMULATION: OBJECTIVE FUNCTIONS AND CONSTRAINTS

- **The objective functions**

In this paper, minimum power losses and voltage profile improvement are accomplished by using reconfiguration with multi-objective optimization technique using GA.

The real power losses and the loadability index of the system are proposed as two objective functions that need to be optimized. The total active power losses of a distribution system are generally computed by summing the losses of all branches as represented by Eq. (1) [17]

$$F_1 = Power\ Losses = \sum_{k=1}^{N_{br}} R_k \times \left(\frac{P_k^2 + Q_k^2}{V_K^2}\right) \qquad (1)$$

where $P_k$is the active power, Q_k is the reactive power, R_k is the resistance, V_k is the voltage magnitude of each branch numbered k and N_{br} is the total number of branches.

To achieve higher load demand and stable system operation, the system's voltage stability or loadability limit must be incorporated into the objective problem formulation [5]. Here, the distribution system voltage stability index (i.e. loadability index L_S) developed in [18] is proposed. The determination of L_S is described by using a simple distribution network shown in Figure 1. The line loadability index is represented by Eq. (2)

$$F_2 = L_S = \frac{V_i^2}{2\left[r_{ij}P_{ij} + X_{ij}Q_{ij} + \sqrt{\left(r_{ij}^2 + X_{ij}^2\right)\left(P_{ij}^2 + Q_{ij}^2\right)_0^0}\right]} \geq 1 \qquad (2)$$

where $r_{ij} + X_{ij}$ and b_{ij} are the line impedance and the line susceptance respectively, $V_i\angle\theta_i$ and $P_i + jQ_i$ are the voltage and power flow at the sending bus i and $V_j\angle\theta_j$ and $P_{ij} + jQ_{ij}$ are the voltage and power flow at the receiving bus j.

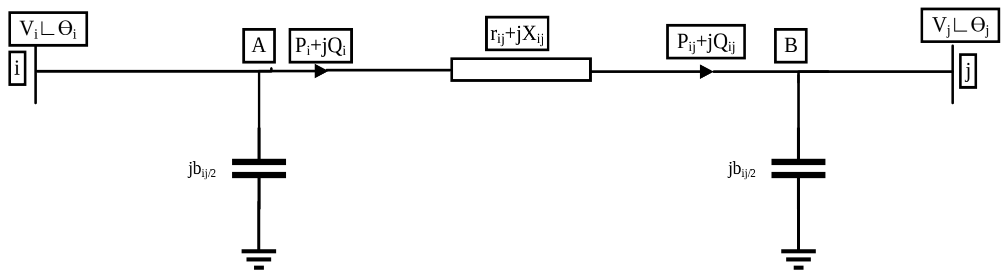

Figure 1: One-line diagram of a simple distribution network

The value of L_S ranges from ∞ at no load to 1 at maximum load. The system prone to voltage instability when L_S value is 1.0 [18].

- **The Constrains**

Load Balance Constraint

For a typical branch of a radial distribution system in Figure 2 [13], the following equations (3 and 4) must be satisfied for each bus.

$$P_{Gni} - P_{dni} - V_{ni} \sum_{j=1}^{N} V_{nj}\, y_{NJ} \cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \qquad (3)$$

$$Q_{Gni} - Q_{dni} - V_{ni} \sum_{j=1}^{N} V_{nj}\, y_{NJ} \sin(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \qquad (4)$$

where n_i is the receiving bus number n_i =1,2, 3……n_n, m_i is sending bus number ($m_2 = n_1$ = 1), I_{ni} is branch number fed bus i, V_{ni} is voltage of bus n_i, V_{mi} is the voltage of bus m_i, the generated power is designated by P_{Gni} and Q_{Gni} at bus n_i, power demand is designated by P_{dni} and Q_{dni} at bus n_i, R_{ni} and X_{ni} are the resistance and reactance of branch i, δ_{ni} and δ_{mi} are the phase angle of voltage at bus n_i and bus m_i respectively and Y_{ni} is the admittance between bus n_i and bus m_i.

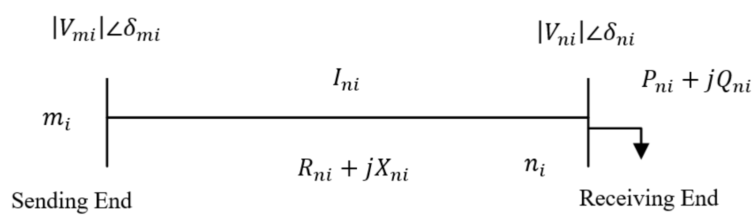

Figure 2: Typical branch of a radial distribution system

Voltage Limits

The generator voltage is the summation of the load or bus voltage and some values associated to the line impedance and power flows along that line. The voltage at each bus must be maintained within normal operating limits.

$$V_{ni}^{min} < V_{ni} < V_{ni}^{max}$$

where the minimum and maximum voltage are designated by V_{ni}^{min} and V_{ni}^{max} at bus n_i respectively.

The DG Technical Constraints

Because DG size is essentially constrained by the energy sources at any specified place, the capacity limitation of the generators must be considered.

$$P_{Gni}^{min} < P_{Gni} < P_{Gni}^{max}$$

where the minimum and maximum real power are designated by P_{Gni}^{min} and P_{Gni}^{max} respectively.

3 THE PROPOSED OPTIMIZATION APPROACH

The major distribution systems have typically consisted of a radial network with numerous feeders and laterals that are powered by these feeders. Radial circuits are organized into groups that make up the distribution system. By moving loads between feeders, switching operations can change the arrangement. In primary distribution systems, two different types of switches are identified which are sectionalizing switches (generally closed) and tie switches (generally open). These two different types of switches are utilized for system protection and configuration management. The topology of the distribution system can be changed via changing the status of switches [11]. By altering the topology of the system, feeder load balancing and real power losses reduction can be achieved [9].

Genetic algorithms (GA) have been lately emerged as viable approaches for solving optimization problems. Due to the flexibility and capacity of GAs in optimizations when applied to non-differentiable cost functions, this technique is becoming increasingly popular within the research community as design tools and issue solvers [19]. GAs can be employed for addressing combinatory optimization problem. GAs finds solutions inside a substance of the overall search space allowing them to efficiently produce an acceptable result for a specific problem within a reasonable computational duration [20]. The selection of the best result is achieved through a random process applied to a population of solutions. The current population are used to create a new generation by using through three operators (i.e. reproduction, crossover and mutation) [20].

In this paper, multi-objective GA based on the pareto front is utilized to obtain the best solution for the problem among a set of the solutions.

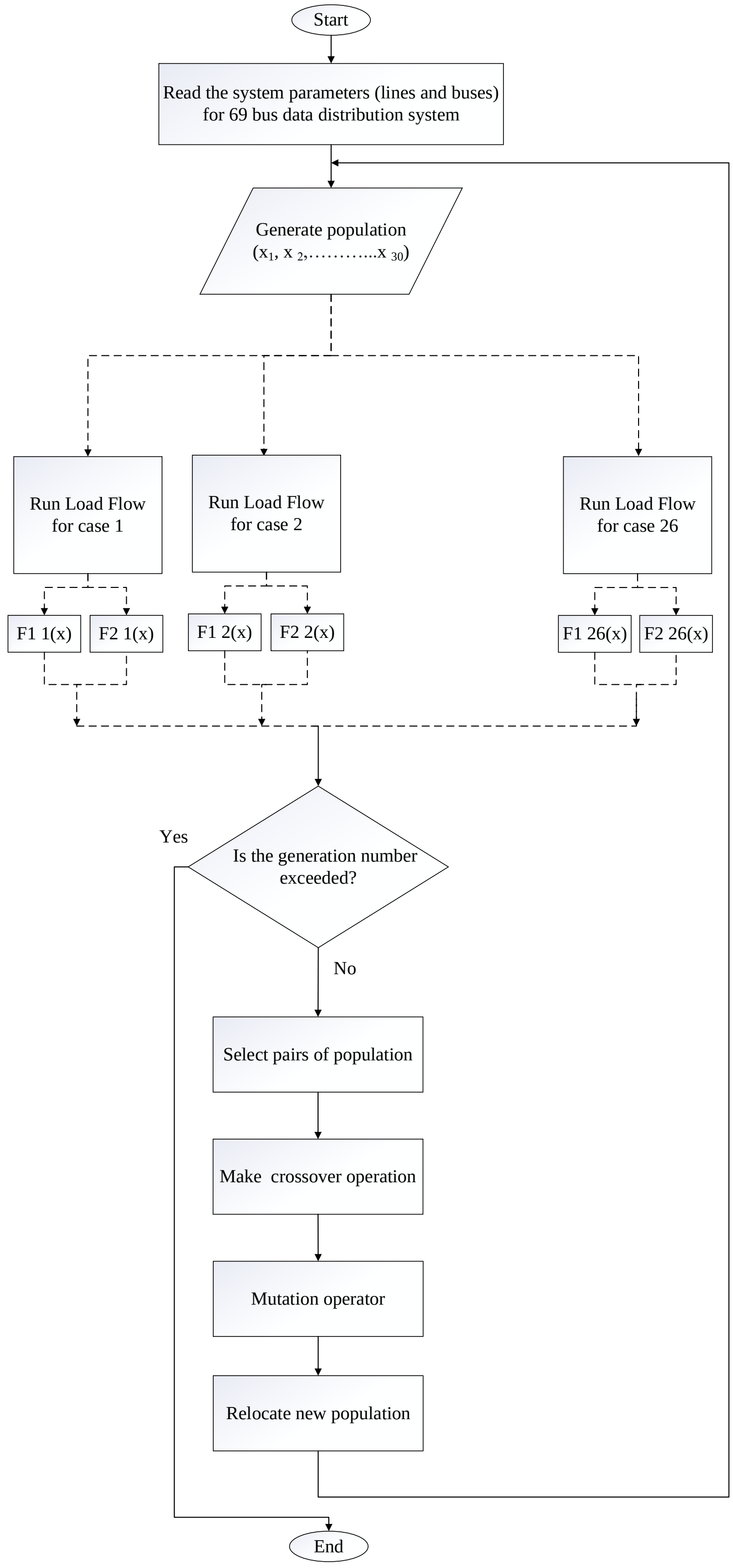

Figure 3: The proposed optimization algorithm flowchart

Figure 3 represents the flowchart for the proposed optimization approach, and the following steps explain the flowchart contained:

1- Generate population: The population variables are x_1 to x_{30}. Numbers 1, 2, ….26 represent the number of combinations of the tie switches to be closed. Each T has upper and lower values representing the combinations of lines to be opened by the sectionalizing switches. The ratio of the DGs capacity is represented by x_{27}, x_{28}, x_{29} and x_{30}. The ratio is varied between 0 and 1.

2- Objective functions: There are two functions, F_1 which represents the evaluation of the minimum power losses (P_L) and F_2 which represents the calculation of the maximum line loadability index (L_s).
The distribution system parameters, system reconfiguration (on/off switches) and sizing DGs are used to minimize F_1 and to maximize L_s,
min $\{F_1(x) = P_L\}$
max $\{F_2(x) = L_s\}$
The objectives $F(x)$ are related to a bound of constraints

$$L_i \leq x_i \leq U_i$$

where x_i is a decision variable and L_i and U_i are the upper and lower bounds on the ith variable respectively.
Pareto front has to be applied because a collection of solutions is obtained that are non-dominated to each other. The best result of each function component will be selected from the results of the optimization.

3- After the algorithm sets these new values, the creation of the next generation will start via selection, crossover and mutation operations.

4 RESULTS AND DISCUSSION

The proposed approach is tested on IEEE 69- bus distribution system. The system is consists of 69 buses with 7 laterals and 5 tie-lines as shown in Figure 4 [7]. The system is installed with four DGs. The total capacity of DGs is 1,000 kW. Initially, the capacity of generators is DG1 = 300kW, DG2 =100kW, DG3 = 200kW, and DG4 = 400kW. Here, a common base voltage and power are assumed to be 12.66 kV and 100 MVA respectively.

Before reconfiguration, the initial positions of all sectionalizing switches are closed while all the tie-switches are opened. After reconfiguration, twenty-six cases are examined. Each case contains number of combinations of lines to be opened by sectionalizing switches when the tie switches are closed. The numbers 1,2, 3, …. and 26 represent all switches probability (69 – 70 – 71 – 72 and 72) to be closed.

The proposed approach is tested on the system with and without DGs. The best minimum power losses and line loadability index are obtained using pareto function which comprises the result of each function component and finally produce minimum power losses and maximum loadability index. MATLAB Toolbox is used to carry out the optimization and to obtain the numerical results.

1- The system without DGs

Table 1 shows the results of the study when there are no DGs connected to IEEE 69-bus distribution system. It investigates two situations before and after reconfiguration. Before reconfiguration, the power losses and line loadability index are 190 kW and 11.5621 respectively. After reconfiguration and among all cases, better results are obtained in Case 22 when three tie switches are closed and three lines are opened by the sectionalized switches. The minimum power losses and line loadability index are 91 kW and 10.6817 respectively. The total real power losses are reduced by 52% as compared with the real power losses before reconfiguration. However, the loadability index decreased by 7.6% as compared to the loadability index before reconfiguration. Figure 5 shows voltage level improvement before and after reconfiguration.

Table 1
Results for the Case Study without distributed generators

IEEE 69 bus distribution system	Without Distributed Generators	
	Before reconfiguration	After reconfiguration Case 22
Power Losses (P_L)	190 kW	91.236kW
Line Loadability Index (L_s)	11.5621	10.6582
Tie Switches to be closed	-	71 – 72 – 73
Lines to be opened by sectionalizing switches	-	62 – 58 - 14

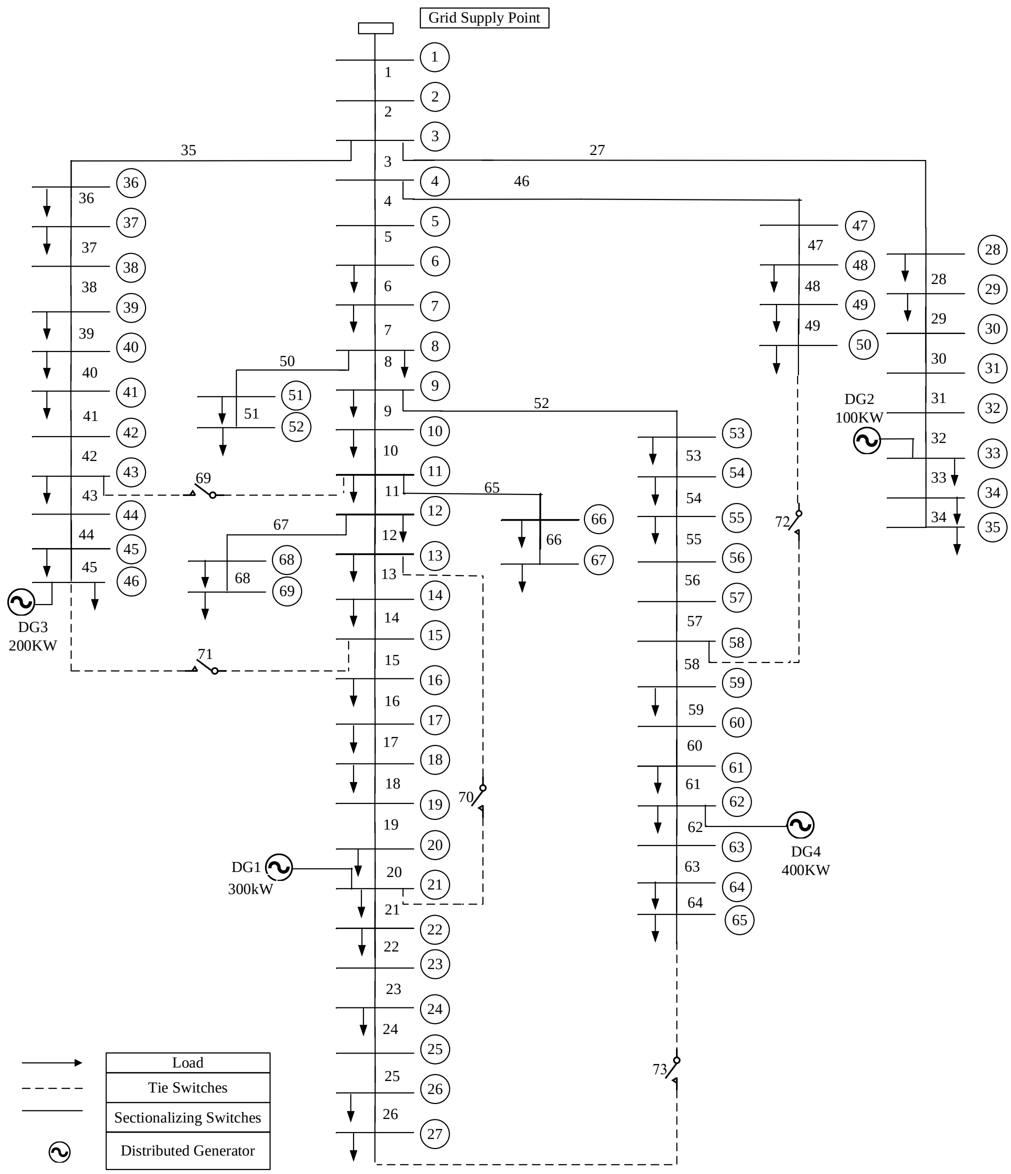

Figure 4: Single line diagram of IEE 69 – bus System

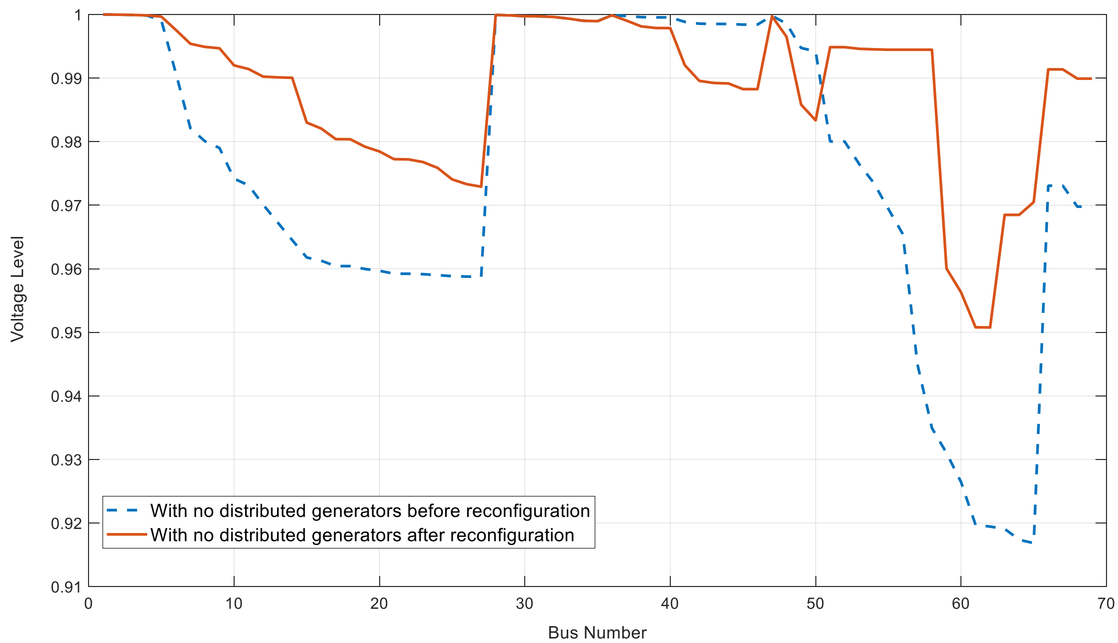

Figure 5: Voltage levels for a 69-bus radial distribution system

2- The system with DGs

The four DGs are connected to 69 bus distributed system (DG1 to DG4). The results shown in Table 2. The results of only two cases are explained; Case 19 and Case 22.

The minimum power losses were obtained from Case 22 which was carried out by closing the tie switches 71,72,73 and opening the lines 62,58,14 using the sectionalizing switches. The power losses and the line loadability index changed from 440 kW and 12.97 before reconfiguration to 94.637 kW and 17.2151 after reconfiguration. The distributed generators values DG1 to DG4 changed from 300.00, 100.00, 200.00 and 400.00 kW to 300.000, 41.3547, 200.000 and 399.9999 kW respectively. The results revealed 78.5% reduction in real power losses when compared to power losses before reconfiguration. Also, the line loadability and thus the voltage stability improved by 24.7% as compared to the line loadability before reconfiguration.

Table 2
Results for the Case Study (with distributed generators)

69 bus distribution system	With Distributed Generators		
	Before reconfiguration	After reconfiguration	
		Case 22 Minimum Power Losses (P_{Lmin})	Case 19 Maximum Line Loadability Index ($L_{S\ max}$)
DG1 (LINE 21)	300.000 kW	57.2264 kW	237.3112 kW
DG2 (LINE 33)	100.000 kW	92.7317 kW	54.6705 kW
DG3 (LINE 46)	200.000 kW	143.6771 kW	45.58837 kW
DG4 (LINE 62)	400.000 kW	196.3852 kW	188.2497 kW
Power Losses (P_L)	440 kW	94.637 kW	140 kW
Line Loadability Index (L_s)	12.97	17.2151	19.8223
Tie switches to be closed	-	71,72,73	69,71,72
Lines to be opened by sectionalizing switches	-	62,58,14	45,41,19

The minimum power losses with line loadability index for all cases from 1 to 26 were shown in Figure 6.

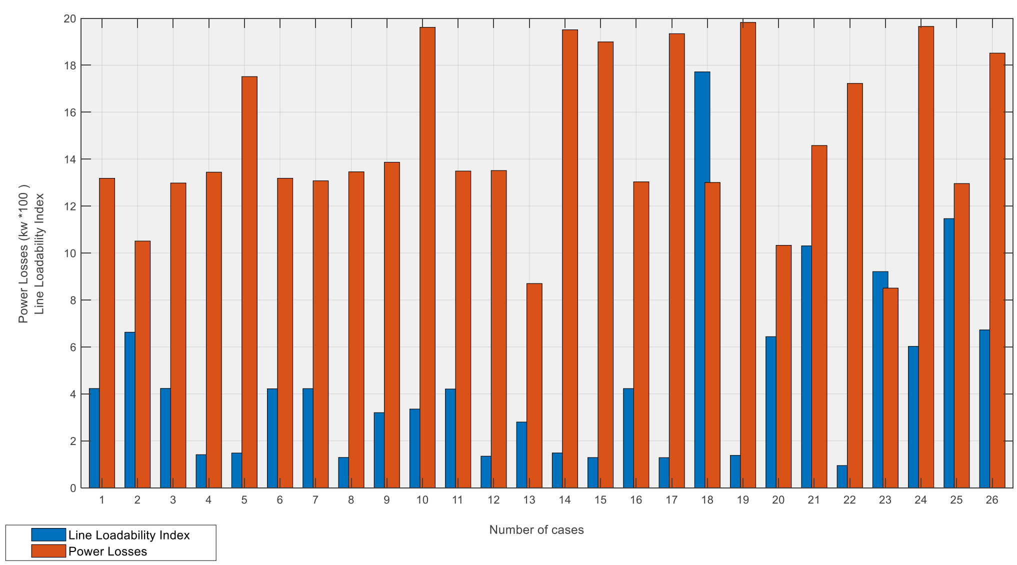

Figure 6: Power losses and the loadability line index

5 CONCLUSION

In this paper, the reconfiguration and sizing of DGs were utilized to minimize the total power losses and enhance the loadability and voltage stability of radial distribution systems. The problem was formulated as multi objective functions. Multi-objective GA was used to determine optimal pareto solutions for the problem.

The optimization technique was conducted to find the optimum DGs capacities in radial distribution systems before and after reconfiguration. The network feeders are reconfigured by changing the states of the tie and sectionalizing switches so the power from grid supply and the DGs can be re-routed. Tow situations, with and without DGs, were examined when the approach tested on IEEE 69-bus distribution system.

The obtained results showed the effectiveness of the approach in reducing power losses and improving the line loadability. When DGs connected to the system and after the reconfiguration, the real power losses reduced by 78.5%. and the line loadability improved by 24.7%.

REFERENCES

[1] R. Ramakumar and P. Chiradeja, "Distributed generation and renewable energy systems," in *IECEC'02. 2002 37th Intersociety Energy Conversion Engineering Conference, 2002.*, 2002, pp. 716-724: IEEE.

[2] B. Muruganantham, R. Gnanadass, and N. P. Padhy, "Challenges with renewable energy sources and storage in practical distribution systems," *Renewable and Sustainable Energy Reviews,* vol. 73, pp. 125-134, 2017.

[3] B. Ismail, N. I. A. Wahab, M. L. Othman, M. A. M. Radzi, K. N. Vijyakumar, and M. N. M. Naain, "A comprehensive review on optimal location and sizing of reactive power compensation using hybrid-based approaches for power loss reduction, voltage stability improvement, voltage profile enhancement and loadability enhancement," *IEEE access,* vol. 8, pp. 222733-222765, 2020.

[4] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power Loss Minimization in Distribution System Using Network Reconfiguration in the Presence of Distributed Generation," *IEEE Transactions on Power Systems,* vol. 28, no. 1, pp. 317-325, 2013.

[5] A. K. Barnwal, L. K. Yadav, and M. K. Verma, "A Multi-Objective Approach for Voltage Stability Enhancement and Loss Reduction Under PQV and P Buses Through Reconfiguration and Distributed Generation Allocation," *IEEE Access,* vol. 10, pp. 16609-16623, 2022.

[6] M. A. Kashem, V. Ganapathy, G. Jasmon, and M. Buhari, "A novel method for loss minimization in distribution networks," in *DRPT2000. International conference on electric utility deregulation and restructuring and power technologies. Proceedings (Cat. No. 00EX382)*, 2000, pp. 251-256: IEEE.

[7] N. Rugthaicharoencheep and S. Sirisumrannukul, "Feeder reconfiguration with dispatchable distributed generators in distribution system by Tabu Search. Universities Power Engineering Conference (UPEC)," in *Proceedings of the 11th International*, 2009, vol. 2118, pp. 1-5.

[8] A. Merlin and H. Back, "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system," in *Proc. 5th Power System Computation Conf., Cambridge, UK*, 1975, pp. 1-18.

[9] M. Guimaraes, C. Castro, and R. Romero, "Distribution systems operation optimisation through reconfiguration and capacitor allocation by a dedicated genetic algorithm," *IET generation, transmission & distribution,* vol. 4, no. 11, pp. 1213-1222, 2010.

[10] B. Venkatesh, S. Chandramohan, N. Kayalvizhi, and R. K. Devi, "Optimal reconfiguration of radial distribuion system using artificial intelligence methods," in *2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH)*, 2009, pp. 660-665: IEEE.

[11] C.-T. Su, C.-F. Chang, and J.-P. Chiou, "Distribution network reconfiguration for loss reduction by ant colony search algorithm," *Electric Power Systems Research,* vol. 75, no. 2-3, pp. 190-199, 2005.

[12] N. Gupta, A. Swarnkar, K. Niazi, and R. Bansal, "Multi-objective reconfiguration of distribution systems using adaptive genetic algorithm in fuzzy framework," *IET generation, transmission & distribution,* vol. 4, no. 12, pp. 1288-1298, 2010.

[13] M. H. Moradi and M. Abedini, "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,* vol. 34, no. 1, pp. 66-74, 2012.

[14] A. J. G. Mena and J. A. M. García, "An efficient approach for the siting and sizing problem of distributed generation," *International journal of electrical power & energy systems,* vol. 69, pp. 167-172, 2015.

[15] S. Jazebi, M. Moghimi Haji, and R. A. Naghizadeh, "Distribution Network Reconfiguration in the Presence of Harmonic Loads: Optimization Techniques and Analysis," *IEEE Transactions on Smart Grid,* vol. 5, no. 4, pp. 1929-1937, 2014.

[16] R. Kyomugisha, C. M. Muriithi, and M. Edimu, "Multiobjective optimal power flow for static voltage stability margin improvement," *Heliyon,* vol. 7, no. 12, p. e08631, Dec 2021.

[17] R. Rajaram, K. S. Kumar, and N. Rajasekar, "Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)," *Energy Reports,* vol. 1, pp. 116-122, 2015.

[18] J. Yu, W. Li, and W. Yan, "Letter to the Editor: A New Line Loadability Index for Radial Distribution Systems," *Electric Power Components and Systems,* vol. 36, no. 11, pp. 1245-1252, 2008.

[19] J. Horn, N. Nafpliotis, and D. E. Goldberg, "A niched Pareto genetic algorithm for multiobjective optimization," in *Proceedings of the first IEEE conference on evolutionary computation. IEEE world congress on computational intelligence*, 1994, pp. 82-87: Ieee.

[20] K. Y. Lee, M. M. Farsangi, and H. Nezamabadi-pour, "Hybrid of analytical and heuristic techniques for FACTS devices in transmission systems," in *2007 IEEE Power Engineering Society General Meeting*, 2007, pp. 1-8: IEEE.