# A Comparative Study of Pareto Optimal Approaches for Distribution System Reconfiguration

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***Abstract*-Reconfiguration of a power distribution system consists in changing the functional links among its elements and represents one of the most important actions for the improvement of system performance in operation. In the last few years, some authors have proposed approaches based on Pareto optimality for problem formulation of reconfiguration, with active power losses and reliability indices as objectives. The study highlights the optimization importance of reliability indices which refer to the interruption frequency, especially because, in the context of smart grids, the fastness of the reconfiguration method contributes, by itself, to reduce the duration of interruptions. There is no unique recognition concerning which approach is the most suitable to be used in order to solve the reconfiguration as a Pareto-optimal problem. The most important aspect is the way in which the specific information of the problem field is modelled in the implementation. Also, the dimension of a Pareto-front can vary widely from a test system to another.**

***Index Terms*--power distribution system. reconfiguration. multi-objective optimization. Pareto optimality, genetic algorithm.**

## I. Introduction

Usually, power distribution systems are operated in radial configurations. Reconfiguration of a power distribution system consists in changing the functional links among its elements and represents one of the most important actions for improvement of system performance in operation. There are also other measures which can improve the distribution system performance in operation (e.g., variation of the reactive power flow through the system using bank capacitors or power generators; variation of the voltage by using on-load tap-changers for power transformers, etc) but the reconfiguration still represents an important and difficult one, especially, due to its combinatorial nature.

Ever since 1975, when *Merlin and Back* [1] have demonstrated the effectiveness of reconfiguration for power loss reduction, a lot of researchers have proposed various methods and algorithms to solve this problem. Moreover, nowadays, the reconfiguration is specified in some strategies for smart grids, e.g. those of the International Electrotechnical Commission [2] and the European Commission [3]. In smart grids, equipped with control, protection, automation and power quality monitoring complex systems [4, 5], the reconfiguration can be automated without the disconnection of consumers during the manoeuvres (using the parallelism during the loads are transferred between feeders). In this context, the manoeuvres for parallelism are preceded by studies which verify their feasibility [6, 7, 8]. Not least, in the context of smart grids, intra-day system reconfiguration can also be performed [9].

The optimization of power distribution systems through reconfiguration, as a single objective problem with constraints, was the most investigated. Typically, *active power losses* ($\Delta P$) were adopted as the objective function. Also, usually, bounds for currents flowing through lines, bounds for voltages in each node and radial configuration were imposed as constraints [10-19].

Nevertheless, in 1993, *Tsai* [20] demonstrated the effectiveness of reconfiguration for improving the *reliability* of distribution systems. Furthermore, in [21] a method, based on reconfiguration for the minimization of the *interruptions frequency* in power supply of consumers, was proposed. In that approach, interruptions frequency was adopted as the objective function (main criterion) and active power loss was treated as a constraint.

On the other hand, some authors have introduced, at the same time, active power losses and the interruptions in the objective function, using aggregation functions [22-24]. They converted the multi-objective problem into a single objective one that assumes a sum of the selected criteria. In such approaches, the major difficulty consists in the incompatibility between criteria. In order to create an aggregation function, the criteria must be converted into the same measurement unit. In this case, the solution consists in the conversion of the criteria into costs, often, a disputable and an inaccurate solution for practical applications [23, 24].

Consequently, the existence of a tool which gives the possibility to take into account more criteria in the objective function is of great interest. In order to eliminate the rigidity caused by the aggregation functions, in recent years, some authors have proposed approaches based on *Pareto optimality* for problem formulation of reconfiguration, with active power losses and reliability indices as objectives [26-31]. Pareto optimality is based on a non-dominated solution as central concept. A non-dominated solution must satisfy two conditions: (i) there is no other solution that is superior at least in one objective function; (ii) it is equal or superior with respect to other objective function values. In such approaches, typically, the result consists of a set of acceptable optimal

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solutions named Pareto optimal. The set of Pareto solutions forms the Pareto front associated with the problem. The Pareto front allows an informed decision to be made by visualizing a wide range of options; it contains the solutions that are optimal from an overall standpoint.

In this paper, the authors present a comparative study of Pareto optimal approaches for distribution system reconfiguration. Section II highlights the most important attributes of a Pareto optimal approach (problem description) and identifies the most relevant reliability indices. The most promising ways which must be followed for a proper solving of this problem are presented in Section III. Section IV presents some illustrative numerical test cases. Finally, the comparative study is concluded in Section IV.

## II. Pareto Optimality Problem Formulation

The reconfiguration problem, as an optimization one, is arduous from two points of view. First, the formulation of the problem represents a critical issue, because there is more than one objective. Second, the searching for the optimal solution represents another critical issue because of its combinatorial nature (Fig. 1).

Generally speaking, for a power distribution system with a meshed structure (as illustrated in Fig. 1), a reconfiguration method/algorithm must obtain the optimal radial operational configuration. A proper meaning for the optimization problem must be established in advance in order to develop a searching algorithm for the optimal configuration. In other words, the first issue consists in the problem formulation. Basically, there are three possibilities to formulate the *objective function*:

- choosing the main criterion: *minimizes the active power losses* ($\Delta P$) [10-19]:

$$min\ [\Delta P]. \quad (1)$$

- building an aggregation function: *a sum of active losses cost and interruptions cost* [23, 24]:

$$min\ [Cost_{ActiveLosses} + Cost_{Interruptions}]. \quad (2)$$

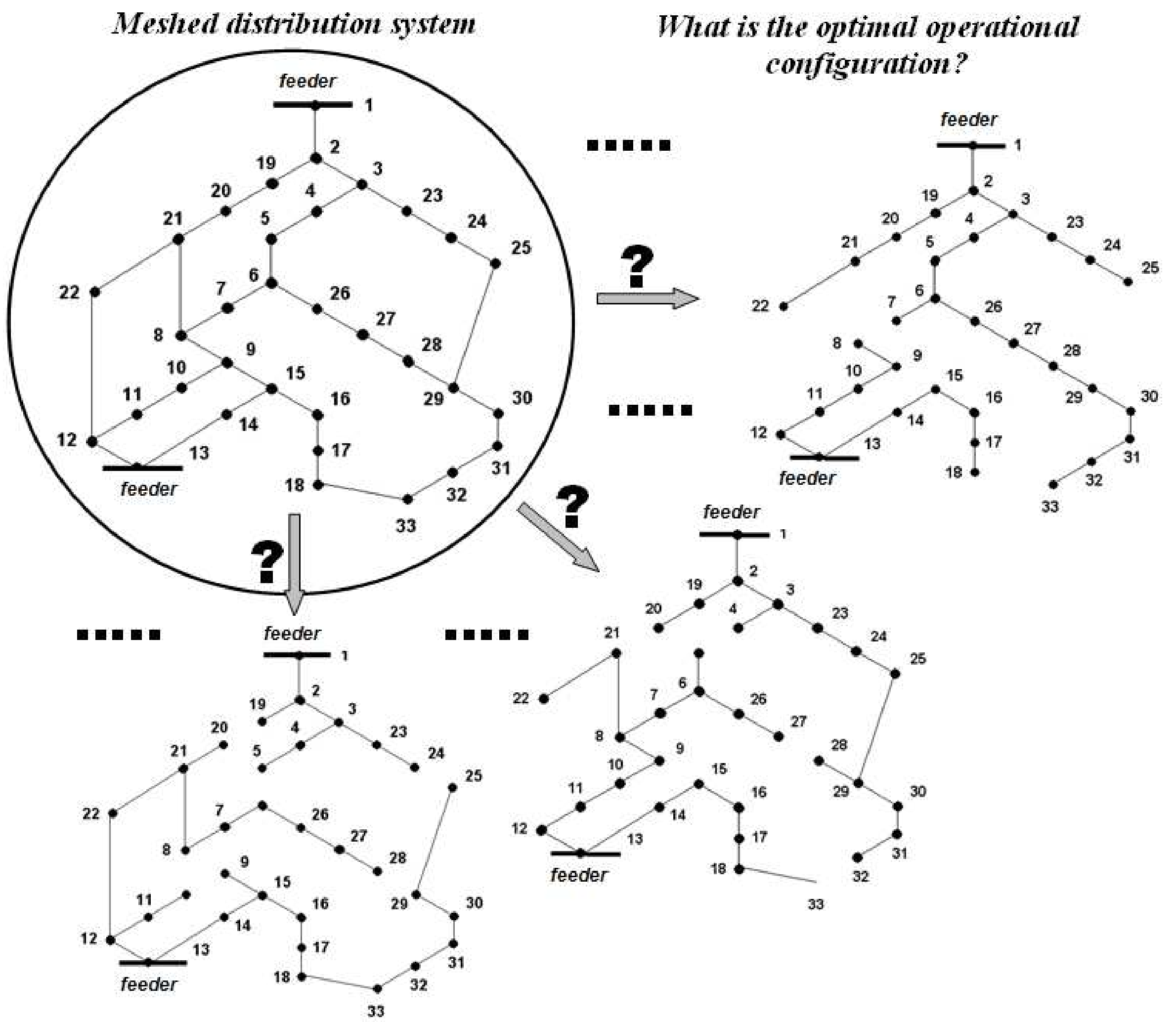


Fig. 1. An illustrative example regarding the combinatorial nature of the reconfiguration problem [11].

- using Pareto optimality [26-30]:

$$min\ [\Delta P,\ ReliabilityIndex]. \quad (3)$$

Usually, as constraints, bounds for voltages in each node, limits for currents flowing through lines, and radial configuration are imposed [29].

$$\begin{array}{l} V_i^{\min} \le V_i \le V_i^{\max};\forall i \in X \\ I_{ij} \le I_{ij}^{\max};\forall ij \in E \\ \sum_{ij \in E} \lambda_{ij} = n - p \end{array} \quad . \quad (4)$$

where:

$V_i$ – nodes voltages;
$I_{ij}$ – electric current through a branch $ij$;
$n$ – the number of electric system nodes;
$p$ – the number of connected components;
$X$ – the set of power system nodes;
$E$ – the set of power system lines (branches).

In this case, the solution is not unique and consists of a set of acceptable optimal solutions, named Pareto front (Fig. 2). The essential characteristics of interruptions in the power supply of customers are the frequency and the duration. While duration is predominantly influenced by the distribution system structure (radial, meshed, weak meshed) and the existing automations, frequency is mostly influenced by the operational configuration and can be minimized by the suitable choice of configuration. Otherwise, the reliability of a distribution system can be considered from two different points of view [29]:

- that of a particular customer;
- that of the entire supply system.

It is obvious that reliability indices which refer to the *entire supply system* must be taken into consideration for the objective function. The existing approaches, based on Pareto optimality for problem formulation of reconfiguration, besides active power losses, different reliability indices have proposed as objectives. In what follows, the reliability indices used in Pareto based approaches for optimal reconfiguration, are presented:

- system average interruption frequency index (*SAIFI* [25]) [26, 27, 28, 29, 30];
- system average interruption unavailability index [27];
- system average duration interruption index (*SAIDI* [25]) [27];
- non-supplied energy (*ENS* [25]) [27, 31].

*SAIFI* represents the most used reliability index for distribution system reconfiguration problems and it has to be minimized. The most important arguments are:

- The problem of reconfiguration is relevant for meshed systems where, in general, the restoring of supply is performed after the fault isolation through manoeuvres. Consequently, in most cases, minimization of *SAIFI* implies also the minimization of *SAIDI* and *ENS* because the time required to restore service is similar to the time necessary to isolate a fault [20]. In practice, the differences between these two time intervals is negligible;
- The duration of an interruption cannot be estimated accurately. Only the fact that the restoration time exceeds three minutes can be accurately estimated [30], because the automatic manoeuvres performed by the auto-reclosers are not taken into account. However, just sustained interruptions are taken into account in order to estimate *SAIFI*. Moreover, in [27] constant and equal values for restoration times were used for each branch (*repair time = 1 h, manoeuvre time = 0.5 hours*).
- Also, in [27], four pairs of Pareto-fronts are obtained ($\Delta P$, a reliability index) and it is difficult for the decision maker to work with this amount of data. It is important to establish a minimum number of indices (in practice).

Consequently, the minimization of *SAIFI* is the most important aim in order to prevent the occurrence of interruptions. In other words, through reconfiguration, it is important to improve those reliability indices which refer to the interruption frequency [30]. I.e., a configuration with a minimal *SAIFI* ensures minimization of interruption occurrences at the minimum possible. Moreover, in the context of smart grids, where the manoeuvres are fully automated, the fastness of the reconfiguration method contributes, by itself, to reduce the duration of interruptions.

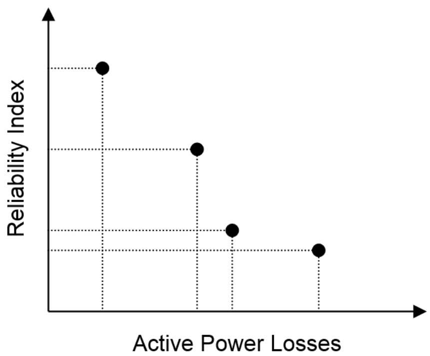


Fig. 2. A Pareto front for bi-objective reconfiguration problem with two objectives: active power losses and a reliability index.

## III. PROBLEM SOLVING

Regardless of the problem formulation, the searching for the optimal solution represents another critical issue because of its combinatorial nature. To generate the entire universe of potential solutions in order to choose the best one, requires a prohibitive execution time. Moreover, in such approaches, linear programming cannot be used because there is more than one objective function. Consequently, in order to minimize the computation burden, the following methods have been proposed:

- heuristic rules [28, 29];
- microgenetic [27];

- Non-dominated Sorting Genetic Algorithm (NSGA) [26];
- Non-dominated Sorting Genetic Algorithm – II (NSGA-II) [30, 31];

Generally speaking, for Pareto based multi-objective problems, there are several strong genetic procedures proposed in literature:

- Multi Objective Genetic Algorithm – MOGA [32];
- Niched Pareto Genetic Algorithm – NPGA [33];
- Non-dominated Sorting Genetic Algorithm - NSGA/NSGA-II [34];
- Strength Pareto Evolutionary Algorithm - SPEA/SPEA-II [35].

In Fig. 3, a generalized logical diagram of a genetic algorithm dedicated to the reconfiguration of a power distribution system is given. Genetic encoding represents the key action in order to approach any optimization problem through a genetic algorithm. Different encoding methods are proposed in the literature for such problems: status of switches [14], [16], Prufer number [15] or set of fundamental loops [27]. The representation via *branches lists* [36] and the binary codification ensures the minimal information necessary to represent the entire topology of a distribution system [26, 30].

The implementation of the selection operator represents another key action. The selection must ensure a balance between reproduction for the best chromosomes and the weak chromosomes in order to increase the diversity of a population. Using the ecological niche method [37] this aim is achieved [30].

Different procedures for the crossover operator have been proposed in accordance with the chromosome encoding (e.g., using Kruskal's algorithm [16]). By choosing the number of cut points equal to the *cyclomatic number – 1* [30], other suitable chromosomes are frequently obtained, rising the variety of the population. Such implementation does not ensure only valid chromosomes because, in some cases, non-radial chromosomes are obtained. However, in combination with the mutation operator, this disadvantage can be transformed in a significant advantage due to the fact that the diversity of the population is increased and new zones from the research universe are covered. Also, the inversion operator, randomly applied to the chromosomes, can expand the search space sufficiently in order to find good quality results [30].

In graphs theory, for a distribution system with one feeder ($p = 1$, one connected component), the result must be an optimal tree. Also, for a system with more than one feeder ($p > 1$) the result must be an optimal forest; the number of trees, connected components, is equal to that of feeders. Even if a system contains more than one feeder, by a proper modelling, the problem can be condensed to an optimal tree replacing real feeders by a single compact fictitious source [19]. In this case, a radial configuration will be validated as a tree, if the graph satisfies two conditions: it contains $n-1$ branches and it is connected. The condition of connectivity can be proven using the *union-find* procedure.

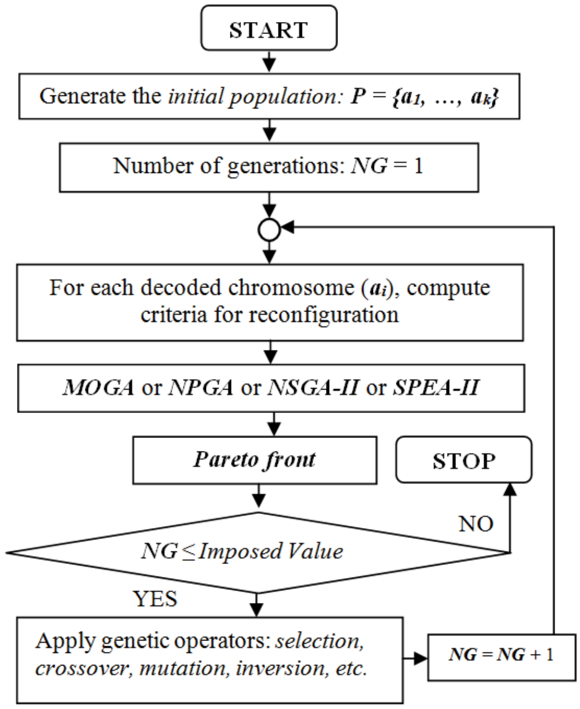


Fig. 3. A generalized logical diagram of a genetic algorithm dedicated to the reconfiguration of a power distribution system.

Consequently, there is no unique recognition concerning which approach is the most suitable to be used in order to solve the reconfiguration as a Pareto-optimal problem. The most important thing is how the specific information of the problem field is modelled in the implementation.

## IV. Numerical Test Cases

The final index which can measure the value of a reconfiguration algorithm consists in the quality of the obtained result and this index can be established only through experimental results. An extensive numerical comparison, among the existent Pareto based reconfiguration methods, cannot be made because they was tested on different test systems.

Nevertheless, some remarks can be made. A well-known test system (Fig. 4) [11] contains one source and five loops and was used in numerous reconfiguration simulations. If this system is reconfigured considering only power losses as objective function, for the obtained configuration, $\Delta P = 139.55$ *kW* [19]. The same system, if it is reconfigured with the microgenetic algorithm, the result consists in a Pareto front with *14* optimal solutions (Table I) [27].

In contrast, another test system is analysed (Fig. 5) [38]. In this system, there are eight distributed generators (DG units) installed on nodes: *7*, *12*, *19*, *28*, *34*, *71*, *75* and *79*. When the system is reconfigured considering, just power losses as objective function, for the obtained configuration, $\Delta P = 380.656$ *kW* [30]. If the same system is reconfigured with a NSGA-II based algorithm, the Pareto front consists of *4* optimal solutions (Table II) [30]. Consequently, the dimension of a Pareto-front can vary widely from a test system to another.

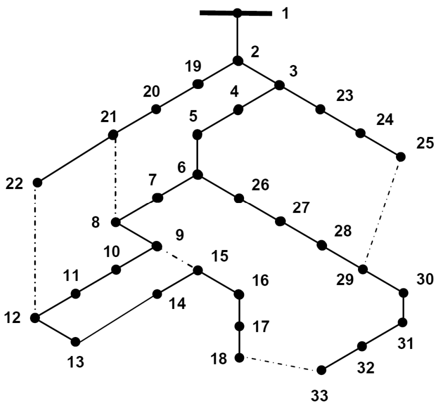


Fig. 4. Baran's test distribution system [11].

TABLE I
A PARETO FRONT FOR BARAN'S TEST SYSTEM [27]

| Active power losses: ΔP [kW] | System average interruption frequency index: SAIFI |
|---|---|
| 139.6 | 3.136 |
| 140.2 | 3.123 |
| 141.3 | 3.110 |
| 147.6 | 3.078 |
| 147.9 | 3.065 |
| 148.4 | 3.052 |
| 152.3 | 3.045 |
| 152.7 | 3.032 |
| 160.0 | 3.026 |
| 163.7 | 2.997 |
| 167.6 | 2.970 |
| 172.7 | 2.955 |
| 175.9 | 2.952 |
| 187.4 | 2.947 |

TABLE II
A PARETO FRONT FOR WU'S TEST SYSTEM [30]

| Active power losses: ΔP [kW] | System average interruption frequency index: SAIFI |
|---|---|
| 380.656 | 1.143 |
| 396.143 | 0.751 |
| 409.526 | 0.648 |
| 425.131 | 0.472 |

## V. CONCLUSION

In this paper, a comparative study of Pareto optimal approaches for distribution system reconfiguration was presented. Through reconfiguration, it is important to improve those reliability indices which refer to the interruption frequency, and a configuration with a minimal *SAIFI* ensures maintaining interruptions occurrence at the

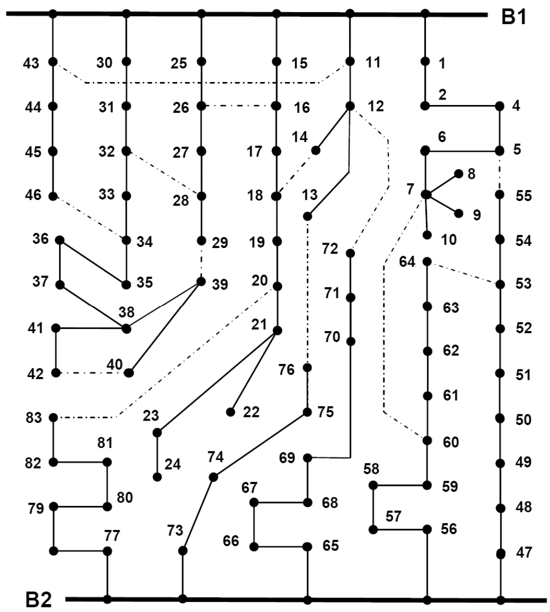


Fig. 5. Wu's test distribution system [38].

minimum possible. Moreover, in the context of smart grids, where the manoeuvres are fully automated, the fastness of the reconfiguration method contributes, by itself, to reduce the duration of interruptions.

There is no unique recognition concerning which approach is the most suitable to be used in order to solve the reconfiguration as a Pareto-optimal problem. The most important thing consists in the way in which the specific information of the problem field is modelled in the implementation. Also, the dimension of a Pareto-front can vary widely from a test system to another.

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## REFERENCES

[1] A. Merlin and H. Back, "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system," in *Proc. 1975 Fifth Power Systems Computer Conference (PSCC)*, Cambridge, UK, 1-5 September 1975, pp. 1-6.

[2] International Electrotechnical Commission, "Smart Grid Standardization Roadmap," Prepared by SMB Smart Grid Strategic Group (SG3). Edition 1.0, June 2010: http://www.iec.ch/smartgrid/downloads/sg3_roadmap.pdf.

[3] European Commission, "Strategic Deployment Document for Europe's Electricity Networks of the Future," European Technology Platform SmartGrids, April 2010: http://www.smartgrids.eu/documents/SmartGrids_SDD_FINAL_APRIL2010.pdf.

[4] P. Zhang, F. Li, N. Bhatt, "Next-Generation Monitoring, Analysis, and Control for the Future Smart Control Center," *IEEE Transactions on Smart Grid*, Vol. 1, Issue 2, pp. 186-192, July 2010.

[5] B. Tomoiagă, M. Chindriş, "A challenge in the operation of distribution smart grids: the global optimization," *Acta Electrotehnica*, Vol. 52, pp. 471-475, 2011.

[6] L.L. Pfitscher, D.P. Bernardon, L.N. Canha, V.F. Montagner, L. Comasseto, and M.S. Ramos, "Studies on parallelism of feeders for automatic reconfiguration of distribution networks," in *Proc. 2012 47th International Universities Power Engineering Conference (UPEC)*, September, 2012 pp. 1-5.

[7] L.L. Pfitscher, D.P. Bernardon, L.N. Canha, V.F. Montagner, A.R. Abaide, and J.J.A. Saldanha, "A methodology for real time analysis of parallelism of distribution networks," *Electric Power Systems Research*, Vol. 105, pp. 1-8, 2013.
[8] I. Bilibin and F. Capitanescu, "Contributions to thermal constraints management in radial active distribution systems," *Electric Power Systems Research*, Vol. 111, pp. 169-176, 2014.
[9] I. Coroamă, G. Chicco, M. Gavrilaş, and A. Russo, "Distribution system optimisation with intra-day network reconfiguration and demand reduction procurement," *Electric Power Systems Research*, Vol. 98, pp. 29-38, 2013.
[10] S. Civanlar, J.J. Grainger, H. Yin, and S.S.H. Lee, "Distribution feeder reconfiguration for loss reduction," *IEEE Transactions on Power Delivery*, Vol. 3, pp. 1217–1223, 1988.
[11] M.E. Baran and F.F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Transactions on Power Delivery*, Vol. 4, pp. 1401–1407, 1989.
[12] H.D. Chiang, and R. Jean-Jumeau, "Optimal network reconfigurations in distribution systems: Part 2: Solution algorithms and numerical results," *IEEE Transactions on Power Delivery*, Vol. 5, pp. 1568–1574, 1990.
[13] W.M. Lin and H.C. Chin, "A new approach for distribution feeder reconfiguration for loss reduction and service restoration," *IEEE Transactions on Power Delivery*, Vol. 13, pp. 870-875, 1998.
[14] J.Z. Zhu, "Optimal reconfiguration of electrical distribution network using the refined genetic algorithm," *Electric Power Systems Research*, Vol. 62, pp. 37-42, 2002.
[15] B. Enacheanu, B. Raison, R. Caire, O. Devaux, W. Bienia, and N. Hadjsaid, "Radial network reconfiguration using genetic algorithm based on the matroid theory," *IEEE Transactions on Power Systems*, Vol. 23, pp. 186–195, 2008.
[16] M.A.N. Guimaraes, C.A. Castro, and R. Romero, "Distribution systems operation optimisation through reconfiguration and capacitor allocation by a dedicated genetic algorithm," *IET Generation, Transmission & Distribution*, Vol. 4, pp. 1213-1222, 2010.
[17] C. Ababei and R. Kavasseri, "Efficient network reconfiguration using minimum cost maximum flow-based branch exchanges and random walks-based loss estimations," *IEEE Transactions on Power Systems*, Vol. 26, pp. 30–37, 2011.
[18] A. Samui, S. Singh, T. Ghose, and S.R. Samantaray, "A direct approach to optimal feeder routing for radial distribution system," *IEEE Transactions on Power Delivery*, Vol. 27, pp. 253-260, 2012.
[19] B. Tomoiagă, M. Chindriş, A. Sumper, R. Villafafila-Robles, and A. Sudria-Andreu, "Distribution system reconfiguration using genetic algorithm based on connected graphs," *Electric Power Systems Research*, Vol. 104, pp. 216-225, 2013.
[20] L.H. Tsai, "Network reconfiguration to enhance reliability of electric distribution systems," *Electric Power Systems Research*, Vol. 27, pp. 135-140, 1993.
[21] C. Bud, M. Chindriş, B. Tomoiagă, "A method based on reconfiguration for the minimization of the interruptions frequency in power supply," in *Proc. 2006 Sixth World Energy System Conference*, Torino, Italy, 10-12 July 2006, pp. 641-645.
[22] I. Roytelman, V. Melnik, S.S.H. Lee, and R.L. Lugtu, "Multi-objective feeder reconfiguration by distribution management system," *IEEE Transactions on Power Systems*, Vol. 11, pp. 661–667, 1996.
[23] I. Tristiu, M. Eremia, C. Bulac, and L. Toma, "Multi-criteria reconfiguration of distribution electrical networks for minimization of power losses and damage cost due to power supply interruption," in *Proc. 2007 IEEE Lausanne Power Tech*, Lausanne, 1-5 July 2007, pp. 385 - 390.
[24] B. Amanulla, S. Chakrabarti, and S.N. Singh, "Reconfiguration of power distribution systems considering reliability and power loss," *IEEE Transactions on Power Delivery*, Vol. 27, Issue 2, pp. 918-926, 2012.
[25] IEEE Guide for Electric Power Distribution Reliability Indices. *IEEE Standard 1366-2003*, December 2003.
[26] B. Tomoiagă and M. Chindriş, "Reconfiguration of distribution networks with dispersed generation by Pareto optimality and evolution strategies," in *Proc. 2008 7th Balkan Power Conference (BPC)*, Šibenik, Croatia, 10-12 September 2008, pp. 1-6.
[27] J.E. Mendoza, M.E. Lopez, C.A. Coello, and E.A. Lopez, "Microgenetic multiobjective reconfiguration algorithm considering power losses and reliability indices for medium voltage distribution network," *IET Generation, Transmission & Distribution*, Vol. 3, Issue 9, pp. 825–840, 2009.
[28] D.P. Bernardon, V.J. Garcia, A.S.Q. Ferreira, and L.N. Canha, "Multicriteria distribution network reconfiguration considering subtransmission analysis," *IEEE Transactions on Power Delivery*, Vol. 25, Issue 4, pp. 2684-2691, 2010.
[29] A. Zidan and E.F. El-Saadany, "Multi-objective network reconfiguration in balanced distribution systems with variable demand," in *Proc. 2011 2nd International Conference on Electric Power and Energy Conversion Systems (EPECS)*, Sharjah, 15-17 November 2011, pp. 1-6.
[30] B. Tomoiagă, M. Chindriş, A. Sumper, A. Sudria-Andreu, and R. Villafafila-Robles, "Pareto optimal recon-figuration of power distribution systems using a genetic algorithm based on NSGA-II," *Energies*, Vol. 6, Issue 3, pp. 1439-1455, March 2013.
[31] A. Mazza, G. Chicco, and A. Russo, "Optimal multi-objective distribution system reconfiguration with multi criteria decision making-based solution ranking and enhanced genetic operators," *International Journal of Electrical Power & Energy Systems*, Vol. 54, pp. 255-267, 2014.
[32] C. Fonseca and P.J. Fleming, "Genetic algorithms for multiobjective optimization: formulation, discussion, generalization," in *Proc. 1993 5th International Conference on Genetic Algorithms*, San Mateo, CA, USA, 17–21 July 1993, pp. 416–423.
[33] J. Horn, N. Nafpliotis, and D.E. Goldberg, "A niched Pareto genetic algorithm for multiobjective optimization," in *Proc. 1994 1st IEEE Conference on Evolutionary Computation, IEEE World Congress on Computational Intelligence*, Piscataway, NJ, USA, 27–29 June 1994; Volume 1, pp. 82–87.
[34] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Trans. Evol. Comput.*, Vol. 6, pp. 182–197, March 2002.
[35] E. Zitzler, L. Thiele, and J. Bader, "On set-based multiobjective optimization," *IEEE Trans. Evol. Comput.*, Vol. 14, pp. 58–79, March 2010.
[36] M. Chindriş, B. Tomoiagă, P. Taylor, and L. Cipcigan, "The identification of critical equipment and optimum configurations for electrical substations," in *Proc. 2006 41st International Universities Power Engineering Conference (UPEC*, Newcastle, UK, 6-8 September, 2006 pp. 277 - 281.
[37] D.E. Goldberg and J. Richardson, "Genetic algorithms with sharing for multimodal function optimization," in *Proc. 1987 The 2nd International Conference on Genetic Algorithms and Their Applications*, Hillsdale, NJ, USA, 28–31 July 1987, pp. 41–49.
[38] Y.K. Wu, C.Y. Lee, L.C. Liu, and S.H. Tsai, "Study of reconfiguration for the distribution system with distributed generators," *IEEE Transactions on Power Delivery*, Vol. 25, pp. 1678–1685, 2010.