International Journal of Recent Engineering Science
ISSN: 2349-7157/ https://doi.org/10.14445/23497157/IJRES-V12I2P108
Volume 12 Issue 2, 69-78, Mar-Apr 2025

Original Article

Recurring Questions Throughout the Research on Electrical Distribution Networks Reconfiguration: Insights from Ph. D. Training

Gustavo Crespo Sánchez[1], Ignacio Pérez Abril[2]

[1]*Engineering School, University of Cienfuegos "Carlos Rafael Rodríguez", Cienfuegos, Cuba.*
[2]*Electroenergetic Studies Center, Electric Engineering School, Central University of Las Villas "Marta Abreu", Santa Clara, Villa Clara, Cuba.*

[1]*Corresponding Author : gcsanchez@ucf.edu.cu*

Received: 14 February 2025 Revised: 19 March 2025 Accepted: 03 April 2025 Published: 16 April 2025

Abstract *- Network reconfiguration is one of the best current solutions to achieve balanced systems that improve voltage regulation with load distribution between lines, reduce losses and increase their efficiency, availability and reliability, reducing the interruptions risk and increasing failure response capacity. However, despite the large number of approaches and methods proposed in the literature since its first publication in 1975, especially in the last twenty years, researchers have not reached a consensus on the best method to solve the problem. Therefore, it remains an active investigation area and is in permanent development. The paper compiles the questions recurrent in the different stages of the Ph.D. training process in electrical engineering of the primary author, with the proposal of Multi-objective distribution systems reconfiguration by using the Non-dominated Sorting Genetic Algorithm II and local improvement. It provides the answers and theoretical foundations given to the questions requested by the different convened tribunal members, which constitute a very valuable tool for future studies on the topic and its upcoming challenges that entail an opportunity for future doctoral students to improve research and strengthen critical and communicative skills, which contribute to better future researchers understanding on technical sciences evaluation and defence processes and which suggest effective response strategies to the questions that will be formulated during the doctoral training process.*

Keywords *- Local improvement, NSGA-2 algorithm, Radiality, Static networks, Test circuits.*

1. Introduction

The doctoral training process in technical sciences (Ph. D) in electrical engineering that successfully concluded on November 21, 2024, at the Electrical Engineering School of the Central University "Marta Abreu" of Las Villas had as research topic: multi-objective distribution systems reconfiguration by using the non-dominated classification algorithm II and local improvement. In this research, the non-dominated classification algorithm II (NSGA-II) was adapted and implemented in MATLAB to solve the network reconfiguration problem. Some developments and modifications were made, constituting the main research scientific novelties and contributions.

Distribution Network Reconfiguration (DNR) was first proposed by A. Merlin and H Back in 1975 [1]. Since then, authors have come a long way from early single-objective, computationally slow and mostly heuristic methods to today's modern multi-objective, stochastic methods equipped with ultra-fast simulators and the latest visualization tools [2]. DNR is one of the best current solutions to achieve balanced systems that improve system voltage regulation with load distribution among lines and reduce losses [3]. It allows for optimised energy distribution and system efficiency improvement by reducing maintenance and repair costs, making it more sustainable, and allowing more energy with better quality to reach end users. In addition, it also reduces the interruption risk, enabling greater response capacity in failure events and improving electric power supply availability and reliability [4].

However, despite the numerous methods and approaches used, especially in the last two decades, there is no consensus on the most appropriate method for optimally solving the problem [5]. What is most important is the specific problem knowledge and how it is modelled and implemented.

Given the above considerations and recognizing that the key challenge in DNR lies in effectively leveraging problem-specific knowledge through modeling and implementation, the following scientific question was proposed to be resolved: How can genetic crossover and mutation operators - based on branch exchange techniques and efficient chromosome encoding, as well as to add local improvement step to explore solution neighbourhoods - within a multi-objective genetic algorithm? The goal was to create a novel method, distinct from existing approaches in the literature, that effectively solves the DNR optimization problem while delivering results that match or surpass the best currently available.

The main algorithm developments and modifications that constituted the main scientific novelties of the work consisted of:

- Prim's algorithm modification to ensure that the solutions population initial generation with only feasible chromosomes increased the randomness, diversity and genetic richness.
- Two genetic crossover and mutation operators were developed based on the branch exchange technique and on an efficient chromosome coding that always guarantees the obtaining of a feasible offspring.
- A local improvement step was added in a multi-objective optimization environment that is applied once a descendant solution has been obtained, which consists of performing a search in the obtained solution neighbourhood to improve it (if possible) in the objective function considered sense and that, instead of preselecting the objective function for improvement, it is selected randomly. The added local improvement step accelerates convergence and reduces the solution dispersion in consecutive runs, increasing the results' stability.

Moreover, the proposed method delivers another significant breakthrough: it not only matches the optimal solutions reported in the literature for single-objective loss reduction—all of which lie on the identified Pareto frontier—but also finds additional high-quality solutions previously undocumented when tackling multi-objective optimization with conflicting objectives. The method outperforms most existing approaches, as evidenced by its solutions' superior quality, diversity, and completeness. Rather than yielding a single optimal point for a lone objective, it generates a well-distributed Pareto frontier, offering a broader and more robust optimal trade-off set.

The new application developed for multi-objective distribution networks reconfiguration based on the non-dominated sorting algorithm II (NSGA-II), which includes the developed genetic operators and the added local improvement step, allowed to obtain results that are comparable or improve those obtained by the authors referenced in the literature on the subject. The obtained method is flexible, and it can include additional objective functions or modify those considered in the written defended research report and incorporate other additional constraints to those considered in the problem formulation by including penalty functions $\mu r_i(x)$. For each constraint i that is desired to be taken into account, in which μ is a large number (after several tests, the constant μ can be evaluated as 10^6 for the formulated optimization problem) so that all feasible solutions $(r_i(x) = 0)$ have a better classification than non-feasible solutions $(r_i(x) > 0)$.

$$f_i(x) = f_i(x) + \mu \sum r_i(x) \text{ subject to } r = r_i(x) > 0 \quad (1)$$

This flexibility and adaptability of the developed method constitute a strength that can enhance its usefulness in a broad context range, practical situations, and problems to be solved.

Among many radial distribution networks present in the literature, four circuits (used by all authors) were chosen to test the newly developed method: Circuits of 33, 84, 136 and 415 bars. It was also tested with the system formed by the circuits Y-410, Y-283 and Y-285 of the city of Camagüey, Cuba [6]. For each example, two cases were solved, with constant demand minimizing power losses and variable demand minimizing the daily cost of losses as the first objective function. The second objective function for both cases was to minimize the maximum voltage drop. In both cases, the positive effect of the added local improvement step was verified by running the algorithm with and without local improvement. The runs were performed on an Intel® Core™ i5-4440 CPU@ 2x3. 10 GHz with 4 GB-RAM computer.

Throughout the research development in the different doctoral training process stages: research seminars, scientific sessions, pre-defence and thesis defence, questions were formulated by the different tribunal members, which ultimately became recurring questions that gained a significant connotation in the culmination of the research carried out and in the successful training as a doctor of science.

2. Materials and Methods

The following methods were used to compile the recurrent questions in the different doctoral training process stages: inductive-deductive, analytical-synthetic and historical-logical.

The inductive-deductive method started from the facts of individual study, answers, and concepts accepted as valid to reach general conclusions through reasoning and use them as foundations for particular responses. The analytical-synthetic method allowed the network reconfiguration study to start from the decomposition process into different postulates and concepts, to study them individually (analysis), and to integrate them to complete the answers holistically and comprehensively (synthesis). For its part, the use of the historical-logical method was not limited only to the simple distribution network reconfiguration description and its results but also to discover the objective logic of the historical process development itself and to the study of its development, making reference to the process events true reasoning, relating them to objective reality and investigating the functioning and development general laws of the reconfiguration process as well as studying its essence.

The use of the above methods allowed grouping the questions into significant concepts and postulates within the network reconfiguration process: Radial configuration, voltage deviation as a constraint and objective function, quality, effectiveness and advantages of the method used, the addition of a local improvement step in a multi-objective optimization environment, electrical protections during network reconfiguration and presence of renewable energy sources in the networks.

3. Results and Discussion

The results and discussion are presented through the answers given by the PhD student in training to the recurrent questions throughout the training process, which have been grouped by network reconfiguration topics and in which the DNR process can have effects and consequences for the electrical power system.

3.1. Radiality Constraint

3.1.1. Why is the DNR Problem Formulation Subject to Radiality Constraint Maintaining?

The requirement to subject problem formulation to the constraint of maintaining radiality is because the primary distribution networks to which the method proposed in the developed research is applied operate in this configuration by design (by the technical rules and standards).

The distribution companies prefer to remain radial to maintain the operation simplicity and not have to complicate the protection scheme considerably [7]. The radiality also ensures that the regulations governing the electrical system's safe and efficient operation, essential for electrical supply reliability, are met.

Radial networks are more straightforward to design, analyse, operate, and protect, and they are used in primary distribution in most countries worldwide. This simplicity allows problems and faults to be identified and isolated more efficiently and to achieve faster service restoration.

By having only one current path, the protection devices coordination (such as in tie and sectionalize switches) is simpler (less complex to control), reducing the error risk during operation, an aspect especially important in emergencies requiring a rapid response. Less equipment and materials than other more complex configurations translates into lower installation and maintenance costs.

In addition, these network operations in other configuration types are much more complicated and are practically not used in primary distribution systems worldwide. They are not used in Cuba.

3.1.2. Why does Radiality Constraint in DNR Usually Introduce Additional Complexities in Large Networks?

First of all, the radiality constraint in DNR complicates the determination of the feasible solution regardless of the network size since, when performing crossover, mutation operations, or simply creating a random configuration, if this constraint is not taken into account, it is very easy to obtain a non-radial configuration. On the other hand, for large networks, additional complexities are introduced due to the exponential possible combinations or configurations growth with the switches number rise, generating a much more complex search space with considerably high reconfiguration possibilities, which means that problem complexity surges dramatically with each new switch, making it much more difficult to identify optimal radial configurations. The network reconfiguration possibilities number equals 2n, where n is the switch number. For example, for a 33-bar network, the branch number to keep open to achieve the radial configuration is 5, whereas for a 415-bar network, it is 59.

Radiality is also subject to several operational constraints, which turn the optimization problem into a combinatorial one, where finding the optimal solution may require significant computational time, especially when all possible combinations of switches are evaluated. Consequently, to ensure the algorithm correct functioning algorithm used in the research (NSGA-II), a modified Prim algorithm [8] was used so that the initial population, in addition to being more random, diverse and with greater genetic richness, contained only feasible chromosomes and so that the new crossover and mutation operators developed started from feasible parents always to generate feasible offspring. In the case of using the usual operators used by traditional genetic algorithms, any operation can close a loop and, therefore, make the variant infeasible.

Since the optimal reconfiguration is solved by evaluating all possible combinations to find the feasible or radial ones that optimize the objective functions considered by achieving that the developed application generates only radial configurations, the NSGA-II algorithm used can sufficiently approach the optimal solutions by examining only a fraction of the possible combinations, requiring thus less computational effort and shorter computing times.

3.1.3. If the proposed method -among its scientific novelty- always guarantees feasible individuals (solutions) obtaining (radial networks), which constitutes the primary distribution network main operational constraint, by using Prim's algorithm and introducing two new genetic crossover and mutation operators developed, what sense does it make then, to introduce into the model the network radiality constraint?

Evidently, using Prim's algorithm [8] so that the initial population of solutions contains only feasible chromosomes (radial networks) and introducing two new crossover and mutation operators developed always to generate feasible offspring makes radiality checks unnecessary. i.e., the problem is subject to radiality constraint when developing the algorithm to prevent a non-radial solution from being generated in any case and thus avoid the tedious checking of said condition in the solutions.

Radiality is also an everyday and fundamental essential in technical instructions and standards of electrical distribution networks and primary distribution network optimization problems since these circuits are designed and operated to work under these conditions, guaranteeing that the guidelines managing system secure and successful operation are encountered a vital requisite for a reliable power supply.

3.1.4. Why not use a ring or mesh configuration, which nevertheless offers better service continuity, improved voltage regulation and superior reliability, although at a higher cost?

However, despite the advantages of ring-or-meshed-connected networks, maintaining network radiality is one of the main exigencies and, therefore, a constraint in primary DNR, which is the study object of the carried-up investigation. Besides, supply organizations choose whatever the case so that the network operation is effortless and the protection system is less difficult [7].

Ring or mesh configurations, although they offer redundancy and better service continuity, are more complex to implement for reconfiguration [9] due to the need to use directional protections. Thus, as stated in the question, their initial cost and associated maintenance expenses are significantly higher. On the other hand, these topologies are not only more awkward but are usually - as mentioned above - currently very little used in electrical systems anywhere in the world.

In-ring or mesh network reconfiguration, the search space is much more tangled than in a radial configuration. These configurations often have additional constraints related to current flow and system stability, which must be handled by the algorithm during the optimization process and which can further complicate the search and limit its effectiveness if not properly implemented.

Consequently, the NSGA-II algorithm may have difficulty efficiently exploring this large and complicated search space; the evaluation of each candidate solution can be computationally intensive, with long run times, and there may be a tendency to prematurely converge towards suboptimal solutions, an aspect especially critical in configurations where multiple paths may offer viable solutions. Otherwise, radial configuration, using fewer components and devices than more intricate configurations, is cheaper, system analysis and control is less complex and minimizes the errors operating probability, a critical factor in extreme scenarios where swift and efficient response is essential.

3.2. Minimize the Voltage Deviation as both Constraint and Objective Function

3.2.1. What is the point of considering among the objective functions, minimizing the maximum voltage deviation at the load nodes, if the problem formulation is also subject to the constraint of maintaining the voltage at the nodes within a permissible range?

Although the problem formulation is subject to the voltage-maintaining constraint at the nodes within an allowable range,

$$V_{imin} \leq V_i \leq V_{imax} \tag{2}$$

Among the objective functions, it is considered to minimize the maximum voltage deviation at the load nodes in order to optimize system performance.

$$f_2(x) = max\left|\Delta V_{i,k}(x)\right| \tag{3}$$

This implies that, although the voltages must be within the permissible range, they are sought to be as close as possible to the nominal value. This is crucial to ensure all nodes receive an adequate and stable power supply.

Minimizing the maximum voltage deviation at load nodes helps prevent voltages from approaching permissible limits, reducing any unexpected variations risk (such as load or generation changes) leading to established constraint violations. Maintaining a low voltage deviation is essential to ensure the electrical supply quality and to ensure that the system not only meets the minimum required voltages but operates at optimal levels, avoiding significant fluctuations that can affect the electrical and electronic equipment operation, causing damage or reducing its useful life and directly affecting the end consumer well-being.

Setting an objective to minimize the maximum voltage deviation also allows greater flexibility in the search for the solution, which means that configurations that may not be optimal from the point of view of losses or another objective function but that offer a better voltage profile can be explored. Ultimately, the specialist must interpret the Pareto frontier obtained and determine which solution to choose, which may not be the one with the lowest losses or the best voltage.

3.3. Method used Quality, Effectiveness and Advantages

3.3.1. Is it not possible to aspire to obtain a new, superior method and not be satisfied with obtaining results comparable to the best obtained to date?

Of course, aspiring to a new and better method is possible. The goal was never to develop one equivalent to the current ones but rather a better one, in spite of persistent disagreement among researchers about which is the best to use in-network reconfiguration [5]. Setting the initial objective of obtaining similar results to the best existing methods is a more realistic and effective strategy, allowing the gradual new method to obtain validation and subsequent continuous improvement. Different methods have solved DNR since its first proposal in 1975 [1], including mathematical algorithms, heuristic and metaheuristic techniques and even hybrid ones (two or more algorithms combination) [10] that have come a long way to reach the current methods and that have permitted to adjust operational variables until reaching a significant optimization of objective functions considered.

For the application developed in the research validation, several IEEE test circuits (test and also static) were used, which have been examined by multiple algorithms for loss minimization. Although there is always a potential for improvement, the results previously obtained by different methods and authors are practically optimal and cannot be improved further (some have even been verified by exhaustive enumeration in the literature), so they constitute a reference pattern or "benchmark", that serves to compare the optimal solution found in terms of losses, which are in the Pareto frontier obtained by the NSGA-II used.

If the intention was to compare the results obtained with the previous ones, it was necessary to validate or test the method with the same circuits used by the previous researchers on the subject.

That an obtained method brings this successful comparison off is proof of the proposed algorithm's effectiveness with other algorithms since its solutions contain the optimal responses reported in the literature for the used test circuits, when only the loss reduction is optimized and which are on the determined Pareto frontier.

Additionally, it can determine other solutions - not found by the preceding methods and which do not appear in the literature -when solving a multi-objective problem in which several conflicting objectives are considered simultaneously and can be chosen at convenience without major program modifications.

In fact, the new method obtained is considered better than most existing ones, expressed in the solutions found in quality and variety and in the determination of a set of optimal solutions or Pareto frontier and not a single solution for a single objective. Obtaining this set of optimal solutions is a benefit of multi-objective optimization that makes it superior by offering a solution range to engineers and/or decision-makers, who will choose the one that best fits the interests considered.

On the other hand, the method has shown very good convergence, mainly when the local improvement step is used. The proposed method can continue to be investigated and developed in later stages, considering that network reconfiguration continues to be an active area in research and development.

3.3.2. If there is no consensus among researchers on the subject as to the best method to use in DNR, how is the developed application effectiveness justified regarding to other applications reported in the literature?

The developed application effectiveness regarding others in the literature reported ones is manifested in that found solutions not only contain the optimal responses socialized by other authors in the bibliography when the objective is only to minimize active losses for testing and validation circuits employed, but it is also capable of determining other solutions neither obtained by preceding methods nor published in advance when solving multi-objective problems that simultaneously considers various in conflict objectives.

On the other hand, the application shows very good convergence, especially when using local improvement, which also reduces the solution dispersion in consecutive runs, increasing the stability of the results.

3.3.3. Considering that asymmetries and imbalances significantly affect and constitute critical DNR challenges and system-efficient operation, especially in contexts where networks are inherently asymmetric and/or present single-phase or two-phase with neutral configurations and branches with single-phase lines and loads, does the developed method foresee three-phase power flow use?

As the research's general objective was to get a new DNR multi-objective optimization whose results were on a level with the best in the reported bibliography, the same circuits utilized by previous authors were used for its validation and more precise performance comparison. These are test circuits [11] that enable a standardized and controlled environment with known characteristics and behaviours, designed to represent real-world electrical distribution networks and widely accepted as a reference point. Referred circuits above also correspond to static networks [2] that neither vary over time nor are they analyzed in real-time nor online. They are traditional networks with fixed and predefined topology, unidirectional power flow direction, and relatively constant load and generation conditions that let the study be carried out for sure given conditions.

Asymmetries [12] and imbalances [13] treatment in DNR depend on whether the optimization is considered for static or dynamic networks [3]. The developed method has no problems for static DNR since load and generation conditions are relatively constant. On the other hand, for dynamic networks with shifting load and generation, the algorithm must adapt to these varying conditions. In dynamic DNR, where the load influences the results, it is possible to adjust the network topology to maintain adequate balances and symmetries.

Nevertheless, the algorithm does foresee using a three-phase power flow in its version for optimizing imbalanced systems without causing problems with the optimization method developed since the genetic algorithm and its operators do not vary from one case to another. The method is very flexible and easy to implement DNR for dynamic networks; it is enough to change the power flow to three-phase and modify the function that evaluates the objective functions that depend on the power flow. It should be noted that, in asymmetries and imbalances cases, considering that, sometimes, in some network sections, single-phase or two-phase with neutral configurations and branches with single-phase lines and loads are present, the switches are located in the three-phase sections, so this condition does not affect the genetic algorithm, making the balanced model can be used with some success in DNR studies.

3.3.4. Considering that the developed method uses the non-dominated classification algorithm II for the multi-objective DNR, does this algorithm present any particular limitation as a stochastic search method in ring or mesh electrical distribution configurations?

The non-dominated sorting algorithm II (NSGA-II) is a highly successful genetic algorithm in multi-objective optimization and is used in various problems. In principle, the algorithm works in the most diverse optimization of electrical distribution topologies. Therefore, it has no limitations for electrical distribution structures configured in ring or mesh, provided the problem is formulated appropriately. Its operation is based on a mathematical model (variables, objective functions, and constraints) that depends greatly on the type of problem to be optimized.

The mathematical model used to formulate the radial network reconfiguration problem and its expression in the modification of Prim's algorithm, the new genetic crossover and mutation operators developed, and the added local improvement step has enabled an NSGA-II implementation that behaves very well with respect to other methods as has been demonstrated in the research developed. As with any genetic algorithm, it has to evaluate many solutions so that solution selection and improvement through its optimization mechanism are revealed, which increases the computational burden to other algorithms. However, it is a multi-objective algorithm that allows obtaining a Pareto front with multiple solutions, which makes it superior to single-objective optimization methods. Another genetic algorithm characteristic is that they can converge to different solutions in the same problem runs; this occurs with NSGA-II, although the added local improvement step favours convergence to optimal solutions.

Although ring or mesh configurations provide extra power supply options and better-uninterrupted supply possibilities, their accomplishment is more complicated [9] due to the additional flow control devices' necessity and ensure voltage stability. Therefore, greater infrastructure and technology investments are required. Furthermore, the proposed application to non-radial networks is outside the research scope. However, with an appropriate mathematical problem representation, it can solve problems with these other network types.

3.3.5. There are numerous NSGA-III and NSGA-IV algorithms' references in the literature, which are theoretically superior to the NSGA-II used, as well as highlight their advantages such as accurate Pareto front approximation, large objectives number handling and balance between convergence, diversity, and scalability. Explain then, why NSAG-II algorithm was selected in the research to solve the DNR problem

Indeed, numerous references to NSGA-III and NSGA-IV algorithms are theoretically superior to those of NSGA-II, as shown in the technical literature. The NSGA-III is specifically designed to handle problems with more than three objectives (four or more), introduces improvements in diversity and efficiency preservation, and is more effective in exploring solution space for a high number of objectives [14]. For its part, the NSGA-IV, although it is not widely documented, continues handling multiple objective optimization and refinement trends, which is expected with the incorporation of additional techniques to improve optimization process efficiency and effectiveness further [15].

However, due to its theoretical superiority, an NSGA-IV MATLAB code was unavailable during the research development. Although a downloaded NSGA-III from the Internet was tested, its operation with other examples raised doubts about its results. In contrast, an NSGA-II MATLAB implementation has been available for years. It has been successfully tested at the Central University Marta Abreu of Las Villas (CULV) Electro Energy Studies Centre in multiple works. This implementation was modified and adjusted to solve the proposed problem with the successful results displayed in the investigation report. On the other hand, the consulted bibliography does not recognize any method, regardless of its possible theoretical superiority, as the most suitable for usage in DNR [5]. The NSGA-II has in its favour a long successful history and familiarity in the literature and brings together a series of advantages for the other algorithms reported, which position it as a solid and effective option for the optimal electrical DNR.

3.3.6. Could the proposed NSGA-II algorithm advantages over other algorithms in the literature reported be summarized?

The main proposed NSGA-II algorithm advantages for the other algorithms reported in the literature [16] and that attractively and privileged position it as a consistent candidate are:

1. It maintains dominant solutions across generations, ensuring the preservation of high-quality solutions during the optimization process.

2. It uses a crowding distance metric to maintain population diversity, helping to ensure that the Pareto front is well distributed and has trade-offs representative between objectives.
3. It can effectively handle multiple objectives in the optimization process, making it suitable for complex problems involving multiple criteria optimizations simultaneously.
4. It utilizes an elitist strategy to ensure that the best solutions are carried over to the next generation, which helps algorithm convergence improve and ensures that the Pareto front continuously improves.
5. It has a balance between convergence towards optimal and diverse solutions, which prevents premature convergence and encourages solution space exploration.
6. It is computationally efficient and scalable, meaning that it can handle different sizes and complexities of large-scale problems (with a large number of variables and objectives number) effectively, making it a robust choice for DNR.
7. It is sturdy and effective in solving optimization problems in a wide range, including DNR, making it a popular multi-objective optimization choice in the DNR context.

3.4. A Local Improvement step Addition in a Multi-Objective Optimization Environment

3.4.1. The written report proposes a local improvement step to be included for the first time in a multi-objective optimization environment and that, to carry this off, instead of improving a preselected objective for each variant, one of the considered objective functions is randomly selected to be improved. What consequences can the function-to-be-improved random selection have on the results?

The carried literature review determined that although many authors with single-objective optimization formulations use a local improvement step to increase optimization efficiency, multi-objective reconfiguration problem formulations do not incorporate it.

Diverse previous contributions employ a local improvement step to increase the optimization effectiveness for a single objective function, generally active power loss minimization [17]. This local improvement step performs an obtained solution neighbourhood search to improve it [18]. The study conducted incorporates, for the first time, a local improvement step addition in a setting involving multi-objective optimization not considered by former authors in the technical bibliography reviewed, in which, alternatively of improving a preselected objective, it is haphazardly selected for each variant or case being analyzed, which of the considered objective functions is going to be enhanced.

The local improvement step performs the previously obtained enhancement solution by crossing or mutating any problem objectives. Once the function to be locally improved has been selected, the upgrading is executed by exchanging the configuration´s branches regarding the previously selected objective function.

Figure 1 shows the 33-bus test circuit [19] to illustrate the branch exchange performed in DNR to the previously selected objective function.

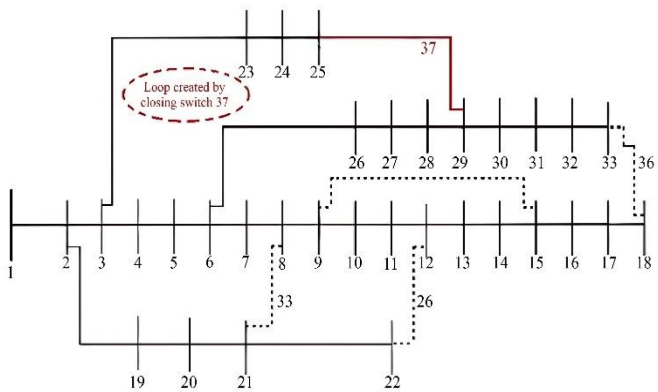

Fig. 1 33-Bus test circuit [19]

When closing the tie switch 37, a loop is created. Therefore, another branch must be opened (exchange), opening a sectionalizing switch to satisfy the radiality constraint and break the created loop. Following the procedure explained below, it must be determined which branch of the created loop must be opened to break the loop and maintain the network radial configuration.

To attain this local solution furtherance, it is necessary to generalize the branch exchange method so that it can heuristically get better any objective functions chosen. For this:

1. The open branches set is determined, and the initial losses and the initial objective function value are calculated.
2. The analysis, from the first to the last open branches set, begins until no elements are left to examine.
3. Each open branch is closed, creating a loop and the said loop branch that opens to break it and that minimizes the analyzed objective function is determined. If such a branch exists, it is added to the open branch"s set end, and the objective function value is updated.

For determining the created loop branch that breaks or opens it:

1. A load flow is executed with the loop closed, and each branch of the loop currents is calculated and ordered in ascending currents value order.
2. Subsequently, the circuit is examined with a load flow by consecutively opening the loop´s branches one by one until finding the one that the most decreases the objective function when opened.
3. If the losses increase when opening a branch, the search ends.

Obviously, the function to be improved random selection can result in a very good quality solution for an objective function being "locally improved" with respect to it, resulting in a lower quality configuration with respect to another objective function. However, the genetic algorithm's own mechanism for ordering and selecting offspring ensures that local improvements ultimately contribute to convergence and reduce the dispersion between the final solutions obtained by the optimization.

The local improvement step incorporation enhances convergence speed and decreases the variability of the solutions across successive runs, thereby improving the outcome's stability.

3.5. Electrical Protections during Network Reconfiguration

3.5.1. How does DNR affect Protections, Reliability and System Stability?

DNR – by changing feeders' topological structure – significantly impacts protections, reliability and electrical system stability. Reconfiguration can alter network current flows and short-circuit levels, requiring adjustments to protection relays, switches and fuses to ensure their correct operation.

The network topology altering can influence the sensitivity, reliability and electrical protections safety, affecting coordination between them and potentially leading to miscoordination and problems during fault isolation.

Proper reconfiguration can increase the electrical system reliability by reducing outage times, improve fault isolation more efficiently by minimizing affected areas affected by these raising reliability indices, as well as increase system stability by balancing loads and reducing losses, contributing to a more stable voltage profile; careful protections adjustment is required to ensure safe and efficient system operation.

As network configuration changes, fault levels and/or power flow direction vary. Therefore, the protection of new configuration devices must have proper coordination as in a pre-configured network) (coordination in all directions and for any condition) [20]. To maintain coordination, relay parameters must be adjusted to suit the new configuration [21]. Therefore, after reconfiguration, protections must be readjusted for the new conditions.

If the network is fully automated, there are no problems because relay parameter values readjustment for any new configuration obtained may be done in real-time (online), but for manually operated switch systems (non-automated), switching actions causing undesired fault levels must be removed from algorithm´s solution space. In contrast, the reconfiguration problem is solved, i.e., until protections are adjusted locally by service personnel.

3.6. Renewable Energy Sources Presence Consideration in Networks

3.6.1. What elements should be added to the proposal to consider the current renewable energy sources distributed generation presence (wind and photovoltaic) in present networks?

The scope of the research proposal does not consider Distributed Generation (DG) presence with renewable sources. Its inclusion would result in a very complicated, requiring a specific and detailed approach, several elements incorporation and additional considerations such as its variability and dynamic behaviour, which depend on multiple factors (solar radiation, wind speed, weather conditions, etc.) [22].

Among the elements that should be incorporated are: Models that capture the intermittent and variable wind and photovoltaic generation nature; typical generation profiles integration for both sources, considering factors such as solar irradiation, temperature, wind speed and geographic location; objective function modification to include network energy losses, considering renewable sources energy penetration; constraints implementation that reflect specific operating conditions associated with DG, such as power injection limits into the network and service requirements quality; DG impact assessment on network voltage profiles, ensuring that they remain within permitted bounds; metrics incorporation that evaluate network stability in rapid fluctuations cases in renewable generation; ensuring that the balance between generation and demand is maintained at all times, even with renewable sources variability; constraints addition such as transformer capacity, lines current´s utmost and switch capacity; algorithm adaptation to handle uncertainties; renewable DG costs inclusion in the total network operating costs and carry a sensitivity analyses out to determine how renewable generation changes affect optimal DNR [23].

They can be regarded as constant loads carrying a negative value, as they produce energy rather than consume it to model their effect in a simplified way.

However, it would limit the analysis by not considering their variability and dynamic behaviour. Wind and photovoltaic generation are intermittent and depend on many factors [24], so their productions can vary significantly over time, which implies additional challenges for DNR.

It should also be highlighted that research focused on primary distribution circuits, which, in Cuba, do not include renewable sources distributed generation.

Distributed generation in Cuba is located in sub-transmission circuits (34.5 kV). Since DNR, considering the intermittent distributed generation presence (wind and photovoltaic), requires a more detailed analysis, it could be an excellent

4. Conclusion

The article gathers recurring questions that emerged throughout various stages of the doctoral training process during the research on Multi-objective Distribution Systems Reconfiguration using the Non-dominated Sorting Genetic Algorithm II and Local Improvement. Providing answers to the inquiries posed by evaluation committee members, along with the necessary theoretical foundation, serves as a highly valuable resource for future research on the topic and its evolving challenges. This is particularly relevant as DNR is a dynamic and rapidly advancing research field, especially in the ongoing energy transition context toward more sustainable and decentralized systems.

The recurring questions highlighted the key aspects deemed crucial by the academic community for technical sciences doctoral research within electrical engineering, particularly on DNR. These questions can serve as a benchmark for assessing future research's strength, originality, and scientific rigour. They also provide guidance for enhancing the clarity of the exposition, strengthening the validation of the results, and improving the practical impact articulation. Furthermore, addressing these questions can contribute to training new researchers and elevate the quality of doctoral theses in the field.

The recurring questions that once represented a challenge now present a valuable opportunity for future PhD students. They offer a chance to refine their research, sharpen their critical thinking, and enhance their communication skills.

Additionally, these questions provide deeper insight into the evaluation and defence processes within the technical sciences, equipping aspiring researchers with practical tools for their scientific training. They also suggest effective strategies for addressing questions that may arise during their academic journey, ultimately preparing them for success in their field. Undoubtedly, future PhD students will benefit from facing challenges in doctoral training and research.

The compilation of these question types during a doctoral training process holds significant value for academic interaction. It fosters meaningful and enriching dialogues between doctoral students and the broader academic community, driving knowledge advancement in the technical sciences. Moreover, it helps build professional relationships and lays the groundwork for future collaborations, creating a dynamic and interconnected academic environment.

Author contribution statement

GCS and IPA conceived and designed research. GCS and IPA conducted experiments. IPA programmed and fine-tuned the algorithm. GCS and IPA analyzed data. GCS wrote the manuscript. All authors read and approved the manuscript.

Acknowledgement

The authors of the paper would especially like to thank professors, both undergraduate and postgraduate, for their influence, discipline and perseverance, for their wisdom, dedication and time, and especially to the memory of Ph. D Leonardo Casas Fernández ✝ and José Antonio González Cueto Cruz ✝, paradigms of professors and electrical engineering professionals' trainers as well as integrity and good men examples. Likewise, a sincerely grateful to the electrical engineering school and the Central University Marta Abreu of Las Villas for the constant support, for giving me the permanent opportunity to grow both personally and professionally and for the commitment to academic excellence and the permanent willingness to encourage improvement, which have been fundamental in the training. Thank you for being a space that not only imparts knowledge but also inspires, motivates and prepares students to face future challenges with solid tools and a transformative vision and for integral development, valuing and promoting students.

References

[1] A. Merlin, and H. Back, "Search for a Minimal-loss Operating Spanning Tree Configuration in an Urban Power Distribution System," *Proceedings of the 5th Power System Computation Conference*, Cambridge, UK, vol. 5, pp. 1-18, 1975. [Google Scholar] [Publisher Link]

[2] Milad Rahimipour Behbahani et al., "Comprehensive Review on Static and Dynamic Distribution Network Reconfiguration Methodologies," *IEEE Access*, vol. 12, pp. 9510-9525, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[3] Hossein Lotfi, Mohammad Ebrahim Hajiabadi, and Hossein Parsadust, "Power Distribution Network Reconfiguration Techniques: A Thorough Review," *Sustainability*, vol. 16, no. 23, pp. 1-33, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[4] Puttamsetty Ushashree, and K. Sathish Kumar, "Power System Reconfiguration in Distribution System for Loss Minimization using Optimization Techniques: A Review," *Wireless Personal Communications*, vol. 128, pp. 1907-1940, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Cheng Yang et al., "Optimal Power Flow in Distribution Network: A Review on Problem Formulation and Optimization Methods," *Energies*, vol. 16, no. 16, pp. 1-42, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Irina Salazar-Fonseca, and Gustavo Torres-Guerrero, "Multi-objective Reconfiguration in Primary Power Distribution Systems," *Ingeniare. Chilean Engineering Journal*, vol. 25, no. 2, pp. 196-204, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[7] Beenish Sultana et al., "Review on Reliability Improvement and Power Loss Reduction in Distribution System Via Network Reconfiguration," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 297-310, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[8] Miguel Campaña, Esteban Inga, and Roberto Hincapié, "Optimal Placement Of Universal Data Aggregation Points For Smart Electric Metering Based On Hybrid Wireless," *CEUR Workshop Proceedings*, Germany, pp. 1-5, 2017. [Google Scholar] [Publisher Link]

[9] Deycy Camila Monar Arguello, "*Reconfiguration Scheme in the Electrical Network in the Distribution System Considering Voltage Restrictions*," Salesian Polytechnic University, Quito Campus Electricity Degree Program, Thesis, pp. 1-36, 2022. [Google Scholar] [Publisher Link]

[10] Meisam Mahdavi et al., "Reconfiguration of Electric Power Distribution Systems: Comprehensive Review and Classification," *IEEE Access*, vol. 9, pp. 118502-118527, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Saeed Peyghami et al., "Standard Test Systems for Modern Power System Analysis: An Overview," *IEEE Industrial Electronics Magazine*, vol. 13, no. 4, pp. 86-105, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Ansar Berdygozhin, and David Campos-Gaona, "Asymmetric Operation of Power Networks, State of the Art, Challenges, and Opportunities," *Energies*, vol. 17, no. 20, pp. 1-19, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[13] H.F. Zhai et al., "Dynamic Reconfiguration of Three-phase Unbalanced Distribution Networks," *International Journal of Electrical Power & Energy Systems*, vol. 99, pp. 1-10, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Jingrui Zhang et al., "NSGA-III Integrating Eliminating Strategy and Dynamic Constraint Relaxation Mechanism to Solve Many-Objective Optimal Power Flow Problem," *Applied Soft Computing*, vol. 146,2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Hongfeng Ma et al., "A Decomposition-Based Evolutionary Algorithm with Neighborhood Region Domination," *Biomimetics*, vol. 10, no. 1, pp. 1-25, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[16] Haiping Ma et al., "A Comprehensive Survey on NSGA-II for Multi-objective Optimization and Applications," *Artificial Intelligence Review*, vol. 56, pp. 15217-15270, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Samson Ademola Adegoke et al., "Network Reconfiguration Using Hybrid Archimedes Optimization Algorithm for Multiobjective Functions," *Journal of Electrical and Computer Engineering*, vol. 2024, pp. 1-15, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[18] Sivkumar Mishra, Debapriya Das, and Subrata Paul, "A Comprehensive Review on Power Distribution Network Reconfiguration," *Energy Systems*, vol. 8, pp. 227-284, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[19] 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, no. 2, pp. 1401-1407, 1989. [CrossRef] [Google Scholar] [Publisher Link]

[20] Bita Khorshid-Ghazani et al., "Reconfiguration of Distribution Networks Considering Coordination of the Protective Devices," *IET Generation, Transmission & Distribution*, vol. 11, no. 1, pp. 82-92, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[21] Khandoker Islam, Dowon Kim, and Ahmed Abu-Siada, "A Review on Adaptive Power System Protection Schemes for Future Smart and Micro Grids, Challenges and Opportunities," *Electric Power Systems Research*, vol. 230, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[22] Alejandro López Aguirre, "*Optimal Location and Sizing of Renewable Dg in Dc Distribution Networks Using a Multi-Objective Stochastic Approach*," Master Thesis, Technological University of Pereira, pp. 1-61, 2023. [Google Scholar] [Publisher Link]

[23] Sergio F. Santos et al., "Dynamic Distribution System Reconfiguration Considering Distributed Renewable Energy Sources and Energy Storage Systems," *IEEE Systems Journal*, vol. 16, no. 3, pp. 3723-3733, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Ana Cristina Rios Melgar, Carlos Alberto Medina, and Guadalupe González, "Flexibility and other Challenges of Massive Integration of Wind and Solar Generation into Power Systems," *Technological Prism*, vol. 13, no. 1, pp. 88-96, 2022. [CrossRef] [Google Scholar] [Publisher Link]