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Original Article

Recent Progress and Challenges of Algorithms for Reducing Power Losses and Optimal Reconfiguration of Voltage Profiles for Distribution Networks

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***Abstract** - This article presents the most recent algorithms for reducing power losses with optimal reconfiguration of voltage profiles with the aim of improving the management of increasingly complex distribution networks which now integrate decentralized production in renewable energies. A classification and comparison of the performances of its algorithms constitute the first part of this article, with an in-depth description each time of the objective functions and mathematical optimization constraints for each scenario, which will make it possible to make recommendations for use, according to the operating scenarios of the distribution networks. In the second part the biclustering algorithm is proposed as a novelty by thus making it possible to group the data of the nodes by groups or clusters for defined levels of constraints and tested it directly to an IEEE-68 distribution network node. A comparison of the results obtained is carried out with recent literature, in addition, a statistical validation is also proposed with a Principal Component Analysis (PCA). The biclustering algorithm offers satisfactory results with a reduction in power losses of 27.79KW. This work is positioned as a contribution to the race for optimal management of distribution networks with the integration of renewable energies and all their logistical and technological complexities*.

***Keywords** - Biclustering algorithm, Distribution network, Reconfiguration, Power losses, Voltage profile.*

1. Introduction

Algorithms for reconfiguring distribution networks touch the combinatorial reality, which is very complex and involves a modification of architectures or topologies (opening or closing of interconnection switches). All its approaches aim, for example, at reducing power losses and better management of decentralized renewable energies connected to the distribution network for a better voltage profile [1]. Several algorithms have been proposed in the literature. However, the difficulty of analyzing their algorithms on the basis of common indicators are justified remains current due to the nature of the algorithms, the computer hardware used, the operating hypotheses, and the size of the distribution network [2]. In this article, the most recent algorithms are clearly identified in the literature with an organization by families of membership: METAHEURISTICS. Therefore, the strong point is the reconfiguration of large systems with satisfactory results but which necessarily, in return, computing power and very high standard computer hardware, including the heuristic family and, finally, the last mathematical programming family used extensively for non-linear systems [3]. It is also important to note that all of its major families of algorithms, depending on the operating hypotheses of the network, ensure:

- Better planning of the operation of the distribution network by integrating operating interruptions linked to natural causes or maintenance needs.
- Reduction of short-circuit currents and contributing to the coordination of operational protection means for low and medium-voltage electrical equipment in networks.
- Satisfying a set of operational equality and inequality constraints.

The challenges in mastering algorithms for reconfiguring electrical networks by a family of membership are therefore clearly summarized in Figure 1 for its organization chart and Figure 2 for their presence in the literature in terms of quantity and quality, based on a combination of keywords in the different search engines: Google Scholar, Taylor & Francis, Web of Science, Science Direct, over a range going from 2012 to 2024. By analyzing each time the solutions proposed and especially the limits respected over time according to the operating scenarios in order to remedy this. The major contributions of this article are:

- Propose an in-depth summary analysis of the most recent articles on algorithms for reconfiguring electrical networks by large families of membership, specifying each time the nature of the objective function of the application case, the relevance of the results obtained and their operational limits.
- A proposal for comparison criteria for reconfiguration algorithms by family of membership which will make it possible to propose classifications with precise recommendations based on operating hypotheses.
- A proposal for a new algorithm with a flowchart based on the Biclustering technique, therefore the particularity and the coherent novelty of grouping by classes or clusters the different nodes having voltage profiles fulfilling certain constraints beforehand.
- A statistical validation by associating a principal component analysis for the application case which is tested on the IEEE-68 node network with a comparison made with the literature.

This article is therefore organized into several sections: section 2 develops in depth the most recent types of algorithms with their organization chart and by families of membership and application conditions by associating their strengths and weaknesses. Then, in section 3 of the criteria, Comparisons of performances for the different families of algorithms are proposed. In section 4, a new algorithm is developed to be tested on IEEE-68 node networks with statistical validation. Finally, in section 5, a conclusion is proposed with suggestions for better valorization of the results obtained.

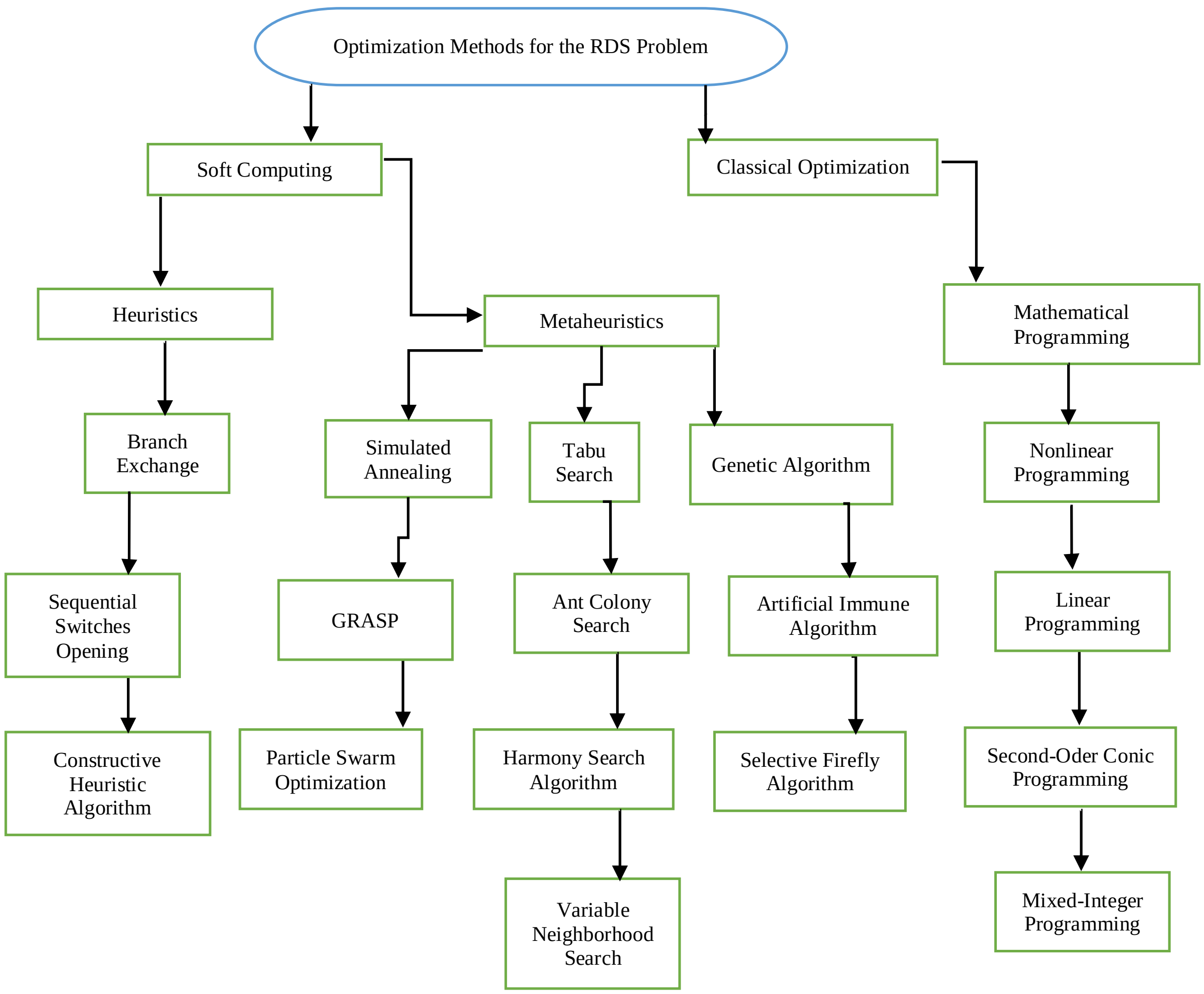
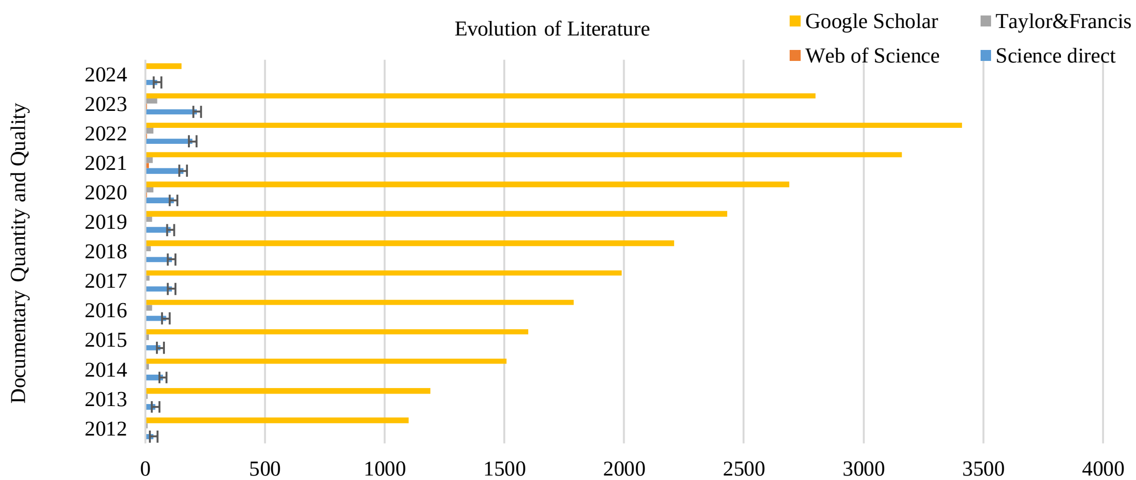


Fig. 1 Optimization methods applied to the reconfiguration of distribution systems



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Google Scholar	1100	1190	1510	1600	1790	1990	2210	2430	2690	3160	3410	2,800	152
Taylor&Francis	11	9	15	16	29	19	24	28	35	32	33	50	2
Web of Science	0	0	0	0	0	0	0	3	6	15	7	6	0
Science direct	34	43	74	63	86	110	111	106	119	159	198	216	51

Evolution over the Years

Fig. 2 Evolution of documentary quality and quantity by year

2. Major Recent Optimization Strategies Used in Distribution Systems Reconfiguration

Several optimization strategies are developed and used in the literature, each of them presenting advantages that are specific to the different operating scenarios of the networks for which they are used.

2.1. Heuristic Algorithm

This family of algorithms develops strategies based on artificial intelligence. In this case, the experience of the decision maker is capital or essential [3] the percentage of success of his algorithms in the reconfiguration of distribution networks remains satisfactory [4-11]. The methodology here consists of initially closing the switches or power switches interconnection; then, during the different iterations, the switch with the smallest power flow trips to open.

The process is, therefore, repeated until a radial configuration is obtained [12]. This is how [2] proposed a multi-objective algorithm with a fuzzy approach by balancing loads between power supplies while minimizing power losses, voltage deviation and limiting currents. The major accidents with its algorithms are [13]:

- Low computational effort compared to other approaches;
- Simplicity of implementation**.**

However, difficulties such as the lack of precision when the number of nodes is large or even sometimes unrealistic solutions due to learning or training errors.

2.2. Metaheuristic Algorithms

This large family improves the shortcomings observed in the first heuristic family. The methodology for opening the switches is different; the problem of optimal management or reconfiguration is managed in two phases: a sequential opening of the switches is carried out [14] until a radial system is obtained, and the second step is one or optimization with retention of the best results. It is done one after the other.

This is how [15-21] developed matheuristic strategies on the objective functions of power losses, load balancing, the reliability index, the cost of the number of switchings and the stability of the voltage. The systems are, therefore, better controlled in terms of variables. However, they do not guarantee optimality and do not provide information on the gap between the solution obtained and the overall optimal.

2.3. Mathematical Programming

This large family is based on a classic mathematical formulation with several constraints for several objective functions, which are therefore optimized [22-24]; only this classic approach requires a lot of calculation time and very high-level computing resources.

2.4. Strategies and Application Scenarios

This section analyzes in depth the different application cases available in the literature, specifying their strengths but also their limits with the ultimate goal of proposing an original method based on the biclustering algorithm. Table 1 (Appendix) presents this content in detail.

3. Power Transit in Branches

A branch of a radial distribution network is modeled as a resistor in series with a pure inductor. The power flow results in the following diagram (Figure 3).

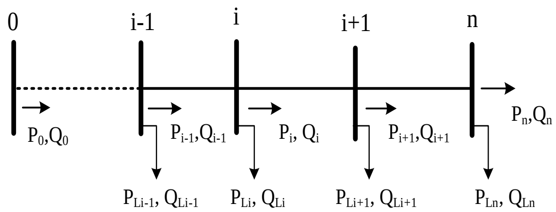


Fig. 3 Power flow diagram

The active power transferred Pi between busbars i and k (k=i+1) is described by the following equation.

$$P_i = P'_K + R_i \frac{(P'^2_K + Q'^2_K)}{V^2_K} \quad (1)$$

$$\text{With } P'k = Pk + PLk \quad (2)$$

p_{Lk}: The active power of the load at the busbar level (i)
Pk: The active power transited in the branch (i)

The reactive power transferred from the busbar (i) at the busbar *k (k=i+1)* is given by the relation :

$$Q_i = Q'_K + X_i \frac{(P'^2_K + Q'^2_K)}{V^2_K} \quad (3)$$

$$\text{With } Q'k = Qk + QLk \quad (4)$$

Q_{LK}: The reactive power of the load at the busbar level (i)
Q_k: The reactive power transited in the branch (i)

The current flowing through a branch (i) is written as follows.

$$I_i = \frac{(\underline{V_i/\theta_i} - \underline{V_k/\theta_k})}{R_i + jX_i} \quad (5)$$

3.1. Formulation of the Problem

This algorithm is part of a representation of the monitoring data of a probabilistic evaluation, which depends directly on the constraints of our system at the level of its objective function [12] by also including the choice of nodes with well-defined upstream profiles. It is important to emphasize that this intelligent predefined approach in the selection of data into membership classes makes it possible to reduce the iterations and directly the computational load for a compilation of the different possibilities.

This principle is therefore applied in the context of this study by making an association with the OSP approach. Figure 4, therefore, illustrates in the form of a flowchart the technique and the program used to optimize the reconfiguration of the nodes of the IEEE-69 network in this work. Thus, a simulation of the reconfigured network and a diagram of its networks will also be proposed in this work for each operating case. Obviously, after having presented above all the characteristics of our initial network before reconfiguration.

3.2. Initial IEEE-69 Node Network Data

Initially, the network has the following characteristics.

3.2.1. Network Settings

The technological characteristics of the initial network are present in Table 2 and other data concerning the distribution of the loads and the characteristics of the lines.

Table 2. Network parameters

Network	IEEE-69
Rated Active Power (KW)	3802.19
Reactive Rated Power (KVAr)	2694.6
Nodes (Busbar)	69
Lines	73
Number of Branches	68
Origin Voltage	12.66KV
Number of Link Switches	5
Link Switches	69 ; 70 ; 71 ; 72 ; 73
Active Power Losses	225 KW
Reactive Power Losses	100 kVAr
Maximum Voltage	1.000 p.u
Minimum Voltage	0.909 p.u.
Maximum Current	400(1–9), 300(46–50, 53–65), 200(10–45, 51, 52, 66–73)

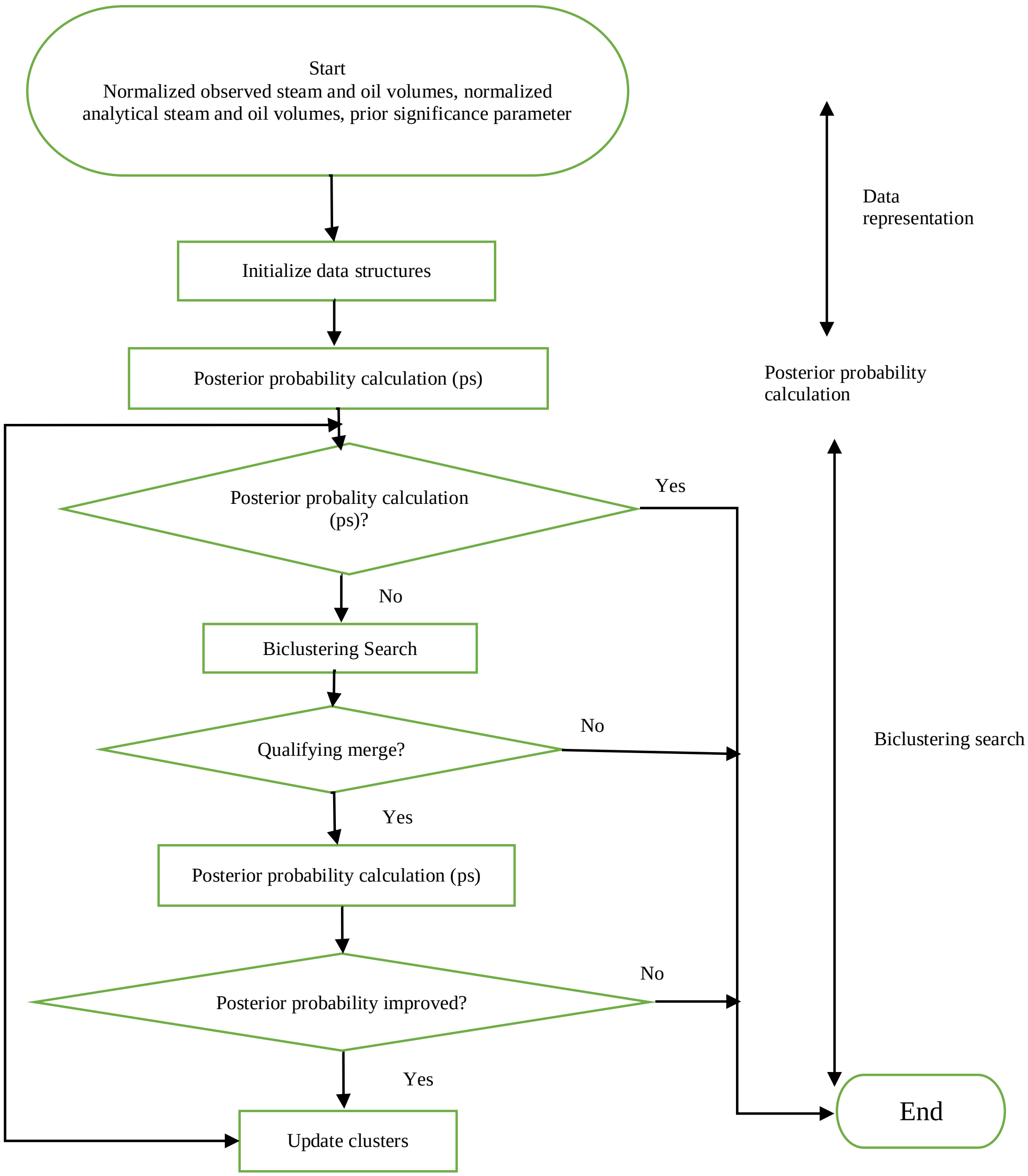


Fig. 4 Flowchart of buclistering algorithm proposed

3.2.2. Initial Network Topology

This topology (Figure 5) informs us about the structure of the network and the branches which can be the subject of a possible modification with a view to the reconfiguration. It can be seen that the four lateral branches containing the nodes (28 to 35), (51 and 52), (66 and 67), and (68 and 69) do not participate in the reconfiguration because they can only be supplied by one and one way:

- The branch containing the nodes (28 to 35) can only be powered by bus 3; no other channel is possible;
- The branch containing the nodes (51 and 52) can only be supplied by bus 8, no other alternative is possible;
- The branch containing the nodes (66 and 67) can only be powered by bus 11; no other alternative is possible;
- The branch containing the nodes (68 and 69) can only be powered by bus 12; no other alternative is possible;

This is why these branches are removed from the topology during loop analysis. We can here make the remark that these branches are closer to the source in order to avoid any voltage fluctuation situation or to reduce line losses. The other three branches following the first are only provided with two nodes each, so in the event of a failure on these side branches, a small number of subscribers will be disturbed.

Table 3. Active and reactive losses of the IEEE69-radial bus network

Branches	Active Losses (kW)	Reactive Losses (kvar)	Branches	Active Losses (kW)	Reactive Losses (kvar)	Branches	Active Losses (kW)	Reactive Losses (kvar)
1	0,72	0,21	24	0,01	0,01	47	8,37	2,44
2	0,72	0,23	25	0,001	0,001	48	10,35	2,83
3	0,19	0,37	26	0,001	0,001	49	11,81	5,49
4	2,72	3,06	27	0,001	0,001	50	3,08	1,06
5	39,77	19,73	28	0,001	0,01	51	0,09	0,97
6	49,47	20,58	29	0,01	0,001	52	0,34	0,18
7	10,85	4,92	30	0,001	0,001	53	0,51	0,26
8	3,03	1,56	31	0,001	0,001	54	0,01	0,001
9	6,01	1,66	32	0,01	0,001	55	0,001	0,001
10	2,06	0,35	33	0,02	0,01	56	0,01	0,001
11	4,02	1	34	0,01	0,001	57	0,001	0,001
12	3,774	0,74	35	0,001	0,001	58	0,001	0,001
13	2,1	0,36	36	0,02	0,05	59	0,01	0,03
14	2,07	0,35	37	0,07	0,17	60	0,01	0,02
15	0,19	0,06	38	0,001	0,01	61	0,001	0,001
16	0,36	0,12	39	0,52	0,27	62	0,001	0,001
17	0,001	0,001	40	0,46	0,16	63	0,3	0,04
18	0,015	0,05	41	5,55	2,29	64	0,01	0,01
19	0,05	0,02	42	6,57	2,7	65	0,001	0,001
20	0,08	0,03	43	8,51	3,72	66	0,001	0,001
21	0,001	0,001	44	8,04	3,56	67	0,001	0,001
22	0,001	0,001	45	18,82	12,92	68	0,001	0,001
23	0,002	0,002	46	19,98	6,36			
Total Active Losses					**224.98 kW**			
Total Reactive Losses					**100,48 kVAr**			

3.2.3. Losses in the Network

Table 3 illustrates the status of active and reactive losses at the level of each branch. Thus, we note that the greatest values of active losses Ploss = 49.47 kW and reactive losses Qloss = 20.58 kVAr are found at the level of the 6th branch. The total active and reactive losses of the network are, respectively, 224.9804 kW and 100.48 kVAr.

3.2.4. Voltage Profile

Table 4 illustrates the voltage levels of this network. This voltage profile is represented by Figure 5 (normal load), which reflects the voltage level at each busbar where the lowest value (0.909) can be found at busbar 65.

3.3. Data from the Initial Network for the Case Studies

Table 5 shows the losses for the different scenarios.

Table 4. Voltage values at the different network nodes

JB	Tension (pu)	JB	Tension (pu)	JB	Tension (pu)
1	1	24	0,9565	47	0,9997
2	0,9999	25	0,9564	48	0,9985
3	0,9999	26	0,9563	49	0,9946
4	0,9998	27	0,9563	50	0,9941
5	0,9990	28	0,9999	51	0,9785
6	0,9900	29	0,9998	52	0,9785
7	0,9807	30	0,9997	53	0,9746
8	0,9785	31	0,9997	54	0,9714
9	0,9774	32	0,9996	55	0,9669
10	0,9724	33	0,9993	56	0,9625
11	0,9713	34	0,9990	57	0,9400
12	0,9681	35	0,9989	58	0,9290
13	0,9652	36	0,9999	59	0,9247
14	0,9623	37	0,9997	60	0,9197
15	0,9594	38	0,9995	61	0,9123
16	0,9589	39	0,9995	62	0,9120
17	0,9580	40	0,9995	63	0,9116
18	0,9580	41	0,9988	64	0,9097
19	0,9576	42	0,9985	65	0,9091
20	0,9573	43	0,9985	66	0,9712
21	0,9568	44	0,9985	67	0,9712
22	0,9568	45	0,9984	68	0,9678
23	0,9567	46	0,9984	69	0,9678

Table 5. Initial characteristics for different imagined scenarios

Case Reviewed			
Charge Level	**Low Load**	**Normal Load**	**High Load**
Load Percentage (%)	50	100	130
Total Power (KW)	1901.1	3802.19	4942.85
Total Active Power Lost (kW)	47.200	224.9804	358
Total Reactive Power Lost	25.400	111.457	197.417
Minimum Voltage (pu)	0.917	0.909	0.8891
Maximum Voltage (pu)	1.00	1.00	1.00

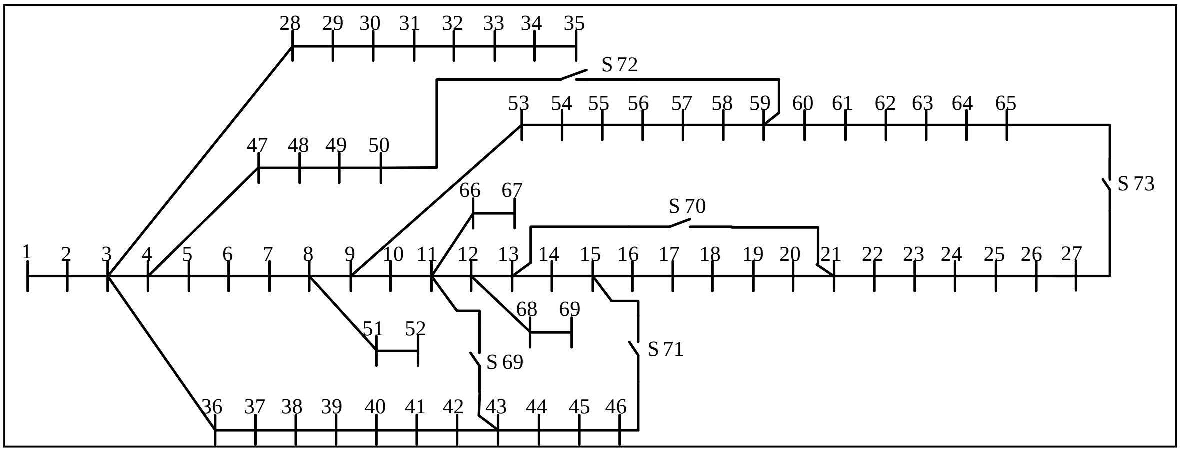


Fig. 5 Initial network topology

4. Results of Simulations and Discussions

The voltage profile is represented by the graph above for different loads before reconfiguration in Figure 6. This graph allows us to have a general overview of the network voltage profile by stopping the three scenarios. We note that this voltage is degraded in the case of large loads compared to the other cases because of the strong currents which circulate in the circuit.

4.1. Results for the Low Load

When the light load condition is assumed, the load level decreases to 50% of the normal load. The results for this load level are shown in Table 6. The voltage profiles with respect to each bus before and after reconfiguration are shown in Figure 7. The minimum voltage level before and after network reconfiguration is 0,9585 p.u. and 0,9715 p.u., respectively.

Switches open in the test system in the initial configuration of the network are 33, 34, 35, 36, and 37. After reconfiguring the network using the proposed Biclustering algorithm, four-link switches are closed, i.e. 33, 35, 36, and 37, while sectioning switches 7, 9, 14, 32, and 37 are open, and the results are shown in the table below. The calculation time is 22.289629 seconds.

This graph shows the voltage improvement for a low load: it can be seen that between nodes 1 and 5, the voltage before and after reconfiguration is almost the same. But from node 6, there is an improvement in the initial tension, which sees improvements.

This voltage degrades to node 27. From node 28, the voltages before and after the reconfiguration almost merge and are equal to 1pu until node 36. From node 37, it is seen that the voltage after the reconfiguration is worse than the voltage before the reconfiguration. This graph translated the tension profile before the reconfiguration by the swarm of particles and after the reconfiguration. Table 6 below summarizes the results obtained in this case.

4.1.1. Reconfigured Network Topology

Figure 8 below shows the topology of the new network obtained after this reconfiguration. The structure of the new allows us to check the radial conditions of the network and it can be seen by this fact that each node is connected to the source through a single path.

The topology has indeed been changed. The switches 69 and 70 initially open retain their state, and the switches initially open 71, 72, and 73 switch their state to the closed position to the detriment of the switches 14, 58, and 61, which take the open position.

4.2. Case of the Normal Load

When the normal load condition is assumed, the results of the voltage profile against each bus before and after reconfiguration is shown in Figure 9 below. The minimum voltage level before and after network reconfiguration is 0.9130 p.u. and 0.950 p.u. respectively. The results show that the actual power loss is reduced to 98.6 kW compared to the total value, which is 224.98 kW.

This indicates that 126.39 kW of real power can be saved compared to using the existing network topology. The percentage reduction is 56.18% of the total power loss under normal load conditions. Network reconfiguration using the PSO algorithm resulted in the tie switches 71, 72, and 73 being closed while the disconnect switches 14, 57, and 61 were opened. The open switches are then 14, 57, 61, 69, and 70, as shown in Figure 11 below.

The calculation time is 22.904553 seconds. The Figure 9 voltage profile shows us that between nodes 1 and 5, the voltage is stable and remains almost identical between the instants of the reconfiguration and the initial. Between node 6 and node 27, the voltage after reconfiguration is significantly above that before the reconfiguration. From node 28 to node 36, the forward and after voltages are nearly equal to the reference value.

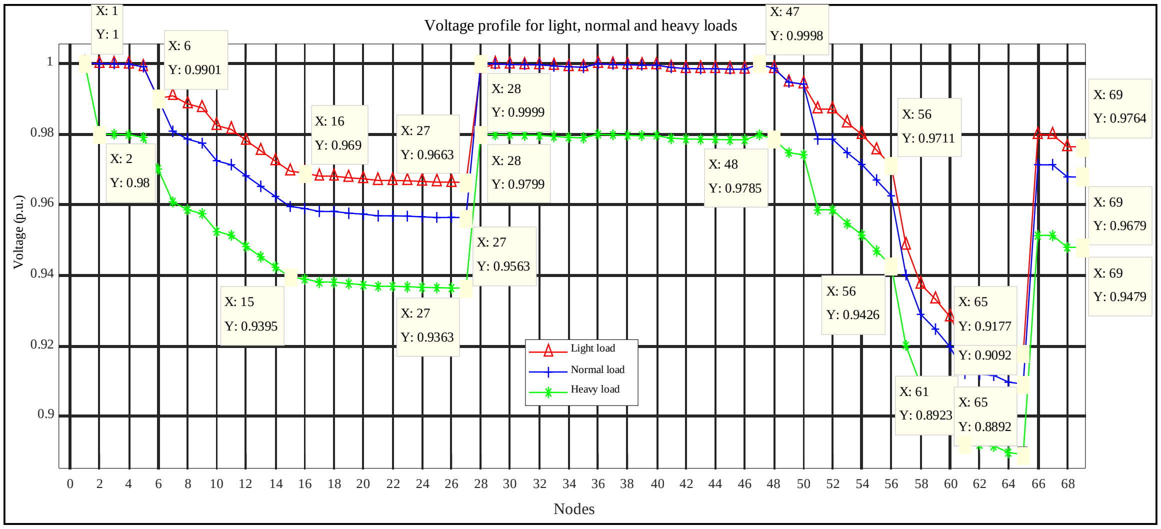


Fig. 6 Voltage profile for different loads before reconfiguration

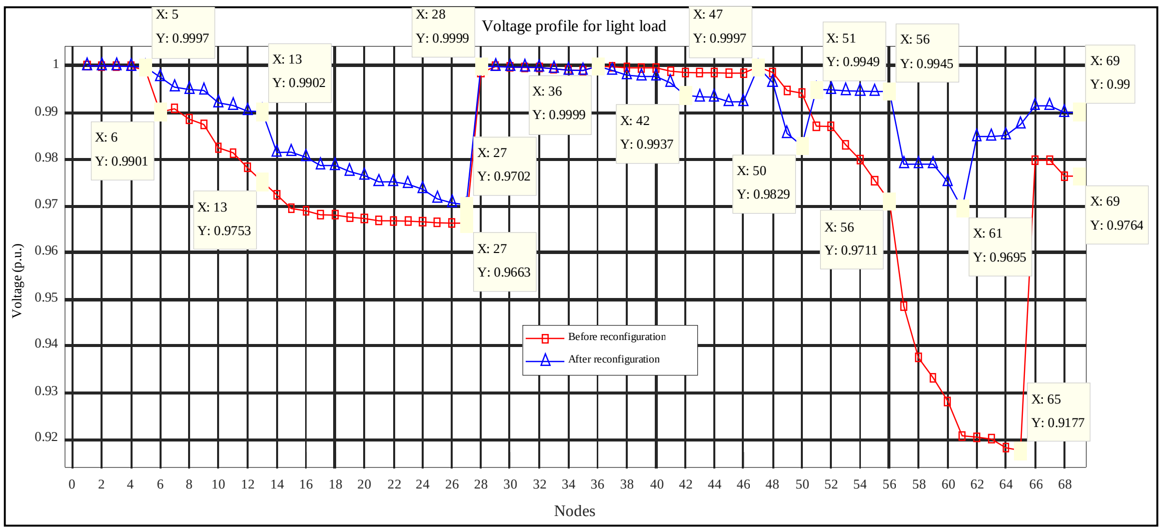


Fig. 7 Voltage profile for low load

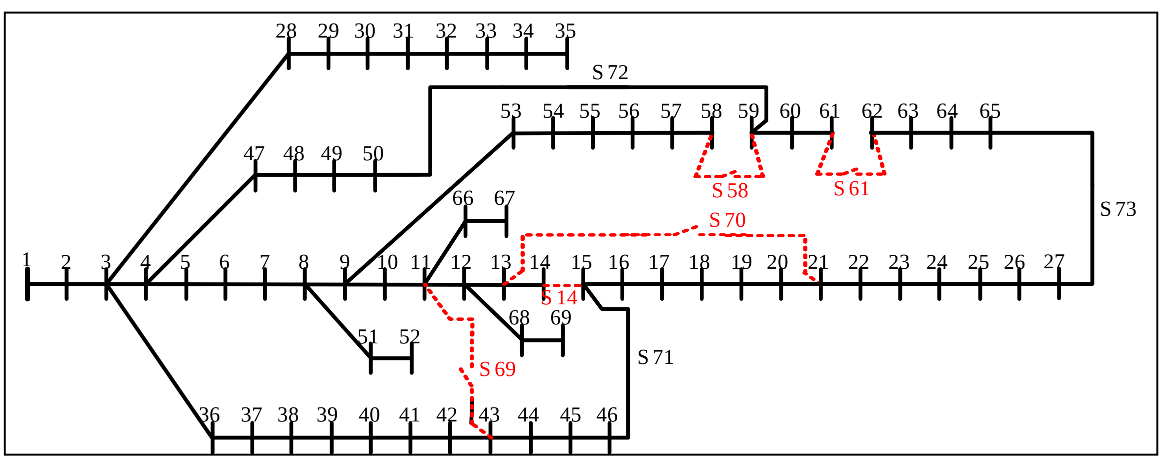


Fig. 8 Small load reconfiguration topology

Table 6. Simulation results for low load

	Forward Reconfiguration	After Reconfiguration
Switch State Change	69 70 71 72 73	14 58 61 69 70
Power Lost (KW)	112.4902 kW	98.5952 kW
Power Loss Reduction (%)	-----	12.3522 %
Minimum Voltage	0.91769 pu	0.96947 pu

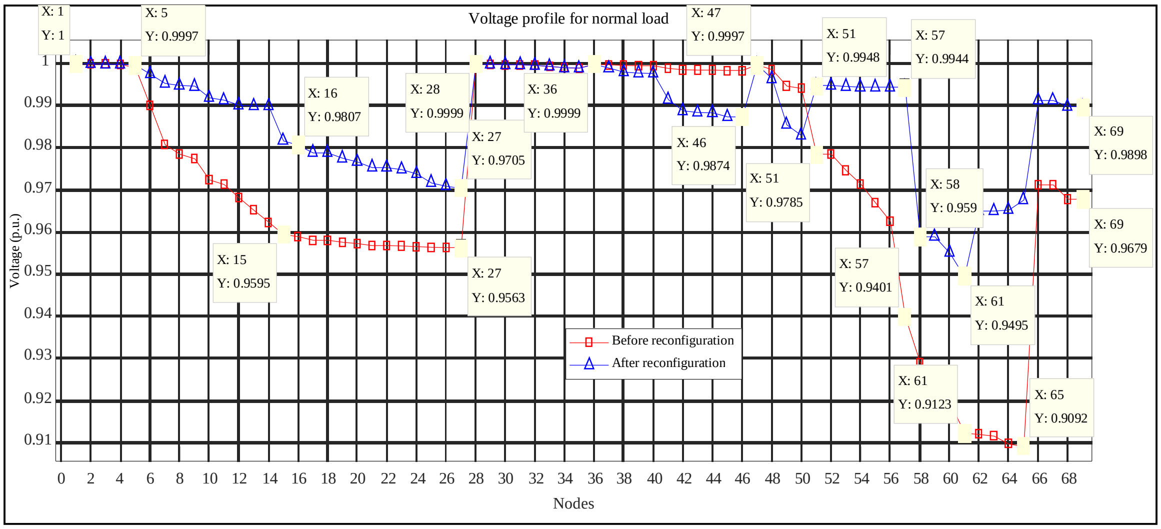


Fig. 9 Voltage profile for normal load

From node 37 to 46, the voltage after the reconfiguration degrades and reaches the minimum of 0.9873pu against the value of 0.9984pu before the reconfiguration. At node 47, the before and after voltages are equal, but from node 48, the previous scenario repeats itself until node 50, where the minimum voltage is 0.9829pu at node 50 against 0.9942pu before the reconfiguration. From node 51 to node 69, the voltage after the reconfiguration remains higher than before. It is also noted that the voltage is stable between nodes 51 and 57, whose value is 0.9949pu, and drops to the value of 0.959pu at the next node, reaches its minimum value of 0.949pu at node 61, and then increases to the last node.

4.2.1. Losses

Table 7 below summarizes the results obtained in this case.

4.2.2. Reconfigured Network Topology

The new network Figure 10 structure is shown below, and we can see that the network structure is tree-like, and a single lane powers each node. The red dotted lines show the new lines opened in order to keep the tree structure of the network.

4.3. Case of High Load

Similarly, the high load condition is assumed, and the load level is increased to 130% of the normal load level. The worst-case scenario, which occurs when the load increases on each bus at the same time, was also retained. The results of this load level are shown in Figure 11 and Table 8.

Figure 11 shows that the minimum voltage level is improved from its minimum value of 0.8892 p.u at the front 65 bus to its minimum value of 0.9395 p.u to bus 61 after reconfiguration using the proposed approach. The reconfiguration of the network using the PSO algorithm resulted in the closing of three switches, namely, 71, 72, and 73, while also resulting in the opening of the sectioning switches 14, 58, and 61.

The open switches are 14, 58, 61, 69 and 70. The calculation time is 22.552395 seconds. This graph translated the tension profile before the reconfiguration by the particle swarm before and after the reconfiguration. Table 8 below summarizes the results obtained in this case.

Contrary to what is observed in the other scenarios, the tension improves here at all nodes except nodes 42 to 46, where it is almost constant.

- Reconfigured network topology
- Description

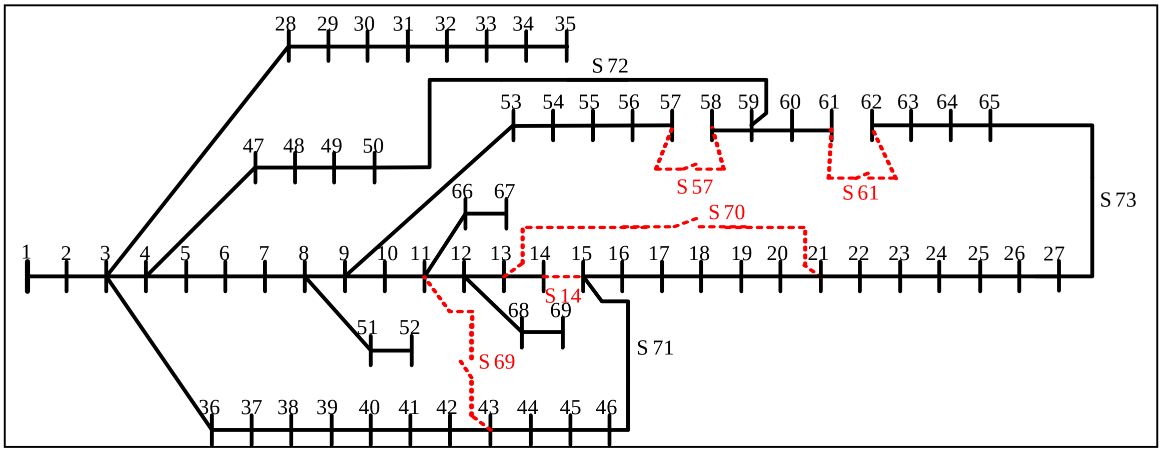


Fig. 10 Reconfiguration topology for normal load

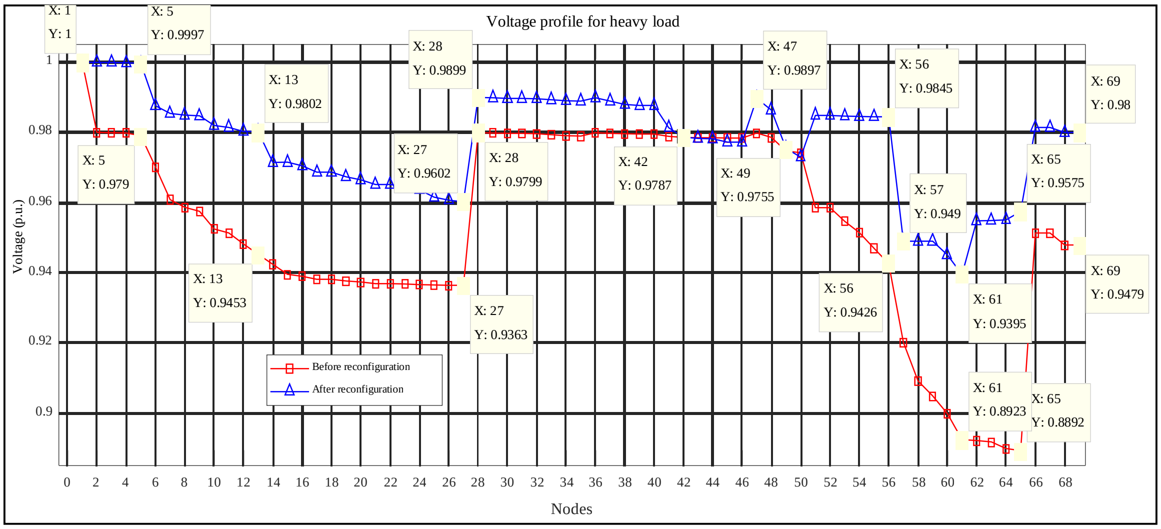


Fig. 11 Voltage profile for high load

Table 7. Simulation results for normal load

	Forward Reconfiguration	After Reconfiguration
Switch State Change	69 70 71 72 73	14 57 61 69 70
Power Lost (KW)	224.9804 kW	98.5952 kW
Power Loss Reduction (%)	-----	56.1761 %
Minimum Voltage	0.90919 pu	0.94947 pu

Table 8. Simulation results for high load

	Forward Reconfiguration	After Reconfiguration
Switch State Change	69 70 71 72 73	14 58 61 69 70
Power Lost (KW)	292.4745 kW	106.547 kW
Power Loss Reduction (%)	-----	63.57 %
Minimum Voltage	0.88919 pu	0.9395

Table 9. Situation of the voltage profile at the different nodes

Situation of the Tensions at the Nodes	Improved Tension	Degraded Voltage	Steady Voltage
Low Load	6 à 7 ; 51 à 69	48 à 50	1 à 5; 28 à 35 ; 47
Normal Load	6 à 27 ; 51 à 69	36 à 46 : 48 à 50	1 à 5 ; 28 à 35 ; 47
High Load	2 à 41 ; 50 à 69 ; 47 ;49	42 à 46	1 ; 50

The voltage profile curves immediately show an improvement in the voltage profile although this is not in all the nodes. On the 69 nodes, there is a large part where the tension has been improved but a small non-negligible part where this tension has rather experienced a degradation of its profile. Table 9 summarizes this situation for the different scenarios. The new network topologies presented above (Figure 7, Figure 9, and Figure 11) prove that the network has changed topology and retains its tree structure.

5. Analysis of Results

Summary of the different scenarios in Table 10. With the aim of contributing to the improvement of power quality in electrical distribution networks following the literature, we have set ourselves two objectives:

- Improve the voltage profile
- Reduce power losses

In a 69-node IEEE network. After implementing the chosen method, the results obtained show an improvement for each scenario considered. Compared to the works carried out for a normal load, we can compare these results to the additional works using Table 11. The analysis of the profiles of tensions reveals situations with the nodes where the tension after the reconfiguration is worse than the tension before the reconfiguration.

This is for some nodes of these various scenarios. This result induces the remark that the reconfiguration does not improve the voltage profile at all the nodes but improves it at the majority of the nodes. The reduction of the tension at these nodes is justified by the fact that during the reconfiguration, while certain loads are brought back close to the source, others, on the other hand, move away from it.

The reconfigurations obtained in the different scenarios are identical to a ready scenario. This reconfiguration of the normal load differs from the low and high loads at branches 57 and 58. It appears that during a reconfiguration, the state of the open switches depends on the load. The voltage profile of the different scenarios has greatly improved except for a few nodes where it has deteriorated as we specify in Table 9.

The power losses have been greatly reduced but remain generated in the case of heavy load because of the strong currents circulating in the network. It should be noted that the results obtained by the PSO [8] and our approach indicate the same switches after the reconfiguration for a normal load, but there is a slight difference in the power lost, i.e. a difference of approximately 1.0264 KW in absolute value.

This difference may be due to the calculation parameters. On the other hand, these switches are almost the same as those of SPSO [24] with a ready switch. However, the lost power difference is 25.0588 KW.

5.1. Statistical Validation of the Comparison Results of Table 11

In this section, a statistical validation and analysis of the main characteristics are developed. By observing the Total Power Loss (kW) behavior as a function of loss reduction (kW), Loss reduction (kW), and Improved voltage profile from Table 11, respectively F1, F2, F3, and F4 in the eigenvalues, correlations between the variables and the factors, coordinates of the observations. 8 cases of observations are therefore analyzed with particular attention to case 1, which illustrates the contribution in this article for the biclustering algorithm. Tables 12, 13, 14, 15 help to understand the principal component analyzes for: F1/F2; F1/F3; F1/F4;

The studied variables are in red: Total power lost (kW), Loss reduction (kW), Loss reduction (kW), and Improved voltage profile. The initial information is at 75.02% Figures 12 and 13 allow us to appreciate the impact of the buclisting algorithm on the different variables while respecting the constraints fixed at the start.

Case 1, which represents the contribution in this article, has a positive correlation for a power loss of 98.5 KW in comparison with an average of 100,317 KW of power losses for the results available in the literature. These obtained results are in agreement with cases 6 and cases 8. Finally, they also comply with the IEEE-519-2022 standard. The biclustering algorithm succeeded in improving the performance of the system by proposing a reconfiguration alternative that contributes to better management of the network.

Table 10. Summary table

	Initial	Low (50%)	Normal (100%)	High (130%)
Switches	69 ; 70 ;71 ;72 ;73	14 58 61 69 70	14 57 61 69 70	14 58 61 69 70
Initial Losses (KW)	224.9804	112.4902	224.9804	292.4745
Reduced Losses	-	12.3522 %	56.1761 %	63.57 %
Voltage Profile (min)	0.9019pu	0.96947 pu	0.94947 pu	0.9292 pu

Table 11. Comparison of results with those in the literature

Methods	Switches to Open	Total Power Lost (kW)	Loss Reduction (kW)	(%) Improvement	Improved Voltage Profile
Initial	69 ;70 ;71 ;72 ;73	224,98	-	-	0,90919
In this Work	**14 57 61 69 70**	**98.5952**	**126,3852**	**56,176**	**0.94947**
SPSO [24]	14, 56, 63, 69, 70	123,654	101,3264	45,0378	-
UVDA [23]	7, 9, 14, 32, 37	139.55	85,4304	37,972	0.9378
HAS [20]	7, 9, 14, 32, 37	138.06	86,9204	38,634	0.9342
GA [22]	69, 70, 14, 53, 61	103,29	121,6904	54,089	0,9411
FWA [21]	14, 56, 61, 69, 70	98.59	126,3904	56,1784	0.9495
PSO [8]	14 ;57 ;61 ;69 ;70	99,6216	125,3588	55,719	0.9428
SSA [24]	69 ;14 ;71 ;61 ;58	98.63	129.3504	56.15	0.9492

Table 12. Total power lost (F1) according to loss reduction (F2)

Variable	Comments	Obs. with Missing Data	Obs. without Missing Data	Minimum	Maximum	Mean	Standard Deviation
Total Power Lost (kW)	9	0	9	98,590	224,980	124,997	41,209
Loss Reduction (kW)	9	0	9	0,000	129,350	100,317	41,461
(%) Improvement	9	0	9	0,000	56,178	44,440	18,316
Improved Voltage Profile	9	0	9	0,000	0,950	0,835	0,313

Table 13. Eigenvalue

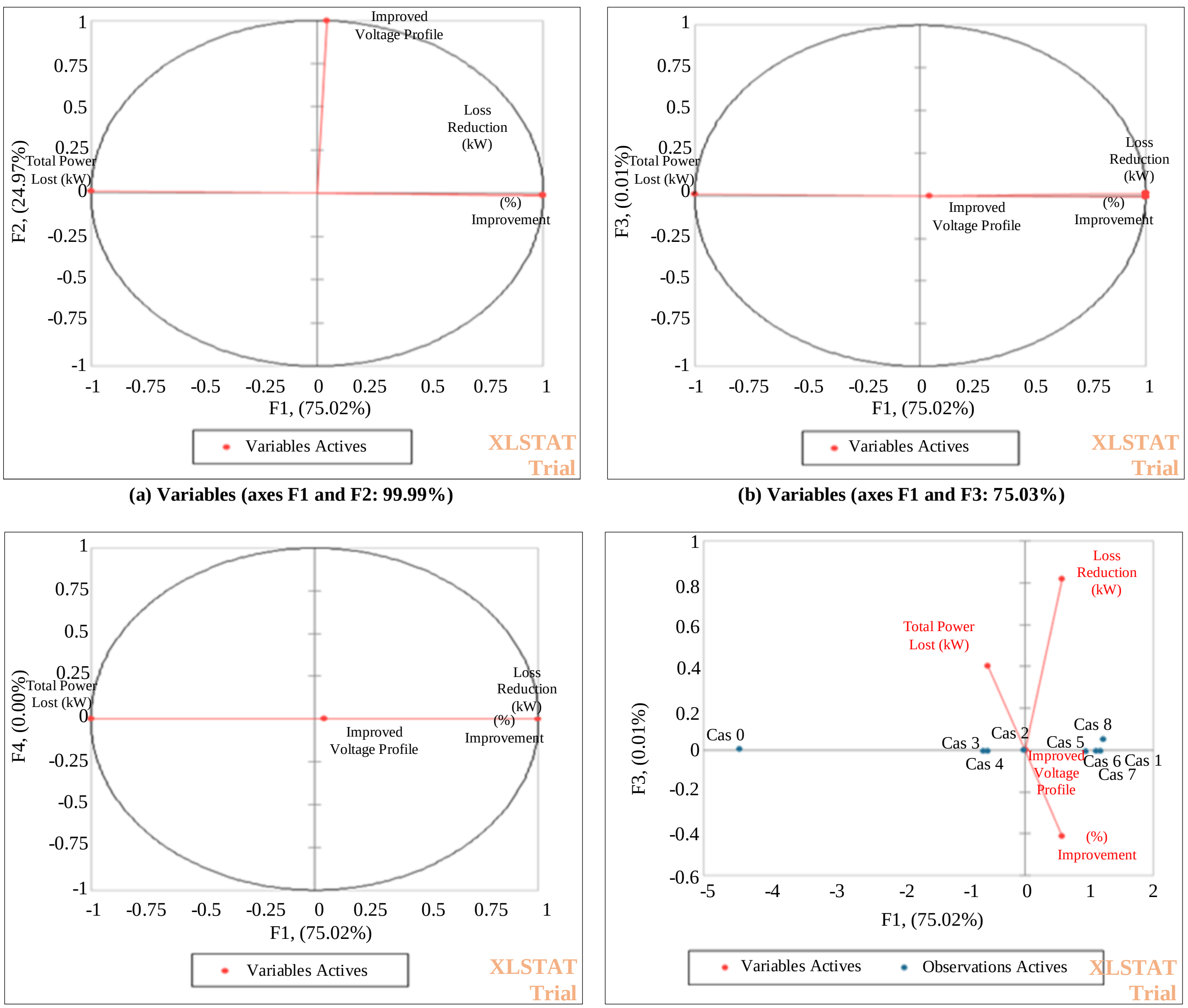
	F1	F2	F3	F4
Eigen Value	3,001	0,999	0,000	0,000
Variability (%)	75,020	24,971	0,009	0,000
% Cumulative	75,020	99,991	100,000	100,000

Table 14 Correlations between variables and factors

	F1	F2	F3	F4
Total Power Lost (kW)	-1,000	0,015	0,008	0,000
Loss Reduction (kW)	1,000	-0,012	0,016	0,000
(%) Improvement	1,000	-0,015	-0,008	0,000
Improved Voltage Profile	0,042	0,999	0,000	0,000

Table 15. Coordinates of observations

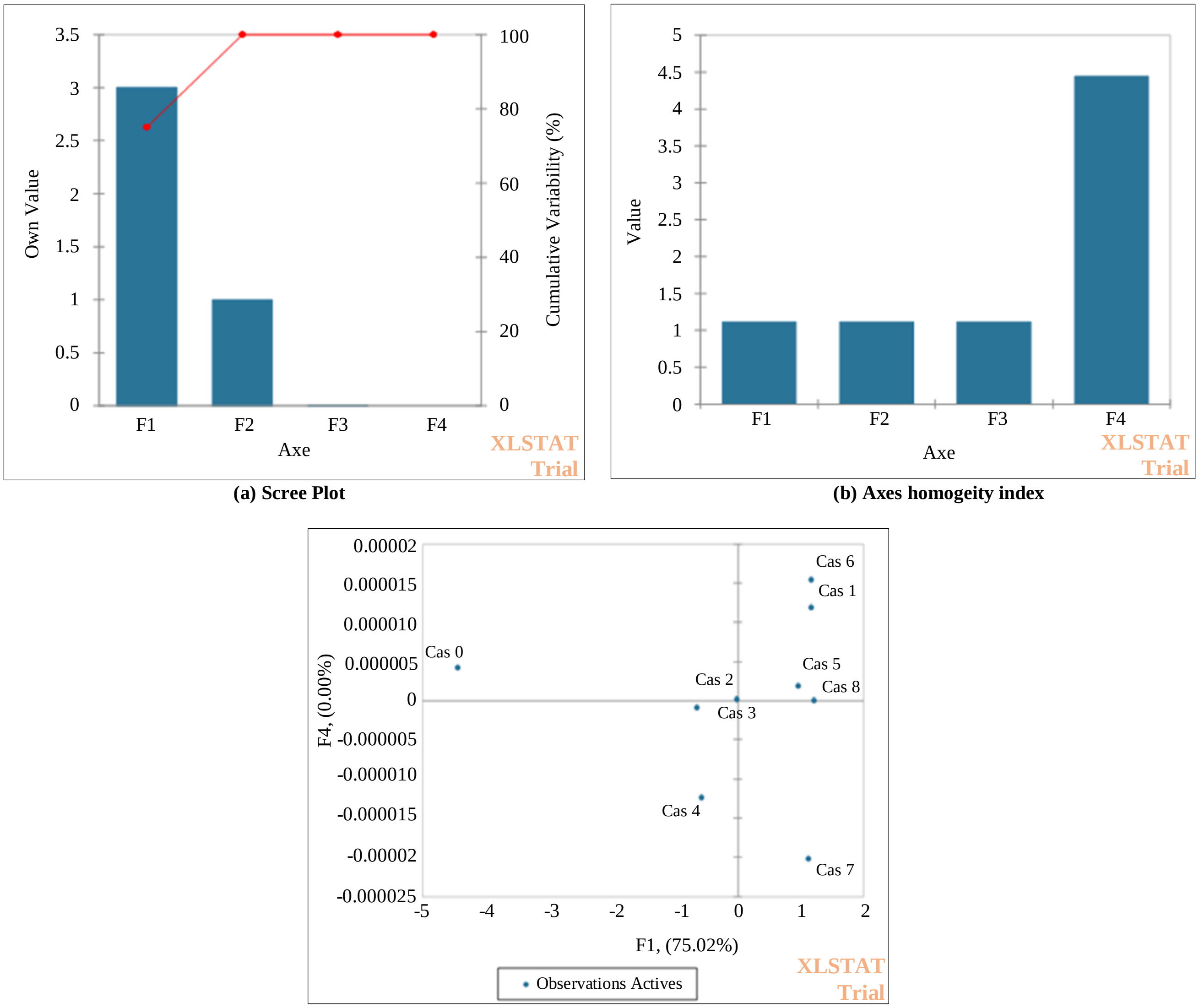
	F1	F2	F3	F4
Cas 0	-4,446	0,359	0,005	0,000
Cas 1	1,179	0,360	-0,011	0,000
Cas 2	-0,013	-2,827	0,000	0,000
Cas 3	-0,644	0,364	-0,006	0,000
Cas 4	-0,578	0,350	-0,006	0,000
Cas 5	0,969	0,337	-0,011	0,000
Cas 6	1,179	0,360	-0,011	0,000
Cas 7	1,133	0,338	-0,011	0,000
Cas 8	1,221	0,358	0,052	0,000



(a) Variables (axes F1 and F2: 99.99%) **(b) Variables (axes F1 and F3: 75.03%)**

(c) Variables (axes F1 and F4: 75.02%) **(d) Biplot (axes F1 and F3: 75.03%)**

Fig. 12 Principal component analysis



(a) Scree Plot

(b) Axes homogeity index

(c) Observations (axes F1 and F4: 75.02%)

Fig. 13 Observations of the axes and eigenvalues of the data given in table 11

6. Conclusion

In this article, there was a question of proposing an optimal reconfiguration of the electrical distribution network IEEE-69 radial type nodes from a hybrid algorithm: BICLUSTERING by regulating the voltage profile of the tensions and by reducing the losses by a direct action on the switches by switching open and close.

This method is implemented under MATLAB R2022.b installed on windows10 running in an HP computer equipped with an 'Intel(R) Core(TM) i5-3320M CPU @ 2.60GHz' processor and 4 GB RAM. Results are presented for three example load types representing three network phenomena: low load(50%), normal load (100%), and high load (130%).

The results obtained for this study demonstrated that changing the topology (reconfiguration) of the network allows us to reduce the losses for our system; the loss reduction is 12.3522%, 56.1761%, and 63.57% for low, normal, and high loads, respectively, and to improve the voltage profile which is 0.96947pu; 0.94947 pu and 0.9292 pu for low, normal and high loads respectively.

The advantage of the reduction of the latter allows us the evolve the security of the network in a state of activity by having more stability at the level of the tension and thus offering an optimization of the minimization of the losses and the improvement of the voltage profile. Key contributions to this work include:

- A detailed presentation of the strategies for controlling and reconfiguring electrical networks by major families, each time specifying the strengths and limits according to the different operating scenarios.

- The proposal and use of the biclustering algorithm in the context of improving the performance of reconfiguration of the 68-node network. With a comparison of the results obtained with those available in the literature.
- A descriptive statistical analysis with principal component analysis for better validation of the results compared to the literature.

This work is thus positioned as a multi-objective contribution in a context in which the management of distribution networks now presents several challenges with the arrival of decentralized hybrid production generally connected to the main network with operating constraints.

Availability of Data and Materials

The datasets generated during and/or analyzed during the current study are available in the:

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Appendix

Table 1. Optimization techniques used in the literature to reconfigure the network in order to minimize losses and enhance the voltage profile

Authors	Years	Goals	Methods	Results	Application (IEEE Network)	Contribution	Disadvantages
Rao et al.	2012	Loss minimization	HSA	Placement of production units and simultaneous reconfiguration	33 and 69 nodes	It uses stochastic random search instead of gradient search, eliminating the need for derived information	Premature convergence
Dahalan and Mokhlis	2012	Minimization of losses and improvement of the voltage profile	PSO	Placement of production units and simultaneous reconfiguration	33 nodes	In this approach, the location of the DG is identified using a voltage stability factor method. the voltage stability factor and the PSO is used for the dimensioning of the DGs.	Particle clinging tendency
Khalil et al.	2012	Reduction of losses	SPSO	Reconfiguration	33 and 69 nodes	Modification of BPSO using switches as search space which can be different for different dimensions	Fast speed of convergence
De Souza et al.	2013	Minimization of losses and improvement of the voltage profile	GA	Placement of productions	70 nodes	Initially, the location is identified using the sensitivity index method and the sizing of power plants by the GA is used	The applicability of the method to standard systems is not mentioned.
Imran et al.	2014	Minimization of losses and improvement of the voltage profile	FWA	Simultaneous production placement and reconfiguration	33 and 69 nodes	The radial nature of the system is ensured by the generation of an appropriate path between the parent and child nodes of the network during the power flow	Weak mathematical foundation, Lent, Complex settings
Nguyen et al.	2015	Minimization of losses and improvement of the voltage profile	CSA	reconfiguration	33, 69 and 119 nodes	Searches for optimization based on the technique of cuckoos that lay their eggs in the nests of other species	Lent to converge after about 100 iterations
Sudhakara and Damodar	2016	Minimization of losses and improvement of the voltage profile	PSO	Reconfiguration	33 and 69 nodes	Use PSO by applying it to multiple scenarios	Group stagnation during convergence
Kanwar et al.	2016	Minimization of annual energy	IPSO	Optimal placement of compensation capacitors	33 and 69 nodes	Improved version of the PSO that avoids snagging situations	Less precise convergence

		losses and improvement of the voltage profile		and decentralized productions			
Bayat et al.	2016	Loss minimization	UVDA	Simultaneous production placement and reconfiguration	33 and 69 nodes	Simultaneous distributed generation reconfiguration and sizing and placement	Not recommended
Reddy et al.	2017	Minimization of losses and improvement of the voltage profile	WOA	Optimal placement of decentralized productions	33 and 69 nodes	The WOA is modeled based on the unique hunting behavior of humpback whales.	Very fast convergence
Kola Sampangi Sambaiah et al.	2019	Minimization of losses and improvement of the voltage profile	SSA	Placement of productions	15, 33, 69 and 85 nodes	The algorithm is based on the swarm behavior of salps in deep oceans. The optimal location of the feed is considered to be the optimal solution.	The results obtained are based on the random generation of variables.
S.Essallah and A.Khedher	2020	Minimization of losses and improvement of the voltage profile	MPSO	Placement of alternate/simultaneous productions and reconfiguration	33 and 69 nodes	Combination of BPSO and PSO	Combined convergence