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Power Loss Reduction in Distribution System by Network Reconfiguration Using MPSO Algorithm.

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Abstract
This study demonstrates an effective technique for reconfiguring a power distribution system. To find the best combination of switches that results in the least amount of power network loss in a distribution radial design, the Modified Particle Swarm Optimization (MPSO) approach is Proposed. MPSO is a variant of "Binary Particle Swarm Optimization (BPSO)" that modifies particle velocity in the search space. A relative investigation of MPSO with "Genetic algorithm (GA)", "Ant-colony algorithm (ACA)", and "Selective particle swarm optimization (SPSO)" to modify a power distribution system at base case loading constraints on IEEE 33 bus radial network & IEEE 69 bus radial network is proposed to demonstrate the appropriateness of the suggested strategy.
It is discovered that MPSO outperforms "GA", "ACA", and "SPSO" in terms of output significance and voltage profile.

Keywords:*Binary Particle Swarm Optimization (BPSO),Power Distribution System, Particle SwarmOptimization (PSO), Modified Particle Swarm Optimization (MPSO).*

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I. INTRODUCTION

The expanding electricity distribution network Because of the tight settings in a radial network, the complication has increased. Engineers are especially concerned about the exponential increase of people and the high present situation demands on electricity distribution systems as each day passes. According to Indian conditions, network losses of roughly 19% are distribution power losses [1]. To reduce these losses, power distribution system automation is an acceptable option, which includes the installation of reactive compensating power devices, improved optimization systems, and power system design via switching configuration [2] Power network reconfiguration is one of the most effective ways for improving radial network performance, consistency, and customer end power profile. Distribution Network Reconfiguration (DNRC) may be defined as the process of revising the organized configuration of a power distribution system [3-4] by changing the open/close position of tie (usually opened) and sectionalizing (typically closed) switches. Following goals can be achieved by distribution network reconfiguration:

- Reduced active power loss.
- Reduced violations of branch voltage limitations.
- Reduced node current limits violations.
- Asymmetry in conductor load is reduced.
- Reduced number of switching jobs.
- Enhancement of consistency.
- Supply continuity following fault occurrence.

"Merlin and Back" [2] first proposed reducing active power losses by restructuring the radial network. The branch and bound approach was intended to identify the functional spreading tree structure of a radial network with the least active power loss. The recommended technique has a few disadvantages, including a long processing time and a reliance on only the active part of the current for power measurements in [2]. "Civanlar et al." [3] present a new approach for assessing the variance in active power losses caused by moving load from one feeder to another in a radial network. Switching configuration for the least amount of loss may be determined quickly, however radial network reconfiguration is depending on the initial condition of reconfigurable switches. “Shirmohammadi and Hong” [4] proposed a heuristic approach that uses a power flow scheme to determine the radial network architecture with the fewest feasible power losses. The suggested system in [4] has two limitations: the exploration method is inept, and the optimum global outcome cannot be guaranteed. This issue was reported by several researchers who used heuristic approaches. Rao et al. [5] used a Genetic algorithm to implement a lowest power losses configuration. The problem of load balancing and power loss reduction is demonstrated in [6] using integer programming. Gosami and Basu [7] provide a heuristic technique for minimal power flow during NR by effectively turning on one breaker while turning off the other is complemented to keep the system radial, the strategy is suited for small networks and gives output in vast computation for large networks. Simulated annealing [8-9] is also expected for NR with loss reduction problems, however the approach has a high mathematical burden and a long calculation time.

K. Parsad et al. [10] propose a fuzzy mutant genetic approach for efficient radial network reconfiguration. Several different heuristic-based approaches, such as “Skilled system” [11], “Ant colony search” [12], “Adaptive genetic algorithm” [13], “Redefined genetic algorithm” [14], and “Selective particle swarm optimization” [15], are proposed to handle the loss reduction problem by redesigning the radial network. For bigger systems, the methodologies outlined above have a long operational time, which might be a restriction for a real-time process. The NR Modified Particle Swarm Optimization (MPSO) method is used in this report to decrease active power losses in radial networks. The proposed technique is tested on a 33-bus system and 69-bus systems under base loading conditions. The following sections are included in the paper: Segment II contains the formulation for the computational problem. Segment III summarizes the proposed MPSO approach and mathematical problem flow. Segment IV displays the results of the IEEE radial distribution system under consideration. Finally, in Segment V, the paper's conclusion is provided.

II. PROBLEM FORMULATION

The fundamental goal of the DNRC issue is to compute the best radial functional design that minimizes network active losses while meeting the required operational constraints. Reduction in Active Power losses of Radial network (P_{loss}) is the primary goal of the DNRC issue, despite its operational constraints, which include network voltage level, feeder current carrying capacity, and network radial layout. The aim function of reducing active power losses is described as follows:

Minimize F = Minimum(P_{loss}) (1)

Subjected to:

$$V_{i_{min}} \leq V_i \leq V_{i_{max}} \quad i = 1,2,3,\ldots..N_b \tag{2}$$

$$I_i \leq I_{i_{max}} \quad i = 1,2,3,\ldots\ldots,(N_{br} + N_{ts}) \tag{3}$$

$$Det(A) = 1 \; or - 1 \; (radial\ system) \tag{4}$$

$$Det(A) = 0 \; (Non - radial\ system) \tag{5}$$

Where, (P_{loss}) is the overall loss of the system in active power; V_i is the bus I voltage magnitude; V_{max} and, V_{min} respectively, are the maximum and lowest voltage bus Constraints ($V_{max} = 1.0\ p.u$ &$V_{min} = 0.9$ p.u); $I_{i_{max}}$, I_i are the branch maximum current constraint and magnitude of Current respectively. A is the bus incidence matrix.

Fig. 1. depicts a single line schematic of the distribution feeder. And its power flow equation is as follows:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}\frac{(P_i^2+Q_i^2)}{|V_i^2|} \tag{6}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - L_{i,i+1}\frac{(P_i^2+Q_i^2)}{|V_i^2|} \tag{7}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2R_{i,i+1}P_i + X_{i,i+1}Q_i + (R_{i,i+1}^2 + X_{i,i+1}^2)\frac{(P_i^2+Q_i^2)}{|V_i^2|} \tag{8}$$

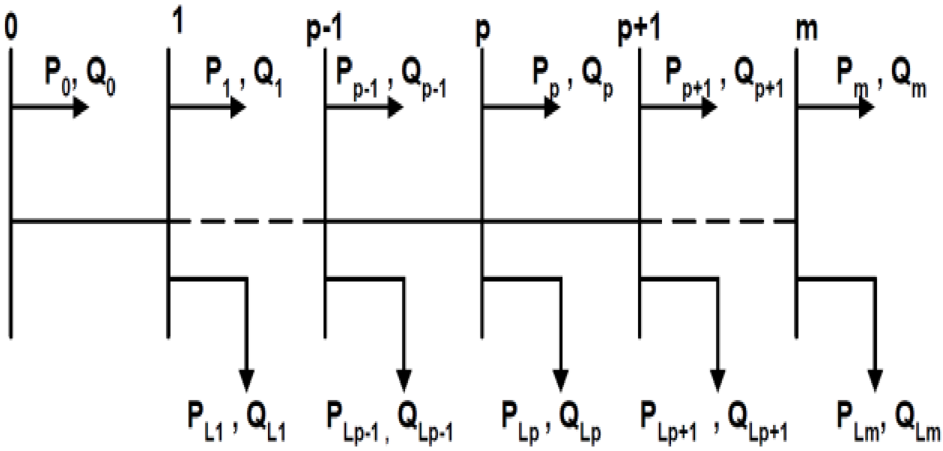

Fig. 1. Single Line Diagram of Main Feeder

Where, P_i is line active power that is flowing out of bus i.

Q_i is line compensative power that is flowing out of bus i.

P_{Li} is load active power that is at bus i.

Q_{Li} is load compensative power that is at bus i.

$R_{i,i+1}$ is line resistance that is between bus i and i +1.

$X_{i,i+1}$ is line reactance that is between bus i and i +1.

The active power losses among buses i and i +1 are estimated as follows:

$P_{L,Loss\,(i,i+1)} = R_{i,i+1} \frac{(P_i^2+Q_i^2)}{|V_i^2|}$(9)

The total active power losses on the line are calculated as follows:
$P_{Loss} = \sum_{i=1}^{k} P_{L,Loss\,(i,i+1)}$(10)

Where P_{Loss} is the overall network power loss, which is calculated by summing the feeder power losses of all line segments.

III. MODIFIED PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) [17] was initially developed by Eberhart and Kennedy in 1995. This approach is based on a self-learning population that is inspired by a bird flock coupled movement, a bee swarm, or a school of fish.

Several variants of PSO have been proposed during the last two decades to improve solution quality, speed of convergence, and application. Eberhart and Kennedy proposed the discrete form of PSO [18] by changing the search space to binary. The suggested Modified PSO is an alteration of binary PSO in which the particle velocity in search space is changed, narrowing the particle search to a higher quality solution. This section presents a mathematical layout for the suggested approach.

The velocity and location vectors for i^{th} particle in a D-dimensional search space can be provided as follows:

$$V_1 = (V_{i1}, V_{i2}, \dots\dots, V_{iD}),\; X_i = x_{i1}, x_{i2}, \dots\dots, x_{iD})$$

Similarly, the optimum earlier particle location is identified and encapsulated as:

$$P_{best\,1} = (p_{i1}, p_{i2}, \dots\dots, p_{iD}).$$

If the i^{th}particle is the best of all the particles in the group, it is represented as:

$$g_{best} = p_{bestg}\,(p_{g1}, p_{g2}, \dots\dots, p_{gD}).$$

The particle velocity and position are rearranged by Muhammad Junaid Tahir [24] in 2018as follows:

$v_{iD}^{k-1} = (1-w) * w * v_{iD}^{k+1} + w * v_{iD}^{k} + c_1 * r_1\left(p_{bestiD}^{k} - x_{iD}^{k}\right) + c_2 * r_2\left(g_{bestiD}^{k} - x_{iD}^{k}\right)$(11)

$x_{iD}^{k+1} = x_{iD}^{k} + x_{iD}^{k+1}$(12)

Where i = 1,2,3,..........,m, w is the weight of inertia, and c1 and c2 are the acceleration constants.r1 and r2 are random variables that vary between [0,1]; Weight Function may be determined as follows:

$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}}$(13)

w_{max} , w_{min} are the opening and closing weight values respectively; $iter_{max}$ are the maximum number of repetitions; $iter$ represents the current number of iterations.

To keep the velocities inside the range [0,1] in MPSO, sigmoid conversion is employed for velocity elements and restrict particle deployments to either 0 or 1.

$sig(v_{iD}^{k+1}) = \frac{1}{1+exp\,(-v_{iD}^{k+1})}$(14)

$x_{iD}^{k+1} = \begin{cases} 1, \; if\ \sigma < sig(v_{iD}^{k+1}) \\ 0, \; if\ \sigma \geq sig(v_{iD}^{k+1} \end{cases}$(15)

Abdelaziz et al offered a simple adjustment to binary PSO [15] by changing the iteration number and population size in the search space. Particle velocities are restricted to approximately maximum and lowest values [v_{max} ,v_{min}] using (16).

$v_{iD}^{k+1} = \begin{cases} v_{max} \quad if\ v_{iD}^{k+1} > v_{max} \\ v_{iD}^{k+1} if\ v_{iD}^{k+1} \leq v_{max} \\ v_{min} \quad if\ v_{iD}^{k+1} \leq v_{min} \end{cases}$ (16)

(17) is used to restrict the value of i^{th} particle velocity in D-dimension between the highest and lowest ranges.

$v_{iD}^{k+1} = \begin{cases} rand * \ v_{iD}^{k+1} \quad if\ \left|v_{iD}^{k+1}\right| = \left|v_{iD}^{k}\right| \\ \qquad v_{iD}^{k+1} \quad otherwise \end{cases}$(17)

The sequence of the approach provided in Fig. 2 is given. MPSO's three critical steps for resolving the DNRC issue are:

1. To define the range of dimensions.

2. To locate in the search space's corresponding dimensions.

3. Use MPSO to find the best solution in the search space.

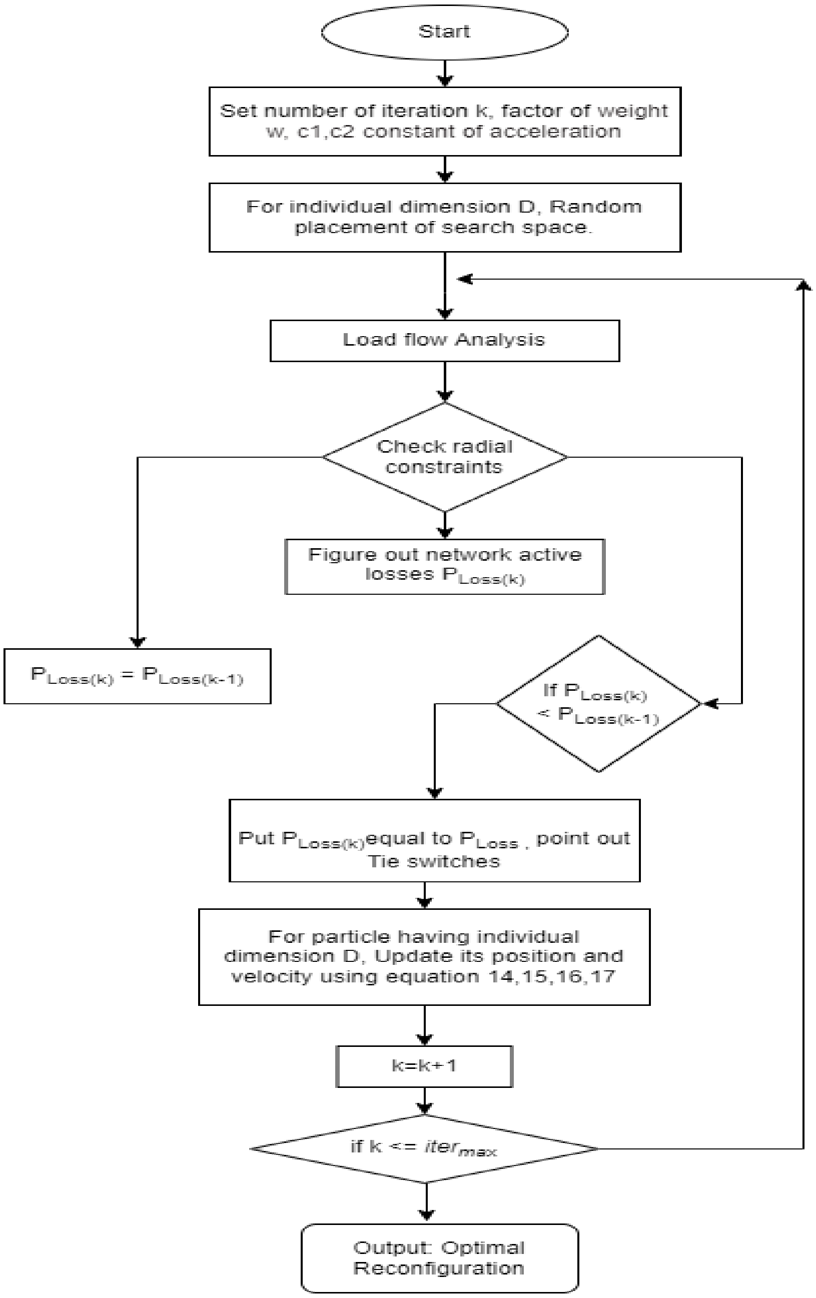

Fig. 2. Flowchart of MPSO method

When all the tie switches are locked, the set of dimensions in a radial network is identical to the set of loops generated. This dimension denotes a dimension in the search space that consists of loop branches. Network branches that do not present in any mesh are not included in any search space and so are not accounted for in the optimization approach. The common branching for loops and dimensions must have just one dimension that may be executed randomly at a time. The MPSO may be used to achieve the best possible result when the dimensions and individual dimensions of the search space are specified.

IV. DISCUSSION OF RESULTS

Case (i) : On IEEE 33-bus System

The given approach is tested using an IEEE 33-bus radial network. To calculate the efficacy of the proposed approach under base loading circumstances, a comparison of MPSO with GA and ACA for NR is allowed. To put the suggested approach to the test, MATLAB is utilized, and the simulations are run on a machine with an Intel(R)Core (TM)i5-6500 processor running at 3.20GHz and 8 GB of RAM.

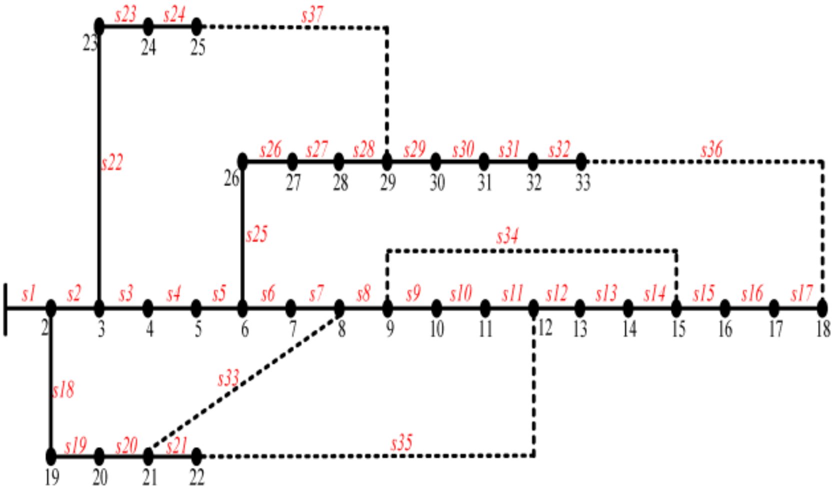

Fig. 3. Single Line Diagram of IEEE-33 Bus System

Fig. 3. depicts a single line schematic diagram of the IEEE 33 bus system. There are 5 typically open tie switches and 32 normally closed sectionalizing switches in the radial network. The five tie Switches are notably 33,34,35,36,37. In Fig. 3, the dotted lines represent the tie switches, while the solid lines show the sectionalizing switches.

The active power losses calculated prior to reconfiguration is 208.46kW, and the minimum voltage at bus 18 is 0.91075 p.u. Five loops are created when five tie switches are closed, as shown in Fig. 3. As a result, the dimensions of this network, 33 bus, are five. Table I displays the specific loops, dimensions, and search space for each dimension. The "S1" switch is not included in any loop and so is not considered for when MPSO sorts the best solution. The common switches of two dimensions are included at random in one dimension, as described in section III. Following an explanation of the search space and identification of the dimensions, the (MPSO) approach is offered to perceive the radial optimum reconfiguration for the base loading case circumstances.

The radial optimum reconfiguration under base loading conditions is also acquired using MPSO to measure the efficiency of the proposed method. Table II lists the parameters utilized in the MPSO power distribution system simulation.

Table I : LOOPS OF 33 BUS SYSTEM

Loops	Dimension	Switches
1	S_{d1}	8 ,9, 10, 11, 21, 33, 35
2	S_{d2}	2, 3, 4, 5, 6, 7, 18, 19, 20
3	S_{d3}	12, 13, 14, 34
4	S_{d4}	15, 16, 17, 29, 30, 31, 36, 32
5	S_{d5}	22, 23, 24, 25, 26, 27, 28, 37

Table II : PARAMETERS OF MPSO

Parameters	MPSO
Maximum Weight	0.9
Minimum Weight	0.4
$iter_{max}$	60
c_1,c_2	2.0

A. Distribution Losses:

Table III demonstrates that when the NR is accomplished via the MPSO approach, the reduction in active power loss is more visible in base loading. Power losses for the Basic condition are 208.46 kW prior to optimal switching design., which are reduced to 33.36% after switching configuration using MPSO, compared to 31%

when SPSO [15] is used, 32.07% when GA [19]is used, and 33.08% when ACA [20] is used. As a result, it can be concluded that MPSO outperformed SPSO, GA, and ACA in terms of reducing active power losses.

TABLE III. COMPARISON OF MPSO WITH OTHER TECHNIQUES.

Item	**Initial Configuration**	**Final Configuration**			
		GA [19]	**ACA [20]**	**SPSO [15]**	**Proposed Method [MPSO]**
Tie Switches	33,34,35,36,37	7,11,14,28,32	7,9,14,32,37	7,9,14,32,37	**7,9,14,32,37**
Power Loss (KW)	208.459	141.6	139.55	143.8	**138.9275**
Loss Reduction (%)	------	32.07	33.08	31	**33.355**
Minimum Voltage p.u	0.91075	0.9290	0.9375	0.936	**0.94234**

B. Voltage Profile of the Network:

The voltage profile is improved by the switching configuration implemented as a consequence of the provided methodologies; when NR is performed by the MPSO algorithm, a significant increase is observed for base loading situations. The effect of switching arrangement on voltage altitudes using MPSO is depicted visually in Fig. 4. After reconfiguration, the bus's least voltage is increased to 0.94234 p.u. at bus 32 using the MPSO method for base Case.

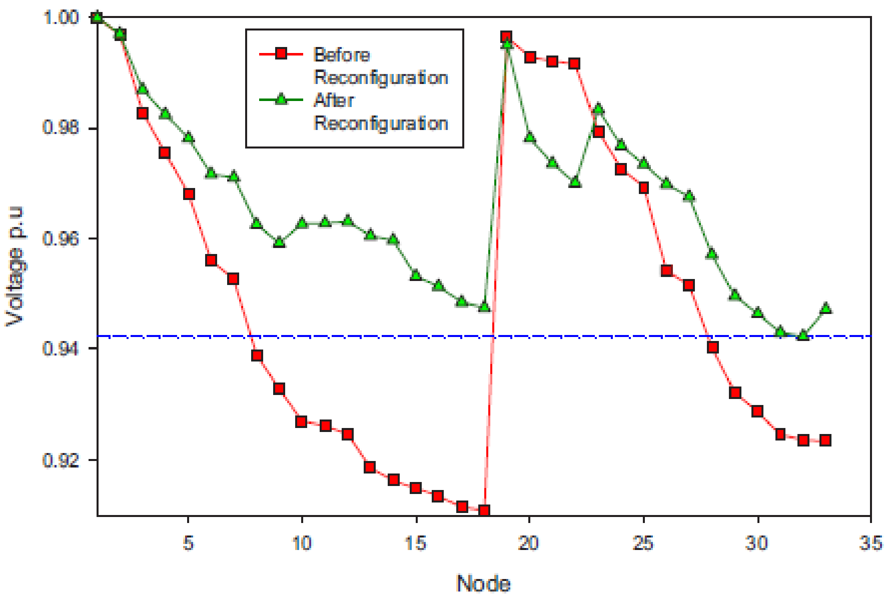

Fig. 4. Voltage Profile of IEEE 69 Bus system Before & After Reconfiguration by MPSO.

Case (ii) : On IEEE 69-bus System

The Proposed approach is tested using an IEEE 69-bus radial network. To calculate the efficacy of the proposed approach under base loading circumstances, a comparison of MPSO with GA and ACA for NR is allowed. To put the suggested approach to the test, MATLAB is utilized, and the simulations are run on a machine with an Intel(R)Core (TM)i5-6500 processor running at 3.20GHz and 8 GB of RAM.

Fig. 5. depicts a single line schematic diagram of the IEEE 69 bus system. There are 5 typically open tie switches and 68 normally closed sectionalizing switches in the radial network. The five tie Switches are notably 69,70,71,72,73. In Fig. 5, the dotted lines represent the tie switches, while the solid lines show the sectionalizing switches.

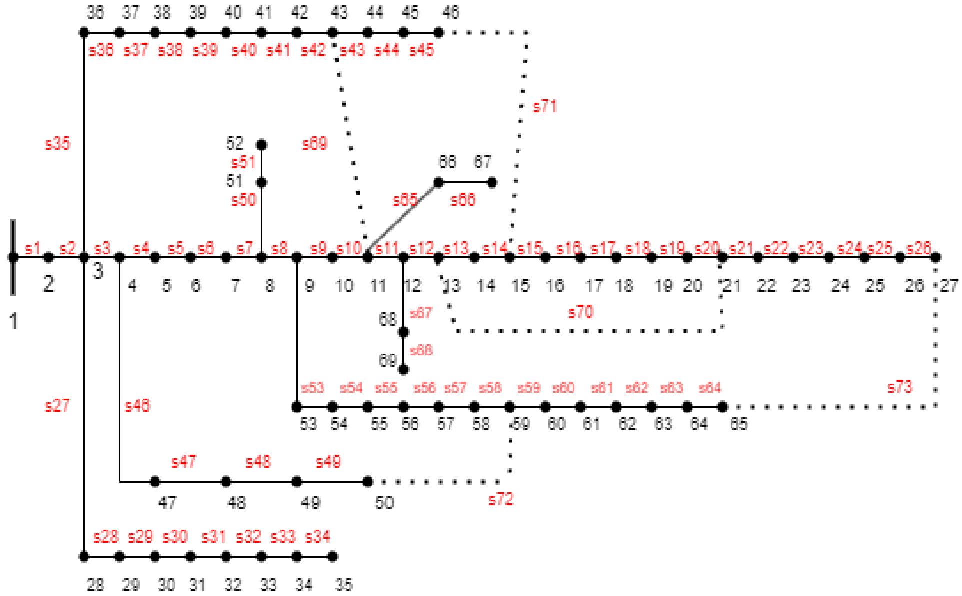

Fig. 5. Single Line Diagram of IEEE-69 Bus System

The active power losses calculated prior to reconfiguration is 225.024kW, and the minimum voltage at bus 18 is 0.90918 p.u. Five loops are created when five tie switches are closed, as shown in Fig. 5. As a result, the dimensions of this network, 69 bus, are five. Table IV displays the specific loops, dimensions, and search space for each dimension. The "S1" switch is not included in any loop and so is not considered for when MPSO sorts the best solution. The common switches of two dimensions are included at random in one dimension, as described in section III. Following an explanation of the search space and identification of the dimensions, the (MPSO) approach is offered to perceive the radial optimum reconfiguration for the base loading case circumstances.

The radial optimum reconfiguration under base loading conditions is also acquired using MPSO to measure the efficiency of the proposed method. Table II lists the parameters utilized in the MPSO power distribution system simulation.

Table IV : LOOPS OF 69 BUS SYSTEM

Loops	**Dimension**	**Switches**
1	S_{d1}	11, 12, 13, 14, 43, 44, 45, 71
2	S_{d2}	4,5,6,7,8,46,47,48,49,52,53,54,55,56,57,58
3	S_{d3}	3,9,10,35,36,37,38,39,40,41,42,69
4	S_{d4}	21,22,23,24,25,26,59,60,61,62,63,64,73
5	S_{d5}	15, 16, 17, 18, 19, 20, 70

A. Distribution Losses:

Table V demonstrates that when the NR is accomplished via the MPSO approach, the reduction in active power loss is more visible in base loading. Power losses for the Basic condition are 225.024 kW prior to optimal switching design., which are reduced to 67.89% after switching configuration using MPSO, compared to 55.7% when ICA [21] is used, 55.5% when NSGA-II [22] is used, and 55.72% when Boolean-PSO [23] is used. As a result, it can be concluded that MPSO outperformed ICA, NSGA-II, and Boolean-PSO in terms of reducing active power losses.

TABLE V. COMPARISON OF MPSO WITH OTHER TECHNIQUES.

Item	**Initial Configuration**	**Final Configuration**			
		ICA [21]	**NSGA-II [22]**	**Boolean-PSO [23]**	**Proposed Method [MPSO]**
Tie Switches	69,70,71,72,73	69,13,14,50,47	61,69,58,13,12	61,14,58,69,70	**14,58,62,69,70**
Power Loss (KW)	225.0236	99.62	99.911	99.594	**72.2516**
Loss Reduction (%)	------	55.70	55.57	55.72	**67.8916**
Minimum Voltage p.u	0.90918	0.9428	0.9378	0.9428	**0.96002**

B. Voltage Profile of the Network:

The voltage profile is improved by the switching configuration implemented as a consequence of the provided methodologies; when NR is performed by the MPSO algorithm, a significant increase is observed for base loading situations. The effect of switching arrangement on voltage altitudes using MPSO is depicted visually in Fig. 6. After reconfiguration, the bus's least voltage is increased to 0.96002 p.u. using the MPSO method for base Case.

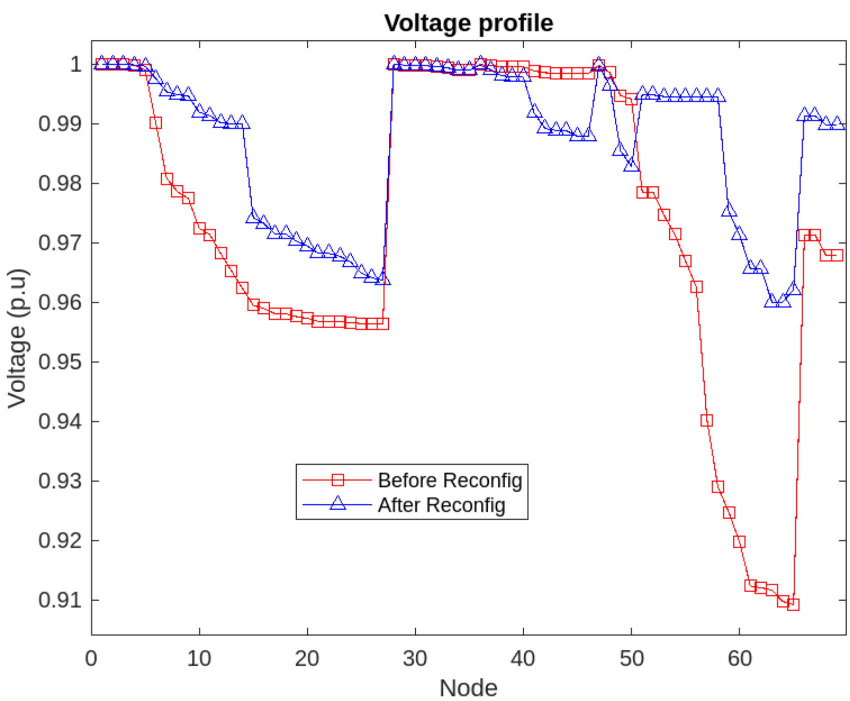

Fig. 6. Voltage Profile of IEEE 69 Bus system Before & After Reconfiguration by MPSO

V. CONCLUSION

In this article, MPSO is effectively implemented for IEEE 33 bus & IEEE 69 bus systems under base loading circumstances to reduce active power losses by optimizing the power distribution radial system and improved voltage profile. The simulation results are compared with GA, ACA, SPSO algorithms for 33 bus system and with ICA, NSGA-II, Boolean PSO algorithms for 69 bus system. The results show that MPSO outperformed the other analyzed algorithms in terms of loss minimization and enhancement to the voltage profile of a radial distribution network.

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