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Radial Distribution System Network Reconfiguration for Reduction in Real Power Loss and Improvement in Voltage Profile, and Reliability

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***Abstract*— Distribution systems play a crucial role in delivering power to customers and bridging the gap between bulk power transmission and end-users. Increasing energy demand due to factors like industrial development and population growth necessitates efficient distribution system management. A low X/R ratio in distribution networks leads to higher real power losses, lower voltage profiles, and reduced system reliability. Selecting optimal combinations of sectionalizing and tie switches for network reconfiguration is a complex and time-consuming task. This article introduces the Modified load flow (MLF) method, which combines the backward/forward sweep method with an effective approach for selecting sectionalizing and tie switches to minimize real power loss. The MLF method offers advantages such as ease of implementation, requiring fewer control parameters, and scalability to large distribution systems. The proposed MLF method is compared with particle swarm optimization (PSO) and other existing algorithms in literature such as the cuckoo search algorithm (CSA), Improved sine cosine algorithm (ISCA), and Improved harmony search algorithm (IHSA). Results obtained from MLF and PSO to IEEE-33, 69, and 118 bus radial distribution systems demonstrate significant reductions in real power loss, with MLF outperforming PSO in terms of efficiency and effectiveness. Voltage profiles at critical buses before and after network reconfiguration are examined, showing improvements in MLF better than the PSO method. Various reliability indices are evaluated to assess system performance before and after network reconfiguration, demonstrating improvements in system reliability. Overall, the proposed modified load flow method offers a promising approach to address the challenges of real power losses and system reliability in radial distribution systems.*

Keywords—Radial distribution system, network reconfiguration, modified load flow, particle swarm optimization, distributed generation, substation.

1. INTRODUCTION

Network reconfiguration is a fundamental aspect of power distribution system management. By strategically adjusting the configuration of switches, such as sectionalizing and tie switches, utilities can optimize the flow of electricity, reduce losses, enhance reliability, and improve voltage regulation. Sectionalizing switches are used to isolate sections of the distribution network, allowing for targeted restoration efforts in case of outages and reducing the impact of faults. Tie switches, on the other hand, provide flexibility by allowing different sections of the network to be interconnected or isolated based on operational requirements.

In the last decade, many researchers have proposed numerous solutions for optimal reconfiguration of the distribution system. The research in [1] developed a mathematical model for the NR. The authors claimed that this technique is more effective in terms of solution time and computational complexity. Salkuti and Battu [2] developed an effective approach for NR in RDS that minimizes loss and improves voltage profile. Srividhya *et al.* [3] solved the NR problem in RDS for three indices by increasing reliability and reducing power loss and voltage deviation using a binary PSO. The Cuckoo search algorithm (CSA) applied for NR in RDS to reduce power loss while improving bus voltage in articles [4, 5]. The authors proved that this approach requires fewer initialization parameters and computational time.

In [6], Grey wolf optimization (GWO) was used to diminish power loss and boost the voltage profile in RDS by integrating DG at the best location and capacity. The effectiveness of this algorithm was tested on various RDS with different sorts of DGs. Proper DG sizing and positioning in RDS with NR is a complex problem due to the huge solution search space caused by non-radial network architecture. The authors of article [7] solve this problem using the water cycle algorithm (WCA). It is applied to 33 and 69 RDS. The outcomes show a higher percentage reduction in power loss compared to existing methods. Kumar *et al.* [8] reduced real power loss while improving reliability in RDS when combined with DG and NR. The loss sensitivity approach is used to choose the appropriate location of DG and switch combination. In [9], a new NR approach for minimizing overall active power loss was developed using the salp swarm algorithm (SSA). The study [10, 11] presented concurrent DG allocation and NR for RDS utilizing a modified plant growth simulation approach (MPGSA) and the multi-swarm cooperative PSO, and resulted in a larger reduction in power loss. In Ref. [12], authors devised a hybrid PSO to discover the appropriate DG capacity while maximizing system loadability and minimizing power loss. The authors of the study [13] solve integration of capacitor bank with NR using a quasi-reflected slime mould method (QRSMA). The key advantage

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of this strategy is that it is independent of the successive bus numbering structure. As a result, it is easily adaptable to larger distribution systems as well. Artificial intelligence is also one of the solutions for NR in RDS described in literature [14]. In Ref. [15], a unique algorithm for NR is proposed that integrates DGs and EVs to recover the power quality and economics of RDS. For that stochastic behaviour of load, DGs and EVs are considered. In Ref. [16], an imperialist competitive algorithm (ICA) is devised to minimize reliability indices through the simultaneous allocation of sectionalizing switches and DER. A modified version of the Monte Carlo simulation technique was reported in [17] for evaluating RDS adequacy indices in the company of DG. Another method for reducing power loss in RDS is to integrate DPFC (Distributed power flow controller) at the best location and size as presented in [18]. A new Jellyfish optimization technique is designed to fix the perfect position and size of DPFC in distribution system. The authors demonstrated that their strategy achieves a high convergence rate with fewer iterations, reducing power loss. Raut and Mishra [19] used an improved sine cosine algorithm (ISCA) to solve NR in RDS. The authors proposed that ISCA still requires fine-tuning parameters to minimize objective function and recover convergence speed. Khetrapal [20] solved NR problem for medium and large-scale RDS using the Improved Harmony Search Algorithm (IHSA). In this paper, various loading situations are also taken into account.

In the proposed work, authors describe the implementation of NR on RDS to diminish total real power loss while concurrently improving the voltage profile at critical buses and system reliability. Because of the low X/R ratio, the load flow methods used in transmission systems are not relevant to DS. In this research work, the MLF method is performed using the backward/forward sweep method, and an algorithm is developed to determine the best sectionalizing and tie switch combinations to minimize the TRL of the RDS. PSO is also used to compare the findings obtained by the MLF method. This technique is used to reconfigure the network for three test systems i.e. IEEE-33, 69, and 118 bus, and the outcomes are contrasted with those of other existing techniques.

The paper is planned as follows: Section 1, presents an introduction about the research topic. Section 2 describes the problem formulation. Section 3 presents an LFA of RDS using the Backward/forward sweep method and a proposed algorithm for NR to minimize TRL. Section 4 gives a proposed algorithm for NR using Particle swarm optimization (PSO) to minimize TRL. Section 5 elaborates on results and discussion for IEEE 33, 69, and 118 bus RDS, and Section 6 presents conclusions.

2. PROBLEM FORMULATION

Mathematically, the minimization of total real power loss (TRL) through network reconfiguration can be stated as follows using Eq. (1).

$$TRL = \sum_{j=1}^{N_{br}} I_j^2 \mathrm{R}_j \tag{1}$$

Where N_{br} is the total number of branches, and I_j is real part of current in j^{th} branch, and R_j resistance of j^{th} branch.

Subjected to different constraints

A) *Power flow equation*

$$P_S = TRL + \sum_{i=1}^{N_b} P_i \tag{2}$$

$$Q_S = TQL + \sum_{i=1}^{N_b} Q_i \tag{3}$$

Where P_S and Q_S are real and reactive power produced by substation, TRL and TQL are the total real and reactive power loss of RDS, N_b is total number of buses, P_i and Q_i are real and reactive power at i^{th} bus.

B) *Voltage limits of bus*

$$0.95 \leq V_i \leq 1.02 \; for \; \mathrm{i} = 1, 2, \ldots\ldots\mathrm{N_b} \tag{4}$$

Where V_i is the voltage at i^{th} bus .

C) *Capacity limit of feeder*

$$0 \leq I_j \leq I_{j,\max} \; for \; \mathrm{i} = 1, 2, \ldots\ldots\mathrm{N_{br}} \tag{5}$$

Where $I_{j,\max}$ is maximum capacity of j^{th} branch current.

D) *Radial configuration* After NR, the system must continue to function radially. To put it another way, NR does not permit loops.

2.1. Reliability indices evaluation

A crucial part of organizing distribution network upgrades is reliability analysis, which helps satisfy new and growing demands. To assess the system's reliability, load point indices are employed.

The following equations are used to assess the fundamental reliability indices of the system at each load point, including system failure rate ($\lambda_{sys,i}$), system average outage duration ($U_{sys,i}$), and system average repair time ($r_{sys,i}$), respectively at i^{th} bus.

$$\lambda_{sys,i} = \sum_i \lambda_j (\text{per year}) \tag{6}$$

$$U_{sys,i} = \sum_i \lambda_j r_j (\text{hrs/year}) \tag{7}$$

$$r_{sys,i} = \frac{U_{sys,i}}{\lambda_{sys,i}} (\text{hrs}) \tag{8}$$

Where λ_j and r_j are failure rate and repair time of j^{th} branch N_i is total number of customers connected at i^{th} load point.

Eqs. (9) to (15) is used to estimate the reliability indices based on energy and customers.

SAIFI: System average interruption frequency index:

$$SAIFI = \frac{\sum \lambda_{sys,i} N_i}{\sum N_i} (\text{interuptions/customer}) \tag{9}$$

SAIDI: System average interruption duration index:

$$SAIDI = \frac{\sum U_{sys,i} N_i}{\sum N_i} (\text{hrs/customer}) \tag{10}$$

CAIDI: Customer average interruption duration index:

$$CAIDI = \frac{\sum U_{sys,i} N_i}{\sum \lambda_{sys,i} N_i} (\text{hrs/customer interruption}) \tag{11}$$

ASAI : Average system availability index:

$$ASAI = \frac{\sum N_i \times 8760 - U_{sys,i} N_i}{\sum N_i \times 8760} \tag{12}$$

ASUI: Average system unavailability index:

$$ASUI = \frac{\sum U_{sys,i} N_i}{\sum N_i \times 8760} \tag{13}$$

ENS: Energy not supplies:

$$ENS = \sum L_i U_{sys,i} (\text{kwh/year}) \\ \text{where Li} = \frac{Energy\ \text{consumed in year}}{8760} \tag{14}$$

AENS: Average energy not supplies:

$$AENS = \frac{\sum L_i U_{sys,i}}{\sum N_i} (\text{kwh/year customer}) \tag{15}$$

3. LFA of RDS USING THE BACKWARD/FORWARD SWEEP METHOD

Reconfiguring the network requires first performing a load flow study. In this work, LFA is executed with the backward/forward sweep approach [21]. The following are detailed algorithms for LFA.

Step 1: Set voltages to zero.

$$V_i^{(0)} = 1 < 0^0 \text{ for i} = 2, 3, \ldots\ldots \text{N}_\text{b} \tag{16}$$

Step 2: Set the iteration count to t=1.

Step 3: Use Eq. (17) to compute load current at each iteration.

$$I_i^{(t)} = \left(\frac{P_i + jQ_i}{V_i^{(t-1)}} \right)^* \text{for i} = 2, 3, \ldots\ldots \text{N}_\text{b} \tag{17}$$

Where P_i is real and Q_i reactive power at i^{th} bus.

Step 4: Use Eq. (18) to calculate branch current, also known as backward sweep.

$$\text{I}_{mn}^{(t)} = \text{I}_n^{(t)} + \sum all \text{ current of branches} \tag{18}$$

Where I_{mn} is branch current between m and n.

Step 5: Use Eq. (19) to determine the voltages at each bus, also known as the forward sweep.

$$V_n^{(t)} = \text{V}_m^{(t)} - \text{Z}_{\text{mn}} \text{I}_{mn}^{(t)} \tag{19}$$

Step 6: Calculate error at each bus using Eq. (20).

$$e_i^{(t)} = \left| V_i^{(t)} - V_i^{(t-1)} \right| \text{for i} = 2, 3, \ldots\ldots\ldots \text{N}_\text{b} \tag{20}$$

Step 7: Use Eq. (21) to save the maximum error.

$$e_{\max}^{(t)} = \max\{\text{e}_2^{(t)}, \text{e}_3^{(t)}, \text{e}_4^{(t)}, \ldots\ldots\ldots\ldots, \text{e}_{N_b}^{(t)}\} \tag{21}$$

Step 8: If the situation is met as specified by Eq. (22). Print the total real power loss (TRL), and voltages at each bus. If not, move to step 3 and adjust the iteration count to $t = t + 1$.

$$e_{\max}^{(t)} \leq \varepsilon \quad \text{where } \varepsilon(tolerance) = \ 0.0001 \tag{22}$$

3.1. Computational algorithm of modified load flow (MLF) method for NR aimed at minimizing real power loss

The suggested algorithm looks for a superior switching configuration that lowers TRL, boosts voltage profiles, and increases reliability as follows:

Step 1: Read the system line, load, tie switches (N_{tie}), and reliability data [22].

Step 2: Execute LFA for the base case [21]. Evalaute for the base case and store it in a temporary variable.

Step 3: Evaluate various reliability indices decribed in section 2.1.

Step 4: Choose system's tie switches in the following step. The process ends if the no of tie switches (k) that have been chosen up to this point is ($k >= N_{tie}$) . Move on to the next stage if ($k < N_{tie}$).

Step 5: Next, verify voltage at both ends i.e. the sending (V_{se}^{tie}) and receiving ends (V_{re}^{tie}). Add a tie switch to the sending end and open the branch attached to the receiving end if ($V_{se}^{tie} > V_{re}^{tie}$). If the, ($V_{se}^{tie} <= V_{re}^{tie}$) add a tie switch to the receiving end node. Open the branch that is associated to the sending end.

Step 6: Execute the LFA once more for modified network and assess network's overall real power loss (TRL^n).

Step 7: Next step involving measuring the voltages of the branch which was opened during network if ($V_{se}^{br} > V_{re}^{br}$) and ($\text{TRL} - \text{TRL}^\text{n} > error$). Then TRL is modified and sent to different variable. Finally opened the branch is added to the sending end node which is associated to the receiving end and load flow program is executed , and undergoing same analysis. Proceed to step 4 and choose the next tie switch if the criteria are not met.

Step 8: Evaluate numerous reliability indices for the modified network.

Fig. 1 shows detailed flow chart for NR of RDS for real power loss minimization using MLF method.

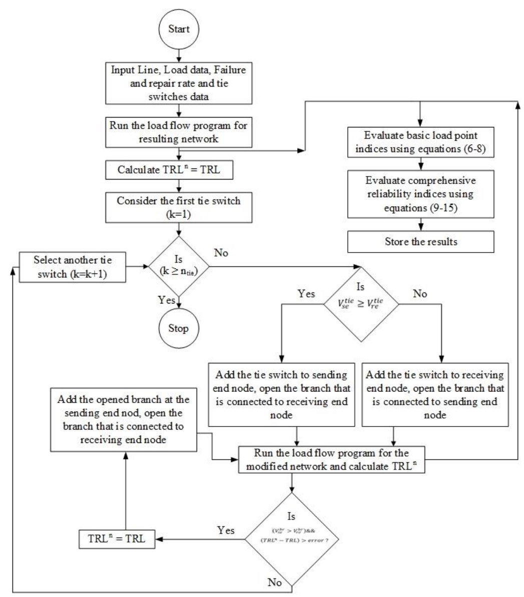

Fig. 1. Flow chart for MLF for NR of RDS for minimization of TRL.

4. COMPUTATIONAL ALGORITHM FOR NR USING PARTICLE SWARM OPTIMIZATION (PSO)

PSO aims to find ideal combination of sectionalizing and tie swiches in RDS to minimize TRL [23]. The algorithm can be outline as follow:

Step 1: Input system load and line data, and intialize parametrs such as population size (N_p) and number of tie switches (N_{tie}).

Step 2: Generate a specified number of particles randomly.

Step 3: Calculate the objective function i.e.TRL for each particle, and the position of each particle with minimum TRL value.

Step 4: Identify the best local position value (P_b) from all individual particles' TRL values, and determine the best global position value (G_b) among best (P_b) values.

Step 5: Update velcitiy of all particle using Eq. (23).

$$v_{i,j}^{(t+1)} = \omega v_{i,j}^{(t)} + \text{c}_1 \text{r}_{1,j}^t [\text{P}_{b,i}^t - \text{X}_{i,j}^t] + \text{c}_2 \text{r}_{2,j}^t [\text{G}_{b,i}^t - \text{X}_{i,j}^t] \tag{23}$$

Table 1. Parameters selected and applied for three standard RDS using both methods.

Method/algorithm	33 and 69 bus RDS	118 bus RDS
MLF	No of sectionalizing switches (S)= 32 (33 RDS) & 68 (69 RDS) N_{tie}=5 t_{max}=100	No of sectionalizing switches (S)= 117 N_{tie}=15 t_{max}=500
PSO	NP=30 N_{tie}=5 t_{max}=100 C_1=2 and C_2=1.5 $\omega_{\max}$=0.9 and $\omega_{\min}$=0.4	NP=30 N_{tie}=15 t_{max}=500 C_1=2 and C_2=1.5 $\omega_{\max}$=0.9 and $\omega_{\min}$=0.4

Where c_1 and c_2 are acceleration constants and ω is interia constant.

$P^{t}_{b,i}$ is best position of i^{th} particle at 't' iteration.

$G^{t}_{b,i}$ is gest global position of i^{th} particle at 't' iteration.

r_1 and r_2 are random numbers between [0,1].

$v^{(t)}_{i,j}$ is velocity of i^{th} particle at 't' iteration.

$v^{(t+1)}_{i,j}$ is updated velocity of i^{th} particle at 't+1' iteration.

$X^{(t)}_{i,j}$ is position of i^{th} particle at tth iteration.

Typically, a big inertia constant value (ω) is high initially, allowing all particles to move freely in the search space in small steps, and then gradually diminishes. Eq. (24) describes the positive outcomes that have been obtained with a decreasing value of 'ω' positively influences the algorithm's performance, as described in Eq. (24).

$$\omega = \omega_{\max} - \left(\frac{\omega_{\max} - \omega_{\min}}{t_{\max}}\right)t \tag{24}$$

Where $\omega_{\max}$ and $\omega_{\min}$ are maximum and minimum inertia weight.

Step 6: Update each particle position using Eq. (25).

$$X^{(t+1)}_{i,j} = X^{(t)}_{i,j} + v^{(t+1)}_{i,j} \tag{25}$$

Step 7: Recalculate the objective function using the new positions of all particles. If the new TRL value for any particle is well than the earlier value, update the fitness value of that particle using Eq. (26):

$$P^{(t+1)}_{b,i} = \left\{ \begin{array}{l} P^{(t)}_{b,i},\ \text{if (f(}X^{(t+1)}_{i} > P^{(t)}_{b,i}) \\ X^{(t+1)}_{i},\ \text{if (f(}X^{(t+1)}_{i} \leq P^{(t)}_{b,i}) \end{array} \right\} \tag{26}$$

Step 8: Update the G_b value based on new fitness value using Eq. (27).

$$G_b = \min\{P^{t}_{b,i}\} \tag{27}$$

Step 9: If the iteration count has reached to the t_{max} then the algorithm stops, and the current G_b value gives the final TRL value. Otherwise, repeat from Step 2.

Step 10: The final G_b values provides the optimal reconfiguration status of radial distribution system.

5. RESULTS AND DISCUSSION

Network reconfiguration problems with minimum TRL are assessed using the MLF method, verified using PSO, and compared to outcomes of previously published algorithms. The critical buses are also identified using both methods. Both algorithms are implemented and applied on three standard RDS i.e. IEEE-33, 69, and 118. For each test system, several reliability indices are assessed. The article [22] provides a thorough description of how these reliability indices were calculated. Table 1 represents parameters chosen and applied for three standard RDS using both methods.

5.1. IEEE-33 BUS RDS

The 33 bus RDS has a 12.66 kV as a base voltage and 100 as a base MVA. This system has an aggregate active and reactive load of 3715 kW and 2300 kVAR respectively. Single-line diagram (SLD) for this test system is shown in Fig. 2. It has five tie switches (S33 to S37), each represented by a red colour line in Fig. 2, and 32 sectionalizing switches (S1 to S32) [24].

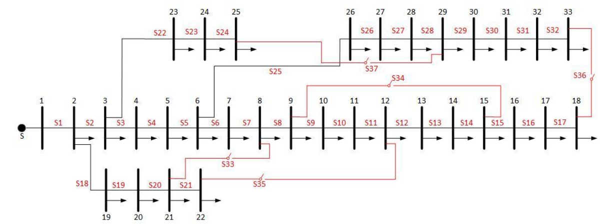

Fig. 2. SLD of IEEE-33 bus RDS.

TRL for the base case i.e. before NR obtained by both method is 210.998 kW with all five tie switches S33 to S37 opened and sectionalizing switches S1 to S32 closed. The critical buses identified before NR are namely 6 to 18 and 26 to 33. Buses classified as critical are those that frequently deviate from their lowest bound as described in Eq. (4). The minimum voltage (V_{min}) is got as 0.9037 per unit at bus 18. Table 2 displays a comparison of outcomes obtained after performing NR by various algorithms for IEEE-33 bus RDS.

Result shows NR obtained by MLF method for this test system with switches S7, S9, S14, S32 and S37 are opened and TRL are diminished from 210.998 kW to 138.548 kW. Fig. 3 shows optimal configuration obtained by both method for this RDS. Table 2 shows that MLF method achieved the biggest decrease in real power loss i.e. 34.336% when compared to base case and outperforming PSO, CSA and ISCA. It is noted that after reconfiguration, critical buses are reduced to 29, 30, 31, 32, and 33. MLF method resulted in slightly higher minimum voltage at bus 31compared to PSO.

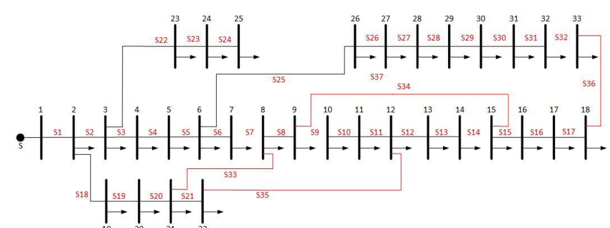

Fig. 3. SLD of IEEE-33 bus RDS with network reconfiguration.

Fig. 4 shows a comparison of convergence curve for 33 bus RDS obtained by NR using MLF and PSO. MLF method shows faster convergence compared to PSO, requiring fewer iterations to reach convergence.

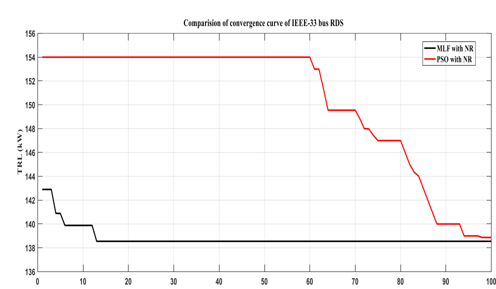

Fig. 4. Comparison of convergence curves of IEEE-33bus RDS.

Table 2. Comparison of obtained results of 33 bus RDS.

Method/algorithm	Open switches (S)	Total real power loss (TRL) (kW)	Critical buses	V_{min} (Per unit)	% Real power loss reduction
Base case (Before NR)	33, 34, 35, 36 and 37	210.998	6 to 18, 26 to 33	@bus 18 i.e.0.9037	-
MLF (After NR)	7, 9, 14, 32 and 37	138.548	29, 30, 31,32 and 33	@bus 31 i.e.0.9432	34.336
PSO (After NR)	7, 9, 14, 32 and 37	138.86	29, 30, 31,32 and 33	@bus 31 i.e.0.938	34.188
CSA [5]	7, 9, 14, 32 and 37	138.87		0.94235	31.81
ISCA [19]	7, 9, 14, 32 and 37	139.55			31.137

Table 3. Evaluation of reliability indices of 33 bus RDS.

Reliability index	Base case	After network reconfiguration
SAIFI	2.412	2.3262
SAIDI	2.043	1.5439
CAIDI	0.847	0.6637
ENS	7097.95	5493.5
AENS	0.3899	0.3018
ASAI	0.9997	0.9998
ASUI	0.00024	0.000176

Fig. 5 represents comparison of voltage magnitudes at critical busses for base case and after NR using both methods. Voltages are progressively improved after NR compared to the base case using both methods. MLF method shows superior improvement in voltage magnitudes compared to PSO.

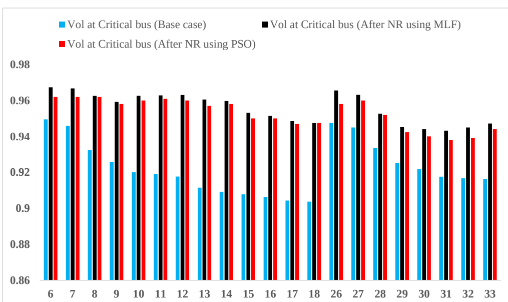

Fig. 5. Comparison of voltage magnitudes at critical buses before and after NR of 33 bus RDS.

Simultaneously, using MATLAB programming, assessment of various energy- and customer-based reliability indices before and after NR., as shown in Table 3. System reliability data collected for this test system is sourced from Ref. [25]. Significant improvements observed in most reliability indices after NR. Customer-based reliability indices such as SAIFI, SAIDI, and CAIDI show notable decreases after NR. Energy-based reliability indices such as ENS and AENS exhibit considerable reductions after NR. ASAI shows a slight improvement after NR.

5.2. IEEE-69 BUS RDS

The 69 bus is medium scale RDS comprising of 68 sectionalizing switches (S1 to S68) and five tie switches (S69 to S73) as exposed in Fig. 6. The system total active and reactive loads are 3801 kW and 2694 kVAR respectively [26]. For base case TRL and V_{min} before NR obtained by both methods are 224.903 kW and 0.9097 per unit (at bus 54). The initial opened tie switches are S69 to S73. For this system, critical buses that were determined before NR are specifically 57 to 65.

The ideal configuration for this system obtained by both method is revealed in Fig. 7. The optimal configuration involves opened switches S14, S57, S61, S69 and S70. Table 4 displays comparison of outcomes found for NR for 69 bus RDS using MLF method and PSO, other existing algorithms in literatures. It is notified that percentage reduction in real power loss got by MLF method is 56.395 with reference to base scenario is superior as compared to PSO and better as compared to CSA and ICSA. It is observed that, after NR, only bus 61 remains critical with an improved minimum voltage.

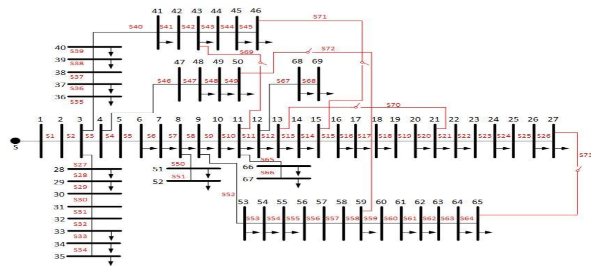

Fig. 6. SLD of IEEE-69 bus RDS.

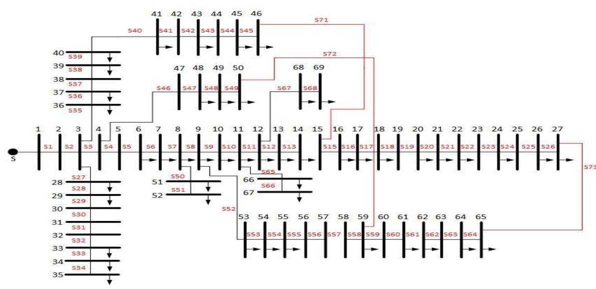

Fig. 7. SLD of IEEE-69 bus RDS with network reconfiguration.

A comparison of the convergence curve for the 69 bus RDS produced by NR utilizing MLF and PSO is shown in Fig. 8. It seems that the MLF method demonstrates faster convergence compared to PSO.

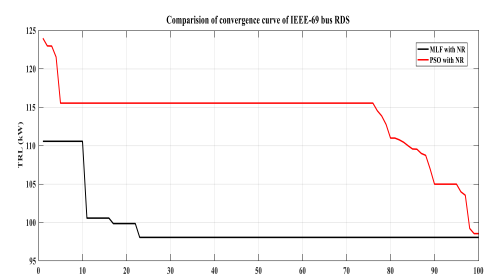

Fig. 8. Comparison of convergence curves of 69 bus RDS.

The voltage profiles at critical busses for the base scenario and after NR using both approaches are compared in Fig. 9. It was observed that, when employing both approaches, voltages are gradually enhanced following NR compared to the base scenario, with MLF approach yielding better results.

As indicated in Table 5, various reliability indices were evaluated concurrently before and after NR. NR notes an improvement in the reliability indices. For this test, system reliability data is gathered from Ref. [25].

5.3. IEEE-118 BUS RDS

The 118 bus is large scale RDS consist of 117 sectionalizing switches (S1 to S117) and 15 tie switches (S118 to S132) represented by red color lines as shown in Fig. 10. There are

Table 4. Comparison of obtained results of 69 bus RDS.

Method/algorithm	Open switches (S)	TRL (kW)	Critical buses	V_{min} (Per unit)	% Real power loss reduction
Base case (Before NR)	69, 70, 71, 72 and 73	224.903	57 to 65	@bus 64 i.e.0.909	-
MLF (After NR)	14, 57, 61, 69 and 70	98.068	61	@bus 61 i.e.0.9462	56.395
PSO (After NR)	14, 57, 61, 69 and 70	98.566	61	@bus 61 i.e.0.943	56.178
CSA [5]	14, 57, 61, 69 and 70	98.568		0.9495	56.182
ISCA [19]	14, 56, 61, 69 and 70	98.605			56.17

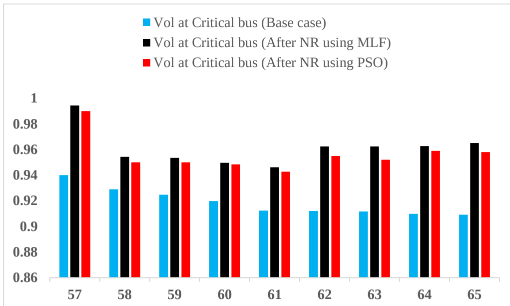

Fig. 9. Comparison of voltage magnitudes at critical buses before and after NR of 69 bus RDS.

Table 5. Evaluation of reliability indices of 69 bus RDS.

Reliability index	Base case	After network reconfiguration
SAIFI	2.2206	1.6303
SAIDI	1.6673	1.4192
CAIDI	0.7508	0.8705
ENS	6250.07	5330.708
AENS	0.3662	0.3124
ASAI	0.9998	0.9998
ASUI	0.00019	0.00016

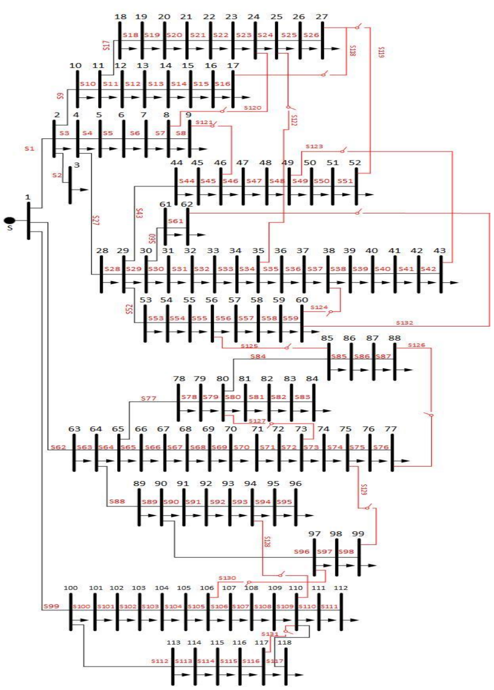

Fig. 10. SLD of IEEE-118 bus RDS.

22709.7 kW of real power and 17041.1 kVAR of reactive load [27]. For the base system TRL and minimum bus voltage obtained before NR using both methods are 1298.04 kW and 0.8691 per unit at bus 77 as revealed in Table 6. The initial opened tie switches are from S118 to S132. The following buses have been identified as critical buses for base case: 34-43, 67-77, 99, 107-112 and 118.

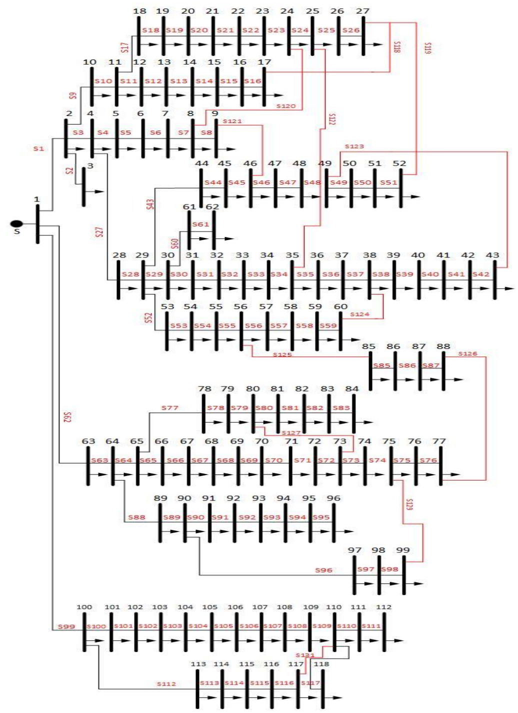

Fig. 11. SLD of IEEE-118 bus RDS with network reconfiguration.

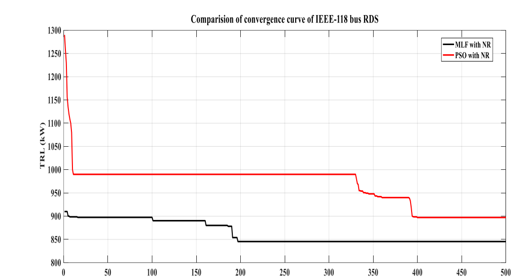

Fig. 12. Comparison of convergence curves of 118 bus RDS.

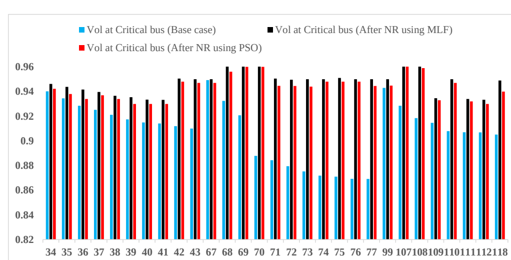

Fig. 13. Comparison of voltage profiles at critical buses without and with NR of IEEE-118 bus RDS.

Fig. 11 displays the ultimate ideal combination obtained for

Table 6. Comparison of obtained results of 118 bus RDS.

Method/algorithm	Open switches (S)	Total real power loss (TRL) (kW)	Critical buses	V_{min} (Per unit)	% Real power loss reduction
Base case (Before NR)	118, 119, 120, 121,122,123, 124, 125,126,127, 128,129,130,131, and 132	1298.04	34 to 43, 67 to 77, 99, 107 to 112,118	@bus 77 i.e.0.8691	—
MLF (After NR)	23, 25, 34, 39, 45, 48, 58, 71, 74, 84, 86,109, 128, 130, and 132	845.43	34 to 41, 109, 111, 112 and 118	@bus 112 i.e.0.933	34.86
PSO (After NR)	23, 25, 34, 39, 45, 48, 58, 71, 74, 84, 86, 109,128, 130, and 132	897.15	34 to 43,109,110,111,112 and 118	@bus 112 i.e.0.93	30.88
CSA [5]	24, 26, 35, 40, 43, 51, 59, 72, 75, 96, 98, 110, 122, 130, 131	855.042		0.9298	34.13
IHSA [20]	23, 25, 34, 39, 42, 50, 58, 71, 74, 95, 97, 109, 121, 129, 130	852.3		0.9324	34.33

Table 7. Evaluation of reliability indices of 118 bus RDS.

Reliability index	Base case	After network reconfiguration
SAIFI	1.6906	1.6777
SAIDI	1.3123	1.2121
CAIDI	0.7762	0.7224
ENS	29758.98	26239.32
AENS	0.2624	0.2424
ASAI	0.9998	0.9998
ASUI	0.000149	0.000138

NR by both method for 118 bus RDS. Table 6 represents detailed comparison of results obtained for NR by MLF, PSO and other existing algorithms. It is observed that TRL obtained after NR using MLF method is reduced form 1298.04 kW to 845.43 kW. Therefore, it is shown that % reduction in real power loss obtained with respect to base case by MLF method is 34.86% which is superior as compared to PSO method and better as compared to CSA and IHSA. It is noted after NR, only few critical buses remain, with an improved minimum voltage observed at bus 112. MLF method demonstrates superior performance in reducing TRL and enhancing voltage profiles.

The convergence curves for TRL generated by NR using MLF and PSO for this system are compared in Fig. 12. It has been noted that the MLF approach demonstrates faster convergence compared to PSO.

A comparison of the voltage profiles at critical busses before and after NR using both methods is shown in Fig. 13. Voltages are gradually enhanced following NR compared to the base scenario, with MLF approach yielding better results.

Numerous reliability indices were assessed both before and after NR simultaneously, as shown in Table 7. Reliability indices show a discernible reduction after NR.

6. CONCLUSION

This paper proposed two algorithms namely the modified load flow (MLF) method and Particle swarm optimization (PSO) which are designed for the reconfiguration of RDS. These algorithms were implemented using MATLAB programming and tested on three standard RDS. The results indicated a significant reduction in real power loss after NR, with MLF achieving notable improvements over the base case. Specifically, MLF reduced real power loss by roughly 34% for 33 and 118 bus RDS, and 56% for 69 bus RDS compared to the base scenario, outperforming PSO and other current algorithms such as CSA, ISCA, and IHSA.

The MLF method stands out for its simplicity and efficiency, requiring fewer control parameters and imposing a lesser computational burden compared to PSO. Moreover, one of the key advantages of the MLF method is its applicability to large distribution systems. Furthermore, MLF method resulted in improved voltage profiles at critical buses across the three test systems when compared to PSO following NR with respect to base case. Additionally, a thorough assessment and analysis of the comprehensive reliability indices have been conducted. These evaluations reveal a marked improvement following NR. Consequently, the optimal reconfiguration of the RDS results in decreased real power loss and an enhanced voltage profile, contributing to overall system reliability. One of the limitations of the MLF method is its inability to optimize distributed generation (DG) capacity concurrently with NR to minimize TRL. However, in future work, it is possible to extend the capabilities of the PSO to evaluate DG capacity in conjunction with NR. This enhancement would enable a more comprehensive optimization approach, facilitating the simultaneous minimization of both power losses and the optimal sizing of DG units within the distribution systems.

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