Feeder Reconfiguration of Distribution Systems for Loss Reduction and Emissions Reduction using MVO Algorithm

A. V. Sudhakara Reddy[1], M. Damodar Reddy[2], Y. V. Krishna Reddy[3]
1- Department of Electrical and Electronics Engineering, Sri Venkatewara University, Tirupati, India.
Email: sreddy4svu@gmail.com (Corresponding author)
2- Department of Electrical and Electronics Engineering, Sri Venkatewara University, Tirupati, India.
Email: mdreddy999@rediffmail.com
3- Department of Electrical and Electronics Engineering, Sri Venkatewara University, Tirupati, India.
Email: yvkrishnareddy36@gmail.com

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ABSTRACT:
This article presents a network feeder reconfiguration in balanced distribution networks using Multi Verse Optimization (MVO) to optimize the total network power losses and reduce emissions by means of step by step switching. Reconfiguration is a considerable manner of altering the power flows through the lines from the main substation to load ends, while maintaining radial structure. The main objective of this paper is to solve feeder reconfiguration problem to reduce the total line losses and emission reduction for an open loop distribution system. MVO is a population based method to resolve the network reconfiguration problem. A precise power flow solution is applied and the objective is formulated. A nature inspired Multi Verse Optimization is utilized to restructure the power distribution system and identify the optimal tie switches for lower line losses in the distribution network. The reduction of resistive losses leads to reduction of emissions. The suggested MVO method has carried out on two standard 16-node and 69-node distribution systems for normal load and overload conditions and results show the performance of the anticipated MVO method. The final outcomes prove a significant reduction in real power losses and emissions.

KEYWORDS: Emissions Reduction, Network Reconfiguration, Primary Distribution System, Radial Nature, Real Power Loss, Multi Verse Optimization, Step by Step Switching, Residential Loads.

1. INTRODUCTION

The electrical power system serves to deliver electrical energy to consumers. An electrical power system deal with electrical generation, transmission, distribution and utilization. In a traditional power system, the electrical energy is generated by different power plants and flows to consumers via the transmission and distribution networks. In electric power systems, about 13-15% of the produced electric power is vanished in distribution systems. "Power loss in a distributed system is high seeing as of low voltage and so high current [24]. The most significant advantages of decrease in energy loss are its optimistic ecological or nature collapse. This theme is so crucial, particularly in developing countries like India, where a huge quantity of power is produced from fossil fuel based power plants. The serious outcomes of increase in conventional power generation is increase of CO_2, SO_x, and NO_x emissions. Since the power and energy losses reduce power plants useful generation, any effective scheme is to decrease the losses, which is essential [18]. On the other hand, power distribution networks are responsible for a momentous percentage of power and energy losses. There are different methods were used for power loss reduction and to improve the performance of over-load branches in the network.

Generally, reconfiguration (RCG) is essential to provide service to as many consumers as possible during a fault condition or for maintenance purposes. In order to meet the required level of load demand, network reconfiguration or capacitor banks or different distributed generating units are integrated in the distribution network to improve the voltage profile, to provide reliable and continuous power supply.

Optimal network reconfiguration (NRCG) is the tree construction of feeders by transforming the open or closed (On - Off) positions of sectional and strap lines with minimum loss while maintaining radial structure in distribution systems. The main feeder initiates from the substation and passes through different consumer points and laterals are connected to individual loads.

Baran [1] proposed to work out the network reconfiguration problem in step by step manner and recognized it by shifting the status of switches for loss reduction. Taylor [2] presented a method for feeder reconfiguration rooted in most excellent tree penetrating tactic under normal operating conditions. Sarma [3] presented a new procedure of network reconfiguration for service restoration to the affected consumer points as early as possible. Kashem [4] described that the network reconfiguration utilizes a explore over several open loop configurations by using branch exchanges. The most effective possible branch exchange corresponding to a maximum decrease in system loss using the distance center technique. Chin [5] proposed an efficient network configuration to decrease loss based on ranking index and number of switching states. Morton [6] described an efficient brute force algorithm for network reconfiguration in various ways to minimize the cable losses. Kashem [7] explained a solution methodology of network reconfiguration and categorized the effective branch exchange for minimum loss.

Gomes [8] presented a new scheme created with a mesh type system by operating the entire possible switches. All the possible switchings are activated, one exchange at a time based on minimum loss criteria. Here, Switch (connection from node 9 to node 12) is excluded from all switching operations. The main disadvantage is that some nodes or loads and some feeders are isolated (not considered) during optimization. But in reconfiguration process, all the feeders or loads must be energized. Hong [9] proposed fuzzy multi-objective genetic algorithm for feeder reconfiguration to minimize the MegaWatt loss under normal conditions and contingencies.

Mishima [10] described Tabu Search (TS) for a loss minimum configuration of open loop networks with the incorporation of distributed generators. Damodar Reddy [11] explained multi-objective approach to solve the network RCG in stepwise manner. In the second stage, fuzzy is used to find the optimal capacitor locations and analytical approach is used to find the size of the capacitors. Gupta [12] presented adaptive particle swarm optimization (APSO) for RCG to reduce total network loss via graph theory. Here switching loops are derived from the loop vectors and the subsequent switch positions in the individual loops. Farahani [13] proposed hybrid optimization of network reconfiguration and capacitor allocation to reduce the losses, reduce energy losses and maintain voltage profiles. Amir [14] described multi-objective genetic algorithm for optimal network topological configuration to reduce power losses.

Almoataz [15] employed ACO and HSA for the feeder RCG to decrease the network losses for a particular load. Sasan [16] proposed heuristic algorithm for reduction in cost due to network losses and damage charge owing to interruption of electrical supply to the end users. Imran [17] described meta-heuristic Fire Works Algorithm (FWA) to optimize the radial networks while all constraints are within limits. Mostafa [18] proposed "Optimal reconfiguration and capacitor placement used to reduce power losses and keep the voltage within its acceptable intervals". The reduction in power losses, which leads to maximum environmental benefits. Shuaib [19] proposed Gravitational Search Algorithm (GSA) for the network reconfiguration problem to minimize network I^2R loss.

Nguyen [20] proposed cuckoo search algorithm for reconfiguration methodology to minimize line loss and enhance magnitudes of voltages. Sudhakara Reddy presented particle swarm optimization (PSO)[22], Ant Lion Optimization (ALO)[24], Grey Wolf Optimization (GWO) [25] and Sine Cosine Algorithm (SCA) [26] Moth Flame Optimization (MFO) [27], with an intention of decreased total I^2R loss with step by step switching for a specific load condition in realistic scenarios. Reza [23] described adaptive firefly algorithm to evaluate the feeder reconfiguration by considering wind turbines for minimizing total cost of active power loss and expenditure due to power production and distributed generation. Sudhakara Reddy [24] described that the Ant Lion Optimization (ALO) is exclusive to the network reconfiguration problem and capacitor placement after reconfiguration.

"Mirjalili [21] implemented a new population based optimization algorithm called Multi Verse Optimization (MVO) for solving different engineering problems." The projected explanation begins with a closed loop distribution system, all tie lines are closed sequentially. The final switching operation depends on lowest line loss and is resolved by power flow solution in the next section.

The main contributions of this paper include:

- A novel tactic for acquiring the lowest loss configuration without islanding of any node in radial network. It can overcome the disadvantage of Gomes [8]. Here all loads are not energized during switching operation.
- Switching loops are designed based on the loop vectors and the corresponding switch positions modified by the constraints of real, reactive power loss and minimum voltage for lowest loss configuration.
- The MVO technique has been applied to network reconfiguration to reduce power loss and maximum reduction in emissions. The quantity of CO_2, SO_x, and NO_x emissions decreased according to the maximum loss reduction.

The proposed methodology has been designed such that it is capable of finding the optimal result by testing the entire possible radial network and also requires much less computational time. In Section II, Problem is formulated and a brief description of the load flow is presented. Detailed description of Network Reconfiguration is presented in Section III. In Section IV, detailed narrative of Multi Verse Optimization (MVO) technique and the method executed for Network Reconfiguration problem is presented. In Section V, comparison results of original network and after reconfiguration for different load conditions are given in tabular form and in Section VI, conclusions are discussed.

2. POWER FLOW FORMULATION

Generally, calculation of load current and nodal voltages to know power system objectives is subjected to several constraints for a given load. The general form of distribution power flow problem can be attained as follows.

2.1. Calculation of Load Current

"The composite power injected into the bus *n* is given by

$$S_{L,n} = P_{L,n} + jQ_{L,n} = V_n . I_{L,n}^{\ *} \quad (1)$$

The load current at any node n is given by

$$I_{L,n} = \left(\frac{P_{L,n} + jQ_{L,n}}{V_n} \right)^* = \frac{P_{L,n} - jQ_{L,n}}{V_n^*} \quad (2)$$

Where $P_{L,n} \rightarrow$ *Active power demand*,
$Q_{L,n} \rightarrow$ *reactive power demand and*
$V_{L,n} \rightarrow$ *voltage magnitude at load n*

2.2. Formation of BIBC Matrix

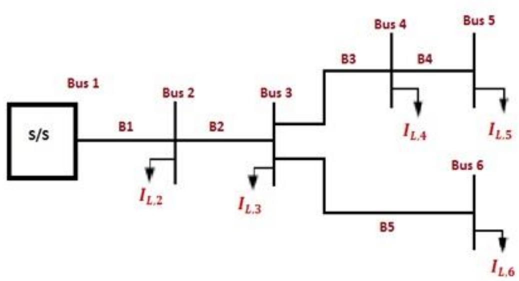

Fig. 1. A Sample 6-node radial distribution system.

The current equations can be found by using KCL for Fig. 1 which is given as

$$I_{B5} = I_{L6} \quad (3)$$

$$I_{B4} = I_{L5} \quad (4)$$

$$I_{B3} = I_{L4} + I_{L5} \quad (5)$$

$$I_{B2} = I_{L3} + I_{L4} + I_{L5} + I_{L6} \quad (6)$$

$$I_{B1} = I_{L2} + I_{L3} + I_{L4} + I_{L5} + I_{L6} \quad (7)$$

Thus, the correlation among load currents $(I_{L,n})$ and line currents $(I_{B,k})$ in Bus-Injection to Branch-Current (BIBC) matrix structure is as

$$[I_B] = [BIBC][I_L] \quad (8)$$

Consider one branch, which is connected between p-q nodes can be represented as shown in below Fig .2.

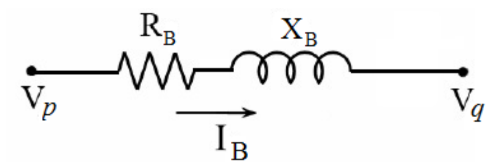

Fig. 2. Representation of a branch B .

The receiving end voltages can be premeditated by forward sweep as

$$V_q(k) = V_p(k) - I_B(k) * Z_B(k) \quad (9)$$

Where, $V_p, V_q \rightarrow$ *represents the voltages at node p and q*
$Z_B = R_B + j * X_B \rightarrow$ *represents the impegance of branch B*
$R_B \rightarrow$ *represents the resistance of branch B*
$X_B \rightarrow$ *represents the reactance of branch B*
$I_B \rightarrow$ *represents the current flow through branch B*

2.3. Total System Real Power Losses

The total real and reactive power loss in a distribution system can be conveyed as

$$P_{L,Real} = \sum_{B=1}^{k} I_B^2 * R_B \quad (10)$$

$$P_{L,Reactive} = \sum_{B=1}^{k} I_B^2 * X_B \quad (11)$$

2.4. Objective Function

The objective function of the problem is originating to minimize the total real power loss in the primary distribution system, which is given by

$$Fitness\_Function = min\{P_{L,Real}\} \quad (12)$$

$$Loss\_Reduction(LR) = \left(\frac{P_{LOSS,Before} - P_{LOSS,AfterRCG}}{P_{LOSS,Before}}\right)*100$$

In conventional power plats, the generated emissions are equal to 720 kg CO_2, 0.1 kg NO_x, and 0.0036 kg SO_2 per megawatt hour. The quantity of emissions decreased according to a reduction in the energy losses is given by

$$Energy\_Losses = T * \Delta Real\_Power\_Losses * L_F \quad (13)$$

Where $L_F \rightarrow Loss\ Facor$. For all residential loads, the loss factor is considered as 0.3 [18] ".

2.5. Radiality Constraint

Any delivery system with 'n' nodes and 'b' branches are said to be a radial network if it satisfies the following two constraints.

1. The total number of branches 'b' is given by

$$N_{br} = (N_{no} - 1) - (N_f - 1) \quad (14)$$

$Where,\ N_f \rightarrow represents\ the\ number\ of\ feeders\ and$

$N_{no} \rightarrow represents\ the\ number\ of\ nodes$

2. The network should satisfy the conservation of power flow constraint, i.e. every node should be linked to the substation node by an exclusive path such that every load at each node is energized.

3. NETWORK RECONFIGURATION

The elementary loops are established for RCG using open loop distribution network via closed all tie lines in step by step manner. The number of basic loops in the closed loop distribution system is identical to the number of tie lines. The several switching's are probable for each loop by closing one tie line to compose a closed loop. The corresponding loop vectors of 16-node system which is revealed in Table 1 [24].

Table 1. Loop Vectors and Switching Positions of standard 16-node system.

Switching	Basic Loop Vectors for the switching		
	Loop-1	Loop-2	Loop-3
1	TS-14	TS-15	TS-16
2	2	6	3
3	8	12	4
4	7	--	13
5	--	--	11

In the reconfiguration approach illustrated here, Generally, distribution systems are considered radial in nature. Every load is supplied by substation transformers through different feeders in the distribution network. The loads are modelled at their peak values, and it is assumed that each branch comprises a switch whose position may be closed or opened.

Step By Step Switching (SBSS) of Network Reconfiguration is the tree structure of feeders or feeder laterals by transforming the closed or open positions of tie and sectional lines in step by step manner to reach the lowest loss configuration, while maintaining radial structure. In switching operation, only one switch is modified at a time in every loop. The best switch is fixed in each loop based on lowest loss configuration using step by step process. It has the advantage of less number of switching’s required to reach, the better configuration of distribution systems.

The different feasible switching operations are tested analytically by altering the status of one switch at a time in each individual loop in step by step manner. Here, the finest loss configuration is emphasized in each switching operation. Loop structures are designed by considering the real, reactive power loss and least amount of voltage as constraints [22].

4. MULTI VERSE OPTIMIZATION

4.1. Introduction

This article proposed a new algorithm is called Multi Verse Optimizer (MVO) [21]. MVO is as an alternative approach to solve optimization problems for global optimization based on white hole, black hole, and wormhole as represented in Fig .3. The inspiration from big bang hypothesis which examines that our universe begins with an immense explosion. It is supposed in this theory that there are more than one big bang and every big bang origins the birth of a universe.

A white hole has never seen in our universe, but physicists trust that the big bang can be considered as a white hole and the main component of the birth of a universe. It is also argued in the cyclic model of multi-verse theory that big bangs/ white holes are created where the collisions between parallel universes occur. Black holes, which have been regularly monitored, perform entirely in discriminate to white holes. They attract light beams with their extremely elevated gravitational force. Wormholes are those holes that connect several components of a universe simultaneously. The wormholes in the multi-verse hypothesis act as space pass through tunnels where objects are capable to move instantly among every turn of a universe.

Every universe has an inflation rate that causes its expansion through space. Inflation speed of a universe is very important in terms of forming planets, stars, wormholes, black holes, white holes, asteroids, and suitability for life. It is argued in one of the cyclic multi-verse models that multiple universes interact via black, white and wormholes to reach a steady situation. White holes are more promising to be created in the universes with high inflation rates, so they convey objects to other universes and assist them to improve their inflation rates.

Black holes are more likely to be appearing in the universes with low inflation rates, so they have a higher probability to accept objects from other universes. This again increases the chance of developing the inflation rate for the universes with low inflation rates.

White hole tunnels tend to transport objects from universes with higher to lower inflation rates, so the average inflation rate of all universes has improved over the course of iterations. Wormholes tend to emerge randomly in any universe in spite of the inflation rate, so the diversity of the universe is sustained over the iterations. While hole tunnels require universes to abruptly change, causing exploration of the search space. Wormholes randomly re-span some of the variables of universes around the best solution obtained so far over the course of iterations, so this guarantees exploitation around the most promising region of the search space.

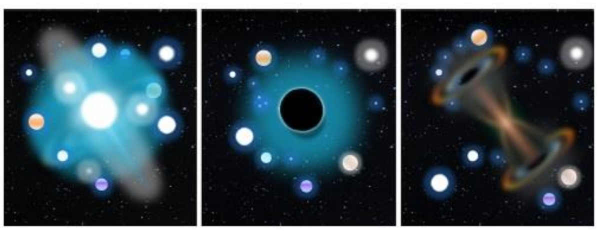

Fig. 3. White hole, Black hole, and Wormhole

The proposed MVO algorithm has a high exploitation ability, which is due to the integrated Travelling Distance Rate (TDR) and wormholes combined that assist MVO to provide high exploitation. After proving the exploitation of MVO, we are going to converse the exploration of MVO algorithm.

4.2. Implementation of the Projected MVO

Step 1: Initialize the no. of Universes, Maximum time counters, branch data and load data.

Step 2: Set lower bound, upper bound and dimensions to the essential parameters.

Step 3: Perform the basic power flow to estimate fitness.

Step 4: Initialize two variables for the position and inflation rate of the best universe.

Step 5: Initialize the positions of universes

$$X = \begin{cases} rand\left(Univ\_no, dim\right).*\left(ub - lb\right) + lb, \; If\text{, boundaries are equal} \\ rand\left(Univ\_no, dim\right).*\left(ub_i - lb_i\right) + lb_i, \; If\text{, boundaries are } \textbf{un}\text{equal} \end{cases}$$

Step 6: Minimum and maximum of Wormhole Existence Probability (WEP). Start the time counter.

$\boldsymbol{W\_Max = 1};\ \boldsymbol{W\_Min = 0.2};\ \boldsymbol{Time = 1};$

$$WEP = WEP\_Min + Time\left(\frac{WEP\_Max - WEP\_Min}{Max\_Time}\right) \quad (15)$$

Travelling Distance Rate (TDR) is defined as

$$TDR = 1 - \left(\frac{Time}{Max\_Time}\right)^{(1/P)} \quad (16)$$

Step 7: Boundary checking to bring back the universes within search space, if they go outside the boundaries.

Step 8: Calculate the inflation rates for each time counter and compare with best universe inflation rate. Sorting the universes (SU) and the new index make Normalize the inflation rates of sorted universe (NSIR).

Step 9: Update the position of universes other than first one. Starting from 2 since the first is the elite.

Step 10: Update the convergence curve and print the best universe details up to max no. of time counters.

Step 11: Display the BUIR (Inflation Rate of Best Universe) which gives the optimum result with respect to best universe.

Pseudo Code of MVO Technique

```
if r1<NSIR
    W_hole_index=RWS(-SIR)
        if W_hole_index==-1
                W_hole_index=1;
        end
    U(B_hole_index)=Sort(White_hole_index);
end
if r2<WEP
    U(i)=BU ±TDR*((ub-lb)*rand+lb)
                Here, + for r3<0.5 ;  - for r3>=0.5
end
Here r1, r2 and r3 are random variables
```

5. SIMULATION RESULTS

The proposed Multi Verse Optimization (MVO) is applied on standard 16-node [8, 18] and 69-node [11, 22] distribution systems. The coding results are simulated in the DELL personal computer of Windows 8.1, 64-bit Intel (R) core(TM) i3 CPU@1.90GHz Clock Speed, 8GB RAM and 500GB Hard disk using MATLAB R2013a version. Here, all methods are simulated for max. iterations=500 and universes=50.

5.1. Three Feeder 16-node System

A 23KV, 100MVA test system with 16 branches, 13 sectional and 3 tie switches was done as shown in fig 4. The overall substation [8, 18] load is (28.7+j*17.3) kVA. As in Fig 4, the red color dotted lines specified the tie lines are of opened position in the original network. In reconfiguration process, closing the tie switches and opening the switches are of green color solid lines which specifies the best combination of switches corresponding to the lowest loss configuration.

The MATLAB coding results using step by step switching are presented in Table 2. The outcomes of the specified network and after reconfiguration for a full load and 5% overload patterns are offered in Table 2.

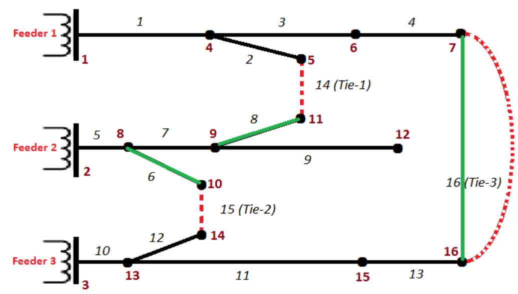

Fig. 4. Reconfiguration of 3-Feeder 16-node system.

Table 2. Reconfiguration Results of 16-node system.

Scenario	Constraints	Load Patterns	
		Normal	5% Overload
Base Case	Switches Opened	14, 15, 16	14, 15, 16
	P_{Loss} (kW)	511.4356	567.8516
Step by Step Switching	Switches Opened	6, 8, 16	6, 8, 16
	Number of Switchings	2	2
	P_{Loss} (kW)	466.1266	517.7859

In the original network, the system loss was 511.4356 kW and after reconfiguration with the proposed step by step switching using Multi Verse Optimization algorithm, total system loss is condensed to 466.1266 kW. The optimal switches of 16-node system are {S6, S8, S10} and loss reduction is 45.3090 kW. The feasible switchings are only 2 for 16-node system. The magnitude of minimum voltage of original network is 0.9693 p.u at node 12 and after RCG enhanced to 0.9716 p.u @ 12 of 16-node system.

5.2. 69-node System

A 100MVA, 12.66KV, 69-node system with 73 branches, 68 sectional and 5 ties as exposed in Fig 5. The entire substation loads of (3802.2+j*2694.6) kVA. Due to the lack of the space, network data is not displayed in this paper and can be requested to the authors. The MATLAB coding results using step by step switching for a peak load and 5% overload patterns are presented in Table 3.

As in Fig 5, red and green colored lines indicate that the tie switches are normally open in the original network. In the reconfiguration process, closing all the tie switches are of green color solid lines and opening the switches are of black color dotted lines. The feasible switchings are only 3 of 69-node system which are of green color solid lines as shown in Fig 5.

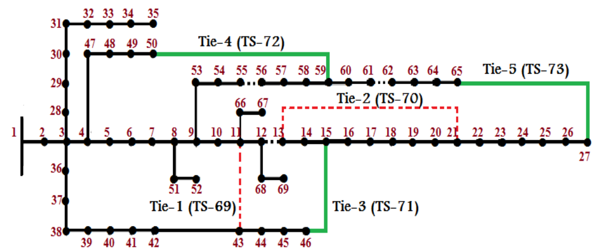

Fig. 5. Reconfiguration of 69-node system

Table 3. Reconfiguration Results of 69-node system.

Scenario	Constraints	Load Patterns	
		Normal	5% Overload
Base Case	Switches Opened	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	P_{Loss} (kW)	225.0044	250.4055
Step by Step Switching	Switches Opened	69, 70, 12, 55, 61	69, 70, 12, 55, 61
	Number of Switching	3	3
	P_{Loss} (kW)	99.8206	110.6179

In the original network, the total power loss was 225.0044 kW and after reconfiguration power loss is decreased to 99.8206 kW using step by step switching. The optimal switches are {S69, S70, S12, S55, S61}. The magnitude of minimum voltage is 0.9092 per unit which is enhanced to 0.9428 per unit using RCG of the 69-node system.

The proposed MVO technique has required less number of iterations to converge the solution compared with other optimization techniques like Moth flame Optimization (MFO) [27], Ant Lion Optimization (ALO)[24], Grey Wolf Optimization (GWO) [25] and Sine Cosine Algorithm (SCA) [26] are presented in Table 4 and Table 5.

Table 4. Computational time of 16-node system.

Optimization Technique	Convergence (Iterations)	Time (Sec)
SCA [26]	176	24.10
ALO [24]	56	12.42
GWO [25]	20	3.29
MFO [27]	19	2.08
Proposed MVO	14	2.30

Table 5. Computational time of 69-node system.

Optimization Technique	Convergence (Iterations)	Time (Sec)
SCA [26]	66	58.08
ALO [24]	57	106.71
GWO [25]	13	12.22
MFO [27]	9	6.70
Proposed MVO	8	7.77

The proposed MVO algorithm achieved the optimum solution for 14 iterations of 16-node and 8 iterations of 69-node system.

5.3. Environmental Benefits

The MVO method in this article is proficient to reduce the quantity of resistive losses using step by step switching in electric distribution networks significantly. The reduction in power losses leads to energy losses, which results in reduction of carbon emissions. The quantity of CO_2, SO_2 and NO_x emissions are significantly decreased, which are revealed in Table 6.

Table 6. Amount of Emissions Reduction.

Parameters	16-Node	69-Node
Annual Energy Losses, MWh	119.0720	328.9830
CO_2 reduction, kg	85,732	2,36,868
NO_x reduction, kg	11.9072	32.8983
SO_2 reduction, kg	0.4286	1.1843

6. CONCLUSIONS

In this article, an efficient Multi Verse Optimization (MVO) technique has executed successfully for the reconfiguration problem in the distribution network. The main advantage of the proposed MVO technique is the less computational to converge the optimum solution when compared with all other optimization techniques.

The MVO technique has executed on two standard distribution systems and it has better performance in terms of excellent convergence characteristics (speed & time) as compared with the ALO, GWO and SCA. In the reconfiguration process, the loss reduction is 8.86% for standard 16-node and 55.64% for 69-node systems. The voltage deviation is decreased from 0.0307 to 0.0284 p.u for 16-node system. Similarly, the voltage deviation is reduced from 0.0908 to 0.0572 p.u for 69-node system with respect to the finest combination of switches.

7. APPENDIX

Table A. Line and Load Data for 16-node test system

Branch	From node	To node	R (Ω)	X (Ω)	P kW	Q kVAr
1	1	4	0.075	0.1	0	0
2	4	5	0.08	0.11	0	0
3	4	6	0.09	0.18	0	0
4	6	7	0.04	0.04	2	1.6
5	2	8	0.11	0.11	2	0.8
6	8	10	0.11	0.11	1.5	1.2
7	8	9	0.08	0.11	4	2.7
8	9	11	0.11	0.11	5	3
9	9	12	0.08	0.11	1	0.9
10	3	13	0.11	0.11	4.5	2
11	13	15	0.08	0.11	1	0.9
12	13	14	0.09	0.12	1	0.7
13	15	16	0.04	0.04	1	0.9
Tie-Switches						
14	5	11	0.04	0.04	3	1.5
15	10	14	0.04	0.04	0.6	0.1
16	7	16	0.09	0.12	2.1	1

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