

## Distribution Network Reconfiguration of Radial Distribution Systems for Power Loss Minimization Using Improved Harmony Search Algorithm

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Abstract: With increase in industrial development, sub urbanization, and population growth, the energy demand is continuously increasing year by year. This excessive power demand has put a strain on the distribution network thus causing increased power losses  $(I^2R)$  due to flow of electric current. It therefore becomes highly important to minimize power losses at distribution level in order to maximize the operational efficiency of distributionl utilities. Network reconfiguration is one of the effective way that has been used by the distribution utilities for distribution system loss minimization. In this paper, an Improved Harmony Search Algorithm (IHSA) inspired from musician's performance is presented to solve network reconfiguration problem with an objective to minimize distribution system power loss. The IEEE – 69 bus and IEEE – 119 bus radial distribution networks have been used to demonstrate the efficacy of the proposed method. The obtained simulation test results demonstrated that proposed IHSA achieved better quality of solutions and can be a promising and efficient optimization technique for solving distribution network reconfiguration problems.

*Keywords* : Improved Harmony Search Algorithm, Loss Minimization, Network Reconfiguration, Radial Distribution System

## NOMENCLATURE

$P_{n+1}$	Real power flowing out of bus $(n+1)$	<i>R</i> <sub>n</sub>	Resistance of the branch line <i>l</i>
$Q_{n+1}$	Reactive power flowing out of bus $(n+1)$	X <sub>n</sub>	Reactance of the branch line <i>l</i>
$P_n$	Real power flowing through branch line <i>l</i>	$P_{T,Loss}$	Total power loss of the feeder
$Q_n$	Reactive power flowing through branch line $l$	V <sub>min</sub>	Bus minimum voltage
$P_{Loss(n,n+1)}$	Real power losses within the branch connecting buses $n$ and $(n+1)$	V <sub>max</sub>	Bus maximum voltage
$Q_{Loss(n,n+1)}$	Reactive power losses within the branch connecting buses $n$ and $(n+1)$	In	Current magnitude through branchronnecting buses $n$ and $(n+1)$
$P_{Load(n+1)}$	Real power demand at $bus(n+1)$	$I_n^{\max}$	Maximum current limit through branch connecting buses $n$ and $(n+1)$
$Q_{Load(n+1)}$	Reactive power demand at bus $(n+1)$	А	Bus incidence matrix
V <sub>n</sub>	Voltage at bus <i>n</i>	HSA	Harmony Search Algorithm
$V_{n+1}$	Voltage at bus $n+1$	IHSA	Improved Harmony Search Algorithml

## 1. Introduction

The electric power supply chain consists of generating station, transmission network, distribution system and end users load. Among all these segments of power sector value chain, distribution business segment has an important role as it is a final interface between the sector and end users. It affects to the cost of supplied energy, quality and reliability of electricity, and

any underperformance at distribution level pollutes the entire power sector value chain. The electric distribution network usually operated in a radial configuration because radial operation in comparison with mesh operation has many advantages such as easy voltage adjustment, better control of power flows, reduced occurrence of faults, uncomplicated coordinated of protection systems and reduced occurrence of faults [1]. Moreover, the distribution networks operate at low voltage and high current, the power loss in the system is high, and the voltage regulation is poor. According to the report published by World Bank in 2018 that only 25% of the total power loss takes place in transmission and sub-transmission system while 75% of the total power losses are occurring in the power distribution network thus making the distribution segment technically inefficient [2]. Further, these huge power losses at distribution level increase the operating cost of electric utilities and consequently result in high cost of electricity supplied to end users. For the distribution system to operate in a reliable manner and provide high service quality to consumers, it therefore becomes imperative to increase the efficiency of distribution system and decrease its operating cost. One of the best possible way to achieve this is by minimizing the real power losses. Power loss minimization can be achieved using various methods such as distribution network reconfiguration (DNR), installation of capacitors, increasing the voltage level, and by optimally placing distributed energy sources [3]. Among these available techniques, the distribution system network reconfiguration is considered to be the most effective technique for the electricity distribution operators since it requires less investment as it allows the utilization of already existing resources available with distribution utilities.

Distribution network reconfiguration refers to alter the network topology by opening and closing of switches (switching status) that connect or disconnect the branches of the system so as to obtain best radial topological configuration. Figure 1 illustrates an example of the basic concept of network reconfiguration process by controlling sectionalize and tie switches to change the topology of the distribution system.



Figure 1. Basic Concept of Network Reconfiguration Approach

As an alternative of loss minimization, the network configuration also offers other advantages that can be leveraged by the distribution system such as [4], [5]:

- a. Improve reliability of the distribution network.
- b. Improve the voltage profile at all network buses.
- c. Restrain the distribution line from being overloaded.
- d. Help to restore supply to the demands when fault occurred.

In the present paper, the distribution network reconfiguration problem is formulated as a single objective function with a goal to reduce the system active power loss while fulfilling all the operating constraints of the system. The major challenge in implementing the distribution network reconfiguration problem is the consideration of high number of different possible switching combinations in a network and analyse as the candidates of the optimal configuration. That is why the distribution network reconfiguration problem is termed as a combinatorial constrained optimization problem with a nonlinear, non-differentiable objective function. In the existing literature, several optimization techniques (or algorithms) with varying degree of success have been widely employed to solve network reconfiguration problem.

Merlin and Back [6] in 1975 were the first to propose an algorithm to determine distribution system reconfiguration with minimum power loss. Their method was based on branch and bound technique with all tie lines initially closed thus creating an arbitrarily meshed system, then the switch opening was continued until radial configuration was restored. Civanlar et al. [7] implemented a branch exchange method to determineithe change in power losses due to load switching from one feeder to another. The concept behind the method is that in a loop, a closed switch will replace the open switch to minimize power loss. The switching configuration which causes the maximum loss minimization is selected. However, the major drawback of this approach is that selection of a pair of switches is very time consuming, and further the procedure does not ensure that multiple switching options provide optimum solution. Shirmohammadi and Hong [8] applied heuristic algorithm based optimal power flow analysis to network reconfiguration for minimising distribution feeder losses. Their approach begins with a meshed distribution system considering all tie switches closed. At that point, the switches are then opened one after another determined by optimal power flow analysis. Baran and Wu [9] applied a branch exchange method using heuristic reconfiguration technique for feeder loss minimization and load balancing. Initially, incumbent spanning tree (parent) is created and all possible (children) trees are then checked by branch exchange method. Wagner et al. [10] presented reconfiguration algorithm based on solution of a linear transportation problem. Quadratic feeder line section losses were approximated by a piecewise linear function, permitting solution using stepping-stone algorithm. K Nara et al. [11] implemented a genetic algorithm approach for minimizing the power losses in distribution network. In the proposed algorithm, the system real power losses and penalty values of voltage drop and current capacity violations were represented by approximate fitness function, and radial configurations or sectionalizing switch status were described by genetic strings. Sarfi et al. [12] proposed for loss minimization. dvnamic programming approach In this approach, the distribution system is first partitioned into groups of load buses, and then applied network partitioning theory to minimize losses within each group of buses. Ji - Yuan Fan et al. [13] presented a heuristic based single – loop optimization technique wherein the switch exchanges within a loop is determined, and then a heuristic approach is applied to develop the optimal switch plan to achieve optimal configuration that minimized power losses in meshed distribution networks. Kashem et al. [14] proposed artificial neural network (ANN) approach in the analysis of network reconfiguration for minimizing real power losses. Taleski and Rajicic [15] offered heuristic Branch Exchange optimization technique for minimizing power losses in radial network. In order to achieve reconfiguration, the loop that describes open tie switch is initially closed, and then opening the sectionalizing switch that produces maximum energy loss saving. Das [16] proposed heuristic rules and fuzzy multi-objective framework to solve distribution network reconfiguration problem. Goswami and Basu [17] presented an optimum poweri flow pattern based heuristic algorithm for power loss minimization in radial distribution systems. The optimum flow pattern with single loop formed by closing a normally open switch is determined, and this flow pattern was established in the radial network by opening a closed switch. This procedure was repeated until the minimum loss configuration was obtained. In addition, the different optimization techniques that have been widely proposed by researchers in recent years to solve distribution network reconfiguration problem so as to minimize power loss include Refined Genetic Algorithm (RGA) [18, 19], Harmony Search Algorithm (HSA) [20], Bacterial Foraging Optimization Algorithm (BFOA) [21], Fireworks Algorithm (FWA) [22], Particle Swarm Optimization (PSO) [5], Ant Colony Search Algorithm (ACSA) [23], Modified Honey Bee Mating Optimization Algorithm (MHBMOA) [24], Plant Growth Simulation Algorithm (PGSA) [4], Modified Tabu Search Algorithm (MTS) [5], Improved Tabu Search Algorithm [25], Uniform Voltage Distribution Based Constructive Reconfiguration Algorithm [26], Hyper Cube – Ant Colony Optimization [27], Modified Plant Growth Simulation Algorithm (MPGSA) [28], Salp Swarm Algorithm (SSA) [29], Heuristic Algorithm [30], etc., as well as Hybrid Optimization Algorithms [31, 32].

In light of the above discussion, it is evident that for minimizing line losses in distribution network using network reconfiguration approach, heuristic and metaheuristic techniques have been mainly employed by most of the researchers in the prevalent literature, and moreover there has been observed a growing interest in nature inspired algorithms to optimally solve the network reconfiguration problem. In this paper, an Improved Harmony Search Algorithm is proposed to solve distribution networkl reconfiguration problem. The benefits of IHSA include: identification of high performance regions of solution space in a reasonable run time, increased convergence speed, and high coverage of a given search space etc. The robustness of proposed IHSA is validated on two standard IEEE radial test systems – IEEE 69 and IEEE 119 bus system. Numerical results show that the proposed IHSA is accurate and efficient, and has fast convergence rate in comparison with results available in the recent existing literature.

#### 2. Problem Formulation

Traditionally, utility companies have designed and developed power distribution systems as radial network topology, meant to carry electric power from the substation to all the existing loads interconnected to the network along a single path. Radial distribution networks often feature tie switches and sectionalizing switches mainly employed for system reconfiguration, power supply recovery and fault isolation. These switches allow for reconfiguring the network topology, with the objectives being enhancing reliability of the system, load balancing, voltage profile enhancement, and minimizing system powerilosses. In this paper, the distribution network reconfiguration problem attempts to determine the best reconfiguration of radial distribution system that minimizes total system power losses while satisfying all operating and technical constraints such as radial topology of distribution system, thermal limits of feeder, and voltage profile of the system.

#### A. Power Flow Equations

Consider a single line diagram of a simple feeder – line configuration as shown in Figure 2, which consists of two buses n and (n+1), connected through a branch line [20]



Figure 2. Single line diagram of a main feeder

The computation of power flow is described by following set of recursive equations as:

$$P_{n+1} = P_n - P_{Loss(n,n+1)} - P_{Load(n+1)} = P_n - \frac{\kappa_n}{|V_n|^2} \left( P_n^2 + Q_n^2 \right) - P_{Load(n+1)}$$

$$Q_{n+1} = Q_n - Q_{Loss(n,n+1)} - Q_{Load(n+1)} = Q_n - \frac{Q_n}{|V_n|^2} \left( P_n^2 + Q_n^2 \right) - Q_{Load(n+1)}$$
(1)

$$Q_{n+1} = Q_n - Q_{Loss(n,n+1)} - Q_{Load(n+1)} = Q_n - \frac{Q_n}{|V_n|^2} \left( P_n^2 + Q_n^2 \right) - Q_{Load(n+1)}$$
(2)

Distribution Network Reconfiguration of Radial Distribution Systems

$$\left|V_{n+1}\right|^{2} = \left|V_{n}\right|^{2} + \frac{R_{n}^{2} + X_{n}^{2}}{\left|V_{n}\right|^{2}} \times \left(P_{n}^{2} + Q_{n}^{2}\right) - 2 \times (R_{n}P_{n} + X_{n}Q_{n}) \qquad n \in \{1, 2, \dots, NB\}$$
(3)

The real power losses in the branch section connecting *nth* and (n+1)th bus is computed using following equations:

$$P_{Loss(n,n+1)} = R_n \frac{\left(P_n^2 + Q_n^2\right)}{\left|V_n\right|^2}$$
(4)

The total real power losses of radial distribution network having *NB* buses may be determined by summing all the line losses as follows:

$$P_{\Gamma,Loss} = \sum_{n=1}^{NB} P_{Loss}(n, n+1)$$
(5)

#### B. Objective Function

The system active power loss minimization without the violation of the system constraints is the main objective of distribution network reconfiguration in the present paper. The objective function is therefore formulated as:

$$Minimize f = min (P_{T,Loss})$$
(6)

Subject to the following operating constraints: a. Power balance:

$$\sum_{n=1}^{NB} P_{nGen} = \sum_{n=1}^{NB} (P_n + P_{Loss,n})$$
(7)

i.e. total active power fed to the network must balance the total load power demand and total active power losses.

b. Bus voltage constraint:

$$V_{\min} \leq |V_n| \leq V_{\max}$$

i.e. operating voltage at all buses of the system must lie within the specified limits of minimum and maximum voltages.

(8)

c. Line thermal limits:

$$I_n \Big| \le I_n^{\max} \tag{9}$$

i.e. all the feeder lines must operate within their thermal limits.

 d. The radial structure of the distribution network must be ascertained. det[Bus incidence matrix] = 1 or -1 (for radial network) det[Bus incidence matrix] = 0 (for non-radial network) (10)

# 3. Overview of Harmony Search Algorithm (HSA) and Improved Harmony Search Algorithm (IHSA)

#### A. Harmony Search Algorithm

In recent years, nature inspired heuristic and meta – heuristic optimization algorithms find widespread use in providing optimal solution for optimization problems of industrial and scientific importance. The harmony search (HS) developed by Geem *et al.* [33] is an emerging meta – heuristic optimization technique conceptualized from the music improvisation process where a group of musicians collectively tune their musical instruments' (population members) pitches developing a perfect state of pleasing harmony (global optimum solution) as

determined by aesthetic standard (fitness function). In comparison to other optimization techniques, HSA is easy to implement, better robustness, and reduces the number of iterations for converging towards optimal solution.

The analogy between improvisation and optimization is shown in the tabular form as follows: Table 1. Analogy between improvisation and optimization

Improvisation	Optimization
Musician / Music Player	Decision Variable
Musical Instrument Pitch Range	Decision Variable Range
Harmony	Solution Vector
Audience Aesthetics	Objective Function

The major steps in implementing HSA are explained as follows:

Step 1: Optimization Problem Description and HSA Parameters Initialization Initially, the optimization problem with constraints is formulated in terms of the objective

function f(x): Minimize f(x) subject to  $x_L \le x_i \le x_U$ , in which  $i \in \{1, 2, 3, \dots, D\}$ ,  $x_L$ and  $x_U$  are the lower and upper bounds for the decision variables, and D is the number of decision variables. The control parameters that govern the performance of HSA: Harmony Memory Considering Rate (HMCR), Harmony Memory Size (HMS), Pitch Adjustment Rate (PAR), Adjusting Distance Bandwidth (*bw*), and Stopping Criteria (i.e., number of improvisation (NI) are also initiated in this step. Here, HM is the repository of solution vectors; HMCR and PAR are used to improve the solution vector.

### Step 2: Harmony Memory Initialization

In this step, Harmony Memory (HM) matrix, is filled with randomly constructed HMS solution vectors.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix}$$
(12)

Step 3: New Harmony Improvisation

In this stage, a new solution  $\vec{x'} = (x'_1, x'_2, \dots, x'_N)$  termed as harmony vector is generated based on memory consideration, random initialization, and pitch adjustment. The generation of new harmony memory is known as improvisation. In the memory consideration, the value of each component is updated as follows: if(rand() < HMCR)

$$x_{i}' \leftarrow x_{i}' \in \{x_{i}^{1}, x_{i}^{2}, x_{i}^{3}, \dots, x_{i}^{HMS}\}$$

$$else$$

$$x_{i}' \leftarrow x_{i}' \in X_{i}$$

$$end$$
(13)

Where *rand* () is a random number uniformly distributed in the range of 0 and 1, and  $X_i$  is the value space of the  $i^{\text{th}}$  variable. HMCR, which lies in the range [0,1], is the rate of selecting one value from already stored historical values in the HM whereas the ratel of randomly selecting one value from the possible range of values is denoted by (1 - HMCR).

Each component obtained by the memory consideration is examined to determine whether it should be pitch adjusted. The PAR parameter is the rate of pitch-adjustment. This operation uses the rate of pitch adjustment as a parameter as follows:

$$if (rand() < PAR)$$

$$x'_{i} = x'_{i} \pm rand() * bw$$

$$else$$

$$x'_{i} = x'_{i}$$

$$end$$

$$(14)$$

Where *bw* is an arbitrary distance bandwidth for the continuous variable design and *rand* () is a uniformly distributed random number ( $rand \in [-1, 1]$ ).

#### Step 4: Harmony Memory Updation

If the fitness value of the new harmony vector  $\vec{x'} = (x'_1, x'_2, \dots, x'_N)$  is better than the worst fit harmony, the worst harmony in HM is then substituted by the new harmony.

#### Step 5: Check the Stopping Criterion

If the termination criterion (i.e. maximum number of iterations) is reached, stop the computation. Otherwise, steps 3 and 4 are repeated.

#### B. Improved Harmony Search Algorithm (IHSA)

The performance of HSA reveals that although this algorithm is good in finding out the high performance regions of the solution space in a short time but weak in performing local search for numerical optimization applications. To improve the performance of HSA technique and overcome the drawbacks involved in the fixed values of *PAR* and *bw*, Mahdavi et al. [34] proposed an improved version of traditional HSA called as Improved Harmony Search Algorithm (IHSA). The IHSA uses variable PAR and bw values in the improvisation step to improve the performance of the HAS. The PAR and bw values change dynamically with the generation number expressed as follows:

$$PAR(gn) = PAR_{\min} + \frac{(PAR_{\max} - PAR_{\min})}{NI} * gn$$
$$bw(gn) = bw_{\max} * \exp\left(\frac{gn}{NI} * \ln\left(\frac{bw_{\min}}{bw_{\max}}\right)\right)$$
(15)

where  $PAR_{\min}$  and  $PAR_{\max}$  indicate the minimum and maximum pitch adjusting rates, respectively. *gn* and *NI* denote the generation number and the maximum number of iterations, respectively. Also, *bw* (*gn*) is bandwidth for each generation, *bw*<sub>min</sub> and *bw*<sub>max</sub> indicate the minimum and maximum bandwidths.

#### 4. Simulation Results and Discussions

For evaluating and validating the efficacy of the proposed method, it was implemented and tested on two standard IEEE radial bus networks – IEEE 69 – bus and IEEE 119 – bus distribution test systems. In order to analyse the robustness of the proposed method in comparison with other optimization techniques found in the existing literature for achieving the function of distribution power loss minimization, two different cases are considered while simulating the network:

Case I (Base Case): The system is without reconfiguration.

Case II (Network Reconfiguration Performed): Same as case I except distribution network reconfiguration problem is performed.

The proposed optimization algorithm was implemented by developing a computer program that is simulated in MATLAB R2014b and run on an Intel Core i3 processor having 3 GHz, 4GB personal computer.

The range of IHSA parameters considered in simulating the distribution network for optimized reconfiguration are shown in Table 2.

IHSA Parameters	Values / Ranges
Harmony Memory Considering Rate (HMCR)	0.95
Size of Harmony Memory (HMS)	30
Minimum Value of Pitch Adjustment Rate (PAR <sub>min</sub> )	0.01
Maximum Value of Pitch Adjustment Rate $(PAR_{max})$	0.99
Minimum Bandwidth ( $bw_{min}$ )	0.0001
Maximum Bandwidth ( <i>bw<sub>max</sub></i> )	1.0
Maximum Number of Iterations	10
Number of Improvisations	5000

Table 2. Range of IHSA Parameters

### A. Test System II – IEEE 69 – Bus Radial Distribution System

The IEEE 69 bus is a standard 12.66 kV medium scale distribution system consists of 68 sectionalizing switches labelled from 1 - 68, 5 tie switches from 69 - 73, 69 nodes and 73 branches [35]. The total load demand for this network are 3.802 MW and 2.694 MVAr, respectively. Further, to evaluate the performance of proposed IHSA, three load levels: light load (0.5), nominal load (1.0), and overload (1.5) are considered while performing the simulation of network for optimized reconfiguration. The base case (i.e. before reconfiguration) network power loss calculated from the load flow at three load conditions are: 56.51 kW (light load), 224.95 kW (nominal load) and 665.32 kW (heavy load). The initial nominal bus system voltage is 0.9091 p.u. The sectionalizing switches that are initially opened in normal operation are - SW - 69, SW - 70, SW - 71, SW - 72, SW - 73. The initial configuration of 69 - bus distribution system is depicted in Figure 3. and the results obtained by the proposed IHSA for two different scenarios are presented in Table 3.



Figure 3. IEEE 69 – bus test system

Saanar	i.	Load Level				
Scenario		Light Load (0.5)	Nominal Load (1.0)	Heavy Load (1.5)		
Scenario – I (i.e. Base Case)	Switches Opened	SW -69, SW -70, SW -71, SW -72, SW -73	SW -69, SW -70, SW -71, SW -72, SW -73	SW -69, SW -70, SW -71, SW -72, SW -73		
	Power Loss (kW) 56.51		224.95	665.32		
	Minimum Voltage (p.u)	0.9576	0.9091	0.8454		
Scenario – II (i.e. Network Reconfiguration Implemented)	Switches Opened	SW -14, SW -15, SW -61, SW -69, SW -70	SW -14, SW -15, SW -61, SW -69, SW -70	SW -14, SW -15, SW -61, SW -69, SW -70		
	Power Loss (kW)	26.12	99.45	271.39		
	% Loss Reduction	53.77	55.79	59.20		
	Minimum Voltage (p.u)	0.9723	0.9495	0.9050		

Table 3. Results of 69 - Bus System

Table 4. Comparison of Simulation Results for IEEE 69 – bus radial distribution system for Nominal Load Condition

Case	Item	ITS [25]	RGA [18]	GA [11]	UVDA [26]	FWA [22]	ACSA [23]	Proposed IHSA
Scenario I (Base Case)	Switches kept open	SW -69, SW -70, SW -71, SW -72, SW -73						
	Power Loss - P <sub>L</sub> (MW)	0.2249	0.2249	0.2249	0.2249	0.2249	0.2249	0.2249
	V <sub>min</sub> (p.u)	0.9091	0.9091	0.9091	0.9091	0.9091	0.9091	0.9091
Scenario II (Network Reconfiguration Performed)	Switches kept open	SW -14, SW -57, SW -69, SW -61, SW -70	SW -13, SW -17, SW -61, SW -55, SW -69	SW -14, SW -53, SW -70, SW -61, SW -69	SW -14, SW -58, SW -61, SW -69, SW -70	SW -69, SW -70, SW -14, SW -56, SW -61	SW -69, SW -70, SW -14, SW -57, SW -61	SW -14, SW -15, SW -61, SW -69, SW -70
	Power Loss - P <sub>L</sub> (MW)	0.1010	0.1002	0.1032	0.1013	0.1057	0.1022	0.0994
	V <sub>min</sub> (p.u)	0.9323	0.9428	0.9411	0.9256	0.9428	0.9432	0.9495
	Loss Reduction (%)	55.09	55.44	54.11	54.95	53.00	54.55	55.80

As seen from the results obtained in this table that after performing proposed reconfiguration problem based on IHSA for IEEE 69 – bus system, switches:  $SW_{14}$ ,  $SW_{55}$ ,  $SW_{61}$ ,  $SW_{69}$ ,  $SW_{70}$  are opened and the network losses are reduced from 224.95 kW (i.e. base case) to 98.59 kW (i.e. scenario 2). For normal loading condition, the corresponding percentage of power loss reduction is 55.79%, and the voltage magnitude after reconfiguration raised to 0.9495 p.u.

The comparison between the results obtained with the proposed method and other methods found in the existing literature is presented in Table 4. The comparative analysis signify that thei proposed method is effective and efficient in bringing down the distribution loss and improving the system bus voltage profile.

The comparison of power loss reduction percentages for IEEE 69 – bus radial system is depicted in Figure 4.



Figure 4. Comparison of power loss reduction percentages for IEEE 69 - bus system

Further, the voltage profile curves for both the scenarios obtained by proposed IHSA method for nominal load is shown in Figure 5.



Figure 5. Voltage Profile Improvement for both the scenarios at nominal load by IHSA for IEEE 69 – bus system

The comparison of convergence characteristics regarding to real power loss for IEEE 69 - bus system is presented in Figure 6. It is observed from the Figure, that the proposed, method as comparedito other approaches converges faster for reconfiguration scenario.



Figure 6. Comparison of convergence characteristics for IEEE 69 – bus radial distribution system

#### B. Test System II – IEEE 119 – Bus Radial Distribution System

The IEEE 119 – node system is a large scale radial distribution network comprising of 119 nodes, 118 sectionalizing switches and 15 ties switches [29]. The system total active and reactive loads are 22.709 MW and 17.041 MVAr, respectively. The initial system real power loss and initial bus voltage before reconfiguration are 1.298 MW and 0.8688 p.u. The initial opened tie switches are:  $SW_{118}-SW_{119}-SW_{120}-SW_{121}-SW_{122}-SW_{123}-SW_{124}-SW_{125}$ -  $SW_{127}-SW_{128}-SW_{129}-SW_{130}-SW_{131}-SW_{132}$ . The single line layout of 119 – bus system is demonstrated in Figure 7.

Similar to IEEE 69 bus radial distribution network, this 119 bus radial distribution system is likewise simulated for both the situations (i.e. base case and network reconfiguration scenario) at same three distinct loading conditions viz light load, nominal load and heavy load, and the findings obtained by the proposed IHSA including optimal tie switches configuration, power loss, percentage loss reduction and minimum p.u. voltage are shown in Table 5. As can be seen from the results obtained that after implementing reconfiguration scenario using IHSA, the system active power loss reduced from 1.298 MW to 0.8523 MW, and minimum bus voltage improved from 0.86880 p.u. to 0.9324 p.u. Further, the proposed IHSA determined the optimal opened switches:  $SW_{23} - SW_{25} - SW_{34} - SW_{39} - SW_{42} - SW_{50} - SW_{58} - SW_{71} - SW_{74} - SW_{95} - SW_{97} - SW_{109} - SW_{121} - SW_{129} - SW_{130}$ .

In Table 6, the results obtained by various methods existing in the literature are compared with proposed IHSA approach. It is observed from the outcomes of Table 6, that the proposed method as compared to other methods provide better solution for minimization of distribution network active power loss and improvement of voltage profile.

		Load Level					
Scenario		Light Load	Nominal Load	Heavy Load			
		(0.5)	(1.0)	(1.5)			
Scenario – I (i.e. Base Case)	Switches Opened	SW 118 - SW 119 - SW 120 - SW 121 - SW 122 - SW 123 - SW 124 - SW 125 - SW 125 - SW 125 - SW 127 - SW 128 - SW 129 - SW 130 - SW 131 - SW 132	SW 118 - SW 119 - SW 120 - SW 121 - SW 122 - SW 123 - SW 124 - SW 125 - SW 127 - SW 128 - SW 129 - SW 130 - SW 131 - SW 132	SW 118 - SW 119 -SW120 - SW121 - SW 122 - SW 123 - SW 124 - SW 125 - SW 125 - SW 127 - SW 128 - SW 129 - SW 130 - SW 131 - SW 132			
	Power Loss (MW)	0.658	1.298	1.845			
	Minimum Voltage (p.u)	0.9025	0.8688	0.8025			
Scenario – II (i.e. Network Reconfiguration Implemented)	Switches Opened	$\begin{array}{c} SW \ _{23} - SW \ _{25} \\ - SW \ _{34} - \\ SW \ _{39} - SW \ _{42} \\ - SW \ _{50} - \\ SW \ _{58} - SW \ _{71} \\ - SW \ _{74} - \\ SW \ _{95} - SW \ _{97} \\ - SW \ _{109} - \\ SW \ _{121} - \\ SW \ _{129} - \\ SW \ _{130} \end{array}$	SW 23 - SW 25 - SW 34 - SW 39 - SW 42 - SW 50 - SW 58 - SW 71 - SW 74 - SW 95 - SW 97 - SW 109 - SW 121 - SW 129 - SW 130	SW 23 - SW 25 - SW 34 - SW 39 - SW 42 - SW 50 - SW 58 - SW 71 - SW 74 - SW 95 - SW 97 - SW 109 - SW 121 - SW 129 - SW 130			
	Power Loss (MW)	0.4527	0.8523	1.1771			
	% Loss Reduction	31.2	34.33	36.20			
	Minimum Voltage (p.u)	0.9568	0.9324	0.9050			

Table 5. Results of 119 – Bus System



Figure 7. Single line diagram of 119 - bus radial distribution system



Figure 8. Comparison of power loss reduction percentages for IEEE 119 - bus system

a	Item	ITS	RGA	GA	MTS	FWA	CSA	Proposed
Case		[25]	[32]	[11]	[5]	[22]	[36]	IHSA
		SW 118-	SW 118-	SW 118-	SW 118-	SW 118-	SW 118-	SW 118-
		SW 119-	SW 119-	SW 119-	SW 119-	SW 119-	SW 119-	SW 119-
		SW 120-	SW 120-	SW 120-	SW 120-	SW 120-	SW 120-	SW 120-
		SW 121	SW 121-	SW 121-	SW 121-	SW 121-	SW 121-	SW 121-
		-SW 122	SW 122-	SW 122-	SW 122-	SW 122-	SW 122-	SW 122-
		-SW 123	SW 123-	SW 123-	SW 123-	SW 123-	SW 123-	SW 123-
	Switches	-SW 124	SW 124-	SW 124-	SW 124-	SW 124-	SW 124-	SW 124-
Soonario I	kept open	-SW 125	SW 125-	SW 125-	SW 125-	SW 125-	SW 125-	SW 125-
(Pasa		-SW 127	SW 127-	SW 127-	SW 127-	SW 127-	SW 127-	SW 127-
(Dase		-SW 128	SW 128-	SW 128-	SW 128-	SW 128-	SW 128-	SW 128-
Case		-SW 129	SW 129-	SW 129-	SW 129-	SW 129-	SW 129-	SW 129-
		-SW 130	SW 130-	SW 130-	SW 130-	SW 130-	SW 130-	SW 130-
		-SW 131	SW 131 -	SW 131 -	SW 131 -	SW 131-	SW 131-	SW 131-
		-SW 132	SW 132	SW 132	SW 132	SW 132	SW 132	SW 132
	Power							
	Loss - P <sub>L</sub>	1.298	1.298	1.298	1.298	1.298	1.298	1.298
	(MW)							
	$V_{min}$ (p.u)	0.8688	0.8688	0.8688	0.8688	0.8688	0.8688	0.8688
		SW 42 -	SW 42-	SW 42-	SW 42-	SW 42-	SW 42-	
		SW 26 -	SW 26-	SW 60-	SW 26-	SW 25-	SW 25-	
	Switches kept open	SW 23 -	SW 22-	SW 23-	SW 23-	SW 23-	SW 23-	$SW_{23} - SW_{25}$
		SW 51 -	SW 51-	SW 61-	SW 51-	SW 121-	SW 121-	$-SW_{34} -$
		$SW_{119}$ -	SW 48-	SW 48-	SW 122-	SW 50-	SW 50-	$SW_{39} - SW_{42}$
		SW 58-	SW 61 -	SW 73-	SW 58-	SW 58-	SW 58-	$-SW_{50} -$
		SW 34 -	SW 39-	SW 34-	SW 39-	SW 39-	SW 39-	$SW_{58} - SW_{71}$
		SW 39-	SW 125-	SW 39-	SW 95-	SW 95-	SW 95-	$-SW_{74}-$
Scenario II		SW 74 -	SW 73-	SW 72-	SW 74-	SW 71-	SW 71-	$SW_{95} - SW_{97}$
Network		SW 95 -	SW 72-	SW 76-	SW 71-	SW 74-	SW 74-	$-SW_{109} -$
Reconfigur		SW 71 -	SW 76-	SW 82-	$S_{97} -$	SW 97-	SW 97-	$SW_{121} -$
ation		SW 97-	SW 82-	SW 30-	SW 109-	SW 129-	SW 129-	$SW_{129} -$
Performed)		SW 129-	SW 32-	SW 125-	SW 34-	SW 34-	SW 34-	$SW_{130}$
- Crionned)		SW 130 -	SW 109-	SW 109 -	SW 129-	SW 109-	SW 109-	
		SW 109	SW 130	SW 119	SW 130	SW 130	SW 130	
	Power							
	$Loss - P_L$	0.8802	0.8860	0.8658	0.8598	0.8732	0.8550	0.8502
	(MW)							
	$V_{min}$ (p.u)	0.9323	0.9323	0.9298	0.9254	0.9269	0.9278	0.9324
	Loss							
	Reduction	32.18	31.70	33.29	33.75	32.72	34.12	34.49
	(%)							

Table 6. Comparison of Simulation Results for IEEE 119 – bus radial distribution system for Nominal Load Condition

For IEEE 119 – bus radial distribution system, the comparison of power loss reduction percentages, and the voltage profile curves for both the scenarios obtained by proposed IHSA at nominal load is depicted in Figure 8 and Figure 9.



Figure 9. Voltage Profile Improvement for both the scenarios at nominal load by IHSA for IEEE 119 – bus system

The curve in Figure 10. indicates that the IHSA gives faster solution (i.e. less computation time) for reconfiguration scenario.



Figure 10. Comparison of convergence characteristics for IEEE 119 – bus radial distribution system

Based on the findings obtained for both the IEEE test systems i.e. IEEE 69 - bus, and IEEE 119 - bus distribution system, it is observed that the robustness of the proposed IHSA method is superior compared to other state - of - the art methodologies available in the prevalent literature. Further, the results also reveal that the proposed IHSA method has better optimization capabilities for solving the large scale distribution network reconfiguration problem.

#### 5. Conclusions

Inspired from musical harmony, an Improved Music Based Harmony Search Algorithm (IHSA) for solving distribution network reconfiguration problem for both medium scale and large scale radial distribution system has been presented in the present paper. The proposed optimization algorithm establishes the optimized configuration of the network with main objective being active power loss minimization while considering operating constraints. The

IEEE 69 – bus and IEEE – 119 bus distribution systems at three different loading conditions namely light load, nominal load and heavy load have been considered to validate the efficacy of the proposed IHSA method. The empirical findings reveal that the proposed method as compared to other methods has high convergence speed in solving network reconfiguration problem and found to be effective and efficient in reducing the system power loss. The computational results also demonstrated that IHSA has significant potential in handling with large scale network reconfiguration problem. Moreover, the results also signify that the proposed IHSA in comparison with other available methods provide better quality of solutions in terms of power loss reduction and enhancement of voltage profile. So, in view of the above discussion, it can be concluded that proposed IHSA method can be a very promising and powerful approach for dealing with network reconfiguration problem.

## 6. References

- [1]. S. Gopiya Naik, D. K. Khatod and M. P. Sharma, "Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks," *International Journal of Electrical Power Energy Systems*, Vol. 53, pp. 967 973, 2013.
- [2]. Y. H. Song, G. S. Wang, A. T. Johns, and P. Y. Wang, "Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming," *Proc. Inst. Elect. Eng., Generation, Transmission, Distribution*, Vol. 144, no. 4, pp. 345 – 350, 1997.
- [3]. J. Zhu, X. Xiong, J. Jhang, G. Shen, Q. Qu and Y. Xue, "A rule based comprehensive approach for reconfiguration of electrical distribution network," *Electric Power Systems Research*, Vol. 79, pp. 311 315, 2009.
- [4]. Wang and H. Z. Cheng, "Optimization of network configuration in large distribution systems using plant growth simulation algorithm," Vol. 23, no. 1, pp. 119 126, 2008.
- [5]. A. Y. Abdelaziz, F. M. Mohamed, S. F. Mekhamer, M. A. L. Badr, "Distribution system reconfiguration using a modified Tabu Search Algorithm," *Electric Power Systems Research*, Vol. 80, pp. 943 953, 2010.
- [6]. Merlin and H. Back, "Search for a minimal loss operating spanning tree configuration in an urban power distribution system," in *Proceedings 5<sup>th</sup> Power System Computation Conference (PSCC)*, Cambridge, U. K., pp. 1 – 18, 1975
- [7]. S. Civanlar, J. Grainger, H. Yin and S. Lee, "Distribution feeder reconfiguration for loss reduction, *IEEE Transactions on Power Delivery*," Vol. 3, no. 3, pp. 1217 1223, 1988.
- [8]. Shirmohammadi and H. W. Hong, "Reconfiguration of electric distribution networks for resistive line losses reduction," *IEEE Transactions on Power Delivery*," Vol. 4, no. 2, pp. 1492 – 1498, 1989.
- [9]. M. E. Baran and F. Wu, "Network reconfiguration in distribution system for loss reduction and load balancing," *IEEE Transactions on Power Delivery*, Vol. 4, no. 2, pp. 1401 – 1407, 1989.
- [10]. T. P. Wagner, A. Y. Chikhani and R. Hackam, "Feeder reconfiguration for loss reduction: an application of distribution automation," *IEEE Transactions on Power Delivery*," Vol. 6, no. 4, pp. 1922–1931, 1991.
- [11]. K. Nara, A. Shiose, M. Kitagawoa and T. Ishihara, "Implementation of genetic algorithm for distribution systems loss minimum reconfiguration," *IEEE Transactions on Power Systems*, Vol. 7, no. 3, pp. 1044–1051, 1992.
- [12]. R. J. Sarfi, M. M. A. Sarama and A.Y. Chikhani, "Distribution System Reconfiguration for Loss Reduction: An Algorithm Based on Network Partitioning Theory," *Proceedings of PICA*, Salt Lake City, Utah, pp. 503-509, 1995.
- [13]. J. Yuan Fan, L. Zhang, J. D. McDonald, "Distribution network reconfiguration: single loop optimization, *IEEE Transactions on Power Systems*, Vol. 11, no. 3, pp. 1643 – 1647, 1996.
- [14]. M. A. Kashem, G. B. Jlasmon, A. Mohamed and M. Moghavvemi, "Artificial neural network approach to network reconfiguration for loss minimization in distribution networks," *Electrical Power and Energy Systems*, Vol. 20, pp. 247 – 258, 1998.

- [15]. R. Taleski, D. Rajicic, "Distribution network reconfiguration for energy loss reduction," *IEEE Transactions on Power Systems*, Vol. 12, no. 1, pp. 398-406, 1997.
- [16]. Das, "A fuzzy multi-objective approach for network reconfiguration of distribution systems," *IEEE Transactions on Power Delivery*, Vol. 21, no. 1, pp. 202–209, 2006.
- [17]. S. K. Goswami and S. K. Basu, "A new algorithm for the reconfiguration of distribution feeders for loss minimization," *IEEE Transactions on Power Delivery*, Vol. 7, no. 3, pp. 1484 – 1491, 1992.
- [18]. J. Z. Zhu, "Optimal reconfiguration of electrical distribution network using the refined genetic algorithm," *Electric Power Systems Research*, Vol. 62, pp. 37–42, 2002.
- [19]. W. M. Lin, F. S. Cheng, and M. T. Tsay, "Distribution feeder reconfiguration with refined genetic algorithm," *IEE Proceedings: Generation, Transmission and Distribution*, Vol. 147, no. 6, pp. 349–354, 2000.
- [20]. R. Srinivasa Rao, S. V. L. Narasimham, M. R. Raju, and A. Srinivasa Rao, "Optimal network reconfiguration of large-scale distribution system using Harmony Search Algorithm," *IEEE Transactions on Power Systems*, Vol. 26, no. 3, 1080–1088, 2011.
- [21]. K. Sathishkumar, T. Jayabarathi, "Power system reconfiguration and loss minimization for distribution system using bacterial foraging optimization algorithm," *International Journal* of Electrical Power Energy Systems, Vol. 36, pp. 13–17, 2012.
- [22]. A. Mohamed Imran and M. Kowsalya, "A new power system reconfiguration scheme for power loss minimization and voltage profile enhancement using Fireworks Algorithm," *International Journal of Electrical Power Energy Systems*, Vol. 62, pp. 312 – 322, 2014.
- [23]. T. Su, C. F. Chang, J. P. Chiou, "Distribution network reconfiguration for loss reduction by Ant Colony Search Algorithm," *Electric Power Systems Research*, Vol. 75, no. 2-3, pp. 190 – 199, 2005.
- [24]. J. Olamaei, T. Niknam, S. Arefi Badali, "Distribution feeder reconfiguration for loss minimization based on Modified Honey Bee Mating Optimization Algorithm," *Energy Procedia*, Vol. 14, pp. 304–311, 2012.
- [25]. Zhang, Z. Fu, L. Zhang, "An improved TS algorithm for loss minimum reconfiguration in large – scale distribution systems," *Electric Power Systems Research*, Vol. 77, pp. 685 – 694, 2007.
- [26]. A. Bayat, A. Bagheri, and R. Noroozian, "Optimal siting and sizing of distributed generation accompanied by reconfiguration of distribution networks for maximum loss reduction by using a new UVDA-based heuristic method," *International Journal of Electrical Power Energy Systems*, Vol. 53, pp. 360–371, 2016.
- [27]. M. R. Nayak, "Optimal Feeder Reconfiguration of Distribution System with Distributed Generation Units using HC-ACO," *International Journal on Electrical Engineering and Informatics*, Vol. 11, no. 2, pp. 308 – 325, 2019.
- [28]. R. Rajaram, K. Sathish Kumar, and N. Rajasekar, "Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)," *Energy Reports*, Vol. 1, 116 – 122, 2015.
- [29]. Kola Sampangi Sambaiah and T. Jayabarathi, "Optimal reconfiguration and renewable distributed generation allocation in electric distribution systems," *International Journal of Ambient Energy*, 2019. DOI: <u>10.1080/01430750.2019.1583604</u>.
- [30]. Ahmet Dogan and Mustafa Alci, "Simultaneous Optimization of Network Reconfiguration and DG Installation Using Heuristic Algorithms," *Elektronika Ir Elektrotechnika*, Vol. 25, no. 1, pp. 8 – 13, 2019.
- [31]. T. Niknam and E. A. Farsani, "A hybrid self-adaptive particle swarm optimization and modified shuffled frog leaping algorithm for distribution feeder reconfiguration," *Engineering Applications of Artificial Intelligence*, Vol. 23, no. 8, pp. 1340 – 1349, 2010.
- [32]. Azad-Farsani, M. Zare, R. Azizipanah-Abarghooee and H. Askarian-Abyaneh, "A new hybrid CPSO-TLBO optimization algorithm for distribution network reconfiguration," *Journal of Intelligent Fuzzy Systems*, Vol. 26, no. 5, pp. 2175–2184, 2014.

- [33]. Z. W. Geem, J. H. Kim and G. V. Loganathan, "A new heuristic optimization algorithm Harmony Search," *Simulation*, Vol. 76, no. 2, pp. 60 – 68, 2001.
- [34]. M. Mahdavi, M, Fesanghary, and E. Damangir, "An improved harmony search algorithm for solving optimization problems," *Appl Math Comput*, Vol. 188, no. 2, pp. 1567–1579, 2007.
- [35]. Chiang, R. Jean-Jumeau, "Optimal network reconfigurations in distribution systems. Part I. A new formulation and a solution methodology," *IEEE Transactions on Power Delivery*, Vol. 5, pp. 1902 – 1909, 1990.
- [36]. T. T. Nguyen, A. V. Truong, "Distribution network reconfiguration for power loss minimization and voltage profile improvement using Cuckoo Search Algorithm," *International Journal of Electrical Power Energy Systems*, Vol. 68, pp. 233 – 42, 2015.



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