Using Hybridizing Harmony Search Algorithm for Network Reconfiguration to Reduce the Losses and Improve Voltage Profile

M. Sai Phaneendra
Department of Electrical Engineering
Chebrolu Engineering College,
Guntur,A.P,India

P. Jayakar,
Department of Electrical Engineering
Chebrolu Engineering College,
Guntur,A.P,India

Ch. Hari Babu,
Department of Electrical Engineering
Chebrolu Engineering College,
Guntur,A.P,India

Abstract: **This paper presents an harmony search algorithm for loss-minimization reconfiguration in large-scale distribution systems. Electrical distribution network reconfiguration is a complex combinatorial optimization process aimed at finding a radial operating structure that minimizes the system power loss while satisfying operating constraints. The Hybridizing Harmony search algorithm is a recently developed algorithm which is conceptualized using the musical process of searching for a perfect state of harmony. It uses a stochastic random search instead of a gradient search so that derivative information is unnecessary. In order to validate the proposed algorithm, simulations are carried out on 33 and results are compared with other approaches available in literature. It is observed that the proposed method outperformed the other methods in terms of the quality of solution.**

Keywords: **Distribution system, Network reconfiguration, Loss reduction, Harmony Search Algorithm.**

I. INTRODUCTION

Power distribution networks are built as interconnected meshed networks; however, they are arranged to be radial in operation to simplify over-current protection. The configuration may be varied with switching operations to transfer loads among the feeders. Under normal operating conditions, optimization of network configuration is the process of changing the topology of distribution systems by altering the open/closed status of switches so as to find a radial operating structure that minimizes the system real power loss while satisfying operating constraints.

Feeder reconfiguration entails altering the topological structure of distribution feeders by changing the open/close status of the switches under both normal and abnormal operating conditions. Since many candidate-switching combinations are possible in a distribution system, finding the operating network reconfiguration becomes a complicated combinatorial, non-differentiable constrained optimization problem. Distribution system reconfiguration for loss reduction was first proposed by Merlin *et al* [1]. They employed a blend of optimization and heuristics to determine the minimal-loss operating configuration for the distribution system represented by a spanning tree structure at a specific load condition. A branch and bound type heuristic algorithm was suggested by Civanlar *et al.* [2], where a simple formula was developed for determination of change in power loss due to a branch exchange. In [3]–[5], the authors suggested to employ a power flow method-based heuristic algorithm (PFBHA) for determining the minimum loss configuration of radial distribution networks. In [6,7,8], the authors proposed a solution procedure employing simulated annealing (SA) to search an acceptable non-inferior solution. Nara *et al.* [9] presented an implementation using a genetic algorithm (GA) to look for the minimum loss configuration. Das [10] presents an algorithm based on the heuristic rules and fuzzy multi-objective approach for optimizing network configuration.

In this paper, improvements developed to make HHSA algorithm more effective and more efficient for loss-minimum reconfigu-ration in large-scale distribution systems. The proposed method is tested on 33 and results obtained are very encouraging.

The rest of this paper is organized as follows: Section II gives the problem formulation. Section III provides an overview of Harmony Search Algorithm. Section IV describes applicationof HSA algorithm for the network reconfiguration problem. Section V presents computational results and section VI outlines conclusions.

II. PROBLEM FORMULATION

The network reconfiguration problem in a distribution system is to find a best configuration of radial network that gives minimum power loss while the imposed certain operating constraints. Which are voltage profile of the system, current capacity of the feeder and radial structure of the distribution system. The objective function for the minimization of power loss is described as:

$$\text{Minimize } f = min(P_{T,Loss}) \quad (1)$$

$$\text{Subjected to} \quad V_{min} \le |V_i| \le V_{max} \quad (2)$$

$$|I_i| \le |I_{i,\max}| \quad (3)$$

where

$P_{T,Loss}$ is the total real power loss of the system;

$|V_i|$ Voltage magnitude of bus *i;*

$V_{\min}, V_{\max}$ are bus minimum and maximum voltage limits respectively;

$I_i, I_{i,\max}$ are current magnitude and maximum current limit of branch *i* respectively;

The power flows are computed by the following set of simplified recursive equations [11] derived from the single-line diagram shown in Fig. 1.

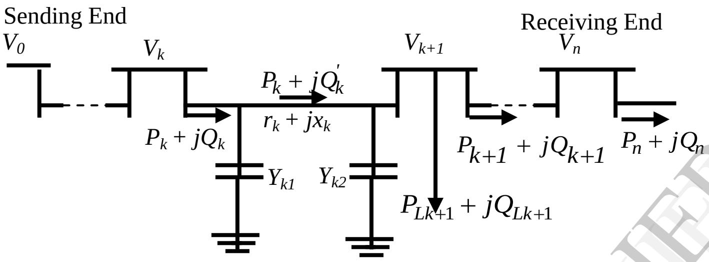

Fig. 1 Single-line diagram of a main feeder

$$\begin{aligned} P_{k+1} &= P_k - P_{Loss,k} - P_{Lk+1} \\ &= P_k - \frac{r_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\right\} - P_{Lk+1} \end{aligned} \quad (4)$$

$$\begin{aligned} Q_{k+1} &= Q_k - Q_{Loss,k} - Q_{Lk+1} \\ &= Q_k - \frac{x_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_{k1}|V_k|^2)^2\right\} - Y_{k1}|V_k|^2 \\ &\quad - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \end{aligned} \quad (5)$$

$$\begin{aligned} |V_{k+1}|^2 &= |V_k|^2 + \frac{r_k^2 + x_k^2}{|V_k|^2}\left(P_k^2 + Q_k'^2\right) - 2\left(r_k P_k + x_k Q_k'\right) \\ &= |V_k|^2 + \frac{r_k^2 + x_k^2}{|V_k|^2}\left(P_k^2 + (Q_k + Y_k|V_k|^2)^2\right) \\ &\quad - 2\left(r_k P_k + x_k(Q_k + Y_k|V_k|^2)\right) \end{aligned} \quad (6)$$

where P_k and Q_k are the real and reactive powers flowing out of bus *k*, and P_{Lk+1} and Q_{Lk+1} are the real and reactive load powers at bus *k+1*. The shunt admittance is denoted by Y_{kl} at any bus *k* to ground. The resistance and reactance of the line section between buses *k* and *k*+1 are denoted by r_k and x_k, respectively.

The power loss of the line section connecting buses *k* and *k*+1 may be computed as

$$P_{Loss}(k,k+1) = r_k \cdot \frac{(P_k^2 + Q_k'^2)}{|V_k|^2} \quad (7)$$

The total power loss of the feeder, $P_{T,Loss}$, may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,Loss} = \sum_{k=1}^{n} P_{Loss}(k,k+1) \quad (8)$$

where *n* is the total number of lines sections in the system.

III. OVERVIEW OF HARMONY SEARCH ALGORITHM

The Harmony Search Algorithm (HSA) is a new metaheuristic population search algorithm proposed by Geem et al [12]. HSA was derived from the natural phenomena of musicians' behavior when they collectively play their musical instruments (population members) to come up with a pleasing harmony (global optimal solution). This state is determined by an aesthetic standard (fitness function). The HS algorithm, is simple in concept, few in parameters, and easy in implementation, has been successfully applied to various benchmarking, and real-world problems like traveling salesman problem [13]. The main steps of HS are as follows [12]:

Step 1: Initialize the problem and algorithm parameters.
Step 2: Initialize the harmony memory.
Step 3: Improvise a new harmony.
Step 4: Update the harmony memory.
Step 5: Check the termination criterion.

These steps are described in the next five subsections.

1. Initialize the problem and algorithm parameters

The general optimization problem is specified as follows:

$$\begin{aligned} &\textit{Minimize } f(x) \\ &\text{Subject to } x_i \in X, \qquad i = 1,2,.............N \end{aligned} \quad (9)$$

where *f(x)* is an objective function; *x* is the set of each decision variable x_i; *N* is the number of decision variables, X_i is the set of the possible range of values for each decision variable, that is ${}_L x_i \le X_i \le {}_U x_i$ and ${}_L x_i$ and ${}_U x_i$ are the lower and upper bounds for each decision variable. The HS algorithm parameters are also specified in this step. These are the Harmony Memory Size (*HMS*), or the number of solution vectors in the harmony memory; Harmony Memory Considering Rate (*HMCR*); Pitch Adjusting Rate (*PAR*); and the number of improvisations (*NI*), or stopping criterion. The harmony memory (*HM*) is a memory location where all the solution vectors (sets of decision variables) are stored. Here, *HMCR* and *PAR* are parameters that are used to improve the solution vector. which are defined in Step 3.

2. Initialize the harmony memory

In this step, the *HM* matrix is filled with as many randomly generated solution vectors as the *HMS*

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & .. & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & .. & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & .. & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & .. & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \quad (10)$$

There is a possibility of infeasible solutions which violate the constraints. However, the algorithm forces the search towards feasible solution area. Static penalty functions are used to calculate the penalty cost for an infeasible solution. The total cost for each solution vector is evaluated using:

$$fitness(\vec{X}) = f(\vec{X}) + \sum_{i=1}^{M} \alpha_i (min[0, g_i(\vec{x})]^2 + \sum_{j=1}^{P} \beta_j (min[0, h_j(\vec{x})]^2 \quad (11)$$

where α_i and β_j are the penalty coefficients. Generally, it is difficult to find a specific rule to determine the values of the penalty coefficients and hence these parameters remain problem-dependent.

3. Improvise a new harmony

A New Harmony vector $\vec{x'} = (x'_1, x'_2, ..., x'_N)$, is generated based on three criteria: (1) Memory consideration (2) Pitch adjustment (3) Random selection. Generating a new harmony is called improvisation. According to memory consideration, i[th] variable $x_i = (x_1^1 - x_1^{HMS})$. The *HMCR*, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the *HM*, while (1-*HMCR*) is the rate of randomly selecting one value from the possible range of values, as shown in eq.(12).

$$\begin{aligned} & if\ (rand(\ ) < HMCR) \\ & x_i' \leftarrow x_i' \in \{x_i^1, x_i^2, ...x_1^{HMS}\} \\ & else \\ & x_i' \leftarrow x_i' \in X_i \\ & end \end{aligned} \quad (12)$$

where *rand( )* is a uniform random number between 0 and 1 and X_i is the set of the possible range of values for each decision variable, that is ${}_L x_i \le X_i \le {}_U x_i$. For example, an *HMCR* of 0.85 indicates that HSA will choose decision variable value from historically stored values in *HM* with 85% probability or from the entire possible range with (100-85) % probability. Every component obtained with memory consideration is examined to determine if pitch is to be adjusted. This operation uses the rate of pitch adjustment as a parameter as shown below:

$$\begin{aligned} & if\ (rand(\ ) < PAR) \\ & \quad x_i' = x_i' \pm rand() * bw \\ & else \\ & \quad x_i' = x_i' \\ & end \end{aligned} \quad (13)$$

where *bw*, is an arbitrary distance bandwidth. In order to improve the performance of the HSA and eliminate the drawbacks associated with fixed values of *PAR* and *bw* [14], a variable values of *PAR* and *bw* are used in improvisation step. The dynamically changed values of *PAR* and *bw* with generation number is expressed as shown below:

$$PAR(gn) = PAR_{min} + \left(\frac{PAR_{max} - PAR_{min}}{NI} \right) gn \quad (14)$$

where $PAR(gn)$ is the pitch adjusting rate for each generation, PAR_{min}, PAR_{max} are the minimum and maximum pitch adjusting rates respectively and *gn* is the generation number, *NI* is number of iterations.

$$bw(gn) = bw_{max}\, exp(c.gn)$$
$$c = \frac{ln\left(\frac{bw_{min}}{bw_{max}} \right)}{NI} \quad (15)$$

where $bw(gn)$ the bandwidth is for each generation, bw_{max} is the maximum bandwidth.

4. Update harmony memory

If the new harmony vector $\vec{x'} = (x'_1, x'_2, ..., x'_N)$, has better fitness function than the worst harmony in the *HM*, the new harmony is included in the *HM* and the existing worst harmony is excluded from the *HM*.

5. Check termination criterion

The HSA is terminated when the termination criterion (e.g. maximum number of improvisations) has been met. Otherwise, steps 3 and 4 are repeated.

In order to demonstrate the convergence capability of harmony search, let us consider the harmony memory with the following parameters: the size of $HM = M$,
the number of instruments (variables) = N,
the number of possible notes (values) of instruments = L,
the number of optimal note (value) of instrument i in $HM = H_i$,
harmony memory considering rate = H_r, and
the optimal harmony (optimal vector) = (X, Y, Z).

The probability to find the optimal harmony, $Pr(H)$ is

$$Pr(H) = \prod_{i=1}^{N}\left[H_r \frac{H_i}{M} + (1 - H_r)\frac{1}{L} \right] \quad (16)$$

where the pitch adjusting rate is not considered because it is an optional operator. Initially, the HM is stuffed with random harmonies. If there is no optimal note of all instruments in the HM,

$$H_1 = H_2 = \ldots\ldots = H_N = 0$$

and $$Pr(H) = \left[(1 - H_r)\frac{1}{L} \right]^{\frac{1}{N}}$$

This means the probability $Pr(H)$ is very low. Consider a solution vector (X, Y, Z). However, if the schema of optimal harmony such as (*, Y, Z), (X, *, Z), (X, Y, *) have better fitness (better evaluation) than other ones, the number of optimal notes of instrument i in the HM, H_i will be increased iteration by iteration. Consequently, the probability of finding the optimal harmony, $Pr(H)$ will increase.

It is observed that, by nature, the Harmony Search incorporates, the structure of existing heuristic methods. It preserves the history of past vectors (Harmony Memory) similar to TS, and is able to vary the adaptation rate (Harmony Memory Considering Rate) from the beginning to the end of computation resembling SA, and manages several vectors simultaneously in a manner similar to GA. However, the major difference between GA and HS is that HS makes a new vector from all the existing vectors (all harmonies in the Harmony Memory), while GA makes the new vector only from two of the existing vectors (the parents). In addition, HS can independently consider each component variable in a vector while it generates a new vector, where as GA cannot since it has to maintain the structure of a gene.

V. APPLICATION OF HSA FOR NETWORK RECONFIGURATION PROBLEM

The optimum distribution network is obtained by first generating all possible radial structures of the given network (without violating the constraints) and subsequently evaluating the objective function. However, real distribution systems contain many nodes, branches, and trees. Conventional optimization methods are ineffective and impractical, because of dimensionality. In this paper HHSA is proven to be an effective and useful approach for the network reconfiguration problem.

In general, the structure of solution vector [15] for a radial distribution system is expressed by 'Arc No.(i)' and 'SW. No.(i)' for each switch i . 'Arc No.(i)' identifies the arc (branch) number that contains the i^{th} open switch, and 'SW. No.(i)' identifies the switch that is normally open on Arc No.(i). For large distribution networks, it is not efficient to represent every arc in the string, since its length will be very long. In fact, the number of open switch positions is identical to keep the system radial once the topology of the distribution networks is fixed, even if the open switch positions are changed. Therefore, to memorize the radial configuration, it is enough to number only the open switch positions. Fig. 2 shows a 33-bus [15] distribution network with five switches that are normally open.

The open switches in the loops L_1 to L_5 for the network given in fig. 2(a) are given as 33, 34, 35, 36, and 37. Similarly other radial topology is generated randomly with the open switches 19, 13, 21, 30, and 24 as shown in fig. 2(b) and open status of these switches satisfy the radial topology without any isolated node in the system. Therefore, in order to represent an optimum network topology, only positions of the open switches in the distribution network need to be known. Suppose the number of normally open switches (tie switches) is N, then the length of a solution vector is N.

The solution vectors for fig. 2(a) and fig. 2(b) are represented as follows:
The solution vector for fig. 2(a):

HW^1= [*33 34 35 36 37*]

The solution vector for fig. 2(b):

HW^2= [*19 13 21 30 24*]

In the similar way all other possible solution vectors of fig. 2 are generated without violating the radial structure or islanding any load in the network. The total number of solution vectors (*HMS*) generated are less than or equal to highest numbers of switches in any individual loop. The total Harmony Matrix generated randomly with objective function values sorted in ascending order is shown below.

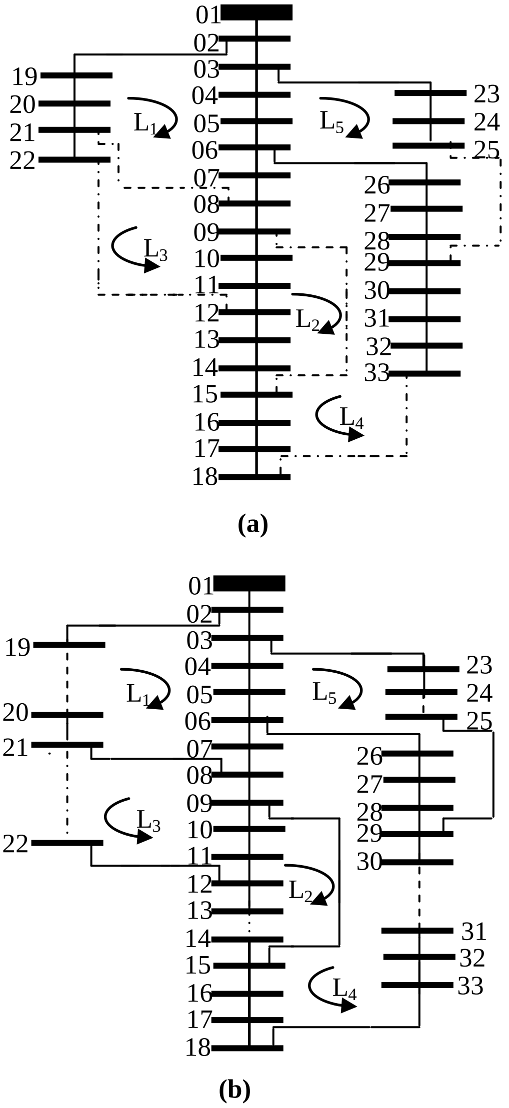

Fig. 2. 33–Bus radial distribution system

$$HM = \begin{bmatrix} 7 & 10 & 14 & 28 & 32 & | & 138.54 \\ 7 & 11 & 34 & 26 & 36 & | & 141.32 \\ 6 & 35 & 14 & 37 & 16 & | & 145.11 \\ 6 & 21 & 34 & 25 & 16 & | & 152.23 \\ 7 & 35 & 13 & 37 & 30 & | & 155.75 \\ 7 & 9 & 13 & 24 & 30 & | & 157.31 \\ 20 & 9 & 14 & 25 & 16 & | & 170.57 \\ 20 & 10 & 14 & 27 & 17 & | & 178.41 \\ 19 & 11 & 14 & 26 & 16 & | & 182.13 \\ 19 & 21 & 34 & 26 & 17 & | & 192.37 \\ 19 & 10 & 13 & 24 & 15 & | & 194.55 \\ 20 & 11 & 14 & 23 & 29 & | & 198.87 \\ 33 & 34 & 35 & 36 & 37 & | & 202.71 \end{bmatrix}$$

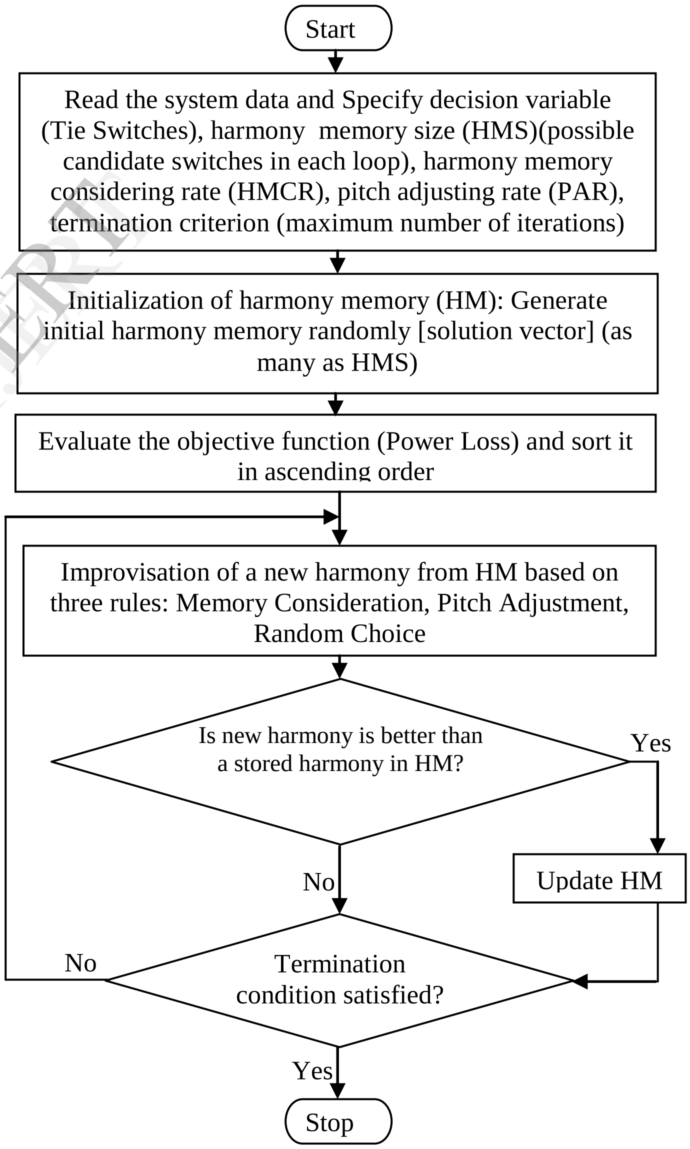

Fig. 3. Flow chart of Harmony Search Algorithm

The new solution vectors are updated by using equation (12). Using the new solution vectors, the worst vectors of previous iteration will be eliminated with a new random vectors selected from the population that has less objective function value.

This procedure is repeated until termination criteria is satisfied. The flow chart of the proposed algorithm is shown in Fig. 3.

V. TEST RESULTS

The proposed method is tested on 33-bus [15] and 119-bus [19] radial distribution systems and results are obtained to evaluate its effectiveness. For all these systems, the substation voltage is considered as 1 p.u. and all tie and sectionalizing switches are considered as candidate switches for reconfiguration problem. The algorithm was developed in MATLAB, and the simulations were done on a computer with Pentium IV, 3.0 GHz, 1GB RAM.

Test Case I - 33-Bus System: The first example system is a 33–bus, 12.66 kV, radial distribution system [15] as shown in fig. 2. It consists of five tie lines and 32 sectionalize switches. The normally open switches are 33 to 37 and the normally closed switches are 1 to 32. The line and load data of the network is obtained from reference [15] and the total real and reactive power loads on the system are 3715 kW and 2300 kVAr. The initial power loss of this system is 202.771 kW. The lowest bus bar voltage limit is 0.9131 p.u which occurs at node 18.

TABLE I
PARAMETERS OF THE HS ALGORITHM

HMS	13
HMCR	0.85
PAR	0.25
bw	0.01
Number of iterations	250

The parameters of Hybridizing HS algorithm used in the simulation of the network are shown in Table I. The optimal configuration obtained by the proposed algorithm is 7,10,14,37,36, which has a real power loss of 138.067 kW. This amounts to a reduction of 31.89 % in total power loss. The minimum node voltage of the system after reconfiguration improved to 0.9342 p.u (node 33).

The voltage profile of the system is as shown in Fig. 4.

.

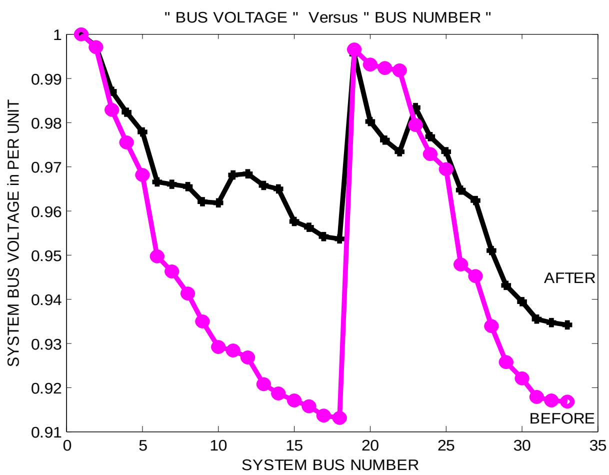

Fig. 4. Voltage Profile of 33-bus system

This shows feeder are relieved from the overloading and makes it possible to load the feeders further. The power loss in each branch is also shown in Fig. 5. It is observed that the losses in almost every branches is drastically reduced except at 18, 19, 20, 21, 33, 34, and 35 where the losses are increased a little because of shifting of loads on to these feeders.

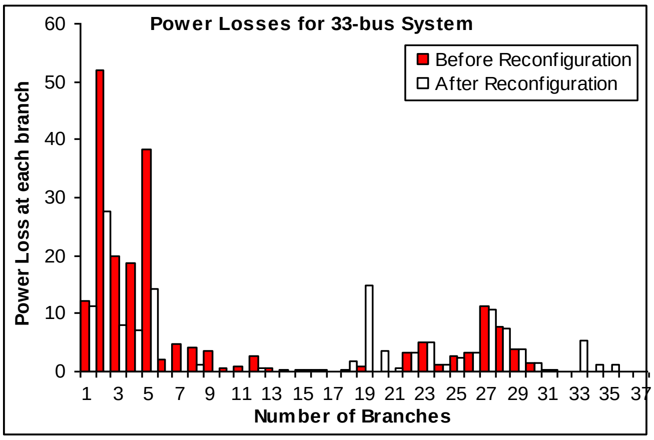

Fig. 5. Losses in the system before and after reconfiguration

The results of the proposed algorithm are compared with Genetic Algorithms [16], Refined Genetic Algorithms [17] and Plant Growth Simulation Algorithm (PGSA) [18] and are presented in Table IV.

TABLE IV
SIMULATION RESULTS OF 33-BUS SYSTEM

Item	Initial Config-uration	Final Configuration			
		GA [16]	RGA [17]	PGSA [18]	Proposed Method HHSA
Tie Switches	33,35,34, 37,36	33,9,34, 28,36	7,9,14, 37, 32	7,9,14, 37, 32	7,10,14, 37,36
Loss (kW)	202.71	140.6	139.5	139.5	138.06
Minimum Voltage (p.u)	0.9131	0.9310	0.9315	0.9336	0.9342
Loss Saving (%)	--	30.63	31.20	31.20	31.89
CPU Time (s)	--	15.2	13.8		6.8

From the results, it is observed that the optimal power loss obtained by the proposed method is 4% less than GA and 2% less than RGA and PGSA. The convergence characteristics of the proposed HHSA algorithm for 33-bus system are shown in Fig.6. Simulations are carried out for 250 iterations and optimum solution is obtained after 160 iterations. The CPU time taken by the processor to carry out the simulations for 250 iterations is 6.8 sec.

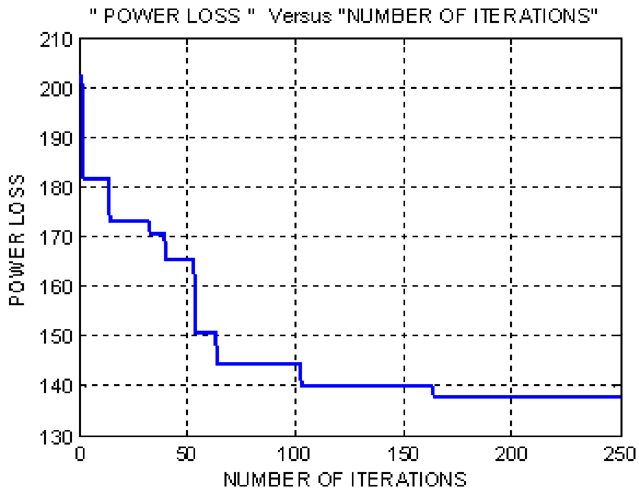

Fig. 6. Convergence characteristics of HHSA for 33-bus system

V. CONCLUSIONS

A recently developed Hybridizing Harmony Search Algorithm is successfully applied for optimizing the large scale radial distribution systems to reduce I^2R loss. The Hybridizing Harmony Search Algorithm is mathematically quite simple concept, easy for implementation as is uses few parameters and effective in finding the solutions of combinatorial optimization problems. It neither needs initial starting values for the variables nor a population of candidate solutions of the problem. Moreover, Hybridizing Harmony Search Algorithm uses a stochastic random search based on the harmony memory considering rate (HMCR) and pitch adjusting rate (PAR), which effectively guide a global search rather than a gradient search, so that derivative information is unnecessary. Furthermore, HHSA generates a new vector after considering all of the existing vectors based on the HMCR and the PAR, rather than considering only two (parents) as in genetic algorithms. These features increase the flexibility of the HHSA and produce better solutions.

Simulations are carried on a medium (33-bus) and results are compared with other methods like GA,RGA,PGSA.Results show that the proposed algorithm can converge to optimum solution with higher accuracy in comparison with other methods mentioned.

REFERENCES

[1] A. Merlin, H. Back, "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system" Proceedings of 5th *Power System Computation* Conference (PSCC), Cambridge, UK, 1975, pp. 1-18.

[2] S. Civanlar, J. Grainger, H. Yin, and S. Lee, "Distribution feeder reconfiguration for loss reduction," *IEEE Trans. Power Del.*, vol. 3, no. 3, pp. 1217–1223, Jul. 1988.

[3] D. Shirmohammadi and H.W. Hong, Reconfiguration of electric distribution networks for resistive line losses reduction," *IEEE Trans. Power Del.*, vol. 4, no. 2, pp. 1492–1498, Apr. 1989.

[4] T. P. Wagner, A. Y. Chikhani, and R. Hackam, "Feeder reconfiguration for loss reduction: an application of distribution automation," *IEEE Trans. Power Del.*, vol. 6, no. 4, pp. 1922–1931, Oct. 1991.

[5] S. Goswami and S. Basu, "A new for the reconfiguration of distribution feeders for loss minimization," *IEEE Trans. Power Del.*, vol. 7, no. 3, pp. 1484–1491, Jul. 1992.

[6] H. C. Cheng and C. C. Kou, "Network reconfiguration in distribution systems using simulated annealing," *Elect. Power Syst. Res.*, vol. 29, pp. 227–238, May 1994.

[7] H. D. Chiang and J. J. Rene, "Optimal network reconfiguration in distribution systems: part 1: a new formulation and a solution methodology," *IEEE Trans. Power Del.*, vol. 5, no. 4, pp. 1902–1908, Oct. 1990.

[8] H. D. Chiang and J. J. Rene, "Optimal network reconfiguration in distribution systems: part 2: solution algorithms and numerical results," *IEEE Trans. Power Del.*, vol. 5, no. 3, pp. 1568–1574, Jul. 1992.

[9] K. Nara, A. Shiose, M. Kitagawoa, and T. Ishihara, "Implementation of genetic algorithm for distribution systems loss minimum reconfiguration," *IEEE Trans. Power Syst.*, vol. 7, no. 3, pp. 1044–1051, Aug. 1992.

[10] D. Das, "A fuzzy multi-objective approach for network reconfiguration of distribution systems," *IEEE Trans. Power Del.*, vol. 21, no. 1, pp. 202–209, Jan. 2006.

[11] Smarajit Ghosh and Karma Sonam Sherpa, " An Efficient method for Load-Flow Solution of Radial Distribution Networks", *International Journal of Electrical Power and Energy Systems Engineering*, vol. 1, no. 2, pp. 108-115, 2008.

[12] 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.

[13] Z.W. Geem, C. Tseng, and Y. Park, "Harmony search for generalized orienteering problem: best touring in China", *Springer Lecture Notes Comput. Sci*., 3412 (2005) 741–750.

[14] M. Mahdavi, M. Fesanghary, and E. Damangir, "An improved harmony search algorithm for solving optimization problems", *Applied Mathematics and Computation*, vol. 188, no. 2, pp. 1567–1579, 2007.

[15] M. E. Baran and F.Wu, "Network reconfiguration in distribution system for loss reduction and load balancing," *IEEE Trans. Power Del.*, *4*(2), 1989, 1401–1407.

[16] Y. Y. Hong and S. Y. Ho, "Determination of network configuration considering multi-objective in distribution systems using genetic algorithms," *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 1062–1069, May 2005.

[17] J. Z. Zhu, "Optimal reconfiguration of electrical distribution network using the refined genetic algorithm," *Elect. Power Syst. Res.*, vol. 62, pp. 37–42, 2002.

[18] Chun Wang and Hao Zhong Cheng, "Optimization of Network Configuration in Large Distribution Systems Using Plant Growth Simulation Algorithm," *IEEE Transactions on Power Systems*, Vol. 23, No. 1, February 2008.

[19] D. 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.