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Optimal Network Reconfiguration and Loss Minimization Using Harmony Search Algorithm In The Presence Of Distributed Generation

[1]Pardhavi Sai Sree.T, [2]Poorna Chandra Rao.N

[1] PG Student, Department of EEE, SVPCET, Puttur, Andhra Pradesh, India
[2]Associate Professor, Department of EEE, SVPCET, Puttur, Andhra Pradesh, India

Abstract: **This paper presents a new method to solve the network reconfiguration problem in the presence of distributed generation (DG) with an objective of minimizing real power loss and improving voltage profile in distribution system. A meta heuristic Harmony Search Algorithm (HSA) Algorithm is used to simultaneously reconfigure and identify the optimal locations for installation of DG units in a distribution network. Sensitivity analysis is used to identify optimal locations for installation of DG units and also Different scenarios are used. The constraints of voltage and branch current carrying capacity are included in the evaluation of the objective function. Here both HSA and PSO methods are used that has been tested on 33-bus and 69-bus radial distribution systems at three different load levels to demonstrate the performance and effectiveness of the HSA and PSO methods. The results obtained are encouraging.**

Keywords: **Distributed generation, distribution system, Harmony Search Algorithm, Particle Swarm Optimization Algorithm, real power loss, reconfiguration, voltage profile.**

I. INTRODUCTION

Due to uncertainty of system loads on different feeders, which vary from time to time, the operation and control of distribution systems is more complex particularly in the areas where load density is high. Power loss in a distributed network will not be minimum for a fixed network configuration for all cases of varying loads. Hence, there is a need for reconfiguration of the network from time to time. Network reconfiguration is the process of altering the topological structure of feeders by changing open/closed status of sectionalizing and tie switches. In general, networks are reconfigured to reduce real power loss and to relieve overload in the network. However, due to dynamic nature of loads, total system load is more than its generation capacity that makes relieving of load on the feeders not possible and hence voltage profile of the system will not be improved to the required level. In order to meet required level of load demand, DG units are integrated in distribution network to improve voltage profile, to provide reliable and uninterrupted power supply and also to achieve economic benefits such as minimum power loss, energy efficiency and load levelling. To date, network reconfiguration and DG placement in distribution networks are considered independently. However, in the proposed method, network reconfiguration and DG installation are deals simultaneously for improved loss minimization and voltage profile.

Since network reconfiguration is a complex combinatorial, no differentiable constrained optimization problem, many algorithms are proposed in the past. Merlin and Back [1] first proposed network reconfiguration problem and they used a branch- and-bound-type optimization technique. The drawback with this technique is the solution proved to be very time consuming as the possible system configurations are, where line sections equipped with switches is. Based on the method of Merlin and Back [1], a heuristic algorithm has been suggested by Shirmohammadi and Hong [2]. The drawback with this algorithm is simultaneous switching of the feeder reconfiguration is not considered. Civanlar *et al.* [3] suggested a heuristic algorithm, where a simple formula was developed to determine change in power loss due to a branch exchange. The disadvantage of this method is only one pair of switching operations is considered at a time and reconfiguration of network depends on the initial switch status. Das [4] presented an algorithm based on the heuristic rules and fuzzy multi-objective approach for optimizing network configuration. The disadvantage in this is criteria for selecting membership functions for objectives are not provided. Nara *et al.* [5] presented a solution using a genetic algorithm (GA) to look for the minimum loss configuration in distribution system. Zhu [6] presented a refined genetic algorithm (RGA) to reduce losses in the distribution system. In RGA, the conventional crossover and mutation schemes are refined by a competition mechanism. Rao *et al.*[7] proposed Harmony Search Algorithm (HSA) to solve the network reconfiguration problem to get optimal switching combinations simultaneously in the network to minimize real power losses in the distribution network.

This paper presents a PSO and HSA algorithms for reconfiguration of unbalanced radial distribution systems for loss minimization. The main contribution of this work is to present an approach to finding the optimal solution of feeder reconfiguration in unbalanced loading distribution systems with the objective of power loss reduction. The algorithms are tested on 33 and 69-bus systems and PSO and HSA results are compared.

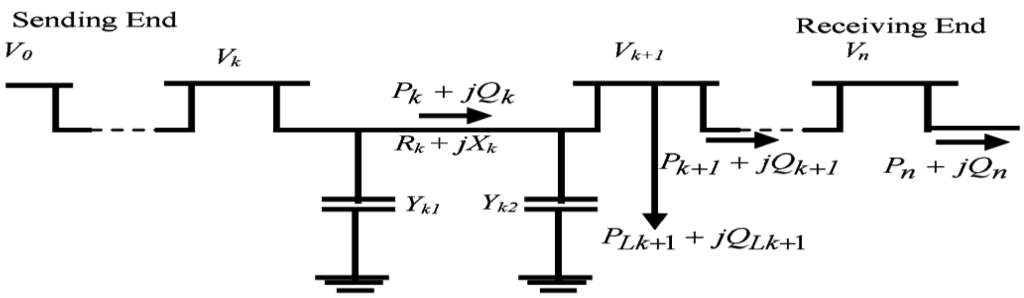


Fig. 1: Single-line diagram of a main feeder.

II. PROBLEM FORMULATION

A. Power Flow Equations

Power flows in a distribution system are computed by the following set of simplified recursive equations [13] derived from the single-line diagram shown in Fig. 1:

$$\begin{aligned} P_{k+1} &= P_k - P_{Loss,k} - P_{Lk+1} \\ &= P_k - \frac{R_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\right\} - P_{Lk+1} \qquad (1) \\ Q_{k+1} &= Q_k - Q_{Loss,k} - Q_{Lk+1} \\ &= Q_k - \frac{X_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_{k1}|V_k|^2)^2\right\} - Y_{k1}|V_k|^2 \\ &\quad - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \qquad (2) \\ |V_{k+1}|^2 &= |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + Q_k'^2\right) \quad 2(R_k P_k + X_k Q_k) \\ &= |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + (Q_k + Y_k|V_k|^2)^2\right) \\ &\quad - 2\left(R_k P_k + X_k\left(Q_k + Y_k|V_k|^2\right)\right). \qquad (3) \end{aligned}$$

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

$$P_{Loss}(k, k+1) = R_k.\frac{(P_k^2 + Q_k^2)}{|V_k|^2}. \qquad (4)$$

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

$$P_{T,Loss} = \sum_{k-1}^{n} P_{Loss}(k, k+1). \qquad (5)$$

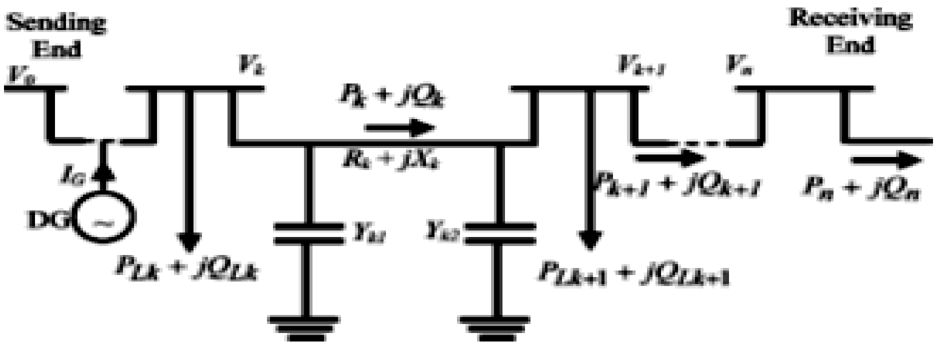


Fig. 2: Distribution system with DG installation at an arbitrary location

B. Power Loss Using Network Reconfiguration

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 operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder and radial structure of distribution system. The power loss of a line section connecting buses between *k* and *k+1* after reconfiguration of network can be computed as

$$P'_{Loss}(k, k+1) = R_k . \frac{(P'^2_k + Q'^2_k)}{|V'_k|^2}. \qquad (6)$$

Total power loss in all the feeder sections, $P'_{T,Loss}$, may then be determined by summing up the losses in all line sections of network, which is written as

$$P'_{T,Loss} = \sum_{k=1}^{n} P'_{Loss}(k, k+1). \qquad (7)$$

C. Loss Reduction Using Network Reconfiguration

Net power loss reduction, ΔP^R_{Loss} , in the system is the difference of power loss before and after reconfiguration, that is (5)–(7) and is given by

$$\Delta P^R_{Loss} = \sum_{k=1}^{n} P_{T,Loss}(k, k+1) - \sum_{k=1}^{n} P'_{T,Loss}(k, k+1). \quad (8)$$

D. Power Loss Reduction Using DG Installation

Installation of distribution generation units in optimal locations of a distribution system results in several benefits. These include reduction of line losses improvement of voltage profile, peak demands having, relieving the overloading of distribution lines, reduced environmental impact, increased overall energy efficiency, and deferred investments to upgrade existing generation, transmission, and distribution systems. The power loss when a DG is installed at an arbitrary location in the network as shown in Fig. 2, is given by

$$P_{DG,Loss} = \frac{R_k}{V_k^2}(P_k^2 + Q_k^2) + \frac{R_k}{V_k^2}(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G)\left(\frac{G}{L}\right). \quad (9)$$

Net power loss reduction, ΔP^{DG}_{Loss} , in the system is the difference of power loss before and after installation of DG unit, that is (9)–(14) and is given by

$$\Delta P_{Loss}^{DG} = \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G\right)\left(\frac{G}{L}\right). \qquad (10)$$

The positive sign of ΔP_{Loss}^{DG} indicates that the system loss reduces with the installation of DG. In contrast, the negative sign of ΔP_{Loss}^{DG}implies that DG causes the higher system loss.

E. Objective Function of the Problem

The objective function of the problem is formulated to maximize the power loss reduction in distributed system, which is given by

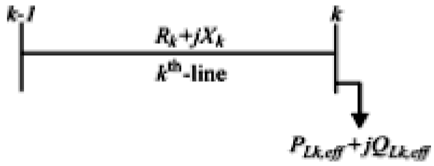
$$\text{Maximize } f = \max.\left(\Delta P_{Loss}^{R} + \Delta P_{Loss}^{DG}\right) \qquad (11)$$

$$\left.\begin{aligned} \text{Subjected to}\quad & V_{\min} \le |V_k| \le V_{\max} \\ \text{and}\quad & |I_{k,k+1}| \le |I_{k,k+1,\max}| \\ & \sum_{k=1}^{n} \mathrm{P_{Gk}} \le \sum_{k=1}^{n}(P_k + P_{Loss,k}) \end{aligned}\right\} \qquad (12)$$

$$\left.\begin{aligned} &\det(\mathrm{A}) = 1 \text{ or } -1 \text{ (radial system)} \\ &\det(\mathrm{A}) = 0 \text{(not radial)} \end{aligned}\right\}. \qquad (13)$$

III. SENSITIVITY ANALYSIS FOR DG INSTALLATION

Sensitivity analysis is used to compute sensitivity factors [14] of candidate bus locations to install DG units in the system. Estimation of these candidate buses helps in reduction of the search space for the optimization procedure. Consider a line section consisting an impedance $R_K + jX_k$ of and a load of $P_{Lk,eff} + jQ_{Lk,eff}$ connected between *k-1* and *k* buses as given below.



Active power loss in the *k*th-line between *k-1*and *k* buses is given by

$$P_{lineloss} = \frac{\left(P_{Lk,eff}^2 + Q_{Lk,eff}^2\right)R_k}{V_k^2}. \qquad (14)$$

Now, the loss sensitivity factor (LSF) can be obtained with the equation

$$\frac{\partial P_{lineloss}}{\partial P_{Lk,eff}} = \frac{2 * P_{Lk,eff} * R_k}{V_k^2}. \qquad (15)$$

Using (15), LSFs are computed from load flows and values are arranged in descending order for all buses of the given system. It is worth to note that LSFs decide the sequence in which buses are to be considered for DG unit installation. The size of DG unit at candidate bus is calculated using HSA.

IV. OVERVIEW OF HARMONY SEARCH ALGORITHM

The HSA is a new meta-heuristic population search algorithm proposed by Geem et al. [15]. Das et al. [16] proposed an explorative HS (EHS) algorithm to many benchmarks problems successfully. HSA was derived from the natural phenomena of musicians' behaviour when they collectively play their musical instruments (population members) to come up with a pleasing harmony (global optimal solution). This state is determined by anaesthetic standard (fitness function). HS algorithm is simple in concept less in parameters, and easy in implementation. It has been successfully applied to various benchmark and real-world problems like travelling salesman problem [17].The main steps of HS are as follows [15]:

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.

A. Initialization of Problem and Algorithm Parameters

The general optimization problem is specified as follows:

$$\begin{aligned} &Minimize\ f(x) \\ &\quad Subject\ to\ x_i \in X_i, \qquad i = 1, 2, \ldots\ldots.N \end{aligned} \tag{16}$$

Where *f(x)* is an objective function; *x* is the set of each decision variable *x*; N is the number of decision variables; X_i is the set of the possible range of values for each decision variable, that is $L^{x_i} \leq X_i \leq$ 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.

B. Initialize the Harmony Memory

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

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS\ 1} & x_2^{HMS\ 1} & \cdots & x_{N-1}^{HMS\ 1} & x_N^{HMS\ 1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N\ 1}^{HMS} & x_N^{HMS} \end{bmatrix}. \tag{17}$$

C. Improvise a New Harmony

A New Harmony vector $\vec{x}\,' = (x_1', x_2', \ldots\ldots. x_N')$ is generated based on three criteria: 1) memory consideration, 2) pitch adjustment, and 3) random selection. Generating a new harmony is called improvisation. 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 (18):

$$\begin{aligned} &if\ (rand() < HMCR) \\ &x_i' \leftarrow x_i' \in \{x_i^1, x_i^2, \ldots\ldots. x_1^{HMS}\} \\ &else \\ &x_i' \leftarrow x_i' \in X_i \\ &end \end{aligned} \tag{18}$$

Where rand() is a uniformly distributed random number between 0 and 1 and X_i is the set of the possible range of values for each decision variable, i.e., $L^{x_i} \leq X_i \leq$ 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 15% 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 follows:

$$\begin{aligned}
&if\ (rand() < PAR)\\
&x_i' = x_i' + rand() * bw\\
&else\\
&x_i' = x_i'\\
&end
\end{aligned} \tag{19}$$

Where is an arbitrary distance bandwidth for the continuous design variable and rand() is uniform distribution between 0 and 1. Since the problem is discrete in nature, is taken as 1 (or it can be totally eliminated from the equation).

D. Update Harmony Memory

If the new harmony vector $\vec{x}' = (x_1', x_2', \ldots\ldots x_N')$ has better fitness function than the worst harmony in the HM, the new harmony is included in the and the existing worst harmony is excluded from the HM.

E. 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.

V. APPLICATION OF HSA FOR POWER LOSS MINIMIZATION

This section describes application of HSA in network reconfiguration and DG installation problems for real power loss minimization. Since both reconfiguration and DG installation problems are complex combinatorial optimization problems, many authors addressed these problems independently using different optimization techniques. In this paper, these two problems are dealt simultaneously using HSA.

To reconfigure the network, all possible radial structures of given network (without violating the constraints) are generated initially. The structure of solution vector (17) for a radial distribution system is expressed by “Arc No. (i)” and “SW .No. (i)” for each switch . “Arc No. (i)” identifies arc (branch) number that contains the open switch ,and “SW. No.(i)” identifies switch that is normally open on Arc No.(i). For large distribution networks, it is not efficient to represent every arc in the string, as its length wills b every long. Therefore, to memorize the radial configuration, it is enough to number only open switch positions [6].

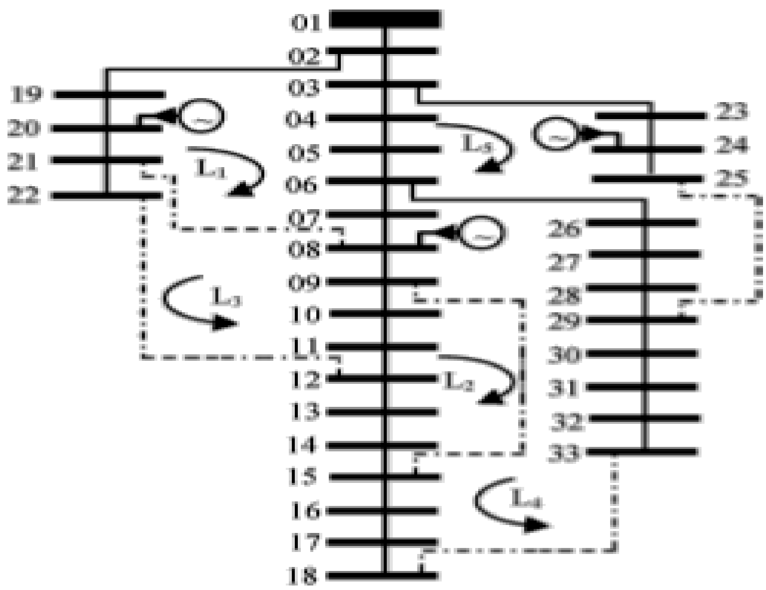


Fig. 3: 33-bus radial distribution for HV^1

In order to simplify the selection of candidate buses for installation of DG units a priori, sensitiveness of buses to the change in active power loss with respect to change in active power injection at various buses are computed. Then buses are sorted according to their sensitivity factors and buses that are more sensitive are picked to install DG units.

Application of HSA for loss minimization problem with reconfiguration and DG installation is illustrated with the help of standard 33-bus radial distribution system. In 33-bus system, there are five open tie switches with branch numbers 33, 34, 35, 36, and 37, respectively, which forms five loops to (if formed) as shown in Fig. 3. Further, assume that candidate buses for optimal installation of DG units are 8, 20, and 24 as shown in Fig. 3. The ratings of units will vary in discrete steps at specified location during optimization process.

In order to represent an optimal network topology, only positions of open switches in the distribution network need to be known. Suppose the number of normally open switches (tie switches) is N, then length of a first part of solution vector for reconfiguration problem is N. Similarly, length of second part of solution vector is the number of candidate buses chosen for DG units installation. Thus, the solution vector using reconfiguration and DG installation is formed as follows:

$$HV^1 = \left[\underbrace{os_1^1 \quad os_2^1 \quad os_3^1 \quad os_4^1 \quad os_5^1}_{reconfiguration} \underbrace{S_1^1 \quad S_2^1 \quad S_3^1}_{DG\ Sizes} \right]$$

Where os_1^1,os_2^1,os_3^1, os_4^1 and os_5^1 are open switches in the loops to corresponding to tie switches 33, 34, 35, 36, and 37, S_1^1, S_2^1 and $S_3^1$are sizes of DG units in kW installed at candidate buses 8, 20, and 24, respectively.

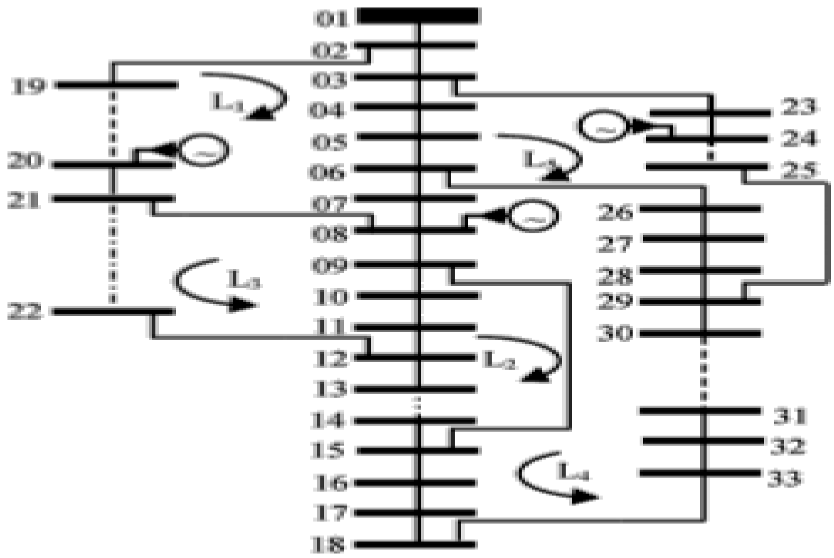


Fig. 4: 33-bus radial distribution system for HV^2

Second solution vector HV^2 is randomly generated with open switches 19, 13, 21, 30, and 24 in same loops and DG units at same locations with different ratings is formed as

$$HV^2 = \left[\underbrace{os_1^2 \quad os_2^2 \quad os_3^2 \quad os_4^2 \quad os_5^2}_{reconfiguration} \underbrace{S_1^2 \quad S_2^2 \quad S_3^2}_{DG\ Sizes} \right]$$

where os_1^1,os_2^1,os_3^1, os_4^1 and os_5^1 are open switches corresponding to tie switches19,13,21,30, and 24 in loops of Fig.4 S_1^1, S_2^1 and $S_3^1$are sizes of DG units in installed at candidate buses 8, 20, and 24, respectively.

Similarly, all other possible solution vectors are generated without violating radial structure or non-isolation of any load in the network. Total number of solution vectors (HMS) generated are less than or equal to the highest numbers of switches in any individual loop.

Total Harmony Matrix randomly generated is shown in (20). For each solution vector of HM, the objective function is evaluated and HM vector is sorted in descending order based on their corresponding objective function values:

$$HM = \begin{bmatrix} os_1^1 & os_2^1 & os_3^1 & os_4^1 & os_5^1 & S_1^1 & S_2^1 & S_3^1 \\ os_1^2 & os_2^2 & os_3^2 & os_4^2 & os_5^2 & S_1^2 & S_2^2 & S_3^2 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ os_1^H & os_2^H & os_3^H & os_4^H & os_5^H & S_1^H & S_2^H & S_3^H \end{bmatrix}. \quad (20)$$

The new solution vectors are generated and updated using (18). Using new solution vectors, inferior vectors of previous iteration will be replaced with a new randomly generated vector selected from the population that has lesser objective function value. This procedure is repeated until termination criteria is satisfied. The flow chart of HSA method is shown in Fig.5.

VI. PARTICLE SWARM OPTIMIZATION

Swarm Intelligence is an optimization technique based on social behaviour of swarming animals, such as a flock of birds or school of fish. It was developed by James Kennedy and Russel Eberhart in 1995.Since then; much has been published about the subject, with applications in several areas like function optimization, electric power systems, the travelling salesman problem, telecommunications, among others. This has become an excellent way towards the solution to optimization- combined problems. There are many similarities between PSO and Genetic Algorithm (GA). The brief concepts of both algorithms are that they will produce an initial solution randomly at first. Through iterations of the evolution process, optimal value can be obtained. The difference between GA and PSO is that PSO have no explicit selection, crossover and mutation operations. Furthermore, the concept of PSO is simple, and is easy to implement. Thus, the PSO is a powerful algorithm to aid and speed up the decision-making process for reconfiguration problem to identify the best switching strategy. However typical PSO is designed for continuous functions optimization, it is not designed for discrete functions optimization. Therefore, Kennedy and Eberhart proposed a modified version of PSO called Binary Particle Swarm Optimization (BPSO) that can be used to solve discrete function problems. Wu-Chang Wu presented Binary Particle Swarm Optimization (BPSO) concept to solve feeder reconfiguration problems. Lambet-Torreset.al and A.Y. Abdelaziz et.al. applied modified Particle Swarm Optimization in the service restoration problem.PSO seems particularly suitable for multi-objective optimization mainly because of the high speed of convergence that algorithm presents for single objective optimisation.

In PSO, in each iteration, each agent is updated with reference to two “best” values: pbest is the best solution (in terms of fitness) the individual particle has achieved so far, while gbest is the best obtained globally so far by any particle in the population. Each agent seeks to modify its position using the current positions, the current velocities, the distance between the current position and pbest, and the distance between the current position and gbest. Almost all modifications vary in some way the velocity update equation as given in eq (21):

$$v_i^{k+1} = w_i v_i^k + c_1 rand_1 * (pbest_i - x_i^k) + c_2 rand_2 * (gbest - x_i^k) \quad \dots (21)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (22)$$

In eq.(21), c1 and c2 are positive constants, defined as acceleration coefficients, c1 and c2, are often equal to 2, though other settings are used in different papers, typically with c1 = c2 and in the range [1.5- 2.5];w is the inertia weight factor; rand1 and rand2 are two random functions in the range of [0-1]; xi represents the ith particle and pbesti the best previous position of xi; gbesti is the best particle among the entire population; vi is the rate of the position change (velocity) for particle xi. Velocity changes in the eq. (21) comprise three parts, i.e. the momentum part, the cognitive part, and the social part. For number of particles, the typical range is 20 – 40.This combination provides a velocity getting closer to pbest and gbest. Every particle’s current position is then evolved according to the eq. (22), which produces a better position in the solution space.

VII. TEST RESULTS

In order to demonstrate the effectiveness of the proposed method (simultaneously reconfiguring the network and instal-

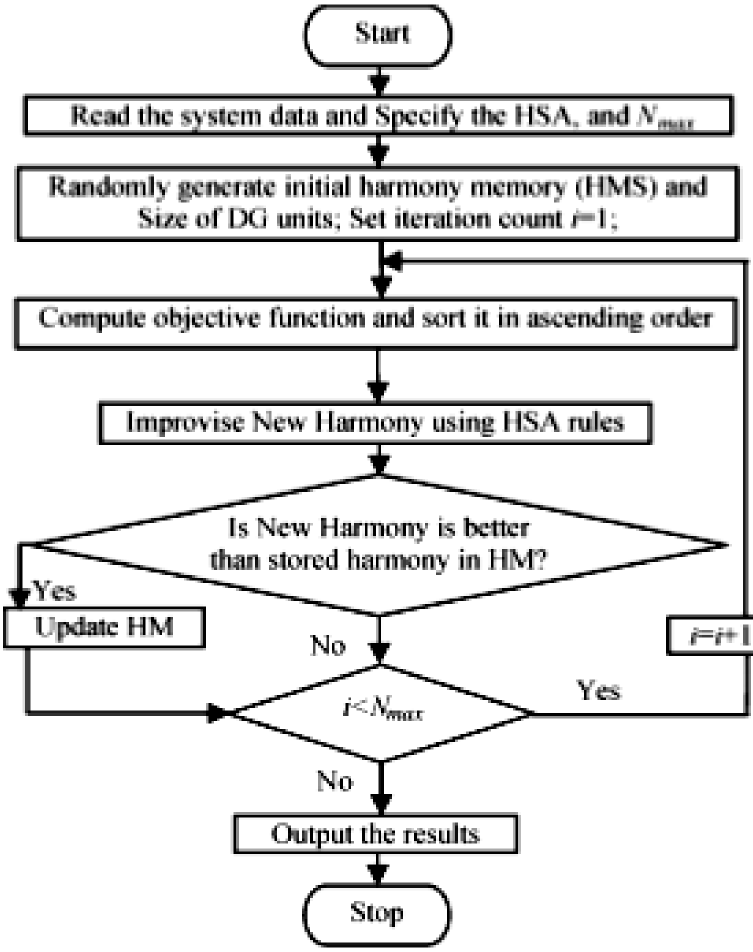


Fig. 5: Flow chart for HSA method

lation of DG units) using HSA, it is applied to two test systems consisting of 33 and 69 buses

Scenario I: The system is without reconfiguration and distributed generators (Base case);

Scenario II: same as Scenario I except that system is reconfigured by the available sectionalizing and tie switches;

Scenario III: same as Scenario I except that DG units are installed at candidate buses in the system;

Scenario IV: DG units are installed after reconfiguration of network;

Scenario V: System with simultaneous feeder reconfiguration and DG allocation.

A. Test System 1

This test system is a 33-bus radial distribution system [18] with five tie-switches and 32 sectionalizing switches. In the network, sectionalize switches (normally closed) are numbered from 1 to 32, and tie-switches (normally open) are numbered from 33 to 37.The line and load data of network are taken from [7], and the total real and reactive power loads on the system are 3715 kW and 2300 KVAR.

Using sensitivity analysis [14] sensitivity factors are computed to install the DG units at candidate bus locations for scenarios III, IV, and V. After computing sensitivity factors at all buses, they are sorted and ranked. Only top three locations are selected to install DG units in the system. The limits of DG unit sizes chosen for installation at candidate bus locations are 0 to 2 MW. The candidate locations for scenarios III, IV, and V are given in Table 1. To assess the performance, the network is simulated at three load levels: 0.5 (light), 1.0 (nominal), and 1.6 (heavy) and simulation results are presented in Table 1.

Table 1: Results of 33-bus system for HSA algorithm

Scenario		Load level		
		Half(0.5)	Unity(1.0)	Over(1.6)
Base Case(Scenario I)	Switches opened	33,34,35,36,37	33,34,35,36,37	33,34,35,36,37
	Power loss(KW)	47.0766	202.7069	575.4683
	Minimum voltage(p.u)	0.9582	0.9130	0.8527
Only Reconfiguration (Scenario II)	Switches opened	7,9,14,32,37	7,9,14,32,37	7,9,14,32,37
	Power loss(KW)	33.2703	139.5585	380.4720
	%Loss reduction	29.327	31.152	33.884
	Minimum voltage(p.u)	0.9698	0.9378	0.8967
Only DG Installation (Scenario III)	Switches opened	33,34,35,36,37	33,34,35,36,37	33,34,35,36,37
	Size of DG in MW(Bus number)	0.1303(18) 0.1777(17) 0.5029(33)	0.1070(18) 0.5724(17) 1.0462(33)	0.1939(18) 0.9108(17) 1.6115(33)
	Power loss(KW)	23.2978	96.7703	261.0130
	%Loss reduction	50.510	52.260	54.643
	Minimum voltage(p.u)	0.9831	0.9673	0.9436
DG Installation after Reconfiguration (Scenario IV)	Switches opened	7,14,9,32,37	7,14,9,32,37	7,14,9,32,37
	Size of DG in MW(Bus number)	0.1015(32) 0.1843(31) 0.2568(30)	0.2686(32) 0.1611(31) 0.6612(30)	0.2443(32) 0.3068(31) 1.2185(30)
	Power loss(KW)	23.5361	97.1328	259.6497
	%Loss reduction	50.0046	52.082	54.880
	Minimum voltage(p.u)	0.9745	0.9478	0.9139
Reconfiguration with simultaneous DG Installation (Scenario V)	Switches opened	7,11,14,27,32	7,10,14,28,32	7,10,14,28,32
	Size of DG in MW(Bus number)	0.1954(32) 0.4195(31) 0.2749(33)	0.5258(32) 0.5586(31) 0.5840(33)	0.5724(32) 1.2548(31) 0.9257(33)
	Power loss(KW)	17.7950	73.4659	194.3189
	%Loss reduction	62.199	63.757	66.232
	Minimum voltage(p.u)	0.9859	0.9703	0.9515

It is observed from Table 1, at light load, base case power loss (in kW) in the system is 47.07 which is reduced to 33.27, 23.29, 23.53, and 17.79 using scenarios II, III, IV, and V, respectively. The percentage loss reduction for scenario II to V is 29.3, 50.5, 50.00, and 62.19, respectively. Similarly the percentage loss reduction for scenarios II to V at nominal and heavy load conditions is 31.15, 52.26, 52.08 and 63.75; 33.88, 54.64, 54.88, and 66.23, respectively. This shows that for all the three load levels, power loss reduction using scenario V is highest. However, as load increases from light to heavy, improvement in percentage loss reduction in all scenarios is almost the same.

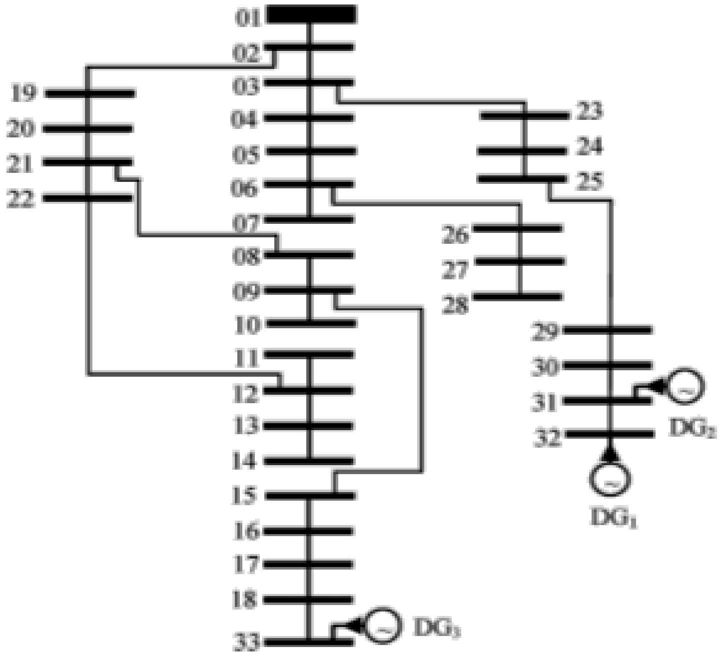
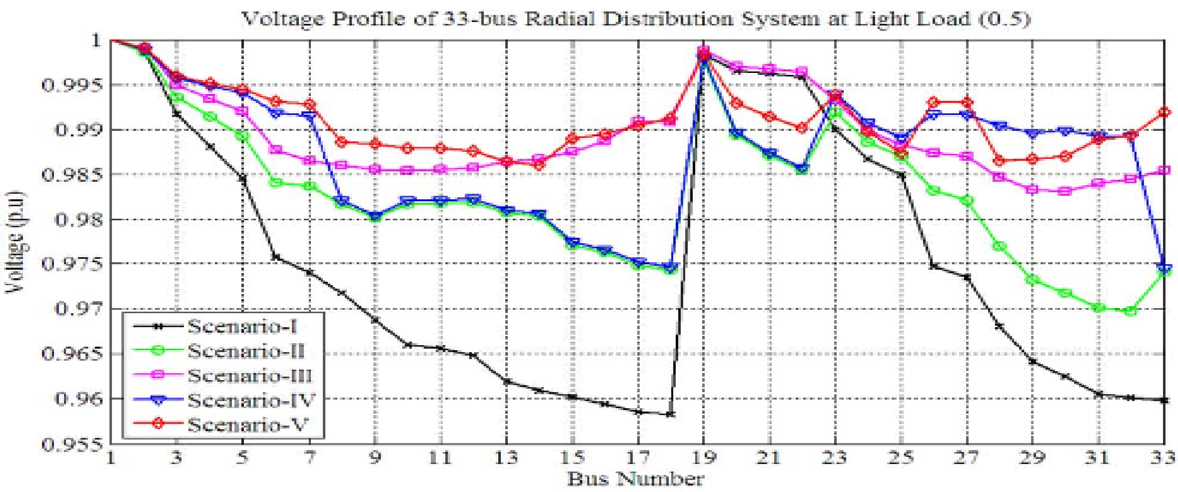


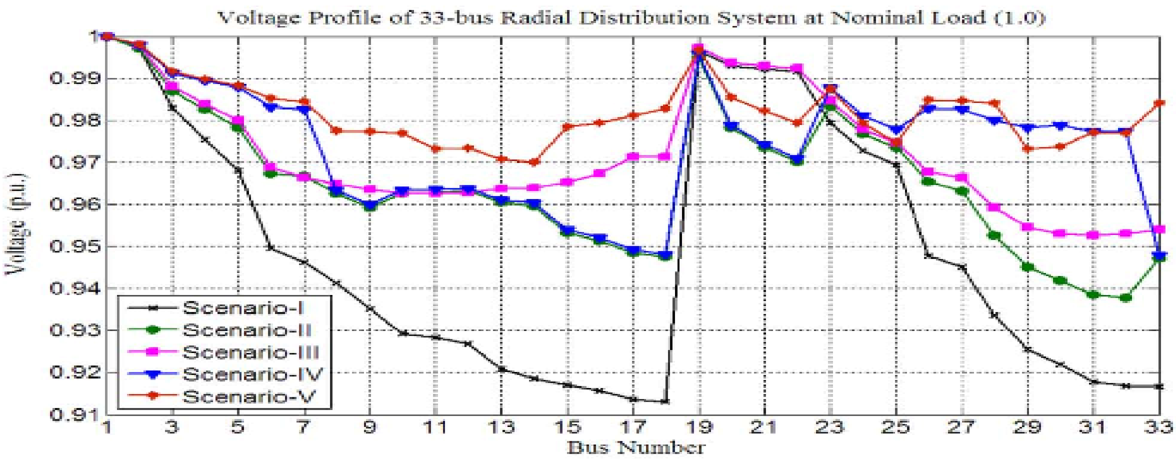
Fig. 6: Optimal network structure after simultaneous reconfiguration and DG installation

From Table 1, it is seen that improvement in power loss reduction and voltage profile for scenario V are higher when com-pared to scenario IV. This implies that DG Installation after reconfiguration (scenario IV) does not yield desired results of maximizing power loss reduction and improved voltage profile. The percentage improvement in minimum voltage of the system for scenario II to V at light, medium, and heavy load is {1.1, 2.53, 1.67, 2.80}, {2.64, 5.61, 3.67, 5.96}, and {4.90, 9.66, 6.69, 10.37}, respectively. From this, it is seen that improvement in minimum voltage of the system for scenario V is the highest. Further, it is also observed that fall in minimum voltage with increase of load from light to peak is least in case of scenario V.

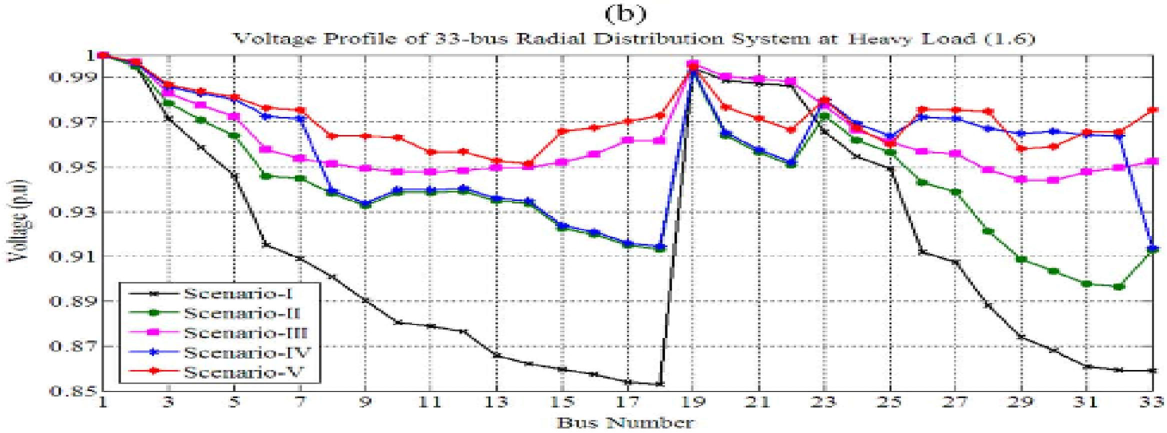
The optimal structure of network after simultaneous reconfiguration and DG installation for scenario V is shown in Fig.6. The voltage profile curves of all scenarios at light, nominal, and heavy load conditions are shown in Graph 1(a)–(c), respectively. The shapes of voltage profiles at all three load levels for five scenarios are almost the same except minor change in voltage magnitude.



(a)



(b)



(c)

Graph 1: Voltage profiles of 33-bus system at (a)light (half), (b)nominal (unity) and (c)heavy (over) load conditions for HSA algorithm

B. Test System 2

This is a 69-bus large-scale radial distribution system with 68 sectionalizing and five tie switches. Configuration, line, load, and tie line data are taken from [19]. Total system loads for base configuration are 3802.19KW and 2694.06 KVAR. The sectionalizing switches are labelled from 1 to 68 and tie switches from 69 to 73, respectively. HSA parameters are used to simulate this test system are same as test system 1. Similar to test systems 1, this test system is also simulated for five scenarios at three load levels and results are presented in the Table 2. The limits of DG unit sizes chosen for installation at candidate bus locations are same as test case 1. The base case power loss (in kW) at light, nominal, and heavy load conditions is 51.65, 224.98, and 654.92, respectively. From Table 2, it is observed that scenario V is more effective in improving minimum voltage and reducing power loss compared to other scenarios.

Table 2: Results of 69-bus system for HSA algorithm

Scenario		Load level		
		Half(0.5)	Unity(1.0)	Over(1.6)
Base Case (Scenario I)	Switches opened	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73
	Power loss(KW)	51.6537	224.9803	654.9278
	Minimum voltage(p.u)	0.9563	0.9092	0.8429
Only Reconfiguration (Scenario II)	Switches opened	69,70,14,57,61	69,13,18,56,61	69,18,13,55,61
	Power loss(KW)	23.7200	99.3500	271.4200
	%Loss reduction	54.078	55.840	58.557
	Minimum voltage(p.u)	0.9754	0.9495	0.9165

OnlyDG Installation (Scenario III)	Switches opened	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73
	Size of DG in MW(Bus number)	0.2579(65) 0.1280(64) 0.5857(63)	1.3020(63) 0.3690(64) 0.1018(65)	1.9710(63) 0.8308(64) 0.1589(65)
	Power loss(KW)	23.100	86.7700	230.6100
	%Loss reduction	55.27	61.432	64.788
	Minimum voltage(p.u)	0.9849	0.9669	0.9478
DG Installation after Reconfiguration (Scenario IV)	Switches opened	69,70,14,57,61	69,18,13,56,61	69,18,13,55,61
	Size of DG in MW(Bus number)	0.1052(58) 0.1835(60) 0.4462(61)	0.4257(58) 0.3525(60) 1.0666(61)	0.2703(58) 0.3305(60) 1.8208(61)
	Power loss(KW)	12.5500	51.3000	135.7100
	%Loss reduction	75.703	77.198	79.278
	Minimum voltage(p.u)	0.9827	0.9619	0.9377
Reconfiguration with simultaneous DG Installation (Scenario V)	Switches opened	10,16,14,56,62	69,17,13,58,61	10,18,13,58,61
	Size of DG in MW(Bus number)	0.3481(61) 0.3143(62) 0.3482(64)	0.3525(60) 1.0666(61) 0.4527(62)	0.8219(60) 1.5935(61) 0.9674(62)
	Power loss(KW)	11.0700	44.124	104.6700
	%Loss reduction	78.568	80.38	84.018
	Minimum voltage(p.u)	0.9866	0.9799	0.9800

For PSO algorithm, the test systems are same (i.e., 33 and 69 bus systems) at half, unity, overload (only with reconfiguration and without reconfiguration) are used. Comparison of HSA and PSO for 33 and 69 bus systems results are shown in Table 3 and Table 4.

Table 3: Comparison results of PSO and HSA for 33 bus system

Scenario		PSO Load level			HSA Load level		
		Half(0.5)	Unity (1.0)	Over(1.6)	Half(0.5)	Unity(1.0)	Over(1.6)
Without Reconfiguration	Switches Opened	33,34,35, 36,37	33,34,35, 36,37	33,34,35, 36,37	33,34,35,36, 37	33,34,35,36, 37	33,34,35,36, 37
	Power Loss (KW)	47.07	202.706	575.46	47.07	202.706	575.46
	Switches Opened	7,9,13,32,37	7,9,14,32,37	7,9,14,32,28	7,9,14,32,37	7,9,14,32,37	7,9,14,32,37

With Reconfiguration	Power Loss (KW)	34.37	158.714	404.059	33.2703	139.558	380.4720

Table 4: Comparison results of PSO and HSA for 69 bus system

Scenario		PSO			HSA		
		Load level			Load level		
		Half(0.5)	Unity(1.0)	Over(1.6)	Half(0.5)	Unity(1.0)	Over(1.6)
Without Reconfiguration	Switches Opened	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73
	Power Loss (KW)	51.6534	225.4365	654.9246	51.6537	224.9803	654.9248
With Reconfiguration	Switches Opened	13,58,61,69,70	10,17,57,61,71	14,58,61,69,70	14,57,61,69,70	13,18,56,69,61	13,18,55,69,61
	Power Loss (KW)	23.7446	112.66	272.147	23.7200	99.3500	271.4200

VIII. CONCLUSION

In this paper, a new approach has been proposed to reconfigure and installs DG units simultaneously in distribution system. In addition, different loss reduction methods (only network reconfiguration, only DG installation, DG installation after reconfiguration) are also simulated to establish the superiority of the proposed (simultaneously reconfiguring the network and installation of DG units) method. The HSA and PSO methods are tested on 33 and 69-bus systems at three different load levels viz., light, nominal, and heavy. The results show that simultaneous network reconfiguration and DG installation method is more effective in reducing power loss and improving the voltage profile compared to other methods. The effect of number of DG installation locations on power loss reduction is studied at different load levels. From the table 3 and 4 by using HSA algorithm the decrement of power loss is more efficient when compared to PSO algorithm. That means the computational results showed that performance of the HSA is better than PSO algorithm.

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Authors Profile:

T.PARDHAVI SAI SREE She received her B.Tech (Electrical and Electronics Engineering) degree from the Jawaharlal Nehru Technological University, Anantapur in 2011 at Vaishnavi institute of technology,Tirupati and Currently she is pursuing M.Tech (Electrical Power Systems) at S.V.P.C.E.T, Puttur, India.

N.POORNA CHANDRA RAO He received his B.Tech (Electrical and Electronics Engineering) degree from JNTU, Hyderabad, at In S.V.C.E.T Chittoor and M.Tech (EPS) from the Sree Vidyaniketan Engineering College, Rangampet. He is currently working as Associate Professor at Dept. Of Electrical Engineering, S.V.P.C.E.T, Puttur. His area of interest Power Systems, operation and Control, Distribution Systems, Electrical Machines and Power Stability.