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Reconfiguration with Simultaneous DG installation to Improve the Voltage Profile in Distribution Network using Harmony Search Algorithm

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Abstract

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, Reconfiguration & 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 leveling. This work proposes minimization of real power losses and improvement of voltage profile using network reconfiguration in the presence of distributed generation. Generally distributed generations (DG) are preferred with objective of minimizing real power loss and improving voltage profile in distribution system. In this work A meta heuristic Harmony Search Algorithm (HSA) 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. The proposed method has tested in MATLAB for 33-bus and 69- Bus radial distribution systems at three different load levels and the analysis is presented for loss minimization.

Keywords: *Distributed generation, Distribution system, Harmony Search Algorithm Real power loss Reconfiguration, Voltage profile*

1. Introduction

Distribution system plays a very important role in the power system. Effective planning of radial distribution network is essential to meet the current rising domestic, industrial and commercial load day by day. It is mandatory to maintain the supply of electrical power with the requirements of many types of consumers in the world. The necessary requirements of a good distribution system are Availability of power demand, reliability and Good voltage profile at load ends. In order to meet power demand there is a need to increase power loss reduction. There are many methods used to minimize the power losses in distribution systems like optimal placement of Capacitors, Synchronous condensers, Tap changing techniques, Network Reconfiguration and DG installation etc. Among those method Network reconfiguration and DG installation are the best methods.

Most of distribution feeders are configured radially, for effective coordination of their protection systems [1]. Due to dynamic nature of loads the Power losses in a distributed network will not 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. Especially with the introduction of remote control capability to the switches, on line network reconfiguration become an important part of distribution automation. The network is reconfigured for two purposes: (i) to reduce the system power loss, (ii) to relieve the overloads in the network. The first problem is referred to as network reconfiguration for loss reduction and the second as load balancing. In general, networks are reconfigured to reduce real power loss and to relieve over load in the network.

In recent years, considerable research has been conducted for loss minimization in the area of network reconfiguration of distribution systems. Distribution system reconfiguration for loss reduction was first proposed by Merlin and Back [2]. They have used a branch-and-bound-

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type optimization technique; in this method all network switches are first closed to form a meshed network. The switches are then opened successively to restore radial configuration. From Merlin and Back [2] method, a heuristic algorithm has been suggested by Shirmohammadi and Hong [3]. Here, the solution procedure starts by closing all of the network switches which are then opened one after another so as to establish the optimum flow pattern in the network. Borozan *et al.* [4] have presented a network reconfiguration technique which contains three main parts: real-time load estimation, effective determination of minimum power loss configuration, and cost/benefit evaluation. Civanlar *et al.* [5] have proposed a heuristic method to determine a distribution system configuration which would reduce line losses by using a simplified formula to calculate the loss reduction as a result of load transfer between two feeders Das [6] 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.* [7] presented a solution using a genetic algorithm (GA) to look for the minimum loss configuration in distribution system. Zhu [8] 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. Srinivasa Rao *et al.*[9] 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.

Distributed generation technologies are renewable and nonrenewable. Renewable technologies include solar, photovoltaic or thermal, wind, geothermal, ocean. Nonrenewable technologies include internal combustion engine, ice, combined cycle, combustion turbine, micro turbines and fuel cell. [10] Most of the DG energy sources are designed using green energy which is assumed pollution free [11]. Basically DG units are installed nearer to the end-user to provide the electrical power with the capacities of 5-kW to 10-MW. Since selection of the best locations and sizes of DG units is also a complex combinatorial optimization problem, many methods are proposed in this area in the recent past. Rosehart and Nowicki [12] presented a Lagrangian based approach to determine optimal locations for placing DG in distribution systems considering economic limits and stability limits. Celli *et al.* [13] presented a multi-objective algorithm using GA for sitting and sizing of DG in distribution system. Wang and Nehrir [14] proposed an analytical method to determine optimal location to place a DG in distribution system for power loss minimization. Agalgaonkar *et al.* [15] discussed placement and penetration level of the DGs under the SMD framework. Sreenivasa Rao *et al.* [16] presented a methodology for multiple DG placements in primary distribution systems.

In this paper, HSA [19] has been proposed to solve the distribution system network reconfiguration problem in the presence of distributed generation. The algorithm is tested on 33 Bus and 69 Bus systems and results obtained are compared with other methods available in the literature. The rest of this paper is organized as follows: Section II gives the problem formulation, Section III provides sensitivity analysis for DG allocation, Section IV gives the overview of proposed optimization algorithm, Section V explains the application of HSA to network reconfiguration problem in the presence of distributed generation, Section VI presents results, and Section VII outlines conclusions.

2. Problem Formulation

2.1. Objective Function

My objective function is to maximize the power loss Reduction in distribution system using simultaneous Network Reconfiguration and DG Installation problems using Harmony Search Algorithm (HSA). The objective function to maximize the power loss Reduction is described as

$$\text{Maximize } f = \max\left(\Delta P_{Loss}^{R} + \Delta P_{Loss}^{DG}\right) \quad (1)$$

Subjected to $V_{\min} \le |V_k| \le V_{\max}$

and $|I_{k,k+1}| \le |I_{k,k+1,\max}|$

$$\sum_{k=1}^{n} P_{Gk} \le \sum_{k=1}^{n} \left(P_k + P_{Loss,k}\right) \tag{2}$$

$$\det(A) = 1 \text{ or } -1 \text{ (radial system)}$$
$$\det(A) = 0 \text{(not radial)} \tag{3}$$

The Voltage, Real power and Reactive power at respective buses are calculated by using an efficient method for Load-flow solution of radial distribution networks proposed by S. Ghosh and K. S. Sherpa [17]. Those equations are derived from the single-line diagram as shown in Figure 1.

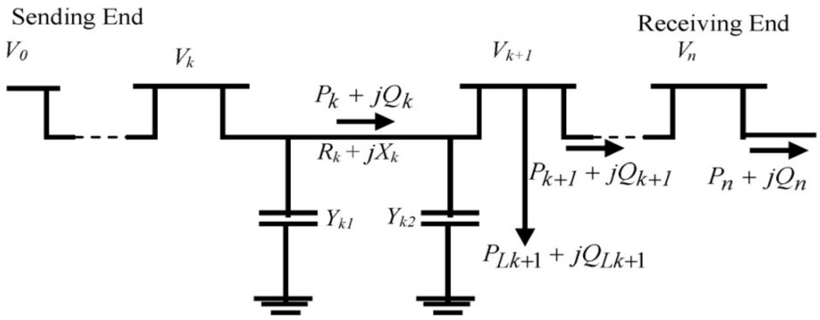


Figure 1. Single-line diagram of a main feeder

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

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

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

The following equation is used to calculate the power loss between the buses *K* and *K+1.*

$$P_{Loss}(k, k+1) = R_k \frac{\left(P_k^2 + Q_k^2\right)}{\left|V_k\right|^2} \tag{7}$$

The total power loss of the feeder can be calculated by summing up the all individual line sectional losses of the feeder, which is given

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

Power losses in a distribution network are reduced by using so many methods like placing capacitors at load ends, by injecting reactive power at load side using synchronous condensers, Network reconfiguration and DG installation etc. In that Network Reconfiguration and Distributed Generation (DG) installation are the best methods to minimize the power losses in distribution systems.

2.2. Power Loss Reduction using Network Reconfiguration

After network Reconfiguration of the distribution system, the power loss between the line sections is calculated as follows.

$$P'_{Loss}(k, k+1) = R_k \frac{\left(P_k'^2 + Q_k'^2\right)}{\left|V'_k\right|^2} \tag{9}$$

The total power loss of the feeder after network reconfiguration can be calculated by summing up the all individual line sectional losses of the feeder, which is given by

$$P'_{T,Loss} = \sum_{k=1}^{n} P'_{Loss}(k, k+1) \tag{10}$$

The Net Power loss reduction using network Reconfiguration is the difference of power losses between before and after Reconfiguration of a distribution network, which is given by

$$\Delta P_{Loss}^{R} = \sum_{k=1}^{n} P_{T,Loss}(k, k+1) - \sum_{k=1}^{n} P'_{T,Loss}(k, k+1) \tag{11}$$

2.3. Power Loss Reduction using DG Installation

To improve voltage profile & minimize the power losses in distribution system, DG units are integrated at arbitrary locations. Basically DG's are integrated at load end. Integration of DG units at respective buses to improve the voltage profile is shown in Figure 2.

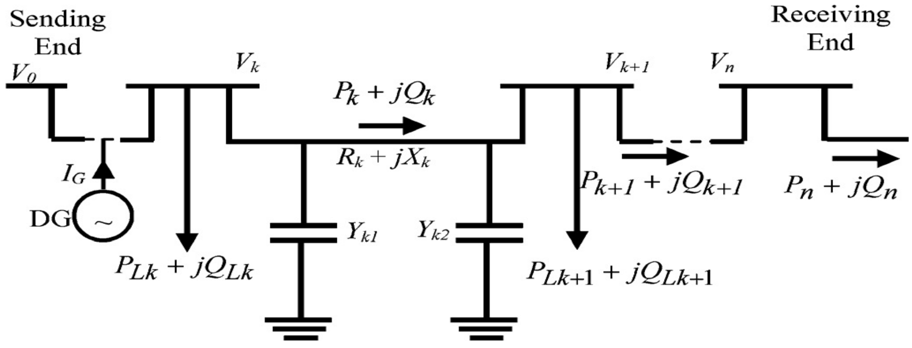


Figure 2. Distribution system with DG installation at an arbitrary location

The following equation is used to calculate the power loss by the integration of Dg units at an arbitrary location, which is given by

$$P_{DG,Loss} = \frac{R_k}{V_k^2}\left(P_k^2 + Q_k^2\right) + \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_k P_G - 2Q_k Q_G\right)\left(\frac{G}{L}\right) \tag{12}$$

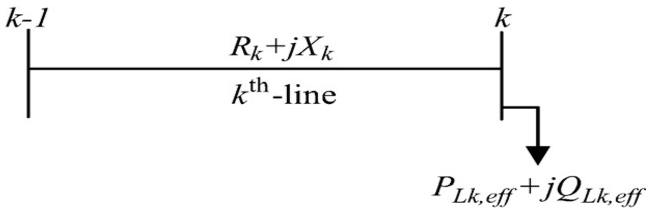
The net power loss reduction using DG installation is the difference of power loss before and after DG installation is given by

$$\Delta P_{Loss}^{DG} = \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_K P_G - 2Q_k Q_G\right)\left(\frac{G}{L}\right) \tag{13}$$

Here the question is where the DG's are installed and how to select the sizes of DG units are discussed in sensitivity analysis for DG installation topic.

2.4. Sensitivity Analysis for DG installation

A new methodology is used to determine the candidate locations for the placement of DG units using Loss Sensitivity Factors [18]. The estimation of these candidate locations basically helps in reduction of the search space for the optimization procedure Consider a line section consisting an impedance of $R_K + jQ_k$ and a load of $P_{LK,eff} + jQ_{LK,eff}$ connected between *K-1*and *K* buses as given below.



In order to calculate the active power loss in the K^{th} line between *K-1* and *K* buses, the values of voltage, real power and reactive power at the respective buses calculated by using equations 1, 2 and 3. The equation is as follows

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

Now, both the Loss Sensitivity Factors can be obtained as shown below:

$$\frac{\partial P_{lineloss}}{\partial P_{Lk,eff}} = \frac{2 * P_{Lk,eff} * R_k}{V_k^2} \tag{15}$$

The Loss Sensitivity Factors are calculated from the base case load flows and the values are arranged in descending order for all the lines of the given system. The line section which is having the highest LSF at which the DG unit is installed fist. Like that the locations of DG units are found out. The selection of sizes of DG units is calculated using HSA, which is discussed in application of HSA for power loss minimization topic.

3. Harmony Search Algorithm

Harmony Search (HS) algorithm was recently developed in an analogy with music improvisation process where music players improvise the pitches of their instruments to obtain better harmony proposed by Z.W. Geem *et al.* [19]. HS algorithm is simple in concept, less in parameters, and easy in implementation. So the HS algorithm has been successfully applied to various benchmarking and real world problems including traveling salesperson problem [19], parameter optimization of river flood model [20], design of pipeline network [21], and design of truss structures.

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, whereas GA cannot since it has to maintain the structure of a gene.

The steps of HS for the generalized orienteering problem are as follows:

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.

3.1. Initialization of Problem and Algorithm Parameters

In Step 1, the optimization problem is specified as follows:

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

Where is $f(x)$ 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 $L_{xi} \le X_i \le U_{xi}$; here L_{xi} and U_{xi} are the lower and upper bounds for each decision variable.

The HS algorithm parameters are also specified in this step. Those are the

HMS = Harmony Memory Size.
$HMCR$ = Harmony Memory Considering Rate.
PAR = Pitch Adjusting Rate.
NI = Number of Improvisations.

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.

3.3. Initialize the Harmony Memory

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

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

3.3. Improvise a New Harmony

A New Harmony vector $x' = (x'_1, x'_2, \cdots\cdots\cdots N)$ is generated by following three rules: 1) HM consideration; 2) Pitch adjustment; and 3) Totally random generation. For instance, the value of the first decision variable (x'_1) for the new vector can be chosen from values stored in $HM\ (x'_1 \sim x_1^{HMS})$. Value of other variables (x'_i) can be chosen in the same style. There is also a possibility that totally random value can be chosen. $HMCR$ Parameter, which varies between 0 and 1, sets the rate whether a value stored in HM is chosen or a random value is chosen, as follows:

$$x'_i \leftarrow \begin{cases} x'_i \in \left\{x_i^1, x_i^2, \ldots, x_i^{HMS}\right\} & \text{for} \quad HMCR \\ x'_i \in X_i & \text{for} \quad (1 - HMCR) \end{cases} \tag{18}$$

The $HMCR$ is the rate of choosing one value from historical values stored in HM while $(1 - HMCR)$ is the rate of randomly choosing one value from the possible value range. After choosing the New Harmony vector $x' = (x'_1, x'_2, \cdots\cdots\cdots N)$, pitch-adjusting decision is examined for each component of the new vector. This procedure uses the PAR parameter to set the rate of pitch adjustment as follows:

$$x'_i \leftarrow \begin{cases} \text{Adjusting Pitch} & \text{for} \quad PAR \\ \text{Doing Nothing} & \text{for} \quad (1 - PAR) \end{cases} \tag{19}$$

In the pitch adjusting process, a value moves to its neighboring value with probability of PAR, or just stays in its original value with probability $(1 - PAR)$. If the pitch adjustment for x'_i is determined, its position in he value range X_i is identified in the form of $x_i(k)$ (the Kth element in X_i), and the pitch-adjusted value for $x_i(k)$ becomes $x'_i \leftarrow x_i(k+m)$.

Where $m \in \{\ldots, -2, -1, 0, 1, 2, \ldots\}$ a neighboring index is used for discrete-type decision variables. The $HMCR$ and PAR parameters in Harmony Search help the algorithm find globally and locally improved solution, respectively.

3.4. Update Harmony Memory

If the New Harmony vector $x' = (x'_1, x'_2, \cdots\cdots\cdots N)$ is better than the worst harmony in the HM, judged in terms of the objective function value, the New Harmony is included in the HM and the existing worst harmony is excluded from the HM.

3.5. Check Termination Criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated.

4. Application of HSA for Poiwer Loss Minimization

Both the network Reconfiguration and DG installation problems are complex combinational optimization problems. In past many authors proposed many methods to solve the Network reconfiguration and DG installation problems separately to minimize the power losses in distribution systems. So in existing methods we will discuss about the network reconfiguration and DG installation problems independently by using HSA to minimize the power losses. But in Proposed method, for effective minimization power losses we are considered the Simultaneous Reconfiguration and DG installation problems by using HSA.

4.1. Existing Methods
Only Reconfiguration Using HSA

In this, we are considering only reconfiguration to minimize the power losses in distribution system. The optimum distribution system is obtained by first generating all possible radial structures of the given network without violating constraints and subsequently evaluating the objective function. However, real distribution system contains many nodes, branches, and trees. So the conventional methods are ineffective and impractical, because of dimensionality. Here the HSA is proven to be effective and useful approach for the network reconfiguration problem.

Let us consider a 33-Bus radial distribution system with 33 sectionalizing switches (from 1 to 32) and 5 Tie line switches (33, 34, 35, 36 and 37) which is shown in Figure 3. Here the five Tie line switches forms the five lopes i.e. L1, L2, L3, L4 and L5. Similarly the other radial topology is generated based on random selection with the open/Tie line switches of 7, 14, 9, 32, and 37 which is shown in Figure 4.The solution vector size depends up on the number of Tie line switches considered. Suppose the number of open switches is N, then the length of a solution vector is N. The Solution vector for before reconfiguration and after reconfiguration is given by HV^1 and HV^2.

Like that all other possible solution vectors are generated for reconfiguration without violating the distribution network constraints. The total numbers of generated solution vectors are less than are equal to the highest number of switches in any individual loop. If the new solution vectors are having better solution vector than the previous solution vector, then it is updated and this process is continued until the termination criteria is satisfied.

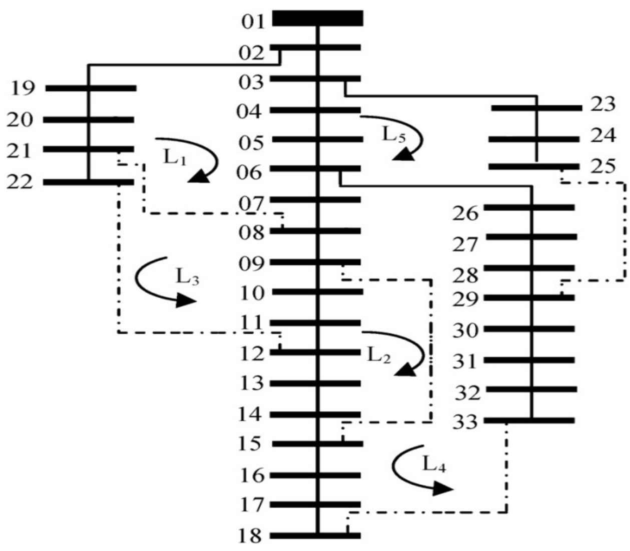


Figure 3. 33-Bus radial distribution system for Reconfiguration of HV^1

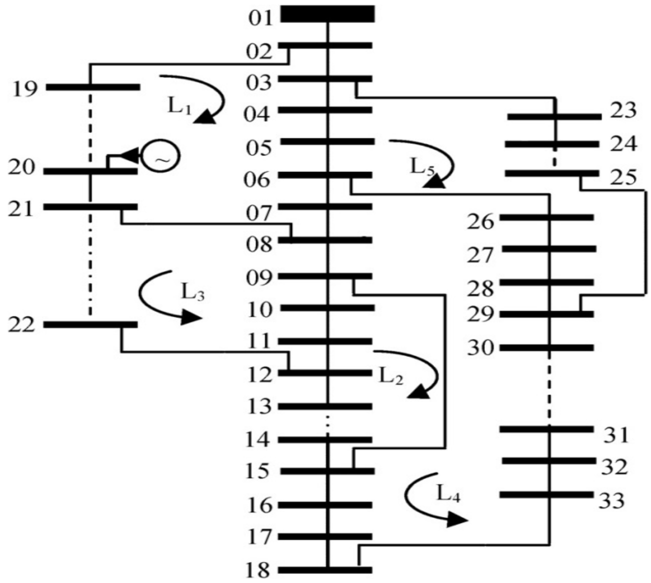


Figure 4. 33-Bus radial distribution system for Reconfiguration of HV^2

$$HV = \left[\underbrace{os_1^1 \;\; os_2^1 \;\; os_3^1 \;\; os_4^1 \;\; \mathrm{os}_5^1}_{reconfiguration} \right]$$

Solution vector for Figure 3: $HV^1 = [33 \;\; 34 \;\; 35 \;\; 36 \;\; 37]$

Solution vector for Figure 4: $HV^2 = [07 \;\; 14 \;\; 09 \;\; 32 \;\; 37]$

Only DG Installation using HSA

In this, we are considering only DG installation to minimize the power losses in distribution system as shown in Figure 5. Here we are mainly focused on optimal location and suitable sizes of DG installation. Sensitivity analysis [18] is used to calculate the optimal locations of buses to install the DG units. The Loss sensitivity factors (LSF) are calculated using load flows from base case. The LSFs are arranged in descending order and at which the bus is having highest LSF, at that place the DGs are placed first. Here we are considered only top three locations to install the DG units. In that way we can choose the number of DG's is required. The sizes of DG units are selected after the location buses by using HSA. The size of solution vector is depends on number of DG units are need to be installed.

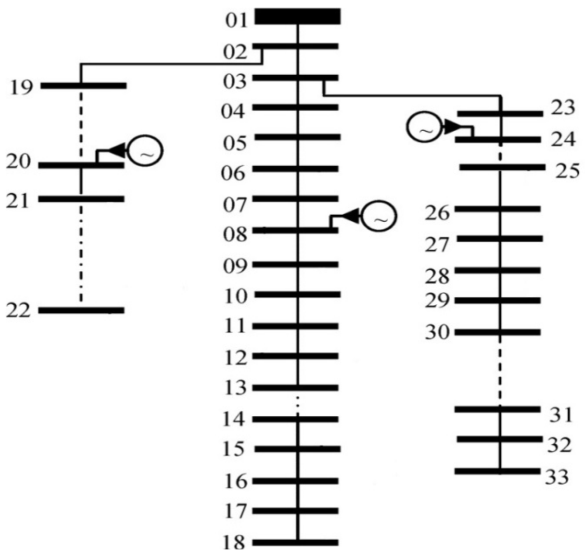


Figure 5. 33-Bus radial distribution system for DG installation

$$HV = \left[\underbrace{S_1^1 \;\; S_2^1 \;\; S_3^1}_{DG\ Sizes} \right]$$

Solution vector for DG installation $HV^1 = [18 \;\; 17 \;\; 33]$

4.2. Proposed Method (Simultaneous Reconfiguration & DG installation)

As in the above discussion we are considered Network reconfiguration and DG installation problems separately. But here we are considering the Simultaneous network reconfiguration and DG installation for the effective minimization of power losses. To reconfigure the network, initially all possible structures of given network are generated fist and by using sensitivity analysis we are finding the optimal locations for DG installation which is done simultaneously by using HSA. During optimization process the rating of DG units will vary in discrete steps at specified location by using HSA.

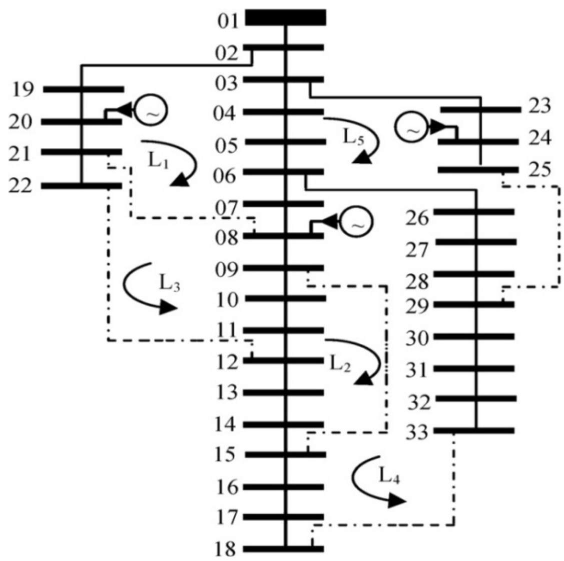


Figure 6. 33-bus radial distribution system for HV^1

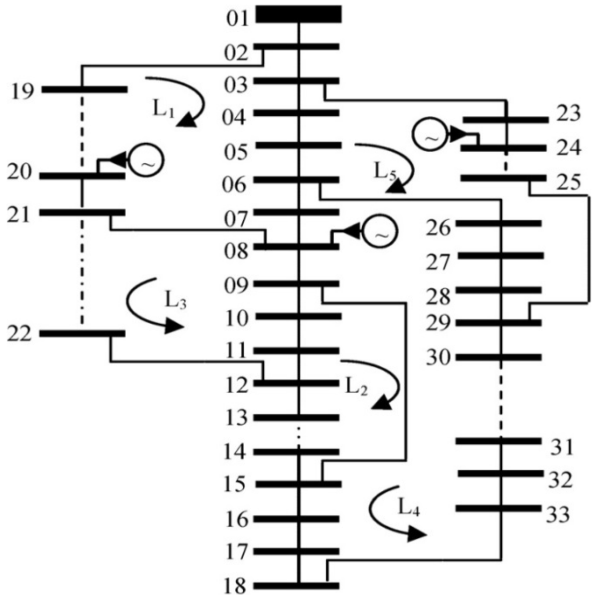


Figure 7. 33-bus radial distribution system for HV^2

Here the generated solution vector consisting of number of reconfiguration Tile line switches and number of DG installation locations. For reconfiguration only number of Tie line switches is to be known. Suppose the number of Tile line switches is N, then the length of a first part of solution vector is N. For second part of solution vector only number of DG installation locations should be known. Like that the solution vector HV1 is formed from Figure 6.

$$HV^1 = \left[\underbrace{os_1^1 \;\; os_2^1 \;\; os_3^1 \;\; os_4^1 \;\; \mathrm{os}_5^1}_{reconfiguration} \underbrace{S_1^1 \;\; S_2^1 \;\; \mathrm{S}_3^1}_{DG\ Sizes} \right]$$

The second solution vector HV2 is generated with the same Tie line/open switches (19, 13, 21, 30 and 24) and same DG installation locations with different ratings is formed as shown in the Figure 7.

$$HV^2 = \left[\underbrace{os_1^2 \;\; os_2^2 \;\; os_3^2 \;\; os_4^2 \;\; \mathrm{os}_5^2}_{reconfiguration} \underbrace{S_1^2 \;\; S_2^2 \;\; \mathrm{S}_3^2}_{DG\ Sizes} \right]$$

Similarly all other possible solution vectors are formed without violating the constraints is stored in main HM with the descending order (20) based on their corresponding objective function values. The Total number of solution vectors (HMS) generated are less than or equal to the highest number of switches in any individual loop. The flow chart of proposed method is shown in Figure 8.

$$\mathrm{HM} = \begin{bmatrix} \mathrm{os}_1^1 & \mathrm{os}_2^1 & \mathrm{os}_3^1 & \mathrm{os}_4^1 & \mathrm{os}_5^1 & \mathrm{S}_1^1 & \mathrm{S}_2^1 & \mathrm{S}_3^1 \\ \mathrm{os}_1^2 & \mathrm{os}_2^2 & \mathrm{os}_3^2 & \mathrm{os}_4^2 & \mathrm{os}_5^2 & \mathrm{S}_1^2 & \mathrm{S}_2^2 & \mathrm{S}_3^2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \mathrm{os}_1^H & \mathrm{os}_2^H & \mathrm{os}_3^H & \mathrm{os}_4^H & \mathrm{os}_5^H & \mathrm{S}_1^H & \mathrm{S}_2^H & \mathrm{S}_3^H \end{bmatrix} \qquad (20)$$

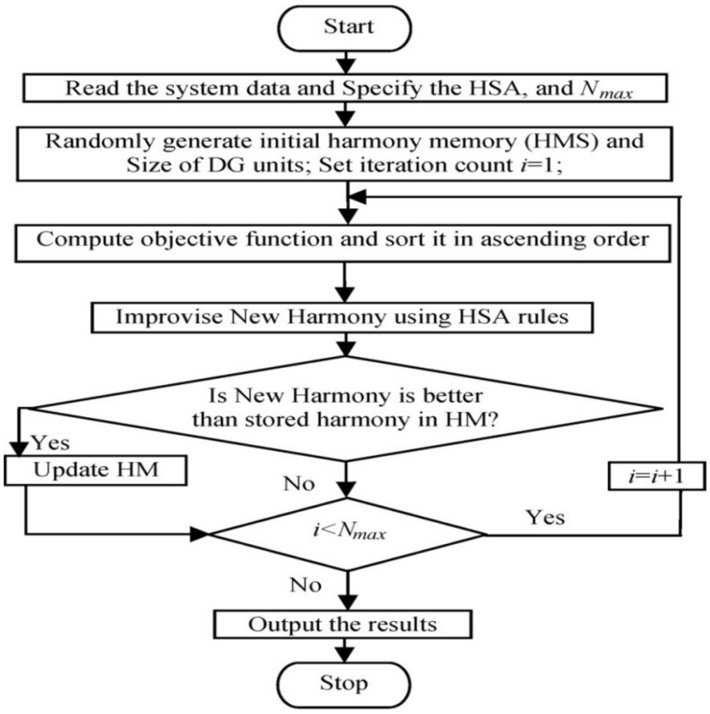


Figure 8. Flow chart of the proposed method

5. Test Results

In order to effective minimization of power losses in distribution systems, the proposed method (Simultaneous Network Reconfiguration and Dg installation) using HSA is applied to two test systems consisting of 33 and 69 buses. In the simulation of network, five scenarios are considered to analyze the superiority of the proposed method.

Scenario I: The system is without reconfiguration and distributed generation (Base case).

Scenario II: Only Reconfiguration of a Distribution Network.

Scenario III: Only DG units are installed in a Distribution Network

Scenario IV: DG units are installed after reconfiguration.

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

All scenarios are programmed in MATLAB 2009, and simulations are carried on a computer with Pentium IV, 3.0 GHz, 1 GB RAM.

5.1. Test System 1

In this a 33-bus radial distribution system [22] with five tie-switches and 32 sectionalizing switches are considered. In the 33-bus system, the sectionalizing switches are numbered from 1to 32 and the tie line switches are numbered from 33 to37. The line data and load date of network are taken from the [9]. The total real and reactive power loads on the system are 3715 kW and 2300 KVAR. The parameters of HSA algorithm used in the simulation of network are *HMS* = 20, *HMCR* =0.85, *PAR*=0.3 and *NI* =20 and number of runs, N=9. The network is reconfigured based on the number of open switches. Using sensitivity analysis the DG units are installed at optimal locations in scenarios III, IV and V. 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.

It is clearly observed from Table 1, at light load base case power loss (in KW) is 47.06 and which is reduced to 33.27 and 23.29 using only network reconfiguration and only DG installation. The power losses are effectively reduced to 17.78 in the Simultaneous Reconfiguration and DG installation at the scenario V. Similarly the Minimum voltage is also improved to 0.9859 in scenario V, which is almost nearer to unity. Like that the power losses are also reduced at medium and heavy load also by using proposed method.

The voltage profile curves drawn between Voltages with respect to the Bus nodes for all scenarios at three different load conditions is shown in Figure 9. After network reconfiguration with simultaneous DG installation, the optimal structure for scenario V is shown in Figure 10. By increase the number of DG units need to be installed we can reduce the power losses effectively.

Table 1. Results of 33-bus system

Scenario		**Load Level**		
		Light (0.5)	**Nominal (1.0)**	**Heavy (1.6)**
Base Case (Scenario 1)	Switches Opened	33, 34, 35, 36 and 37	33, 34, 35, 36 and 37	33, 34, 35, 36 and 37
	Power Loss (KW)	47.06	202.67	575.27
	Minimum Voltage (p.u)	0.9583	0.9131	0.8529
Only Reconfiguration (Scenario 2)	Switches Opened	7, 14, 9, 32 and 37	7, 14, 9, 32 and 37	7, 14, 9, 32 and 37
	Power Loss (KW)	33.27	138.06	380.43
	Minimum Voltage (p.u)	0.9698	0.9342	0.8967
Only DG Installation (Scenario 3)	Switches Opened	33, 34, 35, 36 and 37	33, 34, 35, 36 and 37	33, 34, 35, 36 and 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)	23.29	96.76	260.97
	Minimum Voltage (p.u)	0.9831	0.9670	0.9437
DG installation after Reconfiguration (Scenario 4)	Switches Opened	7, 14, 9, 32 and 37	7, 14, 9, 32 and 37	7, 14, 9, 32 and 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 (33)
	Power Loss (KW)	23.54	97.13	259.63
	Minimum Voltage (p.u)	0.9745	0.9479	0.9140
Reconfiguration with simultaneous DG installation (Scenario 5)	Switches Opened	7, 14, 11, 32 and 27	7, 14, 10, 32 and 28	7, 14, 10, 32 and 28
	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)	17.78	73.05	194.22
	Minimum Voltage (p.u)	0.9859	0.9700	0.9516

Table 2. Improvement of Voltage profile in 33 Bus System

Different Load conditions	**Maximum Voltage (p.u) at Bus 18**				
	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**
Light	0.9582	0.9744	0.9865	0.9747	0.9908
Nominal	0.9130	0.9475	0.9759	0.9475	0.9844
Over	0.8527	0.9133	0.9599	0.9145	0.9737

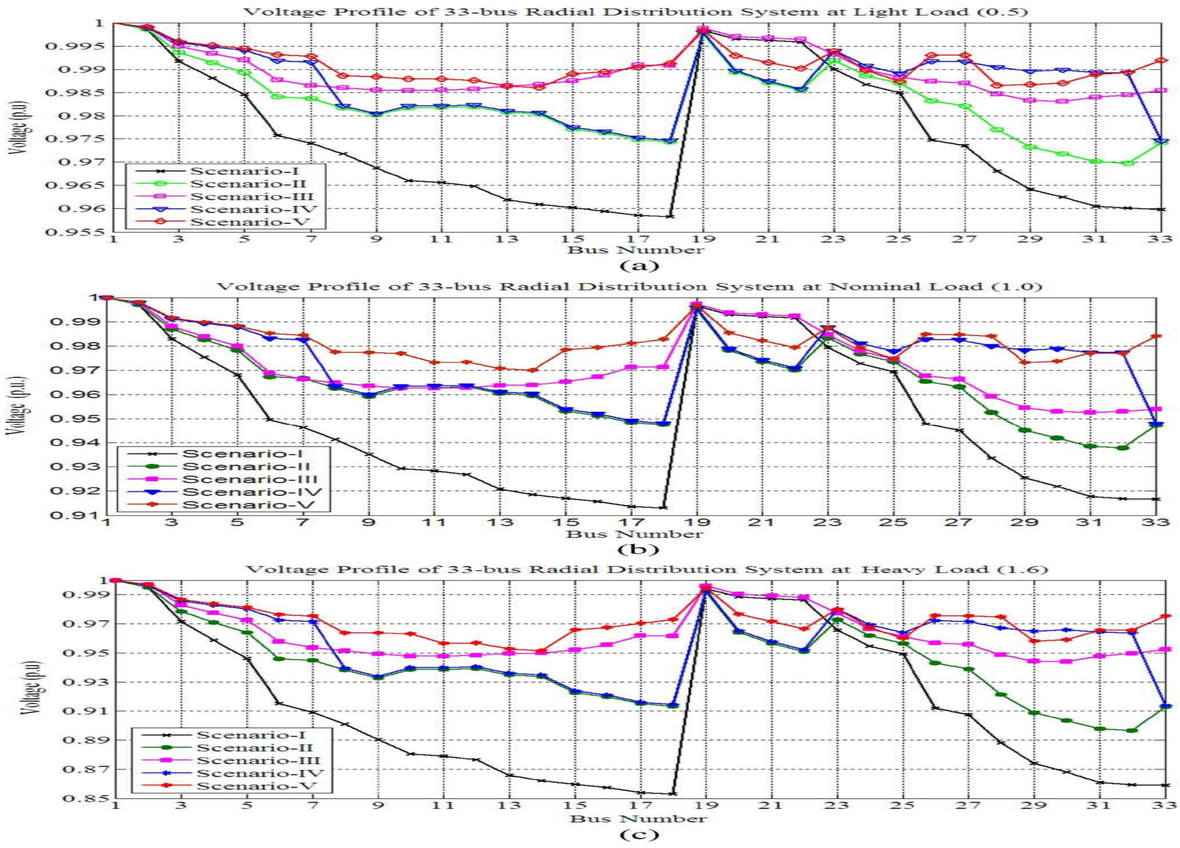


Figure 9. Voltage profiles of 33-bus system at light, nominal, and heavy load conditions

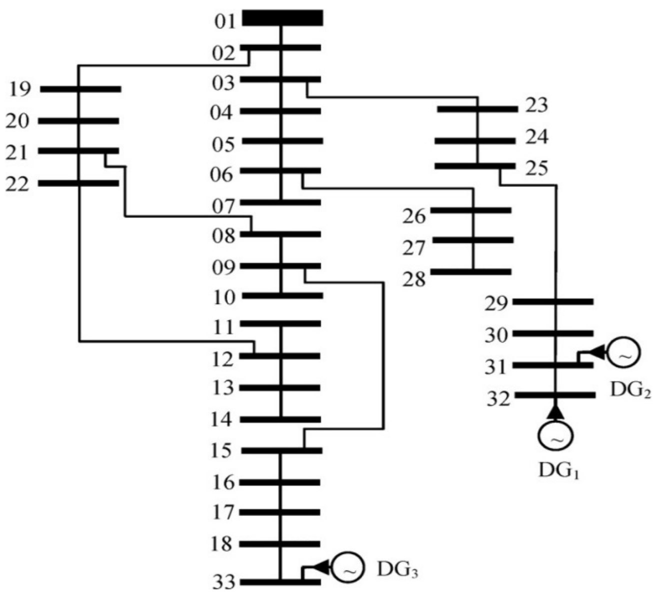


Figure 10. Optimal network structure after simultaneous reconfiguration and DG installation

It is observed from Table 2, in which bus 18 having the minimum voltage (0.9582) and maximum power loss when compared to the other buses in 33bus system. By using HSA at Light load, at bus number 18, the minimum voltage is improved from the different scenarios. In that by using scenario II, scenario III, and scenario IV we are improving the minimum voltages up 0.9744, 0.9865 and 0.9747. But by using proposed method we are improving the voltage value up to 0.9908, which is nearer to the unity. Similarly at Nominal load and over load conditions also the bus voltages are improved effectively using proposed method.

The results are also compared with all other method like GA and RGA, but HSA gives the better results compared to other methods. This shows that for all three load levels, the improvement of voltage using proposed method (scenario V) is highest, which elicits the superiority of the proposed method over all others.

5.2. Test System 2

In this a 69-bus large-scale radial distribution system with 68 sectionalizing and five tie switches are considered. The sectionalizing switches are numbered from 1 to 68 and tile line switches are numbered from 69 to 73. Configuration, line, load and tie line data are taken from the [23].

Similar to the test system the algorithm parameters are used. Total system loads for base configuration are 3802.19 kW and 2694. 06 KVAR. Similar to test systems 1, this test system is also simulated for three scenarios at three load levels and results are presented in the Table 3.

Table 3. Results of 69-bus system

Scenario		**Load Level**		
		Light (0.5)	**Nominal (1.0)**	**Heavy (1.6)**
Base Case (Scenario 1)	Switches Opened	69, 70, 71, 72 and 73	69, 70, 71, 72 and 73	69, 70, 71, 72 and 73
	Power Loss (KW)	51.61	225.00	652.53
	Minimum Voltage (p.u)	0.9567	0.9092	0.8445
Only Reconfiguration (Scenario 2)	Switches Opened	69, 70, 14, 57 and 61	69, 18, 13, 56 and 61	69, 18, 13, 55 and 61
	Power Loss (KW)	23.72	99.35	271.42
	Minimum Voltage (p.u)	0.9722	0.9428	0.9048
Only DG Installation (Scenario 3)	Switches Opened	69, 70, 71, 72 and 73	69, 70, 71, 72 and 73	69, 70, 71, 72 and 73
	Size of DG in MW (Bus Number)	0.2579 (65) 0.1280 (64) 0.5857 (63)	0.1018 (65) 0.3690 (64) 1.3024 (63)	0.1589 (65) 0.8308 (64) 1.9710 (63)
	Power Loss (KW)	21.92	86.77	230.61
	Minimum Voltage (p.u)	0.9846	0.9677	0.9478
DG installation after Reconfiguration (Scenario 4)	Switches Opened	69, 70, 14, 57 and 61	69, 18, 13, 56 and 61	69, 18, 13, 55 and 61
	Size of DG in MW (Bus Number)	0.4462 (61) 0.1835 (60) 0.1052 (58)	1.0666 (61) 0.3525 (60) 0.4257 (58)	1.8208 (61) 0.3305 (60) 0.2703 (58)
	Power Loss (KW)	12.55	51.30	135.71
	Minimum Voltage (p.u)	0.9817	0.9619	0.9377
Reconfiguration with simultaneous DG installation (Scenario 5)	Switches Opened	10, 16, 14, 56 and 62	69, 17, 13, 58 and 61	10, 18, 13, 58 and 61
	Size of DG in MW (Bus Number)	0.3143 (62) 0.3481 (61) 0.3397 (64)	1.0666 (61) 0.3525 (60) 0.4527 (62)	1.5935 (61) 0.8219 (60) 0.9674 (62)
	Power Loss (KW)	11.07	40.30	104.67
	Minimum Voltage (p.u)	0.9860	0.9736	0.9592

It is clearly observed from Table 3, at light load base case power loss (in KW) is 51.06 and which is reduced to 23.72 and 21.92 using only network reconfiguration and only DG installation. The power losses are effectively reduced to 11.07 in the Simultaneous

Reconfiguration and DG installation at the scenario V. Similarly the Minimum voltage is also improved to 0.9860 in scenario V, which is almost nearer to unity. Like that the power losses are also reduced at medium and heavy load also by using proposed method. By increase the number of DG units need to be installed we can reduce the power losses effectively.

It is observed from Table 4, Similar to the 33 bus system, in 69 bus system also having the minimum voltage (0.9563) and maximum power loss at bus number 65 when compared to the other buses in 69bus system. By using HSA at Light load, at bus number 65, the minimum voltage is improved from the different scenarios. In that by using scenario II, scenario III, and scenario IV we are improving the minimum voltages up to 0.9841, 0.9850 and 0.9841. But by using proposed method we are improving the voltage value up to 0.9866, which is nearer to the unity. Similarly at Nominal load and Over load conditions also the bus voltages are improved effectively using proposed method.

Table 4. Improvement of Voltage profile in 69 Bus System

Different Load conditions	Maximum Voltage (p.u) at Bus 65				
	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**
Light	0.9563	0.9841	0.9850	0.9841	0.9866
Nominal	0.9092	0.9645	0.9801	0.9645	0.9827
Over	0.8429	0.9420	0.8429	0.9421	0.9990

6. Conclusion

In this paper harmony search algorithm is proposed for Simultaneous Network Reconfiguration & DG Installation in distribution system to minimize the Real power losses. 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 the different scenarios in the 33 and 69 Bus systems at three different load conditions.

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