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Optimal Placement and Sizing of Distributed Generators in Balanced/Unbalanced Distribution Systems Using Backtracking Search Optimization (BSA)

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Abstract- **Over the last quarter of 20th century, many developments have been made in the power generation and major transmission networks optimization. For achieving this, digital computers have been used in the study of load flows, system stability and in optimum load allocation of generators. Until recently, concentration is confined to optimize the distribution systems, which represent some 50-60% of the overall cost of an electric power system. Often, sub-transmission and distribution systems were designed with a rule of thumb approach which can result in the system becoming more expensive. This thesis presents various methods for power loss reduction of unbalanced radial distribution systems. The base case load flow solution becomes the initial solution in realization of the algorithms presented here for transformer modeling, network reconfiguration, optimal sizing and sitting of capacitors as well as distributed generators in unbalanced radial distribution systems. Distributed Generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy. Proper locations and sizing of DGs in Distribution systems is important for obtaining their maximum potential benefits. In this paper, finding the optimal location and size of DGs is dealt keeping active power loss as the objective. A very recent swarm optimization technique namely backtracking search optimization algorithm (BSOA) is considered and compared with conventional Big Bank Big Crunch Method (BBBC). DGs supplying both active and reactive power have been studied. The proposed methodology has been verified on IEEE 33 distributed test system coded in MATLAB.**

I. INTRODUCTION

Integration of distributed generators with the distribution networks sparked broader interest in the last two decades. Distributed generators (DGs) are connected to the distribution network for different purposes: improving the voltage profile, reducing the power loss, enhancement of system reliability and security, improvement of power quality by improving supply continuity, relieving transmission and distribution congestion, reduction in health care costs due to improved environment, reducing the system cost and deferral of new investments. Optimal location and capacity of DGs plays a pivotal rule in maximizing the benefits gained from them, on the other side non-optimal placement or sizing of DGs may cause undesirable effects. The search space of optimal location and capacity of DGs is roomy. Different optimization strategies have been presented in recent literature with objective functions aiming to power loss minimization, cost reduction, profit maximization and environmental emission reduction. The optimization methods are classifies into analytical numerical and heuristic. Analytical expressions for finding optimal size and power factor of different types of DGs were suggested. The authors proposed an improved analytical method for allocating four types of DG units for loss reduction in primary distribution networks along with an approach for optimally selecting the optimal DG power factor.

Linear Programming was used to solve optimal DG power optimization problem for achieving maximum DG penetration and maximum DG energy harvesting. Genetic algorithm (GA) and optimal power flow were combined to solve the optimization problem and GA was applied to solve a DG optimization problem with reliability constraints and for maximizing the profit by the optimal placement of DGs. The DG optimal power was evaluated by the Tabu Search (TS) method for the case of uniformly distributed loads. A continuous stochastic DG model optimal power was evaluated by a GA as well as by a combined TS and scatter search. Reference proposed a method that integrates constant power factor DG unit sin balanced distribution algorithm was implemented to determine the optimal DG size, power factor, and location in order to minimize the total system real power loss is proposed. Big Bang-Big Crunch (BB-BC) optimization method was firstly presented by Erol. The method was successfully applied to nonlinear multidimensional functions and showed good convergence speed. The BB-BC method was applied to solve power flow problem with continuous and discrete control variables. In the BB-BC algorithm for optimal selection of the control parameters for minimizing the fuel cost of generators was presented. This paper presents a supervised BB-BC method for finding the optimal location and capacity of dispatch able DGs connected to unbalanced distribution feeders for power/energy loss minimization without violating the system constraints. The DG in the proposed algorithm is modeled as voltage controlled (PV) node with the flexibility to be converted to constant power (PQ). The proposed algorithm is implemented in MATLAB and tested on the 33-bus feeder and the IEEE 37-node feeder. The results obtained are compared with published results for validation. The comparison proves the effectiveness, and the speed of convergence of the proposed method.

DISTRIBUTION SYSTEMS

Distribution system is defined as the part of power system which distributes electric power for local utilization.

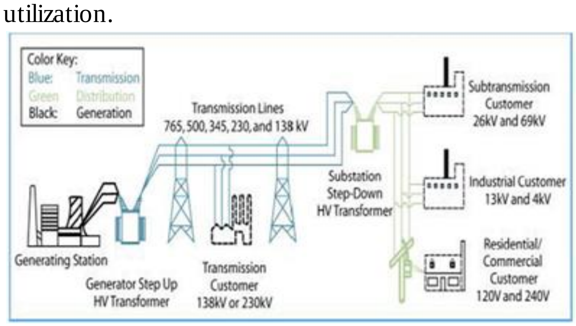

Fig 1.1 Diagram of a distribution system

At the end of the day, the electrical framework between the substation nourished by the transmission framework and the purchaser's meter is known as the dissemination framework. The fundamental components of a dissemination framework are feeders, merchants and the administration mains. Figure 1.1 portrays the single line graph of a run of the mill low strain conveyance framework.

(i) Feeders: A feeder is basically a conductor, interfacing the limited producing station (or the sub-station) to the wanted zone where force must be dispersed. With a specific end goal to keep the present in the feeder same all through, for the most part no tappings are taken from the feeder. The present conveying limit is the fundamental purpose of center amid outline of a feeder.

(ii) Distributor: A wholesaler is essentially a conductor from which tappings are taken for offering supply to the shoppers. Since the tappings are taken at different spots along the length of the merchant; the current through it is not consistent. The voltage drop over the length of the merchant is the fundamental purpose of center amid its configuration, as the statutory furthest reaches of voltage varieties is ± 10% of appraised worth at the purchaser's terminal.

(iii) Service mains: the administration principle is for the most part a little link which associates the merchant to shopper terminals.

II PROBLEM FORMULATION

Force streams in a dissemination framework are figured by the accompanying arrangement of improved recursive mathematical statements got from the single-line chart indicated in Figure 2.1:

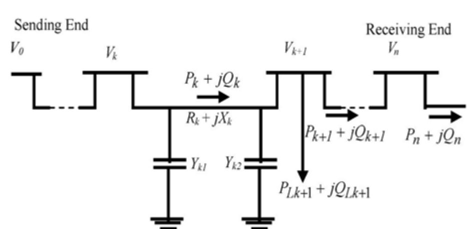

Figure 2.1: Single line diagram of a main feeder

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1}$$
$$= P_k - \frac{R_k}{|V_k^2|}\left\{P_k^2 + \left(Q_k + Y_k|V_k^2|\right)^2\right\} - P_{Lk+1} \quad (2.1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} = Q_k - \frac{X_k}{|V_k^2|}\left\{P_k^2 + \left(Q_k + Y_{k1}|V_k^2|\right)^2\right\} - Y_{k1}|V_k^2| - Y_{k2}|V_{k+1}^2| - Q_{Lk+1} \quad (2.2)$$

$$|V_{k+1}^2| = |V_k^2| + \frac{R_k^2+X_k^2}{|V_k^2|}\left\{P_k^2 + \left(Q_k + Y_k|V_k^2|\right)^2\right\} - 2\left\{R_kP_k + X_k\left(Q_k + Y_k|V_k^2|\right)^2\right\}$$

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

$$P_{Loss}(k, k+1) = \frac{R_k}{|V_k^2|}(P_k^2 + Q_k^2) \quad (2.4)$$

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

$$P_{T,Loss} = \sum_{k=1}^{n} P_{Loss}(k, k+1) \quad (2.5)$$

Power Loss Using Network Reconfiguration:

The framework reconfiguration issue in a transport system is to find a best course of action of winding framework that gives slightest influence hardship structure of flow structure. The force loss of a line area associating transports in the middle of k and k+1 after reconfiguration of system can be processed as

$$P'_{Loss}(k, k+1) = \frac{R_k}{|V'^2_k|}\left(P'^2_k + Q'^2_k\right) \quad (2.6)$$

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

$$P'_{T,Loss} = \sum_{k=1}^{n} P'_{Loss}(k, k+1) \quad (2.7)$$

Loss Reduction Using Network Reconfiguration:

Net power loss reduction, ΔP_{Loss}^{R} in the system is the difference of power loss before and after reconfiguration, that is (2.5)–(2.7) and is given by

$$\Delta P_{Loss}^{R} = \sum_{k=1}^{n} P_{Loss}(k, k+1) - \sum_{k=1}^{n} P'_{Loss}(k, k+1) \quad (2.8)$$

Power Loss Reduction Using DG Installation:

Establishment of dispersion era units in ideal areas of a dissemination framework results in a few advantages. These incorporate decrease of line misfortunes, change of voltage profile, crest interest shaving, assuaging the over-burdening of dissemination lines, lessened ecological effects, expanded general vitality effectiveness, and conceded speculations to overhaul existing era, transmission, and appropriation frameworks.

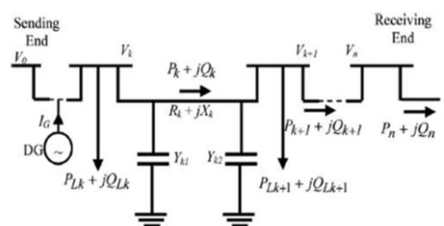

Figure 2.2: Distribution system with DG installation at an arbitrary location

The power loss when a DG is installed at an arbitrary location in the network as shown in Figure2.2, is given by

$$P_{DG,Loss} = \frac{R_k}{|V_k^2|}(P_k^2 + Q_k^2) + \frac{R_k}{|V_k^2|}(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G)\left(\frac{G}{L}\right) \quad (2.9)$$

Net power loss reduction, ΔP_{Loss}^{DG} in the system is the difference of power loss before and after installation of DG unit, that is (2.9)–(2.14) and is given by

$$\Delta P_{Loss}^{DG} = \frac{R_k}{|V_k^2|}(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G)\left(\frac{G}{L}\right) \quad (2.10)$$

The positive indication of ΔP_{Loss}^{DG} demonstrates that the framework misfortune lessens with the establishment of DG. Interestingly, the negative indication of ΔP_{Loss}^{DG} suggests that DG causes the higher framework misfort.

III. SENSITIVITY ANALYSIS FOR DG INSTALLATION

The working states of a force framework in the wake of presenting DG sources can change radically when contrasted with the base case. The arranging of DG establishments ought to, thusly, consider a few variables, for example, what might be the best innovation to be utilized, what number of units of DG and of what limits, where if they be introduced, what sort of association ought to be utilized and so forth. The issue of DG area and estimating ought to be drawn closer with alert. On the off chance that DG units are situated at non-ideal areas, the framework misfortunes may build, along these lines bringing about expanded expenses. Studies have shown that wrong areas of DG may prompt more prominent framework misfortunes than the ones in the current system. Of all advantages and targets of DG execution, the thought of actualizing DG for misfortune decrease needs extraordinary consideration. Affectability element system is predicated on the guideline of linearization of immaculate nonlinear comparison around the introductory working point, which benefits to decrease the quantity of arrangement space. Misfortune affectability variable strategy has been broadly used to settle the capacitor distribution dilemma. Its application in DG allotment is beginning in the field.

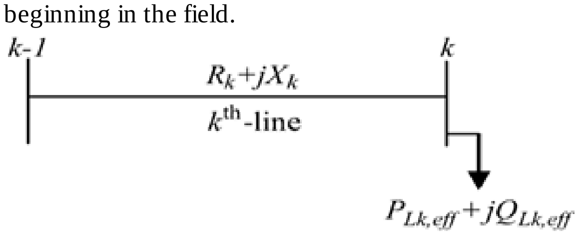

Fig 3.1: connected line between bus k-1 and k

Sensitivity factors are evaluated at each bus to install DG units, firstly using the values obtained from the base case power flow. The fig shows a line impedance of $R_K + jX_K$ between k-1 and k buses connected to the load of $P_{LK,eff} + jQ_{LK,eff}$. The active power loss in kth line as shown in equation [2.1].

$$P_{Loss} = [I_k^2] \times R_k \tag{3.1}$$

Where the branch current is I_k and R is the resistance of line. In addition,

$$I_k = \left[\frac{P_{Lk,eff}+jQ_{Lk,eff}}{V_{Lk,eff}}\right]^* \tag{3.2}$$

Where P, Q, V are the real power load and reactive power load, voltage at the receiving end. By substituting equation (3.2) in (3.1) as given follows, Active power loss in the k^{th}-line between k-1 and k buses is given by,

$$P_{lineloss} = \frac{\left(P_{Lk,eff}^2+Q_{Lk,eff}^2\right)R_k}{V_k^2} \tag{3.3}$$

The sensitivity factor of real power loss is obtained by differentiating equation (3.3) with respect to real power injection from DG at bus k which is given by as follows,

$$\frac{\partial P_{lineloss}}{\partial P_{LK,eff}} = \frac{2*P_{LK,eff}*R_K}{V_K^2} \tag{3.4}$$

Utilizing above mathematical statement (3.4), LSFs are figured from burden streams and estimations of the transports are positioned in diving request of the estimations of their affectability variables to frame a need rundown. The top positioned transports in the need rundown are most delicate to DG arrangement so as to have the best impact on misfortune lessening.

ALGORITHM FOR SENSITIVITY ANALYSIS

Step 1: Run the base case burden stream.

Step 2: Find the ideal size of DG for every transport utilizing comparison HSA calculation.

Step 3: Compute the proper misfortune placing so as to utilize mathematical statement (3.4) for every transport DG of ideal size got in step 2 for that transport. Include the Injection from DG for that transport and utilization base case values for state variables.

Step 4: Locate the transport at which the misfortune is least after DG position. This is the ideal area for DG.

Step 5: Run burden stream with DG to get the last result.

IV. SUPERVISED BIG BANG BIG CRUNCH

Randomness can be seen as equivalent to the energy dissipation in nature while convergence to a local or global optimum point can be viewed as gravitational attraction. Since energy dissipation creates disorder from ordered particles, we will use randomness as a transformation from a converged solution (order) to the birth of totally new solution candidates (disorder or chaos). The proposed method is similar to the GA in respect to creating an initial population randomly. The creation of the initial population randomly is called the Big Bang phase. In this phase, the candidate solutions are spread all over the search space in a uniform manner. Fig.4.1 is drawn to give an idea how the candidate solutions are spread in the optimization problem of Rosenbrock function with two 2-bytes long integer variables symbolizing the real values between [0, 10]. Since the normal random number generator can produce numbers greater than unity, it is therefore necessary to limit their values in order to keep them in the search space. The effect of this limitation can be seen in Fig. 4.1 as an accumulation of candidates at the boundaries. The population size is kept fixed as 30 in the example and the benchmark tests. However, this size can be reduced or increased according to the convergence or the number of iterations. The Big Bang phase is followed by the Big Crunch phase. The Big Crunch is a convergence operator that has many inputs but only one output, which can be named as the center of 'mass', since the only output has been derived by calculating the center of mass. Here, the term mass refers to the inverse of the fitness function value.

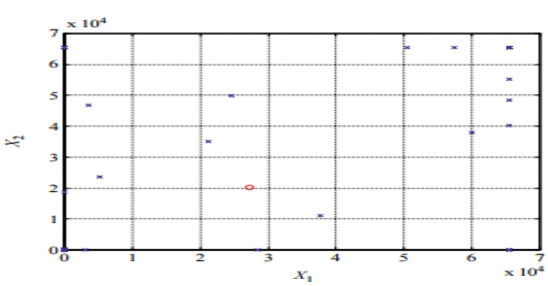

Fig. Initial spread of candidate solutions for two-dimensional case where the parameters are denoted by 'x1 and x2' and their respective center of mass is marked with 'o' for the Rosenbrock function.

PROBLEM STATEMENT FOR POWER LOSS MINIMIZATION

The optimization problem under study can be stated as follows: *Given:* the input data comprises the distribution feeder structure, series impedances, mutual impedances, shunt capacitances, feeder loads values and load types.

Required: to determine exactly the optimal DG capacity and optimal DG location for the sake of minimizing the distribution feeder active power loss as well as energy loss using (1) and (2) without violating the system constraints:

Minimize the active power loss=$\sum_{f=1}^{Nf} P_{loss,f}$ (4.1)

Minimize the daily energy loss=$\sum_{h=1}^{24} P_{loss,h}$ (4.2)

where is feeder number, is total number of feeders ,is the power loss at certain feeder , is the hour number and is the total system power loss at certain hour .The system constraints are as follows:

• Voltage limits: voltage at each bus should be within a permissible range usually

$$0.9 \text{ p.u.} \leq V \leq 1.1 \text{ p.u.} \quad (4.3)$$

• DG power limits: active, reactive and complex powers of the DG unit are constrained between minimum and maximum value and this range should not be violated:

$$0 \leq P_g \leq P_g^{\max} \quad (4.4)$$

$$Q_g^{\min} \leq Q_g \leq Q_g^{\max} \quad (4.5)$$

$$0 \leq S_g \leq \sum S_{load}. \quad (4.6)$$

In the proposed method DG maximum active power is limited by

$$P_g^{\max} \leq \sum P_{loads}. \quad (4.7)$$

The previous relation is bounded by the thermal capacity limit of the feeder lines. The DG power factor is bounded between two preset values; hence, the reactive power is also bounded in return.

• Lines thermal limit (line Ampacity): it represents the maximum current that the line can withstand at certain DG penetration, exceeding this value leads to melting of the line:

$$I_{flow} \leq I_{Thermal}. \quad (4.8)$$

• Power balance: the sum of input power should be equal to the sum of output active power in addition to the active power loss. The input power may include the DG active power and the active power supplied by the utility.

$$P_{substaion} + \sum P_{DG} = \sum P_{loads} + P_{loss}. \quad (4.9)$$

Approach: apply the supervised BB-BC method to solve the optimization problem and find the optimal location and capacity of DGs in order to minimize the power loss or the energy loss. Rummage for the optimal location and capacity of DGs connected to unbalanced distribution systemby using the proposed method is faced by some obstacles that can be summarized in the following challenges:

1) Nature of the distribution system: a distribution system has a radial topological structure. Newton Raphson and fast decoupled Newton Raphson are the most widely used methods for transmission systems but they are UN suitable for the distribution networks because distribution networks are ill-conditioned. The backward forward sweep method is selected for the developed power flow, as it involves limited matrix operations and no matrix inversions.

2) Modeling of voltage controlled DGs: small capacity DGs cannot supply sufficient reactive power to control the output voltage, this leads to representing the generation node as PQ or constant negative load with current injection into the node. Large capacity DG can supply required reactive power; hence the generator node in this case must be modeled as PV node. Steps for modeling DG when operating at specified terminal voltage are minutely discussed. DG in the proposed algorithm is modeled as PV node with the flexibility to be converted to PQ node in case of reactive power limit violation.

IV PROPOSED BACKTRACKING SEARCH ALGORITHM

Problem Formulation

The problem statement here is to reduce active power loss as well as voltage deviation in distribution system.

Objective Function

This objective function aims at minimizing the total active power loss occurring while supplying the respective loads.

$$Min: fn() = Ploss = \sum_{i=1}^{nl} I^2 R \quad - (5.1)$$

Constraints

The voltage at each node of the radial distribution network is defined as

$$V^{min} \leq V \leq V^{max} \quad - (5.2)$$

V^{min} and V^{max} are minimum and maximum allowable voltage of given bus.

The line power transfer limits is given as

$$|Plineij| \leq |Pmaxij| \quad - (5.3)$$

Plineij is the total power flow through the line and Pmaxij is the maximum allowable power flow through the line.

Load Flow with BSOA

Conventional NR and Gauss Seidel (GS) methods may become inefficient in the analysis of distribution systems, due to the special features of distribution networks, i.e. radial structure, high R/X ratio and unbalanced loads, etc. These features make the distribution systems power flow computation different and somewhat difficult to analyze as compared to the transmission systems. Various methods are available to carry out the analysis of balanced and unbalanced radial distribution systems and can be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as NR and GS methods. On the other hand, the second group of methods is based on backward and forward sweep processes using Kirchhoff's laws. Due to its low memory requirements, computational efficiency and robust convergence characteristic, backward and forward sweep based algorithms have gained the most popularity for distribution systems load flow analysis. In this study, backward and forward sweep method is used to find out the load flow solution.

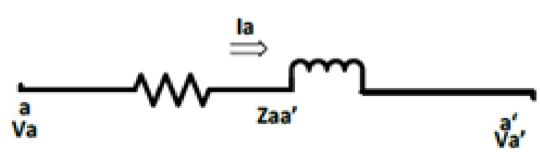

Fig4.1: Typical Single Phase Feeder

$$V_{a^n} = V_a - Z_{aa}..I_a \quad - (5.4)$$

$$Il_i = (P_i - jQ_i)/V_i^* \quad i=1\ldots\ldots nb \quad - (5.5)$$

Figure 1 shows the typical section of a single phase feeder. The fb sweep considers the complex load at each bus to be constant. The load is then converted into equivalent current injection at each bus using equation (5.5). The fb sweep method takes two steps in each iteration. The first step is called backward sweep wherein starting from the last bus we calculate the branch current till the first bus, given by (5.6). Now the second step is called forward sweep wherein starting from the first bus, voltage is calculated for all the buses using equation (4)

Ij =Current of' jth branch=$\sum Il_i$ - (5.6)

Where, i=all subsequent buses to 'j'

Voltage Dependent Load Model

In conventional load flow analysis, it is assumed that active and reactive power loads are constant values, regardless of the magnitudes of voltages in the same bus. However, it is not the case always, as quoted in [5], [10], in more practical scenario the loads are considered to be voltage dependent and based on their relationship they are classified as commercial, residential and industrial loads. In this voltage dependent load model the relation between voltage and load is expressed as

$$P_L = P_{Lo} * V^{np} \quad - (5.7)$$

$$Q_L = Q_{Lo} * V^{nq} \quad - (5.8)$$

Where np and nq are active and reactive power exponents, respectively. P_L and Q_L are the values of real and reactive powers, while P_{LO} and Q_{LO} are the values of real and reactive powers at nominal voltages, respectively. V is the voltage magnitude at a load node. Each load node consists of three components of load consumption. Let α,β,ν are the percentages of residential, commercial and industrial load at each load node respectively, the voltage dependent load model can therefore be expressed as follows.

$$P_L = \alpha P_{Lo} V^{npr} + \beta P_{Lo} V^{npc} + \nu P_{Lo}{}^{npi} \quad - (5.9)$$

$$Q_L = \alpha Q_{Lo} V^{nqr} + \beta Q_{Lo} V^{nqc} + \nu Q_{Lo}{}^{nqi} \quad - (5.10)$$

And $\alpha + \beta + \nu = 1$ - (5.11)

The values of the real and reactive power components used in present work for industrial, residential and commercial loads are given. According to Table 1, the voltage exponent (nq) of the reactive load is quite high in most of the load types when compared to the real power exponent (np), particularly for industrial loads, therefore consideration of voltage dependency of reactive loads is necessary for DG planning studies.

Overview of the BSOA

The BSOA is a population-based iterative EA designed to be a global minimize. The BSOA can be explained by dividing its functions into five procedures: (i) initialization, (ii) selection-I, (iii) mutation, (iv) Crossover, and (v) selection- II. The structure of BSOA is quite simple; thus, it can be easily adapted to different numerical engineering optimization problems. BSA, unlike most other optimizations which maximize the objective function, it minimizes the objective function. The BSOA's strategies for generating trial populations and controlling the amplitude of the search-direction matrix and search-space boundaries give it very powerful exploration and exploitation capabilities. In particular, the BSOA possesses a memory in which it stores a population from a randomly chosen previous generation for use in generating the search-direction matrix. The BSOA has strong strategy for both a global exploration and local exploitation with good feature of avoiding local minima. The BSOA five main procedures are outlined below:

(i) Initialization

The BSOA initializes the population P as defined in below Eq

$$P_{ij} = LB_j + rand(...).(UB_j) \;\; i\forall N \; \& \; j\forall D$$

(ii) Selection – 1

The BSOA's Selection – I stage determines the historical population oldP to be used for calculating the search direction. The initial historical population is determined as

$$oldP_{ij} = LB_j + rand(...).(UB_j - LB_j) \; i\forall N \; \& \; j\forall D$$

After oldP is determined, the permuting function is applied to randomly change the order of the individuals in oldP using random shuffling function formulated as

oldP := Permuting (oldP)

(iii) Mutation

The BSOA's mutation process generates the initial form of the trial population mutant. The historical population is used in the calculation of the search-direction matrix; the BSOA generates a trial population, taking partial advantage of its experiences from previous generations.

iv) Crossover

The BSOA's crossover process produces the final arrangement of the trial population T. The initial value of the trial population is Mutant, as set in the mutation process. Trial individuals with better fitness values for the optimization problem are used to evolve the target population individuals. The BSOA's crossover approach is quite dissimilar to the crossover strategies used in DH and its variants.

(v) Selection - II

In selection- II stage, the trial populations T_is that have better fitness values than the corresponding P_is are used to update the P_is based on a greedy selection. If the best individual of P (P_{best}) has a better fitness value than the global minimum value obtained, the global minimizer is updated to be P_{best} and the global minimum value is updated to be the fitness value of $P_{best.}$

Proposed Methodology

Optimal DG placement basically involves fulfillment of one or more objectives without compromising on bus voltages, line loadings and the system reliability. Here the system active losses are minimized along with minimizing the voltage deviation of the system. This is achieved by searching the potentially best position and size of DGs and enforcing the bus voltages to lie within 0.95-1.05 p.u. DGS operating at 0.85 power factors are considered.BSA uses two sets of population, one trial population and other historical population which acts as swarm memory. Thus the offspring contains the characteristics of both present and historical population which is helpful in obtaining quick and reliable results. The probable locations for the DG can be anywhere between first bus to the total number of buses while the DG size is considered to lie between 0MW and 2MW.

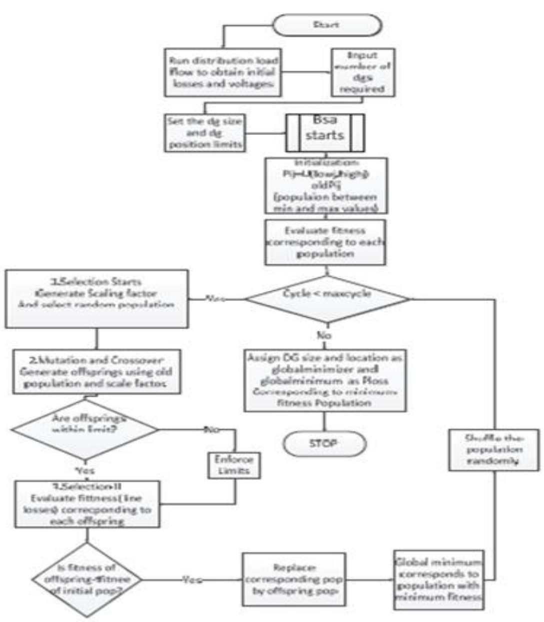

Fig. . Flowchart of BSA for optimal DG placement.

Initially objective function (net power loss) for the trial population is calculated using fb sweep method. Then using mutation, crossover and selection processes off springs are generated. The power loss is calculated for the off springs, the offspring with lower fitness value replace the members from initial population thus creating a new set off population with lower fitness. The difference between the fitness of trial and historical population decide the direction operation of the optimization. The BSA steps are repeated until maximum cycles are met where the global minimize contains the best DG location and sizes.

IV. RESULTS

The proposed algorithm has been implemented in MATLAB and the following studies were done on the IEEE 33-bus and the IEEE 37-node feeders presented in Figs. 6.1 and 3 respectively to evaluate the optimal DG location and size. The IEEE 33-bus feeder is a balanced feeder with constant active and reactive power loads while the IEEE 37-node feeder is complex as it is characterized by spot loads, single phase and three phases balanced and unbalanced loads, delta connected loads, constant active and reactive power, constant impedance, and constant current type loads. The regulator was removed in order to clearly evaluate the effects of the DG on the system voltage profile for the IEEE 37-node feeders. The substation node is numbered as (0) as it is the reference node which has a constant voltage of 1 per-unit

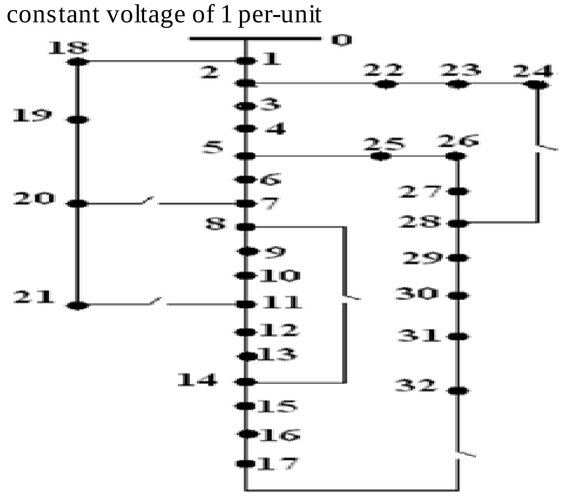

Fig. 5.1 Layout of the 33-bus feeder.

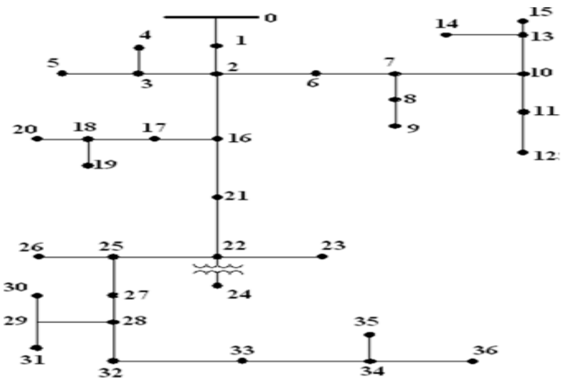

Fig. 5.2. Renumbered IEEE 37- node feeder.

The numbering of the other nodes is done in ascending order. Whenever a lateral branches off of the main feeder the lateral is indexed before returning to the main feeder.

The reactive power limits is calculated by varying the power factor from 0.8 lagging to 0.8 leading. Moreover, the DG model could be switched to PQ node only whenever required.

Comparative Study

1) Validation of the Unbalanced Load Flow: Unbalanced load flow without DG was done on the IEEE 37-node feeder and the results of voltages were compared. Table I shows a sample of the per unit line to line nodes voltages of the proposed load flow. It is clear that the results obtained matched closely the results.

2) Validation of DG Integration to the Load Flow: Different sizes of constant power factor DG were tested and compared to results done on the 33-bus feeder and presented. Table II confirms that the results are almost identical.

3) Validation of the Supervised BB-BC Algorithm: The proposed algorithm is applied to the 33-bus feeder and the optimal DG active power and location are compared with the results published which uses analytical method for finding the optimal location, size and power factor of DG in order to minimize the power loss.

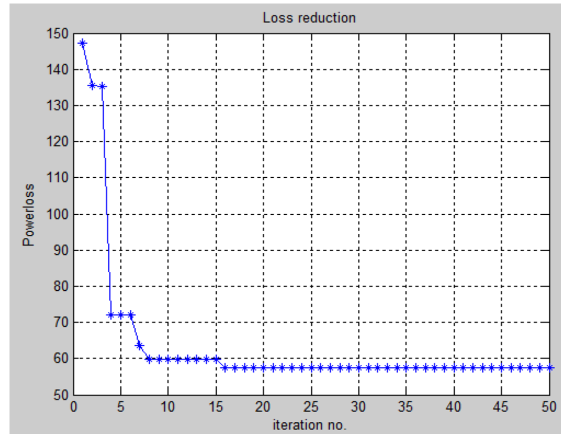

Fig. 5.3. Active power loss versus iteration of 33-bus feeder.

The daily energy loss at the base case where no DG is connected is equal to 972.8961 kWh. The supervised BB-BC method is applied at every hour, the hourly candidate optimal location and the corresponding power loss, and the results show that the candidate optimal locations are buses 2, 16, 21, 22, 25, and 27 for daily energy loss minimization. To find exactly the optimal location for daily energy loss minimization, a DG is placed at every candidate location and the optimal power at every location at each hour is determined. The energy loss in kWh at every candidate location are displayed in Fig. 7, show that the optimal location for daily energy loss minimization is bus 22 with energy loss of 361.60835 kWh (i.e., 62.83% reduction in daily energy loss as compared to the base case where no DG is connected). The daily active power schedule of a DG connected to bus 22 to achieve the minimum energy loss is presented in Fig.

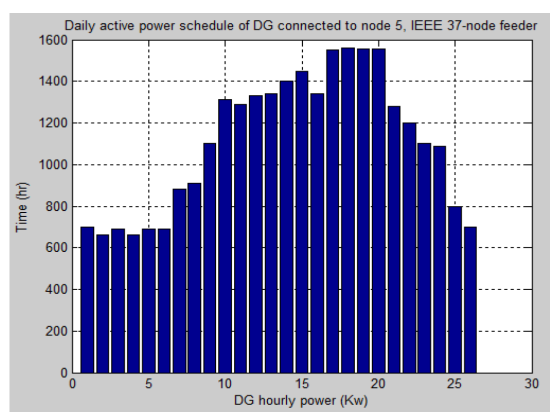

Fig.5.4. Daily active power schedule of DG connected to node 22, IEEE 37-node feeder.

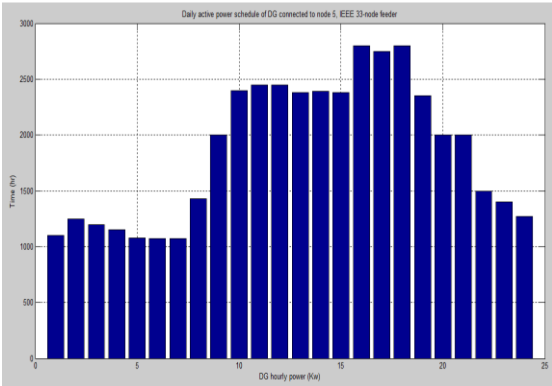

Fig. 5.5. Daily active power schedule of DG connected to node 5, IEEE 33-node feeder.

Proposed Backtracking Search Algorithm

The Backtracking Search Algorithm (BSA) has been applied IEEE -33 bus radial distribution system. Under base conditions the distribution load flow results for both the cases has been given in tables. Optimization has been done with single and multiple DGs, the results are tabulated. For 33 bus system the total real power loss of the system is 202.5635 Kw and the reactive power loss is 135.0556 KVARS. The minimum voltage is 0.9148 p.u which occurs at bus number 18. However, even with a single DG operating at 0.85 power factor the real power loss is reduced to 74.925Kw and the minimum system voltage shoots up to 0.9399p.u. Figures show the voltage profile of IEEE-33 bus system with and without DGs. From the plot we can observe that the profile is more or less similar for two and three DGs. Hence if cost is constraint, then only two DGs can be preferred. The optimal capacity of DG units for load models differs from the case of constant load. This shows that the consideration of load model has an important effect on DG capacity and location .The results obtained prove that by using BSA for different load models the voltage profile is improved to great extent and the system losses are reduced.

Table I

Results Comparison of Base case, BB-BC and Proposed BBC

	Base Case	BB-BC	Proposed BSA
Dg's Place	-	5	30,24,13
DG's Size(Mw)	-	2.3	1.2,1,0.782
Ploss(Kw)	202.65	57.584	21.3178
Vmin(p.u)	0.9131	0.9854	0.9918
% Loss(%)	-	71.58	89.48

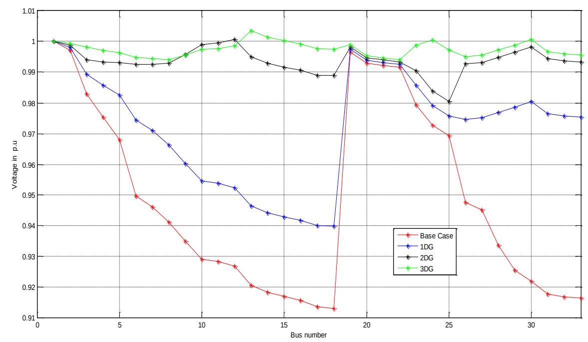

Fig.5.6: Voltage profile before and after DG placement for 33 bus system

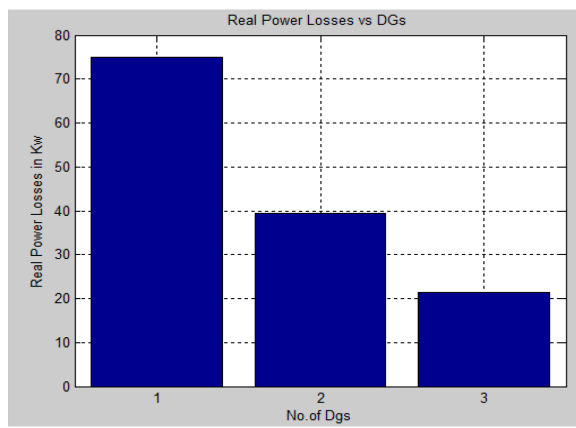

Fig5.7.Real Power reduction using Backtracking Search Algorithm (1DG, 2DG, 3DG)

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