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Impact of various load models in distribution system with DG using Harmony and Backtracking Search Algorithms

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Abstract- *In recent few years, the implementation of distributed generator into a distribution system has been increasing rapidly in many parts of the world, due to the liberalization of the electricity markets, constraints on constructing a new distribution network, transmission lives and environmental concerns . Proper locations and sizing of DGs in power 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 (BSA) is considered. DGs supplying both active and reactive power have been studied. The proposed methodology and Harmony search algorithm (HSA) is verified on IEEE-69 bus system with different load models.*
Keywords*- Backtracking search algorithm, Harmony search algorithm, Distributed generation, Load models, optimal location and sizing.*

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I. Introduction

Distributed Generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy. The distribution system aims to supply the customers with higher levels of demand. Ackermann et al. [1] have given the most recent definition of DG as: ''DG is an electric power generation source connected directly to the distribution network or on the customer side of the meter." The DG benefits in distribution systems can be summarized as economic, technical and environmental advantages. In recent research, different aspects of these benefits have been verified [2-4]. Therefore, the optimization problem of determining the siting and sizing of DGs [5] under the network constraints including load flow and bus voltage are of primary task.

Different methods have been proposed for optimal location and sizing of DG units. Power loss reduction [6 – 7] has remained keen area of interest for placement and sizing. However, other objectives such as voltage profile and reliability improvement, cost minimization and maximizing DG capacity and penetration level have been considered in different studies. Lie Han et al [8] presented analytical method for DG placement in order to enhance the reliability and obtain the benefits of DG placement. Genetic Algorithm has been found useful in dealing with DG placement and sizing [11]. The authors of [10] have used ABC optimization technique to find optimize DG size, power factor and location considering active power was as the network constraint.

In distribution system, voltage stability becomes very important, several works [6], [9] have been done in this area to maintain voltage profile while DG placement. Most of the DG planning studies consider the loads as constant power sinks that are independent of the feeder voltage magnitude. But in practical systems the load does not remain constant and varies differently for different customer type and at different time of day. The load in a distribution system generally consists of three main types i.e., residential, commercial and industrial loads. The nature of these three types of loads is such that their active and reactive power components respond differently to variations in the voltage and frequency of the system [12, 13]. Optimal DG placement considering various load models has been considered by Zonkoly [15] using PSO technique. Singh et al [14] have shown the effects of different load models on DG sizing and sitting.

Considering the effect of voltage dependent loads has a main impact on distribution system planning studies. The authors of [16] has used a multi-objective approach for DG placement and sizing using PSO. P.S. Georgilakis et al [17] has complied various methods, optimization techniques, constraints, etc. which has already been used for DG placement as well as the future research which can be done in this area.

This paper deals with a new evolutionary algorithm i.e. Backtracking search optimization Algorithm [18] , to determine the optimal location and sizing of DGs e to reduce power loss. Its results are compared with the results of Harmony search algorithm and are found to be better.

II. Problem Formulation

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

A. Objective Function

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

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

B. Constraints

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

$$V^{min} \leq V \leq V^{max} \qquad - (2)$$

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

The line power transfer limits is given as

$$|\text{Pline}| \leq |\text{Pmaxij}| \qquad - (3)$$

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

C.Different types of DG resources

DG resources are classified into 4 groups based on the ability of delivering active and reactive powers [21]: Type 1: Active power producers like PV arrays and fuel cells, which are connected to the grid by means of inverters. This type can only produce active power.

Type 2: Reactive power (Q) producers like synchronous condensers, which can only produce reactive power.

Type 3: Active power producers and reactive power consumers (PQ). This type of DG unit produces active power and absorbs reactive power from the grid. For example, fixed speed wind turbines that use an induction generator to produce electricity are placed within this type of DG. In fixed speed, wind turbines' reactive power is consumed to produce active power.

Type 4: Active and reactive power producers (PV bus voltage regulator). This type of DG unit produces reactive power to maintain the voltage of the bus to which they are connected. Wind turbines that have converters and diesel generators are categorized as this type of DG.

By considering the properties of these resources and in order to model them in the mentioned optimization problem, the injected active and reactive powers to the ith node are modeled as follows:

$$P_i = PDG_i - PD_i, \qquad - (4)$$

$$Q_i = QDG_i - QD_i = \alpha_i \times PDG_i - QD_i, \qquad - (5)$$

$$\alpha_i = (\text{sign}) \times \tan(\cos-1\ (PF_{DGi})), \qquad -(6)$$

where PD_i and QD_i are the demanding active and reactive powers of the ith node load; PDG_i and QDG_i are the generating active and reactive powers of the DG unit connected to the ith node; and PF_{DGi} is the DG power factor.

The power factor depends on the DG type and the operating condition of the DG unit. For type 1: $PF_{DG} = 1$, for type 2: $PF_{DG} = 0$, for type 3: $0 < PF_{DG} < 1$ and sign = −1; and, finally, for type 4: $0 < PF_{DG} < 1$ and sign = +1

D. Load Flow

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 [19] is used to find out the load flow solution.

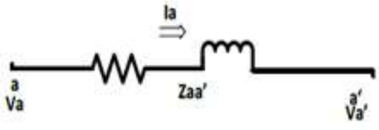

Fig1: Typical Single Phase Feeder

$$V_a^n = V_a - Z_{aa} I_a \qquad - (7)$$

$Il_i = (P_i - jQ_i)/V_i^*$ i=1……..nb   - (8)

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 (8). 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 (9). Now the second step is called forward sweep wherein starting from the first bus, voltage is calculated for all the buses using equation (7)

I j =Current of' jth branch=Il_i - (9)

where, i=all subsequent buses to 'j'

III. 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 [6], [11], 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

$P_L = P_{Lo} * V^{np}$ - (10)

$Q_L = Q_{Lo} * V^{nq}$ - (11)

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.

$P_L = \alpha P_{Lo} V^{npr} + \beta P_{Lo} V^{npc} + \gamma P_{Lo} V^{npi}$ **-** (12**)**

$Q_L = \alpha Q_{Lo} V^{npr} + \beta Q_{Lo} V^{npc} + \gamma Q_{Lo} V^{npi}$ - (13)

and $\alpha + \beta + \gamma = 1$ -(14)

The values of the real and reactive power components used in present work for industrial, residential and commercial loads are given in Table – 1 [20].

Table – 1: Load types and exponent values

Load Type	**np**	**nq**
Constant	0	0
Industrial	0.18	6
Residential	0.92	4.04
Commercial	1.51	3.04
Mixed	-	-

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.

IV. Harmony Search Algorithm (HSA)

The Harmony search algorithm (HSA) was initially proposed by Geem [22] and applied to solve the optimization problem of water distribution networks in 2000. As a novel population-based meta-heuristic algorithm, during the recent years, it has gained great research success in the areas of mechanical engineering, control, signal processing, etc. HS algorithm was conceptualized using the musical process of searching for a perfect state of harmony. Musical performances seek to find pleasing harmony (a perfect state) as determined by an aesthetic standard, just as the optimization process seeks to find a global solution (a perfect state) as determined by an objective function. The pitch of each musical instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable. The new HS meta-heuristic algorithm was derived based on natural musical performance processes that occur when a musician searches for a better state of harmony, such as during jazz improvisation.The basic steps of this algorithm are as follows:

i) Initialize the optimization problem and algorithm parameters:

The optimization problem is formulated as:

Minimize f(x) subjected to $x_i \in X_i$,   i= 1, 2, . . .,N.

Where

f(x) is the objective function

x is a solution vector composed of decision variables to $x_{i;}$
X_i is the set of values for each decision variable to
x_i , i.e., $L^x{}_i \leq X_i \leq U^{xi}$;
$L^x{}_i$ and U^{xi} are lower and upper bounds for each decision variable, respectively
$L^x{}_i$ and U^{xi} are lower and upper bounds for each decision variable, respectively
N is the number of decision variables.

(ii) Initialize the harmony memory (HM)

Each component of each vector in parental HM, i.e. size of HMS, initialized with a uniformly distributed random number in between upper and lower bounds i.e. $[L^x{}_i, U^{xi}]$,where

$1 \leq i \leq N$

This is done for *i*th component of *j*th solution vector using following equation

$$x^i{}_j = L^x{}_i + \text{rand}(0, 1) \cdot (U^{xi} - L^x{}_i)$$

where

j = 1, 2, 3 . . . , HMS.

rand (0, 1) is a uniformly distributed random number lies between 0 and 1.

iii) Improvise a new harmony from the HM

A new harmony vector

$$x_i' = \{ x_1', x_2', \ldots\ldots\ldots, x_N' \}$$

has been generated based on 3 rules:
(i) memory consideration
(ii) pitch adjustment
(iii)random selection.

Generating a new harmony is called improvisation, the value of first decision variable .For new vector, in memory consideration, is chosen from any value already existing in current HM, i.e., from $\{x_1^1 \ldots\ldots x_1^{HMS}\}$ with probability HMCR. The values of rest of the decision variables $x_1', x_2', \ldots\ldots\ldots x_N'$ are also selected in the same manner. HMCR, which varies between 0 and 1, is rate of selecting one value from previous set of values stored in HM, when (1 − HMCR) is rate of the randomly choosing a fresh value from possible range

$$x_i' \leftarrow \{ x_i^1, x_i^2, x_i^3, \ldots\ldots\ldots\ldots x_i^{HMS} \} \text{ with probability of HMCR}$$

also, $x_i' \leftarrow x_i' \in X_i$

with probability of (1 − HMCR)

E.g. an HMCR=0.70 shows that HS algorithm will choose a decision variable value from already stored values in HM with 70% of probability or from entire possible range with 30% of probability. Each component obtained by this memory consideration is examined to decide whether it should be pitch adjusted or not. This process uses PAR as follows:

Pitch-Adjusting Decision :

$$x_i' = x_i' \pm \text{rand}(0, 1)*bw$$

with probability PAR

Also $x_i' = x_i'$ with probability (1 − PAR)

Where

bw shows an arbitrary distance bandwidth

rand () represents a uniformly distributed random number between 0 and 1.

This step is used to generate a new potential variation in algorithm and it is comparable to mutation in standard EAs.

iv) Update the HM

If new harmony vector

$$x_i' = \{ x_1', x_2', \ldots\ldots\ldots, x_N' \}$$

is better than worst harmony in HM, in terms of the objective function, new harmony is included in HM, and already existing worst harmony is excluded from HM. This is a selection step of algorithm, where objective function value is evaluated in order to determine whether the new variation should be included in HM or not.

v) Check stopping criterion

If maximum NI is reached, the computation is terminated.
If not, step(iii) and step (iv) are repeated.

V. A. Backtracking Search Algorithm (BSA)

The Backtracking search algorithm (BSA) is a population-based iterative EA designed to be a global minimizer. The BSA 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 BSA 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 BSA'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 BSA possesses a memory in which it stores a population from a randomly chosen previous generation for use in generating the search-direction matrix. The BSA has strong strategy for both a global exploration and local exploitation with good feature of avoiding local minima. The BSA five main procedures are outlined below:

(i) Initialization

The BSA initializes the population P as defined in below Eq

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

(ii) Selection – 1

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

$OldP_{ij}=LB_j+rand(\ldots).(UB_j) \quad i\forall N \ \& \ j\forall D$

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 BSA'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.

Mutant = P+F. (oldP-P)

F controls the amplitude of the search direction matrix.

(iv) Crossover

The BSA'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.

(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}

B.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.

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.

Initially objective function (net power loss) for the trial population is calculated using fb sweep method. Then using mutation, crossover and selection processes offsprings are generated. The power loss is calculated for the offsprings, 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 minimizer contains the best DG location and sizes.

VI. Results And Discussions

The optimization techniques are applied on 69 bus IEEE test system. The total active power demand of the 69 bus system is 3.802 MW and the total reactive power demand is 2.695 MVAr. The minimum voltage is 0.9096 p.u., active power loss is 224.9032 kW and reactive power loss is 102.1234 kW before DG placement.

Harmony search algorithm and Backtracking search algorithm are applied on 69 bus system for different load models. Results are tabulated and the obtained graphs are shown in below figures

Table 2: Optimization results for 69 Bus System with HSA

	Ploss (KW)	**Reduction of Power loss in KW**	**Power loss reduction in %**	**V_{min}**	**DG Size**	**DG Locations**
Constant load						
With 1 DG	25.4088	199.49	88.7	0.9724	1.880	61
With 2 DGs	9.2627	215.641	95.88	0.9930	1.790,0.565	61, 17
With 3 DGs	6.3343	218.87	97.32	0.9943	1.776,0.516, 0.400	61, 11,20
Industrial load						
With 1 DG	24.1653	149.49	86.08	0.9731	1.814	61
With 2 DGs	9.041	164.614	94.8	0.9934	1.761,0.543	61, 17
With 3 DGs	5.3240	168.33	96.93	0.9943	1.748,0.390 0.572	61, 20, 10
Residential load						
With 1 DG	24.9885	143.108	85.13	0.9732	1.816	61
With 2 DGs	9.0841	159.012	94.6	0.9935	1.764, 0.544	61, 17
With 3 DGs	5.9667	162.012	96.44	0.99543	1.780,0.571 0.402	61, 11, 21
Commercial load						
With 1 DG	24.5249	138.733	84.98	0.9734	1.811	61
With 2 DGs	9.1556	154.102	94.39	0.9934	1.763, 0.547	61, 18
With 3 DGs	6.0253	157.213	96.13	0.9943	1.760,0.425 0.568	61, 20, 11
Mixed load						
With 1 DG	24.0956	145.979	85.83	0.9732	1.815	61
With 2 DGs	9.0430	161.031	94.68	0.9934	1.763, 0.541	61, 17
With 3 DGs	5.2961	164.778	96.89	0.9943	1.770,0.432 0.505	61, 11, 21

Table 3: Optimization results for 69 Bus System with BSA

	Ploss (KW)	**Power loss reduction of in KW**	**Power loss reduction in %**	**V_{min} (p.u)**	**DG Size in MW**	**DG Locations**
Constant load						
Without DG	224.9032	-	-	0.9096	-	-
With 1 DG	24.0090	200.8942	89.32	0.9730	1.904	61
With 2 DGs	8.7050	216.1982	96.13	0.9943	1.827, 0.5450	61, 17
With 3 DGs	5.4154	219.4878	97.59	0.9948	1.80400.39500. 5540	61, 50, 16
Industrial load						
Without DG	173.6553	-	-	0.92	-	-
With 1 DG	22.9545	150.7008	86.78	0.9740	1.8580	61
With 2 DGs	8.2079	165.4474	95.27	0.9943	1.8, 0.5360	61, 18
With 3 DGs	5.2762	168.3791	96.96	0.9948	1.78100.37700.	61, 49, 19

					5450	
Residential load						
Without DG	168.0963	-	-	0.9219	-	-
With 1 DG	23.8142	144.2821	85.83	0.9742	1.8590	61
With 2 DGs	8.4669	159.6294	94.96	0.9943	1.80300.5380	61, 18
With 3 DGs	5.9762	162.1201	96.44	0.9950	1.7710 0.37, 0.5650	61, 49, 19
Commercial load						
Without DG	163.2575	-	-	0.9236	-	-
With 1 DG	23.5176	139.740	85.59	0.9744	1.8530	61
With 2 DGs	8.7040	154.554	94.67	0.9943	1.80100.5400	61, 18
With 3 DGs	6.0952	157.162	96.27	0.9948	1.78800.41500. 5510	61, 49, 19
Mixed load						
Without DG	170.0743	-	-	0.9211	-	-
With 1 DG	22.0361	148.0382	87.043	0.9741	1.8580	61
With 2 DGs	8.0524	162.022	95.27	0.9943	1.80200.5350	61, 18
With 3 DGs	5.2014	164.873	96.94	0.9950	1.78500.4770 0.5550	61, 49, 18

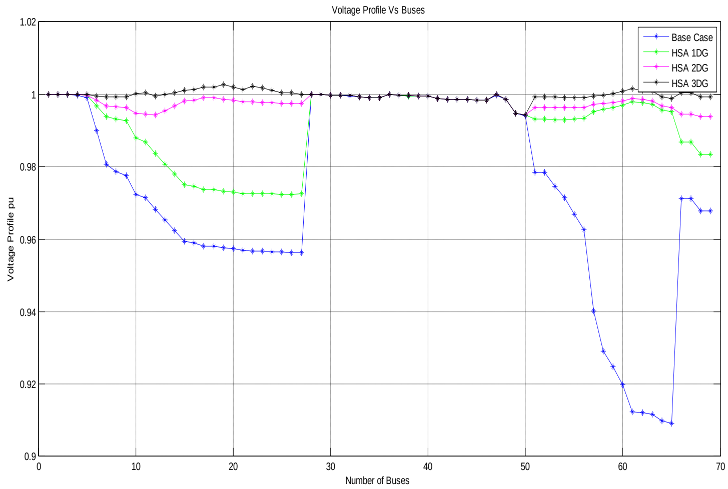

Fig.2: Voltage profile before and after DG placement of 69 bus system for constant load with HAS

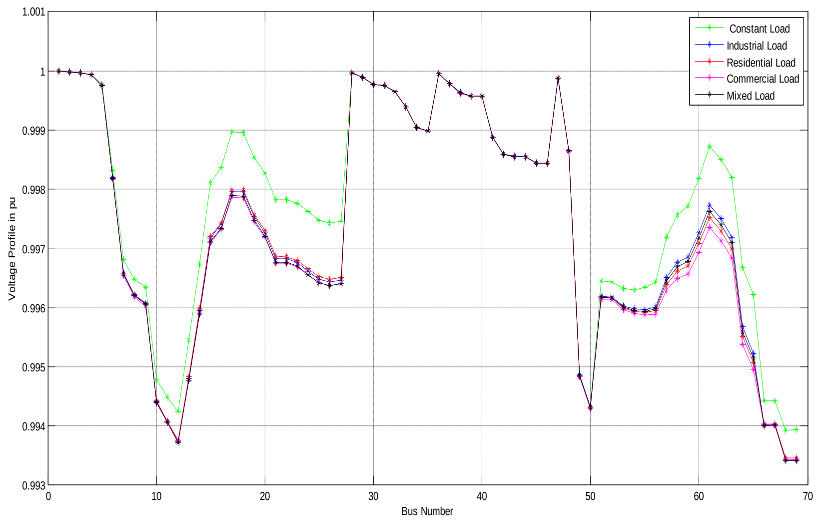

Fig.3: Voltage profile after 2 DGs placement for 69 bus system for different load models with HSA

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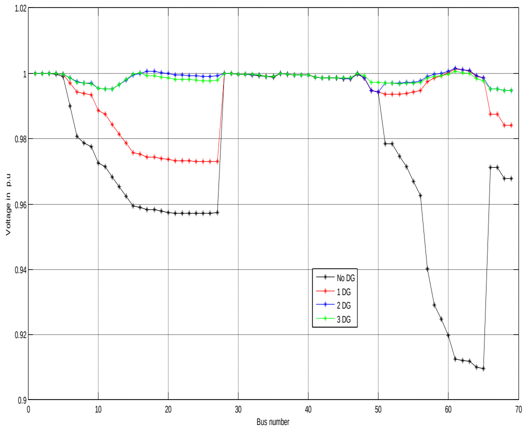

Fig.4: Voltage profile before and after DG placement for 69 bus system for constant load with BSA

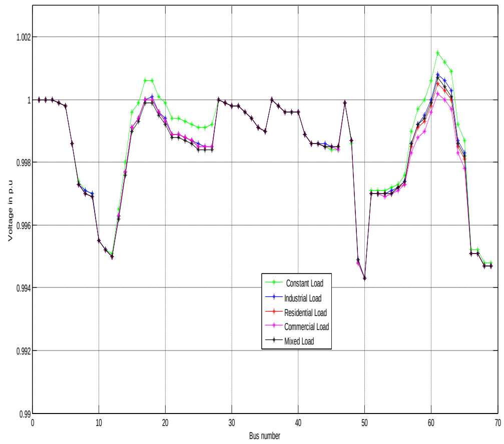

Fig.5: Voltage profile after 2 DGs placement for 69 bus system for different load models with BSA

The DGs are placed optimally using HSA &BSA considering maximum DG size to be 2 MW and voltage limits as 0.95-1.05p.u. The active and reactive generated power by the DGs is kept well within limits. However with HSA, a single DG operating at power factor of 0.85 for constant load model the active power loss is reduced to 25.4088 KW, and the minimum bus voltage shoots up to 0.9724 p.u. Whereas with BSA, a single DG operating at power factor of 0.85 for constant load model the active power loss is reduced to 24.0090 KW, and the minimum bus voltage shoots up to 0.9730 p.u.

The results of HSA & BSA applied on various load models are shown in Tables 2 & 3. The results of BSA are compared with HSA has proved to produce better results. Figures 2 & 4 shows the voltage profile of 69 bus system with and without DG. From Fig.4 we can see that by using BSA, DGs has improved the voltage profile to great extent thus reducing the system losses without exceeding the line limits. However, we can see that the profile is more or less similar for 2 and 3 DGs, hence if cost is a constraint then we could manage with 2 DGs. Figures 3 & 5, shows the voltage at each bus for 69 bus system when two DGs are placed which are operating at 0.85 pf. for different load models. Among the different load models the mixed load model, which is more close to actual system, has been found to produce minimum losses for the given number of DGs while losses are maximum for constant load models. This also tells that if loads are managed according to the bus voltages then greater efficiency is achieved in distribution systems.

VII. Conclusion

In this paper a new evolutionary algorithm, BSA, has been proposed. Mathematical modeling of voltage dependent loads i.e., residential, industrial, commercial, and mixed loads has been presented. The results of proposed method has been compared with Harmony search algorithm and it is seen that Backtracking search algorithm provides better results.BSA method is easy to implement and the results obtained are found to be good, as the optimal locations and size of DGs have improved the voltage profile as can be seen by graphs and the system losses are also reduced.The results highlight the fact that voltage dependent load models have an impact on the power and voltage characteristics of a distribution system. Hence in order to improve DG planning results assessment of different load models is necessary.

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