Loss Minimization by DG Allocation in Radial Distribution Sytems using HS Algorithm-Cost Benefit Analysis

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Abstract- This paper presents a novel method for optimal location and sizing of distributed generation (DG) unit. The objective of this paper is to curtail the total line losses of the radial distribution network, the cost of investment and payback period are calculated for different renewable sources of generation using cost benefit analysis. For setting up of DG unit the Improved Analytical (IA) Expressions is used. The optimal sizing of the sources has also been carried out using Harmony Search Algorithm for better voltage profile and reduced network power loss in the radial distribution system. Harmony search algorithm is concept from natural musical performance processes. In music improvisation, each musician plays within possible pitches to make a harmony vector. If all the pitches create good harmony, the musician saved them in memory and increases good or better harmony for next time. To check the feasibility, the proposed approach is tested on 10, 33 and 69 bus radial systems and the results were compared with other existing techniques.

***Key words* - Distribution system, Distributed generation, Active power loss, Improved Analytical Expression, Harmony Search Algorithm, Cost benefit analysis**

I. INTRODUCTION

The central power plants are thermal, nuclear or hydro powered and their rating lies in the range of several hundred MW to few GW [1]. Central power plants are economically unviable in many areas due to diminishing fossil fuels, increasing fuel costs, and stricter environmental regulations about acid deposition and green house gas emission [2]. Also, generators with renewable sources as wind or solar energy became more economically and technically feasible. This has resulted in the installation of small power plants connected to the distribution side of the network, close to the customers and hence referred to as "embedded" or "distributed" generation (DG) [3]. Installing DGs at the load centers will prevent the new transmission lines extension to energize new substation, DG is capable of providing some or all of the required power without the need for increasing the existing traditional generation capacity or T&D system expansion. DG capital cost is not large due to its moderate electric size and modular behavior as it can be installed incrementally unlike installing new substations and feeders, which require large capital cost to activate the new expanded distribution system [4].

The potential benefits of DGs are

- Reduced/negligible transmission and distribution losses.
- Improved voltage profile in the system and hence the quality of the power is improved.
- Possibility of selling excess power to the Grid and to the neighboring customers.
- Most of the DG energy sources are designed using green energy which is assumed pollution free.

Electrical energy is continuously lost due to resistance in power system networks, and distribution system loss accounts for more compared to transmission system [5]. Moreover, distribution systems are well known for a higher R/X ratio compared to transmission systems and significant voltage drops can result in substantial power and energy losses along distribution feeders. As a result, loss reduction in distribution systems is one of the greatest challenges to many utilities around the world. Reconfiguration and capacitors placement are two major methods for loss reduction in distribution systems. If DGs are placed properly and appropriately sized, they could also be considered as an effective way to reduce losses, improve voltage profiles and increase reliability [6].

II. Types of DG

DG can be classified into four major types based on their terminal characteristics in terms of real and reactive power delivering capability as follows:

- Type 1: DG capable of injecting *P* only.
- Type 2: DG capable of injecting *Q* only.
- Type 3: DG capable of injecting both *P* and *Q*.
- Type 4: DG capable of injecting *P* but consuming *Q*.

Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters, are good examples of Type 1. Type 2 could be synchronous compensators such as gas turbines. DG units that are based on synchronous machine (cogeneration, gas turbine, etc.) fall in Type 3. Type 4 is mainly induction generators that are used in wind farms [7].

DG plays an important role in modern power system to achieve the requirements and satisfaction of the end users while transmitting and distributing the power from one point to another point. The system efficiency decreases due to line losses and variation of voltage level which causes the consumers to suffer from poor power quality, higher cost, variation in voltage and insufficient power [8]. Even if the location is fixed due to some other reasons, improper size would increase the losses in the system beyond the losses for case without DG. Optimal sizing and location depend on the type of DG as well. Hence, in this paper, for setting up optimal location by using Improved Analytical Expressions and the optimal sizing of the sources has also been carried out using Harmony Search Algorithm for better voltage profile and reduced network power loss in the radial distribution system.

III. LOSS REDUCTION TECHNIQUES

Earlier studies have indicated that inappropriate placement and sizing of DG, may lead to increase in the system losses than the losses without DG [9]. In the developing countries, utilities are facing problem of poor voltage profile and high power loss. By optimum placement and sizing of DG units, utilities take advantage of improving voltage profile, reduction in system losses and improvement in the reliability of supply [10]. To find out the optimum place and size of the DG units, multiple methods have been proposed by different authors. Analytical expressions are used to identify the location and size of the DG units [11]. The analytical expression and the methodology are based on the exact loss formula. Reduction in the thermal capacity of the main feeder, voltage profile improvement and better voltage regulation are the consequent results apart from the reliability improvement and power quality [7]. In a distribution network the location and sizing of DG sources found to be more important on the system losses and voltage stability. An efficient approach, to determine the location of DG by loss sensitivity factor and size by simulated annealing method with the objective to minimize losses, has been proposed in [12]. The sensitivity factor is employed to determine the optimal placement and sizing of DG so as to minimize the total power losses by an analytical method without use of jacobian matrix [13]. Genetic algorithm (GA) based system energy minimization and power loss minimization approach for optimal placement and sizing of DG is used for unity power factor system and it has slow convergence [14]. Ant Colony optimization is proposed to find out the placement of DG with an objective of enhancing the system reliability [15]. Reduction of real power losses and enhancement in voltage profile is achieved using the particle swarm optimization (PSO) [16–19]. A novel combined GA and PSO method is presented for optimal placement and sizing of DG in order to improve the voltage stability and minimize network losses [20]. Many algorithms have been proposed by various researchers' to determine the location and size of DGs. Particle swarm optimization (PSO) is a population based meta-heuristic algorithm which works in two steps such as calculating the particle velocity and updating the position. It reduces the computation time and requires little memory. But, PSO easily suffers from partial optimization [21]. Shuffled frog leaping is a population based algorithm which can used for solving many complex nonlinear, multi-modal and non-differentiable problems. But the limitation is that it slows the convergence speed and also causes premature convergence [22]. Genetic algorithm (GA) is a method which is easy to understand and it can be used to solve non-differential, non-dimensional and non-continuous problems. GA applications which are performed in real time are limited due to random solutions and less convergence speed [23]. Bacterial foraging optimization algorithm (BFOA) is applied to solve various optimization problems in power systems due to its ability in searching the promising areas of the solution space but the complexity of BFOA algorithm forces the researchers to find a simple way to speed up the convergence [24]. A technique for DG placement using "2/3 rule" has been presented in [25]. Although the 2/3 rule is simple and easy to apply, this technique may not be effective in distribution with not uniformly distributed loads. Besides, if a DG is capable of delivering real and reactive power, applying the method that was developed for capacitor placement may not work. In [26], an analytical approach has been presented to identify appropriate location to place single DG in radial as well as loop systems to minimize losses. But, in this approach, optimal sizing is not considered. Recently, an analytical approach based on exact loss formula was presented to find the optimal size and location of DG [7]. In this method, the load flow is required to be conducted only twice. The first load-flow calculation is needed to calculate the loss of base case. The second load-flow solution is required to find the minimum total loss after DG placement. The technique requires less computation. However, the Harmony search algorithm can be applied to DG capable of delivering only real power.

IV. PROBLEM FORMULATION

The total real power loss in the systems is given by equation (1), based on exact loss formula [20] as

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \quad (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\delta_i - \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j) \quad (3)$$

$V_i \angle \delta_i$ is the complex voltage at i^{th} bus;

$Z_{ij} = r_{ij} + j\,x_{ij}$ the ij^{th} element of [*Zbus*] impedance matrix

N-Number of buses

P_i and Q_i the Real and Reactive power injections at node '*i*' respectively

P_j and Q_j the Real and Reactive power injections at node 'j' respectively

(A) Improved Analytical Expressions:

Type 1 DG: This DG is capable of injecting real power only. The power factor of DG is $0<PF_{DG}<1$. The optimal size of DG at each bus for minimizing losses can be given by [27].

$$P_{DGi} = \frac{\alpha_{ii}\left(P_{Di} + aQ_{Di}\right) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}} \quad (4)$$

Where

$$a = \pm\tan(\cos^{-1}(PF_{DG}))$$

$$X_i = \sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)$$

$$Y_i = \sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right)$$

(B) Building algorithm for Backward-Forward load flow can be developed as follows:

This method includes two steps: the backward sweep and the forward sweep [28]. In backward sweep currents are computed using KCL from the farthest node from the source node. In forward sweep, the downstream voltage is calculated starting from source node. The input data of this algorithm is given by node-branch oriented data. Basic data required are, active and reactive powers, nomenclature for sending and receiving nodes, and positive sequence impedance model for all branches.

Listed below summarize major steps of the proposed solution algorithm with appropriate equations.

(i) Assume rated voltages at end nodes only for 1st iteration and equals the value computed in the forward sweep in the subsequent iteration

(ii) Start with end node and compute the load current using equation (5). Apply the KCL to determine the current flowing from node m towards node n using equation (5), start from end nodes

$$\bar{I}_L(m) = \left\{\frac{P_L(m) - jQ_L(m)}{\bar{V}^*(m)}\right\} \quad (5)$$

$$\bar{I}(mn) = \bar{I}_L(n) + \sum_{m=\Gamma}\bar{I}_L(m) \quad (6)$$

Where the set Γ consists of all nodes which are located beyond node n

(iii) Compute the node voltage in forward direction from reference node to end nodes using equation (7).

$$\bar{V}(n) = \bar{V}(m) - \bar{I}(mn)Z(mn) \quad (7)$$

(iv) Compare the calculated magnitude of the rated voltage at reference node with specified source voltage If it is converged go to next step otherwise increment iteration number and go to step (ii), (iii)

(v) Calculate the Real and Reactive power losses for all branches and also total real and reactive power losses using equations

$$P_{loss} = \sum_{mn=1}^{nb} I^2(mn) * R(mn) \tag{8}$$

$$Q_{loss} = \sum_{mn=1}^{nb} I^2(mn) * X(mn) \tag{9}$$

Where n_b = Total number of branches in a system

R(mn) = Branch Resistance

X(mn) = Branch Reactance

Based on above equation computation from load flow, buses are arranged in ascending order. The optimum size of the generators to be installed is calculated by using Harmony search algorithm.

V. HARMONY SEARCH ALGORITHM

The harmony search algorithm (HSA) is a new meta-heuristic algorithm. The harmony search algorithm (HSA) is simple in concept, few in parameters and easy in implementation. Harmony search algorithm is concept from natural musical performance processes [29]. In music improvisation, each musician plays within possible pitches to make a harmony vector. If all the pitches create good harmony, the musician saved them in memory and increases good or better harmony for next time. Similarly, in the field of engineering optimization, at first each decision variable value is selected within the possible range and formed a solution vector. If all decision variable values lead to a good solution, each variable that has been experienced is saved in memory and it increases the possibility of good or better solutions for next time. Both processes intend to produce the best or optimum

Step 1: Initialize the optimization problem and algorithm parameters

In this step the optimization problem is specified as follows:

$$\text{Minimize } f(x)$$

$$\text{Subject to } x_i \in X_i, = 1, 2, ..., N \tag{10}$$

Where f(x) is the objective function; x is a candidate solutions consisting of N decision variables (x_i); Xi is the set of possible range of values for each decision variable, that is, $L_{Xi} \leq X_i \leq U_{Xi}$ for continuous decision variables where Lx_i and Ux_i are the lower and upper bounds for each decision variable, respectively and N is the number of decision variables. In addition, HS algorithm parameters that are required to solve the desired optimization problem are specified in this step.

Step 2: Initialize the Harmony Memory (HM)

In this step, the Harmony Memory (HM matrix), is filled with as many randomly generated solution vectors as HMS and sorted by the values of the objective function.

Step 3: Improvise a new harmony from the HM

A New Harmony vector is generated from the HM based on memory considerations, pitch adjustments, and randomization. For instance, the value of the first decision variable for the new vector can be chosen from any value in the specified HM range Values of the other decision variables can be chosen in the same manner. There is a possibility that the new value can be chosen using the HMCR parameter, which varies between 0 and 1 as follows:

$$X_i' = \begin{cases} x_i^i \in \{x_i^1, x_i^2, \ldots\ldots x_i^{HMS}\} & \text{with probablity HMCR} \\ x_i^i \in X_i & \text{with probability (1-HMCR)} \end{cases} \tag{11}$$

The HMCR sets the rate of choosing one value from the historic values stored in the HM and (1-HMCR) sets the rate of randomly choosing one feasible value not limited to those stored in the HM. For example, a HMCR of 0.9 indicates that the HS algorithm will choose the decision variable value from historically stored values in the HM with the 90% probability or from the entire possible range with the 10% probability. Each component of the New Harmony vector is examined to determine whether it should be pitch adjusted. This procedure uses the PAR parameter that sets the rate of adjustment for the pitch chosen from the HM as follows:

Pitch adjusting decision for

$$x_i' = \begin{cases} \text{Yes with probability PAR} \\ \text{No with probability (1-PAR)} \end{cases} \tag{12}$$

A PAR of 0.3 indicates that the algorithm will choose a neighboring value with 30% × HMCR probability.

Step 4: Update the HM

In this stage, if the New Harmony vector is better than the worst harmony vector in the HM in terms of the objective function value, the existing worst harmony is replaced by the New Harmony.

Step 5: Repeat steps 3 and 4 until the termination criterion is satisfied

Termination criterion: The computations are terminated when the termination criterion (maximum number of improvisations) is satisfied. Otherwise, steps 3 (improvising New Harmony from the HM) and 4 (updating the HM) are repeated [30].

VI. NUMERICAL RESULTS

(A) Test Systems

The proposed methodology is tested on three test systems with varying sizes and complexities. The first system used in this paper is a 10 bus test radial distribution system with a total load of 12.368 MW and 4.186 MVAr [31]. The second one is a 33-bus test radial distribution system with a total load of 3.7 MW and 2.3 MVAr [32]. The last one is a 69-bus test radial distribution system with a total load of 3.8 MW and 2.69 MVAr [33]. Based on the proposed methodology, an analytical software tool has been developed in MATLAB environment to run the load flow, calculate power losses, and identify the optimal size and location of single and multiple DG units. Here Type 1 DG is considered.

(B) Assumptions

The assumptions for this paper are as follows:

- The maximum number of DG units is three, with the size each from 250 kW to the total load plus loss.
- The maximum voltage at each bus is 1.0 p.u.

(C) 10 Bus Test System

The Improved Analytical Expressions is used for the placement of the DG. The bus which has high sensitivity is capable of causing voltage instability. The Improved Analytical Expressions of all buses are computed from power flow and then they are arranged in ascending order. The first three buses are considered as an optimum places for DGs to be installed. The bus numbers chosen as per Improved Analytical Expressions are 10, 9 and 8. The DG installation at more than three locations does not result in significant reduction in power loss [34]. The optimum size of the DG is found by using HSA algorithm.

Comparison of IEEE-10 bus system results

Comparison of IEEE-10 bus system results for single DG placement is shown in Table 1 and placement of 3 DG units for IEEE-10 bus system in Table 2.

Table.1 Comparison of IEEE-10 bus system results for single DG placement

Initial loss before placing DG (kW)	786.37 [17]	786.37
Minimized loss after placing DG(kW)	246.76 [17]	225.88
DG size (MW)	4.7 [17]	3.6
DG location(Bus no)	8 [17]	10
% loss reduction	67.75 [17]	71.27

Table 2 Placement of 3 DG units for IEEE-10 bus system

Method	$P_{DG,Tloss}$ (kW)	%Loss Reduction	DG Location	DG size MW)	P_{DGT} (MVA)
IWD [8]	161.14	79.50	9 2 1	3.025 1.532 0.423	4.98
HSA	131.59	83.26	10 9 8	1.385 1.516 1.489	4.39

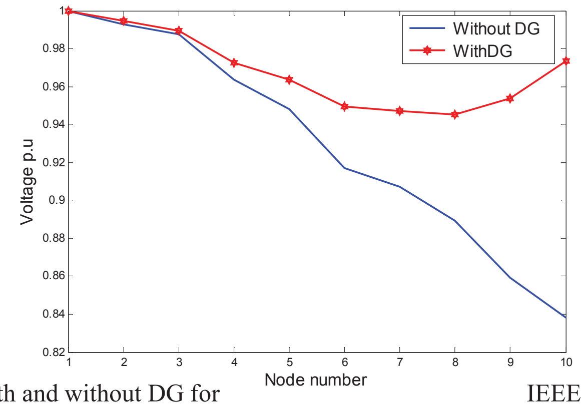

Fig.1 Voltage profile with and without DG for IEEE 10 bus system

From the Table 1 it is observed that the optimal size of DG placement is 4.7 MW by PSO but in the case of HSA the optimal size of DG placement is 3.6 MW. Hence there is a saving of DG size is 1.1 MW. The loss obtained after placement of DG using PSO is 246.76 kW but in case of HSA the loss is 225.88 kW. So there is a saving of 20.88 kW in HSA compared to PSO. The percentage loss reduction after placement of DG is 67.75 by PSO and 71.27 by HSA. Hence it is observed that there is the percentage loss reduction is 3.57 more by HSA compared to PSO.

From the Table 2 it is observed that the optimal size of DG placement is 4.98 MW by IWD but in the case of HSA the optimal size of DG placement is 4.39 MW. Hence there is a saving of DG size is 0.59 MW. The loss obtained after placement of DG using IWD is 161.14 kW but in case of HSA the loss is 131.59 kW. So there is a saving of 29.55 kW in HSA compared to IWD. The percentage loss reduction after placement of DG is 79.50 by IWD and 83.26 by HSA. Hence it is observed that there is the percentage loss reduction is 3.76 more by HSA compared to IWD. This shows the good applicability and effectiveness of the proposed method. Voltage profiles of IEEE-10 bus systems with and without DG are shown in the Fig.1. From the Fig. 1 it is observed that the voltage profile has improved after installing the DG.

(D) 33-Bus Test System

The Improved Analytical Expressions is used for the placement of the DG. The bus which has high sensitivity is capable of causing voltage instability. The Improved Analytical Expressions of all buses are computed from power flow and then they are arranged in ascending order. The first three buses are considered as an optimum places for DGs to be installed. The bus numbers chosen as per Improved Analytical Expressions are 6, 15 and 33. The DG installation at more than three locations does not result in significant reduction in power loss [34]. The optimum size of the DG is found by using HSA algorithm.

Comparison of IEEE-33 bus system results

Comparison of IEEE-33 bus system results for single DG placement is shown in Table 3 and Placement of 3 DG units for IEEE-33 bus system is shown in Table 4.

Table.3 Comparison of IEEE-33 bus system results for single DG placement

Initial loss before placing DG (kW)	211.00 [18]	211.00 [13]	211.20 [7]	211 [35]	211
Minimized loss after placing DG (kW)	115.29 [18]	111.15 [13]	111.24 [7]	111.01 [35]	111
DG size (MW)	3.15 [18]	2.49 [13]	2.49 [7]	2.59 [35]	2.50
DG location (Bus no)	6 [18]	6 [13]	6 [7]	6 [35]	6
% loss reduction	45.36 [18]	47.32 [13]	47.33[7]	47.39 [35]	47.06

From the Table 3 it is observed that the optimal size of DG placement is 2.50 MW by HSA. The loss obtained after placement of DG using HSA is 111 kW. The percentage loss reduction after placement of DG is 47.06 by HSA. The loss obtained and the percentage loss reduction from the HSA method is comparable with other methods.

From the Table 4 it is observed that there is an increase in the percentage loss reduction by placement of multiple DG units compared to single DG placement. This shows the good applicability and effectiveness of the proposed method. Voltage profiles of IEEE-33 bus systems with and without DG are shown in the Fig. 2. From the Fig. 2 it is observed that the voltage profile has improved after installing the DG.

Table 4 Placement of 3 DG units for IEEE-33 bus system

Method	$P_{DG,Tloss}$ (kW)	%Loss Reduction	DG Location	DG size (MW)	P_{DGT} (MVA)
GA [20]	106.30	49.61	11 29 30	1.5000 0.4228 1.0714	2.9942
PSO [20]	105.35	50.06	13 32 8	0.9816 0.8297 1.1768	2.9881
GA/PSO [20]	103.40	50.99	32 16 11	1.2000 0.8630 0.9250	2.9880
BFOA [24]	89.90	57.38	14 18 32	0.6521 0.1984 1.0672	1.9176
IWD [8]	85.78	59.34	9 16 30	0.6003 0.3000 1.0112	1.9115
HSA	79.69	62.23	6 15 33	1.1034 0.6248 0.1844	1.9126

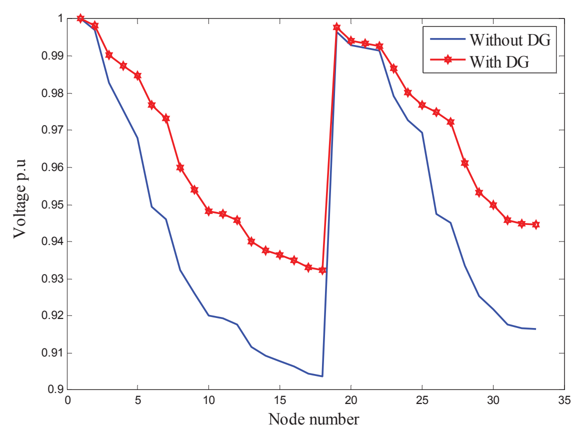

Fig.2 Voltage profile with and without DG for IEEE 33 bus system

(E) 69-Bus system:

The Improved Analytical Expressions is used for the placement of the DG. The bus which has high sensitivity is capable of causing voltage instability. The Improved Analytical Expressions of all buses are computed from power flow and then they are arranged in ascending order. The first three buses are considered as an optimum places for DGs to be installed. The bus numbers chosen as per Improved Analytical Expressions are 63, 18 and 61. The DG installation at more than three locations does not result in significant reduction in power loss [34]. The optimum size of the DG is found by using HSA algorithm.

Comparison of IEEE-69 bus system results

Comparison of IEEE-69 bus system results for single DG placement is shown in Table 3 and Placement of 3 DG units for IEEE-69 bus system is shown in Table 5.

Table 5 Comparison of IEEE-69 bus system results for single DG placement

Initial loss before placing DG (kW)	225.00 [18]	224.88 [13]	219.28 [7]	225.27 [35]	224
Minimized loss after placing DG (kW)	83.37 [18]	83.19 [13]	81.44 [7]	83.49 [35]	83.23
DG size (MW)	1.80 [18]	1.83 [13]	1.81 [7]	1.87 [35]	1.8577
DG location (Bus no)	61[18]	61 [13]	61 [7]	61 [35]	61
% loss reduction	62.95 [18]	63.00 [13]	62.86 [7]	62.94 [35]	62.84

Table 6 Placement of 3 DG units for IEEE-69 bus system

Method	$P_{DG,Tloss}$ (kW)	%Loss Reduction	DG Location	DG size (MW)	P_{DGT} (MVA)
GA [20]	89.00	60.44	21 62 64	0.9297 1.0752 0.9925	2.9974
PSO [20]	83.20	63.02	61 63 17	1.1998 0.7960 0.9925	2.9879
GA/PSO [20]	81.10	63.95	63 61 21	0.8849 1.1960 0.9105	2.9880
BFOA [24]	75.23	66.56	27 65 61	0.2954 0.4460 1.3451	2.0081
IWD [8]	73.55	67.18	17 60 63	0.2999 1.3200 0.4388	2.0587
HSA	71.58	68.04	63 18 61	0.1709 0.4305 1.5175	2.1189

From the Table 5 it is observed that the optimal size of DG placement is 1.85 MW by HSA. The loss obtained after placement of DG using HSA is 83.23. The percentage loss reduction after placement of DG is 62.84 by HSA.

From the Table 6 it is observed that there is an increase in the percentage loss reduction by placement of multiple DG units compared to single DG placement. This shows the good applicability and effectiveness of the proposed method. This shows the good applicability and effectiveness of the proposed method. Voltage profiles of IEEE-69 bus systems with and without DG are shown in the Fig. 3. From the Fig. 3 it is observed that the voltage profile has improved after installing the DG. This reveals the effectiveness of the proposed algorithm.

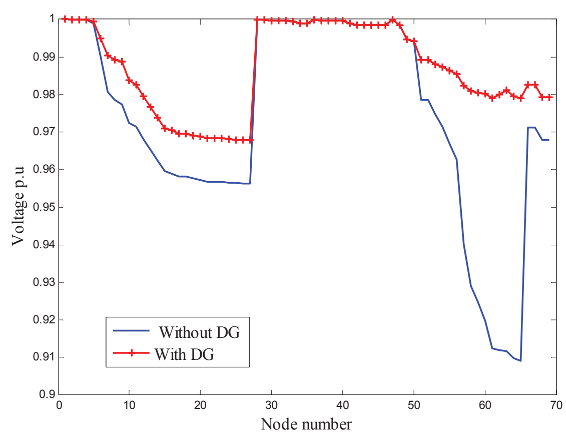

Fig.3 Voltage profile with and without DG for IEEE 69 bus system

VII. COST-BENEFIT ANALYSIS

Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy, electricity access for all, reduced price volatility and the promotion of social and economic development. The reality is that today we are witnessing the beginning of what will one day be the complete transformation of the energy sector by renewable energy technologies [36]. The unit costs of different non conventional sources of energies are shown in fig.4, results obtained from Aggregate Revenue Requirement and Retail supply business for the year FY 2014and 2015, SPDCL of Andhra Pradesh [37-38].

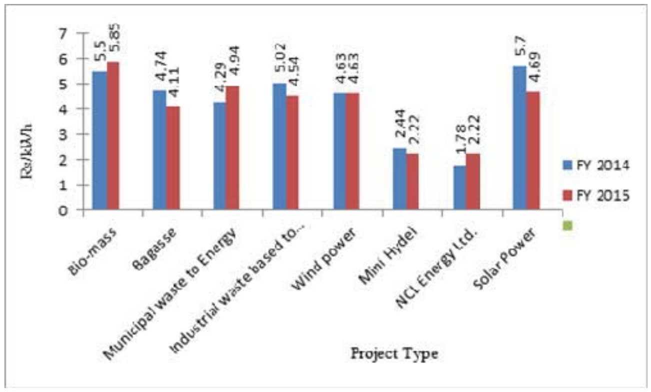

Figure.4 Unit cost (Rs/kWh) of different renewables

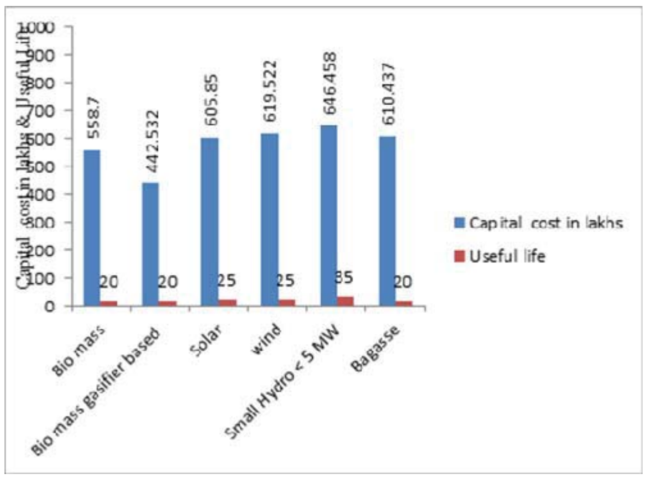

Fig.5 Capital cost and useful life of different renewables

In fig.4 shows the unit cost (Rs/kWh) of different renewables for the FY 2014 and 2015. It is observed that the cost of unit is less in NCL energy Ltd., compared to the other renewables but capital cost is more. In fig.5 shows the capital cost in lakhs and useful life in years of the each project. It is observed that the capital cost of the small hydro per MW is less and also useful life of the project is more compare to other projects.

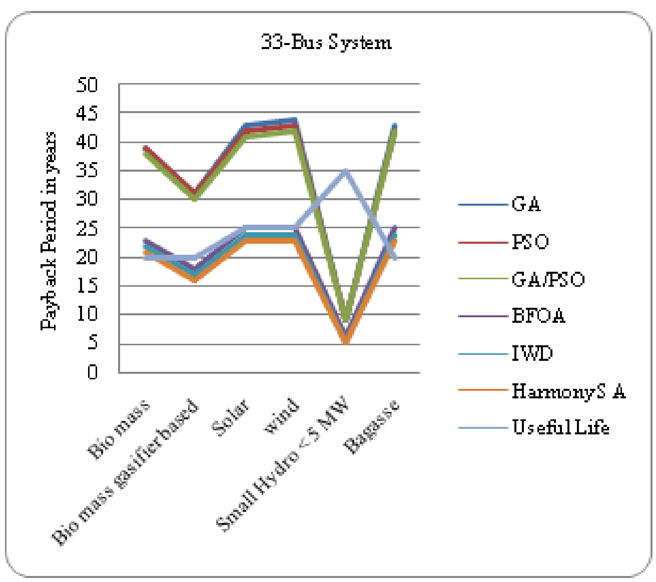

Fig. 6 Payback periods of different renewables sources for placement of 3 DG units for IEEE-33 bus system

$$\text{Pay back period} = \frac{\text{Cost of Renewable Energy}}{\text{Money Saved per Year}} \tag{13}$$

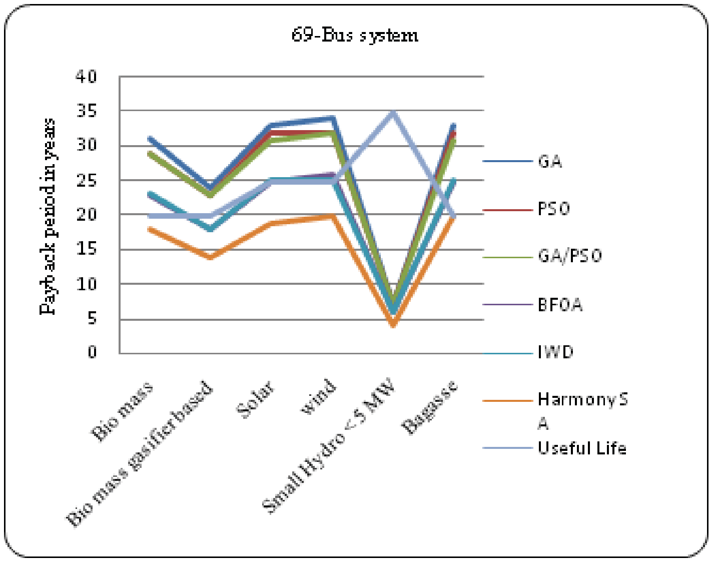

Fig. 7 Payback periods of different renewables sources for placement of 3 DG units for IEEE-69 bus system

Fig 6 and 7 shows the payback periods are calculated for different renewables sources for placement of 3 DG units for IEEE-33 and 69 bus system. Hence it is observed that the payback period is less for Harmony search algorithm compared to other methods.

VIII. CONCLUSION

This paper presents the allocation of DG using HSA method to minimize the losses and to improve the voltage profile. The Improved Analytical Expressions is used for DG placement and HSA method is used for sizing of DG. The feasibility of the method is demonstrated using three test systems comprising of IEEE 10 bus, IEEE-33 bus and IEEE-69 bus. The HSA method is faster and easy to implement for given accuracy. It is shown that the method compares favourably against the several other methods and it is appropriate for the distribution systems. From the obtained results it can be concluded that the proposed method is highly suitable for determining the optimal placement and sizing of the DG units in distribution networks. The cost of investment and payback period are calculated for different sources of generation. It is observed that out of all renewables sources only mini hydro is feasible for less than 5 MW DG. Useful life of mini hydro is high and payback period is less. If the total DG size is less than the 1 MW, biomass, biomass with gasifier, solar, Bagasse and wind preferred.

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