A SIMPLE AND EFFICIENT COMBINED TECHNIQUE FOR OPTIMAL PLACING AND SIZING OF MULTIPLE DG UNITS IN RADIAL DISTRIBUTION SYSTEM

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Abstract: *As the use of Distributed Generation (DG) units increase in distribution networks, optimal placing and sizing of DGs have become important, to reduce the losses and improve the voltage profile. Moreover, higher loss reduction and better voltage profile are also obtained, when DGs supply reactive power along real power. This paper proposes a two phase combined method for optimal placement of single and multiple DG units capable of supplying either real (Type-I) or both real and reactive power (Type-III). To reduce the search space, potential candidate buses are selected for the placement of DGs, using a Fuzzy Logic system in the first phase of the combined method. In the second phase, optimal locations and sizes of DGs are obtained by the Differential Evolution algorithm.*

The proposed method is implemented in IEEE 33-bus and IEEE 69-bus radial distribution systems and the results are compared with F-BSOA, LSF-SA and CLS-MINLP methods using two phase combined method for optimal placing and sizing of DGs in Radial Distribution System (RDS). Test results show that the proposed method is very simple, more effective and has a higher capability in finding optimum solutions.

Key words: *Distributed Generation, Differential Evolution, Fuzzy Expert System, Loss Reduction, Radial Distribution System*

1. Introduction

Distributed Generation (DG) is an electricity generating technology, which includes solar PV (<1MW), small wind turbines (<500kW), stationary fuel cells, natural gas generator sets (<6MW), and diesel generator sets (<6MW).They generate electricity on-site or at the distribution grid level. The rise of distributed generation is one of the most important trends in the energy industry today. As per the Global trends in renewable energy investment 2015 report [1], the cost of wind and solar generation is continuing to fall. Driven by cost reductions, Government incentives and rising interest in replacing fossil fuel sources of energy, the global market for distributed electricity generation is expanding at a rapid pace. According to recent report [2] from Navigant Research, the worldwide installed capacity of distributed generation is expected to grow from 87.3 GW in 2014 to 165.5GW in 2023. Also worldwide revenue from DG is expected to grow from $97 billion in 2014 to more than $182 billion by 2023. This scenario challenges the optimal siting and sizing of DGs in the radial distribution system.

Due to the nature of the high R/X ratio, distribution systems cause a large voltage drop and power losses. If DG is sited close to the customer load, the distribution system losses are significantly reduced with improvement of voltage profile. However, the non-optimal placement of DG increases the system losses and voltage drop than the losses and voltage profile obtained without DG [3, 4]. Hence, the greatest attention should be paid in the siting and sizing of DG units.

In [5, 6], separate analytical methods are implemented to determine the optimum location and size of Type-I single DG for minimizing real power losses in the radial distribution system. A new analytical expression is proposed by Duong Quoc Hung [7] to calculate the optimum size and power factor of single DG. Four types of DGs are considered for analysis and concluded that the power factor of the single DG is more or less same as that of the power factor of the test system. Also, multiple DG (Three) units are optimally placed with optimal size and power factor to minimize the active power losses using the improved analytical method in [8], by Duong Quoc Hung.

A mixed-integer linear programming approach is given in [9] to solve the problem of optimal type, size and allocation of different types of distributed generators in radial distribution systems. The objective function minimizes the annualized investment and operation costs.

In [10-12], GA is used for solving the problem for siting and sizing of Type -I DGs in the radial distribution system to minimize the losses in the system and maximize the economic savings.

A.M. El-Zonkoly [13] proposes a PSO based approach to optimally determine the size and location of multiple DG units in the distribution system with non-unity power factor considering different load models. Fahad S. Abu-Mouti [14] presents a new optimization approach that employs an Artificial Bee Colony algorithm to determine the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss. An Improved Particle Swarm Optimization algorithm) is presented by M.R. AlRashidi [15] for optimal planning of multiple distributed generation sources (DG) with predetermined power factor.

Komail Nekooei [16] proposed an Improved Multi-Objective Harmony Search algorithm to evaluate the optimum sizes and locations of multiple DG units with predetermined power factor. Satish Kansal [17] has presented PSO based technique for the allocation of different types of DGs simultaneously to minimize the real power losses in the primary distribution networks. Sneha Sultana [18] presents a novel Quasi-Oppositional Teaching Learning Based Optimization methodology in order to find the optimal location of multiple DGs with unity power factor to simultaneously optimize power loss, voltage stability index and voltage deviation of the radial distribution network.

Mohammad H. Moradi proposed combined technique based on Genetic Algorithm /Particle Swarm Optimization [19] for optimal placement of DGs and Imperialist Competitive Algorithm and Genetic Algorithm [20] for optimal placement and sizing of multi DGs with optimum power factor and capacitor banks simultaneously for reducing real power loss in radial distribution systems.

In [21, 22 and 23], problem of optimal placement of Type-I and Type-III DGs are formulated and solved in two phases. In the first phase possible potential nodes are selected for placement of DGs using analytical or artificial intelligence technique and in second phase optimal locations are found out with the optimal size of the DGs at optimal power factor from the potential nodes using analytical or numerical or optimization method. More or less 30-35% of the actual number of nodes in the radial distribution system only allowed to the second phase. Resulting in the search space is reduced and better optimal solution is obtained with reasonably less computational time.

In [21], potential nodes are selected based on Loss Sensitivity Factor in phase I and optimal location with optimal size of multiple DGs are evaluated using Simulated Annealing in phase II to minimize the active power loss. Power factor of Type-III DG is taken as constant. Also, in [22], potential nodes are selected based on Combined Loss Sensitivity (CLS) in phase I and optimal location with optimal size of multiple DGs are evaluated using integrating Sequential Quadratic Programming (SQP) and Branch and Bound (BAB) algorithm in phase II for loss minimization. Similarly, Attia El-Fergany [23] proposes a two-stage method of optimal placement of DG. In the first stage, potential locations for the placement of DGs are identified using fuzzy logic. Based on the normalized Loss Sensitivity Factor (LSF) and bus voltage, fuzzy rules are framed. In the second stage, optimal locations are found out from the potential locations. Also, optimal size and power factor are evaluated for optimal locations using Backtrack Search Optimization Algorithm (BSOA).

In this paper, optimal placement of DG problem is formulated and solved in two phases. In the first phase, potential bus locations for installing DGs are identified using Fuzzy Expert System (FES). FES takes active power line losses and bus voltages as inputs and gives potential candidate buses as output. In the second phase, optimal locations of multiple DGs are identified with the optimal sizing of DGs using Differential Evolution (DE) so as to minimize the real power losses. Also, optimal power factor of the Type III multiple DGs is determined individually using DE. Among the four types of DGs shown in Table 1, only Type I and Type III DGs are considered in the present analysis. A single feeder section of RDS to load, Type-I and Type-III DGs are shown in Figure 1.

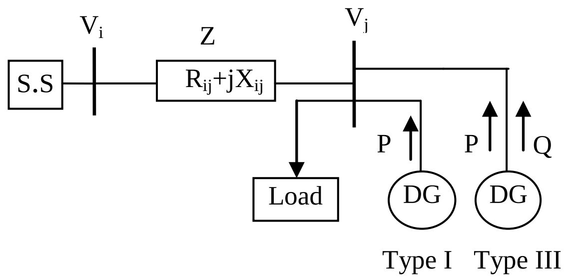

Fig. 1 Single feeder section of RDS with load and Type-I and Type-III DGs

The proposed technique is applied in the 33-bus and 69-bus radial distribution systems. To validate the effective performance of the proposed methodology, results are compared with the results of recently published work [21, 22 and 23].

Table 1
Classification of DGs

S.NO	Type of DG	Real power (P)	Reactive Power (Q)	Examples
1	I	Supplies	Nil	Photo Voltaic and Fuel Cells
2	II	Nil	Supplies	Synchronous Condenser and Capacitors
3	III	Supplies	Supplies	Synchronous Machines
4	IV	Supplies	Consumes	Induction Generators

The organization of the paper is as follows: Section 2 describes the problem formulation, section 3 presents the method of optimal siting and sizing of DGs (Phase-I and Phase-II), section 4 provides numerical results and discussion, and final conclusions are drawn in section 5.

Nomenclature:

RDS	Radial Distribution System
N_B	Number of buses in RDS
N_L	Number of lines in RDS
V_i, V_j	Voltage at *i* th and *j* th bus
G_{ij}, B_{ij}	conductance and susceptance of branch connecting ith bus to jth bus
R_{ij}, X_{ij}	resistance and reactance of branch connecting ith bus to jth bus
α_{ij}, β_{ij}	loss coefficient between bus i and j
δ_i, δ_j	Voltage angle at ith, jth bus
P_i, Q_i	Real and reactive power injected at ith bus
P_L	Total real power losses in the RDS
LR	Loss reduction
P_{DGi}	Real power injected by DG at ith bus
P_{Di}	Real power demand at ith bus
Q_{DGi}	Reactive power injected by DG at ith bus
Q_{Di}	Reactive power demand at ith bus
$V_{i,min}$	Minimum permissible voltage at ith bus
$V_{i,max}$	Maximum permissible voltage at ith bus
S_{ij}	Power flow in feeder section between ith and jth bus(MVA)
S_{ijmax}	Power flow limit in feeder section between ith and jth bus (MVA)
$P_{DGi}^{\min}$	Minimum real power generation by DG at ith bus
$P_{DGi}^{\max}$	Maximum real power generation by DG at ith bus
pf_{DGi}	Power factor of DG at ith bus
$pf_{DGi}^{\min}$	Minimum power factor of DG at ith bus
$pf_{DGi}^{\max}$	Maximum power factor of DG at ith bus
N_{DG}	Number of DGs in RDS

2. Problem formulation

Distribution system losses are reduced by optimal siting and sizing of Type-I and Type-III DGs [8]. Considering 'n' bus distribution system, the loss minimization problem may be formulated using exact loss formula [24] as given below:

$$MinP_L = \sum_{ij=1}^{N_L} G_{ij}[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \quad (1)$$

where, $i, j \in \{1,2.....N_B\}$

Subjected to:

(i) Load balancing constraint:

$$P_{Gi} - P_{Di} - V_i\sum_{j=1}^{N_B} V_jY_{ij}\cos(\delta_i - \delta_j - \theta_j) = 0 \quad (2)$$

$$Q_{Gi} - Q_{Di} - V_i\sum_{j=1}^{N_B} V_jY_{ij}\sin(\delta_i - \delta_j - \theta_j) = 0 \quad (3)$$

where, $i \in \{1,2.....N_B\}$ and $ij \in \{1,2.....N_L\}$

(ii) Voltage Limits:

$$V_{i\min} \le V_i \le V_{i\max} \quad (4)$$

Where, $i \in \{1,2.....N_B\}$

(iii) Line power flow:

$$S_{ij} \le S_{ij\max} \quad (5)$$

Where, $ij \in \{1,2.....N_L\}$

(***iv) DG power generation limits:***

$$P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max} \quad (6)$$

$$Q_{DGi}^{\min} \le Q_{DGi} \le Q_{DGi}^{\max} \quad (7)$$

Where, $Q_{DGi} = P_{DGi}\tan[\cos^{-1}(pf_{DGi})] \quad (8)$

$i \in \{1,2.....N_{DG}\}$

(v) DG power factor limit:

$$pf_{DGi}^{\min} \le pf_{DGi} \le pf_{DGi}^{\max} \quad (9)$$

Where, $i \in \{1,2.....N_{DG}\}$

3. Optimal Siting and Sizing of DGs

Optimal allocation of DG is a non-convex mixed integer nonlinear problem. Due to the inherent nonlinearity and exhaustive search space, these formulations become computationally extensive and sometimes fail to converge to the optimal solution.

To reduce this computational burden, this optimization problem is solved in two-phase as shown in Figure 2 and modeled as follows:

Phase-I: Implementation of fuzzy expert system to identify the potential locations of DGs and

Phase-II: Implementation of DE algorithm for optimal location, capacity and power factor of DGs

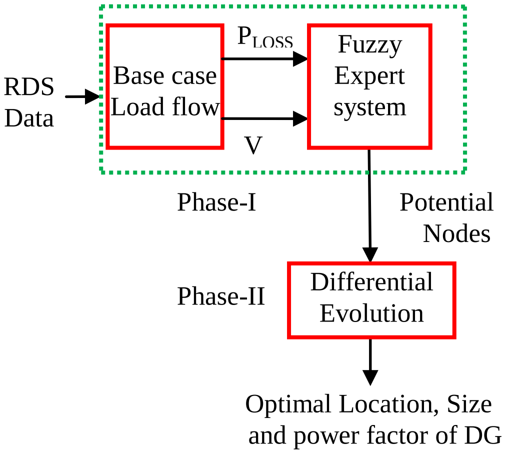

Fig. 2 Framework of the approach

3.1 Phase-I: Implementation of fuzzy expert system to identify the potential locations for DGs

In this stage, an FES approach is used to determine the potential locations for DG placement.

3.1.1 Fuzzy Expert System

Per unit voltages and normalized real power losses of distribution system nodes are modeled by fuzzy membership functions. A Fuzzy Inference System (FIS) containing a set of if-then rules is used to determine the list of prospective best locations for DG units in a distribution system

For the DG placement problem, an approximate reasoning is employed in the following manner: it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of DGs, whereas a low loss section with good voltage is not ideal for DG placement.

3.1.2 Algorithm for identification of potential candidate nodes

Step1: Run the base case power flow without DG to find the real power losses (P_{LOSS}) for all the lines and per unit node voltages (V_{NODE}) for all the nodes.

Step 2: Find the Real Power Loss Index (RPLI) by normalizing the real power losses as follows:

$$RPLI = \frac{P_{Loss} - P_{Loss,\min}}{P_{Loss,\max} - P_{Loss,\min}} \qquad (10)$$

Step 3: Assign input and output variables with ranges and their linguistic variables as shown in Table 2. For convenient choose a triangular membership function for all variables.

Step 4: Create a set of (5 x 5 = 25) fuzzy if-then rules as in Table 3.

Step 5: Calculate the DG Suitability Index (DGSI) for all buses using FES.

Step 6: Arrange DGSI for all buses in descending order.

Step 7: Calculate the normalized node voltage (V_{NORM}) for all the buses as follows:

$$V_{NORM} = \frac{V_{NODE}}{0.98} \qquad (11)$$

Step 8: The first 33% of buses in the bus position vector, whose normalized voltage is less than 1.02, can be chosen as candidate buses for DG placement.

Table 2
Membership functions for Input and Output variables

Input Variables				Output Variable	
Real Power Loss Index (RPLI)		Bus Voltage in p.u		DG Suitability Index(DGSI)	
VL	<0.25	L	<0.92	L	<0.5
L	0-0.5	BN	0.90-0.94		
M	0.25-0.75	N	0.92-0.98	M	0-0.5
H	0.5-1.0	AN	0.96-1.0	H	>0.5
VH	>0.75	H	>0.98		

VL- Very Low; L-Low; M-Medium; H-High
N-Normal; BN-Below Normal; AN-Above Normal

Table 3
Decision matrix for determining suitable locations (Output) for DG placement

AND		**Per Unit Node Voltage(Input 1)**				
		L	BN	N	AN	H
Normalized Real Power Loss Index (Input 2)	VL	L	L	L	L	L
	L	M	M	M	L	L
	M	H	M	M	L	L
	H	H	M	M	L	L
	V H	H	H	M	M	L

Figure 3 shows the order of top ranked potential candidate buses for 33-bus RDS. First 11 number of potential candidate buses (33%) except the buses with normalized voltage more than 1.02 are considered as input nodes for Phase II, which results in reduced search space. The lists of potential candidate nodes of 33-bus RDS and 69-bus RDS obtained from the proposed method are compared with that reported in the literature and they are given in Table 4 and 5 respectively. The potential candidate buses identified by the proposed method almost match with the CLS-MINLP [22]

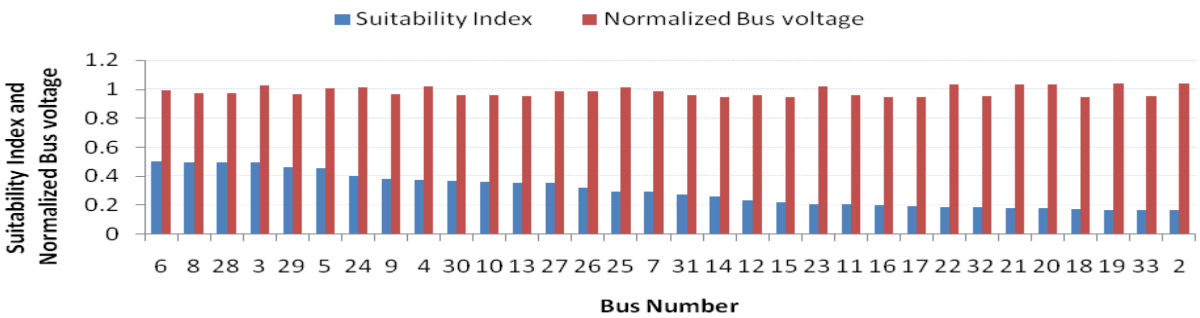

Fig. 3 Order of top ranked potential candidate buses for 33-bus RDS

Table 4
33-bus RDS data and results of base case load flow

Descriptions	Methods			
	LSF-SA[21]	F-BSOA [23]	CLS-MINLP [22]	F-DE
Real power load (kW)	3720	3715	3700	3715
Reactive power load (kVAr)	2300	2300	2300	2300
Real power loss (kW)	210.99	210.84	211.00	210.99
Reactive power loss (kVAr)	143.0	143.12	NA	143.03
Minimum Voltage in p.u @ bus	0.9038@18	0.9040@18	NA	0.9038@18
Order of top ranked potential buses	6, 26, 27, 28, 29, 30, 7, 8, 9, 10 ….	6, 8, 13, 10, 28, 9, 29, 3, 31, 30, 14, 17	5, 6, 8, 9, 10, 13, 24, 28, 29, 30	6, 8, 28, 29, 5, 24, 9, 4, 30, 10, 13
Potential buses passed to next phase	NA	15-25% buses	First 10 buses (30%)	First 11 buses (33%)

Table 5
69-bus RDS data and results of base case load flow run

Descriptions	Methods		
	LSF-SA[21]	CLS-MINLP[22]	F-DE
Real power load(kW)	3800	3800	3802.2
Reactive power load (kVAr)	2690	2690	2694.6
Real power loss (kW)	224.7	225.27	225.0
Reactive power loss (kVAr)	102.13	NA	102.0
Minimum Voltage in p.u @ bus	0.9092@65	NA	0.9092@65
Order of top ranked potential buses	NA	NA	61,57,58,60,59,56,55,54,10,53 ,12,9,11
Potential buses passed to next phase	NA	First 20 buses (30%)	First 22 buses (33%)

3.2 Phase-II: Implementation of DE algorithm for the selection of optimum- location, capacity and power factor of DGs

3.2.1 Differential evolution

Differential Evolution (DE) is introduced to solve the global optimization by Storn and Price [25].It is stochastic and population based search algorithm. The search process starts with the initialization of decision variables of a problem having the value between the minimum and maximum. Then, DE guides the population towards the global optimum by implementing the repeated cycles of process of mutation, crossover and selection.

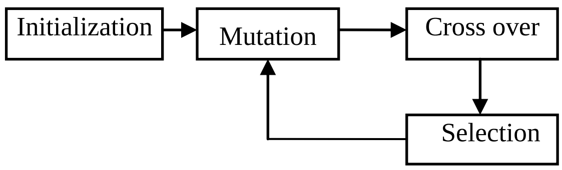

Fig.4 Differential evolution cycle of stages

The main stages of DE are shown in Figure 4 and are explained in detail as follows.

i) Initialization: At $G = 0$, the problem decision variables are initialized with feasible numerical range. Therefore, if the j^{th} variable has its lower and upper bounds as x_j^{Min} and x_j^{Max}, respectively, the j^{th} component of i^{th} population member may be initialized as:

$$x_{i,j}^{0} = x_j^{Min} + rand(0,1)(x_j^{Max} - x_j^{Min}) \qquad (12)$$

Where *rand (0, 1)* is a uniformly distributed random number between 0 and 1; $i = 1,2,...N_P$; $j = 1,2,....D$; N_P is number of population and D is the number of decision variables or control parameters. N_p does not change during the optimization process.

ii) Mutation: In order to explore the search space, new or mutant or donor vector is generated by adding the weighted difference of two vectors to third. At generation G, an associated mutant individual $Y_i^G = \{y_{i,1}^G, y_{i,2}^G, ..., y_{i,D}^G\}$ can be created for each individual $X_i^G = \{x_{i,1}^G, x_{i,2}^G, ..., x_{i,D}^G\}$ using one of the mutation strategies. Among the variety of mutation strategies, the most basic one DE/rand/1 is used to produce mutant or donor vector as

$$y_{i,j}^G = x_{r1,j}^G + F(x_{r2,j}^G - x_{r3,j}^G) \qquad (13)$$

Where $r_1, r_2, r_3 \in \{1,2,....N_P\}$ are chosen as different from each other. In Eq (13), F is a real and constant factor $\in [0, 2]$ which has an effect on the difference vector $(x_{r2}^G - x_{r3}^G)$, G is the generation number.

iii) Crossover: To increase the diversity of the population, successful solutions from the previous generation is mixed with current donors. By applying binomial crossover operator on X_i^G and Y_i^G the offspring individual $Z_i^G = \{z_{i,1}^G, z_{i,2}^G, ...z_{i,D}^G\}$ is generated. The genes of Z_i^G are inherited from X_i^G or Y_i^G and is determined by a parameter called crossover probability CR ϵ [0, 1], as follows:

$$z_{i,1}^G = \begin{cases} y_{i,j}^G, if rand \le CR or j = j_{rand} \\ x_{i,j}^G, else \end{cases} \qquad (14)$$

Where *rand* is a uniformly distributed random number in the range [0, 1], and j_{rand} is a uniformly distributed random number in the range [1, N_P]. $z_{i,1}^G$ represents the child that will compete the parent $x_{i,j}^G$.

iv) Selection: DE actually involves the survival of the fittest principle in its selection process. The selection process can be expressed as,

$$X_i^{G+1} = \begin{cases} z_i^G, iff\ (Z_i^G) \le f(X_i^G) \\ X_i^G else \end{cases} \qquad (15)$$

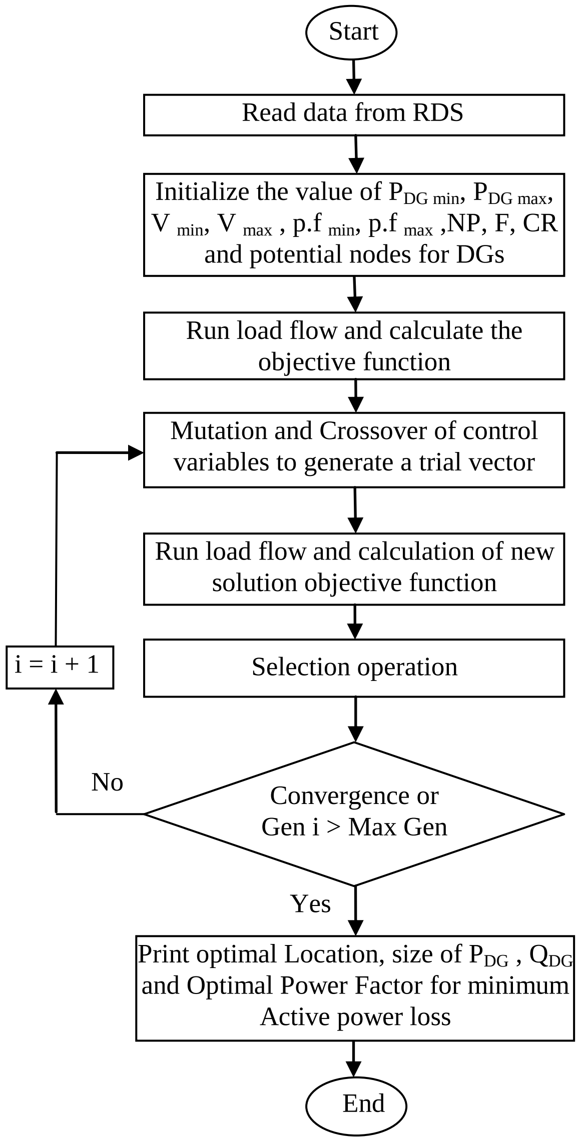

Fig.5 Flow chart of the DE algorithm for optimal siting and sizing of DGs (Phase-II)

Finally, in the next generation, child replaces its parent,if it yields a better value of the fitness function; otherwise,the parent is retained in the population.

The step wise implementation of a DE algorithm to the problem is as follows:

Step 1: Read the data from the network: Line number, Bus number, R, X, P_D and Q_D

Step 2: Initialize the value of P_{DGmin}, P_{DGmax}, V_{min}, V_{max} , $p.f_{min}$, $p.f_{max}$,NP, F, CR and potential locations of DGs

Step3: Randomly generate an initial population comprising the parameters within the parameter space.

Step 4: Run the load flow. Obtain total active power loss and Voltage magnitude.

Step 5: Compute the objective function of each vector of the population using equation (1)
Step 6: Update the generation count.
Step 7: Perform mutation, crossover, selection and evaluation of the objective function.
Step 8: If the generation count is less than the preset maximum number of generations, go to step 6, otherwise continue the next step.
Step 7: Print the optimal location, capacity and optimal power factor of DGs corresponds to the minimum real power loss. Flow chart of the DE algorithm for optimal siting and sizing of DGs (Phase-II) is shown in Fig.5

4. Numerical results and Discussion

The proposed DE algorithm is explained in section 3, and implemented in MATLAB version R2009b environment on an Intel core™i3 PC with 2.66-GHz speed and 2 GB RAM. Initially, several runs are done with DE parameters such as differentiation constant F,crossover constant CR, size of population N_P and maximum number of generations G_{Max} which is used here as a stopping criteria. The parameters of DE algorithm used for solving the problems are furnished in Table 6.

Table 6
DE parameters

Population size(N_P)	**Mutation (F)**	**Crossover (CR)**	**Maximum Generation (G_{Max})**
20	1.5	0.8	500

The effectiveness of the proposed methodology for optimal siting and sizing of DGs has been tested in two different radial distribution systems consisting of 33 and 69 buses. Case studies are carried out for the above systems and are as follows:

4.1 33-bus Radial Distribution System

First, the proposed approach is implemented by the placement of Type I and Type III single and multiple DGs in the 33-bus RDS [26]. The real and reactive power loads of 33-bus RDS with the active and reactive power losses at base case condition are given in Table 4.

The simulation results of the placement of Type I and Type III single and multiple DGs with the 33-bus is presented in Table 7. From Table 7, it is clear that the optimal location for Type I and Type III single DG is identified as bus number {6} for minimum losses. However, it will not identify the optimal location, when two and three number of Type I and Type III DGs are considered. The new sets of optimal locations {13, 30} and {13, 24, 30} are identified for minimum losses.

Placement of two numbers of Type I DGs at optimal locations depicts minimum losses with lower DG capacity than the placement of Type I single DG. In the meanwhile, the placement of 3 numbers of Type I DGs at optimal locations offers very low losses with higher DG capacity than the placement of single and double numbers of Type I DGs.

Similarly, Placement of two numbers of Type III DGs at optimal locations gives minimum losses with lower size of DG than the placement of Type III single DG. Whereas the, placement of 3 numbers of Type III DGs at optimal locations provides very low losses with higher size of total DG than the placement of single and double numbers of Type III DGs. The optimal power factor of the DG installed at a location {30} is very low compared to other DGs connected at locations {12} and {24}. The comparison results of the proposed method with the results obtained from other methods are given in Table 8.

Table 7
Performance analysis of 33-bus RDS connected with the Type I and Type III DG units

	Type I DGs						Type III DGs					
No. of DGs	1	2		3			1	2		3		
Power loss (kW)	111.02	87.17		72.81			67.87	28.50		12.44		
Optimal location	6	13	30	13	24	30	6	13	30	13	24	30
Optimal DG size (MW)	2.590	0.839	1.16	0.78	1.121	1.055	2.551	0.84	1.13	0.75	1.09	1.09
Optimal DG size (MVAr)	-	-	-	-	-	-	1.754	0.39	1.06	0.45	0.56	0.88
Power Factor	1						0.824	0.90	0.73	0.85	0.889	0.776
Total DG (MVA)	2.590	2.001		2.96			3.096	2.489		3.517		

4.1.1 Comparison of results from 33-bus RDS connected with the Type I DG units

The placement of the single and multiple number of Type I DG using proposed method yields very high loss reduction in the slightly higher size of total DG compared to other methods, F-BSOA and LSF-SA. Because, the potential candidate nodes selected by F-BSOA and LSF-SA methods in Phase-I are not same as that of the proposed method. Hence, optimal locations obtained from Phase-II using the above mentioned methods are different from the proposed method. At the same time, compared to CLS-MINLP method, placement of single and multiple Type I DGs using the proposed method gives same loss reduction in the same size of total DG for the same locations{13,24,30}.

Because, same potential candidate nodes are selected in Phase-I by the proposed method and CLS-MINLP method.

4.1.2 Comparison of results from 33-bus RDS connected with the Type III DG units

From the Table 8, it is observed that, compared to CLS-MINLP method, the proposed method gives same loss reduction for the same location and power factor with slightly less size of DG during the placement of single DG. However, the proposed method yields a maximum loss reduction in higher size of DG than that of the F - BSOA method. In case of two and three DGs, maximum loss reduction in higher size of DG is obtained by the proposed method in comparison with other methods. As the proposed optimal power factor for the DG located at bus {30} is low, and the reactive power injected by the DG is high, the total capacity of the DG gets higher than other methods.

Voltage profile of the 33-bus RDS connected with 3 numbers of Type I DG units is shown in Figure 6. Because of the optimal locations {13, 24, 30}, the voltage profile better than the methods F-BSOA and LSF-SA. Similarly, Figure 7 shows the voltage profile of 33-bus RDS connected with the Type III DG units. Compared to F-BSOA and LSF-SA methods, better or flat voltage profile is obtained by the proposed method. Because, the voltage profile obtained from F-BSOA and LSF-SA methods are not constant, due to non-optimum locations. Moreover, in the LSF-SA method, power factor of DGs is given as fixed (0.866).

Table 8

Comparison of results from 33-bus RDS connected with the Type I and Type III DG units

No. of DGs	Methods	Type I DGs				Type III DGs				
		Optimal		Total Size of DGs (MVA)	LR (%)	Optimal			Total Size of DGs (MVA)	LR (%)
		Bus No.	Size of DGs (MW)			Bus No.	Size of DGs (MW)	Power Factor		
1 DG	F-BSOA [22]	8	1.85	2.46	43.98	8	1.85	0.82	2.256	60.73
	CLS-MINLP[21]	6	2.59	2.59	47.39	6	2.546	0.82	3.105	67.84
	F-DE	6	2.59	2.59	47.38	6	2.552	0.824	3.097	67.83
2 DGs	F-BSOA [22]	13	0.73	2.08	58.22	13	0.78	0.89	2.347	84.83
		29	1.35			29	1.03	0.70		
	CLS-MINLP[21]	13	0.85	2.00	58.69	13	0.819	0.88	2.47	86.10
		30	1.15			30	1.55	0.80		
	F-DE	13	0.839	2.01	58.69	13	0.843	0.901	2.489	86.49
		30	1.162			30	1.138	0.731		
3 DGs	F-BSOA[22]	13	0.632			13	0.698	0.86		
		28	0.487	1.669	57.76	29	0.402	0.71	2.317	85.93
		31	0.550			31	0.658	0.70		
	LSF-SA[20]	6	1.112			6	1.197	0.86[#]		
		18	0.487	2.46	61.11	18	0.477		2.996	87.33
		30	0.867			30	0.92			
	CLS-MINLP[21]	13	0.80			13	0.766	0.88		
		24	1.09	2.94	65.50	24	1.044	0.87	3.481	93.96
		30	1.08			30	1.146	0.80		
	F-DE	13	0.784			13	0.751	0.857	3.517	94.10
		24	1.121	2.96	65.49	24	1.095	0.889		
		30	1.055			30	1.095	0.776		

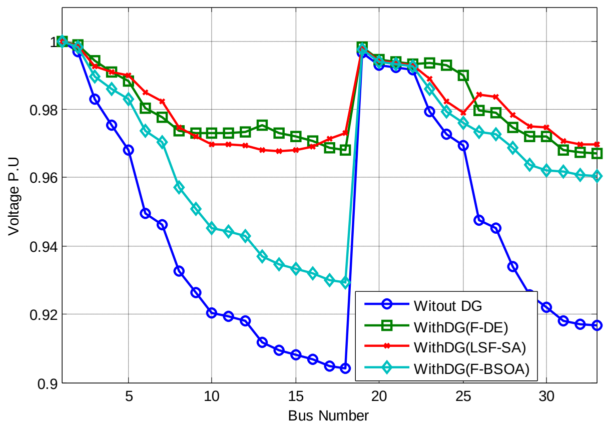

Fig.6 Voltage profile of 33-bus RDS with 3 numbers of Type I DG units

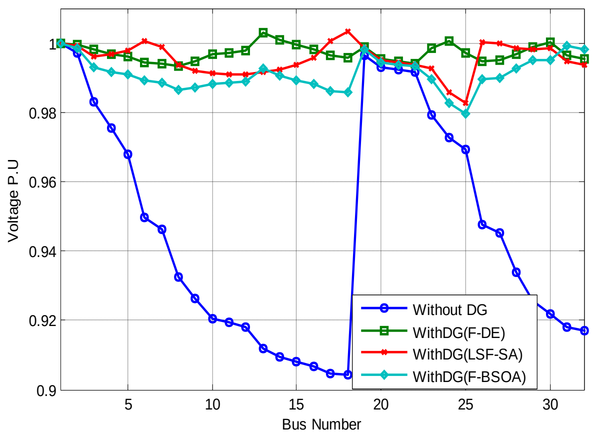

Fig. 7 Voltage profile of 33-bus RDS with 3 numbers of Type III DG units

4.2 69-bus Radial Distribution System

The second test system used to implement the proposed approach is 69-bus RDS. The real and reactive power loads of 69-bus RDS [27] with the active and reactive power losses at base case condition are given in Table 5.

Performance analysis of 69-bus RDS connected with the Type I and Type III DG units is given in Table 9. In the case of 69-bus system, losses are reduced, as the number of DGs connected with the system increases. The total size of the DG also increases with the reduction of losses.

4.2.1 Comparison of results from 69-bus RDS connected with the Type I DG units

It is observed from the comparison of results presented in Table 10, the proposed method gives a minimum loss reduction with same size of DGs than any other methods with the placement of single and double DGs at optimal locations. However, the maximum loss reduction is achieved by the proposed method with the placement of three DG units with higher size than LSF-SA method. But, compared to CLP-MINLP method, higher loss reduction is obtained with the slightly lower size of DG for the same locations {11, 17, and 61}.

4.2.2 Comparison of results from 69-bus RDS connected with the Type III DG units

It is observed from the comparison of results presented in Table 10, same loss reduction with same size of DG, location and power factor are achieved in the case of single and two DG units by proposing method when compared to CLS-MINLP method. In case of 3 DGs, loss reduction with the size of total DG given by the proposed method for the optimal locations {11,17and 61} is higher than the results obtained by LSF-SA method for the optimal locations {18, 60 and 65}. However, compared to CLS-MINLP method, same loss reduction is achieved by the proposed method for the same optimal locations {11, 17 and 61} and size of total DG (3.123MVA).

Table 9
Performance analysis of 69-bus RDS connected with the Type I and Type III DG units

	Type I DGs						Type III DGs					
No. of DGs	1	2		3			1	2		3		
Power loss in kW	83.22	71.68		69.48			23.17	7.20		4.27		
Optimal location (Bus No.)	61	17	61	11	17	61	61	17	61	11	17	61
Optimal DG size in MW	1.873	0.53	1.781	0.573	0.35	1.68	1.82	0.51	1.73	0.49	0.37	1.67
Power Factor	1						0.81	0.82	0.81	0.80	0.83	0.81
Total DG in MVA	1.873	2.318		2.613			2.243	2.762		3.123		

Table 10
Comparison of results for 69-bus RDS after placement of Type I and Type III DGs

No. of DGs	Methods	Type I DGs				Type III DGs				
		Optimal		Total Size of DGs (MVA)	LR (%)	Optimal			Total Size of DGs (MVA)	LR (%)
		Bus No.	Size of DGs (MW)			Bus No.	Size of DGs (MW)	Power Factor		
1 DG	CLS-MINLP [21]	61	1.87	1.87	62.94	61	1.828	0.815	2.244	89.65
	F-DE	61	1.873	1.873	63.01	61	1.828	0.815	2.243	89.70
2 DGs	CLS-MINLP[21]	61 17	1.78 0.53	2.31	68.07	61 17	1.735 0.522	0.824 0.814	2.765	96.80
	F-DE	61 17	1.781 0.536	2.318	68.14	61 17	1.735 0.522	0.814 0.818	2.762	96.80
3 DGs	LSF-SA[20]	18 60 65	0.420 1.331 0.429	2.181	65.68	18 60 65	0.549 1.195 0.312	0.86#	2.722	92.79
	CLS-MINLP[21]	61 17 11	1.72 0.38 0.53	2.63	69.07	61 17 11	1.674 0.379 0.494	0.81 0.82 0.81	3.123	98.10
	F-DE	61 17 11	1.687 0.354 0.573	2.613	69.12	61 17 11	1.677 0.384 0.488	0.814 0.835 0.808	3.123	98.10

Given power factor

The voltage profiles of the 69-bus RDS connected with Type I DGs and Type III DGs are shown in Figures 8 and 9 respectively. Better and flat voltage profile is obtained by the proposed method than LSF-SA due to optimal power factor and optimum locations of DG units. Because, in the LSF-SA method, power factor of DGs are taken as constant (0.866)

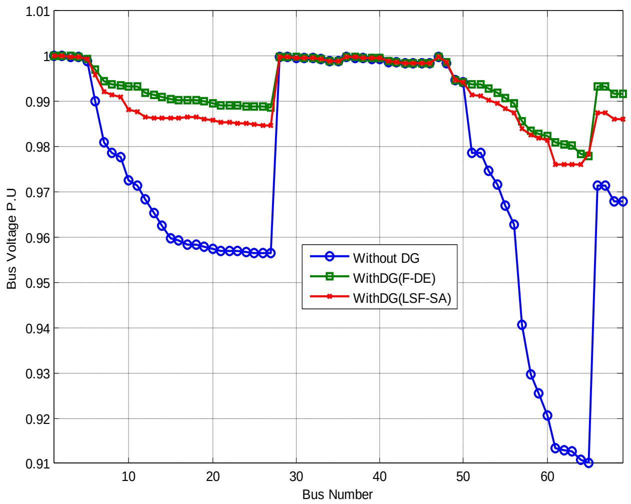

Fig.8. Voltage profile of the 69-bus RDS connected with Type I DG

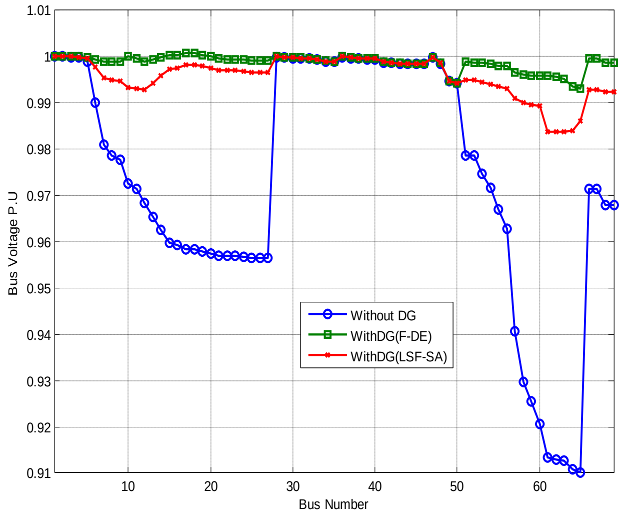

Fig.9 Voltage profile of the 69-bus RDS connected with Type III DG units

Figure 10 shows the effectiveness of the proposed method to find the minimum losses in the RDS than other methods.

4.4 Discussion

This section presents the discussion of the performance of the proposed method in terms of active power loss and voltage profile when compared to F-BSOA, LSF-SA, and CLS-MINLP methods using combined techniques.

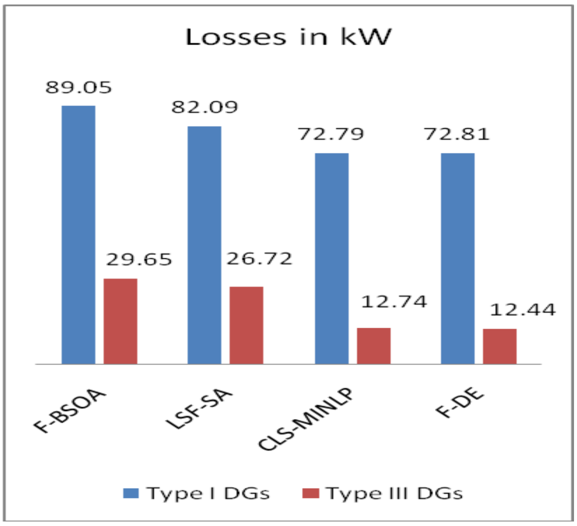

Fig.10 Comparison of losses in the 33bus-RDS with optimal placement of Type I and Type III DGs

In the F-BSOA method, after calculating loss sensitivity factor from the results of base case load flow, the potential candidates are selected in the phase-I using FL system. But, in the proposed method, directly from the results of base case load flow, FL system is used to select the potential candidates in the phase-I.

4.4.1 Objective function value

The proposed method provides maximum loss reduction with the placement of single/multiple number of Type-III DG units and maximum or equal loss reduction with placement of single/multiple Type-I DG units in 33-bus RDS (Table-7), when compared to all other methods. The proposed method gives maximum loss reduction with the placement of single/multiple number of Type-I DG units and maximum or equal loss reduction with the placement of single/multiple Type-III DG units in 69-bus RDS (Table-9), when compared to all other methods.

4.4.2 Voltage profile

After the placement of Type-I and Type-III DG units with both RDS, the proposed method shows better improvement in the voltage profile than other methods, particularly for the F-BSOA and LSF-SA methods. (Figs. 6-9)

5. Conclusion

In the present work a combined novel technique comprising two phases is proposed for optimal placing and sizing of single and multiple DGs supplying real and/or reactive power in the distribution system. In the first phase of this technique, potential candidate buses are selected very easily and accurately to locate the DGs using FL system, resulting in the search space and computational time is reduced. In the second phase, from the potential candidate buses, optimal locations of DGs with optimal sizes and optimal power factors are determined using the DE algorithm. Developed technique is implemented in IEEE 33-bus and 69-bus RDS to minimize the losses and to improve the voltage profile. The results of the proposed method are compared with F-BSOA, LSF-SA and CLS-MINLP methods using the combined techniques for the placement DGs. Comparative studies are carried out in terms of real power loss, voltage profile. Compared to F-BSOA and LSF-SA methods, proposed method depicts better results in terms of real power loss and voltage profile. At the same time, compared to CLS-MINLP method, proposed method gives more or less same or better results in terms of both real power loss and voltage profile.

References:

1. "*Global Trends in Renewable Energy Investment 2015*", by Frankfurt School-UNEP Collaborating Centre and Bloomberg New Energy Finance .http://www.fs-unep-centre.org

2. "*Global Distributed Generation Deployment Forecast-2014-2023*", by Navigant Research, December 5, 2014. www.navigant research.com

3. W. El-Khattam, M.M.A. Salama.: *Distributed generation technologies, definitions and benefits*. In: Electric Power Systems Research 71 (2004) 119–128

4. Borges Carmen LT, Falca~o Djalma M.: *Optimal distributed generation allocation for reliability, losses, and voltage improvement*. In: Electrical Power and Energy System -2006; 28:213–20.

5. Acharya Naresh, Mahat Pukar, Mithulananthan N.: *An analytical approach for DG allocation in primary distribution network.* In: Electrical Power and Energy System- 2006; 28:669–78.

6. Tuba Gözel, M. Hakan Hocaoglu.: *An analytical method for the sizing and siting of distributed generators in radial systems.* In: Electric Power Systems Research 79 (2009) 912–918

7. Duong Quoc Hung, Nadarajah Mithulananthan.: *Analytical Expressions for DG Allocation in Primary Distribution Networks.* In: IEEE Transactions on Energy Conversion, Vol. 25, No. 3, September 2010.

8. Duong Quoc Hung, Nadarajah Mithulananthan.: *Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction.* In: IEEE Transactions on Industrial Electronics, Vol. 60, No. 4, April 2013

9. Augusto C. Rueda-Medina, John F. Franco.: *A mixed-*

integer linear programming approach for optimal type, size and allocation of distributed generation in radial distribution systems. In: Electric Power Systems Research 97 (2013) 133– 143

10. Gianni Celli, Emilio Ghiani, Susanna Mocci , Fabrizio Pilo.: *A Multi-objective Evolutionary Algorithm for the Sizing and Siting of Distributed Generation*. In: IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005.

11. T. N. Shukla, S. P. Singh, V. Shrinivasarao, and K. B. Naik.: *Optimal sizing of distributed generation placed on radial distribution systems.* In: *Electric Power Components and Systems*, vol. 38, no. 3, pp. 260–274, Jan. 2010

12.Seyyed Mehdi Hosseini, Mohammad Vatankhah.: *Determination of optimum size and location of Distributed Generators for loss reduction using GA*. In: Journal of Electrical Engineering: Volume 13 / 2013 - Edition: 1

13. A.M. El-Zonkoly.: *Optimal placement of multi-distributed generation units including different load models using particle swarm optimization.* In: Swarm and Evolutionary Computation 1 (2011) 50–59.

14. F. S. Abu-Mouti, M. E. El-Hawary.: *Optimal Distributed Generation Allocation and Sizing in Distribution Systems via Artificial Bee Colony Algorithm.* In: *IEEE Transactions on Power Delivery*, vol. 26, 2011.

15. M. R. AlRashidi and M. F. AlHajri.: *Optimal planning of multiple distributed generation sources in distribution networks: A new approach*. In: *Energy Conversion and Management* - vol. 52, no. 11, pp. 3301–3308, Oct. 2011.

16. Komail Nekooei, Malihe M. Farsangi, Hossein Nezamabadi-Pour, and Kwang Y. Lee.: *An Improved Multi-Objective Harmony Search for Optimal Placement of DGs in Distribution Systems.* In: IEEE Transactions on Smart Grid, Vol. 4, No. 1, March 2013

17. Satish Kansal , Vishal Kumar, Barjeev Tyagi .: *Optimal placement of different type of DG sources in distribution networks.* In: International Journal of Electrical Power and Energy Systems -53 (2013) 752–760

18. Sneha Sultana , Provas Kumar Roy.: *Multi-objective quasi-oppositional teaching learning based optimization for optimal location of distributed generator in radial distribution systems.* In: International Journal of Electrical Power and Energy Systems 63 (2014) 534–545.

19. Moradi MH, Abedini M.: *A combination of genetic and particle swam optimization for optimal DG location and sizing in distribution system. In:* International Journal of Electrical Power and Energy Systems -34 (2012) 66–74.

20. Mohammad H. Moradi.: *An efficient hybrid method for solving the optimal sitting and sizing problem of DG and shunt capacitor banks simultaneously based on imperialist competitive algorithm and genetic algorithm.* In: International Journal of Electrical Power and Energy Systems -54 (2014) 101–111

21. Satish Kumar Injeti , N. Prema Kumar.: *A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems.* In: International Journal of Electrical Power and Energy Systems- 45 (2013) 142–151.

22. Sandeep Kaur , Ganesh Kumbhar, Jaydev Sharma .: *A MINLP technique for optimal placement of multiple DG units in distribution systems.* In: International Journal of Electrical Power and Energy Systems -63 (2014) 609–617.

23. Attia El-Fergany .: *Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm.* In: International Journal of Electrical Power and Energy Systems- 64 (2015) 1197–1205.

24. Elgerd IO.: *Electric energy system theory – an introduction.* In: McGraw-Hill- 1971

25. R. Storn, K. Price.: *Differential evolution—A simple and efficient heuristic for global optimization over continuous space.* In: Journal of Global Optimization, vol. 11, pp. 341–359, 1997.

26. Baran ME, Wu FF.: *Optimal capacitor placement on radial distribution systems*. In: IEEE Transactions on Power Delivery 1989; 4(1):725–34.

27. Baran ME, Wu FF.: *Network reconfiguration in distribution systems for loss reduction and load balancing.* In: IEEE Transactions on Power Delivery, Vol. 4, No. 2, April 1989