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Enriched Technique for DG Placement and Sizing by GA Optimization

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Abstract: The demand of efficient and high quality power is escalating in the world of electricity. Power utilities are facing major challenges as the demand of power system is growing exponentially. To meet this demand, the present need is to provide the consumer demand locally by Distributed Generation (DG). However, a large number of DG units in a distribution system may sometimes contribute to high levels of harmonic distortion even though the emission level of the individual DG units comply with the harmonic standards. Hence there arises a need for finding an optimised method for locating the DG with the optimised size as well as to reduce harmonic distortion. In this paper a novel genetic algorithm (GA) based optimization for placing and sizing the DG is proposed. The proposed technique adopts five objectives for finding the optimal location as well as the size of DG unit. The total power loss, total cost, total emission, total voltage profile and total harmonic distortion are the five different objective functions we are considering in this paper. The appropriate location of DG unit is found based on the total power loss, total cost, total emission and voltage profile. Then suitable size is determined based on the harmonic distortion. The proposed technique is implanted in MATLAB/Simulink platform and tested in IEEE 18 bus distorted distribution system and the performance is verified by comparing with the conventional differential evolution (DE) optimization algorithm.

Key words: Distribution Generation (DG) • Total Harmonic Distortion (THD) • Voltage Profile (VP) • Genetic Algorithm (GA) • Multi Objective Optimization • DG Placement • DG Sizing

INTRODUCTION

In the current era electric power has become a fundamental part of the infrastructure of modern society, with most of daily activity is based on the assumption that the desired electric power is readily available for utilization [1]. In the near future, electric supply to houses, offices, schools and factories is taken for granted. The complex power distribution system provides the required electricity to the customers [2]. This highly complex distribution system require suitable design of new effective and reliable devices in deregulated electric power industry for flexible power flow control and also uninterrupted power supply [3].

With the introduction of restructuring concepts to traditional power systems, a great deal of attention has been given to utilization of distributed generations. DG is defined as small generators, typically ranging from 15 to 10000 KW, scattered throughout a power system, to provide the electric power needed by customers [4] [5]. The Distributed Generation (DG) technologies are developed from the distribution systems which include both conventional and non-conventional type of energy sources for generating power, are gaining momentum and play major role in distribution system as an alternative distribution system planning option [6].

Earlier the distribution systems had been designed to convey electrical energy from high voltage transmission networks, whereby the majority of electrical generation plants were connected, to the customers [7]. Electricity generation constraints such as Centralized Power plants deliver the electricity to the end-user via transmission system [8].Distribution system makes a link between the high voltage transmission system and consumers [9]. In distribution system, the voltage levels are low but current levels are high in the compare of transmission system, so the loss, in distribution system is greater than in transmission system [10].

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In recent times, due to the increasing interest on renewable sources such as hydro, wind, solar, geothermal, biomass and ocean energy etc., the number of studies on integration of distributed resources to the grid have rapidly increased [11]. Distributed generation (DG), which consists of distributed resources, can be defined as electric power generation within distribution networks or on the customer site of the network [12].When DG can be installed at customer sites it increases utility. DG technologies include conventional and nonconventional energy technologies such as diesel engine driven generators, wind turbines, fuel cells and micro turbines [13]. Recent technical advances have significantly reduced the cost of DG and could eventually compete with gas turbines [14].These optimization techniques should be employed for deregulation of the power industry, by applying the best allocation of the distributed generations (DGs) [15]. The advancement in technology and the demand of the customers for cheap and reliable electric power has led to an increasing interest in distributed generation [16]. The issues related to reliability and maintenance has impeded the penetration of DG resources in distribution systems [17].

DG placement impacts critically the operation of the distribution network. Inappropriate DG placement may increase system losses and network capital and operating costs [18]. On the contrary, optimal DG placement (ODGP) can improve network performance in terms of voltage profile, reduce flows and system losses and improve power quality and reliability of supply [19]. The DG placement problem has therefore attracted the interest of many research efforts in the last fifteen years [20], since it can provide DSOs, regulators and policy makers useful input for the derivation of incentives and regulatory measures.

The outline of the paper is as follows: A brief discussion about the recent research works related to the DG placement in distribution system is given in section 2. The proposed system for the integration of DG in distributed system is briefly explained in section 3. The experimental result discussion is given in section 4 and the conclusion of this paper is given section 5.

Related Work: The integration of distributed generation (DG) units in power distribution networks has become increasingly important in recent years. The aim of the optimal DG placement (ODGP) is to provide the best location and sizes of DGs to optimize electrical distribution network operation and planning taking into account DG capacity constraints. Several models and methods have been suggested for the solution of the ODGP problem and some of the much resent technique is listed as follows.

R. S. Al Abri *et al.* [21] have proposed a method of locating and sizing DG units so as to improve the voltage stability margin. The load and renewable DG generation probabilistic nature were considered. That method starts by selecting candidate buses into which to install the DG units on the system, prioritizing buses which were sensitive to voltage profile and thus improved the voltage stability margin. The DG units' placement and sizing was formulated using mixed-integer nonlinear programming, with an objective function of improving the stability margin; the constraints were the system voltage limits, feeders' capacity and the DG penetration level.

R. Srinivasa Rao *et al.* [22] have presented a method to solve the network reconfiguration problem in the presence of distributed generation (DG) with an objective of minimizing real power loss and improving voltage profile in distribution system. A meta-heuristic Harmony Search Algorithm (HSA) was used to simultaneously reconfigure and identify the optimal locations for installation of DG units in a distribution network. Sensitivity analysis was used to identify optimal locations for installation of DG units. Different scenarios of DG placement and reconfiguration of network were considered to study the performance. The constraints of voltage and branch current carrying capacity were included in the evaluation of the objective function.

Junqi Liu *et al.* [23] have presented an optimal meter placement system for the distribution generation. The lack of detailed information on distributed generation was considered in the optimal meter placement procedure, so that the distributed measurement system could provide accurate estimates even with limited knowledge of the profile of the injected power. Possible non-Gaussian distribution of the distributed power generation was considered. The occurrence of either loss of data or degradation of metrological performance of the measurement devices was also considered. Tests performed on a UKGDS 16-bus distribution network.

Soma Biswas *et al.* [24] have proposed a method of solving the distributed generations (DGs) placement problem by considering multiple aspects of a power system operation. In addition to the commonly considered objectives of reduction of the loss and improvement of the voltage profile, that work also optimized other power quality related objectives such as minimization of the voltage sag and harmonic distortion. The system under consideration was a complex one consisting of both linear and non-linear loads as well as the power factor correcting capacitors. The effect of the non-linear harmonic generating loads and the compensating capacitors on the penetration of the DGs in the distribution system was investigated. This optimization problem was solved for several distribution systems by using several meta-heuristic optimization techniques. However, detailed results were presented on a benchmark IEEE 33 bus radial distribution system using genetic algorithm to demonstrate the effectiveness of the method.

Salem Elsaiah *et al.* [25] have introduced an analytical method for placement and sizing of distributed generation on power distribution systems for loss reduction. The proposed analytical method was developed based on a new formulation for the power flow problem, which was non-iterative, direct and involves no convergence issues even for systems with high R/X branch ratios. Further, the power flow solution was extremely useful whenever fast and repetitive power flow estimations were required. A priority list based on loss sensitivity factors was developed to determine the optimal locations of the candidate distributed generation units. Sensitivity analysis was performed to estimate the optimal size and power factor of the candidate distributed generation units. Various types of distributed generators (DGs) have allocated with and viable solutions were proposed to reduce total system loss. The method was tested on 33-bus and 69-bus distribution systems, which were extensively used as examples in solving the placement and sizing problem of DGs. Exhaustive power flow routines were also performed to verify the sizes obtained by the analytical method. The test results showed that the analytical method could lead to optimal or near-optimal solution, while requiring lower computational effort.

The review clearly describe the resent trend in the ODGP problem solving, the most common ODGP model had the following characteristics: installation of multiple DGs, the design variables are the location and size and the objective is the minimization of the total power loss of the system. The solution methodologies for the ODGP problem were classified into three major categories: analytical, numerical and heuristic methods. The most frequently used techniques for the solution of the ODGP problem are the genetic algorithm and various practical heuristic algorithms. Moreover the most of the previous research work were concentrated one or two major objectives like voltage profile, harmonic distortion, etc. In order to make a well suitable optimal DG placement system, it is essential to concentrate each and every factor which affects the performance of DG system. In this work we intend to develop one of the best suitable systems for the DG placement. In order to achieve the enhanced performance we are planned to consider at least five major objectives. The detail discussion about our system will be given from the next section.

Proposed System for the Integration of Dg in Distribution System: In distribution power system the distribution generation (DG) is integrated to meet the additional power requirement. Distributed Generation is an electric power source connected directly to the distribution network or on the customer site of the meter. In this case while the direct interconnection of DG units in an inappropriate location make addition power quality problems like high power loss, low voltage profile, high cost and high emission. Hence finding of suitable location of DG is becoming more prominent in distribution systems due to their overall progressive influences on power networks. So the Distributed Generation Sizing and location at optimal places gathers a great importance in the field of power system. The installation of DG at non-optimal places leads to higher losses and reduced voltage profile and a huge size of DG units in a distribution system leads to high levels of harmonic distortion. In order to, overcome the complexity in finding the location of DG unit an optimization approach is proposed in this paper, it is also aimed to reduce the harmonic level by finding a suitable size of DG.

The major goal of this paper is to develop a novel technique for finding of optimal location as well as size of DG in a distribution system. The proposed system comprises of two phases, in the first phase the DG location is find out and in the second phase suitable size of DG is find. The optimal location of DG is finding based on four objective functions they are, active power loss, total cost, total emission and voltage profile. The size of the DG unit is determined based on the harmonic level in the distributed system. From these two phases we can obtain a well suitable place and an appropriate size of the DG unit in distributed power system. The architecture of the proposed method is shown in Fig 1.

The genetic algorithm (GA) is employed to perform global optimization to find the optimal location and size.The GA is a way of solving problems by emulating the mechanism of evolution as found in natural processes. They use the principles of selection, recombination and mutation to evolve a set of solutions toward a “best” one. The optimization problem is resolved with the GA which can discover the best optimal solution for DG location. The problem is to be solved as an input and the solutions

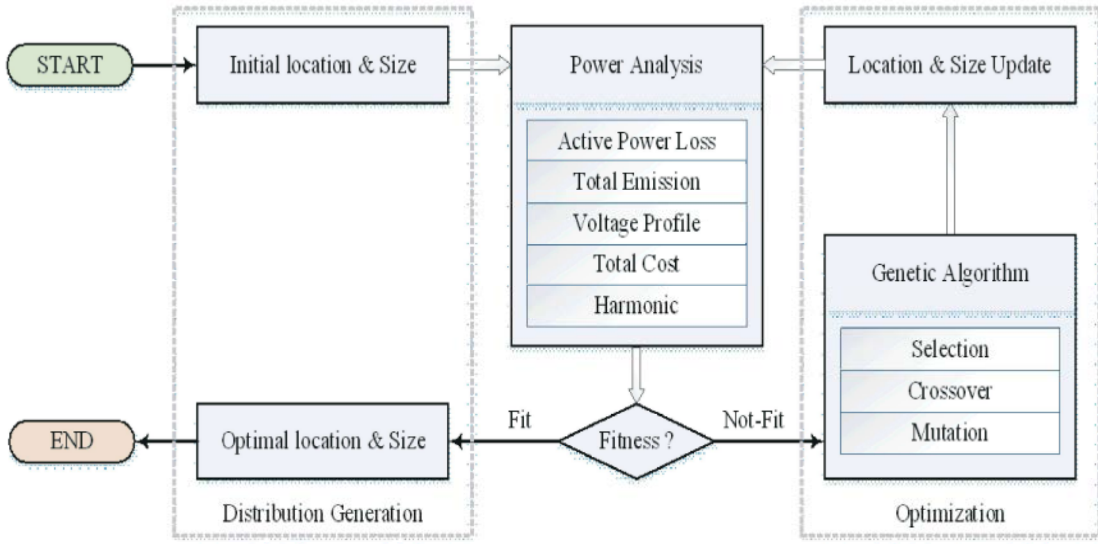

Fig. 1: Architecture of proposed system for optimal placement and sizing of DG

are determined in the solution space. Fitness function appraises each solution most of them selected randomly. Each solution is defined as a chromosome and each chromosome is a two string solution. The first one indicated the location of DG in power system and the second one gives its size.

Initially in GA the initial population is generated randomly and the fitness value for every chromosome is evaluated based on the objective function. Some of solutions are not satisfied the system constraints, these solutions are called infeasible solutions. Infeasible solutions are eliminated, then using mutation and crossover operators the new population is generated, by repeating this procedure the best solution is attained. The subsequent description demonstrates that the steps convoluted in GA approach. The benefits of using GA are that they necessitate no knowledge or gradient information about the response surface; they are resilient to becoming trapped in local optima and they can be employed for a wide variety of optimization problems.

In this method the initial population is defined in a way that all of them are possible solution. For each *solution* a pair of size and location (bus) which is produced by the designer with technical and economic justification. Genetic algorithm relates the new produced population with the old and chooses the best one. When the maximum irritation of the algorithm is reached or the difference between objective function values is smaller than the expected accuracy the algorithm is stopped, then the best solution is chose as a final solution.

Algorithm 1: Genetic Algorithm

Choose an initial random population of individuals
Evaluate the fitness of the individuals
repeat
    select the best individuals to be used by the genetic operators
    Generate new individuals using crossover and mutation
    Evaluate the fitness of the new individuals
    Replace the worst individuals of the population by the best new individuals
until *some stop criteria*

The Genetic Algorithm is optimizing a single entity, the fitness function. Hence, the objective function and the constraints of the problem must be transformed into some measure of fitness. The phases of finding optimal location and sizing of the DG using the genetic algorithm are, creating an initial population, evaluating a fitness value and producing a new population.The step by step procedure of the proposed system for the DG placement and sizing is listed below:

Stage 1: Initialization: In the stage the initial population for the GA is initialized in random, which contains the location and size of DG units. The design of chromosome is very modest in this problem and as only the DG's location and size is to determine thus the location and size of the chromosome one unit vector is shown in Fig 2 and that represents the position of DG and the size of the DG. The position can contain the node number and maximum size of the DG is 2 Mega Watt (MW).

Location (Bus)	Size (Max. 2 MW)

Fig. 2: Chromosome Encoding for one DG Unit

The first component signifies the location, the node in which the DG should be connected and can yield values from 1 to the total number of buses in the network. The second component represents the DG size and can take values from 0 to 2000 kW. A population of probable solutions will be progressed from one generation to another, in order to achieve an optimum setup, i.e. a very well fitted individual.

Stage 2: Fitness Evaluation: In this stage the quality of each initialized chromosome is evaluated based on the objective function or the fitness function. The objectives consider in this paper are active power loss, total cost, total emission, voltage profile and total harmonic distortion. Among these objectives based on four objectives like active power loss, total cost, total emission and voltage profile the location of DG is find out and based on the total harmonic distortion the suitable size of DG is determined.From these five objective functions single fitness function is formulated which is given in equation (1). This function is the overall objective function also acts as the fitness function.

$$F = \min\left[\frac{f_1 + f_2 + f_3 + f_5}{f_4}\right] \quad (1)$$

where,
‘f_1’- Fitness based on power loss
‘f_2’- Fitness based on total cost
‘f_3’- Fitness based on total emission
‘f_4’- Fitness based on voltage profile
‘f_5’- Fitness based on total harmonic distortion

A best performed distributed generation system must produce low active power loss. Hence we consider the active power loss as one of the minimizing objective function. The expression [26] to determine the active power loss is given in equation (2).

$$f_1 = \min\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right]\right] \quad (2)$$

where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

‘r_{ij}’ - Resistance of line between buses ‘i’ and ‘j’
‘P_i’ & ‘Q_i’ - Net real & reactive power injection in bus ‘ ’
‘P_j’ & ‘Q_j’ - Net real & reactive power injection in bus ‘j’
‘V_i’ & ‘δ_i’ - Voltage magnitude & angle at bus ‘i’
‘V_j’ & ‘δ_j’ - Voltage magnitude & angle at bus ‘j’

The total installation cost is also one of the important factors to concentration while forming the distributed generation system. In order to form a well efficient DG system the total cost also in minimum level. So we have considered the total cost as one of the objective function for our optimal location finding of DG. The total cost of the DG system is represented as given in equation (3).

$$f_2 = \min\left[T_c\right] \quad (3)$$

where, ‘T_c’- Total installation cost. The gas emission from the distributed generation may produce air pollution and it became a major environmental hazard. Hence the calculation of emission and also maintain the emission in minimum level is also necessary for a perfect DG system. The emission function can be presented as the sum of all types of emission considered, such as NO_X, SO_X, thermal emission, etc., with suitable pricing or weighting on each pollutant emitted. In the present study, two important types of emission gases are taken into account. The generated NO_X and SO_X level is given in equation (4).

$$f_3 = \min\left[\sum_{i=1}^{N}\left(\gamma_iP_i^2 + \eta_iP_i + \mu_i + \xi_i\exp\left(\lambda_iP_i\right)\right)\right] \quad ton/h \quad (4)$$

where, ‘γ_i’, ‘η_i’, ‘μ_i’, ‘ξ_i’ and ‘λ_i’ are related to the emission coefficient of i the unit, while ‘γ_i’, ‘η_i’ and ‘μ_i’ are related to SO_X and ‘ξ_i’ and ‘λ_i’ are related to NO_X [27].One of the advantages of proper location of the DG is the improvement of voltage profile. This voltage profile could also be used to find prohibitive locations for DG considering pre-established voltage deviation limit and to ensure the rated voltage of each bus within the permissible limits. In this way, according to equation (5), the lower the index, the better the network performance, where V_1 is the rated voltage (normally V_f = 100%), "n" is the number of nodes and V_i voltage at bus i.

$$f_4 = \max\left[\frac{|V_f - V_i|}{|V_i|}\right] \quad , i = 1,2,3,4.....n \tag{5}$$

A large size of DG units in a distribution generation may sometimes contribute to high levels of harmonic distortion. For a perfect DG system the harmonic distortion should in the minimum level. In order to obtain the minimum total harmonic distortion the DG unit must be low. Hence, while placing the DG the size also concentrated, so that the system must produce the minimum harmonics distortion. In our system the total harmonic distortion is calculated by the expression given in equation (6).

$$f_5 = \min\left[\frac{\sqrt{\sum_{i=2}^{N} V_i^2}}{V_1} \times 100\right] \tag{6}$$

Then based on this fitness value some of the chromosomes are selected to perform the genetic operation like crossover and mutation which is done in the subsequent stages.

Stage 3: Selection: The selection methods specify how the genetic algorithm chooses parents for the next generation. In this phase the parent selection is made based on the fitness function. In our work the fitness function is modeled as a minimization function, so the chromosomes produce minimum fitness is consider as the parent chromosome. These parent chromosomes are sent for the next process, where a new set of chromosomes will produced.

Stage 4:Crossover: The crossover mechanism is responsible for the way in which the genetic material is mixed between individuals. The one-point crossover exchanges the genetic information found after a random position in the two selected parents. The crossover is applied in each successive generation with a certain probability, known as the crossover fraction or rate. A large crossover rate decreases the population assortment, but in this problem a higher exchange of genetic material is desirable. In the proposed system the crossover rate (c_r) is set as 0.5 so the number of gene to crossover is 1, i.e.,

$$Number\ of\ Gene\ to\ Crossover = c_r \times length\ of\ Chromosome$$

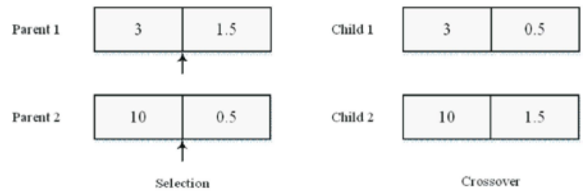

Fig. 3: Selection and Crossover

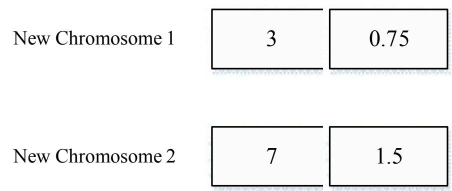

Fig. 4: Mutation

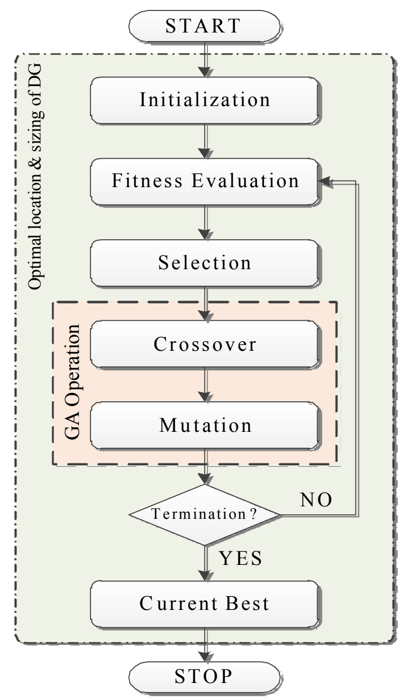

Fig. 5: Process flow of optimal DG system

Stage 5 Mutation: Mutation is very essential from the genetic diversity perspective and it precludes landing a local, sub-optimal solution. The mutation rate is exceedingly associated with the crossover fraction and the mutation rate (m_r) used in this proposed system is 0.5. The mutation mechanism used for suggests to generating a random gene number and flipping the bit found at that situation.

Stage 6:termination Criteria: This is the final stage of the proposed approach for the optimal placement of DG along with the reduction of total harmonics distortion. In which the termination condition is checked if the iteration meets the termination criteria the process get stopped, otherwise the iteration is repeated from the stage 2. Then the process is repeated up to the termination criteria meet. The graphical representation of process flow is given in Fig. 5.

By the completion of these processes our system would place the DG in an appropriate location, so that the DG system can produce high voltage profile and minimized the power loss, total cost, total emissions and total harmonic distortions.

RESULTS AND DISCUSSION

The proposed system for the optimal placement and sizing of DG system is implemented in the working platform of MATLAB/Simulink 2013a with the following system configuration.

Processor	: Intel Core i5
CPU Speed	: 3 GHz
RAM	: 8 GB
Operating System	: Windows 8

The proposed optimization approach for finding the location and size is tested in the IEEE 18 distorted bus system and the bus data are given in appendix. The single line diagram of IEEE 18 distorted bus system [28] is given in the Fig 6.

In this experimental discussion we are considering seven nonlinear loads in the IEEE 18-bus distorted distribution system. The parameter setting for these nonlinear loads is given in Table 1.

In our proposed paper we are using GA for finding the optimal location as well as the size of the DG.The general process involved in the GA are executed and the optimal location as well as the size of DG unit is find out based on the five different objective function. From this proposed approach the voltage profile gets increased and the harmonic distortion gets reduced and also the power loss, emission and the total cost gets minimized. In order to verify the performance of proposed method it is compared with the Differential Evolution Optimization (DEO) algorithm.The results obtained from experimental implementation without DG and with DG placed by GA and DEO is given in the Table 2 and Table 3.

The graphical representation for the comparison of proposed GA technique with the conventional method is given in Fig 7.

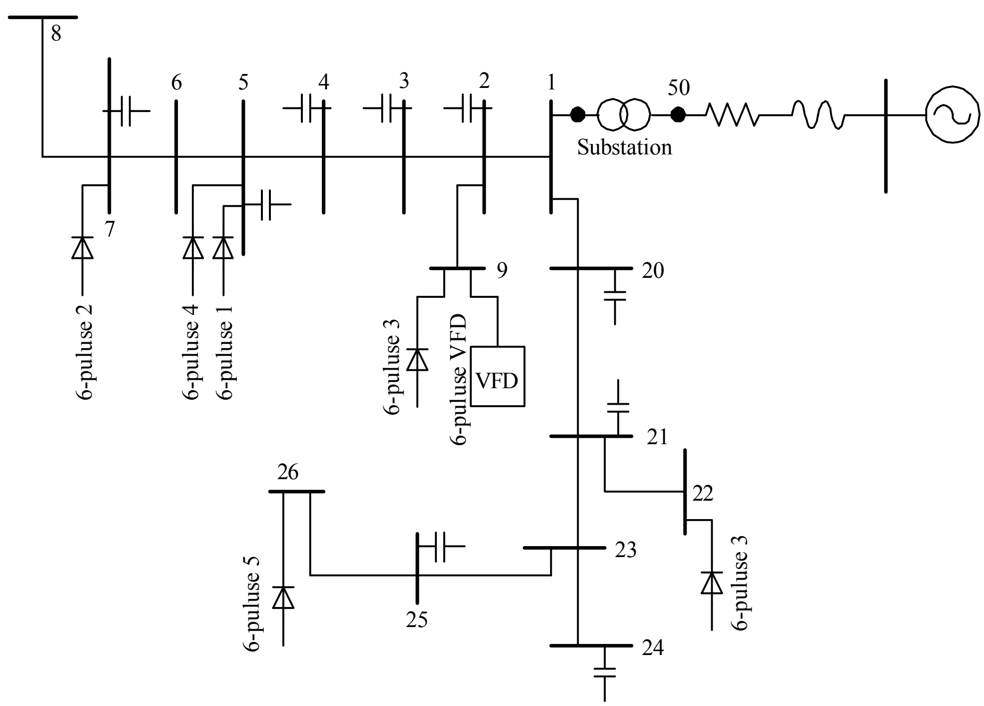

Fig. 6: IEEE 18-bus distorted distribution system

Table 1: Nonlinear Loads Used In IEEE 18-Bus System

Nonlinear Load		Power	
Bus	Name	MW	MVAR
5	six-pulse 1	1.2	0.75
5	six-pulse 4	0.75	0.5
7	six-pulse 2	1	0.6
9	six-pulse VFD	1.5	0.75
9	Six-pulse 3	1.5	0.75
22	six-pulse 3	0.8	0.5
26	six-pulse 5	1	0.6

Table 2: Optimal location and size of the DG unit

	Optimized value by	
Objective	Conventional (DEO)	Proposed (GA)
Location (Bus)	7	7
Size (MW)	0.2281	0.2683

Table 3: Power loss and Total harmonic distortion value

Technique	Power Loss (kW)	THD (%)
Without DG	290.84	22.86
DG placed by DEO	156.49	12.61
DG placed by GA	152.31	9.08

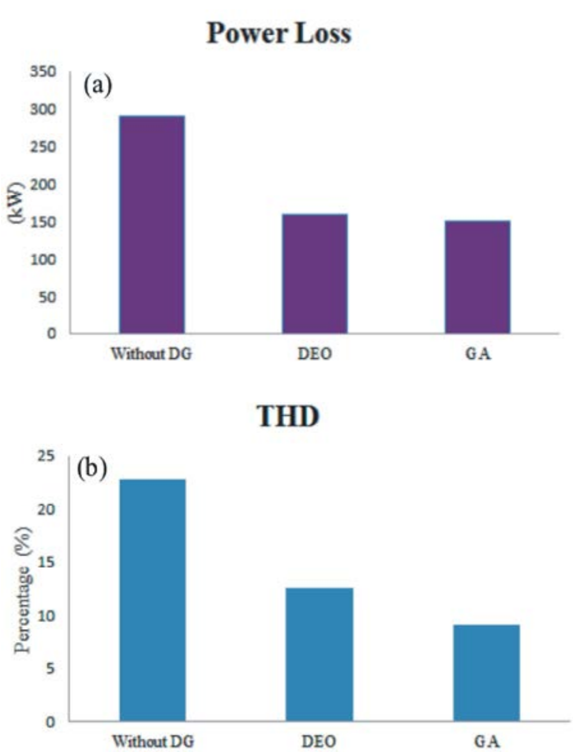

Fig. 7: Comparison of:(a) Power loss and (b) Total harmonic distortion

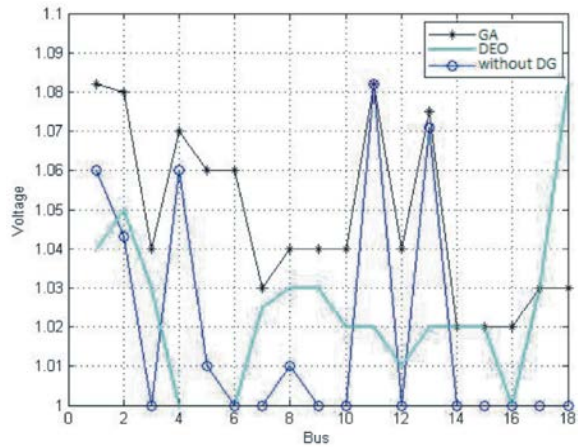

Fig. 8: Voltage profile comparison

In the Figure 7 the comparison chart based on power loss and THD is given. From the Fig 7 (a)or table 3 the power loss without DG is 290.84 kW and after placing the DG the power loss becomes 156.49 kW by DEO and 152.31 kW by GA. Thus we can show that the DG is very essential to control the power loss after that the GA placed by our proposed GA approach is lower than that of the conventional DEO approach. Hence we can prove that the proposed technique reduced the power loss. In Fig 7(b) the total harmonic distortion obtained by the various methods is shown. From the fig 5(b) or table 3 the total harmonic distortion without placing the DG is 9.86%, after placing the DG is 4.61% by DEO and 3.08% by GA. These results also showed that the DG is very much essential to reduce the total harmonic distortion and our proposed method produced minimum harmonic distortion than the other technique. Hence we can prove that our proposed method is suitable for the reduction of harmonic distortion in distribution system.Then the total voltage profile and the total cost obtained without DG and with DG by our proposed GA and DEO are given in the Fig 8.

In Fig 8 the voltage profile obtained by the various techniques is compared, from the chart we can show that the voltage of a distribution system is very low without placing the DG unit. After placing the DG unit the voltage profile gets improved, the improvement is high in the case of GA based placement than the DEO based placement. Hence we can prove that our proposed technique for the placement of DG also improves the voltage profile. To the show the benefits of using GA instead of the DEO the convergence is compared and is given in the Fig 9.

The Fig 9 proves that the GA is more suitable for the placement of DG than the DEO, from the figure the GA optimization is converged well than the DEO technique.

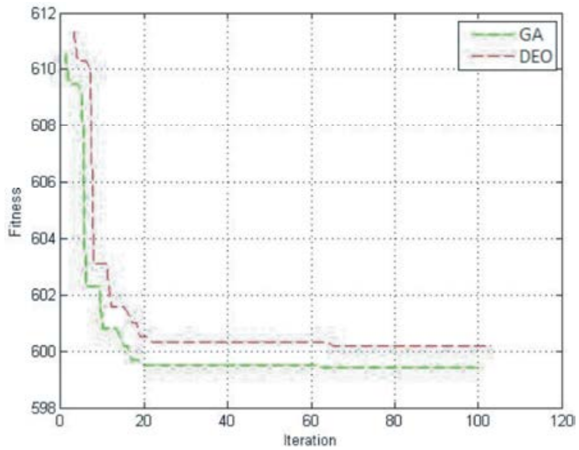

Fig. 9: Convergence Chart

Hence the GA based DG placement gives improved performance than the DEO based placement. Up to now the performance of the proposed optimization technique for finding the location and size of DG unit is verified in this section. The analysis proved that the proposed system is well suitable to gain the voltage profile as well as to reduce the total harmonic distortion along with some other reductions like cost, emission and power loss. From this analysis we can suggest that the proposed GA based approach is one of the best suitable techniques for the placement and sizing of DG unit.

CONCLUSION

The optimal DG placement and sizing by considering multi objectives by using the GA is presented in this paper. The proposed approach considered five different objective like total voltage profile, total emission, total cost, total power loss and total harmonic distortion. The optimal location of the DG is found out by considering the total power loss, total emission, total cost and voltage profile. On the other hand the optimal size of the DG unit is determined based on the total harmonic distortion. The performance of the proposed approach is tested in the IEEE 18 bus distorted distribution system and analyzed by comparing without DG and DG placed by the GA and DEO. The obtained results proved that the DG is very much is essential to provide the high voltage profile and to reduce the power loss, emission, total cost and total harmonic distortion. Moreover the proposed GA based DG placement provided improved performance than the DEO based placement. Thus we can suggest that the voltage profile of a distribution system can be improved by placing the DG in an appropriate location and the total harmonic distortion can be reduced by selecting the suitable size of DG unit. Our GA technique enhanced the voltage profile and reduced the total harmonic distortion up to 9.08%. In future we will develop a new technique for the placement of DG, so that the voltage profile will improve more and further reduced the total harmonic distortion.

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Appendix:

Table: Bus Data of IEEE 18 Distorted Bus System

Bus Num	Bus Name	Bus Type	P- Gen (%)	Q- Gen (%)	S VA (%)	P Load (%)	Q Load (%)	Bus Volt (%)	Shunt Load (%)
1	gar12.5	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	cap1-2	03	0.0	0.0	0.0	2.0	1.2	0.0	-10.5
3	cap4	03	0.0	0.0	0.0	4.0	2.5	0.0	-6.0
4	cap3	03	0.0	0.0	0.0	15.0	9.3	0.0	-6.0
5	sixpulse	23	0.0	0.0	0.0	30.0	22.6	0.0	-18.0
6	six	03	0.0	0.0	0.0	8.0	5.0	0.0	0.0
7	cap6	03	0.0	0.0	0.0	2.0	1.2	0.0	-6.0
8	eight	03	0.0	0.0	0.0	10.0	6.2	0.0	0.0
9	nine	03	0.0	0.0	0.0	5.0	3.1	0.0	0.0
20	cap7	03	0.0	0.0	0.0	10.0	6.2	0.0	-6.0
21	cap8-9	03	0.0	0.0	0.0	3.0	1.9	0.0	-12.0
22	bus22	03	0.0	0.0	0.0	2.0	1.2	0.0	0.0
23	bus23	03	0.0	0.0	0.0	8.0	5.0	0.0	0.0
24	cap10-11	03	0.0	0.0	0.0	5.0	3.1	0.0	-15.0
25	cap12	03	0.0	0.0	0.0	10.0	6.2	0.0	-9.0
26	bus 26	03	0.0	0.0	0.0	2.0	1.2	0.0	0.0
50	gar138	03	0.0	0.0	0.0	0.0	0.0	0.0	-12.0
51	swing	01	0.0	0.0	0.0	0.0	0.0	105.0	0.0

Table: Line Data of IEEE 18 Distorted Bus System

Bus		R(+)	X(+)	Line Chg	Lgth		
to	from	%	%	%	[mi]	Base Imp	Harm Only
1	2	0.431	1.204	0.0035	0.318	15.625	0
2	3	0.601	1.677	0.0049	0.443	15.625	0
3	4	0.316	0.882	0.0026	0.233	15.625	0
4	5	0.896	2.502	0.0073	0.661	15.625	0
5	6	0.295	0.524	0.0024	0.218	15.625	0
6	7	1.720	2.120	0.0046	0.455	15.625	0
7	8	4.070	3.053	0.0051	0.568	15.625	0
2	9	1.706	2.209	0.0043	0.451	15.625	0
1	20	2.910	3.768	0.0074	0.769	15.625	0
20	21	2.222	2.877	0.0056	0.587	15.625	0
21	22	4.803	6.218	0.0122	1.269	15.625	0
21	23	3.985	5.160	0.0101	1.053	15.625	0
23	24	2.910	3.768	0.0074	0.769	15.625	0
23	25	3.727	4.593	0.0100	0.985	15.625	0
25	26	2.208	2.720	0.0059	0.583	15.625	0
25	26	2.208	2.720	0.0059	0.583	15.625	0
50	1	0.312	6.753	0.0000	0.000	0.000	0
50	51	0.050	0.344	0.0000	0.000	0.000	0
51	0	0.000	0.010	0.0000	0.000	0.000	1

Table: Nonlinear Bus Data of IEEE 18 Distorted Bus System

			Transformer	
	R	X-DC Circuit	--	
Bus	[%]	[% @60Hz]	X - [% @60Hz]	Type
5	2.26	226	20.45	1