Genetic Algorithm for Optimum Siting and Sizing of Distributed Generation

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Abstract-**This paper presents a powerful approach to find the optimal size and location of distributed generation units in a distribution system using Genetic Optimization algorithm (GA). The total active and reactive power losses are minimized and voltage profile is improved. GA fitness function is introduced including the active power losses, reactive power losses and the cumulative voltage deviation variables with selecting weight of each variable. GA fitness function is subjected to Voltage Constraints, active and reactive power losses constraints and DG size constraint.**

Keywords: **Genetic Algorithm "GA"; Distributed Generators "DG" ; Cumulative Voltage Deviation; Active and Reactive Power Loss; Weight; MATLAB; Load Flow**

1. INTRODUCTION

The large amount of capital cost needed to install large power stations, abnormal operation conditions which can lead to black out added with economical and environmental pressures, changed the generation approaches of traditional electric power utilities in the recent past. The alternative after considering the above factors, is to introduce distributed and dispersed generation which can be conveniently located closer to load centers. The main idea behind the Distributed Generation (DG) is that generation in small scale and can be easily placed closer to the point of consumption [1].

By definition, the distributed or dispersed generators are small size generators, which can come from traditional or some revolutionary technologies or it is an electric power source connected directly to the distribution network or on the customer side of the meter as mentioned in [2].

DG is expected to play an increasing role in emerging power systems. Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG, such as wind turbines, photovoltaic, fuel-cells, biomass, micro turbines, small hydroelectric plants, etc., ranging from sub-kW to multi-MW sizes) (3,4). Its impact on distribution systems may be either positive or negative depending on the system's operating condition DGs characteristics and location. The potential positive impacts are improving system reliability, loss reduction, and deferment of new generation and improving power quality. To achieve these benefits, DG must be reliable, dispatchable, of appropriate size, and at suitable locations. More important, DGs should be properly coordinated with protection systems [5].

The planning of the electric system with the presence of DG requires several factors to be taken into considerations, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance.

The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem [6].

Genetic algorithms offer a new and powerful approach to these optimization problems made possible by the increasing availability of high performance computers at relatively low costs.

These algorithms have recently found extensive applications in solving global optimization searching problems when the closed-form optimization technique cannot be applied. Genetic algorithms (GAs) are parallel and global search techniques that emulate natural genetic operators. The GA is more likely to converge toward the global solution because it, simultaneously, evaluates many points in the parameter space. It does not need to assume that the search space is differentiable or continuous. The optimal power flow problem is solved based on the use of a Genetic Algorithm load flow [7]. The advantages of using GA are that they require no knowledge or gradient information about the response surface; they are resistant to becoming trapped in local optima and they can be employed for a wide variety of optimization problems. On other hand GA could have trouble in finding the exact global optimum and they require a large number of fitness functions evaluations. It is very difficult to achieve analytic relationship between sensitivity of simulated power system and the parameters values to be optimized. Since GA don't need this kind of information, it is suitable in our optimization task. If there is an explicit knowledge about the power system being optimized, that information can be included in the initial population. In this work we initialize the population to the best-fit results [8].

Comprehensive methodology using Genetic Algorithm is proposed considering both PV and PQ models of DG to determine the best location and size of the DG simultaneously. The best solution is achieved by minimizing the Fitness Function "objective function" which includes the cumulative voltage deviation, active and reactive power losses under some constraints.

2. PROBLEM FORMULATION

The solving of placement and sizing of DG units problem requires to define the Fitness Function that can be optimized in the presence of some constraints. The fitness function is selected for reducing power losses and increasing of voltage stability margin in the system or reducing cumulative voltage deviation.

GA starts the process by automatically proposing different DG sizes within the proposed DG size limits and internally executes the load flow program which is properly linked with GA package till the minimum solution is obtained for the suggested location. This process is repeated for each of the proposed locations. Different scenarios are proposed to consider multiple of DG's at different suggested locations and to consider both DG PV and PQ models to determine the best location and size of the DG's. The suggested algorithm is programmed under MATLAB software. Comparison between the proposed GA approach and the traditional method is conducted.

2.1. Objective Function

A precise evaluation for the Objective Function has been selected. The main goal of the proposed algorithm is to determine the best locations and size for new Distributed Generation resources by minimizing different function, related to project aims. Two main goals are taken into considerations to determine the Objective Formula that is used in point of start: Power Losses reduction and voltage profile improvement. The Fitness Function is determined as following:

$$F = W_p \times P_L + W_q \times Q_L + W_v \times CVD$$

Where:

P_L : Active Power Loss

Q_L : Reactive Power Loss

CVD: Cumulative Voltage Deviation

F : Fitness Function.

The active and reactive power losses are obtained from load flow program. The cumulative voltage deviation norm is defined as "the normalized sum of the deviations of the obtained value from the desired value at every node on the feeder. The desired value being 1.0 p.u and the obtained value being the value obtained from the three-phase distribution power flow [9]. In this work the CVD is determined the same way as following:

$$CVD = \left| \sum_{i}^{n} (1 - V_i) \right|$$

Where:

N: The total number of nodes

W_p, W_q and W_v : The Objective Function weights (Active, Reactive power losses and Cumulative Voltage Deviation weights), subjected to:

$$W_p + W_q + W_v = 1$$

2.2. Constraints

The main constraints in the optimization process in the proposed methodology are:

1. Active and reactive power losses constraints
2. Voltage Constraints
3. DG size constraint

2.2.1. Active and reactive power losses constraint:

The losses after installing DG in power grid should be less than or equal losses before installing DGs .

PL with DG $\leq$ PL without DG

QL with DG $\leq$ QL without DG

2.2.2. Voltage constraint:

To ensure the voltage of any bus should be within predefined limits the following constraint is considered:

$$V_{bus-\min} \leq V_{bus} \leq V_{bus-\max}$$

V_{bus} : Bus Voltage

$V_{bus-\min}$: Bus minimum voltage

$V_{bus-\max}$: Bus maximum voltage

2.2.3. DG Size constraint:

To obtain a reasonable and economic solution, the size of generators should not be so small or so high with respect to load value. The DG size is considered not less than one quarter of the load and not more than three quarters of the load as following:

$$25\%\ L \leq DG_Z \leq 75\%\ L$$

L : Load value

DG_Z : DG size

3. SYSTEM DESCRIPTIONS

The system used in this work is the same system used in [10] as shown in figure (1). It is a balanced three-phase system that consists of 69 nodes and 69 segments. It is assumed that all the loads are fed from the substation located at node l. The loads belonging to one segment are placed at the end of each segment. The system has 50 loads totaling 3.801 MW and 1.616 MVAR, real and reactive power loads respectively.

4. SOLUTION METHODOLOGIES

4.1. General Aspects :

The available locations to install the suggested distributed generators are selected among the nodes with the lowest voltage value in addition to the physical factors and right of way which are considered as important factors affecting this selection. The nodes with the lowest voltage are identified by

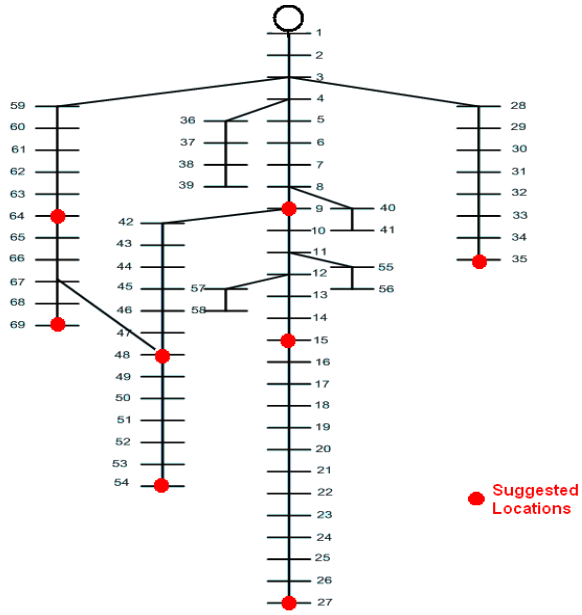

Figure (1): Application System

applying load flow program; it is found they are mainly the terminal nodes. Some intermediate nodes are also selected when noticed that their voltage is low after sitting the DG at the terminal nodes. Based on previous criteria, eight locations at nodes 9, 15, 27, 35, 48, 54, 64, and 69 in this work are suggested. The maximum number of DGs allowed for installation in this application is three. DGs sizes limits are considered as percentage of the total load. Six methodologies have been suggested and studied.

In the first methodology one DG, as a PV bus, within the suggested limits at the predefined eight locations is considered. The second methodology is the same as first methodology but with considering the DG as a PQ bus. Another four methodologies are suggested using two and three DGs in sequence instead of one DG in the previous two methodologies.

4.2. Genetic Algorithm "GA" Method Main Program :

The proposed methodology is composed mainly of applying Load flow program interacted with GA program using Input System Data under MATLAB package as shown in Figure (2). The main modules of the proposed technique are explained as following:

4.2.1. Input System Data

Input system data module includes:

- Network data:_ Buses data and Lines data
- DG data:Number of locations, number of DGs, DG types (models) and DG sizes
- Objective function data: Weights

4.2.2. Load Flow Program

A power-flow study for a system operating under actual or projected normal operating conditions is called a base case. The results from the base case constitute a benchmark for

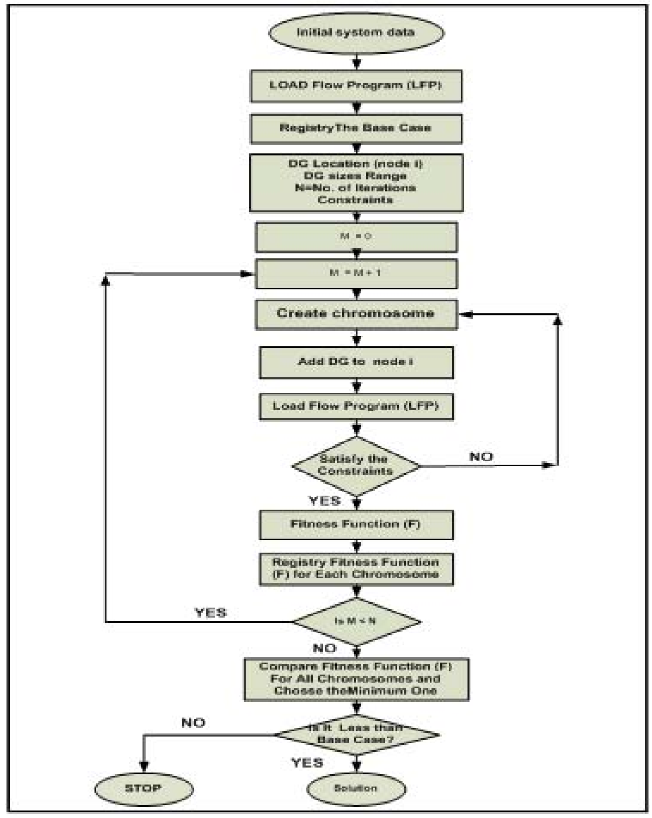

Figure (2): Genetic Algorithm Method

comparison of changes in network flows and voltages under changing in network topology. System weakness such as low voltages, line over-loads, or loading conditions deemed excessive can be discovered and removed by making design studies involving changes and/or additions to the base case system.

DGs, number of buses, number of lines, type of buses ("PQ" bus or "PV" bus), voltage magnitude and its angle, slack bus selection, load at each bus, limits of reactive power at each generation bus ("PV") and line parameters, all these data are previously defined by the operator. There are three well-known power flow solution techniques, which are Gauss-Seidel, Newton-Raphson (N-R) and the Fast decoupled methods. Among the three methods the N-R method is chosen for its accuracy and computational time. An N-R load flow, losses calculation are implemented in "line flow", which is written in MATLAB [11].

After installation of the DG unit, the power-flow program is executed and then the objective function calculated. The developed algorithm which is programmed in MATLAB reduces the computation time.

4.2.3. GA Program

Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time [12]. GA Program comprises three different phases of search [13] :

phase 1: creating an initial population; phase 2:evaluating a fitness function; phase 3: producing a new population. The proposed GA method starts with a randomly generated initial population (chromosomes) within which each individual is evaluated by means of a fitness function as in figure (2). Individuals and subsequent generations are duplicated or eliminated according to their fitness values. Number of iterations should be selected to obtain the needed convergence and accuracy. All obtained solutions and satisfy all constraints are registered and finally compared. The least solution which is less than the base case is considered the optimum solution for the proposed location. If no solution is less than the base case, the proposed location is considered unsuitable for adding DGs. The GA is executed again to study the problem at the next suggested location. Comparison between all solutions can be done to identify the best solution. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals as following:

(i) They rely on the information obtained by the evaluation of several points in the search space. Each "current point" is called an individual, and the set of "current point" is called the population. The algorithm keeps this set of "current points", instead of keeping a single "current point" as would be the case of in most optimization algorithms.

(ii) The population converges to a problem optimum through sequential applications, at each iteration of genetic operators.

Genetic algorithm that yields good results in many practical problems is composed of three operators:

- Crossover: The individuals, randomly organized pair-wise, have their space locations combined, in such a way that each former pair of individuals gives rise to a new pair.
- Mutation: Some individuals are randomly modified, in order to reach other points of the search space.
- Selection: The individuals, after mutation and crossover, are evaluated. They are chosen or not chosen for being inserted in the new population through a probabilistic rule that gives a greater probability of selection to the "better" individuals.

4.2.4. Fitness Function

Fitness Function (Objective Function) extracts its required data from Input Data System. The losses and node voltages are used as an evaluation function, called objective function, to search the optimal size and location of DG. In this work, the cumulative voltage deviation weight is chosen with the highest priority where the voltage has the most important effect of network operation.

Active power loss weight is chosen the next priority after Cumulative voltage deviation and higher than the reactive power loss where it is more effective. The weights are chosen as following:

$$W_p = 0.35, \quad W_q = 0.1, \text{ and } W_v = 0.55$$

The fitness function is computed when DG is added at each of the selected eight nodes, for each methodology. It is calculated with simultaneous operations as shown in Figure (2).

4.3. First Methodology:

In this methodology, one DG is added to the original network and considered as PV bus in one of the eight possible locations applying the voltage and power loss constraints at all cases, it is found that case # 1 ((0.9501MW) DG size nearly 25% of total load installed at node 9) is the lowest objective function value (F=0.6606 unit) and satisfies all constraints. Figure (3) indicates the effect of voltage constraint for all cases. It shows the maximum voltage and the minimum voltage at each case where the voltage limits are 1.05 pu and 0.95 pu. It can be noted that only one case (cases #1) satisfies the voltage constraint.

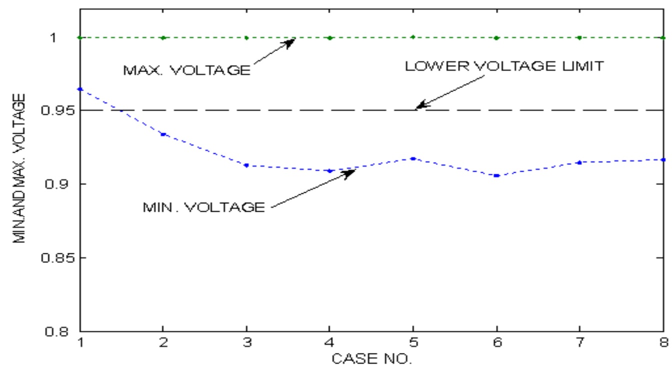

Figure (3): Voltage Constraint Effect for all cases (First Methodology- One "PV" DG)

4.4. *Second Methodology*:

In this methodology, one DG is added as PQ bus at one of the eight possible locations. The main program is executed for all possible cases applying the voltage and power loss constraints at all cases, it is found that Case # 1, adding DG at node 9 with size of 55.3 % of load (2.103 MW) will lead to the lowest objective function value (F=0.0289 unit). Also it can be noticed that the objective function in the second methodology is improved than the First Methodology (one DG as PV).

4.5. Third Methodology:

In this methodology, two DGs are added as PV bus at two of the eight possible locations. The main program is executed for all possible cases (28 Cases) considering all constraints. It is found that the lowest objective function (F=0.5153 unit) generated by case # 4 (two DGs, 0.8115 MW each, installed at nodes 9 and 48). The total DGs sizes are equal to 42.7 % of the total load.

4.6. Fourth Methodology:

In this methodology, two DGs are added to the original network and considered as PQ bus in two of the eight possible locations (28 combinations) and the Genetic Algorithm Program (GA) is executed to obtain the optimal size for each case. It is found that case # 4 (two DGs, 1.0534 MW each, installed at nodes 9 and 48) is the lowest objective function value (F=0.0274 unit) and satisfies all suggested constraints. The total DGs sizes are equal to 55.4 % of the total load.

4.7. *Fifth Methodology:*

In this methodology, three DGs are added to the original network and considered as PV bus in three of the eight possible locations and the Genetic Algorithm Program (GA) is executed to obtain the optimal size for each case. It is found that the lowest objective function (F=0.0.4828 unit) generated by case # 31 (three DGs, 0.3205 MW each, installed at nodes 15, 48 and 54). The total DGs sizes are equal to 25.3 % of the total load.

4.8. *Sixth Methodology:*

In this methodology, three DGs are added to the original network and considered as PQ bus in three of the eight possible locations and the Genetic Algorithm Program (GA) is executed to obtain the optimal size for each case. It is found that the lowest objective function (F=0.0.0217 unit) generated by case # 3 (three DGs, 0.3785 MW each, installed at nodes 9, 15 and 48). The total DGs sizes are equal to 29.9 % of the total load.

5. COMPARISON BETWEEN METHODOLOGIES

The optimum solution of the six suggested methodologies that have been studied in previous paragraphs can be identified directly by selecting the minimum objective function between all methodologies. As the value of objective function is based on certain priorities of the three major variables, cumulative voltage deviation, active and reactive power loss, certain weights were selected as previously explained. The cumulative voltage deviation has the highest priority followed by active power loss and finally the reactive power loss.

An assessment can be achieved by comparing all variables including the objective function for each methodology and comparing the best methodology with respect to the base case without adding DGs. Table (1) shows a comparison between the value of added DG/s, location of DG/s, active and reactive power loss, minimum and maximum resulted voltage, average voltage and the objective function value for the previous six methodologies results.

Table (1) and figure (4) shows that the best location can be achieved by using methodology 6 (three DGs are added with 0.3785 MW and 0.1703 MVar at each node as PQ bus at nodes 9, 15& 48) with F= 0.0217. The total DGs sizes are equal to 29.9 % of the total load.

The comparison between the active and reactive power loss against each methodology is represented in figure (5). It shows that the minimum active and reactive power loss can be achieved by using methodology 6. The comparison between the minimum and maximum voltage, average voltage and accumulative voltage against each methodology is represented in figure (6). It shows that the minimum accumulative voltage deviation (CVD) can be achieved by using methodology. Taking all previous considerations and using the selected weights the optimal solution is by installing three DGs at nodes 9, 15 and 48 with size of 0.3785 MW and 0.1703 MVar per each DG as a PQ bus.

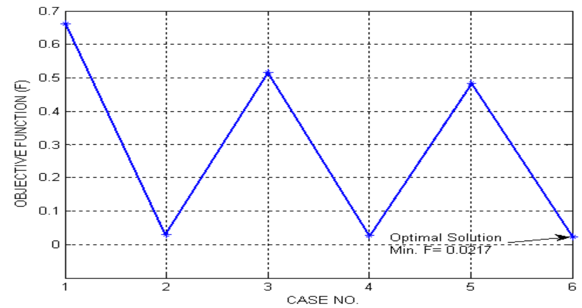

Figure (4): Objective Function (F) for each Methodology.

Table (1) Results of the proposed six methodologies

NO. OF DG	ONE DG		TWO DGs		THREE DGs	
DG MODELS	PV	PQ	PV	PQ	PV	PQ
CASE NO.	1	2	3	4	5	6
OPTIMAL LOCATION	NODE 9	NODE 9	NODES 9&48	NODES 9&48	NODES 15&48& 54	NODES 9&15&48
OPTIMAL DG SIZE	0.950	2.1028 MW& 0.9462 MVar	0.8115 at each node	1.0534 MW& 0.4740 MVAR at each node	0.3205 at each node	0.3785 MW & 0.1703 MVAR at each node
P_L	0.055	0.0656	0.0729	0.0594	0.1019	0.0471
Q_L	0.058	0.0588	0.0670	0.0646	0.0754	0.0479
V_{Min}	0.9647	0.9704	0.9647	0.9703	0.9618	0.9702
V_{Max}	1.0000	1.0325	1.0001	1.0453	1.0011	1.0369
V_{av}	0.9833	1.0000	0.9843	1.0000	0.9884	1.0000
CVD	1.1550	0.0001	0.8783	0.0003	0.7992	0.0009
F	0.6606	0.0289	0.5153	0.0274	0.4828	0.0217

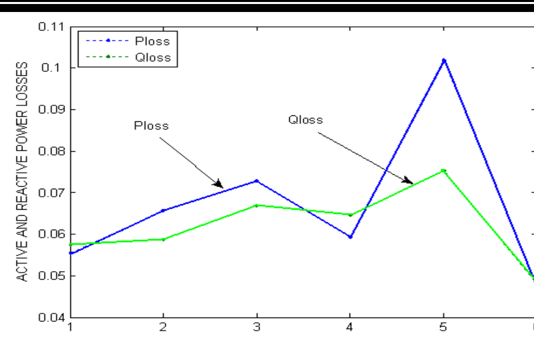

Figure (5): Active "P_L" and Reactive "Q_L" power loss for each Methodology.

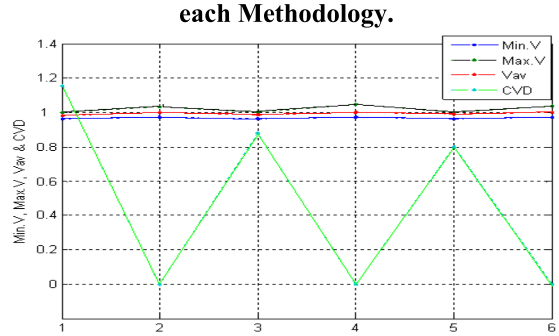

Figure (6): Minimum voltage (Vmin), Maximum voltage (Vmax), Average voltage (Vav), and Cumulative voltage deviation (CVD) for each methodology.

6. Comparison Between The Base Case and The Final Optimal Solutions By GA :-

Table (2) shows a comparison between the base case, without installing DG, and when installing three DGs (0.3785 MW and 0.1703 MVar each) installed at nodes 9, 15 & 48. From table (2), it can be observed that installing the three DGs will save the indicated amount of active and reactive power loss which can be represented in a separate figure as in figures (7,8).

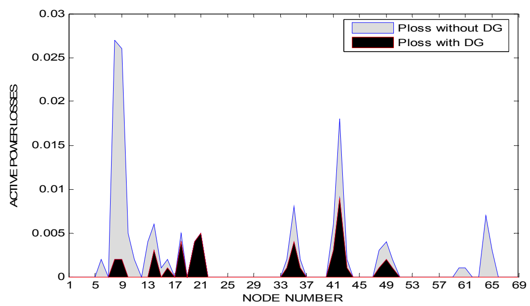

Figure (7): Total active power losses saving when installing three DGs at nodes 9, 15, and 48 than base case

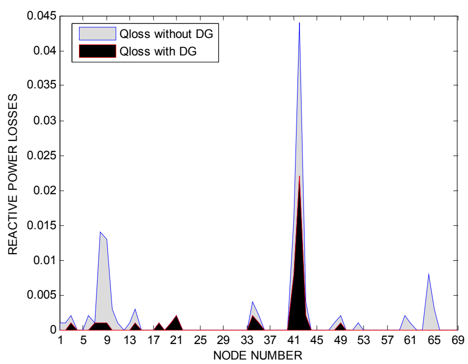

Figure (8): Reactive power losses saving when installing three DGs at nodes 9,15 and 48 than the base case

7. Comparison Between The Traditional Method (TM) And The Genetic Algorithm (GA):-

Comparison between solving DG sizing and siting using the Traditional Method introduced in [14] by the same authors with the Genetic Algorithm (GA) Method introduced in this paper is illustrated in tables (3, 4 and 5). It can be noticed that the same size and locations were obtained by both methods (TM and GA) when using one or three DGs as PV model. Slightly different sizes at the same Locations were obtained by both TM and GA when using one or two DGs as PQ model. Slightly different sizes at different Locations were obtained when using three DGs as PQ model.

The best solution is found by solving the problem with GA which enables the planner to choose the exact and smooth sizes of three DG's (0.3785 Mw and 0.1703 Mvar each) installed at nodes 9, 15 & 48.

8. Conclusion

Genetic Algorithm can be used as a better tool than traditional methods to enable the planners to choose the best size and location of DGs to distribution system. GA method is more faster, easier, and smooth accurate size. Adding DG to the distribution system reduces the active and reactive power loss and improves the system voltage. The amount of effect is greatly affected by the location of DG and the number of DGs that can be installed. Using GA through MATLAB package and automatic interaction with the load flow program proved obtaining the optimum solution to the problem. Selecting the most effective terms in distribution system in fitness function such as cumulative voltage deviation, active and reactive power loss with reasonable weights play an important role to get the best solution. The cumulative voltage deviation is selected with the highest priority followed by active power loss and finally the reactive power loss from our point of view. So, it is needed to assess the changing of all variables and how much sacrificing of some variables to obtain the optimum final solution. It is found that the optimum solution achieved when installing three DG's (0.3785 Mw and 0.1703 Mvar each) installed at nodes 9, 15 & 48 and that all nodes voltages increased while voltage constraint are satisfied (all node voltage values are located between 95% and 105%).

Table (2) Comparison Between The Base Case Without DG And With Installing Three DGs

Case	Without DG	With Installing three DGs (0.3785 MW and 0.1703 MVar each) installed AT NODES 9, 15 & 48	Notes
Active Power Losses (P_L) (MW)	0.1085	0.0471	0.0614 unit decreasing **56.60 % Saving**
Reactive Power Losses (Q_L) (MVar)	0.0926	0.0479	0.0447 unit decreasing **48.30 % Saving**
Voltage Deviation (CVD) (PU)	3.1885	0.0009	3.1876 unit decreasing **99.97 % Improvement**
Minimum Voltage (PU)	0.9092	0.9702	0.0610 unit increasing **6.71% slightly improvement**
Maximum Voltage (PU)	1.000	1.0369	0.0369 unit increasing **0.415 % Slightly worsening**
Average Voltage (PU)	0.9538	1.0000	0.0462 unit increasing **4.84 % improvement**
Objective Function (F) (unit)	1.8009	0.0217	1.7792 decreasing **98.80 % Saving**

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Table (3): Comparison Between TM and GA For One DG

No.of DGs	ONE DG			
Model	PV		PQ	
Method	TM	GA	TM	GA
DG Size	0.9503	0.9501	1.901 +j0.808	2.1028 +j0.9462
Location	9	9	9	9
PL	0.0559	0.0554	0.0542	0.0656
QL	0.0576	0.0576	0.0535	0.0588
CVD	1.1550	1.1550	0.3161	0.00014
Min. V	0.9647	0.9647	0.9703	0.9704
Max. V	1.000	1.000	1.0240	1.0325
F	0.6606	0.6606	0.1982	0.0289
Notes	Same Size, Same Location		Slightly Different Sizes, Same Location	

Table (4): Comparison Between TM and GA For Two DGs

No. of DGs	TWO DGs			
Model	PV		PQ	
Method	TM	GA	TM	GA
DG Size	0.9503	0.8115	0.4753 +j0.202	1.0534 +j0.4740
Location	9 & 48	9 & 48	15 & 48	9 & 48
PL	0.0754	0.0729	0.0708	0.0594
QL	0.0750	0.0670	0.0576	0.0646
CVD	0.8797	0.8783	0.0027	0.0003
Min. V	0.9647	0.9647	0.9669	0.9703
Max. V	1.0005	1.0001	1.0457	1.0453
F	0.5177	0.5153	0.0320	0.0274
Notes	Slightly Different Sizes, Same Locations		Slightly Different Sizes, Same Locations	

Table (5): Comparison Between TM and GA For Three DGs

No.of DGs	THREE DGs			
Model	PV		PQ	
Method	TM	GA	TM	GA
DG Size	0.3168	0.3205	0.4223 + j0.1796	0.3785 +j0.1703
Location	15 , 48 & 54	15 , 48 & 54	15 , 64 & 69	9, 15 & 48
PL	0.1004	0.1019	0.0725	0.0471
QL	0.0747	0.0754	0.0630	0.0479
CVD	0.7982	0.7992	0.0817	0.0009
Min. V	0.9618	0.9618	0.9701	0.9702
Max. V	1.0011	1.0011	1.0356	1.0369
F	0.4816	0.4828	0.0766	0.0217
Notes	Same Size, Same Location		Slightly Different Sizes, Different Locations	