DETERMINATION OF OPTIMOM SIZE AND LOCATION OF DISTRIBUTED GENERATORS FOR LOSS REDUCTION USING GA

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Abstract: *In this paper optimum size and location of distributed generators (DGs) are determined for loss reduction in distribution systems. For this purpose, genetic algorithm (GA) optimization approach is proposed. The significant innovation of this research paper is using new coding in genetic algorithm (GA) which includes both active and reactive powers of DGs to achieve more loss reduction. Furthermore, two types of DG consisting of DGs with capability of supplying both real power and reactive power and DGs with only capability of supplying real power but consuming of reactive power are considered and comparative studies are conducted in the different cases to investigate the impacts of optimal DGs placement and its size determination on loss reduction. The effectiveness of the proposed method is examined in the 33 bus and 69 bus distribution systems. The results show that determination of optimum size and location of DGs has a considerable effect on loss reduction.*

Key words: *Distributed Generation, loss reduction, Genetic algorithm, optimal placement*

1. Introduction.

Distributed generation (DG) is small-scale power generation that is usually connected to distribution system. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network. The Electric Power Research Institute defines DG as generation from 'a few kilowatts up to 50MW' [1]. Recently, the placement of distributed generation systems (DGs) such as photovoltaic cells, fuel cells, battery energy storage systems and cogeneration system on the distribution system can significantly impact power quality and voltage conditions at customers[2]. Meanwhile distributed generators can reduce distribution loss and replace large-scale generators if they are placed appropriately in the distribution systems. DGs are closer to customers so that transmission and distribution cost are avoided or reduced.
DG technologies can be divided into renewable and non-renewable energy resources. Renewable DGs include solar, wind, small-hydro, biomass, geothermal and etc. the non-renewable includes combustion turbines, steam turbines, micro turbines, reciprocating engines and etc

[3],[4].
Using of DGs has many benefits and positive effects To the customers and the distribution systems and they also have negative effects sometimes.
The positive impacts of the performing of DG are as follows [3],[4]:
• Line loss reduction
• Voltage profile improvements
• Power quality improvements
• Short lead time and located close to load
• Low cost
• Reduction of peak power requirements
• Increased electric system reliability
• Increased efficiency levels
• Reduced environmental impacts
The negative impacts of the performing of DG might be as follows [3], [6], [7]:

• Harmonics
• Unsteadiness of the voltage profile owing to the bi-directional power flows
• Unsteadiness of the voltage profile owing to the bi-directional quality of the supply
• System frequency deviations; the installations of DG increases the burden on the system operator to maintain the system frequency.
• Less choice between more costly primary fuels; most DG technologies are based on gas.
• Higher harmonics; some DG technologies produce direct current. Thus, these units have to be connected to the grid via a DC–AC interface, which may contribute to higher harmonics.

On the other hand, power losses exist in all levels of power systems such as generation, transmission and distribution systems. But most of them occur in distribution systems because of the low voltage and high current levels and radial configuration of these systems. Distribution systems are organized radially because of better harmony of protective devices which are used in systems. Using distributed generators with the best placement and sizing will decrease the overall losses of the system. Solving of problem of finding best placement and sizing of DGs squanders very time that

requires testing very large number of network configurations. Hence, the evolutionary algorithms are used to implement it. There are several evolutionary algorithms that can be used to solve distribution problems like Ant Colony Search (ACS) [8], [9],Genetic Algorithm (GA) [10],[11],[12], Particle Swarm Optimization(PSO) [13], Tabu Search (TS)[14].

Using of evolutionary algorithms has been reported in many previous literatures. Rau and Wan present the method to identify optimal locations of distributed resources in a network to minimize losses, line loadings, and reactive power requirement by the second order algorithms [15]. T. K.A. Rahman et al. [16] discussed the sizing and allocation of DG in two separate steps using the evolutionary programming (EP) techniques. Nara and Hayashi presents tabu search application for finding the optimal allocation of DGs from a viewpoint of loss minimization [17]. In another approach, M. F. AlHajri et al. [18] discussed the DG sizing and placing in a single step using the combination of load flow and particle swarm optimization algorithm and Edwin Haesen et al. [19] enhanced Deependra's study by applying the GA method in each of the loading conditions for both summer and winter. Wichit Krueasuk et al. [20] applied the particle swarm optimization (PSO) algorithm in three different types of DG to determine the optimal sizes and location of DG.

In this paper, Genetic algorithm (GA) method based on new coding is proposed for determination of the best location and size of two type DGs in three cases for loss reduction. The proposed approach has been tested on IEEE 33-bus and IEEE 69-bus distribution radial test system and the program was simulated using MATLAB software.

The rest of this paper is organized as follows: Section II presents problem formulation for minimization of losses in distribution system, briefly. In section III, the genetic algorithm is described briefly and structure of new coding for sizing determination and DGs placement problems in genetic algorithm are presented. The results of application of DGs placement on 33-bus and 69-bus test systems by reconfiguration using genetic algorithms are presented and discussed in section IV. Finally, section V summarizes the main points and results of this paper.

2. Problem formulation

The optimal sizing and sitting for DG installations lead to the highest value of overall advantageous such as voltage profile improvement, line-loss reduction, and load balancing. In this paper determination of size and location of DGs for loss reduction is considered as objective function. Therefore, objective function is expressed as bellows:

$$Max\ LLR\% = \frac{LL_{wo/DG} - LL_{w/DG}}{LL_{wo/DG}} * 100 \qquad (1)$$

Where

$$LL_{w/DG} = \sum_{l=1}^{N} I_{l,w/DG}^2 R_l D_l \qquad (2)$$

$$LL_{wo/DG} = \sum_{l=1}^{N} I_{l,wo/DG}^2 R_l D_l \qquad (3)$$

And also, LLR% is percentage reduction of line-loss due to DG; $LL_{w/DG}$ is line-loss with the DG ,pu; $LL_{wo/DG}$ is line-loss without considering the DG, pu; R_l, is line resistance of line l, pu/km; D_l, is line length of line in km; $I_{l,w/DG}$, is current value of line l in pu after DG installation; $I_{l,wo/DG}$, current value of line l in pu before DG installation, the following constraints are considered in the optimization problem using genetic algorithm:

a. Traditional generation capacity constraints
For secure and stable operation, the active power at each traditional generator using DG ($P_{gw/DG}$) is restricted by its lower and upper limits.
$$P_g^{min} \le P_{gw/DG} \le P_g^{max} \qquad (4)$$

b. Total number of DG

Number of DG (N_{DG}) must be less than or equal to the maximum number of DG ($N_{DG/MAX}$) :

$$N_{DG} \le N_{DG/MAX} \qquad (5)$$

c. DG generation capacity constraints

The active power at each DG (P_{gd}) is limited by its lower and upper limits:

$$P_{gd}^{min} \le P_{gd} \le P_{gd}^{max} \qquad (6)$$

d) Voltage and current constraints
Voltage magnitude at each bus and Current magnitude of each feeder must satisfy permissible ranges as follows:

$$V_{min} \leq |V_i| \leq V_{max} \qquad (7)$$

$$|I_i| \leq I_{i,max}$$

Where,

$|V_i|$ -the voltage magnitude of nod I,

V_{min}, V_{max} -the maximum and minimum voltage limits, respectively.

$|I_j|$ -Current magnitude of each line j,

$|I_{j,max}|$ -maximum current limit of line j

3. Genetic algorithm

A) Overview of GA:

Genetic algorithms use the principle of natural evolution and population genetics to search and arrive at a best global solution. The GA begins with a very large set of initial candidate solutions. Each candidate solution is known as a chromosome, and the set of all chromosomes is created from the previous set through the so-called genetic operators (crossover, mutation, etc.)[22], [23]. Selection: The higher fitness solution string has more probability to have more copies, it has been verified that the average fitness improves from one generation to the next.
Crossover: takes two individuals and produces two new individuals, when two parents exchange parts of their corresponding chromosomes to allow chromosomes to exchange, that lead to innovating the solution strings.
Mutation: alters one individual to produce a single new solution; it can help the solution strings to have a wider area of feasible solutions. After these three genetic operations, the new generation solution strings exist. These new generation solution strings start the genetic operations repeatedly until the feasible solution is satisfied [22].
Crossover rate: The number of chromosomes that undergoes the crossover operation is determined by the crossover rate [22].
Mutation rate: The probability of mutation is usually small. The number of
Bits that undergo the mutation operation is determined by the mutation probability.
These new generation solution strings start the genetic operations repeatedly until the feasible solution is satisfied.
The flowchart of genetic algorithm is presented in Fig. 2.

### B)Coding for DGs installation

Coding of the solution is very important aspect of a correct implementation of the GA to achieve the results.

B-1) size and state of DGs

A string named Z of 9 binary bits represents each generator. This string consists of 3 parts. The first bit (part 1) represents the state of the generator (0 for off, 1 for 0n).The remaining 8 bits (part 2 & part 3) represent the power level of the generator, the first 4 bits (2nd to 5th) represented the active power of DGs and the second 4 bits (6th to 9th) represented the reactive power of DGs.
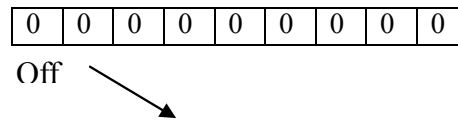
Examples:
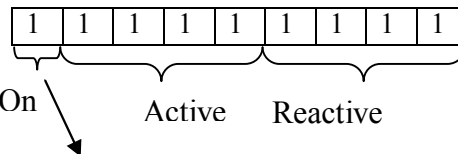Some examples indicates this string

Z= [100000000]

1	0	0	0	0	0	0	0	0

On   Active   Reactive
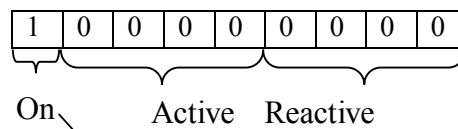
This chromosome represents a generator working at minimum capacity

Z= [000000000]

0	0	0	0	0	0	0	0	0

Off

This chromosome represents a generator which is not operating or not existing

Z=[111111111]

1	1	1	1	1	1	1	1	1

On   Active   Reactive

This chromosome represents a generator working at full capacity.

Z=[110100011]

1	1	0	1	0	0	0	1	1
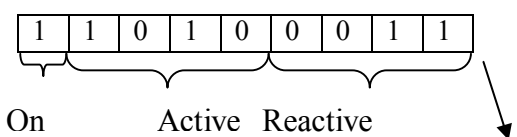
On   Active Reactive

This chromosome represents a generator working at 5/15% active power capacity and 12/15% reactive power capacity.

B-2) Location of DG

Each string Z represents the generator size to be placed at a given node, the representation of the general location of the generators over the grid is straightforward. A string P is defined directly as the concatenation of (Z×No. of nodes), bits. If system contains 32 nodes, the number of bits is equal to nodes number (32) ×bits per node (9) = 288 bits. As any string P describes a valid placement and size configuration of generators over the grid, therefore the string P is the chromosome used within the GA.

Namely for 33bus test system, Chromosome P is presented in Fig. 1. According to this figure, some of the generators are on and some of them are off. It means that some buses don't need any DGs. whereas, in buses which the first bit of chromosome is "1" (like Z1 & Z32), the DGs should be located, and afterwards it is possible to calculate the active power and reactive power by using of other 8 bits. The first 4 bits (2nd to 5th) are used to calculate the active power , while the reactive power calculation is achieves by contribution of other 4 bits (6th to 9th).
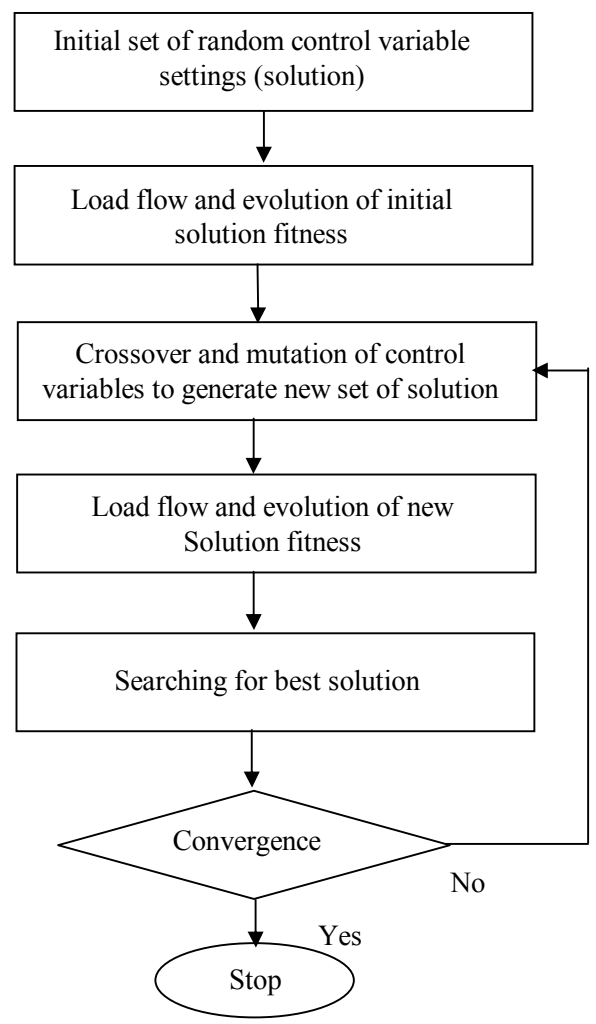
C) Algorithm

Initial set of random control variable settings (solution)

↓

Load flow and evolution of initial solution fitness

↓

Crossover and mutation of control variables to generate new set of solution

↓

Load flow and evolution of new Solution fitness

↓

Searching for best solution

↓

Convergence

No

Yes

Stop

Fig. 2. Genetic algorithm flowchart.

Active power   Reactive power   Active power   Reactive power

On   Off   On

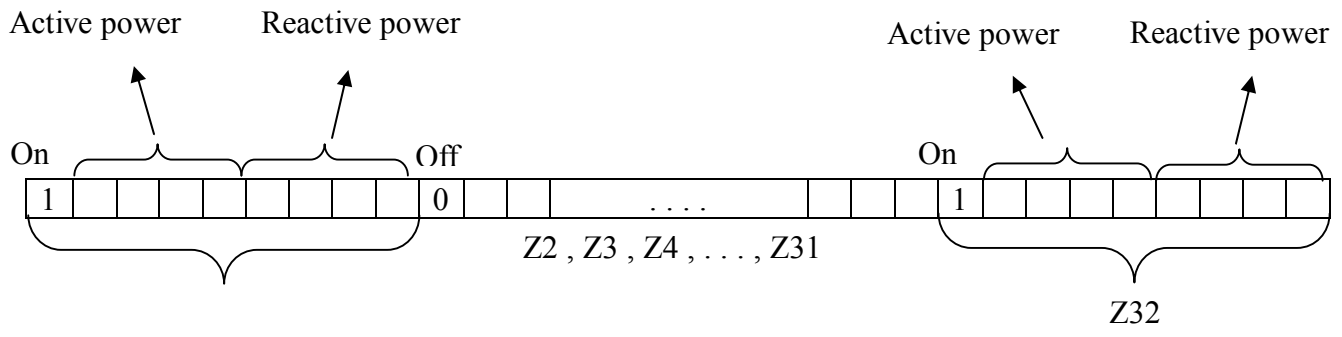| 1 | | | | | | | | | 0 | | | . . . . | | 1 | | | | | | | | |

$Z2 , Z3 , Z4 , . . . , Z31$

Z32

Fig. 1. Chromosome P.

4. Case study

Two distribution systems consisting of 33 and 69 buses are selected for DGs installation. For this purpose two type of DG are considered as follows:
1. DG is capable of supplying both real power and reactive power.
2. DG is only capable of supplying real power but consuming reactive power. For example, wind turbines use induction generators to generate electricity and consume reactive power to produce real power [24].

In order to indicate and compare the effects of DGs placement in the distribution systems, different three cases are considered and the results are compared to the case that there is no DG in the systems. Details of case studies are as follows:

Case 'I':One DG installation.
Case 'II':Three DGs installation.
Case 'III': Five DGs installation.

The results obtained in these systems are briefly summarized in the following sections.

A) 33-Bus Test System

The single line diagram of the 12.66 kV, 33-bus, 4-lateral radial distribution system is shown in Fig. 3. The data of the system are obtained from [26]. The total load of the system is considered as (3715+ j 2300) kVA and total active and reactive power losses in the system before DG installation are 202.64 kW and 134.37 kW, respectively.

Optimum size and locations of DGs in the type 1 for minimization of loss using GA in the different cases are determined and are shown in Table I. Also, total active and reactive losses in the system after DGs installation in the different cases are presented in this table. It can be seen from this table that determination of optimum size and location of DGs has a considerable effects on loss reduction in the test system. From Table I, it is observed that 16.09% and 16.34% active and reactive power loss reduction in the case I, 37.53% and 38.55% active and reactive power loss reduction in the case II and 58.78% and 59.92% active and reactive power loss reduction in the case III are achieved rather than to the base case. Also, Table II shows the results of Optimum size and locations of DGs in the type 2 for loss reduction in the different cases. Comparing tables I and table II shows using DGs in type 1 may result in more both of active and reactive power loss reduction compare to the case that DGs are used in type 2. Table II shows that using DGs installation in type 2 in the test system causes to 2.93% and 3.27% active and reactive power loss reduction in the case I, 3.51% and 3.78% active and reactive power loss reduction in the case II and 3.70% and 3.97% active and reactive power loss reduction in the case III, compare to the base case. Furthermore, convergence characteristic of genetic algorithm in the 33 bus test system is presented in Fig. 5.
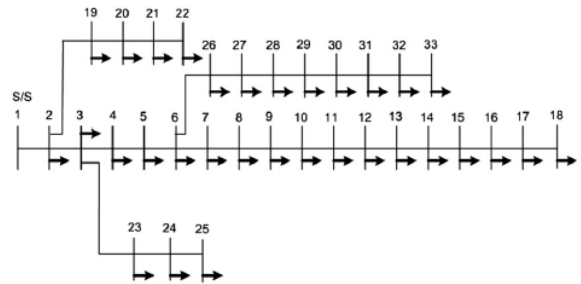

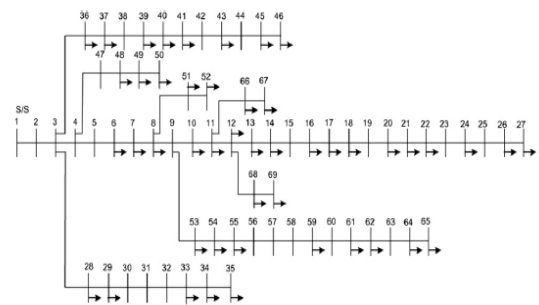Fig. 3. Single line diagram of 33 bus distribution test system.

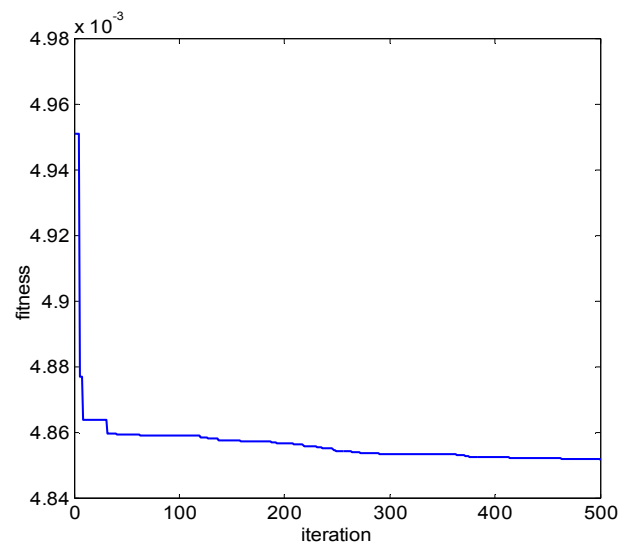Fig.4. Single line diagram of 69 bus distribution test system.

Fig. 5. Convergence characteristic of genetic algorithm in the 33 bus test system.

TABLE I
THE RESULT OF DGS INSTALLATION IN TYPE1 IN THE 33BUS TEST SYSTEM

Method		Bus. No	DG Size (KW)	DG Size (KVar)	P_{loss} (KW)	Q_{loss} (Kvar)	Loss reduction %	
							Real	Reactive
Base Case					202.64	134.37		
	Case I	17	12.5	112	170.0292	112.63	16.09	16.34
GA	Case II	10	125	0	126.5850	82.7238	37.53	38.55
		13	0	12.5				
		31	112.5	37.5				
	Case III	6	175	100	82.88	53.32	58.78	59.92
		11	12.5	25				
		14	112.5	87.5				
		27	75	187.5				
		31	187.5	100				

TABLE II
THE RESULT OF DGS INSTALLATION IN TYPE2 IN THE 33BUS TEST SYSTEM

Method		Bus .No	DG Size (KW)	DG Size (KVar)	P_{loss} (KW)	Q_{loss} (Kvar)	Loss reduction %	
							Real	Reactive
Load flow analysis					202.64	134.64		
	Case I	13	12.5	25	196.6937	130.2328	2.93	3.27
GA	Case II	4	112.5	0	195.5118	129.5381	3.51	3.78
		12	75	150				
		24	162.5	175				
	Case III	5	37.5	75	195.1342	129.29	3.70	3.97
		8	137.5	25				
		15	25	62.5				
		22	187.5	25				
		24	150	100				

B) 69-Bus Test System

The 12.66 kV, 69-bus, 8-lateral radial distribution system is considered as another test system that shown in Fig. 4. The data of the system are obtained from [25]. The load of the system is considered as (3.80+ j 2.69) MVA. The results of load flow show that total real and reactive line losses of the system in the base case are 224.9345 KW and 102.1359 KVar, respectively.

The results of DGs installation in type 1 and type 2 in 69 bus test system are presented in Table III and Table IV, respectively. Similar to 33-bus test system, the results obtained in tables III and table IV shows using DGs in type 1 may result in more both of active and reactive power loss reduction compare to the case that DGs are used in type 2. it can be seen from table III that using DGs in type 2 reduces 21.31% and 37.56% of active and reactive power loss reduction in the case I, 36.02% and 33.86% active and reactive power loss reduction in

in the case II and 42.72% and 41.72% active and reactive power loss reduction in the case III, while table IV shows that DGs installation in type 2 causes to 3.04% and 2.78% of active and reactive power loss reduction in the case I, 3.44% and 3.31% active and reactive power loss reduction in the case II and 3.57% and 3.28% compare to the base case.

Totally, in comparing the effect of DGs installation in type1 and type 2 in the two cases in the test systems, it is concluded that the effects of DGs on loss reduction in the systems as well as their effectiveness are similar.

TABLE III
THE RESULT OF DGS INSTALLATION IN TYPE1 IN THE 69BUS TEST SYSTEM

Method		Bus. No	DG Size (KW)	DG Size (KVar)	P_{loss} (KW)	Q_{loss} (Kvar)	Loss reduction %	
							Real	Reactive
Load flow analysis					224.93	102.13		
GA	Case I	61	50	37.5	176.98	81.76	21.31	37.56
	Case II	16	125	50	143.906	67.54	36.02	33.86
		62	100	175				
		64	37.5	125				
	Case III	10	100	137.6	128.82	59.52	42.72	41.72
		53	125	50				
		60	0	112.5				
		63	50	187.5				
		66	87.5	150				

TABLE IV
THE RESULT OF DGS INSTALLATION IN TYPE2 IN THE 69BUS TEST SYSTEM

Method		Bus. No	DG Size (KW)	DG Size (KVar)	P_{loss} (KW)	Q_{loss} (Kvar)	Loss reduction %	
							Real	Reactive
Load flow analysis					224.93	102.13		
GA	Case I	60	25	50	218.28	99.288	3.04	2.78
	Case II	8	0	112.5	217.17	98.74	3.44	3.31
		18	87.5	62.5				
		62	87.5	100				
	Case III	7	162.5	187.5	217.1313	98.7823	3.57	3.28
		17	100	62.5				
		58	75	0				
		63	12.5	0				
		67	0	100				

5. Conclusion

Optimum size and location of distributed generators using genetic algorithm (GA) for loss reduction in distribution systems are proposed in this paper. For this purpose, a new coding is employed in genetic algorithm which considers state, size and location of DGs. Also, two types of DG consisting of DGs with capability of supplying both real power and reactive power (type 1) and DGs with only capability of supplying real power but consuming of reactive power (type 2) are considered and comparative studies are conducted in the different cases to investigate the impacts of optimal DGs placement and its size determination on loss reduction. Two distribution systems consisting of 33 and 69 buses are selected for DGs installation. The results presented indicate that Installation of DGs in type 1 in the optimum size and Location has a considerable effect on loss reduction in the test systems. Moreover, the results show that using DGs in type 1 may result in more both of active and reactive power loss reduction compare to the case that DGs are used in type 2.

APPENDIX

The parameters of GA used for solving the problem presented in this paper are furnished in Table V.

TABLE V
THE PARAMETRS OF GA

Pop. Size	Crossover rate	Mutation rate	Algorithm Termination method
100	0.95	0.1	Termination the iteration

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