Losses Reduction and Voltage Improvement with Optimum DG Allocation using GA

MohdRuddinAb Ghani[1], Ihsan Jabbar Hasan[2], Chin Kim Gan[3], Z. Jano[4]

[1,2,3]Faculty of Electrical Engineering, UniversitiTeknikal Malaysia Melaka, Melaka, Malaysia
[2]Foundation of Technical Education, Baghdad, Iraq
[4]Centre for Languages and Human Development, UniversitiTeknikal Malaysia Melaka, Melaka, Malaysia

Abstract: The technology advancement in Distributed Generation (DG) has significantly influenced the environmental pollution; in power system, more specifically in distribution networks, DG is able to mitigate the total losses of a network which has a significant effect on environmental pollution. Optimal location and size of DG in distribution networks are among the important issues of the power system. This paper aims to investigate the best solution for optimal operation of distribution networks by taking DG into account. The optimal allocation of DG can be considered as an integer problem that can be formulated using metaheuristic methods. In this paper, the Genetic Algorithm (GA) has been used to solve the DG placement and sizing. The IEEE 123 bus test system has been utilized to demonstrate the effectiveness of the GA algorithm on herein mentioned problem. The result illustrates the losses minimization and the voltage profile improvement.

Keywords: DG Allocation, Distribution Network Planning, GA.

1. Introduction

Power system management has been facing with major changes during the past decades. The competitive environment has caused the development of various sectors such as generation, transmission and distribution. These developments and other issues such as environmental pollution, construction problems of the new transmission lines, and technology development in the construction of small generation units haveresulted in the increase in the utilization of Distributed Generation (DG).

Much research of Electric Power Research Institute (EPRI) ascertains that more than 25 present capacities of DGs have been installed by 2010. DGs are able to connect to the distribution network in most of the cases without transmission lines. Accordingly, the impact of DGs on losses and voltages of networks should be investigated comprehensively on distribution network operation and planning [1], [2].

Optimal operation of distribution networks refers to an optimal use of resources and equipment’s control such as the ability of transformer tap changer based on loads, AVRs and capacitors. An optimization of DG allocation has been applied to minimize the objective function by considering the technical problem constraint[3]. In the past, distribution networks were not able to connect the DG resources into the main utility grid whereas the present networks are able to simply connect DGs into the utility grid. More utilization of DG into the network may cause serious impact on conventional distribution networks. The problem formulation of optimal utilization of DG aims to reduce grid losses based on active power resources control pattern[4], [5].

In recent years, researchers have developed the optimum allocation of the DG in distribution networks utilizingvarious methodologies based on analytical tools and optimization programming methods [6]–[9]. In a study [8],the optimal sizing of DG by Improved Analytical (IA) method and Harmony search algorithm was used but the optimum placement of DG was not considered. The optimization based algorithms have also been utilized by many researchers [7], [9]. In [7]the optimum allocation of wind-based DG unit was presented by using particle swarm optimization technique. The results were compared with the analytical approach and verified. In [9] the dynamic programming application was performed for DG allocation in terms of loss reduction and reliability improvement.

Consequently, according to the literature reviewed on the DG allocating problem in

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network planning, the objective functions of distribution network planning need to be modified for future networks[10]–[13]. This can provide the appropriate patterns to control their impact and effect on distribution networks. This paper presents the impacts of connected DG into distribution networks and investigates the optimal locations and sizes of DGs using the GA method. Section 2 discusses the GA method that is used for a minimization of total cost of the network.

2. Methodology

Genetic Algorithm (GA) wasintroduced in 1975 by John H. Holland that simulated the process of gradual evolution[14]. In this section, the basic uses of genetic algorithm operators are investigated. This operator is used to generate a new population from the existing population. GA is searching algorithms based on the mechanics of natural selection and natural genetics. Invented and developed by John Holland and his colleagues in 1975 at the University of Michigan, GA is based on the Darwin's theory of evolution thus GA belongs to the larger class of Evolutionary Algorithms (EA)[15], which generates solutions to optimization problems using techniques inspired by natural processes of the selection of individuals and the evaluation of species as well as a reproduction mechanism and genetic transmission of characteristics. As a result of natural mechanisms, new species are originated ousting those that are not adjusted to their environment as well as themselves. Fig. 1 shows the GA flowchart. Crossover and mutation are the genetic algorithm operators and the steps as follows:

a) Create aninitialrandom solution and evaluate itscost or fitness. Initially, the algorithm begins with a randomly selected population in order to create the initial solution. The cost and fitness of the solution were evaluated as well.
b) Choose parents for the crossover operation in order to create the offspring population.
c) Choose the population of mutation operator to create the mutated population.
d) Integratethe first population, offspring, with mutated population to create the new population. Note that offspring population is generated by crossover operation and mutated population is obtained from mutation function.

2.1. GA Procedure

The procedures of GA [10] in a basic concept that can be outlined as shown in Table 1.

Table 1.GA procedures

Start		Generate random population of chromosomes, which makes the random solutions for the problem.
Cost		Evaluate the cost of each chromosome in the population.
New population		Create a new population by repeating the following steps until the new population is complete.
	Selection	Select two parent chromosomes from a population according to their cost or fitness. The better the cost, the bigger chance to be selected to be the parent.
	Crossover	With a crossover probability, crossover the parents to form new offspring, that is, children. If no crossover was performed, offspring is the exact copy of parents
	Mutation	With a mutation probability, mutate new offspring at each locus.
	Accepting	Place new offspring in the new population.
Replace		Use new generated population for a further run of the algorithm.
Test		If the end condition is satisfied, stop, and return the best solution in current population.
Loop		Go to step 2.

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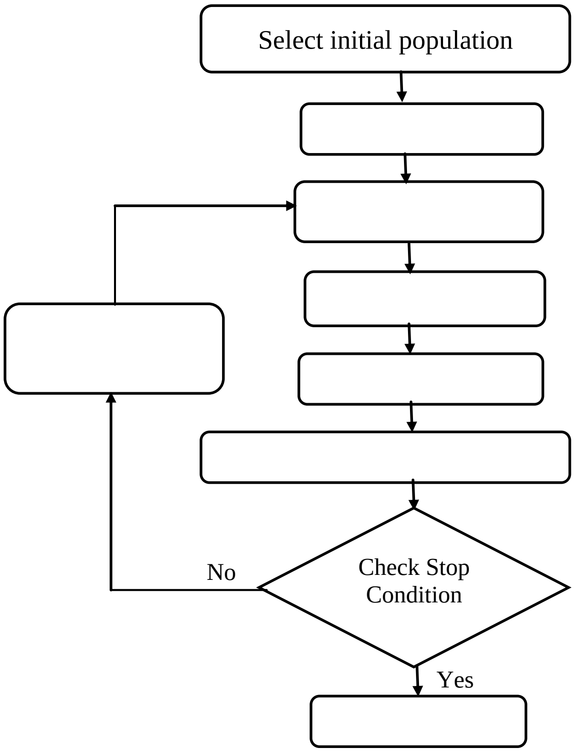

Fig.1. Genetic Algorithm flowchart

3. The impacts of DGs on voltage drop and transformer tap position

Due to the small ratio of X to R in distribution networks and the radial structure of these grids, the impact of DGs on distribution network voltage is significant. By considering this issue, the voltage drop for the network can be written as follows [16], [17]:

$$\Delta V = V_1 - V_2 = (R + jX)I \quad (1)$$

$$I = \frac{P - jQ}{V_2^*} \quad (2)$$

$$|\Delta V|^2 = \frac{(RP + XQ)^2 + (RP - XQ)^2}{V_2^2} \approx \frac{(RP + XQ)^2}{V_2^2} \quad (3)$$

where,ΔV is the line voltage drop,$R+jX$ is the line impedance, Q is the reactive power, $P$is the active power, $V1$ & $V2$ and I, are the Bus 1 and 2 voltage amplitude and the current flow through the line, respectively. The above equations should be considered as one of the constraints of the optimization problem. This constraint can be considered as a penalty factor into the objective function. The transformer taps positions can be influenced by a voltage improvementin distribution networks, which is important for a voltage regulation.

Once the voltage at the secondary terminal of the transformer has improved as possibly close to one per unit, the tap position steps can be situated in initial position. This act provides more opportunity to a voltage regulation by tap changer and will increase the lifecycle of transformers that would be cost effective[18]. In other word, the voltage improvement by means of allocating DG units into the distribution network will cause more flexibility for the transformer tap changer to regulate the voltage.

4. Objective function & problem formulation

The objective function and constraints are formulated in this section. DG placement and sizing have influenced the total network losses in distribution networks. Therefore, the power losses reduction and voltage improvement will be obtained from the following objective functions of Sections 4.1 and 4.2 for the radial distribution network. The power losses and voltage improvement formulations have beendescribed indetails [19], [20].

4.1 Power losses formulation

The total power losses equation can be introduced as follows:

$$L_{real\ power} = \sum_{i=2}^{n} (APO_i - APD_i - (Vs_i * Vr_i * Ysr_i * \cos(\delta r_i - \delta s_i + \theta y_i)) \quad (4)$$

where,

$L_{real\ power}$ Real Power Losses

APO_i Active power from bus i

APD_i Active power on demand bus i

Vs_i Voltage from sending bus i

Vr_i Voltage on receiving bus i

Ysr_i Admittance of sending and receiving bus i

δs_i Phase angle of sending bus i

δr_i Phase angle of receiving bus i

θy_i Phase angle of $Y_i < \theta_i$

4.2 Improve the voltage profile

The drop voltage equation can be written as follows [15, 16]:

$$V_P = \sum_{i=1}^{n} (Vr_i - V_{rate})^2 \qquad (4)$$

where,

V_P Voltage profile objective function

V_{rate} Rated voltage [p.u.]

Those equations (4) and (5) represent the main objective function which can be written as follows :

$$Z = Min[(L_{real\ power} + \gamma * V_P) + DP] \, (5)$$

where, γ is the violation coefficient and $DP$is the Penalty factor (derived from problem constraint) Z Evaluation function (minimized with GA).

4.3 The problem constraints

The following shows the problem constraints of distribution network planning:

Bus voltage $V_i^{\min} \le V_i^t \le V_i^{\max}$

Current feeders $I_{fi} \le I_{fi}^{rated}$

Reactive power of capacitors $Q_{ci}^{\min} \le Q_{gi}^t \le Q_{ci}^{\max}$

Maximum power line transaction $\left|P_{ij}^{line}\right|^t \le P_{ij\ \max}^{line}$

5. Case Study

The test case that is used in this paper is the IEEE 123 node which is shown in Fig.2. This case has been used to demonstrate the functionality of the proposed algorithm in order to find the optimum placement and sizing of the DG into the predefined test case. There are a few initial assumptions of the DG sizes and constraints which are specified as follows:

- Maximum number of DG units: 123 units (all nodes)
- Minimum power generation for each DG unit: 100kW
- Maximum power generation for each DG unit: 1MW
- Voltage constraint ($0.95 \le V_{node} \le 1.05$)

DG units are considered as constant output generation with power factor unit.

Table 2 shows the comparison between the IEEE 123 node standard and optimum DGs allocation cases. As obtained from the result, after allocating the optimum DG to the standard test case, the losses of the network have been reduced, significantly. Table 2 illustrates the number of installed DG units after optimum allocation of capacitors into the related distribution network. The total loss of the network is reduced from 95.2kW to 18.54kW after installation of DG units. It should be noted, the losses reduction is obviously causing the total cost decreases. The optimization cost reduction is based on iteration number as shown in Fig.3. It illustrates the proposed algorithm which is gradually converging to the minimum possible losses as defined in optimum DG case in Table 2. In addition, Table 2 indicates the minimum and maximum voltages of the network for both cases. The distance voltage drop profile for the case without DG installation is shown in Fig.4 (a) and after optimum DG allocation is shown in Fig.4 (b). It shows the voltage profile has been improved by allocating the optimum DG compared to the standard case.

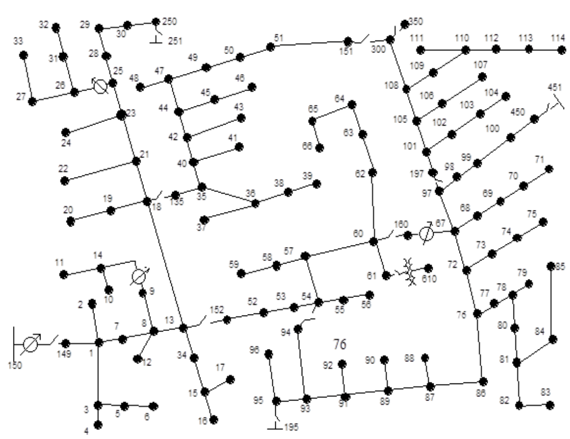

Fig.2. One line diagram of IEEE 123 nodes

Table 3 illustrates the transformer tap changer position which is extremely important in terms of the voltage regulation controller of the transformers. The transformer tap position

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number has been decreased in optimized DG allocated case compared to the standard case. In other word, transformers have more flexibility in order to perform a voltage regulation if the position of tap changer is close to zero. The results of tap position show the positive impact of DG on transformer tap position which may increase the transformer lifecycle. For instance, in 'reg1a' the initial tap position was situated at 6, but after DG implementation it was changed to 3. The maximum taps position was 16 steps, in which,initially, DG allocation transformer was able to improve the voltage just 10 more tap steps whereas afterward, DG was able to provide 13 free tap steps. Table 4 shows the OpenDSSfile for DG placement and size.

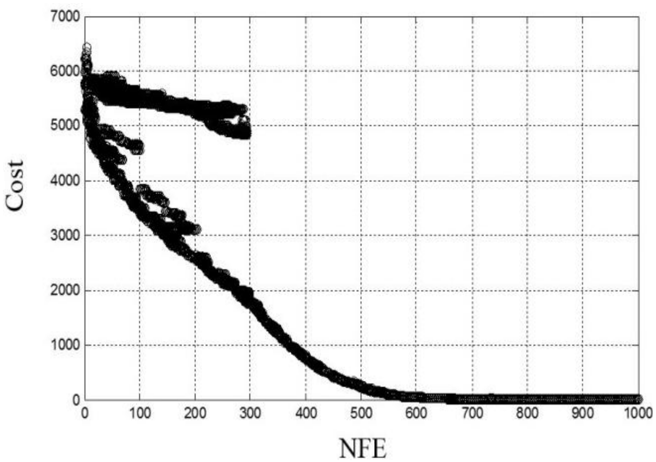

Fig.3.The losses minimization

Table 2: Comparison between standard and optimum case

	Standard case	After optimum DGs allocation	
Numbers of DG units	No DG units	Node 30:150kW Node 38:100kW Node 51:100kW Node 67:100kW Node 77:150kW Node 80:150kW Node 104:100kW Node 106:100kW Node 117:100kW	
		Total	9 units: 1050kW
Total Losses[kW]	95.2	18.54	
Min.voltage[p.u.]	0.9792	0.9886	
Max.voltage[p.u.]	1.0500	1.0461	

Table 3: Transformer taps changercomparison

	Standard case		After optimum DGs allocation	
	Tap[p.u]	Position	Tap[p.u]	Position
reg1a	1.03750	6	1.01875	3
reg2a	1.00000	0	1.00625	1
reg3a	1.01250	2	1.00625	1
reg3c	1.00000	0	0.99375	-1
reg4a	1.06250	10	1.04375	7
reg4b	1.01250	4	1.02500	4
reg4c	1.03750	6	1.03125	5

Table 4: The OpenDSS file for DG placement and size (Generation.dss)

Generator number	Bus number	Phases	Voltage Base	Real Power	Power factor
New Generator.DG.30	Bus1=27.1.3	Phases=2	kv=2.4	kW=150	pf=1
New Generator.DG.38	Bus1=36.1.2	Phases=2	kv=2.4	kW=100	pf=1
New Generator.DG.51	Bus1=49.1.2.3	Phases=3	kv=2.4	kW=100	pf=1
New Generator.DG.67	Bus1=65.1.2.3	Phases=3	kv=2.4	kW=100	pf=1
New Generator.DG.77	Bus1=76.1.2.3	Phases=3	kv=2.4	kW=150	pf=1
New Generator.DG.80	Bus1=77.1.2.3	Phases=3	kv=2.4	kW=150	pf=1
New Generator.DG.104	Bus1=101.1.2.3	Phases=3	kv=2.4	kW=100	pf=1
New Generator.DG.106	Bus1=105.1.2.3	Phases=3	kv=2.4	kW=100	pf=1
New Generator.DG.117	Bus1=114.1	Phases=1	kv=2.4	kW=100	pf=1

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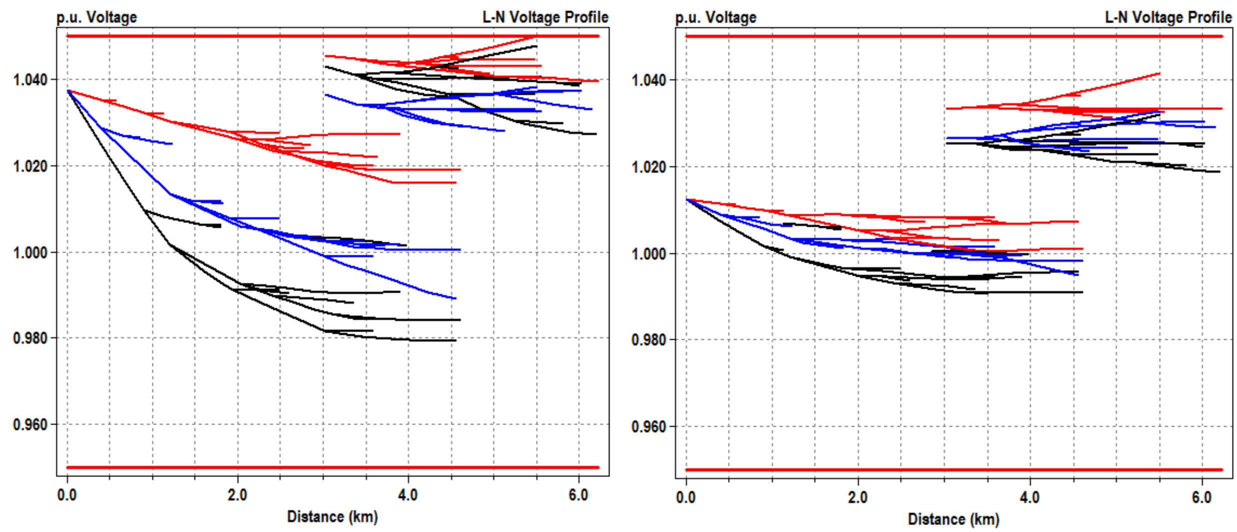

(a) (b)

Fig.4. The voltage drops in distance for both (a) before DG and (b) after DG installation

6. Conclusion

In conclusion, more studies should be geared in terms of the impact of DG on distribution networks. This paper analyzes optimal placement and sizing of DGs. The Genetic Algorithm (GA) is used to solve the objective functions of optimum DG placement and size in distribution network. The results show the total losses can be minimized significantly by allocating the optimum size of DG in the optimum placement. In addition, the minimum voltage profile of the network is reinforced to the specified standard range and in general, voltage profile is improved. In short, using DG units in distribution networks is the proper solution in reinforcing the network operation, if the size and placement of units allocated adequately.

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