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Optimal Allocation and Contingency Analysis Studies of Embedded Generation in Distribution Systems

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Abstract – *This paper presents two areas of studies of embedded generation (EG) viz. optimal allocation and contingency analysis. The paper is started by introducing a method that uses real code genetic algorithm technique to allocate the location and the size of EG in distribution system. It follows by the evaluation of the impact of the location and size of EG to the system. The analysis will cover before and after the contingency is created in the system due to fault. The allocation method and contingency analysis study are demonstrated using 24 bus and IEEE 69-bus radial distribution systems.*

Keywords – Contingency analysis, deregulation, distributed generation/embedded generation, real coded genetic algorithm.

1. INTRODUCTION

In the past, information concerning embedded generation (EG) penetration levels in transmission grid studies and voltage stability effects could not be evaluated. Analytical approaches and modeling techniques for transmission system planning were not available to guide bulk transmission engineers in the evaluation of optimal incorporation of EG technologies. This is due to the fact that distributive technologies have not been considered as having impact on the bulk transmission system. This modeling concern became even more apparent in the new millennium. One of the key alternatives proposed was the utilization of EG to meet the requirements of the electrical system. This question could not be properly answered at the time and is one of the motivations for engaging in this research.

As a result of restructuring of electricity markets and the target laid down for renewable energy, increasing amounts of EG are being connected to distribution networks. To accommodate this new type of generation, the existing distribution network should be utilized and developed in an optimal manner. Most distribution systems have been designed to operate with the main source as the only supplier of the loads with the power flowing from the source to the end of the feeder. However, EG involvement has changes the convention of the power flow being radial. Now the power flow can be reversed with the EG sending power in either direction from where it is placed, thus disturbing the radial nature. The power flow changes with change in EG location and size and loading conditions. It is paramount to focus on the optimal placement and size of EG on a distribution system to keep the system in an economical and secured state. To date, the application of artificial intelligence and optimization techniques become the choice of many researchers to determine the optimal allocation of EG. The using of evolutionary programming (EP) in optimal allocation of distributed generation has been proposed in [1]. The authors use the sensitivity indices as the tools to predict the placement of EG at a particular bus. The optimal allocation problem using ant colony optimization (ACO) is proposed in [2]. A cost based model to find the optimal size and location of DG sources which using a minimization of DG investment cost and total operation cost of the system are presented. ACO also has been applied to solve optimization problem of voltage and reactive power control with considering the distributed generators [3]. The incorporation of particle swarm optimization (PSO) for distribution generation sizing and location is proposed in [4]. The authors emphasize on improvement of voltage profile, total harmonic distortion and losses in their approach to determine the location and size of DG. The incorporation of genetic algorithm (GA) in this problem also has been proposed [5]. However, the implementation of GA is not explained in details.

With rapid penetration of EG into distribution systems, it is critical to assess power system impacts accurately so that these EG units can be applied in a manner that avoids causing degradation of power quality, reliability and control of the utility system. The impact of large scale EG penetration on the stability of bulk power transmission networks has been done in [6]. However, the study of EG’s impact to the current practice of distribution system offers a lot of opportunity to be explored to improve distribution system performance. The impact of the EG in term of fault analysis that utilizes an inverter interface distributed generator (IIDG) has been proposed in [7]. The authors developed a method to capture IIDG behavior during the fault period.

This paper focuses on a method (real coded genetic algorithm) to find the optimal size and location of EG on a test cases with respect to losses. It is expected that once optimal solution is found, the voltage profile of the

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test system is also will be improved. Later on, this paper presents a contingency analysis of the system due to fault. The analysis will cover before and after contingency is created and explores the impact of EG after the system is reconfigured to continue the operation.

2. REAL CODED GENETIC ALGORITHM

Genetic Algorithm (GA) is a subset of evolutionary algorithms that model biological processes to solve the optimization problems. GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the "fitness" (i.e. minimizes the cost) function. The method is developed by Holland (1975) [8] over the course of the 1960s and 1970s and finally popularized by Goldberg [9]. GA approach can be divided into two: binary and continuous real number. For this paper, real coded GA (RCGA) is used since it has an advantage in the accurate representation of the continuous parameter.

Representation

If the chromosome has N_{par} parameters (an *N*-dimensional optimization problem) given by $p_1, p_2, \ldots, p_{Npar}$, then the single chromosome is written as an array with 1 x N_{par} elements as follows:

$$chromosome = [p_1, p_2 ....., p_{Npar}] \tag{1}$$

Initialization

RCGA does not work with a single string but with a population of strings, which evolves iteratively by generating new individuals taking the place of their parents. Normally, the initial population is generated at random.

Evaluation Function

The performance of each string is evaluated according to its fitness. Fitness is used to provide a measure of how individuals have performed in the problem domain. The choice of objective and fitness function is proposed in the next section.

Genetic Operators

With an initial population of individuals and evaluated through its fitness, the operators of RCGA begin to generate a new and improved population from the old one. A simple RCGA consists of three basic operations: selection, crossover and mutation.

Selection determines which individuals are chosen for crossover and a process in which individual chromosomes are copied according to their fitness. Parents are selected according to their fitness performance and this can be done through several methods. For this paper, *roulette wheel* selection method [9] is used.

Crossover is a process after the parents chromosomes are selected from *roulette wheel* method. It is a process that each individual will exchange information to create new structure of chromosome called offspring. In this paper, the single-point arithmetic crossover method is used. The concept is modified from [10] to prevent loss of information if extrapolation method is used. It begins by randomly selecting a parameter in the first pair of parents to be crossover at point:

$$\alpha = round\{random * N_{par}\} \tag{2}$$

Let

$$parent_1 = [p_{m1}, \ldots p_{m\alpha}, \ldots, p_{mNpar}] \tag{3}$$

$$parent_2 = [p_{d1}, \ldots p_{d\alpha}, \ldots, p_{dNpar}] \tag{4}$$

where *m* and *d* subscripts discriminate between the *mom* and *dad* parent. Then the selected parameters are combined to form new parameters that will appear in the offspring, as follow:

$$p_{new1} = p_{m\alpha} - \beta[p_{m\alpha} - p_{d\alpha}] \tag{5}$$

$$p_{new2} = p_{d\alpha} + \beta[p_{m\alpha} - p_{d\alpha}] \tag{6}$$

where β is also a random value between 0 and 1. The final step is to complete the crossover with the rest of the chromosome, as follow:

$$offspring_1 = [p_{m1}, \ldots p_{new1}, \ldots, p_{mNpar}] \tag{7}$$

$$offspring_2 = [p_{d1}, \ldots p_{new2}, \ldots, p_{dNpar}] \tag{8}$$

The modification has been made in Equations 7 and 8. In [10], all the parameters of mum and dad to the right of selected parameter are swapped. Several simulations show that much iteration is required to obtain optimal results due to a lot of information at each chromosome have been changed. Thus in this paper, only selected parameter is changed to prevent loss information of each chromosome.

Although selection and crossover are applied to chromosome in each generation to obtain a new set for better solutions, occasionally they may become overzealous and lose some useful information. To protect these irrecoverable loss or premature convergence occur, mutation is applied. Mutation is random alteration of parameters with probability of mutation is normally set around 0-10%. Multiplying the mutation rate by the total number of parameters gives the number of parameters that should mutated. Next, random numbers are chosen to select of the row and columns of the parameters to be mutated. A mutated parameter is replaced by a new random parameter.

3. RCGA FOR OPTIMAL ALLOCATION OF EG

In this section, the incorporation of RCGA technique is used to find the optimal location and size of EG units in the distribution system. The main objective is to minimize the total losses in the system. By minimizing the losses, the voltage profile at each bus are also expected to be improved. This approach requires load flow to be run several times. After finding the best location and the size of EG simultaneously, the algorithm is terminated. The objective function is the result of total loss obtained from load flow study, P_{Loss}^{j} to be minimized, H as follows:

$$H = \min\left(\sum_{j=1}^{nline} P_{Loss}^{j}\right) \tag{9}$$

where *nline* is the number of transmission lines in the system. Before incorporated RCGA to optimal allocation of EG, some factors need to be considered: (1) coding the variables into a finite string or chromosome and (2) mapping the objective function into a fitness form. The variables of the optimal allocation of EG problem are coded in the following manner. Firstly, each variable X is coded as the continuous floating numbers that range from 0 to 1. Then, the variables are concatenated to construct a multivariable string. The total multivariable or the length of chromosome is equal to *(num_EG* x *2)* as shown in Figure 1. Each EG representatives need to multiple with 2 because the first variable represents the location and the second one represents the size of EG.

After evaluating each chromosome, the objective function in Equation 9 is transformed and normalized to a fitness scheme to be maximized as follows:

$$f = \frac{1}{1+H} \tag{10}$$

The flow of incorporation of RCGA to optimal allocation of EG is shown in Figure 2.

4. OPTIMAL ALLOCATION OF EG

The method has been tested on two test systems, viz. 24 bus and IEEE-69 bus radial distribution systems. The reason of using two test systems is to show the robustness of the technique and also to prove that this method can be worked at any system. The proposed technique has been programmed in MATLAB. The load flow program of Newton-Raphson that has been developed in [11] is used.

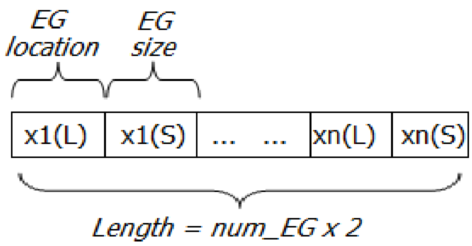

Fig. 1. Chromosome.

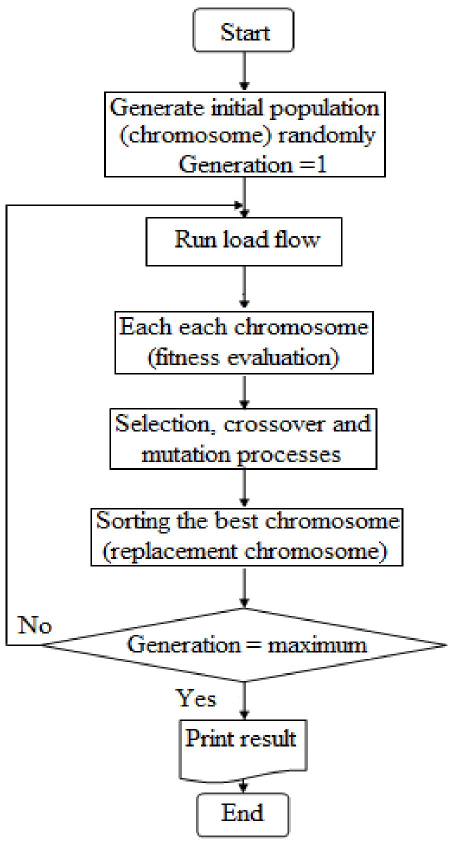

Fig. 2. Flow of optimal allocation of EG using RCGA.

24-Bus System

This test system consists of one substation and 23 buses of customers as shown in Figure 3. The data for this system is tabulated in Tables A and B in Appendix. To obtain the optimal location and size of EG, the GA properties are set as follow:

- Selection: *roulette wheel*
- Crossover probability, $\rho_c = 0.9$,
- Mutation probability, $\rho_m = 0.1$,
- Population = 40,
- Number of EG unit = 1,
- EG size = 0.01 MW<P^{EG}<2.5 MW,
- Maximum iteration = 50.

Figure 4 shows the result of objective function, *H* versus iteration for this system. The minimum value of loss is 0.0099 MW. From this simulation, EG unit that needed to be installed is at bus 10 with the size of 0.3446 MW. The installation of EG unit at bus 10 has improved about 60% for the power losses compared to base case, which is no installation of EG unit in the system.

Table 1 shows the comparison of voltage profile at each bus in the system before and after installation of EG unit in the system. From this table, it can be seen that the voltage profile is improved from the base case.

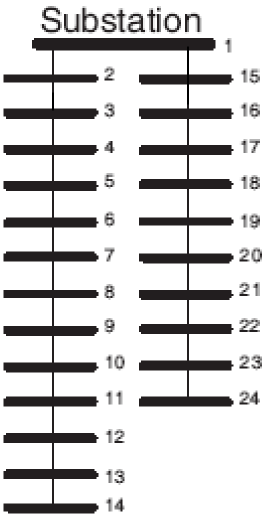

Fig. 3. 24–bus radial distribution system.

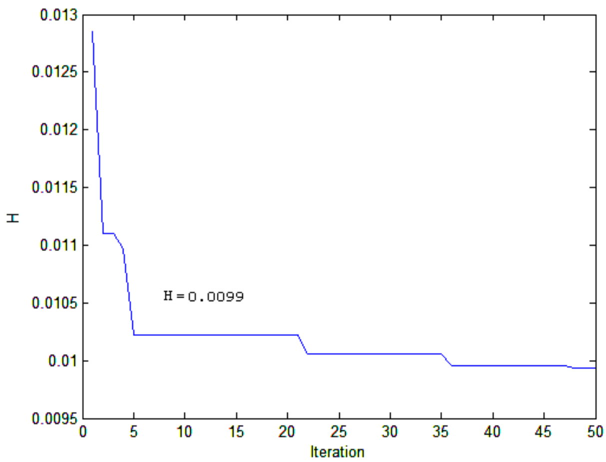

Fig. 4. Objective function, *H* versus iteration for 24 bus system.

Table 1. Voltage profiles before and after EG installation.

Bus Number	Voltage before EG		Voltage after 1 EG	
	|V|	Angle(°)	|V|	Angle(°)
1	1	0	1	0
2	0.98743	-0.23999	0.9937	0.07932
3	0.9771	-0.42443	0.9892	0.19713
4	0.96839	-0.58252	0.9858	0.31986
5	0.96105	-0.71805	0.9834	0.44728
6	0.95482	-0.83452	0.9818	0.57994
7	0.94945	-0.9361	0.9809	0.72067
8	0.94641	-0.86057	0.9819	0.80514
9	0.94307	-0.9241	0.9822	0.94122
10	0.94059	-0.97158	0.9829	1.07094
11	0.93907	-1.0008	0.9815	1.04415
12	0.93811	-1.01923	0.9806	1.02728
13	0.93777	-1.02594	0.9802	1.02113
14	0.93766	-1.02803	0.9801	1.01921
15	0.99768	-0.04062	0.9977	-0.04062
16	0.99539	-0.08103	0.9954	-0.08103
17	0.99169	-0.14642	0.9917	-0.14642
18	0.98844	-0.20434	0.9884	-0.20434
19	0.98578	-0.25229	0.9857	-0.25229
20	0.9837	-0.29026	0.9837	-0.29026
21	0.98228	-0.31686	0.9823	-0.31686
22	0.98111	-0.33891	0.9811	-0.33891
23	0.98023	-0.35534	0.9802	-0.35534
24	0.97975	-0.36443	0.9798	-0.36443

IEEE 69-Bus System

This test system can be obtained in [12]. Figure 5 depicts this test system with a total real and reactive power demand is 3802.19 kW 2694.60 kVar, respectively. The GA properties are set same as 24-bus system with number of EG unit that need to be installed is either one or two units. The reason of using until two units of EG is due to the cost of installation issue. Since this test system is moderate in size, it is adequate to install up to two units of EG. However, this time, the following three cases are considered:

Case 1: Calculate the distribution network losses and minimum voltage magnitude before the EG installation.

Case 2: Repeat case 1 with the 1 EG unit included once its optimal location and sizing are determined.

Case 3: Repeat case 1 with the 2 EG units include once their optimal locations and sizing are determined.

Figure 6 shows the objective function, *H* versus iteration for case 2. The minimum value of loss is 0.0832 MW. From this simulation, the EG unit that needed to be installed is at bus 61 with the size of 1.8737 MW. The installation of EG unit at bus 61 has improved about 60% for the power losses in the system.

Figure 7 shows the simulation result of two units of EG installed in the system (case 3). EG units that needed to be installed at bus 61 with the size of 1.706 MW and at bus 12 with the size of 0.8311 MW. The installation of EG units at these buses has improved about 67% for the losses in the system. The comparison from case 1, case 2 and case 3 are reported in Table 2.

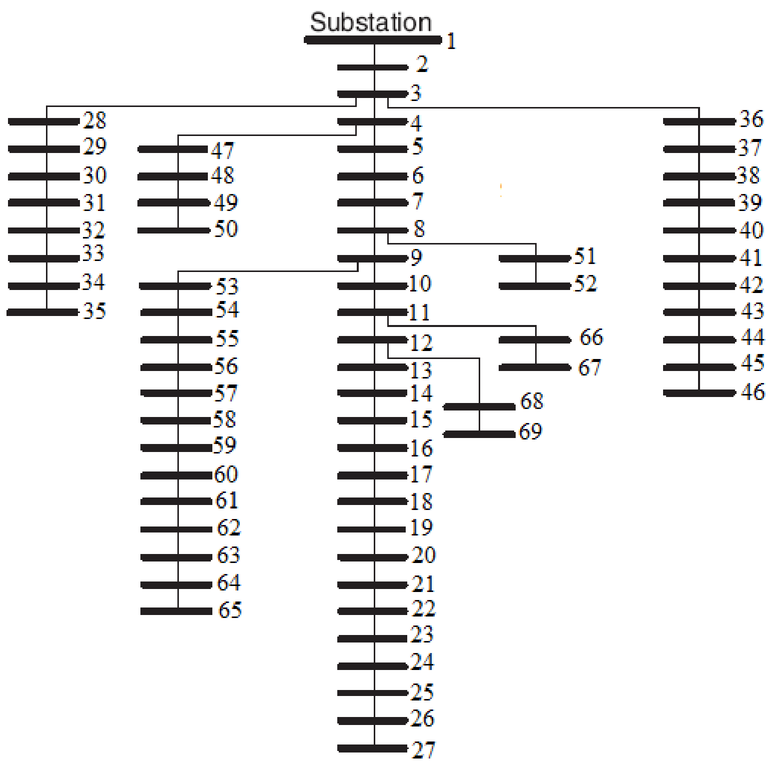

Fig. 5. IEEE 69-bus radial system.

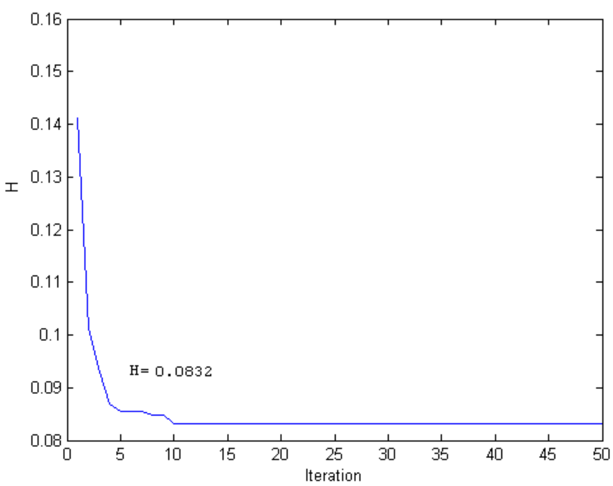

Fig. 6. Objective function, *H* versus iteration for case 2.

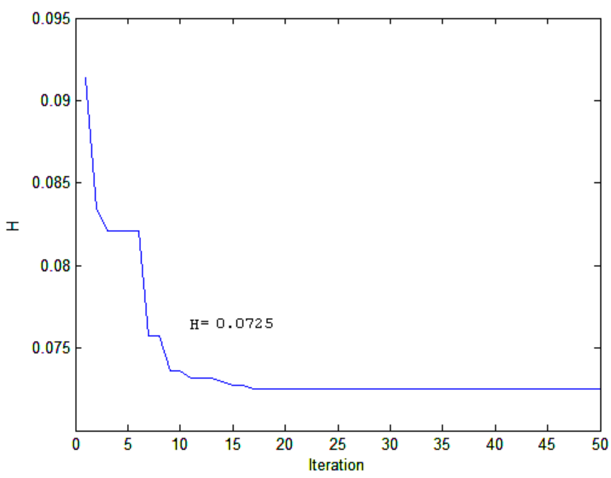

Fig. 7. Objective function, *H* versus iteration for case 3.

Table 2. Results for cases 1, 2 and 3.

	Case 1	Case 2	Case 3
Real Power Losses (MW)	0.2249	0.0832	0.0725
Minimum Bus Voltage (p.u)	0.9092 @ bus 65	0.9683 @ bus 27	us 65

5. CONTINGENCY ANALYSIS STUDY

This section focuses on the IEEE 69-bus test system only, which is the analysis is done by introducing a contingency situation which is referring to the fault to see the impact of EG that has or have been installed in the system. The study will emphasizes on the changes of voltage profiles of the system and the system losses before and after reconfigurations caused by the fault. However, the type of faults will not be considered since it is assumed that the system is reconfigured after the isolation of the faulted area. This study may help in finding the trends of optimal size and location of EG in this test system. In this study, two cases (Case 4 and Case 5) are analyzed where line 12-13 and line 61-62 are assumed suffer a fault. Thus buses 13 to 27 and buses 62 to 65 are isolated from the system for Cases 4 and 5 respectively. Figures 8 and 9 show the test system where the bus numbers after reconfigurations are shown in brackets.

To observe the changes in the voltage and losses due to the contingency and impact of EG, the study is divided into the following scenarios:

For Case 4:

Case 4a: The base case, viz. without EG and without the contingency.

Case 4b: with one unit of EG and without contingency.

Case 4c: with two units of EG and without the contingency.

Case 4d: without EG and with the contingency.

Case 4e: with one unit of EG and with the contingency.

Case 4f: with two units of EG and with the contingency.

For Case 5:

Cases 5a: repeat case 4d.

Case 5b: repeat case 4e.

Case 5c: repeat case 4f.

These two cases are emphasized to see the impact of EG into the system with separate contingency location. Figure 10 shows the comparisons of voltage profiles at each bus for cases a, b and c where the contingency is not considered. It can be seen that the result for case c gives the better results. This is due to two units of EG alleviate the burden of generator bus 1 and therefore improve the voltage profiles of the system. The minimum voltage is at bus 65, which is 0.9781p.u. For case 4b, the minimum voltage is different from cases 4a and 4c, where the minimum voltage is at bus 27 which is 0.9683p.u. The minimum voltage for base case is 0.9092p.u.

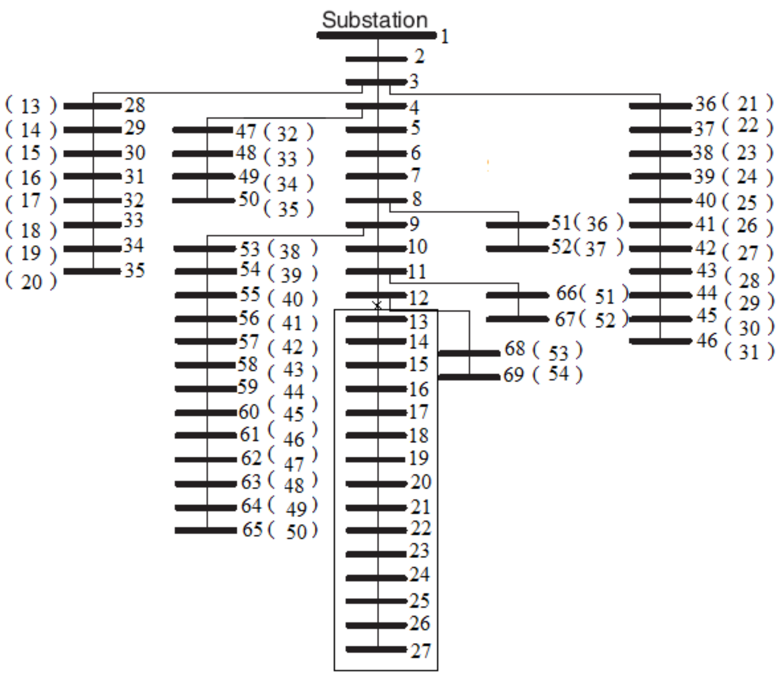

Fig. 8. IEEE 69-bus system after reconfigurations for Case 4.

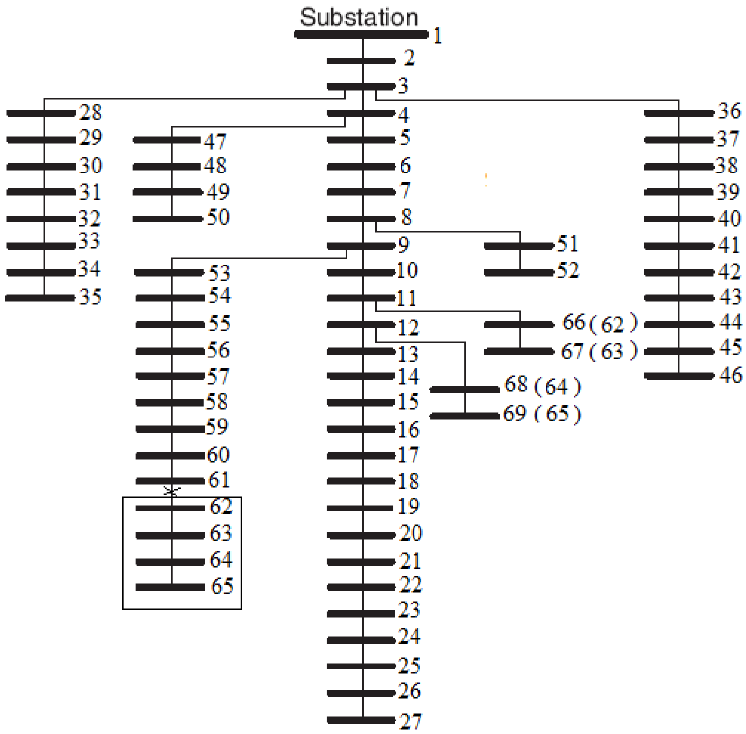

Fig. 9. IEEE 69-bus system after reconfigurations for Case 5.

Figure 11 shows the comparison of voltage profiles when the contingency is considered where fault is assumed occurred at line 12-13. From this result, it can be seen that the pattern of voltage profiles are slightly different with from previous cases which is shown in Figure 10. It can be seen that for Case 4f, the voltage at buses 12, 68 (53) and 69 (54) are exceeding 1.0 p.u. However, the maximum voltage magnitude that exceeds 1.0 p.u for this case is not more than 0.15%. It also can be noted that the minimum voltage has been changed for Case 4e where after contingency, the minimum voltage is now at bus 65 (50). The impact of contingency to the base case (Case 4d) is the voltage at bus 65(50) is now increased to 0.9124p.u from 0.9092p.u. This is due to the system is less loading condition compared to the system in Case 4a.

For case 5, the pattern of the result is depicted in Figure 12. It can be observed that the minimum voltage for the system with no EG (Case 5a) is occurred at bus 61. From this simulation result, it can be concluded that the selection of bus 61 for EG location is correct since this bus is actually critical for the system. Form this figure also, it can be noted that the minimum voltage is located at bus 27 for both Cases 5b and 5c.

The summary of the simulation results is presented in Table 3. In general, the losses of the system are reduced for the contingency cases compared to the system without contingency. This is due to the reduction of buses in the system which means reducing the demands. It is also worth to highlight the comparison in terms the total system loss between cases 4e and 4f. Even the voltage profiles for Case 4f is better from Case 4e, the total system loss for Case 4e is slightly better compared to Case 4f. This is because of for Case 4f, the reverse power flow is happened from bus 12 to bus 11 which is suffers much losses compared to Case 4e. For Case 4e, since the bus 12 is not a generator bus, the power is flow in radial, which is from bus 11 to bus 12. From this study, it can be conclude that EG installation gives much improvement to losses and voltage profile even for the contingency situation. The issue that needed to be highlighted is the number of EG units to be installed due to cost.

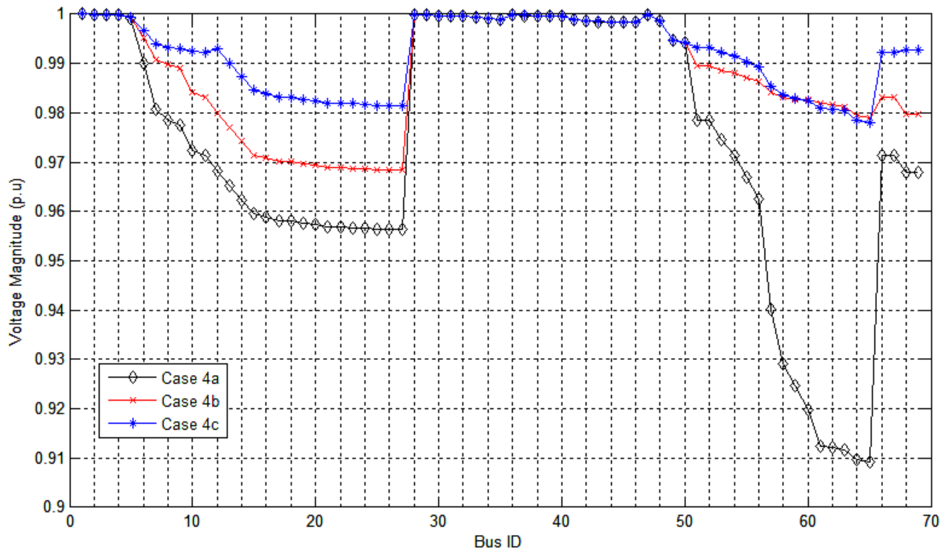

Fig. 10. Voltage profiles for cases 4a, 4b and 4c.

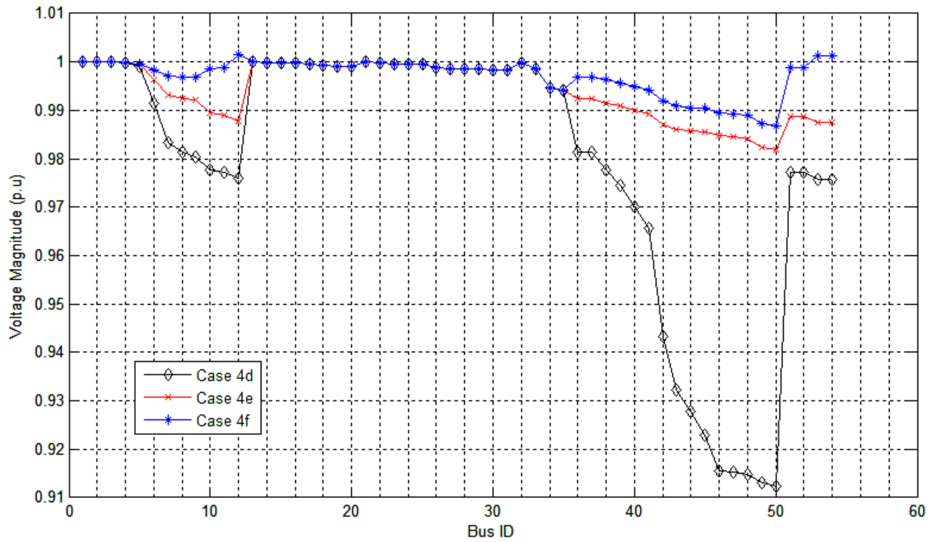

Fig. 11. Voltage profiles for cases 4d, 4e and 4f.

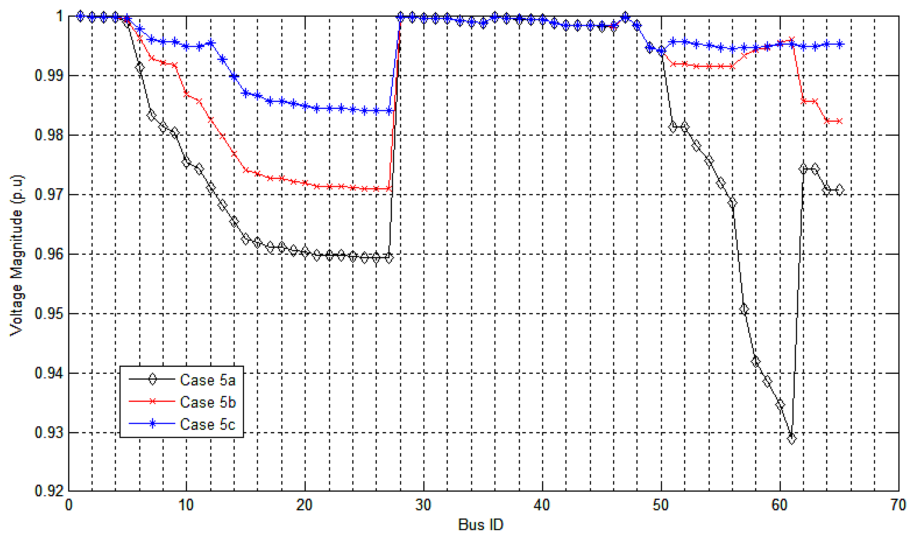

Fig. 12. Voltage profiles for cases 5a, 5b and 5c.

Table 3. Results for cases 4 and 5.

	Real Power Loss (MW)	Minimum Bus Voltage (p.u)
Case 4a	0.2249	0.9092 @ bus 65
Case 4b	0.0832	0.9683 @ bus 27
Case 4c	0.0725	0.9781 @ bus 65
Case 4d	0.1961	0.9124 @ bus 65 (50)
Case 4e	0.0646	0.9819 @ bus 65 (50)
Case 4f	0.0651	0.9867 @ bus 65 (50)
Case 5a	0.1549	0.9092 @ bus 61
Case 5b	0.0668	0.9683 @ bus 27
Case 5c	0.0557	0.9781 @ bus 27

6. CONCLUSION

Two areas of studies of EG installation in the distribution network have been presented in this paper. The first area is the introduction of RCGA to find the optimal location and size of EG in the system. The real continuous floating numbers are used as representation of the parameters in each chromosome. The single-point arithmetic crossover method that used in crossover process makes this approach success to find the best combination of location and sizing of EG simultaneously no matter how many units that needed to be installed in the system. The second part is to see if the EG installations give impact to the system when contingency is simulated in the system due to fault. From the study, the installations of EG gives the better results in term of voltage profile and losses improvements compare to base case whether with or without contingency. The studies have been tested and demonstrated on 24-bus and IEEE 69-bus distribution systems.

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APPENDIX

Table A. Bus data of 24-bus system.

Bus No.	Voltage		Load		Generation	
	Mag.	Angle (°)	MW	MVar	MW	MVar
1	1	0	0	0	1.073	0.513
2	0.9873	-0.24	0.067	0.017	0	0
3	0.9771	-0.42	0.035	0.017	0	0
4	0.96839	-0.58	0.035	0.017	0	0
5	0.96105	-0.72	0.035	0.017	0	0
6	0.95482	-0.84	0.035	0.017	0	0
7	0.94945	-0.94	0.035	0.017	0	0
8	0.94641	-0.86	0.035	0.017	0	0
9	0.94307	-0.92	0.035	0.017	0	0
10	0.94059	-0.97	0.035	0.017	0	0
11	0.93907	-1.00	0.035	0.017	0	0
12	0.93811	-1.02	0.035	0.017	0	0
13	0.93777	-1.03	0.035	0.017	0	0
14	0.93766	-1.03	0.035	0.017	0	0
15	0.99768	-0.04	0.103	0.051	0	0
16	0.99539	-0.08	0.103	0.051	0	0
17	0.99169	-0.15	0.103	0.051	0	0
18	0.98844	-0.20	0.062	0.031	0	0
19	0.98578	-0.25	0.062	0.031	0	0
20	0.9837	-0.29	0.062	0.031	0	0
21	0.98228	-0.32	0.023	0.011	0	0
22	0.98111	-0.34	0.023	0.011	0	0
23	0.98023	-0.36	0.023	0.011	0	0
24	0.97975	-0.36	0.023	0.011	0	0
	Total		1.073	0.511	1.073	0.513

Table B. Line data of 24-bus system.

From bus	To bus	R (p.u)	X (p.u)
1	2	1.7154	1.6248
2	3	1.5957	1.5114
3	4	1.4627	1.3855
4	5	1.3563	1.2847
5	6	1.2766	1.2091
6	7	1.2367	1.1713
7	8	1.1303	0.0706
8	9	1.0239	0.9689
9	10	0.9109	0.8628
10	11	0.6981	0.6612
11	12	0.5851	0.5542
12	13	0.3191	0.3023
13	14	0.1995	0.1889
1	15	0.266	0.2519
15	16	0.3191	0.3023
16	17	0.6516	0.6172
17	18	0.7846	0.7431
18	19	0.8271	0.7834
19	20	0.9069	0.859
20	21	1.0399	0.9849
21	22	1.1462	1.0857
22	23	1.2792	1.2116
23	24	1.4122	1.3376