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Optimization of Multi-Type Distributed Generation Capacity and Location Based on Binary Encoding Genetic Algorithm-Newton Raphson Method

Yusran[1*], Muhammad Abdillah[2], Mochamad Ashari[3], Adi Soeprijanto[3]

[1]Department of Electrical Engineering-Hasanuddin University, Doctoral Program in Electrical Engineering-Institut Teknologi Sepuluh Nopember
[2]Master Program in Electrical Engineering- Institut Teknologi Sepuluh Nopember
[3]Department of Electrical Engineering- Institut Teknologi Sepuluh Nopember

ABSTRACT

This research discussed about optimization of multi-type Distributed Generation (DG) capacity and location. Multi-type DG was used in this research to investigate the effect of DG type to losses and voltage profile of network. The three types of DG were injecting active power only; injecting both active and reactive power; and the one injecting active power and absorbing reactive power. This research used combination of Binary Encoding Genetic Algorithm (GA) and Newton Raphson (NR) load flow method. Optimization was conducted to obtain minimum power losses within specified voltage standard. Optimization program was implemented and tested on the IEEE 30 Bus Test System. The simulation results for the three types of DG were compared each other. The results showed that the DG type affect losses and voltage profile of network. The type of DG injecting active and reactive power generated the smallest power losses and the highest voltage profile improvement comparing with the other two types of DG. The voltage improvement still remained within standard voltage limit 0.95 - 1.1 pu.

Keywords: genetic algorithm, multi-type distributed generation, newton raphson load flow, optimization

INTRODUCTION

The Institute of Electrical and Electronic Engineers (IEEE) defined Distributed Generation (DG) as power plant that using quite smaller facilities than the central power plant, which make it is possible to be connected to every point of power system [1, 2]. The type of DG can be classified with its construction and technology [3]. DG installation can improve electrical network power quality. The DG was installed with optimal capacity and location could reduce power losses and improve voltage profile of electrical network.

The sufficient data about various type of DG effect on network losses and voltage profile had not been obtained from the previous research. It was caused by previous researches using DG single type only. Several optimization of DG capacity and location researches used DG which considered to inject active power only [4, 5, 6, 7]. The other researches used DG injecting active and reactive power [8, 9, 10].

Ghosh et al (2010) conducted a research about optimization of DG sizing and placement on mesh network using DG single type. The type of DG was injecting active and reactive power. The reactive power of DG was set as a constant value. The value was 20 % of its active power. The research used a simple conventional Newton Raphson (NR) load flow method. Optimization conducted to a DG unit. The DG unit with various capacity was tested one by one at each load bus of network. Optimization goal was minimizing the cost of DG investment. DG investment cost was a function of DG active power rating and active power losses. Optimization was performed on IEEE 6 bus, IEEE 14 bus and IEEE 30 bus systems.

El-Ela et al (2010) conducted a research about maximal optimal benefits of DG. The research used single type of DG. DG was modeled to inject active power only. The research used Genetic Algorithm (GA) method. Optimization was applied only to DG active power capacity. While DG location was determined on a particular bus. Optimization was conducted to obtain the highest value of optimization objective function. The objective functions were to increase voltage profile, spinning reserve, losses reduction and power flow reduction. DG optimization was implemented on the Western Delta Network, one of Egypt electrical system.

This research proposed one additional DG type. The type of DG was injecting active power and absorbing reactive power. Thus, this research used multi-type DG consisting of three types:
1. Type of DG was injecting active power (P) only. For example:Photovoltaic and Fuel Cell power plant.
2. Type of DG was injecting both active power (P) and reactive power (Q). DG which using synchronous generator was included in this type. For example: Mini Hydro and Biomass power plant.
3. Type of DG was injecting active power (P) and absorbing reactive power (Q). DG which using induction generator was included in this type. For example: Wind Turbine and Micro Hydro power plant.

This research discussed about optimization of multi-type DG capacity and location. In this research, optimization performed on three unit DG for each type. Optimization was conducted on three variables of

***Corresponding Author:** Yusran, Electrical Engineering Department-Hasanuddin University, Doctoral Program in Electrical Eng-Sepuluh Nopember Institute of Technology. E-mail: yusran@elect-eng.its.ac.id

research. The three variables were DG location, DG active power and DG reactive power. The active and reactive power of DG were set in a range of determined value. The reactive power of DG was not set as a constant value of its active power. The DG could be installed at all of network load bus. This research used one of artificial intelligence method. The method was Binary Encoding Genetic Algorithm (GA). The method was combined with Newton Rapson (NR) load flow method. The optimization program was conducted to obtain minimum power losses within the standar voltage limit (0.95 – 1.1 pu). Optimization program was implemented and tested on the IEEE 30 Bus Test System. The relationship between the DG type with network losses and voltage profile could be determined through comparison of the three types of DG simulation results. The usage of multi-type DG in this research would accomplished the result of previous research using DG single type. The multi-type DG usaging would give comprehensive information about the type of DG effect on network losses and voltage profile.

MATERIALS AND METHODS

Multi-type DG optimization on IEEE 30 Bus Test System

Capacity and location optimization performed on three DG for each type. The range of DG active power capacity was 0.001 to 10 MW. The range of DG reactive power injection capacity was 0.001 to 2 MVAr. The range of reactive power absorption capacity was -2 MVAr until -0.001 MVAr .

This research used the bus data and line data IEEE 30 Bus Test System [11]. Figure 1 showed single line diagram of IEEE 30 Bus Test System. The network consisted of 30 buses, divided into 1 slack bus, 5 generator buses and 24 load buses. A generator with capacity 260.2 MW-j16.1 MVAr was connected to bus 1 and a generator with capacity 40 MW+j50 MVAr was connected to bus 2. The total load of network was 283.4 MW+j126.2 MVAr.

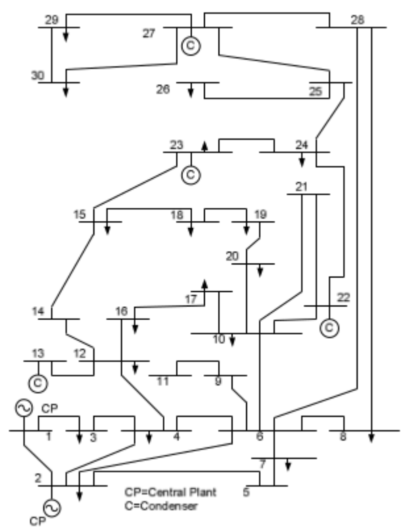

Figure 1: Single line diagram of IEEE 30 bus test system

Optimization method proposed

This research used combination of Binary Encoding GA and NR load flow method. This research conducted NR load flow program developed by Hadi Saadat [12]. Optimization program was created in the MATLAB programming language.

Simulations consisted of three stages. The first simulation used type of DG injecting active power only. The second simulation used type of DG injecting active and reactive power while the third simulation used type of DG injecting active power and absorbing reactive power.

Optimization program started with the determination of the GA parameter values: Nvar, Nbit, Popsize, Maxgen, Pco and Pmut. Nvar was the number of variables to be encoded. Nbit was the number of binary bits used to encode a single variable. Popsize was the total population in a generation while Maxgen was the total number of generations or maximum number of iterations. Pmut was mutation probability whereas Pco was the crossover probability. Table 1 showed the GA parameters used in this research

Table 1. Parameter of GA

No	Parameter	Value
1	Nvar	3
2	Nbit	15
3	Popsize	20
4	Maxgen	20
5	Pco	0.7
6	Pmut	0.2

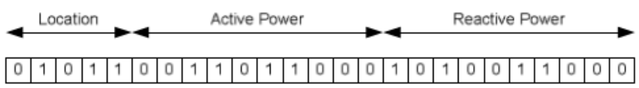

Figure 2: Research variables encoding

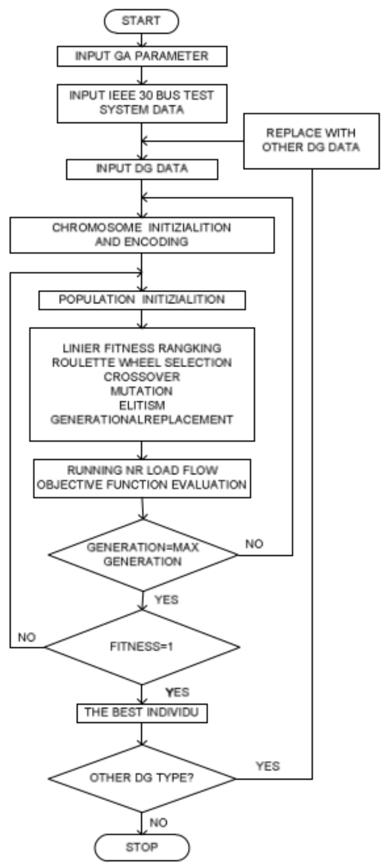

Figure 3: GA-NR optimization method flow chart

The next step was to input IEEE 30 Bus Test System and DG data. Variable of location, capacity of active and reactive power DG then encoded in 5, 10, 10 bit, respectively as figure 2. One chromosome with 75 bits length used to encode three of DG. A number of chromosomes were initiated referring to a predetermined number of the population.

The next process was running Newton Raphson load flow program. Each chromosome was then evaluated using the objective function optimization. The objective function was minimization of power losses as shown in equation (1). This objective functioned as fitness function as well.

Minimization $F = \sum_{i=1}^{N_L} P_{loss-i}, i = 1,,2,3 \ldots N_B$ (1)

The objective function was limited by voltage constraints as shown in equation (2)

$V_{i\min} \le V_i \le V_{i\max}$, V_{imin} = 0,95 pu dan V_{imax} = 1,1 pu (2)

The chromosomes were then sorted by their fitness values. All chromosomes were then selected by roulette wheel method to get a pair of parental chromosomes. Then, the parental chromosomes were crossed over to get two offspring chromosomes. Afterward, mutation process was run against the entire chromosomes. Through the process of elitism, two best chromosomes were copied. Chromosome as result of crossover and mutations would replace the entire chromosome in a population. The process flow would keep continued until maximum generation was reached. The best individual was obtained from the last generation meeting the fitness 1. Figure 3 showed a flow chart of proposed optimization method.

RESULTS AND DISCUSSION

The first simulation results for type of DG injecting active power were shown in table 2. Optimal result obtained: DG was installed at bus 7, 10 and 30 with capacity 8.4 MW+j0 MVAr, 9.600 MW+ j0 MVAr and 9.100 MW+j0 MVAr, respectively.

Table 2. Optimum Capacity and Location of DG-Simulation 1

Location	Bus (Number)	Capacity 1 (MW-j MVAr)	Capacity 2 (MW- j MVAr)	Capacity 3 (MW - j MVAr)
Location 1	7	8.400+j0		
Location 2	10		9.600+j0	
Location 3	30			9.100+j0

The second simulation results for type of DG injecting active and reactive power were shown in table 3. Optimal result obtained: DG was installed at bus 7, 10 and 30 with capacity 8.400 MW+j0.701 MVAr, 9.600 MW+j1.900 MVAr and 9.100 MW+j1.940 MVAr, respectively.

Table 3. Optimum Capacity and Location of DG-Simulation 2

Location	Bus (Number)	Capacity 1 (MW-j MVAr)	Capacity 2 (MW- j MVAr)	Capacity 3 (MW - j MVAr)
Location 1	7	8.400+ j 0.701		
Location 2	10		9.600 +j1.900	
Location 3	30			9.100 +j1.940

The third simulation results for type of DG injecting active power and absorbing reactive power were shown in table 4. Optimal result obtained: DG was installed at bus 7, 10 and 30 with capacity 8.400 MW-j1.300 MVAr, 9.600 MW-j0.101 MVAr and 9.100 MW-j0.061 MVAr, respectively.

Table 4. Optimum Capacity and Location of DG - Simulation 3

Location	Bus (Number)	Capacity 1 (MW-j MVAr)	Capacity 2 (MW- j MVAr)	Capacity 3 (MW - j MVAr)
Location 1	7	8.400 - j 1.300		
Location 2	10		9.600 - j 0.101	
Location 3	30			9.100 - j 0.061

Table 5 showed power losses before and after DG installation for each line. Before DG installation, the largest power losses with value 5.409 MW were occured at line 1. After DG type injecting P and Q installation, the highest losses reduction with value 1.153 MW were occured at line.

Table 5. Power Losses Before and After DG Installation for Each Line

Line			P_{loss} Without DG (MW)	Simulation 1		Simulation 2		Simulation 3	
No	From Bus	To Bus		P_{loss} (MW)	Deviation (MW)	P_{loss} (MW)	Deviation (MW)	P_{loss} (MW)	Deviation (MW)
1	1	2	5.409	4.258	1.151	4.256	1.153	4.259	1.150
2		3	2.862	2.186	0.676	2.184	0.678	2.186	0.676
3		4	1.137	0.863	0.274	0.860	0.277	0.863	0.274
4		5	3.060	2.608	0.452	2.606	0.454	2.610	0.450
5		6	2.083	1.545	0.538	1.545	0.538	1.545	0.538
6	3	4	0.787	0.596	0.191	0.596	0.191	0.596	0,191
7	4	6	0.586	0.425	0.161	0.428	0,158	0.425	0.161
8		12	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	5	7	0.163	0.240	-0.077	0.234	-0.071	0.247	-0.084
10	6	7	0.376	0.309	0.067	0.309	0.067	0.308	0.068
11		8	0.111	0.094	0.017	0.094	0.017	0.095	0.016
12		9	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13		10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14		28	0.062	0.031	0.031	0.033	0.029	0.031	0.031
15	8	28	0.001	0.002	-0.001	0.002	-0.001	0.002	-0.001
16	9	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17		11	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	10	17	0.008	0.015	-0.007	0.015	-0.007	0.015	-0.007
19		20	0.069	0.085	-0.016	0.086	-0.017	0.085	-0.016
20		21	0.113	0.107	0.006	0.105	0.008	0.107	0.006
21		22	0.053	0.049	0.004	0.048	0.005	0.049	0.004
22	12	13	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23		14	0.088	0.077	0.011	0.076	0.012	0.077	0.011
24		15	0.277	0.223	0.054	0.215	0.062	0.223	0.054
25		16	0.098	0.069	0.029	0.064	0.034	0.069	0.029
26	14	15	0.013	0.009	0.004	0.008	0.005	0.009	0.004
27	15	18	0.013	0.044	-0.031	0.042	-0.029	0.044	-0.031
28		23	0.058	0.041	0.017	0.037	0.021	0.041	0.017
29	16	17	0.036	0.023	0.013	0.020	0.016	0.023	0.013
30	18	19	0.011	0.007	0.004	0.007	0.004	0.007	0.004
31	19	20	0.014	0.018	-0.004	0.018	-0.004	0.018	-0.004
32	21	22	0.001	0.001	0.000	0.001	0.000	0.001	0.000
33	22	24	0.038	0.031	0,007	0.029	0.009	0.032	0.006
34	23	24	0.026	0.019	0.007	0.016	0.010	0.019	0.007
35	24	25	0.005	0.030	-0,025	0.033	-0.028	0.030	-0.025
36	25	26	0.047	0.045	0.002	0.045	0.002	0.045	0.002
37		27	0.036	0.067	-0.031	0.072	-0.036	0.067	-0.031
38	27	28	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39		29	0.090	0.016	0,074	0.012	0.078	0.016	0.074
40		30	0.168	0.014	0.154	0.008	0.160	0.014	0.154
41	29	30	0.035	0.001	0,034	0.000	0.035	0.001	0.034
Total			17.9773	14.1495		14.1032		14.1604	

Table 6. Total Power Losses Before and After DG Installation

Simulation	Total of Capacity	Total Losses			
		Without DG (MW)	With DG (MW)	Reduction (MW)	Reduction (%)
Simulation 1	27.1 MW+j0 MVAr	17.9773	14.1495	3.8277	21.29
Simulation 2	27.1 MW+j4.541 MVAr		14.1032	3.8740	21.55
Simulation 3	27.1 MW-j1.462 MVAr		14.1604	3.8168	21.33

Table 6 showed the relationship of total DG capacity and total power losses before and after DG installation. After installation of DG, there was a reduction of total power losses at network for all of DG type. The DG type injecting P and Q with capacity 27.1 MW+j4.541 MVAr, generated the largest power losses reduction compared with other two types of DG. The reduction of power losses was equal to 3.8740 MW or 21.55 %.

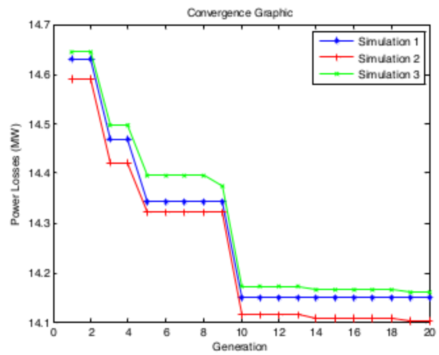

Figure 4: Convergence graphic for optimization program

Table 7. Voltage for Each Bus on IEEE 30 Bus Test System

No Bus	Voltage Without DG (pu)	Simulation 1		Simulation 2		Simulation 3	
		V (pu)	ΔV (pu)	V (pu)	ΔV (pu)	V (pu)	ΔV (pu)
1	1.060	1.060	0.000	1.060	0.000	1.060	0.000
2	1.033	1.043	0.010	1.043	0.010	1.043	0.010
3	1.013	1.022	0.009	1.022	0.009	1.022	0.009
4	1.003	1.013	0.010	1.013	0.010	1.013	0.010
5	1.000	1.010	0.010	1.010	0.010	1.010	0.010
6	1.000	1.012	0.012	1.013	0.013	1.012	0.012
7	0.992	1.005	0.013	1.006	0.014	1.004	0.012
8	1.000	1.010	0.010	1.010	0.010	1.010	0.010
9	1.030	1.041	0.011	1.043	0.013	1.041	0.011
10	1.013	1.024	0.011	1.027	0.014	1.024	0.011
11	1.072	1.082	0.010	1.082	0.010	1.082	0.010
12	1.045	1.051	0.006	1.052	0.007	1.051	0.006
13	1.071	1.071	0.000	1.071	0.000	1.071	0.000
14	1.028	1.034	0.006	1.035	0.007	1.033	0.005
15	1.020	1.028	0.008	1.029	0.009	1.027	0.007
16	1.025	1.032	0.007	1.034	0.009	1.032	0.007
17	1.011	1.021	0.010	1.024	0.013	1.021	0.010
18	1.005	1.014	0.009	1.016	0.011	1.014	0.009
19	1.000	1.009	0.009	1.012	0.012	1.009	0.009
20	1.002	1.012	0.010	1.015	0.013	1.012	0.010
21	1.001	1.012	0.011	1.015	0.014	1.012	0.011
22	1.001	1.013	0.012	1.016	0.015	1.013	0.012
23	1.004	1.013	0.009	1.016	0.012	1.013	0.009
24	0.991	1.003	0.012	1.006	0.015	1.002	0.011
25	0.994	1.010	0.016	1.015	0.021	1.010	0.016
26	0.976	0.992	0.016	0.998	0.022	0.992	0.016
27	1.005	1.023	0.018	1.030	0.025	1.023	0.018
28	0.998	1.011	0.013	1.012	0.014	1.011	0.013
29	0.985	1.012	0.027	1.022	0.037	1.012	0.027
30	0.973	1.010	0.037	1.024	0.051	1.009	0.036
Average	1.0117	1.0231	0.0114	1.0229	0.0140	1.0117	0.0112

Figure 4 showed speed convergence graphic of optimization program. The graphic showed a relationship between convergence value of minimum power losses and number of generations/iterations. Optimization of DG type injecting active and reactive power, generated the smallest power losses. The optimization converging was on the 10th iteration.This means that the minimum value of network losses was reached at 10th iterations.

Table 7 showed the voltage values before and after DG installation. Before DG installation, the lowest voltage 0.973 pu was occured at bus 30. After DG installation, voltage at bus 30 increased. DG type injecting P and Q produced the highest voltage increasing compared to other two types of DG. The voltage was equal to 1.024 pu. The highest increasing of average voltage was also generated by this type of DG. The value was 0.0140 pu.

Figure 5 showed IEEE 30 Bus Test Network voltage profile. The figure showed the difference of voltage levels before and after DG installation. After installation of DG, the voltage levels of all bus almost entirely increased within the range of 0.95 pu - 1.1 pu except bus 1 and 13.

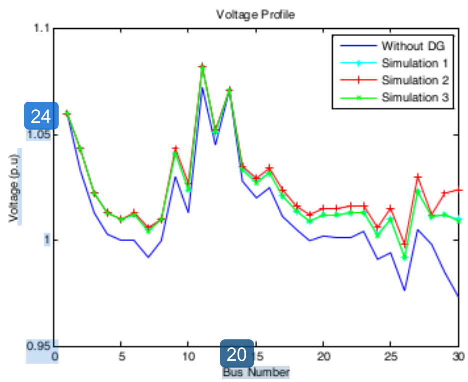

Figure 5: Voltage profile on IEEE 30 Bus Test System before and after DG installation

Simulation results that showing losses reduction after DG installation were similar to the results of previous researches. The work conducted by Ghosh et al (2010) presented the result of losses reduction after DG type injecting P and Q installation on IEEE 30 bus network. The unit DG with capacity of 35 MW and 7 MVAR at bus 11 generated 13.61 MW losses. The research by El-Ela et al (2010) presented similar result. The optimization of DG type injecting P was conducted on West Delta Network,Egypt. The installation of a unit DG with capacity 0.310 pu at bus 50 generated the highest losses reduction was 81.5 %. Sedighizedeh et al (2008) conducted optimization with two unit DG type injecting P and Q on Tehran Distribution Network13 bus. The capacity of each unit was determined 1600 kW and 0.01 kVAr. The optimization result showed that the two DG placed at bus 9 and 13, respectively. After DG installation, the losses were reduced to 92.9 kW.

This research presented that installation of three unit DG type injecting P and Q generated 14.1032 MW losses. The total capacity of DG was 27.1 MW+ j4.541 MVAr. The losses equal to 21.55 % reduction from initial losses. Installation of DG type injecting P with total capacity 27.1 MW generated 14.1495 MW losses or 21.29 % reduction. Installation of DG type injecting P and absorbing Q generated 14.1604 MW losses or 21.29 % reduction. The total capacity of DG was 27.1 MW-j1.462 MVAr. These results indicated that the DG with the same active power capacity but different in reactive power, generated different value of losses.

The simulation result that showing voltage profile improvement after DG installation was similar with other researches. This research generated voltage increasing at 28 from 30 load buses. The average of increasing were 0.0140 pu for DG type injecting P and Q. DG type injecting P was 0.0114 pu while DG injecting P and absorbing Q was 0.0112 pu. The research of Ghosh et al (2010) showed that voltage of all load bus increasing after DG installation. The highest voltage occurred at bus 29 with 1.006 pu. El-Ela et al (2010) presented that installation a DG with 0.3105 capacity at bus 50 generated 24.41 % voltage improvement. The research of Sedighized et al (2008) generated the best mean voltage was 98.823 %. This voltage profile was obtained by two unit DG allocation on bus 13. The capacity of each DG unit was 1600 kW and 0.001 kVAr.

CONCLUSION

Optimization of multi-type DG capacity and and location was conducted in this research. Three types of DG were used in this research. The types of DG were DG that only injecting active power, injecting both active and reactive power, as well as the one injecting active power and absorbing reactive power. A combination method based on Binary Encoding GA and Newton Raphson load flow was proposed in this research. Optimization program was implemented and tested on IEEE 30 Bus Test System. The simulation result showed that type of DG had a corelation with network losses and voltage profile value. DG type injecting active power (P) and reactive power (Q) generated the smallest power losses and the highest voltage improvement compared with the other two types of DG.

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