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Optimal Expenditure and Benefit Cost Based Location, Size and Type of DGs in Micrograds Systems Using Adaptive Real Coded Genetic Algorithm

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Abstract

The economic issue is an essential element to determine whether DG should be installed or not. This work presents the economical approach for multi-type DGs placement in microgrid systems with more comprehensive overview from DG's owner perspective. Adaptive Real Coded GA (ARC-GA) with replacement process is developed to determine the location, type, and rating of DGs so as the maximum profit is achieved. The objectives of this paper are maximizing benefit cost and minimizing expenditure cost. All objectives are optimized while maintaining the bus voltage at the acceptable range and the DGs penetration levels are below of the DGs capacities.The proposed method is applied on the 33 bus microgrids systems using conventional and renewable DG technology, namely Photovoltaic (PV), Wind Turbine (WT), Micro Turbine (MT) and Gas Turbine (GT). The simulation results show the effectiveness of the proposed approach.

Keywords: *adaptive real coded GA, benefit cost, expenditure cost, microgrids*

1. Introduction

The intense competition encourages electric energy producers to do all the effort to provide cheap electrical energy with good quality. Conventional generating systems typically serve loads with centralized power generation. Electrical energy is sent across long transmission lines to the load centers. Recent developments show that this fashion is becoming obsolete. Electrical energy producers began to use small to medium-scale generators that were placed directly in the load center known as distributed generation (DG) [1]. DG is considered as the answer of various limitations on conventional systems, so it is not surprising that DG has reached about 20%-30% of total energy production [2-4].

Basically, DG is used to improve network reliability, security and power quality to customers [5]. However, with large-scale multi-type DG penetration and improper planning, the network system will face some serious problems [6-8]. Therefore multi-type DG planning is a crucial issue. A number of studies have been conducted with various points of view [7] such as power loss reduction [9-10], voltage profiles improvement [9], [11-12], reliability [13], loadability [14], and harmonic mitigation [9], [11], [15]. One of the most discussed elements in almost all DG evaluations is power quality. However, for a comprehensive assessment, various aspects of DG performance need to be examined including economic issues.

The economical issue is an essential element to determine whether DG should be installed or not. Techno-economic analysis of PV and wind turbine WT is performed in [16] using HOMER software. This study focuses on the effort to determine the most economical combination of power plants, but the network costs are not taken into account. Optimal planning of renewable energy based DGs has been performed in [17] to maximize the worth of installing DGs. The optimization is conducted using mixed integer programming. The worth of DG installing is determined based on deferral of upgrade investments, cost of energy losses and interruption cost. Optimal planning of DGs with the aim of profit maximization is presented in [18]. Optimal location of DGs is determined using local marginal price (LMP) and Consumer Paymen (CP) index. Benefit cost is determined by LMP index, while expenditure cost is

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determined based on the cost characteristics of each power plant.References [19] discuss the optimal placement of DG with the aim of minimizing power loss and generation cost. Investment, operating and maintenance costs are not considered in this paper. A hybrid method based on improved particle swarm optimization and Monte Carlo simulation is proposed in [20] to minimize the costs of active and reactive losses. Expenditure costs are not considered in this paper. A complete economic analysis is discussed in [21]. Type DG is not considered, therefore investment, maintenance, and operational costs are the same for all DGs. However, different types of DGs have different characteristics that affect the overall results of the optimization.

This paper discusses the economic analysis of DG on microgrid system with more comprehensive overview from DG's owner perspective. The purpose of this research is to minimize expenditure and maximize benefit costs, so as the maximum profit is achieved. Expenditure costs consist of investment, maintenance, and operational costs while benefit costs consists of cost of power loss reduction and cost of purchasing power. To make this study more realistic, the type of DG is considered using four DG types, two type DG-based renewable energy and two type DG-based conventional. Profit analysis based on the economic index (EI) is also performed after expenditure and benefit cost are determined. To ensure optimal point is reached, this research used ARC-GA with additional replacement process for the worst individuals.

2. Problem Formulation

2.1. Adaptive Real Coded GA

Many studies showed that standard GA (SGA) cannot provide a guarantee the convergence on an optimum solution [22]. Convergence at the local optimum is usually due to the low mutation rate and the inability of the crossover operator to produce different new individuals [23]. Adaptive GA is intended to address this problem, by setting crossover probability (Pc) and mutation probability (Pm) adaptively, based on the ratio between the maximum fitness and average fitness. Pc and Pm can be calculated as follows [24].

$$P_c = P_c^0\left(1 + a\frac{(f_{avg})^N}{(f_{\max} - f_{avg})^N + (f_{avg})^N}\right) \tag{1}$$

$$P_m = P_m^0\left(1 + b\frac{(f_{avg})^N}{(f_{\max} - f_{avg})^N + (f_{avg})^N}\right) \tag{2}$$

f_{max}, f_{min}, f_{avg} are the maximum, minimum and average individual fitness respectively. Pc^0 and Pm^0 are crossover and mutation probabilities respectively. a, b and N are constant numbers. The performance of adaptive GA is improved by protecting the best individuals during the evolutionary process by copying a small portion of the fittest individual of the population into the next generation. Individual replacement is also introduced in this paper. An individual with the worst fitness is replaced with a copy of individual with the best fitness from the previous generation.

2.2. Expenditure Cost of DGs

The optimal location, type, and rating of DGs are determined based on the benefit and expenditure costs. Expenditure costs consist of investment, operation and maintenance cost.

1) Investment cost

Investment cost is the initial cost that must be spent for construction, installation and procurement of DG unit equipment, monitoring equipment, interface, protection system and others. Investment cost is formulated as follows [21]:

$$C_{invest} = \sum\nolimits_{location}[\sum\nolimits_{type-i}(P_{DGi} x IC_i)] \tag{3}$$

Where i denotes the index of DG type i. C_{invest} and P_{DGi} are investment cost and the power generated by unit i (MW) respectively.

2) Operational cost

The operational costs include fuel cost, generation cost, labor cost, and taxes. The operational cost is the future cost. Hence the cost is a cumulative value. The cumulative present value (CPV) can be expressed by the following equation [25]:

$$CPV = \frac{(1-PV^{Nyr})}{(1-PV)} \quad (4)$$

Nyr and PV are the number of planning years and present value respectively. PV can be calculated using the following equation [25]:

$$PV = \frac{(1+InfR)}{(1+IntR)} \quad (5)$$

InfR and IntR are inflation rate and interest rate respectively. The total operational cost can be calculated using the following equation [21]:

$$C_{op} = \sum_{location}[\sum_{type-i}(P_{DGi}xK_i xOC_i x8760xN_{yr}xCPV)] \quad (6)$$

Where K is the capacity factor of DGs unit, and OC is the operational cost (US$/MWh).

3) Maintenance cost

Maintenance costs consist of the cost of repairing, restoring and renewing equipment in the networks. Cumulative value of maintenance cost is formulated as [21]

$$C_M = \sum_{location}[\sum_{type-i}(P_{DGi}xK_i xMC_i x8760xN_{yr}xCPV)] \quad (7)$$

Where MC_i is the maintenance cost of DGs type i. The total expenditure cost due to the placement of DGs consists of investment, operation, and maintenance cost. The total expenditure cost is calculated using the following equation:

$$C_{expenditure}=C_{invest} + C_{op} + C_M \quad (8)$$

2.3. Benefit Cost of DGs

1) Cost of purchasing power

Electric energy production by DGs is cheaper than the market price. The distribution companies will purchase less power from the electricity market. The total cost of purchasing power can be calculated using the following equation [21]:

$$C_{purc} = \sum_{location}[\sum_{type-i}(P_{DGi}xK_i xC_{DG}x8760xN_{yr}xCPV)] \quad (9)$$

Where C_{DG} is the cost of power based on the contract (US $/MW.h).

2) The cost of power loss reduction.

The cumulative value of power loss reduction cost can be formulated as follows [21]:

$$C_{loss} = \sum_{location}[\sum_{type-i}(dP_{Loss})\,x8760xC_{DG}xCPV] \quad (10)$$

dP_{Loss} is the difference in loss before and after placement of DGs.

The benefit cost of DG consists of the cost of purchasing power and cost of power loss reduction. DGs benefit is calculated using the following Equation:

$$C_{benefit} = C_{purc} + C_{loss} \quad (11)$$

The economic index is a ratio between $C_{benefit}$ and $C_{expenditure}$. The economic index can be calculated using the following Equation [25]:

$$EI = \frac{C_{benefit}}{C_{expenditure}} \quad (12)$$

2.4. The Objective

The purpose of this study is to maximize the benefit cost and minimize expenditure cost while maintaining bus voltages within the limit. Thus the objective function based on the expenditure cost and benefit cost can be computed as:

$$\begin{aligned} Max(f) &= (C_{expenditure} - C_{benefit}) \\ &= (C_{invest} + C_{op} + C_M) - (C_{purc} + C_{loss}) \end{aligned} \quad (13)$$

3. Proposed Method

3.1. DGs Model

DGs are modeled as active resources with unity power factor. Four types of DGs are used in this paper, two conventional based DGs (micro turbine and gas turbine) and two renewable based DGs (wind turbine and photovoltaic). The capacities of DGs available in the market are 100kW, 300kW, 100kW and 300kW for MT, GT, WT, and PV respectively. The maximum DGs penetration into the systems is 35%, and the maximum numbers are four. The number of DG connected to a bus is limited to one.

3.2. Optimal Placement of Multi-Type of DGs using ARC-GA

ARC-GA is used to improve the performance of SRC-GA. The crossover and mutation probability are modified so that those GA operators are more adaptive to individual fitness changes. ARC-GA is a natural selection based algorithm. Individual as a potential solution is obtained through random processes. Optimization strategies to specify the optimal location, size and type of DGs are described as follows:

Step 1: Read GA parameters, DG types, and system data.
Step 2: Run initial load flow to obtain the initial condition of the system.
Step 3: Initialize population by generating an individual with the size (nDGs, ukpop). The individual is represented by three strings; the location, size, and types of DG.
Step 4: Determine the actual size of each DG through decode chromosome.
Step 5: Determine the bus voltages and network losses through backward-forward load flow.
Step 6: Determine the fitness of population according to the objective function in Equation (13).
Step 7: Check whether the termination condition is satisfied. If the maximum generation has been reached, go to step 12. Otherwise, go to step 8.
Step 8: Replace the worst individual with a copy of the fittest individual of the population from the previous generation.
Step 9: Select individual of the population using roulette wheel selection.
Step10: Exchange the parent chromosomes using two points simple crossover with adaptive probability.
Step11: Change one of the gene in the chromosome by using non-uniform mutation with adaptive probability.
Step12: Determine the optimal location, type, and size of DGs, including expenditure cost, benefit cost, economic index, bus voltage and network losses.

4. Results and Analysis

4.1. Description of Data Test Systems

The proposed method is performed on the 33 bus radial microgrids systems as shown in Figure 1 [26]. The microgrids systems consist of 32 lines and 32 loads. The total load connected to the network systems is 4.37 MVA (3.715 MW and 2.3 MVAR). All loads are supplied from the main grids (bus 1), which is the only source in the microgrids systems. The voltage level of microgrids systems is 12.66kV.

The Installation cost (IC), operation cost (OC), and maintenance cost (MC) of the DGs are shown in Table 1 [25]. Table 1 also presents the capacity factor (K) of DGs, considering that DGs are not in full output condition for 24 hours per day due to the intermittency of supply. It is assumed that the cost of electrical energy is US$ 75/MWh. Interest rate (IntR) and inflation rate (InfR) are 12.5% and 9% respectively [20-21].

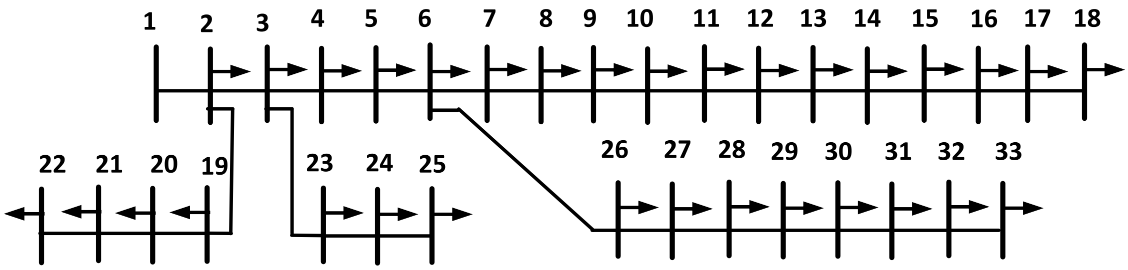

Figure 1. Single line diagram of microgrids systems

Table 1. Technical and Economical Data of DGs

DGs Type	IC (US$/MW)	OC (US$/MWh)	MC (US$/MWh)	Size (MW)	K (%)
PV	3,090,000	0.0	7 [20, 21]	0.100	25
WT	1,030,000	10.9		0.300	20
MT	901,250	47.3		0.100	55
GT	516,500	54.5		0.300	60

4.2. No DG Connected to Microgrid

Load flow results show that most of the bus voltages of the microgrids are below of 0.95 pu. The minimum bus voltage is 0.9133 pu at bus 18. The maximum bus voltage is 1.0 pu at bus 1. Active and reactive power losses are 0.20215 MW and 0.1347 MVar respectively. The system draws active power of 3.91715 MW and reactive power of 2.4347 MVar from the main grid.

4.3. DG Connected to Microgrid

Single type optimization results are shown in Table 2. Table 2 indicates that optimal placement of PV and MT into the microgrids systems has the same results regarding of location, size, and influence on the reduction of active and reactive power losses. The same results are also obtained for GT and WT. Placement of four PV or WT reduces active power loss of 23.086% and reactive power loss of 23.911%, while four GT or WT reduces the active power loss of 50.139% and reactive power loss of 50.752%. Those facts show that replacing a different type of DG with the same size, location and penetration level will not change the technical characteristics of the microgrids systems.

Figure 2 shows the performance of ARC-GA and SRC-GA in the placement of DGs in microgrids systems. The results indicate that ARC-GA has better performance than SRC-GA in term of convergence for all of the schemes.

In Figure 3, after using DGs unit, the magnitude voltages of all buses are improved. Placement of PV or MT can increase the buses voltages, but they do not meet the voltage constraint. The magnitude voltages on some buses are still below 0.95 pu. The placement of WT or GT can improve the voltage profile of microgrids systems significantly, and all voltage buses meet the limit. The minimum bus voltage after placement of WT or GT is 0.951 pu.

Table 2. Optimal Location, Size, and Type of DGs

Scheme	Location	Size (MW)	DG Penetration (%)	Power Losses (MW/MVar)	Power Losses Reduction (%)
PV	16	0.100	10.77%	0.1554/ 0.1025	23.086/ 23.911
	18	0.100			
	32	0.100			
	33	0.100			
WT	13	0.300	32.30%	0.1008/ 0.0664	50.139/ 50.752
	17	0.300			
	31	0.300			
	32	0.300			
MT	16	0.100	10.77%	0.1554/ 0.1025	23.086/ 23.911
	18	0.100			
	32	0.100			
	33	0.100			
GT	13	0.300	32.30%	0.1008/ 0.0664	50.139/ 50.752
	17	0.300			
Multi-type	31	0.300			
	32	0.300			

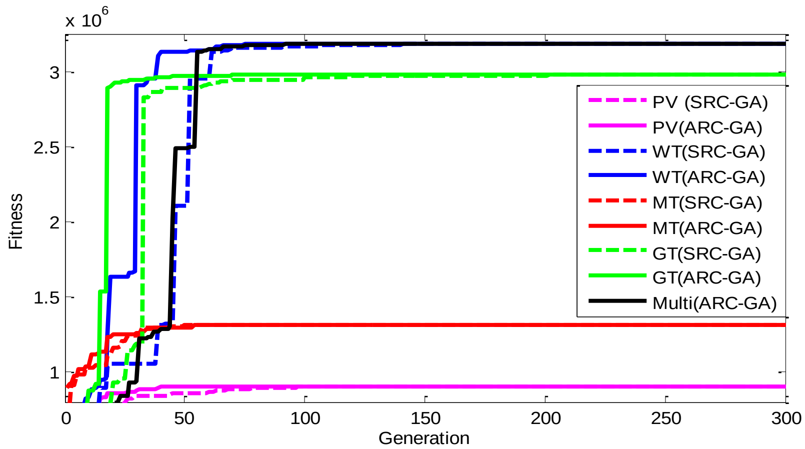

Figure 2. Performance of ARC-GA and SRC-GA

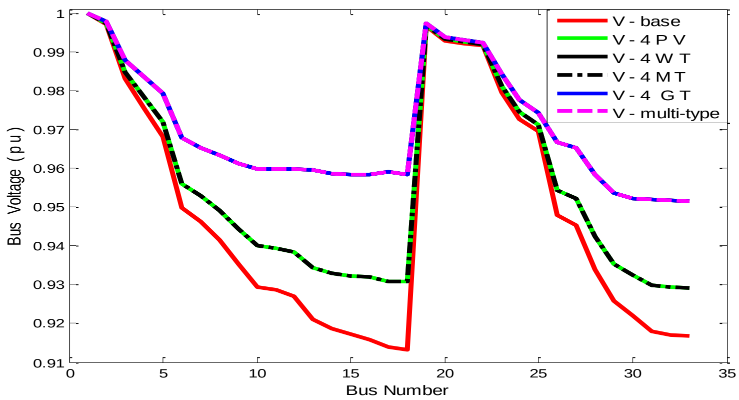

Figure 3. Voltage profile before and after placement of DGs

Table 3 shows that the scheme that provides the largest profit for the DG's owner is WT and the smallest is PV, which is US $ 3,186,656.68 and US $ 938,906.33 respectively. Although GT produces the highest benefit cost, it also produces high expenditure cost, resulting in low of profit. Table 4 shows that more than 80% of expenditure cost of GT comes from the operational cost, while about 17% comes from installation and maintenance cost. PV has no operational costs, so all expenditure costs come from the initial cost of installing a PV unit. PV has a small capacity factor and size (Table 1). Capacity factor affects the amount of energy produced throughout the year, while the size affects the amount of power loss reduction in microgrid. PV has the smallest profit compared to other DG types due to these two factors. Installation cost, operation cost, maintenance, purchasing power and power loss reduction cost are given in Table 4.

The EI of DGs planning is given in Table 5. All EI in Table 5 are greater than 1, indicating that all schemes are beneficial. As seen in Table 5, WT has the highest EI, while the smallest is GT. EI indicates the ratio between the benefits cost and expenditure cost. If the benefit cost is assumed to be the same, then to get the higher EI, it needs a smaller expenditure cost. PV provides lower profit than MT. To obtain the same benefit as MT, expenditure cost of PV is less than MT.

Table 3. Expenditure Cost, Benefit Cost and Profit of DGs Placement

Scheme	Expenditure cost (US$)	Benefit cost (US$)	Profit (US$)
PV	1,381,304.55	2,283,406.17	938,906.33
WT	2,127,754.76	5,314,411.44	3,186,656.68
MT	2,840,225.89	4,151,607.50	1,311,381.61
GT Multi-type	9,811,350.51	12,787,216.73	2,975,866.23

Table 4. Installation, Operational, Maintenance, Purchasing Power, and Loss Reduction Costs

Scheme	Installation cost (US$)	Operational cost (US$)	Maintenance cost (US$)	Purchasing power cost (US$)	Power loss reduction cost (US$)
PV	1,236,000.00	0.00	145,304.55	726,571.74	1,556,834.44
WT	1,236,000.00	543,023.85	348,730.91	1,578,008.80	3,736,402.65
MT	360,500.00	2,160,055.89	319,670.01	726,571.74	3,425,035.76
GT Multi-type	619,800.00	8,145,357.77	1,046,192.74	1,578,008.80	11,209,207.94

Table 5. Economic index of DGs placement

Scheme	Economic index
PV	1.652
WT	2.547
MT	1.455
GT Multi-type	1.303

5. Conclusion

The results show that profit is strongly influenced by type, location, and size of DG. The placement of four WT on buses 13, 17, 31 and 32 is the most optimal scheme. Placement of four WT with the size of 0.3 MW each reduces active power loss of 50.139% and reactive power loss of 50.752%. WT provides benefit cost of US$ 5,314,411.44, and expenditure cost of US$ 2,127,754.76. The total profit is US$ 3,186,656.68 and the economic index (EI) is 2.547. All bus voltages satisfy the bus voltage constraint. The simulation results also show that ARC-GA has better performance than SRC-GA in term of convergence.

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