J Electr Eng Technol Vol. 9, No. 4: 1240-1247, 2014
http://dx.doi.org/10.5370/JEET.2014.9.4.1240

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Optimal DG Placement in a Smart Distribution Grid Considering Economic Aspects

Wirote Buaklee† and Komsan Hongesombut*

Abstract – The applications of Distributed Generation (DG) in a smart distribution grid environment are widely employed especially for power balancing and supporting demand responses. Using these applications can have both positive and negative impacts on the distribution system. The sizing and location of their installations are the issues that should be taken into consideration to gain the maximum benefit from them when considering the economic aspects. This paper presents an application of the Bat Algorithm (BA) for the optimal sizing and siting of DG in a smart distribution power system in order to maximize the Benefit to Cost Ratio (BCR), subjected to system constraints including real and reactive power generation, line and transformer loading, voltage profile, energy losses, fault level as well as DG operating limits. To demonstrate the effectiveness of the proposed methodology and the impact of considering economic issues on DG placement, a simplify 9-bus radial distribution system of the Provincial Electricity Authority of Thailand (PEA) is selected for the computer simulation to explore the benefit of the optimal DG placement and the performance of the proposed approach.

Keywords: Distributed generation, Bat algorithm, Energy losses, Benefit to cost ratio, Smart distribution grid

Nomenclatures

DG	Distributed generation
BA	Bat algorithm
BCR	Benefit to cost ratio
PEA	Provincial Electricity Authority of Thailand
LRR	Loss reduction revenue
EPS	Energy purchase saving
IIC	Initial installation cost
OMC	Operation and maintenance cost
N	Number of buses
N_y	Horizon planning period (year)
N_k	Total number of time duration, defined as 24 duration,
N_{DG}	Number of DG
N_G	Number of generators,
N_L	Number of lines / transformers,
P_{DG_i}	Injected real power generation of the DG at the i^{th} bus (MW)
P_{G_i}, P_{D_i}	Real power generation / demand at i^{th} bus (MW)
t_k	Time duration k^{th}
EL_y	Total system energy losses with DG $(EL_{withDG,\mathrm{y}})$ or without DG $(EL_{noDG,y})$ installation in year y^{th} (MWh),
g	Load growth (%)
d	Discount rate (%)
f	Inflation rate (%)
C_e	Whole sell electric price ($/MWh)
ΔLR_y	Loss reduction deviation in year y^{th} (MWh)
ΔPP	Power purchase deviation in beginning year (MW)
$C_{DG,i}$	Investment cost of DG at i^{th} bus ($/MW)
$C_{O\&M,i}$	Operation and maintenance costs of DG at i^{th} bus ($/year)
Q_{G_i}, Q_{D_i}	Reactive power generation/demand at i^{th} bus (MVAR)
V_i, V_j	Voltage magnitude at i^{th} and j^{th} bus (pu)
δ_i, δ_j	Voltage angle at i^{th} and j^{th} bus (radian)
Y_{ij}	Magnitude of ij^{th} element in the admittance matrix (pu)
θ_{ij}	Angle of ij^{th} element in the admittance matrix (radian)
$P_{G_i}^{\min}, P_{G_i}^{\max}$	Lower and upper limits of the real power generation at i^{th} bus (MW)
$Q_{G_i}^{\min}, Q_{G_i}^{\max}$	Lower and upper limits of the reactive power generation at i^{th} bus (MVAR)
$P_{DG_i}^{\min}, P_{DG_i}^{\max}$	Lower and upper limits of DG's real power generation at i^{th} bus (MVA)
$Q_{DG_i}^{\min}, Q_{DG_i}^{\max}$	Lower and upper limits of DG's reactive power generation at i^{th} bus (MVAR)
$P_{G_i}^{\min}, P_{G_i}^{\max}$	Lower and upper limits of the real power generation at i^{th} bus (MW)
$V_i^{\min}, V_i^{\max}$	Lower and upper limits of the voltage magnitude at i^{th} bus (%)
$S_i, S_i^{\max}$	Apparent power flow loading and loading limit of i^{th} branch (%)

---

† Corresponding Author: Dept. of Electrical Engineering, Kasetsart University, Thailand. (wbuaklee@hotmail.com)

* Dept. of Electrical Engineering, Kasetsart University, Thailand. (fengksh@ku.ac.th)

Received: August 17, 2013; Accepted: March 15, 2014

$IC_i, IC_i^{\max}$	Percentage of short circuit interrupting capacity and limit at i^{th} bus
K_V, K_S	Constant of the penalty function of voltage and branch loading
K_{IC}, K_{IPCC}	Constant of the penalty function of short circuit interrupting capacity and short circuit at PCC
$h(V), h(S)$	Penalty function of the voltage and branch loading
$IPCC_i, IPCC_i^{\max}$	Percentage of short circuit interrupting capacity and limits at i^{th} PCC,
$h(IC), h(IPCC)$	Penalty function of the short circuit interrupting capacity and the short circuit at PCC.

1. Introduction

In recent years, a smart grid is being promoted by many governments as a way of addressing energy independence, global warming and emergency resilience issues. The DG technology using renewable resources installed in a smart distribution system is one way to achieve such problems but their installation can have both positive and negative impact on the distribution system [1] such as impact on the power flow, voltage profile, stability, continuity, reliability, short circuit level and quality of power supply for customers and electricity suppliers. The optimal location and sizing of DG is one important issue to maximize overall system efficiency and to ensure stable and reliable operation in parallel with the smart distribution system.

Various optimization techniques such as analytical method [2] and artificial intelligence approach such as such as genetic algorithm [3-4], simulated annealing, combined genetic algorithm with other algorithms [5] and particle swarm optimization [6] and hybrid particle swarm with other algorithms [7-8], tabu search, non-linear and dynamic programming, differential evolution algorithm, power flow approach, and heuristic methods such as artificial bee colony[9] and cuckoo search [10] have been employed to seek the optimal location, size and operating mode for the DG interconnection. The DG application is very complex multi-objective nonlinear optimization problem. Typically, the DG problem aims at determining the optimal location to achieve optimality for some objective functions [11-12]. Usually, it includes maximizing the power loss reduction and minimizing the cost [13-14]. Therefore, solution criteria may vary from one application to another. Also, achievement of one of the previous objectives does not guarantee satisfying the remaining ones. In addition, future changes in the solved system will alter the obtained results significantly. Therefore, as more objectives and constraints are considered by the algorithm, more data is required, which tends to add difficulty to implementation [15].

In this paper a bat algorithm which has already proved that it is more powerful than genetic algorithm, particle swarm optimization and harmony search [16] is proposed for the optimal DG allocation application to improve the voltage profile which is the main criterion for the power quality enhancement and to mitigate the energy losses as well as the fault level of the distribution network. The performance of the proposed method will be tested by using DIgSILENT software on various study cases of the simplify 9-bus distribution network of the PEA.

2. Problem Formulation

In this paper, the objective function is the benefit to cost ratio of DG application in which DG cost is composed of the initial investment cost, operation and maintenance cost and DG benefit is composed of loss reduction revenue, energy purchase saving due to application of DG. Therefore, the main objective function can be written as in Eq. (1).

$$\text{Maximize}\quad BCR = \frac{Benefit_{DG}}{Cost_{DG}} \tag{1}$$

Where BCR refers to benefit to cost ratio, and $Benefit_{DG}$, $Cost_{DG}$ refer to total benefits and *total* costs of DG application consecutively, which are:

$$Benefit_{DG} = LLR + EPS \tag{2}$$

$$Cost_{DG} = IIC + OMC \tag{3}$$

2.1 DG benefits calculation

DG benefits for each year are composed of Loss Reduction Revenue (LRR) and Energy Purchase Saving (EPS). The present value of these benefits can be calculated in Eqs. (4) and (5) respectively. EPS, particularly, represents the utility saving due to reduction in electric energy that must be purchased from electricity market to supply the customers.

$$LRR = \sum_{y=1}^{N_y}\left[\frac{\Delta LR_y \cdot C_e \cdot (1+f)^{y-1}}{(1+\mathrm{d})^y}\right] \tag{4}$$

$$EPS = 8760\cdot\sum_{y=1}^{N_y}\left[\frac{\Delta PP \cdot C_e \cdot (1+f)^{y-1}}{(1+\mathrm{d})^y}\right] \tag{5}$$

where

$$\Delta LR_y = EL_{withDG,y} - EL_{noDG,y} \tag{6}$$

$$\Delta PP = PP_{withDG} - PP_{noDG} \tag{7}$$

$$EL_y = 365\cdot\sum_{k=1}^{N_k}\left(\left(\sum_{i=1}^{N}\left(P_{G_{i,k}} - P_{D_{i,k}}\cdot(1+g)^{y-1}\right)\right)\cdot t_k\right) \tag{8}$$

$$PP_{withDG} = \sum_{i=1}^{N_{DG}} P_{DG_i} \tag{9}$$

2.2 DG costs calculation

DG costs for each year are consisted of Initial installation cost of DG (IIC) and Operational and Maintenance cost (OMC) of DG. The present value of these costs is calculated by using Eqs. (10) and (11) respectively.

$$IIC = P_{DG,i} \cdot C_{DG,i} \tag{10}$$

$$OMC = \sum_{y=1}^{Ny} \left(\frac{C_{\mathrm{O\&M},i} \cdot (1+f)^{y-1}}{(1+d)^{y}} \right) \tag{11}$$

2.3 Optimization constraints

The main objective function in Eq. (1) is to be solved subjected to the following inequality constraints.

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max} \quad ; \quad \forall_i \in N_G \tag{12}$$

$$Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max} \; ; \quad \forall_i \in N_G \tag{13}$$

$$P_{DG_i}^{\min} \le P_{DG_i} \le P_{DG_i}^{\max} \quad ; \quad \forall_i \in N_{DG} \tag{14}$$

$$Q_{DG_i}^{\min} \le Q_{DG_i} \le Q_{DG_i}^{\max} \quad ; \quad \forall_i \in N_{DG} \tag{15}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \quad ; \quad \forall_i \in N \tag{16}$$

$$S \le S_i^{\max} \quad ; \quad \forall_i \in N_L \tag{17}$$

In considering the inequality constraints, the exterior penalty function in Eq. (18) is also involved and subtracted from the main objective function.

$$PE = h(V) + h(S_i) + h(IC_i) + h(IPCC_i) \tag{18}$$

where

$$h(IC) = \sum_{i=1}^{N} h(IC_i) = \begin{cases} 0; IC_i \le IC_i^{\max} \\ K_{IC} \cdot (IC_i - IC_i^{\max})^2; IC_i > IC_i^{\max} \end{cases} \tag{19}$$

whereas

$$IC = \frac{I_{SC,DG}}{I_{SC,Rated}} \times 100 \tag{20}$$

$$h(IPCC) = \sum_{i=1}^{N} h(IPCC_i$$

$$= \begin{cases} 0; IPCC_i \le IPCC_i^{\max} \\ K_{IPCC} \cdot (IPCC_i - IPCC_i^{\max})^2; IPCC_i > IPCC_i^{\max} \end{cases} \tag{21}$$

when

$$IC = \frac{I_{SC,DG} - I_{SC,noDG}}{I_{SC,noDG}} \times 100 \tag{22}$$

$$h(V) = \sum_{i=1}^{N} h(V_i) = \begin{cases} K_V \cdot (V_i^{\min} - V_i)^2; V_i < V_i^{\min} \\ 0; V_i^{\min} \le V_i \le V_i^{\max} \\ K_V \cdot (V_i - V_i^{\max})^2; V_i > V_i^{\max} \end{cases} \tag{23}$$

$$h(S) = \sum_{i=1}^{N} h(S_i) = \begin{cases} 0; S_i \le S_i^{\max} \\ K_S * (S_i - S_i^{\max})^2; S_i > S_i^{\max} \end{cases} \tag{24}$$

3. Bat Algorithm

Bat Algorithm (BA) is a nature inspired metaheuristic algorithm developed by Xin-She Yang in 2010. This meta-heuristic algorithms use certain trade-off of randomization and local search. Randomization provides a good way to move away from local search to the search on the global scale. Therefore, almost all the meta-heuristic algorithms intend to be suitable for global optimization. This algorithm is based on the echolocation behavior of bats [16]. Bats use a type of sonar, called, echolocation, to detect prey, avoid obstacles and locate their roosting crevices in the dark. These bats emit a very loud sound pulse and listen for the echo that bounces back from surrounding objects. Bat algorithm is developed by idealizing some of the characteristics of bats. The approximated or idealized rules are:

- All bats use echolocation to sense distance and they also know the difference between prey and barriers.
- Bats fly randomly with velocity v_i at position x_i with a fixed frequency ($f_{\min}$), varying wavelength (λ) and loudness (A_0) to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and the rate of pulse emission r □ [0,1] depending on the proximity of the target.
- Loudness varies from a large positive A_0 to a minimum constant value $A_{\min}$.

The procedure and the mathematical formula of the bat algorithm can be summarized as follow [17].

3.1 Population

The initial population i.e., number of virtual bats for BA (n) is generated randomly. The number of bats can be anywhere between 10 and 40. After finding the initial fitness of the population for given objective function, the values are updated based on movement, loudness and pulse rate.

3.2 Movement of bats

In this step, all the parameters of bats are updated based on the following equation:

$$f_{i,j} = f_{\min} + \left(f_{\max} - f_{\min} \right) \cdot rand \tag{25}$$

$$v_{i,j}^{(t)} = v_{i,j}^{(t-1)} + \left(x_{i,j}^{(t)} - x_j^{*} \right) \cdot f_{i,j} \tag{26}$$

$$x_{i,j}^{(t)} = x_{i,j}^{(t-1)} + v_{i,j}^{(t)} \tag{27}$$

Where $x_{i,j}^{(t)}, v_{i,j}^{(t)}$ is the i^{th} bat current position and velocity of the j^{th} variable, x_j^* is the current global best position (solution) of the j^{th} variable which is located after comparing all the solutions among all the *n* bats and *rand* is a random number in the interval [0, 1]. For the local search part, once a solution is selected among the current best solutions, a new solution for each bat is generated locally using random walk

$$x_{new} = x_{old} + rand \cdot A^t \tag{28}$$

where *rand* is a random number in the interval [-1, 1] while A^t is the average loudness of all the bats at this time step.

3.3 Loudness and pulse emission

The loudness A_i and the rate of pulse emission r_i are updated accordingly as the iterations proceed. The loudness decreases and rate of pulse emission increases as the bat closes to its prey, the equations for convergence can be taken as

$$A_i^{t+1} = \alpha A_i^t, \quad r_i^{t+1} = r_i^0 \left[1 - e^{-\gamma t} \right] \tag{29}$$

where α and γ are constants.

For any 0<α<1 and γ>0, it yields to the following fact:

$$A_i^t \to 0, r_i^t \to r_i^0 \quad \text{as} \quad t \to \infty .$$

4. The Proposed Methodology

The proposed algorithm of the optimal distributed generation allocation considering economic which is based on BA assumes that each position of bats will be represented as the location and the capacity of DG.

In order to run the proposed algorithm, the essential aspect is the coding of the potential solutions. Usually a potential solution is a configuration of the distribution system with the DG installed in some sites. The coded variables are, therefore, the location for DG installation and the respective size of the DG. In the proposed methodology, each solution is coded through a vector whose dimension is the DG sizes and whose content is their locations for installation which is an integer between 0 and N. It should be noted that the number 0 means that no DG must be installed.

The mechanism of proposed BA is shown in the following steps:

- **[step1]** Initialize number of bats (*n*), number of iterations, loudness A_0 which can typically be [1,2] and pulse rate *r* which can be [0,1].
- **[step2]** Generate the population randomly.
- **[step3]** Evaluate objective function by perform load flow and short circuit to determine benefit value (LRR and EPS) and cost (IC and OMC) of DG installation and then calculate the benefit to cost ratio (BCR) from the generated population.
- **[step4]** Select maximum value of BCR as current best solution.
- **[step5]** Update frequency, velocity and position of bats using Eqs. (25) to Eq. (27).
- **[step6]** Evaluate objective function as [step 3].
- **[step7]** If the obtained BCR greater than the current best solution, then replace the current best solution with the present obtained value and update loudness and pulse rate using Eqs. (29).
- **[step8]** Repeat [step5] to [step7] until the given number of iterations are completed.

The flowchart of the proposed approach as mentioned above is as shown in Fig. 1.

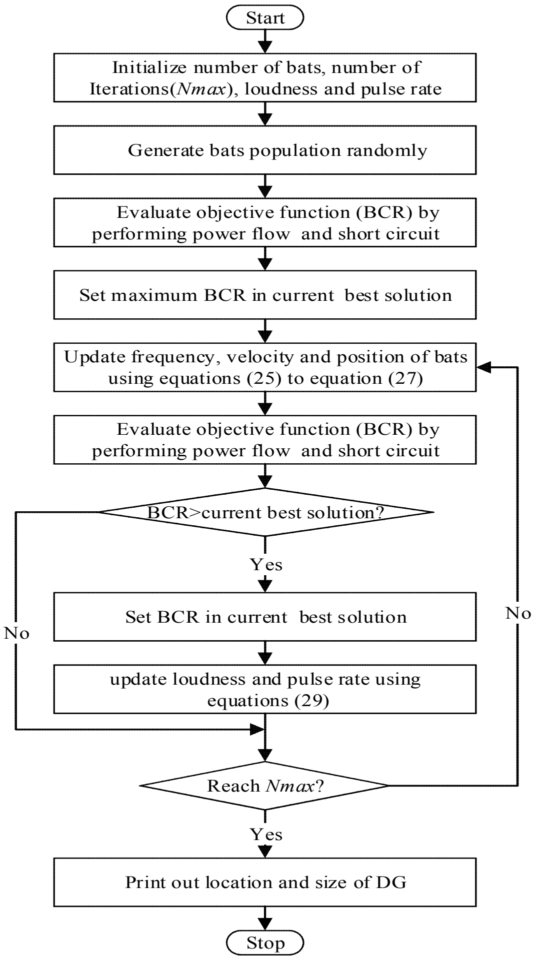

Fig. 1. Proposed algorithm flowchart

5. Numerical Studies

In this section, to test the proposed methodology, a simplified 9-bus distribution system of the PEA [2] which has already taken the geography, useful road condition and fuel resources into consideration is employed in the study. Fig. 2 shows the diagram of the 22kV PEA distribution system. It consists of one slack bus and eight load buses. All buses of the system have be considered as candidate for DG installation except the slack bus which is represented as in-feed of electric power from generation/transmission system. The total real and reactive power demand is 7.76 MW and 3.76 MVAR and the total length of distribution line is 45 km. A typical daily load curve as shown in Fig. 3 is considered in this study.

The BA described in Section 4 is utilized with 25 initial bat's populations. Loudness A_0, and pulse rate r, constant α and constant γ are 1.5, 0.1, 0.9 and 0.1 respectively. The other parameters will be according to data provided in Table 1. The process of OPDG will be performed until the termination criteria is satisfactory when the calculation loop reaches 50 iterations.

To demonstrate the advantage of the main contribution of this paper, two different scenarios are investigated. In the first scenario, the Optimal Placement of DG (OPDG) without considering economic aspects is studies while the second scenario will take the economic aspects into consideration. Besides, the DG which is a small community biomass power plant based on synchronous generator is adopted to install in this distribution system.

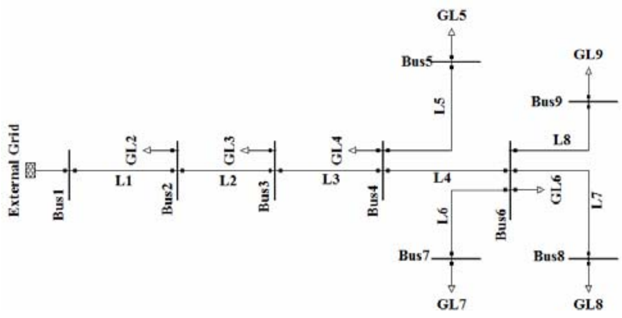

Fig. 2. 9-bus distribution test system

Table 1. The parameter settings

Parameters	Value
Power factor of the DG	0.85
Voltage limit(pu)	0.95-1.05
Line loading limit (%)	80
Percentage of short circuit interruption capacity limit (%)	85
Percentage of short circuit limit at PCC (%)	25
Short circuit interrupting capacity (kA)	25
Whole sell electric price($/kWh)	0.07
Investment cost of DG ($/MW)	1,000,000
O&M cost of DG (% of investment cost)	5
Inflation rate (%)	3
Discount rate (%)	7
Load growth (%)	5
Horizon planning period(Year)	10

5.1 Scenario 1: OPDG w/o economic consideration

In this scenario, the energy loss minimization is set as an objective function and the economic constraint is not considered.

The simulation result of optimal location and size of DG in case of no DG installation compared with the installation of one DG, two DGs and three DGs respectively are tabulated in Table 2. It can be seen that the annual energy loss reduction in case of one DG, two DGs and three DGs installation compared with no DG is 88.42% 89.57% and 93.46% respectively. In addition, the maximum capacity of DG for each case is varied between 5.1343 MW and 5.7228 MW which is the optimal size for this test feeder when the only energy loss constraint is not considered.

5.2 Scenario 2: OPDG with economic consideration

In this scenario, the maximization of benefit to cost ratio is set as an objective function and the energy loss is also included in the calculation of the objective function as describe in Section 2.

The simulation result of optimal location and size of DG in case of no DG installation compared with the installation of one DG, two DGs and three DGs respectively are tabulated in Table 3. It can be seen that the annual energy loss reduction in case of one DG, two DGs and three DGs installation compared with no DG is 38.99% 39.81% and 42.23% respectively. In addition, the maximum capacity of

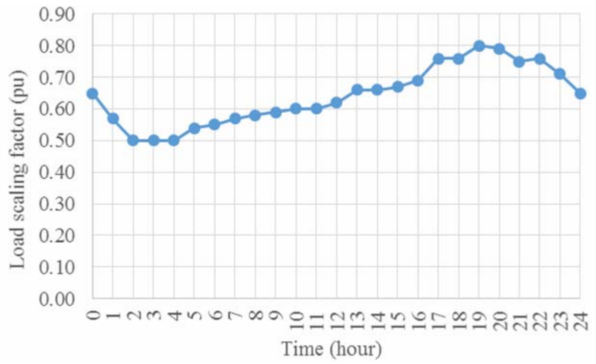

Fig. 3. Typical daily load curve characteristic

Table 2. Optimal sizes and location of DG units for Scenario 1

Case	DG location	DG size (MW)	Total energy loss (MWh)	Loss reduction (%)
No DG	-	-	12.57491	-
1 DG	Bus 6	5.1343	1.45605	88.42
2 DGs	Bus 7 Bus 3	3.4891 1.8635	1.3114	89.57
3 DGs	Bus 2 Bus 4 Bus 6	1.0604 2.6675 1.9939	0.8227	93.46

Table 3. Optimal sizes and location of DG units for Scenario 2

Case	DG location	DG size (MW)	Total energy loss (MWh)	Loss reduction (%)
No DG	-	-	12.57491	-
1 DG	Bus 6	1.2232	7.672551	38.99
2 DGs	Bus 7 Bus 3	1.1396 0.1815	7.568347	39.81
3 DGs	Bus 2 Bus 4 Bus 6	0.3002 0.7552 0.5645	7.264352	42.23

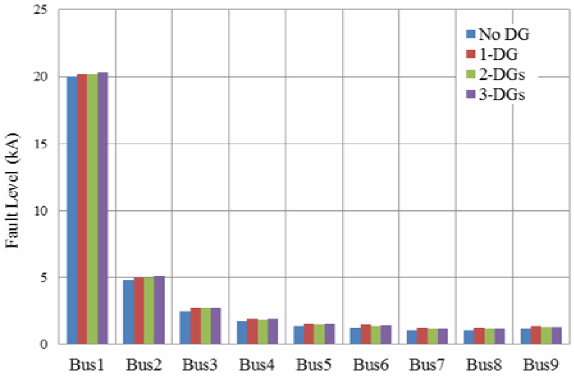

Fig. 4. Fault level at bus

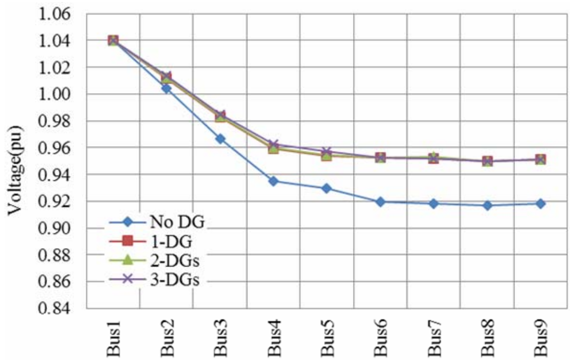

Fig. 5. The voltage profile for each case at peak period

DG for each case is varied between 1.2232 MW and 1.6199 MW which is the optimal size for this test feeder when the economic aspects is taken into account.

From the results in Table 3, it can be observed that the installation of three DGs at three different locations with the proper capacity can reduce the total energy losses in a smart distribution system approximately 42.23% when compared with uninstall DG units while it can maintain the fault level and improve the voltage profile within the permissible limit (+/-5% of nominal voltage) and can also relieve the feeder loading as illustrated in Figs. 4 to 6 respectively.

Even if the improvement voltage profile and feeder loading in case of installation of one DG, two DGs and three DGs are not much distinguish due to less capacity installed of each case, the total energy loss reduction is obviously seen compared with the case without DG unit.

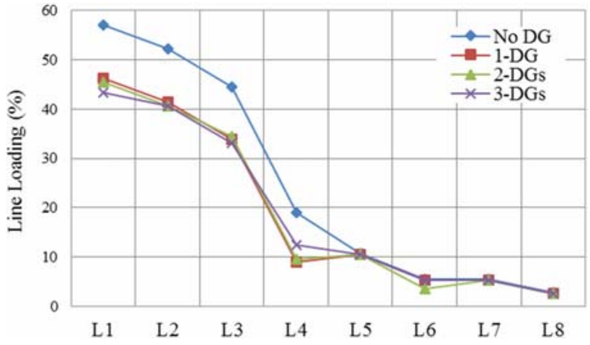

Fig. 6. The feeder loading for each case at peak period

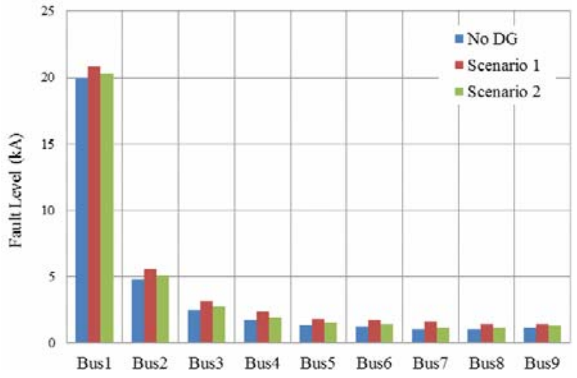

Fig. 7. Fault level for each scenario

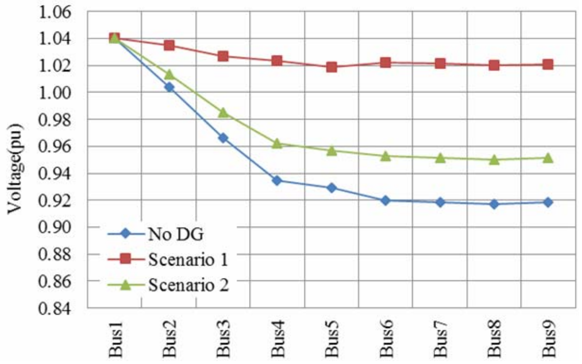

Fig. 8. The voltage profile for each scenario at peak period

Fig. 8 shows the comparison of voltage profile for different scenarios at the peak period (19th hour). The worst voltage profile refers to the system without DG and it can be improved by proper DG allocation considering the objective function. Scenario 1 has the best voltage profile compared with other cases due to considering only energy loss reduction in the objective function without taking the cost of installation and maintenance of DG into account. Although voltage profile in Scenario 2 is inferior compared with Scenario 1, it is still not less than the lower value of the allowance limit (0.95pu) throughout the horizon planning period.

Fig. 9 illustrates the comparison of the line loading at peak period (19th hour) of each scenario. It can be observed

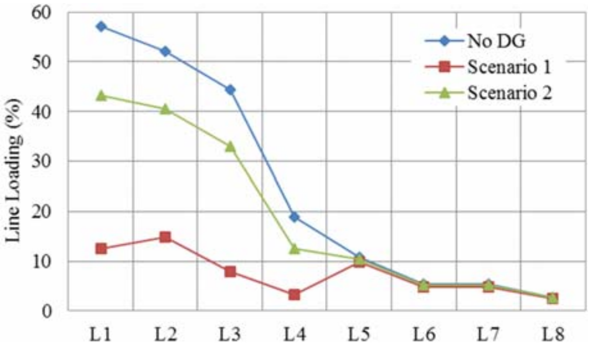

Fig. 9. The line loading for each scenario at peak period

that the loading of line section connecting between source and the location of DG installation can be alleviated while it is not affect the line branch linking between DG and load in both scenarios.

6. Conclusions

This paper has presented the optimum DG allocation considering economic aspects by using BA method. The proposed method has been tested with a simplify 9-bus distribution network of the PEA to show the advantage of the proposed methodology. The impact of determining the objective function, the voltage profile, the fault level, line loading and the total energy loss have been analyzed as well as significant improvement in voltage profile and reduction in total energy system loss is observed. From the result, it can be concluded that in the planning stage, the distribution utility should be considered the economic aspects in the process of the DG placement rather than emphasizing only the system energy loss to avoid the over investment.

Finally, it can also be noted that the proposed method can be applied in the planning of a smart distribution grid connecting with renewable energy DG such as biomass, biogas, solar and wind power.

References

[1] Koutroumpezis, G.N., A.S. Safigianni, “Optimum allocation of the maximum possible distributed generation penetration in a distribution network”, *Journal of Electric Power Systems Research,* 80: 1421-1427, 2010.

[2] Saraisuwan P., Jirapong P., Kalankul A. and Premrudeepreechacharn S., “Allocation Planning Tool for Determining the Optimal Location and Sizing of Distributed Generations in Provincial Electricity Authority of Thailand”, *The International Conference and Utility Exhibition on Power and Energy Systems*, August 28-30, 2011.

[3] S. Chandrahekhar Reddy, P. V. N. Prasad, A. Jaya Laxmi, “Optimal Number and Location of DGs to Improve Reliability of Distribution System Using Genetic Algorithm”, *International Review on Modelling and Simulations (IREMOS)*, vol. 5, no. 2, pp. 561-567, Apr. 2012.

[4] S.A. Hosseini, M. Karami, S.S. Karimi Madahi, F. Razavi and A.A. Ghadimi, “Optimal Capacity, Location and Number of Distributed Generation at 20kV Substations”, *Australian Journal of Basic and Applied Sciences*, 5(10): 1051-1061, 2011.

[5] Jalilvand, S. Jalilzadeh, M. Sabouri, M. R. Javadi, “Optimal Placement of Distributed Generation Using Shuffled Frog Leaping and Genetic Algorithms”, *International Review of Electrical Engineering (IREE)*, vol. 6, no. 5, pp. 2477-2482, Oct. 2011.

[6] J. Moshtagh, A. Jalali, K. Karimizadeh, “Optimum Placement and Sizing of DG Using Binary PSO Algorithm to Achieve the Minimum Electricity Cost for Consumers”, *International Review of Electrical Engineering (IREE)*, vol. 5, no. 6, pp. 2873-2881, Dec. 2010.

[7] M.R. Alemi, M. Fallahnejad, M. Sedighizadeh, “A Novel Approach for Optimal Determination of Number of Distributed Generation Units along with their Sizes and Locations”, *International Review of Electrical Engineering (IREE)*, vol. 7, no. 1, pp. 3461-3469, Feb. 2012.

[8] L. Y. Wong, M. H. Sulaiman, Siti Rafidah Abdul Rahim, O. Aliman, “Optimal Distributed Generation Placement Using Hybrid Genetic-Particle Swarm Optimization”, *International Review of Electrical Engineering (IREE)*, vol. 6, no. 3, pp. 1390-1397, Jun. 2011.

[9] S. M. Ezzati, H. A. Zamani, S. M. M. Tafreshi, “Optimal Sizing of DGs in MicroGrid Considering Loss of Power Supply Probability Technology Solved by Artificial Bee Colony”, *International Review of Electrical Engineering (IREE)*, vol. 7, no. 2, pp. 4226-4235, Apr. 2012.

[10] W. Buaklee, K. Hongesombut, “Optimal DG Allocation in a Smart Distribution Grid Using Cuckoo Search Algorithm” *ECTI Transactions on Electrical Engineering, Electronics, and Communications* (*ECTI-EEC*)*,* vol. 11, no. 2, pp.16-22, Aug. 2013.

[11] Jen-Hao Teng, Tain-Syh Luor, Yi-Hwa Liu, “Strategic Distributed Generator Placements for Service Reliability Improvements”, *IEEE Power Engineering Society Summer Meeting*, vol. 2, pp. 719-724, 2002.

[12] An D. T. Le, M. A. Kashem, M. Negnevitsky, G.Ledwich, “Optimal Distributed Generation Parameters for Reducing Losses with Economic Consideration”, *IEEE Power Engineering Society General Meeting*, pp. 1-8, Jun. 2007.

[13] M Ahmadigorji, A. Abbaspour, A Rajabi-Ghahnavieh, M. Fotuhi- Firuzabad, “Optimal DG Placement in Distribution systems using Cost / Worth Analysis”, *Journal of World Academy of Science, Engineering and Technology*, 2009.

[14] S. Rama Krishna, P.G. Scholar, Injeti S. Kumar, “Analysis on Techno-Economic Benefits of a Strategically Placed Distributed Generator in a Radial Distribution System”, *International Journal of Computer Applications,* vol. 59, no. 10, Dec. 2012.

[15] Aliman, I. Musirin, M. M. Othman and M. H. Sulaiman, “Heuristic Based Placement Technique for Distributed Generation”, *The 5th International Power Engineering and Optimization Conference*, Malaysia, 2011.

[16] X. S. Yang, “A New Metaheuristic Bat-Inspired Algorithm”, *Nature Inspired Cooperative Strategies for Optimisation (NISCO 2010)*, Studies in Computational Intelligence, Springer Berlin, 284, Springer, 66-74.

[17] V. Usha Reddy and A.Manoj, “Optimal capacitor placement for loss reduction in distribution systems”, *IOSR Journal of Engineering*, vol. 2, no. 10, pp. 23-27, Oct. 2012.

Wirote Buaklee He received his M.Eng. degree in electrical engineering from Chulalongkorn University, Bangkok, Thailand in 1997. He is pursuing Doctoral Degree in the Department of Electrical Engineering at Kasetsart University, Thailand. His research interests include power system planning and reliability, power system protection and relaying, power system optimization and smart grid.

Komsan Hongesombut He obtained his Ph.D. in Electrical Engineering from Osaka University, Japan. He is a lecturer in the Department of Electrical Engineering at Kasetsart University, Thailand. His research interests include power system modelling, power system dynamics, controls and stability and smart grid.