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Stochastic Placement and Sizing of Combined Heat and Power Systems Considering Cost/Benefit Analysis

[1]S. Mehrdad Hosseini, [1]Gholamreza Koohsari, [2]M. Mahdi Zarif and [1]D.B. Hossein Javidi
[1]PSRES Lab., Department of Electrical Engineering, Ferdowsi University, Mashhad, Iran
[2]Department of Electrical Engineering, Islamic Azad University, Mashhad Branch, Mashhad, Iran

Abstract: This study presents a cost/worth analysis approach for optimal Placement and sizing of Combined Heat and Power (CHP) systems. Particle Swarm Optimization (PSO) as a powerful optimization technique is employed for optimization. Different benefits brought up by CHP systems are taken into account as a multi-objective decision making. Economical factors such as power and heat selling, reliability improvement, loss reduction, deferred upgrading investment and CHP costs are considered in this study. In order to incorporate stochastic nature of power system in this study, Monte-Carlo method is used to simulate the effect of uncertainty of loads and system on the optimal location and size of the CHPs in the network. This study conducts two separate case studies, 6-bus meshed test system and 14-bus radial test system to demonstrate economical feasibility for investment planning when cost and CHP benefits are taken into account. The impacts of considering different parameters such as the rate of load growth and interest are studied. Results indicate that the proposed methodology is capable of finding the best location and the optimal size of CHP that can cause improvement in network operation along with financial benefits.

Keywords: Combined heat and power systems, cost/worth analysis, loss reduction, Monte-Carlo, reliability

INTRODUCTION

Restructuring of power systems have created an increased interest in Distributed Energy Resources (DERs), which is expected to play an increasingly essential role in electric power systems operation and planning. Several benefits result by integrating DER with power system. Most important economic benefits bring about by DER technologies to the power system are modeled and quantified in economic terms in Gil and Joos (2008). Another researcher proposes a general approach and a set of indices to quantify some of the technical benefits of DER (Chiradeja and Ramakumar, 2004). A cost/worth analysis is used in Ahmadigorji *et al*. (2009) which studies economic consideration of using DG by considering load point reliability indices and loss reduction in the power system. DERs are strategically located and operated in the system to defer or eliminate system upgrades, reduce system losses and to improve system reliability as well as efficiency (Afkousi-Paqaleh *et al*., 2009).

Currently, application of DER and specially Combined Heat and Power (CHP) systems in factories, buildings and houses has an essential role in providing improved energy efficiency and demand-side growth management (Haghifam and Manbachi, 2011). A CHP system simultaneously produces electrical and thermal energy from a single fuel (Strickland and Nayboer, 2004). Generally speaking, CHPs are classified based upon the technology that is used as their prime mover (US Environmental Protection Agency, 2008). While a common gas-powered generation system typically has a heat efficiency of about 30-37% along with an energy loss of almost 40-50% as waste heat (International Energy Agency, 2008) cogeneration systems are able to mitigate this huge loss of energy effectively. Different studies have been conducted about the CHP systems in the literature.

In Basu *et al*. (2010) the impact of deployment of CHP-based DERs on micro grid reliability has been discussed. The loss sensitivity index of each bus has been taken into account for the selection of optimal locations of CHPs. Maximum benefit-to-cost ratio of the micro grid owner has been considered to achieve the optimal size of the CHP.

Reliability and availability modeling of Combined Heat and Power (CHP) systems has been addressed in Haghifam and Mabuchi (2011). Calculation of the reliability from the generation point to the consumer has been considered and the proposed model is based on the state space and the continuous Markov method. Moreover, a sensitivity analysis for island, standby and parallel operational modes of CHP systems has been taken into account.

A mixed integer nonlinear programming model has been developed in Ren *et al*. (2008) for optimal sizing

Corresponding Author: S. Mehrdad Husseini, PSRES Lab., Department of Electrical Engineering, Ferdowsi University, Mashhad, Iran

for residential CHP systems. Minimization of the annual cost of the energy system for a given residential customer equipped with the CHP plant, combining with a storage tank and a back-up boiler has been considered as the objective.

Particle Swarm Optimization (PSO) is a heuristic optimization algorithm that has been widely used in different problems especially the locating problems in power system. It is a heuristic global optimization approach and its main strength is in its simplicity and fast convergence (Kennedy and Eberhart, 1995).

According to the literature mentioned above, objective is to find the best size and location for a CHP. This study presents a new method to solve the complicated problem of finding the optimal location and size of the CHP. PSO is employed as an optimization tool to find the proper location and size of CHPs.

The costs associated with generation of electricity and heat from CHP can be categorized into capital investment cost, Operation and Maintenance (O&M) costs. On the other hand, benefits include earnings on selling of the generated electricity and recovered waste heat, energy loss reduction, reliability improvement and deferral or elimination of upgrade investment. All of these costs and earnings have been calculated in terms of the Present Value Factor (PVF), compounded over the study period. It is a common practice for a decision maker to translate future cash flows into their present values (Basu *et al*., 2010). The interest rate is being used here for the calculation of the PVF.

In this study, because of stochastic nature of bus loading and system components, Monte-Carlo method has been employed to simulate the effect of bus loading uncertainties on the optimal location and size of the CHPs. The results of the stochastic approach are compared with those obtained from deterministic approach. The results of simulations carried out on two separate case studies, 6-bus meshed and 14-bus radial test systems show the capability and effectiveness of the proposed method and demonstrate the essence of considering uncertainties associated with the system loading in planning problems.

PARTICLE SWARM OPTIMIZATION

Heuristic methods may be used to solve some combinatorial multi-object optimization problems. These methods are called “intelligent,” because the move from 1 solution to another is done using rules based upon human reasoning. Heuristic algorithms may search for a solution only inside a subspace of the total search region. Although, they are able to give a good solution for certain type of problems in a reasonable computational time, they do not completely assure to reach the global optimum. The most important advantage of heuristic methods lies in the fact that they are not limited by restrictive assumptions about the search space like continuity, existence of derivative of the objective function, etc., Several heuristic methods can be addressed such as: Tabu Search (TS), Simulated Annealing (SA), Genetic Algorithms (GAs) and Particle Swarm Optimization (PSO) (Glover, 1988; Kirkpatrick *et al*., 1983; Goldberg, 1989). Each 1 has its own pros and cons which make them possible to apply to the appropriate problems, where in this study PSO method is selected as an intelligent optimization method. Kennedy and Eberhart (1995) first introduced PSO method, which is also an evolutionary computation technique, (Shi and Eberhaft, 1998). Similar to Genetic Algorithms (GA), PSO is a population-based optimization tool. The system is initialized with a population of random solutions and searches for the optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation.

In PSO, the potential solutions, called particles, are “flown” through the problem space by following the current optimum particles. Compared to GA, the advantages of PSO are that it is easy to implement and there are few parameters to be adjusted. It can be said that PSO has been successfully applied in many areas. Each individual in PSO flies in the search space with a velocity which is dynamically adjusted according to its own flying experience and its companions’ flying experience. Each individual keeps track of its coordinates in the problem space, which are associated with the best solution (fitness) it has achieved so far. This value is called pbest, while another best value that is tracked by the global version of the particle swarm optimizer is the overall best value and its location the so-called gbest, obtained so far by any particle in the population. At each time step, the particle swarm optimization consists of velocity changes of each particle towards its pbest and gbest.

Acceleration is weighted by a random term, with separate random numbers being generated for acceleration towards pbest and gbest. This new technique for nonlinear optimization involves simulating social behavior among individuals (particles) "flying" through a multidimensional search space, where each particle represents a single intersection of all search dimensions. The particles evaluate their positions relative to a goal (fitness) for any iteration and particles in a local neighborhood share memories of their "best" positions and then use those memories to adjust their own velocities for subsequent positions. In PSO i^{th} particle “X_i” is defined as a potential solution in D-dimensional space, where, $X_i = (x_{i_1}, x_{i_2}, \dots, x_{i_D})$. Each particle also maintains a memory of its previous best position and a velocity along each dimension represented as: $P_i = (P_{i_1}, P_{i_2}, \ldots, P_{i_D})$, $V_i = (v_{i_1}, v_{i_2}, \ldots, v_{i_D})$, At each iteration, the P = [P_1, P_2, … P_i,… P_n] vector of the particle would be adjusted with the best fitness in the local neighborhood. This adjustment will be done by using a factor “gbest” and with the best fitness of the population by a factor “pbest”. Velocity adjustment along each dimension, can be defined by Eq. (11), where it is used to compute a new position for the particle (Kennedy and Eberhart, 1995):

$$v_i = w v_{i-1} + c_1 \times rand(0,1) \times (x_{i_{gbest}} - x_i) + c_2 \times rand(0,1) \times (x_{i_{pbest}} - x_i) \quad (1)$$

$$x_{i+1} = x_i + v_i \quad (2)$$

where,

W : Inertia weight factor, often decrease linearly from about 0.9 to 0.4 during a run (Shi and Eberhaft, 1998)
c_1, c_2 : Acceleration constants
rand (0, 1) : Random numbers
$x_{i_{gbest}}$: The best particle among all individuals in the population
$x_{i_{pbest}}$: The best history of position of particle x_i

The constants c_1 and c_2 represent the weighting of the stochastic acceleration terms that pull each particle x_i towards $x_{i_{pgbest}}$ and $x_{i_{pbest}}$ positions. According to the literature c_1, c_2 were often set to be 2.05. A suitable selection of inertia weight w in Eq. (11) provides a balance between global and local explorations, thus requiring less iteration to find a sufficiently optimal solution. As it is originally developed, w often decreases linearly from about 0.9 to 0.4 during optimization process. The inertia weight w can be set according to Eq. (13) (Kennedy and Eberhart, 1995):

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (3)$$

where, $iter_{max}$ is the maximum number of iterations (generations), while tier is the current number of iterations.

PSO like GA is initialized by a population of random solutions with some advantages. It has memory to support the knowledge of good solutions by all particles. PSO has constructive cooperation between particles in order to share their information.

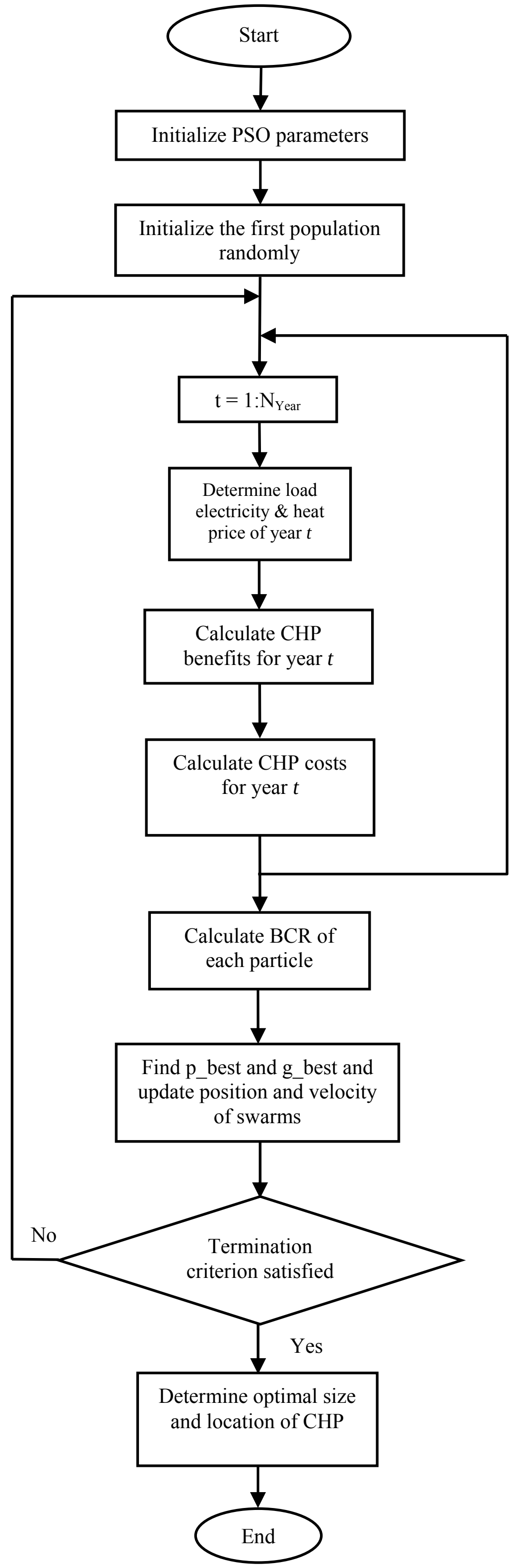

Fig. 1: Flowchart of the proposed deterministic approach

MATHODOLOGY

Optimal CHP placement and sizing is aimed to find the optimal CHP location and size in order to maximize or minimize a specific objective function with respects to considered variables and constraints. An important approach is to incorporate the cost and benefit of CHP application in the objective function.

Deterministic approach: Figure 1 shows proposed optimization procedure. In the proposed procedure after initializing the PSO parameters, first population is randomly initiated. Then for the tth year of the years in the study time horizon (N_{Year}) the load, electricity and heat are determined considering the interest rate. The benefits of the CHP are calculated in the year t in the next step. Then cost associated with application of CHPs in the tth year is calculated. This process is repeated until all the years in the time horizon are considered. Then the overall BCR of the solution (particle) created by the PSO algorithm is calculated. The position and velocity of the particles as well as pbest and gbest are updated in the next step.

This process is repeated until the termination criterion is satisfied. The largest value of BCR that was found and its corresponding design will be selected as the optimal solution.

Considering the load growth rate of α, the load associated with m-th design and t-th year can be calculated using:

$$Pd_t = Pd_1 \times (1+\alpha)^{t-1} \quad (4)$$

where,
Pd_1 : load at the first years
Pd_1 : load at the tth years

Here, a cost/worth approach is explained for placement and sizing of a CHP. The objective function is the benefit to cost ratio of CHP application. CHP cost is composed of the Investment Cost (IC), Operation Cost (OC) and Maintenance Cost (MC). CHP benefit is composed of Reliability Improvement (RI), Upgrade Investment Deferral (UID), Power Purchase Saving (PPS), Heat Purchase Saving (HPS) and Loss Reduction (LR) of the system due to application of CHP. The objective function is defined as follows:

$$Max\ BCR = \frac{Benefit_{CHP}}{Cost_{CHP}} \quad (5)$$

where,
BCR : Benefit to Cost Ratio
Benefit $_{CHP}$: The total benefits of CHP application
Cost $_{CHP}$: The total costs of CHP application

$$Benefit_{CHP} = \sum_{k=1}^{N_{CHP}} \sum_{t=1}^{N_{year}} [PPS_{k,t}^{CHP} + HS_{k,t}^{CHP} + \Delta CIC_{k,t}^{CHP} + UID_{k,t}^{CHP} + \Delta CLoss_{k,t}^{CHP}] \quad (6)$$

$$Cost_{CHP} = \sum_{k=1}^{N_{CHP}} IC_k^{CHP} + \sum_{t=1}^{N_{year}} (OC_{kt}^{CHP} + MC_{kt}^{CHP}) \quad (7)$$

where,
N_{CHP} : Year is the number of CHPs in study period
N : The number of years in study period

DR benefits calculation: All of the benefits of CHP systems cannot be modeled on economic values such as environment benefits and voltage improvement which are quantified in non-economic values in Daly and Morrison (2001). In this study, economic factors such as RI, LR, UID, PPS and HPS are quantified in economic terms to study benefits of CHP.

Upgrade Investment Deferral (UID): As electricity is produced near the loads especially during peak load hours, power flows are essentially reduced (as long as the total DR capacity does not exceed the local load), thus deferring the need to upgrade some overloaded feeders (Gil and Joos, 2008).

The value of this benefit of CHP depends mainly on the power system cost-structure, network configuration and planning strategies, the type of feeder and the area that CHP will be located at and also load growth rate. An annual value of 120 $/kava for the deferral benefit is considered in this study based upon (Gil and Joos, 2008; Masoum *et al*., 2004).

Power Purchase Saving (PPS): PPS represents the saving due to reduction in electric power that must be purchased from electricity market to supply the customers:

$$PPS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} P_{k,t}^{CHP} \times EP_t \quad (8)$$

where,
$P_{k,t}^{CHP}$: The output power of the k-th CHP unit at the t-th year
EP_t : The energy price at the t-th year.

Considering Interest Rate (IR), the value of EP for the t-th year can be calculated using:

$$EP_t = EP_1 \times (1+IR)^{t-1} \quad (9)$$

Heat Purchase Saving (HPS): Our HPS represents the saving due to purchased heat to supply the customers.

$$HPS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{DG}} H_{k,t}^{CHP} \times HP_t \tag{10}$$

where,

$H_{k,t}^{CHP}$: The heat output of the k-th CHP unit at the t-th year

HP_t : The heat price at the t-th year

Considering Interest Rate (IR), the value of HP for the t-th year can be calculated using:

$$HP_t = HP_1 \times (1+IR)^{t-1} \tag{11}$$

Loss reduction: Power losses in distribution systems are very important for the utilities. Losses of the system reduce the efficiency of transmitting energy to customers. The total reduction of real power losses in a distribution system can be calculated by (12):

$$LRR = \sum_{t=1}^{N_{year}} (P_{Loss,t} - P_{Loss,t}^{CHP}) \times EP_t \tag{12}$$

where,

$P_{Loss,t}$: The active power loss before installing CHP units in the distribution system at the t-th year

$D_{Loss,t}^{DR}$: The total active power loss after installation of CHP units in the network at the t-th year

Reliability Improvement (RI): CHP units can have a positive influence on distribution system reliability if they are located properly. It is considered that the CHP can still supply loads in the case of main source unavailability. Therefore, there will be a reduction of the duration related indices since part of the load can be attended by the CHP while the main supply interruption cause is being repaired. Reliability improvement of the system after installation of the CHP is modeled as follows:

$$RI = \sum_{t=1}^{N_{year}} CIC_t - CIC_t^{CHP} \tag{13}$$

CIC_t is the Annual Customer interruption cost, without CHP application ($), at the t-th year and CIC_t^{CHP} is the Annual Customer interruption cost, when CHP is applied in the network at the t-th year. The value of loss load is considered to be 1000 $/MVA (Wang *et al.*, 2003).

DR costs calculation: Cost of DR is composed of three components as follows:

IC_k : Initial cost of the k-th DR

OC_{kt} : Operating cost of the k-th DR at the t-th year

MC_{kt} : Maintenance cost of the k-th DR at the t-th year

Initial Cost (IC) includes procurement, installation costs and costs of required equipments for connection of CHP to transmission system. Operating Cost (OC) is the fuel cost that will be calculated for each year using IR. Maintenance Cost (MC) consists of maintenance and repair costs.

Stochastic approach: Power systems are stochastic in nature due to bus loading and transmission system uncertainties. This stochastic nature causes the system variables to be statistical. Risk assessment is an inseparable part of an economic analysis. In order to reduce the risk of a decision for DER placement it is necessary to simulate the stochastic nature of power system and its parameters. Many different methods have been applied for load forecasting. However, the results can be inaccurate. It is usual to approximate the statistical nature of the load of each bus by a Normal distribution. The standard deviation of each load can be forecasted based on the historical data as well as the mean value (Afkousi-Paqaleh *et al.*, 2010).

Flowchart of the proposed algorithm is shown in Fig. 2. In addition to network data, generation cost function of each unit; forecasted load and its standard deviation at each bus are given to the algorithm as input data.

Monte-Carlo method is used to simulate the effect of stochastic nature of loads and system on the optimal location and size of the CHP units all around the network. For each decision we make for CHP placement the fitness of the design depends on the stochastic benefits and the costs related to CHP application. For each design (ds) and each scenario (sc):

$$BCR(ds,sc) = \frac{Benefit(ds,sc)}{Cost(ds,sc)} \tag{14}$$

where,

BCR (ds, sc) : The benefit cost ration of the design ds and scenario sc

Cost (sc, ds) : The cost for design ds and scenario sc

Benefit (sc, ds) : Benefits for scenario sc and design ds

Cost utilization of CHP units composed of three components as presented in (7) and the benefits are calculated using (6).

After computing BCR for all scenarios and design stochastic BCR of each design is calculated using (15):

$$SBCR(ds) = \sum_{sc}^{SC} prob(sc).BCR(ds,sc) \tag{15}$$

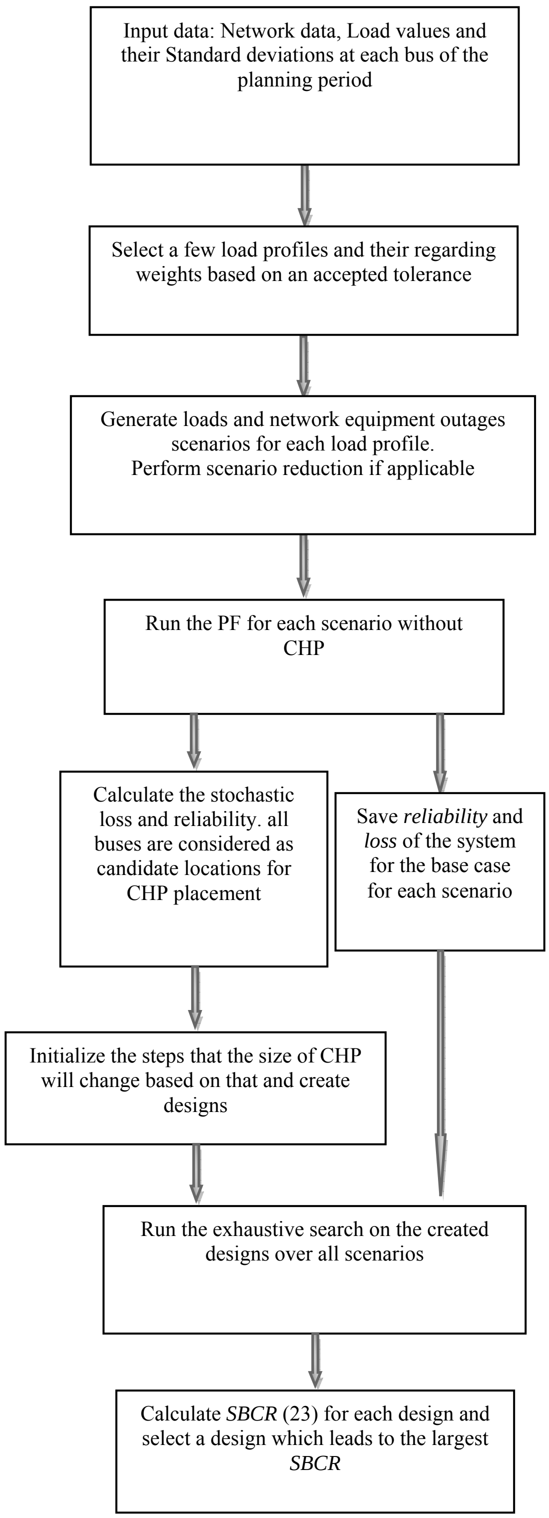

Fig. 2: Flowchart of the proposed stochastic approach

Finally the BCR of each design is calculated using the following:

$$BCR(ds) = \frac{SBCR(ds)}{\sum_{sc}^{SC} prob(sc)} \tag{16}$$

The optimal solution of the CHP planning problem is the 1 which leads to a larger amount of stochastic BCR. An optimization method can be applied to solve this optimization problem but to find the solution a several steps method has been used that is proposed in Afkousi-Paqaleh *et al*. (2010).

All buses are selected for installation of distributed generation units. The capacity of CHP units is considered to be fixed in several values from zero to the maximum available and permitted capacity. Then the stochastic saving values should be checked for all designs and find the largest value and chose the regarding design as the optimal solution.

SIMULATION RESULTS

The proposed method is applied to 2 different case studies. Among the 2, the first 1 is studied on 6-bus meshed network; case 2 is on radial 14-bus test system. Load profiles (thermal and electric), of these test system are borrowed from (Basu *et al*., 2010). The cases are studied at peak demand with the cost benefit of CHPs and heat recovery equipment. PSO parameters are presented in Table 1.

For the cost-benefit analyses, the focuses are mainly given to benefits, such as electricity and heat selling, system-loss reduction, reliability improvement and upgrade investment deferral.

The interest rate is 0.1 p.u.; average utilization (u): 40%; and the economic life cycle is considered to be 5 years (Basu *et al*., 2010). The price of utility electricity is U.S.$0.12/kWh and the cost of heat is U.S.$0.05/kWh (Basu *et al*., 2010).

The data for micro turbine as prime mover of CHP (U.S.$/kW/year): the investment cost is U.S. $1000/kW. The maintenance cost plus operation cost plus fuel cost are 779.64/kW/Year. Data of heat exchanger (in per unit) are: The turnkey cost is U.S.$190/kW. The (O&M) fixed and variable costs are assumed zero. The efficiency is 0.8 (Basu *et al*., 2010). The Heat/electricity ratio is considered to be 1.5 based on Ren *et al*. (2008).

The following assumptions are made based on Haghifam and Manbachi (2011) to model the reliability and the impact of CHP on it. In 98.39999% of the cases, the CHP system generates hot water and in 94.2074% of the cases, the CHP generates electricity. When the generator is in parallel with the distribution network, the total reliability of the system will be 99.9994%, considering the reliability of the distribution network to be 99.9897%. The customer interruption cost is considered to be 1 $/kWh (Wang *et al*., 2003).

Table 1: PSO parameters

Swarm size	C1	C2	W1	W2	Intermix
30	1.70	1.70	0.90	0.40	200

Table 2: Optimal location and size (KW) of electric power of CHP units (deterministic six-bus case)

Bus rank	1	2	3	4	5	6	BCR
1	0	0	0	0	0	14.478	2.046805
2	0	0	0	0	0	14.9498	2.046793
3	0	0	0	0	0	14.949	2.046793
4	0	0	0	0	0	14.949	2.046793
5	0	0	0	0	2.6210	12.541	2.046316
6	0	0	0	0	3.5788	9.0620	2.045554
7	0	0	0	0	4.3246	8.0470	2.045159
8	0	1.4266	6.5753	2.3016	4.1518	7.1828	2.039663
9	0	1.7219	22.664	5.5904	4.1685	5.4389	2.036416
10	0	1.7219	22.664	5.5904	4.1685	5.4389	2.036416

Table 3: Optimal location and size (KW) of electric power of CHP units (stochastic six-bus case)

Bus rank	1	2	3	4	5	6	BCR
1	0	0	0	0	0	5	2.06180
2	0	0	0	0	0	10	2.05860
3	0	0	0	0	0	15	2.05550
4	0	0	0	0	5	5	2.05540
5	0	0	0	5	0	5	2.05473
6	0	0	0	0	5	10	2.05420
7	0	0	0	5	0	10	2.05410
8	0	0	0	0	5	0	2.05250
9	0	0	0	0	0	20	2.05250
10	0	0	0	5	0	15	2.05230

Six-bus meshed test system: Table 2 shows the result of deterministic optimal locating and sizing problem for 6-bus meshed test system. The best solution is a CHP with power capacity of 14.478 kW at bus 6. The maximum heat capacity of this unit will be 21.717 based upon aforementioned assumptions. The results show that BCR is very high for this placement problem and thus it can be concluded that application of CHP in distribution system is economically feasible.

The result of stochastic placement problem for 6-bus meshed test system is presented in Table 3. In this situation as is shown in Table 3 is a CHP with power capacity of 5 kW at bus 6. The maximum heat capacity of this unit will be 9. The results show that BCR is very high for the stochastic problem too. The results show that stochastic saving is higher than deterministic saving and that is because increases in bus loads brings more saving than decreases in bus loads decrease the savings.

14-bus radial test system: Table 4 shows the result of deterministic problem of optimal locating and sizing of 14-bus radial test system. Seven solutions that have the maximum of BCR are ranked in this table. It is interesting that all solutions have the same BCR and the

Table 4: Optimal location and size (KW) of electric power of CHP units (deterministic 14-bus case)

	Solutions priority						
Bus #	1	2	3	4	5	6	7
1-4	0	0	0	0	0	0	0
5	0	0	11.586	11.510	0	0	25.797
6	0	61	0	61	0	5.1060	0
7	0	0	0	0	0	0	6.1010
8	30.500	0	30.500	0	25.765	26.530	22.954
9	0	10.592	0	16.375	18.605	18.605	0
10	0	0	0	0	15.756	17.727	22.588
11-12	0	0	0	0	0	0	0
13	0	0	0	0	27.450	27.450	12.858
14	41.175	27.157	41.175	28.505	41.175	41.175	28.934
BCR	1.9851	1.9851	1.9851	1.9851	1.9851	1.9851	1.9851

Table 5: Optimal location and size (KW) of electric power of CHP units (stochastic 14-bus case)

	Solutions priority						
Bus #	1	2	3	4	5	6	7
1-4	0	0	0	0	0	0	0
5	0	0	11.5860	25.7970	11.5100	0	0
6	61	0	0	0	61	0	5.1060
7	0	0	0	6.10100	0	0	0
8	0	30.5000	30.5000	22.9540	0	25.765	26.530
9	10.5920	0	0	0	16.3750	18.605	18.605
10	0	0	0	22.5880	0	15.756	17.727
11-12	0	0	0	0	0	0	0
13	0	0	0	12.8580	0	27.450	27.450
14	27.1570	41.1750	41.1750	28.9340	28.5050	41.175	41.175
BCR	1.98503	1.98502	1.98502	1.98502	1.98501	1.9850	1.9850

ranking (Considering the land costs) is made based on the solution that has the lower number of CHP units. The best solution is a CHP with power capacity of 30.5 kW at bus 6 and a 41.175 KW CHP unit at bus 14. The maximum heat capacity of these units will be 45.75 and 61.763 KW, respectively. The results show that BCR is still high for this placement problem in this case and the investment costs will be returned in less than 3 year.

The result of stochastic problem of proper sizing and locating of 14-bus radial test system is presented in Table 5. In order to reduce the solution space and decrease the computational burdens only the seven solutions obtained in the deterministic analysis are considered as potential solution of stochastic problem. As it can be seen the ranking of the solutions is not the as the same in the stochastic analysis as in the deterministic solution and the solution with rank of 2 in deterministic solution is the best solution, considering uncertain nature of power system.

DISCUSSION

In this study deterministic and stochastic placement and sizing of CHP units in distribution system has been presented. As the results show considering the stochastic saving in planning of CHP units is really important and can effectively increase the saving of implementation of CHP units considering bus loading fluctuations. Comparing results of Table 2 to 3 and Table 4 to 5 demonstrate that considering the uncertainties associated with power system in decision making change the planning strategy of the CHP systems and the regarding benefits. The results of both stochastic and deterministic analysis demonstrate that implementation of CHP in both meshed and radial distribution systems has many financial benefits and in all cases the value of BCR is about to 2. Application of CHP systems has other benefits like voltage improvement and reduction in pollution that can be considered and modeled in further studies.

CONCLUSION

This study has proposed an efficient method for optimal locating and sizing of CHP units considering stochastic nature of system bus loading. A cost/benefit analysis is applied to find optimal size and location of CHP units. This method considers economic factors such as reliability improvement, loss reduction, upgrade investment deferral and CHP costs. The results of applying proposed method on 2 different distribution test systems show that the proposed method is effective in finding optimal location and proper size of CHP units that reduce total cost of the system operation effectively and increase social welfare.

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