Reliability Indices Utlization in Combined Heat and Power (CHP) Optimal Operation

Hamed Hosseinnia[1], Dariush Nazarpour[2], Masoud Rezaei Benam[3]
1 , 2- Department of Electrical Engineering, Urmia University, Urmia, Iran
Email: Hhosseinnia66@yahoo.com
Email: d.nazarpour@urmia.ac.ir
3- Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
Email: masoudrezaiebenam97@yahoo.com

Received: March 2014 Revised: May 2014 Accepted: August 2014

ABSTRACT
The reason for using cogeneration more that heat and power separately is that, it is more efficient. In this paper the goal is finding the optimized CHP system utility size and thermal storage considering reliability limits of boiler and grid connected bus. Loss of Load Expectation (LOLE) and Expected energy not supplied (EENS) are considered as two reliability indices to insure the security of operation. Non-sequential Monte Carlo simulation method is introduced to the reliability assessment of CHP, and a normal distribution electrical load model is built to simulate the hourly electrical load. CHP model combined with a two-state reliability model is applied to Monte Carlo simulation method, and results show that the CHP reliability model works well with non-sequential Monte Carlo simulation. Non-Sequential Monte Carlo method is used to generate scenarios. Also in order to reduce computation time and due to the large number of scenarios, a scenario reduction technique is used. GAMS software is used for optimization process.

KEYWORDS: CHP, Thermal Storage, .Monte Carlo Sampling, Scenario Reduction, Gams Software.

1. INTRODUCTION

Cogeneration is an optimal solution in order to have energy with higher efficiency in compare with the conventional type. In the conventional type, which is separate use of heat and power, most of the fuel capacity is used to generate electrical energy and the rest is wasted.

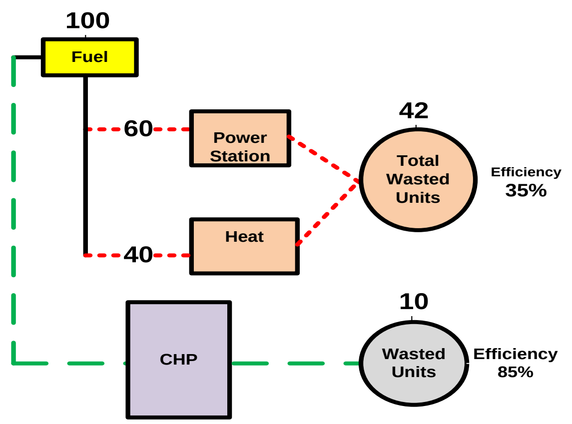

Fig. 1. The efficiency of CHP compared to SHP

The fuel consumption saving and also increasing efficiency in cogeneration type, compared to the conventional type, is shown in Fig. 1. As shown, 24 out of 60 electricity input units are used in the separate use of heat and power (SHP) and the efficiency is 35 percent, while 42 units are wasted. 34 out of 40 heat input units are used and 6 units are wasted. But in cogeneration type, total unused units are 10 units and total efficiency is 85 percent. Fig. 2 shows efficiency of CHP [1, 2].

The main idea behind the use of CHP for residential applications is to supply electricity to customers at a competitive price. The other profits include efficient use of electrical and thermal energy, increased reliability and declined emission [3,4].The aim of this paper is operation of the cogeneration system by using the optimal size of the cogeneration equipment. The reliability indices (LOLE) and (EENS) are used as the constraints of the optimization problem. For this purpose, the objective function is defined as the costs for cogeneration units in a planning horizon. Random outages of the cogeneration units and inaccuracy of load forecasting is modeled by a scenario tree. Non-sequential Monte Carlo method is used to generate scenarios in the planning horizon. Using reliability indices (LOLE, EENS), the number of cogeneration units is measured as a compromise between reliability and economy.

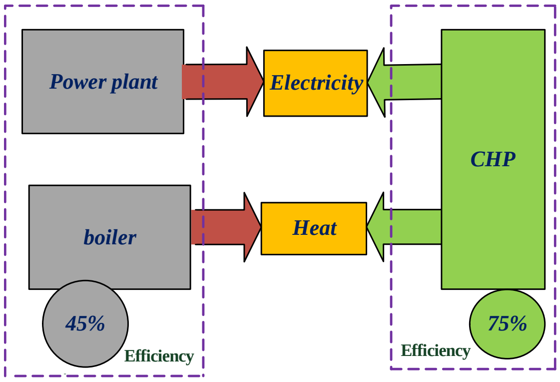

Fig. 2. The efficiency of CHP

2. THE BASIC OF MONTE CARLO

The main idea of Monte Carlo method is to create a series of experimental samples using a random sequence of numbers. According to the central limit theorem, when the sample size is large enough, sample average can be used as an unbiased approximation of the expected (value). Variance of the sample average shows precision of the estimation [5,6].

2.1. Scenario Generation

In order to solve multi-period optimization problems when there is not enough statistical data to support stochastic optimization, scenario analysis is one of the most common methods. Each scenario corresponds to a particular outcome of random variable [7]. This means scenarios are realization of definite multidimensional random processes, which has been illustrated in Fig. 3.

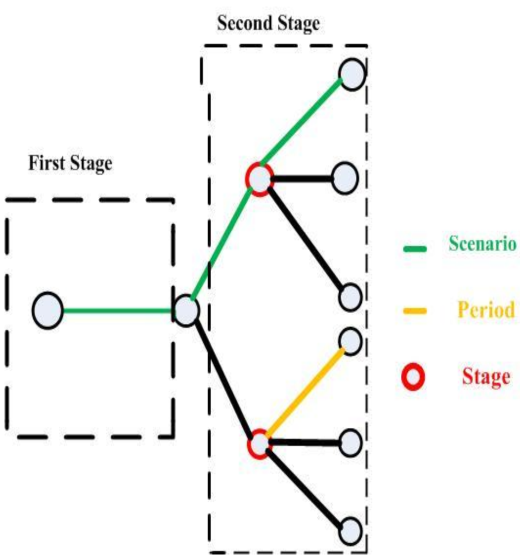

Fig. 3. The scenario trees

2.2. Scenario Reduction

Let P be a probability distribution on R^s with finite support consisting of N scenarios μ^i and their probabilities P^i, $i \in I := \{1 \ldots N\}$. The basic idea of optimal scenario reduction, consist in determining a probability distribution V_n which is the best approximation of P with respect to a given distance d of probability measures and whose support consist of a subset of $\{\mu^1, \ldots, \mu^n\}$ with n<N elements [8].

2.3. Non Sequential Monte Carlo Simulation

Non-sequential Monte Carlo simulation, which called state sampling method, has many applications in power system reliability evaluation. The basis of this method is that the system state is a combination of states of its elements, and state of each element can be obtained by sampling its probability [9]. Each element can be modeled in the interval [0, 1] according to the uniform distribution. Assume that each element has two modes, namely valid and failure phenomenon of each element is independent. M_i represents mode of the ith element and Q_i represents its probability of failure. Q_i which is a random number uniformly distributed in the interval [0, 1], is produced for the ith element.

2.4. Cogeneration System Description

Cogeneration system considered in this project consists of M combined heat and power generation units, K auxiliary boilers and a thermal energy storage tank. Also in order to increase the reliability of the system, a bus bar to interchange electrical energy with the local grid via a 20kv substation is considered [10].

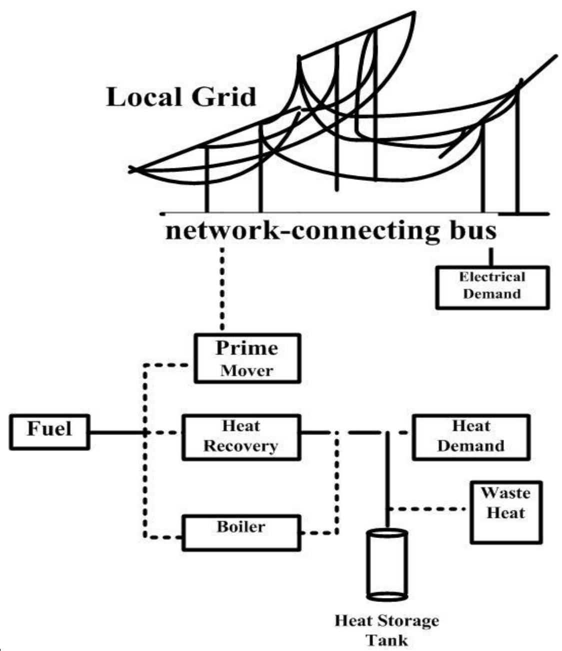

Fig. 4. The proposed CHP system

2.5. Connection to the network
When cogeneration system is able to connect to the network, it can buy electricity from or sell it to the network. It is clear that independent cogeneration system configuration differs from cogeneration system configuration which is connected to the network. Also, type and size of the system that can both buy and sell electricity is different from the system that can only buy electricity from the network.

2.6. Load model
The Five-step normal distribution ($0, \pm\delta, \pm 2\delta$) is often used for load forecasting inaccuracy modeling. Where δ is standard deviation [11]. Fig. 5 shows this model.

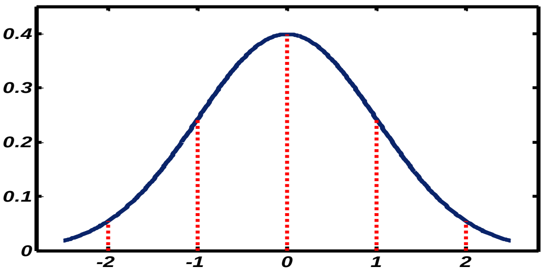

Fig. 5. Five-Step normal distribution.

Fig.6 shows electrical load for one scenario in 300 hours.

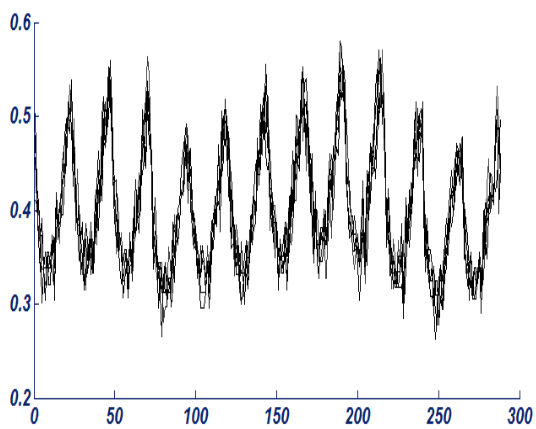

Fig. 6. Electrical load for one scenario in 300 hours

2.7. Objective function
The objective function is considered as a two-stage stochastic programming. The first stage includes minimization of the capital cost of the equipment, without considering scenarios and the second stage recursive objective function includes minimization of the costs of operation, maintenance, emissions and purchasing electrical energy from the network minus revenue from the sale of electricity to the local grid for all the scenarios and taking into account the objective function of the first stage. The objective function is obtained as follows:

$$\sum_{m=1}^{L} Ic^{chp\_m} + \sum_{k=1}^{r} Ic^{Boiler\_k} + Ic^{HS} + \sum_{s=1}^{NS} Ps * \left(\begin{array}{l} \sum_{m=1}^{L} (OC_s^{chp-m} + MC_s^{chp\_m}) + \\ \sum_{L=1}^{L} (OC_s^{Boiler\_k} + MC_s^{Boiler\_k}) \\ + C_s^{LS} + C_s^{Grid\_purchase} - I_s^{Grid\_Sell} \end{array} \right) \quad (1)$$

Where IC, OC and MC are investment, operation and maintenance costs, respectively. HS represents the heat storage tank. P_s is probability of each scenario. C_s^{LS}, $C_s^{Grid\_purchase}$ and $I_s^{Grid\_Sell}$ are cost of load shedding. The cost of purchasing electricity from grid and incoming with selling electricity to grid, respectively [12]. "s" represents scenario and NS is number of scenarios.

2.8. Cost of purchasing electricity from local grid
In most country, the price of electrical utilities is in step rate farms. In the stepped rates, the monthly electricity bill is a function of consumption in each step and electricity price in each step increases with the increasing of consumption, which is shown in Fig. 5. monthly cost of buying electricity in month 'm' and scenario 's' with consideration of stepped prices is given by:

$$C_{m,s}^{Grid\_Purchasing} = \sum_j (Price^j * P_{m,s}^j) - Price^{Low\_Load} * P_{m,s}^{Low\_Load} + Price^{Peak\_Load} * P_{m,s}^{Peak\_Load} \quad (2)$$

Where:
$price^j$ is price of electricity in step 'J', which is shown in Fig. 7.
p^j is monthly consumption in step 'j'.
Price $^{Low\_Load}$ and Price $^{Peak\_Load}$ are remission and surcharge rates that are applied to consumption in low load and peak load hours respectively [13,14].

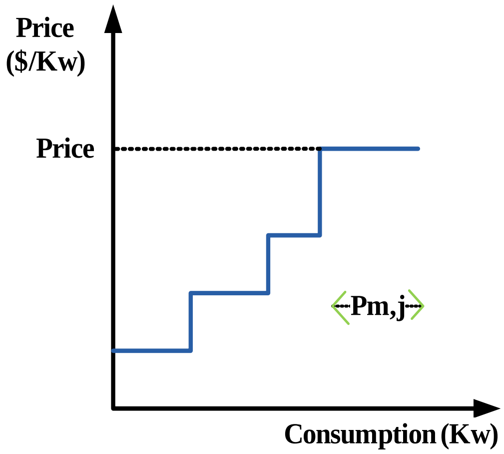

Fig. 7. Step- rates farm of electrical utilities

Loss of load Expected (LOLE) and Expected energy not supplied (EENS) are two Reliability indices that are used in this paper. The LOLE for both of the Electric and heat demands are given by:

$$LOLE = \sum_s P_s * \sum_m \sum_d \sum_h LSIDX_{mdh,s} \le \overline{LOLE} \quad (3)$$

The EENS is given by:

$$EENS = \sum_s P_s \sum_m \sum_d \sum_h LS_{s,mdh} \quad (4)$$

From the first method for both electric and heat demand, we have:

$$EENS \le \overline{EENS} \quad (5)$$

Value of lost load (VOLL) relies on many factors, such as: type of customers, duration of cessation and etc.to implement EENS, in stochastic problem planning, cost of unsupplied energy is added to objective function as a penalty term based on VOLL.

$$C_s^{LS} = \sum_m \sum_d \sum_h (VOLL * LS_{mdh,s}) * \zeta \quad (6)$$

Where 'ζ' is a factor for conversion of annual costs to the percent value in planning horizon and given by:

$$\zeta = K * \frac{K^r - 1}{K - 1}, \quad K = \frac{1+\alpha}{1-\beta} \quad (7)$$

α And β are inflation and interest rates, respectively 'r' is useful life of components (year). Total net present income due to selling electricity is:

$$I_s^{Grid\_sell} = \sum_m \sum_d \sum_h (Price^{sell} * P_{mdh,s}^{Grid\_sell}) * \xi \quad (8)$$

Electricity price for common use and non-common use are stepped rates [15]. Price for both common and non-common electric demands are shown in tables I and II.

Table 1. Utility electricity price for non-common use

Monthly consumption of each unit	Price (Kw/hour)
0-100	300
100-200	350
200-300	750
300-400	1350
400-500	1550
500-600	1950
Excess of 600	2150

Table 2. Price for common use

Period	Peak	Normal	Low
Price(Rial/Kw)	680	340	170

The selling price in normal load hours is half of peak load hours. Also, the low-load hours are half of normal load hours, which are shown in table III.other required parameters to scenario generation are listed in tableIV. Parameters of equation (7) are given in tableV.
For solving this planning problem (1), 1500 scenarios are generated using, non-sequential Mont Carlo sampling. The original scenario tree has 1500 scenarios, each with a probability 1/1500.after reduction only 20 scenarios are left with probabilities shown in tableVI. [14].

Table 3. Selling price

Period	Peak	Normal	Low
Price (Rial / Kw)	980	490	245

Table 4. Force outage rate of CHP Components

Boiler	CHP unit	Storage tank	Grid connection bus
For	For	For	For
0.04	0.06	0.02	0.02

Table 5. Inflation and interest rates.

r	α	β
15	20%	20%

Table 6. Probability of each scenario

Scenario	1	2	3	4	5
Probability	0.03	0.07	0.14	0.02	0.013
Scenario	6	7	8	9	10
Probability	0.02	0.03	.165	0.015	0.017
Scenario	11	12	13	14	15
Probability	0.01	0.112	0.015	0.014	0.045
Scenario	16	17	18	19	20
Probability	0.04	0.088	0.08	0.061	0.025

2.9. CHP system without and with heat storage

The optimized size of system ingredients and economic parameters are as tableVII.the optimal size of heat storage tank is 266m^3.the uncertainty of "operation cost" in tableVII is calculated based on ±95% confidence interval. The ±95% confidence interval is given by 1.96*δ/√N in which δ is the standard deviation for system scenarios. And N is the number of scenarios. Results show that after 98.67% diminution of scenarios (1500 scenarios are decrease to 20 scenarios).The optimized capacity of system components and economic parameters are as table VII.

3. CONCLUSION

In this paper optimized size of CHP component has been considered. In addition, the optimal size of CHP component obtained by considering reliability limitation of each component with optimization software usage (GAMS) and solving two stage stochastic problem, the optimal utility size of boiler and heat storage tank has been obtained. The results show that with proper size selection, CHP installation is one of the best methods to improve service reliability and decrease the power cost overtly.

Table 7. Optimized parameters

		Without heat storage	With heat storage
Total net present cost ($*106)		7.1294	6.8075
Operation cost($)		3701433± 34102	3799251± 36725
Relative error (%)		0. 68	0.85
CHP Capacity (Kw)	Unit1	1150	1170
	Unit2	1160	1180
Boiler Capacity (Kw)	Unit1	1320	1320
	Unit 2	1340	0
LOLE	Electrical	0.80	0.91
	Thermal	0.82	0.93
EENS	Electrical	635	626
	Thermal	1352	2787

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