Particle Swarm Optimization Technique for Stochastic Multi-objective Combined Heat and Power Dispatch

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Abstract

A new stochastic formulation of multi-objective optimization for Combined Heat and Power Economic Dispatch (CHPED) is presented. Both power and heat demand are treated as random variables. Optimization is the art of obtaining optimum result under given circumstance. This paper presents Particle Swarm Optimization (PSO) technique to solve CHPED. The three objective function to be minimized are 1.Total generation cost 2. The expected power generation deviation 3. The expected heat generation deviation. As these objectives are in conflict with each other only a non-inferior solution can be reached. The constraint satisfaction technique has been applied to reduce the computation time and improve the quality of the solution. A fuzzy decision index is proposed here to provide the best compromise solution among all objectives and constraints and a means of maximizing the most underachieved objective. In order to prove the validity and effectiveness of the proposed algorithm a test system with seven generators is considered. Among the seven first four is conventional power units, fifth and sixth are cogeneration units and seventh is heat only unit. The results show that the proposed method is practical and valid for real time applications.

Nomenclature

P	unit power output
$\overline{P}$	expected unit power output
P_D	system power demand.
$\overline{P}_D$	expected system power demand.
h	unit heat output
h_D	system heat demand
$\overline{h}$	expected unit heat output
$\overline{h}_D$	expected system heat demand
P_i	power output of power-only unit I
P_L	system transmission power loss
$\overline{P}_L$	expected system transmission power loss
O_j	power output of cogeneration unit j
H_j	heat output of cogeneration unit j
T_k	heat output of heat-only unit k
$\mathrm{Var}(\bullet)$	variance
$\mathrm{Cov}(\bullet)$	covariance
$\mathrm{V}(\bullet)$	coefficients of variance

$C(\bullet)$	coefficients of covariance
$\bar{\bullet}\min, \bar{\bullet}\max$	capacity limits of expected heat or power output
B_{ij}	loss coefficient of network branch connected between generators i and j
N_p, N_c, N_h	numbers of conventional power units, cogeneration units and heat-only units
a_i b_i c_i	cost coefficients of conventional power-only unit.
$\alpha_j, \beta_j, \gamma_j, \delta_j, \theta_j, \zeta_j$	cost coefficients of Cogeneration unit
x_k, y_k, z_k	cost coefficient of heat- only unit.
w_1, w_2, w_3 W	weight vector and weights attached to objective functions
$J_1^{\max}$ $J_1^{\min}$	maximum and minimum values of each objective function.
CHPED	combined heat power economic dispatch
DM	decision maker
PSO	particle swarm optimization

Introduction

The CHPED problem concerns the distribution of load over the units that are in service so that the total fuel cost is minimum and thermal energy required is obtained. Cogeneration units play an increasingly important role in the utility industry. Cogeneration unit can provide not only electrical power but also heat to the customers. For most co-generation units the heat production capacities depend on the power generation and vice versa. CHPED is regarded as an efficient and economic way of simultaneously producing electric power and district heat [1-2]. In conventional algorithm we have to solve the CHPED problem based on a physical interpretation of the heat power feasible region constraints of cogeneration units in the dispatch process. The CHPED problem can be viewed as a composition of the heat dispatch and power dispatch sub problem that are connected by the heat power feasible region constraints of cogeneration units. The interpretation of the heat power feasible region constraint multipliers naturally leads to the development of two layer algorithm [3]. The outer layer uses the LaGrange relaxation technique [4] to solve the power dispatch iteratively. In each iteration the outer layer passes the heat capacity limits to the inner layer for the heat dispatch. The binding constraints [5] in the heat dispatch solution are feed back to the outer layer to modify the unit power incremental costs. The feed back of the binding constraints between the two layers moves the iteration process to a global optimal solution. Economic dispatch was solved by using separability of the cost function and constraints [6]. Recently there is a upsurge in the use of methods as genetic algorithm, PSO, artificial neural networks that mimic natural process to solve complex combinational optimization problems.

This paper adopts a new stochastic formulation of multi-objective optimization for CHPED by considering the randomness of power and heat demands. Since power and heat demand are random the generation output becomes random. Three objectives: a) Total generation cost, b) the expected power generation deviation and c) the expected heat deviation of the system are minimized in this.

Power and heat demand constraint and other system operating constraints are taken into consideration. The three objectives are in conflict with each other in relation to optimality. The Decision Maker (DM) should realize that there is trade off between the non-inferior solution of the multi objective optimization problem. In this method the problem is converted into a scalar optimization problem. A fuzzy decision index provides the best compromise solution among all objectives and constraints and a means of maximizing the most underachieved objective. PSO technique is proposed to help the DM to search for such a solution mathematically. Application of this method to a seven-generator sample system is discussed in this paper.

Problem Formulation

The basic formulation of CHPED as a stochastic multi-objective optimization problem as presented below. Three objectives will be considered in this paper.

Objective1-Total production cost of heat and power

The formulation minimizes the system production cost for meeting heat and power demands and other system constraints. Three types of generating units are considered namely power only units, the cogeneration units and the heat only unit. A power only unit typically has a convex quadratic cost function.

$$C_i(p_i) = a_i p_i^2 + b_i p_i + c_i \tag{1}$$

A cogeneration unit has a convex cost function in both power output O and heat output H. To show the dependence between the O and H productions a coupling term is added into the cost function. The term is linear in both O and H [5]. The form of cost function is thus

$$C_j(O_j, H_j) = \gamma_j + \beta_j O_j + \alpha_j O_j^{\,2} + \delta_j H_j + \theta_j H_j^2 + \xi_j O_j H_j \tag{2}$$

The cost function of heat only unit is similar to that of a power only unit

$$C_K(T_K) = x_k T_k^2 + y_K T_K + z_K \tag{3}$$

The objective function of the CHPED system is the sum of the cost function of three types of units.

$$J_1 = \sum_{i=1}^{N_P} C_i(P_i) + \sum_{j=i}^{N_C} C_i(O_j, H_j) + \sum_{k=1}^{N_h} C_K(T_K) \tag{4}$$

A stochastic model of function J_1 is formulated by considering the power and heat demand as random variables [7]. Since both the power and heat demands are random the generation output becomes random. If power and heat demands deviate from their nominal values by small amount ΔP_D and ΔH_D then the total system power and heat generation also vary by the same amount. If we incorporate the random properties of power and heat demand the expected fuel cost will be

$$\begin{aligned} J_1 + \Delta J_1 &= \sum_{i=1}^{Np}\left[a_i(P_i+\Delta P_i)^2 + b_i(P_i+\Delta P_i) + c_i\right] + \sum_{j=1}^{N_h}\left[x_k(T_k+\Delta T_k)^2 + y_k(T_k+\Delta T_k) + z_k)\right] + \\ &\sum_{j=1}^{N_c}\left[\alpha_j(O_j+\Delta O_j)^2 + \beta_j(O_j+\Delta O_j) + \gamma_j + \theta_j(H_j+\Delta H_j)^2 + \varepsilon_j(O_j+\Delta O_j)(H_j+\Delta H_j) + \delta_j(H_j+\Delta H_j)\right] \end{aligned}$$

$$\begin{aligned} \overline{J}_1 &= \sum_{i=1}^{N_p}\left[a_i(\overline{P}_i^2 + \operatorname{var}(P_i)\ ) + b_i\overline{P}_i + \overline{C}_i\right] + \sum_{K=1}^{N_h}\left[x_K(\overline{T}_K^2 + \operatorname{var}(T_K)\ ) + y_K\overline{T}_K + z_K\right] + \\ &\sum_{j=1}^{N_C}\left[\alpha_j(\overline{O}_j^2 + \operatorname{var}(O_j)) + \beta_j\overline{O}_j + \gamma_j + \delta_j\overline{H}_j + \theta_j(\overline{H}_1^2 + \operatorname{var}(H_j)\ ) + \varepsilon_j(\overline{O}_j\overline{H}_j + \operatorname{cov}(O_jH_j))\right] \end{aligned} \tag{6}$$

where, var (Pi) = $V^2(P_i).\overline{P}_i^2$, $\operatorname{var}(T_K) = V^2(T_K).\overline{T}_k^2$, Cov $(O_j\ H_j) = C^2(O_j, H_j)\overline{O}_j\overline{H}_j$

Objective 2-Expected power generation deviation

Since the power demand is considered random in this study the power output from each power only and cogeneration unit is also random. The expected deviation is proportional to the expectation of the square of the unsatisfied demand. These expected deviations are formulated into an objective to be minimized. The objective is represented as

$$\overline{J}_2 = E\left[(\overline{P}_D + \overline{P}_L - \sum_{i=1}^{N_p} \overline{P}_i - \sum_{j=1}^{N_c} \overline{O}_j)^2 \right] \tag{7}$$

By extending the equation we obtain

$$\begin{aligned}\overline{J}_2 = &\sum_{i=1}^{N_p} \mathrm{var}(P_i) + \sum_{j=1}^{N_C} \mathrm{var}(O_j) + 2\sum_{i=1}^{N_P-1} \sum_{m=i+1}^{N_P} Cov(P_i, P_m) \\ &+ 2\sum_{j=1}^{N_c-1} \sum_{m=j+1}^{N_C} \mathrm{cov}(O_j, O_m) + \sum_{i=1}^{N_P} \sum_{j=1}^{N_C} \mathrm{cov}(P_i, O_j)\end{aligned} \tag{8}$$

Objective 3-Expected heat generation deviation

We treat expected deviation between the heat demand and heat production as the third objective to be minimized. The objective is represented as

$$\overline{J}_3 = E\left[(h_D - \sum_{j-1}^{N_C} H_j - \sum_{K=1}^{N_h} T_K)^2 \right] \tag{9}$$

$$\begin{aligned}\overline{J}_3 = &\sum_{j=1}^{N_C} Var(H_j) + \sum_{k=1}^{N_h} Var(T_K) + 2\sum_{j=1}^{N_{C-1}} \sum_{m=j+1}^{N_C} Cov(H_i, H_m) \\ &+ 2\sum_{k=1}^{N_{h-1}} \sum_{m=k+1}^{N_h} Cov(T_k T_m) + \sum_{j=1}^{N_C} \sum_{k=1}^{N_h} Cov(H_j, T_k)\end{aligned} \tag{10}$$

Both equality and inequality constraints are considered here

Equality constraints

The equality constraint associated with CHPED are the power and heat balance equations. The power balance equation is

$$\overline{P}_D = \sum_{i=1}^{N_P} \overline{P}_i + \sum_{j=1}^{N_c} \overline{O}_j - \overline{P_L} \tag{11}$$

where, P_L can be calculated by the network loss formula,

$$P_L = \sum_{i=1}^{N_P} \sum_{m=1}^{N_P} \overline{P}_i B_{im} \overline{P}_m + \sum_{i=1}^{N_p} \sum_{j=1}^{Nc} \overline{P}_i B_{ij} \overline{O}_j + \sum_{j=1}^{N_c} \sum_{n=1}^{N_c} \overline{O}_j B_{jn} \overline{O}_n \tag{12}$$

where, B_{ij} is known as the loss coefficient for a network branch connected between generators i and j. Since power generations are random variables the expected transmission loss using Taylor's series is represented as,

$$\overline{P}_L = \sum_{i=1}^{N_P}\sum_{m=1}^{N_P}\overline{P}_i B_{im}\overline{P}_m + \sum_{i=1}^{N_P}\sum_{j=1}^{N_c}\overline{P}_i B_{ij}\overline{O}_j + \sum_{j=1}^{N_C}\sum_{n=1}^{N_C}\overline{O}_j B_{jn}\overline{O}_n + \sum_{i=1}^{N_P} B_{ii} Var(P_i) + \sum_{j=1}^{N_C} B_{jj} Var(O_j)$$
$$+ 2\sum_{i=1}^{N_p-1}\sum_{m=i+1}^{N_p} B_{im} Cov(P_i, P_m) + 2\sum_{j=1}^{N_c-1}\sum_{n=j+1}^{N_C} B_{jn} Cov(O_j, O_n) + \sum_{i=1}^{Np}\sum_{j=1}^{Nc} B_{ij} Cov(P_i, O_j) \quad (13)$$

The heat balance equation is

$$\overline{h}_D = \sum_{j=1}^{N_C}\overline{H}_j + \sum_{k=1}^{N_n}\overline{T}_K \quad (14)$$

Inequality constraints

Inequality constraints associated with CHPED are parametric. Functional constraints such as limit on the expected values of the power production and heat production are written as,

$$\overline{P}_i^{\min} \le \overline{P}_i \le \overline{P}_i^{\max} \qquad i = 1,2 \ \ldots.. N_p \quad (15)$$
$$\overline{O}_j^{\min} \le \overline{O}_j \le \overline{O}_j^{\max} \qquad j = 1,2\ldots\ldots N_c \quad (16)$$
$$\overline{H}_i^{\min} \le \overline{H}_i \le \overline{H}_j^{\max} \qquad i = 1,2 \ldots\ldots N_c \quad (17)$$
$$\overline{T}_k^{\min} \le \overline{T}_k \le \overline{T}_k^{\max} \qquad k = 1,2\ldots\ldots.. N_h \quad (18)$$

In addition the output of each CHPED generator is assumed to lie in the heat -power feasible region.

Decision making (DM)

Considering the imprecise nature of the decision maker's judgment, it is natural to assume that the DM may have fuzzy or imprecise goal for each objective function. Fuzzy sets are defined by equations called the membership functions. By taking account of the minimum and maximum values of each objective function together with the rate of increase of membership satisfaction, the DM must detect membership function μ(Ji) in a subjective manner. μ(Ji) is strictly monotonic decreasing and continuous function defined as

$$\mu((\overline{J}_i) = \begin{cases} 0 & \overline{J}_{i \le} \overline{J}_{u\min} \\ \dfrac{\overline{J}_{i\max} - \overline{J}_i}{\overline{J}_{i\max} - \overline{J}_{i\min}} & \overline{J}_i^{\min} \le \overline{J}_i \le \overline{J}_{i\max} \\ 1 \quad \overline{J}_i \ge \overline{J}_{i\max} \end{cases} \quad (19)$$

$\mu(\overline{J}_i)$ is membership function of objective $\overline{J}_i$. The value of membership function suggest how for a non inferior solution has satisfied the $\overline{J}_i$ objective. The sum of membership function values $\mu(\overline{J}_i)$

(i=1…n)for all objectives can be computed in order to measure how far the accomplishment of each solution is satisfying the objectives.

$$\mu_D^K = \frac{\sum_{i=1}^{3} \mu(\overline{J}_i^k)}{\sum_{k=1}^{k} \sum_{i=1}^{3} \mu(\overline{J}_i^k)} \tag{20}$$

The accomplishment of each non-dominated solution can be rated with respect to all the K non dominated solution by normalizing its accomplishment over the sum of the accomplishments of K non-dominated solution.

The function μ_D can be treated as a membership function for non-dominated solution in a fuzzy set and represented as fuzzy cardinal priority ranking of the non-dominated solution. The solution that attains the maximum membership μ_D^K in the fuzzy set so obtained can be chosen as the best solution. $Max\left[\mu_D^K ; k = 1...k\right]$

Solution approach

The Weighting method is used to generate the non inferior solution of the multi objective optimization problem. In this method the problem is converted into a scalar optimization problem as given below.

$$\text{Minimize} \quad \sum_{k=1}^{3} w_K J_K \tag{21}$$

$$\text{Subject to } \overline{P}_D = \sum_{i=1}^{N_P} \overline{P}_i + \sum_{j=1}^{N_c} \overline{O}_j - \overline{P_L}$$

$$\overline{H}_D = \sum_{j=1}^{N_C} \overline{H}_j + \sum_{k=1}^{N_n} T_K$$

$$\overline{P}_i^{\min} \le \overline{P}_i \le \overline{P}_i^{\max} \qquad i = 1,2 \;..N_P.$$

$$\overline{O}_j^{\min} \le \overline{O} \le \overline{O}_j^{\max} \qquad j = 1\ldots N_C$$

$$\overline{H}_i^{\min} \le \overline{H}_i \le \overline{H}_j^{\max} \qquad i = 1 \ldots\ldots N_C$$

$$\overline{T}_k^{\min} \le T_K \le \overline{T}_k^{\max} \qquad k = 1\ldots\ldots..N_h$$

$$\sum_{k=1}^{3} w_k = 1 \qquad w_k \ge 0$$

where, W_x are the levels of the weighting coefficients. This approach yields result to the DM when solved many times for different values of W_k (k= 1, 2, 3).The values of the weighting coefficients vary from 0 to 1. The scalar optimization problem is solved by PSO.

Particle Swarm Optimization

PSO is a form of evolutionary computation technique. It is a search method based on natural systems developed by Kennedy and Eberhart [8]. PSO like genetic algorithm (GA) is a population based optimization tool. One major difference between PSO and evolutionary computation methods is that particles velocities are adjusted in PSO while in evolutionary computation individual's position are acted upon. It is as if the 'fate' is altered rather than the state of the particle swarm individuals [9]. The system initially has a population of random solutions. Each potential solution called particle is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of previous best position and corresponding fitness. The previous best value is called as p_{best}. Thus p_{best} is related only to a particular particle. It also has another value called g_{best} which is the best value of all the particles in the swarm. The basic concept of PSO technique lies in accelerating each particle towards its p_{best} and the g_{best} location at each time step. Acceleration has random weights for both p_{best} and g_{best} locations. Fig.1 illustrates briefly the concept of PSO where X_i is current position. X_{i+1} is modified position. V_i is initial velocity. V_i^{mod} is modified velocity V_{pbest} is the velocity considering p_{best} and V_{gbest} is velocity considering $g_{best.}$ To keep the particles with in the search space a maximum limit is fixed for velocity which is given by V_{max}. If V_i^{mod} exceeds the limit then it is set to maximum limit.

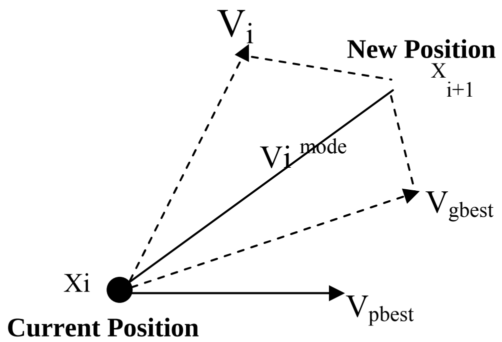

Fig.1 Concept of changing a particle's position in PSO

Steps

i) Initialize a population of particles with random position and velocities of d dimensions in the problem space.

ii) For each particle evaluate the desired optimization fitness function in d variables.

iii) Compare particle's fitness evaluation with particles p_{best}. If current value is better than p_{best} then set p_{best} value equal to the current value and the p_{best} location equal to the current location in d dimensional space.

iv) Compare fitness evaluation with the population's overall previous best. If the current value is better than g_{best} then reset g_{best} to the current particles array index and value.

v) Change the velocity and position of the particle according to equation (22) and (23) respectively. V_{id} and X_{id} represent the velocity and position of ith particle with d dimension respectively and $rand_1$ and $rand_2$ are two uniform random functions.

$$V_{id}^{mod} = W\, V_{id}\, c_1\ rand_1\, (p_{best\ id} - X_{id}) + c_2\ rand_2\, (g_{best\ i} - X_{id}) \quad (22)$$

$$X_{id+1} = X_{id} + V_{id}^{mod} \quad (23)$$

vi) Repeat step 2 until a sufficient good fitness or a maximum number of iterations/epochs is reached.

The inertia weight W controls the exploration and exploitation of the search space because it dynamically adjust velocity. Local minima are avoided by small local neighborhood but faster convergence is obtained by larger global neighborhood and in general global neighborhood is preferred. c_1, c_2, are acceleration constants which changes the velocity of a particle towards p_{best} and g_{best}. (generally somewhere between p_{best} and g_{best})

Numerical Example

The proposed method applies to a sample system with seven generators (Figs. 2 and 3). The system consists of four power only units, two cogeneration units and one heat only unit (Tables 1 and 2). The following coefficient of the covariance and correlation which can be obtained from normal historical data are assumed. V (.)=0.2 and C (.)=0.25.

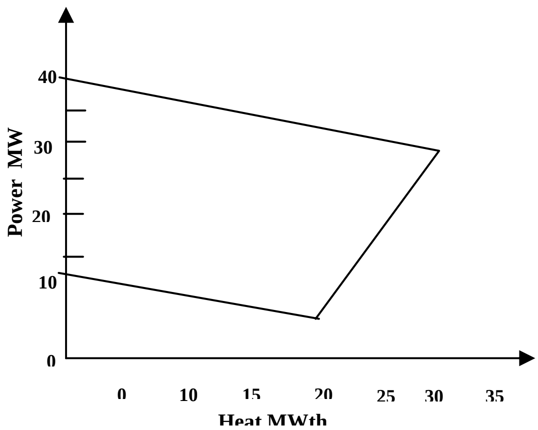

Fig. 2 Heat power feasible regions of generator 5

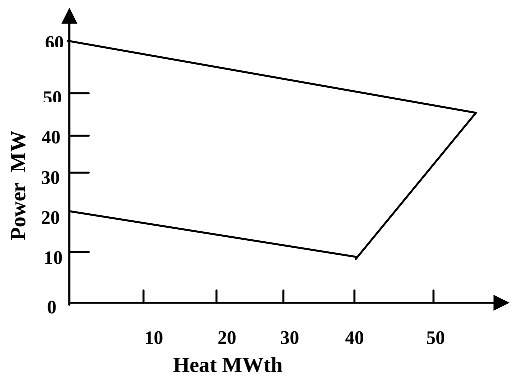

Fig. 3 Heat power feasible regions of generator 6

Sample system data

a) Cost equation of power only units: $

$C_1\ (P_1) = 556.7997 + 18.5401\ P_1 + 0.01202\ P_1^2$
$C_2\ (P_2) = 451.3251 + 16.1592\ P_2 + 0.0102\ P_2^2$
$C_3\ (P_3) = 1049.9983 + 40.3965\ P_3 + 0.0282\ P_3^2$
$C_4\ (P_4) = 1243.5311 + 38.3061\ P_4 + 0.0355\ P_4^2$

b) Cost equation of cogeneration units: $

$C_1\ (O_1, H_1) = 2650.0312 + 34.5011\ O_1 + 0.1035\ O_1^2 + 2.2031\ H_1 + 0.0249\ H_1^2 + 0.0510\ O_1 H_1$
$C_2\ (O_2, H_2) = 1250.0431 + 36.0012\ O_2 + 0.0435\ O_2^2 + 0.6002 H_2 + 0.0270\ H_2^2 + 0.0409 O_2 H_2$

C) Cost equation of heat only unit: $

$C_1(T_1) = 950.0021 + 2.0109T_1 + 0.0380\,T_1^2$

Table 1 Operation limits of power output

Generation no.	Lower limit MWth	Upper limit MWth
Power – only 1	50	200
Power – only 2	20	80
Power – only 3	15	50
Power – only 4	10	35
Cogeneration 1	10	60
Cogeneration 2	6	40

Table 2 Operation limits of heat output

Generation no.	Lower limit MWth	Upper limit MWth
Cogeneration1	0	55
Cogeneration 2	0	30
Heat only 1	0	60

Table 3 shows a set of non inferior solution for power demand of 200 MW and heat demand of 40 MWth. The results indicate the explicit trade off among the three objectives. As all the objectives are in conflict a set of non inferior solution is obtained. Deterministic results for four different power demands 200, 250, 300 and 350 MW and heat demands 40, 60, 80 and 100 MWth are presented in Table 4. Stochastic results for the same power and heat demands are presented in Table 5. In the results shown in Table 5, Objective J_2 (power generation deviation) and J_3 (heat generation deviation) are the risk associated with possible deviation of the random variables from their expected values about their mean while satisfying the expected load, heat demand constraints and expected generation, heat limits. In deterministic case as everything is considered to be known with certainty there is no randomness which leads to the absence of risk. Coefficient of variance and coefficients of covariance is zero in deterministic case. Table 5 shows that stochastic cost including inaccuracies and uncertainties is more accurate and also lower than deterministic case.

Table 3 P_D-200 MW h_D,40 MWth for various values of weight

W_1	W_2	W_3	$\overline{J}_1$	$\overline{J}_2$	$\overline{J}_3$	$\overline{P}_1$	$\overline{P}_2$	$\overline{P}_3$	$\overline{P}_4$	$\overline{O}_1$	$\overline{O}_2$	$\overline{H}_1$	$\overline{H}_2$	$\overline{T}_1$	$\overline{P}_L$
0	0.5	0.5	13314	754.6	36.3	73.5	51.5	20.0	23.3	21.8	22.9	3.66	19.42	16.95	13.21
0.2	0.4	0.4	13275	775.2	35.4	79.2	49.6	21.8	18.2	24.8	20.6	4.77	15.8	19.36	14.06
0.4	0.3	0.3	13202.6	752.5	36.95	72.9	51.46	16.5	24.8	21.5	25.6	3.86	21.98	14.16	12.89
0.5	.25	.25	13068.9	780.4	37.7	80.0	49.6	16.25	19.16	22.25	26.9	4.08	23.6	12.3	14.22
0.6	0.2	0.2	13068	746	37.9	74.9	47.0	15.05	23.59	25.78	25.5	1.97	20.49	17.54	11.87
0.8	0.1	0.1	13065	763	37.9	78.5	47.0	14.3	22.3	25.3	25.19	1.9	20.20	17.89	12.79
0.9	.05	.05	12903	764.9	38.1	77.0	49.43	12.9	19.6	27.2	26.6	2.0	21.48	16.52	12.92
1	0	0	12999	739.4	39.6	74.4	44.6	14.8	23.8	24.3	29.3	1.79	24.3	13.9	11.31
0	1	0	13377.7	751.4	36.5	73.14	50.65	18.02	27.54	20.09	23.39	3.34	19.26	17.32	12.85
0	0	1	13252	777	35.4	75.78	55.1	15.2	23.8	23.1	21.4	4.69	16.23	19.08	14.45

Table 4 Deterministic case

	P_D	h_D	J_1	P_1	P_2	P_3	P_4	O_1	O_2	H_1	H_2	T_1	P_L
1	200	40	13383	72.9	57.7	21.28	21.56	16.6	25.3	2.19	21.65	16.16	14.47
2	250	60	14670	83.9	51.93	36.68	33.73	28.95	31.82	0.69	27.04	32.24	15.38
3	300	80	15352	98.21	69.06	25.34	45.86	47.3	35.18	7.46	33.95	38.6	20.97
4	350	100	16348	145.1	65.6	40.8	31.48	53.35	50.62	17.58	33.95	48.50	36.31

Table 5 Stochastic power and heat generation for four different cases for weight W_1=0.8, W_2=0.1,W_3=0.1

	P_D	h_D	$\overline{J}_1$	$\overline{J}_2$	$\overline{J}_3$	$\overline{P}_1$	$\overline{P}_2$	$\overline{P}_3$	$\overline{P}_4$	$\overline{O}_1$	$\overline{O}_2$	$\overline{H}_1$	$\overline{H}_2$	$\overline{T}_1$	$\overline{P}_L$
1	200	40	13065	763	37.9	78.5	47.0	14.3	22.3	25.3	25.19	1.9	20.20	17.89	12.79
2	250	60	14200	1115	88.2	83.16	52.10	32.67	25.58	38.53	32.40	1.12	27.33	31.54	14.43
3	300	80	15343	1628	144.7	94.82	68.5	24.4	47.2	46.8	37.0	7.37	36.31	36.32	20.0
4	350	100	16165	2413	213.3	122.9	88.24	33.6	34.6	52.1	54.0	17.4	35.6	46.97	35.60

Table 6 Comparison of deterministic and stochastic results

P_D	H_D	$J_1 - \overline{J}_1$ (Cost)		$P_L - \overline{P}_L$ (Transmission Loss)	
Mw	Mwth	$	%	Mw	%
200	40	318	2.37	1.68	11.6
250	60	470	3.2	0.95	6.17
300	80	9	0.05	0.97	4.62
350	100	183	1.11	0.71	1.95

Conclusion

In this paper CHPED is formulated as a stochastic multi objective optimization problem. The important feature of this formulation is that both the power and heat demands are considered to be random. Thus the generator outputs become random. The analysis provides the facility to consider • the inaccuracies and uncertainties in the thermal power dispatch • allows explicit trade off among the operation cost, heat demand of units and risk level and • provides the power system operator with most efficient optimal solution from the non inferior set. PSO can find a desirable global solution for this multi objective optimization problem. Practical viability of the formulation is illustrated though numerical example in diverse situation. From Table 6 it is clearly understood that the proposed stochastic method using PSO shows the significant reduction is cost and transmission loss. A small percentage of saving can be considered significant. Thus it justifies the need for more accurate analysis and consideration.

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