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PSO-IIW FOR COMBINED HEAT AND POWER ECONOMIC DISPATCH

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Abstract- This paper presents a Particle Swarm Optimization with Improved Inertia Wight (PSO-IIW) for Combined Heat and Power Economic Dispatch (CHPED) problem. The proposed PSO-IIW technique, which is a population based global search and optimization technique, has been developed to solve the CHPED problem. The CHPED problem is formulated as an optimization problem which is solved by the PSO-IIW technique that has a strong ability to find the most optimistic results. The effectiveness of these algorithms has been tested on system with four power units, two co-generation units and one heat unit compared to other algorithms such as Real-coded Genetic Algorithm (RGA), Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) techniques for total operating cost. The results show the Particle Swarm Optimization with Improved Inertia Wight is able to achieve a better solution at less computational time.

Keywords: PSO-IIW, Combined Heat and Power, ED.

I. INTRODUCTION

The global energy supply and demand are increasingly dominated by major concerns about multiple factors, most notably climate change, shortage of oil supply and price increase, and rising population levels and per capita energy consumption. Hence it is critically important to find an alternative to fossil fuels, in particular petroleum fuels, from economic, environmental and social perspectives. Renewable energy sources with near zero-emissions such as solar energy, wind, and wave, hydro, and biomass energy offer such an alternative [1, 2]. The co-generation units achieve with combined heat and power generation to produce energy with minimum cost and environment. In the other hand, it is important role in energy production technology recently [3]. Also, the heat production capacity for CHP systems depends on power generation and vice versa. Thereupon, the Combined Heat and Power Economic Dispatch (CHPED) problem introduces complexities in the integration of co-generation units into the power system economic dispatch [4, 5]. Figure 1 show challenge for CHP mechanism.

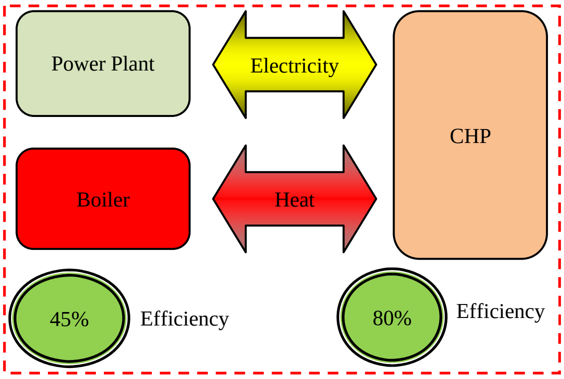

Figure 1. Challenge energy for a CHP system

In the recent researches, global optimization techniques like Genetic Algorithms (GA) [6], Harmony Search Algorithm (HAS) [7], Particle Swarm Optimization (PSO) [8] and Evolutionary Programming (EP) techniques [9] have been applied for optimal tuning of CHPED based restructure schemes. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators. Although, these methods seem to be good methods for the solution of CHPED parameter optimization problem, However, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded efficiency to obtain global optimum solution. In order to overcome these drawbacks, a Particle Swarm Optimization with Improved Inertia Wight (PSO-IIW) algorithm based is proposed for solution of the CHPED problem in this paper.

II. CHPED PROBLEM FORMULATION

The propose CHPED problem is an optimization problem like ELD problem, but it is consider some types of produce units such as pure heat units, combined power and heat (co-generation) and conventional power units. The co-generation is role to produce heat and power with feasible operation region according to Figure 2, where the boundary curve ABCDEF determines the feasible region.

Along the boundary there is a trade-off between power generation and heat production from the unit. It can be seen that along the curve AB the unit reaches maximum output power. In contrast, the unit reaches maximum heat production along the curve CD. Therefore, power generation limits of cogeneration units are the combined functions of the unit heat production and vice versa [7]. Mathematically, problem is formulated as Equation (1).

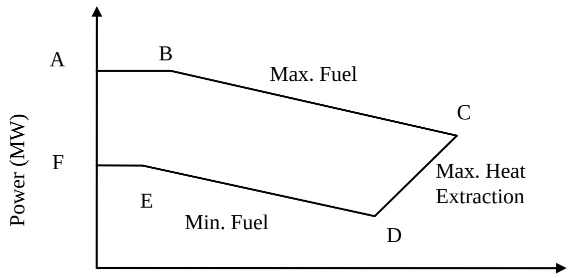

Figure 2. Typical heat-power feasible region for co-generation units

$$\text{minimize} \sum_{i=1}^{\alpha} F_{ti}(P_i) + \sum_{i=\alpha+1}^{\beta} F_{ci}(P_i, H_i) + \sum_{i=\beta+1}^{n} F_{hi}(h_i) \quad (1)$$

subject to

(a) Power balance constraint

$$\sum_{i=1}^{\alpha} P_i + \sum_{i=\alpha+1}^{\beta} P_i = P_D + P_L \quad (2)$$

(b) Heat balance constraint

$$\sum_{i=\alpha+1}^{\beta} H_i + \sum_{i=\beta+1}^{n} H_i = H_D \quad (3)$$

(c) Generation and heat limits constraints

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad i \in 1, 2, ..., \alpha \quad (4)$$

$$P_i^{\min}(H_i) \le P_i \le P_i^{\max}(H_i) \qquad i \in 1+\alpha, 2+\alpha, ..., \beta \quad (5)$$

$$H_i^{\min}(P_i) \le H_i \le H_i^{\max}(P_i) \qquad i \in 1+\alpha, 2+\alpha, ..., \beta \quad (6)$$

$$H_i^{\min} \le H_i \le H_i^{\max} \qquad i \in 1+\beta, 2+\beta, ..., n \quad (7)$$

The active power transmission loss P_L can be calculated by the network loss formula:

$$P_L = \sum_{i=1}^{\beta} \sum_{j=1}^{\beta} P_i B_{ij} P_j \quad (8)$$

III. PARTICLE SWARM OPTIMIZATION

A. Standard PSO

The standard of the PSO are best describe as sociologically inspired, since the original algorithm was based on the sociological behavior associated with bird flocking [10, 11]. PSO is simple in concept, few in parameters, and easy in implementation, besides it has an excellent optimization performance. At first, PSO was introduced for continuous search spaces and because of the aforementioned features; it has been widely applied to many optimization problems after its introduction [12].

To explain how PSO algorithm works, an optimization problem which requires optimization of N variables simultaneously is considered here. PSO is initialized with a population of solutions, called "particles". At first, a random position and velocity is assigned to each particle. The position of each particle corresponds to a possible solution for the optimization problem. A fitness number is assigned to each particle which shows how good its position is.

During the optimization process, each particle moves through the N-dimensional search space with a velocity that is dynamically adjusted according to its own and its companion's previous behavior. Updating the particle velocity is based on three terms, namely the "social," the "cognitive," and the "inertia" terms. The "social" part is the term guiding the particle to the best position achieved by the whole swarm of particles so far (gbest), the "cognitive" part guides it to the best position achieved by itself so far (pbest), and the "inertia" part is the memory of its previous velocity ($\omega.v_n$). The following formulae demonstrate the updating process of a particle position (x_n) and its velocity (v_n) in the nth dimension in an N-dimensional optimization space [13]:

$$v_i^{k+1} = w v_i^k + c_1 R_1 \left(pbest_i^k - x_i^k \right) + c_2 R_2 \left(gbest^k - x_i^k \right)$$
$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (9)$$

In Equation (9), R_1 and R_2 are random numbers uniformly distributed between 0 and 1. c_1 and c_2 are acceleration constants and ω is the inertia weight. These three parameters determine the tendency of the particles to the related terms. Moreover, another parameter is used to limit the maximum velocity of a particle ($V_{\max}$). All these parameters directly affect the optimization behavior; for example, the inertia weight controls the exploration ability of the process while the acceleration constants and maximum velocity are parameters for controlling the convergence rate [10, 11]. The iterative procedure of updating the velocities and positions of particles continues until the best position achieved by the whole swarm of particles (gbest) does not change over several iteration. Figure 3 shows this process of PSO method to CM problem.

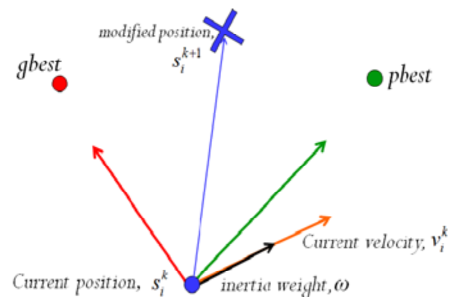

Figure 3. Velocity and location of particle updating process

B. PSO-IIW Algorithm

The main disadvantage of using this PSO method is that once the inertia weight is decreased, the swarm is not able to recover from its exploration mode and loses its ability to search in new areas. Therefore, the particle swarm optimization with Improved Inertia Weight (PSO-IIW) is a new evolutionary algorithm implemented by means of the Direct Search Method (DSM) to meet the requirements of a real-valued particle swarm optimization [12, 13]. The main concept of PSO-IIW is similar to CPSO in which the Equations (14) and (15) are used. However, for PSO-IIW the inertia weight ω is modified by the constriction factor Z. This inertia weight (ω) plays the role of balancing the global and local exploration abilities. Here, for PSO-IIW the inertia weight (ω) is modified. The proposed weighting function is defined as follows:

$$\begin{cases} \omega_{qi}^k = \omega_{\max} - \dfrac{(\omega_{\max}-\omega_{\min})\times Z_{iter,qi}^k}{Z}, & \text{if} \quad v_{qi}^k \times (x_{i,gbest}^k - x_{qi}^k) > 0 \\ \omega_{qi}^k = \omega_{qi}^{k-1} & \text{if} \quad v_{qi}^k \times (x_{i,gbest}^k - x_{qi}^k) < 0 \end{cases}$$

$$q = 1,2,...,Q; \quad i = 1,2,...,N$$

where, $\omega_{\max}$ and $\omega_{\min}$ are maximum and minimum value of weighting factor, respectively. The ω^k_{qi} is element inertia weight i of particle q in iteration k. Also, the parameter Z is replaced with $iter_{\max}$ in original PSO as an important factor to control and balanced mechanism between the global and local exploration abilities. For acquire parameter Z value, thus requiring less runs on average to find a sufficiently optimal solution. Also, for PSO-IIW the velocity update equation is modified by the constriction factor C. Therefore, the velocity of each agent can be modified by the following equation:

$$v_i^{k+1} = C\{wv_i^k + c_1R_1\left(pbest_i^k - x_i^k\right) + c_2R_2\left(gbest^k - x_i^k\right)\} \quad (10)$$

$$C = \frac{2}{\left|2-\phi-\sqrt{\phi^2-4\phi}\right|} \quad , \quad 4.1 \le \phi \le 4.2 \quad (11)$$

where, R_1, R_2 are two random functions they are distributed with uniform probability in the interval [0 1].

IV. PSO-IIW OPTIMIZATION BASED COMBINED HEAT AND POWER ECONOMIC DISPATCH

The CHPED problem is a nonlinear complex optimization problem with feasible operating zones constraints. In this part, to achieve optimal distribution performance, PSO-IIW algorithm is proposed to optimal tune of units under different operating conditions. The sequential steps of the proposed PSO-IIW method are given below:

Step 1: In this step, an initial population based on state variable is generated, randomly. That is formulated as:

$$p^k = [P_1,\, P_2,\, \ldots,\, P_a,\, P_{a+1},\, P_{a+2},\, \ldots,\, P_b,\, H_{a+1},\, H_{a+2},\, \ldots,\, H_b,\, H_{b+1},\, H_{b+1},\, \ldots,\, H_n]^T \quad (12)$$

where, P_a and H_b are the real power outputs of conventional thermal generators and cogeneration units and heat outputs of cogeneration units and heat-only units, respectively. Also, the initial should satisfy the equilibrium equation of heat and power following:

$$\sum_{i=1}^{\alpha} P_i + \sum_{i=\alpha+1}^{\beta} P_i = P_D + P_L \quad (13)$$

$$\sum_{i=\alpha+1}^{\beta} H_i + \sum_{i=\beta+1}^{n} H_i = H_D \quad (14)$$

Step 2: The fitness function to be evaluated is defined as follows:

$$fitness = \frac{1}{\sum_{i=1}^{\alpha} F_{ti}(P_i) + \sum_{i=\alpha+1}^{\beta} F_{ci}(P_i, H_i) + \sum_{i=\beta+1}^{n} F_{hi}(h_i)} \quad (15)$$

Step 3: Each *pbest* values are compared with the other *pbest* values in the population. The best evaluation value among the p-bests is denoted as *gbest*.

Step 4: The member velocity v of each individual x_i is modified according to the velocity update equation.

Step 5: The position of each individual P_i is modified according to the position update equation.

Step 6: If the evaluation value of each individual is better than previous *pbest,* the current value is set to be *pbest*. If the best *pbest* is better than *gbest*, the value is set to be *gbest*.

Step 7: If the number of iterations reaches the maximum, then finish. Otherwise, go to step 2.

The parameters of the proposed PSO-IIW method used in the test system example as following; Q=50; $iter_{\max}$=100; c_1=0.1; c_2=0.1; Z=100; $\omega_{\max}$=1.1; $\omega_{\min}$=0.4.

V. SIMULATION AND RESULTS

The different methods discussed earlier are applied a cases to find out the minimum cost for any demand. The proposed method has been applied to a test system which consists of four conventional thermal generators, two cogeneration units and a heat-only unit. Unit data has been modified from [14]. System data containing coefficients of fuel cost equations, B loss coefficients and heat-power feasible regions are given in below equations. The power and heat demands of the test system are 600 MW and 150 MWth respectively.

(a) Power-only units:

$$F_{t1}(P_1) = 25 + 2P_1 + 0.008P_1^2 + |100\sin\{0.042(P_1^{\min} - P_1)\}|\ \$$$
$$10 \le P_1 \le 75MW$$

$$F_{t2}(P_2) = 60 + 1.8P_2 + 0.003P_2^2 + |140\sin\{0.04(P_2^{\min} - P_2)\}|\ \$$$
$$20 \le P_1 \le 125MW$$

$$F_{t3}(P_3) = 100 + 2.1P_3 + 0.001P_3^2 + |160\sin\{0.038(P_3^{\min} - P_3)\}|\ \$$$
$$30 \le P_1 \le 175MW$$

$$F_{t4}(P_4) = 120 + 2P_4 + 0.001P_4^2 + |180\sin\{0.037(P_4^{\min} - P_4)\}|\ \$$$
$$40 \le P_1 \le 250MW$$

(b) Cogeneration units:

$$F_{t5}(P_5, H_5) = 2650 + 14.5P_5 + 0.001P_5^2 + 4.2H_5 + 0.03H_5^2 + 0.031P_5H_5\ \$$$

The heat-power feasible region of the cogeneration unit is illustrated in Figure 4.

$$F_{t6}(P_6, H_6) = 1250 + 36P_6 + 0.0435P_6^2 + 0.6H_6 + 0.027H_6^2 + 0.11P_6H_6\ \$$$

The heat-power feasible region of the cogeneration unit is illustrated in Figure 5. The Network loss coefficients are given below:

$$B = \begin{bmatrix} 49 & 14 & 15 & 15 & 20 & 25 \\ 14 & 45 & 16 & 20 & 18 & 19 \\ 15 & 16 & 39 & 10 & 12 & 15 \\ 15 & 20 & 10 & 40 & 14 & 11 \\ 20 & 18 & 12 & 14 & 35 & 17 \\ 25 & 19 & 15 & 11 & 17 & 39 \end{bmatrix} \times 10^{-7}$$

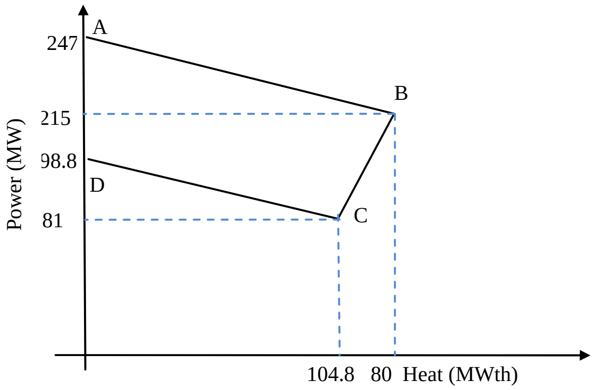

Figure 4. Heat-power feasible operation region for the cogeneration unit 1

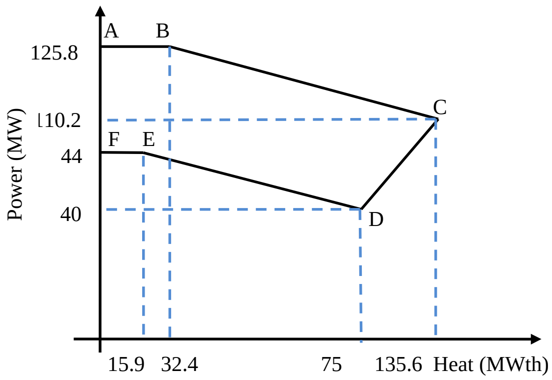

Figure 5. Heat-power feasible operation region for the cogeneration unit 2

To validate the proposed PSO-IIW based approach, the same test system is solved using Evolutionary Programming (EP), Bee Colony Optimization (BCO) Particle Swarm Optimization (PSO), and Real-Coded Genetic Algorithm (RCGA). Table 1 compares the computational results of this test system obtained from PSO-IIW, BCO, EP, PSO and RCGA. It is found that the proposed approach provides lower production cost and CPU time. Fig. 6 shows the cost convergence obtained from propose algorithm. Fig. 6 and Table 1 show the best convergence rate as well as the best solution time among the four is achieved by PSO-IIW, followed by BCO, EP. RCGA is the worst performer, followed by PSO.

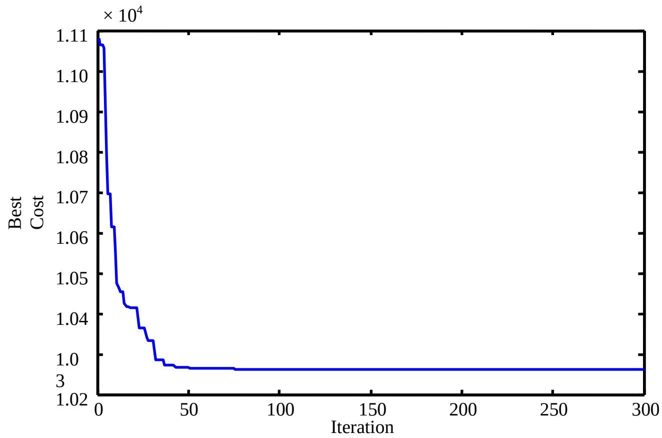

Figure 6. Convergence characteristics of PSO-IIW

Table 1. The best convergence rate as well as the best solution time

	PSO-IIW	BCO [15]	EP [15]	PSO [15]	RCGA [15]
P_1 (MW)	28.5615	43.9457	61.3610	18.4626	74.6834
P_2 (MW)	100.401	98.5888	95.1205	124.2602	97.9578
P_3 (MW)	127.801	112.9320	99.9427	112.7794	167.2308
P_4 (MW)	207.545	209.7719	208.7319	209.8158	124.9079
P_5 (MW)	98.8712	98.8000	98.8000	98.8140	98.8008
P_6 (MW)	44.1432	44.0000	44.0000	44.0107	44.0001
H_5 (MWth)	56.1901	12.0974	18.0713	57.9236	58.0965
H_6 (MWth)	34.8001	78.0236	77.5548	32.7603	32.4116
H_7 (MWth)	59.0312	59.8790	54.3739	59.3161	59.4919
P_L (MW)	7.51421	8.0384	7.9561	8.1427	7.5808
Cost ($)	10265	10317	10390	10613	10667
CPU time (s)	4.0192	5.1563	5.2750	5.3844	6.4723

VI. CONCLUSIONS

Combined heat and power generation (co-generation) units have an increasingly important role in energy production technology recently In this paper, Particle Swarm Optimization with Improved Inertia Wight (PSO-IIW) for Combined Heat and Power Economic Dispatch (CHPED) has been applied to determine the feasible optimal solution. The proposed method convergence rate is really less than in comparison other methods in solving complex mathematical problems. The numerical results demonstrate that the proposed method has better ability in finding optimal answers and possibility of particle placed in local zone. Moreover, the proposed strategy has simple structure, easy to implement and tune and therefore it is recommended to generate good quality and reliable electric energy in the restructured power systems.

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BIOGRAPHIES

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