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Particle Swarm Optimization with Smart Inertia Factor for Combined Heat and Power Economic Dispatch

Naser Ghorbani[1], Babak Adham[2], Payam Farhadi[3]

[1]Eastern Azarbayjan Electric Power Distribution Company ,Tabriz,Iran,Email:Naser.ghorbani@yahoo.com
[2]Eastern Azarbayjan Electric Power Distribution Company ,Tabriz, Iran
[3]Young Researchers and Elite Club, Islamic Azad University,Parsabad , Iran

Abstract

In this paper particle swarm optimization with smart inertia factor (PSO-SIF) algorithm is proposed to solve combined heat and power economic dispatch (CHPED) problem. The CHPED problem is one of the most important problems in power systems and is a challenging non-convex and non-linear optimization problem. The aim of solving CHPED problem is to determine optimal heat and power of generating units with the minimized cost of total system and satisfied constraints of problem. In proposed algorithm inertia coefficients are controlled with respect to cost function in each population. So, each population has unique inertia coefficient and as a result unique velocity in convergent direction for the best group solution. In order to examine the proposed algorithm's capabilities and find optimum solution for CHPED problem, two test systems considering valve-point effect, system power loss and system constraints are optimized. The obtained results demonstrate the superiority of the proposed method in solving non-convex CHPED problem over other new and efficient algorithms.

Keywords: Combined heat and power; Economic dispatch; Non-convex; Particle swarm optimization

1. Introduction

In conventional thermal generating units, all of the produced heat energy is not converted to the electric power and so large amounts of energy are wasted in the form of heat. The use of combined heat and power (CHP) system can increase fuel efficiency up to 90% and decrease production cost by 10 to 40% [1]. In order to utilize CHP units more efficiently, economic dispatch problem is applied to determine the optimal combination of the power and heat sources' outputs to satisfy heat and power demand of system and operational constraints. This problem is known as CHP economic dispatch (CHPED) problem and has attracted a lot of interests in recent years [2].

Due to the non-convex behavior of generation units' input/output characteristics, which is because of the existence of valve-point effects, and etc., the CHPED problem is a non-convex problem with constraints, which cannot be solved directly through the mathematical approaches [3]. Thus, various intelligent techniques, including improved ant colony search algorithm [4], Evolutionary programming (EP) [5], real code genetic algorithm (RGA) [6], harmony search algorithm (HSA) [7], multi-objective particle swarm optimization (MOPSO) [8], and PSO with time varying acceleration coefficients (PSO-TVAC) [1] have been proposed to successfully solve CHPED problem with convex and non-convex fuel cost function.

PSO is a population-based search algorithm and searches in parallel using a group of particles. Kennedy and Oberhart presented the PSO algorithm based on the analysis of the behavior of birds and fishes. In PSO, each particle tries to decide considering its previous experiences and that of its neighbors. The simple concept, easy implementation, relative robustness to control parameters and computational efficiency are some of the advantages of the PSO algorithm [9].

In PSO, once the iteration increases, inertia weight and consequently the velocity of the particles will reduce. The concept of inertia weight was introduced in order to balance the local and global search. A high inertia weight during initial part of search ensures global exploration, while a low value leads to the end facilitated global convergence. Thus, if the algorithm is not able to find the optimum points in the initial iterations and with high inertia weight, it will not discover global points near the optimal point [10]. To overcome the problem of search area of PSO algorithm with increasing the iteration number, the present article puts forward a new and robust version of PSO that called PSO-SIF, in which the value of inertia coefficient, unlike classic PSO, is smart and is not same for all the population. In order to examine the performance of proposed method and find optimum solution for CHPED problem, two test systems including power-only units, CHP units, and heat-only units with valve-point effect, system power loss and operational constraints are optimized.

The remainder of the paper is organized as follows. Section 2 provides the mathematical formulation of the CHPED problem considering valve-point effects and transmission losses. The proposed PSO-SIF algorithm is described in Section 3. Section 4 provides the step by step procedure of proposed PSO-SIF algorithm for solving CHPED problem. Case studies are presented in Section 5. Conclusions are finally given in Section 6.

2. Problem Formulation

The [4-5] have mentioned the formulation and CHPED problem constraints in details. In general, the aim of solving CHPED problem is to determine the generating unit power and heat production such that the system's production cost is minimized while the power and heat demands and other constraints are met appropriately. The objective function of CHPED problem is given by:

$$\min \sum_{i=1}^{N_p} C_i(P_i^p) + \sum_{j=1}^{N_c} C_j(P_j^c, H_j^c) + \sum_{k=1}^{N_h} C_k(H_k^h)(\$/h) \tag{1}$$

Where C_i , C_j and C_k are production cost of the power-only, cogeneration and heat-only units, respectively. N_p , N_c , N_h are the number of above mentioned units, respectively. i , j and k are the indices used for power-only, cogeneration and heat-only units, respectively. In Eq. (1), H and P indicate the heat and power output of unit, respectively. The production cost of different unit types are defined as:

$$C_i(P_i^p) = \alpha_i (P_i^p)^2 + \beta_i P_i^p + \gamma_i \qquad (\$/h) \tag{2}$$

$$\begin{aligned} C_j(P_j^c, H_j^c) = {} & a_j (P_j^c)^2 + b_j P_j^c + c_j + \\ & d_j (H_j^c)^2 + e_j H_j^c + f_j H_j^c P_j^c \quad (\$/h) \end{aligned} \tag{3}$$

$$C_k(H_k^h) = a_k (H_k^h)^2 + b_k H_k^h + c_k \qquad (\$/h) \tag{4}$$

where $C_i(P_i^p)$, $C_j(P_j^c, H_j^c)$ and $C_k(H_k^h)$ are cost function of the power, cogeneration and heat-only units, respectively. α_i , β_i and γ_i stand for cost coefficients of i^{th} conventional thermal unit. a_j , b_j , c_j , d_j , e_j and f_j are cost coefficients of j^{th} cogeneration unit. In Eq. (3), a_k , b_k and c_k show the cost coefficients of k^{th} heat-only unit. P_i^p and P_j^c are the power outputs of power-only and cogeneration units. H_j^c and H_k^h are the heat production by cogeneration and heat-only units. In this case, Eq. (5) is used to show the valve-point effects in cost function of thermal units instead of Eq. (2).

$$C_i(P_i^p) = \alpha_i (P_i^p)^2 + \beta_i P_i^p + \gamma_i + \left| \lambda_i \sin(\rho_i (P_i^{p\min} - P_i^p)) \right| \tag{5}$$

where λ_i and ρ_i are the cost coefficients of thermal unit i for reflecting valve-point effects [9]. Total generated power of the power-only and CHP units should be equal to total system demand and power losses which can be evaluated by Eq. (6):

$$\sum_{i=1}^{N_p} P_i^p + \sum_{j=1}^{N_c} P_j^c = P_d + P_{loss} \tag{6}$$

$$\begin{aligned} P_{loss} = {} & \sum_{i=1}^{N_p} \sum_{m=1}^{N_p} P_i^p B_{im} P_m^p + \sum_{i=1}^{N_p} \sum_{j=1}^{N_c} P_i^p B_{ij} P_j^c + \\ & \sum_{j=1}^{N_c} \sum_{n=1}^{N_c} P_j^c B_{in} P_n^c \end{aligned} \tag{7}$$

Where P_d is the system demand. Parameter P_{loss} is the power losses of transmission line and a function of units output power evaluated by Eq. (7). Total generated heat of cogeneration and heat units should be equal to total system demand heat in order to balance the heat demand:

$$\sum_{j=1}^{N_c} H_j^c + \sum_{k=1}^{N_h} H_k^h = H_d \tag{8}$$

Where H_d is the system heat demand. The outputs of electricity units and heat units are restricted by their own upper and lower boundaries. The power and heat outputs of cogeneration units should be placed in feasible operation region. The inequality constraints of each generating unit in the CHPED problem are given by:

$$P_i^{p\min} \le P_i^p \le P_i^{p\max} \quad i = 1, 2, \cdots, N_p \tag{9}$$

$$P_j^{c\min}(H_j^c) \le P_j^c \le P_j^{c\max}(H_j^c) \quad j = 1, 2, \cdots, N_c \tag{10}$$

$$H_j^{c\min}(P_j^c) \le H_j^c \le H_j^{c\max}(P_j^c) \quad j = 1, 2, \cdots, N_c \tag{11}$$

$$H_k^{h\min} \le H_k^h \le H_k^{h\max} \quad k = 1, 2, \cdots, N_h \tag{12}$$

Where $P_i^{p\min}$ and $P_i^{p\max}$ are the minimum and maximum power generation boundaries of the power-only units. $P_j^{c\min}(H_j^c)$ and $P_j^{c\max}(H_j^c)$ are the minimum and maximum power generation boundaries of the cogeneration units. $H_j^{c\min}(P_j^c)$ and $H_j^{c\max}(P_j^c)$ in (11) indicate the minimum and maximum heat generation boundaries of the cogeneration units. In (12) $H_k^{h\min}$ and $H_k^{h\max}$ are the minimum and maximum heat generation boundaries of the heat units.

3. Particle Swarm Optimization

A) A Review on PSO Algorithm

Kennedy and Oberhart suggested the PSO algorithm based on individuals (particles or ingredients) behavior in a population. Its base refers to the Zoology and models of subjects' manner within a group. It seems that the group members share information between each other, which leads to group efficiency increase. In this algorithm, each particle represents a solution for the problem. Here, each particle moves toward the optimum value considering three factors. These factors are current velocity, previous experiences and neighbors' experiences [11]. The corrected velocity and the position of each particle at the end of any iteration can be illustrated as follows, as respectively:

$$V_i^{k+1} = \omega V_i^k + c_1.r_1.(P_{best}^k - X_i^k) + c_2.r_2.(G_{best}^k - X_i^k) \tag{13}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{14}$$

where V_i^k is the velocity of the i^{th} particle in the k^{th} iteration, ω represents the weight inertia factor, and c_1 and c_2 are the acceleration coefficients. The parameters r_1 and r_2 are random numbers within [0 1] and X_i^k shows the position of the i^{th} particle in the k^{th} iteration. During the updating process of the velocity, the values of parameters such ω should be determined in a progressive form. Generally, in order to increase the convergence feature, the weight inertia (ω) is designed in a way that it linearly decreases and in each iteration has same weight for all population [11]. Decreasing from $\omega_{\max}$ to $\omega_{\min}$ results in:

$$\omega^k = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times k \tag{15}$$

where $iter_{\max}$ shows the maximum iteration number.

B) A Brief Review on PSO-SIF Algorithm

In the PSO-SIF, each population has its own inertia factor changing with the feedback from best obtained cost in the range [0.3, 0.9]. In this state, decline of the inertia factor and the search space of algorithm are prevented by increasing the iterations. In the proposed algorithm, the minimum inertia factor is selected to be 0.3, resulting in a situation in which the populations have the costs near the optimum global cost, searching over an optimal point with lower velocities.

In proposed algorithm, the smart inertia factor is determined by (16):

$$\omega_j = \frac{0.6 \times (\lambda_j - 1)}{\delta_{\mathrm{m}}} + 0.3 \tag{16}$$

$$\lambda_j = \frac{\mathrm{cost}_j}{\mathrm{cost}_{gbest}} \tag{17}$$

$$\delta_{\mathrm{m}} = \delta_1 - \left(\frac{iter}{iter_{\max}}\right) \times \delta_2 \tag{18}$$

where, cost_j is j^{th} population cost, cost_{gbest} refers to the best group cost; λ_j is j^{th} population cost ratio to the cost of the best group solution; and δ_m refers to cost variation percent of j^{th} population from the best group solution rate. $iter$ is program iteration number; $iter_{\max}$ refers to the most number of program iteration; and δ_1 , δ_2 are the adjustment parameters of this algorithm.

4. Implementation of PSO-SIF to Solve Chped Problem

The program implementation process through the PSO-SIF technique is as the following steps:

Step 1: Algorithm initialization,

Step 2: Randomly initial population and particle's initial velocity generation,

Step 3: CHPED problem cost calculation and costs sorting and selecting P_{best} and G_{best} ,

Step 4: calculation of ω_j for each population according to Eq. (16),

Step 5: Updating particles velocity according to (13) and (14),

Step 6: Correcting the new positions of the particles to satisfy the constraints of the problem, *Step 7:* Go to the third step until the problem's ending criterion was not satisfied.

5. Simulation and Numerical Results

In order to examine the proposed algorithm's capabilities, two test systems considering valve-point effect, system power loss and system constraints are optimized. In solving the CHPED problem initial population and iteration are chosen 100 and 1000 respectively and the adjustable parameters of proposed algorithm that are δ_1 and δ_2 are selected 0.005 and 0.004 respectively. The acceleration coefficients of PSO are selected 2. In this section the proposed method was applied to two case studies to comprehensively investigate its performance on the CHPED problem.

Table.1.
Cost function parameters of CHP unit of case 1 and 2

CHP units		a	b	c	d	e	f	Feasible region coordinates [P^C, H^C]
Case 1	Case 2							
2	5	0.0345	14.5	2650	0.03	4.2	0.031	[98.8, 0], [81, 104.8], [215, 180], [247, 0]
3	6	0.0435	36	1250	0.027	0.6	0.11	[44, 0], [44, 15.9], [40, 75], [110.2, 135.6], [125.8, 32.4], [125.8, 0]

A) Test System I

In this section the test system is composed of one power-only unit, two CHP and one heat-only unit. All information related to power-only unit and heat-only unit are based eq. (19) and (20) and information of CHP units (units 2 and 3) and feasible regions are shown in Table 1 [1]. Feasible operation region of CHP unit 1 and 2 in case studies are shown in Fig. 1 and Fig. 2. Power and heat demands are 200 MW and 115MWth respectively.

The obtained results by PSO-SIF in solving this test system in compare with the results of PSO [8] and IACS [4] is given in Table 2.

$$C_1(P_1) = 50P_1 \quad 0 \le P_1 \le 150\ MW \tag{19}$$

$$C_4(H_1) = 23.4H_4 \quad 0 \le H_1 \le 2695.2\ MWth \tag{20}$$

Table.1.
Obtained results by different methods for test system 1

Output	PSO	IACS	PSO-SIF
P_1	0.05	0.08	0
P_2	159.43	150.93	160.00
P_3	40.57	49	40.00
H_2	39.97	48.84	40.00
H_3	75.03	65.79	75.00
H_4	0	0.37	0.00
TP	200.05	200.01	200.00
TH	115	115	115.00
TC	9265.1	9452.2	9257.07

P: Power (MW); H: Heat (MWth); TP: Total Power (MW); TH: Total Heat (MWth); TC:Total Cost ($);

As seen in Table 2, the proposed method has been able to extract the optimal solution of the problem much better than PSO and IACS. A convergence characteristic of the proposed algorithm for solving test system 1 comparison with PSO is shown in Fig. 3.

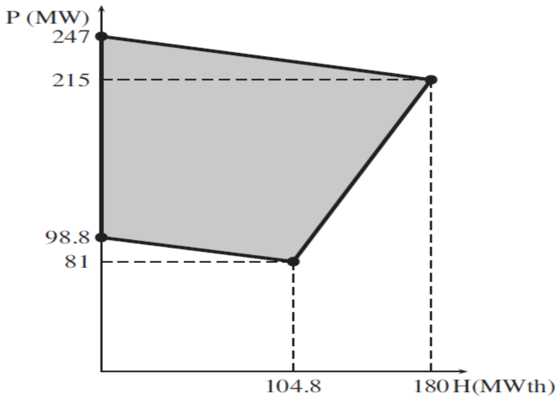

Fig. 1. Feasible operation region of CHP unit 1

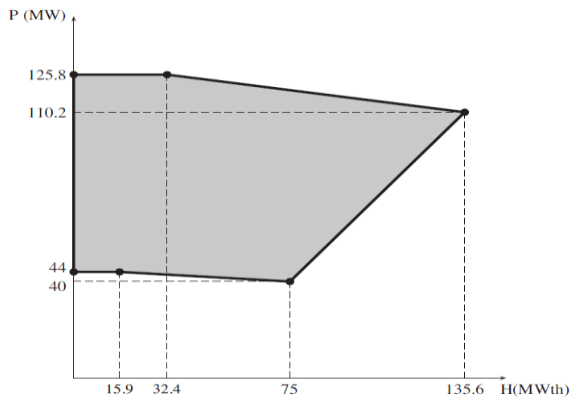

Fig. 2. Feasible operation region of CHP unit 2

B) test system II

In this section, the tests were accomplished on a system considering valve-point effects and transmission losses and are comprised of seven generating units, including four power-only units, two CHP units and one heat-only unit.

Cost function of power-only units (unit 1-4) and heat-only unit (unit 5) are based on Eqs. (21) to (25). Data of CHP units (units 5 and 6) and feasible regions are included in Table 1 [1]. The coefficients of the network loss matrix are based in Eq. (26). The unit of B-matrix elements are 1/MW.

$$C_1(P_1) = 25 + 2P_1 + 0.008P_1^2 + \left|100\sin\left\{0.042(P_1^{\min} - P_1)\right\}\right|\$, \quad 10 \le P_1 \le 75MW \tag{21}$$

$$C_2(P_2) = 60 + 1.8P_2 + 0.003P_2^2 + \left|140\sin\left\{0.04(P_2^{\min} - P_2)\right\}\right|\$, \quad 20 \le P_2 \le 125MW \tag{22}$$

$$C_3(P_3) = 100 + 2.1P_3 + 0.001P_3^2 + \left|160\sin\left\{0.038(P_3^{\min} - P_3)\right\}\right|\$ \quad 30 \le P_3 \le 175MW \tag{23}$$

$$C_4(P_4) = 120 + 2P_4 + 0.001P_4^2 + \left|180\sin\left\{0.037(P_4^{\min} - P_4)\right\}\right|\$ \quad 40 \le P_4 \le 250MW \tag{24}$$

$$C_7(H_7) = 950 + 2.0109H_7 + 0.038H_7^2 \ \$ \quad 0 \le H_7 \le 2695.2 \tag{25}$$

$$B = 10^{-7} \times \begin{pmatrix} 25 & 20 & 15 & 15 & 14 & 49 \\ 19 & 18 & 20 & 16 & 45 & 14 \\ 15 & 12 & 10 & 39 & 16 & 15 \\ 11 & 14 & 40 & 10 & 20 & 15 \\ 17 & 35 & 14 & 12 & 18 & 20 \\ 39 & 17 & 11 & 15 & 19 & 25 \end{pmatrix} \tag{26}$$

The obtained results of solving this test system by proposed algorithm in comparison of those AIS [13], BCO [13], RCGA [13], DE [12], EP [12] and PSO [12] are presented in Table 3. The least cost is obtained by EMA (10111.5115 $) less than PSO, BCO, RCGA, DE and EP. As seen from Table 3, the mean run time by PSO-SIF is 3.0156 sec much less than that of the other techniques. Convergence characteristics of the proposed algorithm in solving test system 2 in comparison with PSO are depicted in Fig. 4.

6. Conclusion

Combined heat and power economic dispatch is one of the most important issues in power systems that play a fundamental role in economic performance of power system. Due to nonconvex characteristic of this problem, evolutionary based algorithms are used to solve the CHPED problem. In this paper PSO-SIF is proposed for solving CHPED problem. In the proposed algorithm required control on inertia coefficient rates is applied for any population through cost function and rate of cost standard deviation of any population from the cost of the best group solution. So in the proposed PSO-SIF algorithm any population has unique inertia coefficient and as a result unique velocity in convergent direction for the best group solution. hence, in proposed method the limitation of PSO is improved.The proposed method has been successfully applied to two convex and non-convex CHPED problems considering valve-point effects and transmission network losses. The numerical results were compared with results of the other existing techniques such as AIS, BCO, RCGA, DE, EP and PSO. This comparison affirmed the robustness and proficiency of proposed coding scheme based PSO over other existing methods.

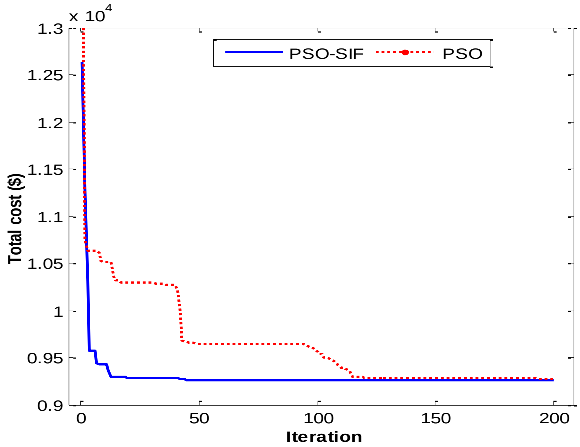

Fig. 3. Convergence characteristics of PSO-SIF & PSO- case 1

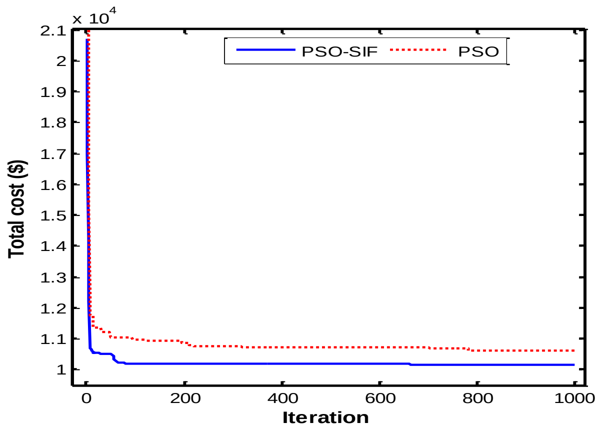

Fig. 4. Convergence characteristics of PSO-SIF & PSO - case 2

References

[1] B, Mohammadi-ivatloo, M. Moradi-Dalvand, A. Rabiee, “Combined heat and power economic dispatch problem solution using particle swarm optimization with time varying acceleration coefficients”, Elect. Power Syst. Res., Vol. 95, pp. 9-18, 2012.

[2] T. Niknam, R. Azizipanah-Abarghooee , A. Roosta and B. Amiri, “A new multi-objective reserve constrained combined heat and power dynamic economic emission dispatch”, Energy, Vol. 42, pp. 530-545, 2012.

[3] Sh. Bin, Y. Lie-Xiang, W. Wei, “Multi-objective optimization for combined heat and power economic dispatch with power transmission loss and emission reduction”, Energy, Vol. 56, pp. 135-143, 2013.

[4] Y.H. Song, C.S. Chou and T.J. Stonham, “Combined heat and power dispatch by improved ant colony search algorithm”, Electric Power Syst. Res., Vol. 52, pp. 115–121, 1999.

[5] K.P. Wong and C. Algie, “Evolutionary programming approach for combined heat and power dispatch”, Electr. Power Syst. Res. Vol. 61, pp. 227-232, 2002.

[6] P. Subbaraj, R. Rengaraj and S. Salivahanan , “Enhancement of combined heat and power economic dispatch using self-adaptive real coded genetic algorithm”, Appl. Energy, Vol. 86, pp. 915–921, 2009.

[7] A. Vasebi, M. Fesanghary and S.M.T. Bathaee , Combined heat and power economic dispatch by harmony search algorithm”, Electric Power Energy Syst. Vol. 29, pp. 713–719, 2007.

[8] L. Wang and C. Singh, “Stochastic combined heat and power dispatch based on multi-objective particle swarm optimization”, Electric Power Energy Syst. Vol. 30, pp. 226–234, 2008.

[9] N. Ghorbani, S. Vakili, E. Babaei, A. Sakhavati, “Particle Swarm Optimization with Smart Inertia Factor for Solving Nonconvex Economic Load Dispatch Problems”, Int. Trans. on Elect. Energy Syst., Vol. 24, pp. 1120-1133, 2014.

[10] N. Ghorbani and E. Babaei, “Exchange Market Algorithm”, Appl. Soft. Comp. Vol. 19, pp. 177–187, 2014.

[11] J. Kennedy and R. C. Eberhart, “Particle swarm optimization,” in Proc. IEEE Int. Conf. Neural Networks (ICNN’95), Perth, Australia, vol. IV, pp. 1942–1948, 1995.

[12] M. Basu, “Combined heat and power economic dispatch by using differential evolution”, Electric Power Components and Systems, Vol. 38, pp. 996–1004, 2010.

[13] M. Basu, “Bee colony optimization for combined heat and power economic dispatch”, Expert Systems with Applications, Vol. 38, pp. 13527–13531, 2011.

Table.2.
Obtained results by various methods in case 2

Output	PSO	EP	DE	RCGA	BCO	AIS	PSO-SIF
P_1	18.4626	61.361	44.2118	74.6834	43.9457	50.1325	53.1444
P_2	124.2602	95.1205	98.5383	97.9578	98.5888	95.5552	98.5398
P_3	112.7794	99.9427	112.6913	167.2308	112.932	110.7515	112.6694
P_4	209.8158	208.7319	209.7741	124.9079	209.771	208.768	209.8175
P_5	98.814	98.8	98.8217	98.8008	98.8	98.8000	93.3773
P_6	44.0107	44	44	44.0001	44	44.0000	40.0000
H_5	57.9236	18.0713	12.5379	58.0965	12.0974	19.4242	31.9314
H_6	32.7603	77.5548	78.3481	32.4116	78.0236	77.0777	75.0000
H_7	59.3161	54.3739	59.1139	59.4919	59.879	53.4981	43.0685
P_{loss}	8.1427	7.9561	8.0372	7.5808	8.0384	8.008	7.5485
TP	608.1427	607.9561	608.0372	607.5808	608.038	608.008	607.5485
TH	150	150	149.9999	150	150	150.0000	150.0000
TC	10613	10390	10317	10667	10317	10355	10111.5115
Cpu time	6.4723	5.2750	-----	6.4723	5.1563	5.2956	3.0156