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Development of an optimal operational planning system for energy plants in steelworks

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Abstract: This paper proposes an optimal operational planning system of energy plants in steelworks. In steelworks, effective utilization of the by-product gas and heat energy can realize energy savings and operational cost reduction. In order to generate optimal operational plans for energy plants, startup/shutdown status (0/1 values) and/or input/output values (continuous values) of the facilities for each control interval should be determined. The facilities may have nonlinear input-output characteristics. Therefore, the problem can be formulated as a mixed-integer nonlinear optimization problem (MINLP). Particle Swarm Optimization (PSO) can be easily expanded to treat MINLP. The proposed PSO-based system is applied to actual energy plant operational planning problems with promising results.

1. INTRODUCTION

In steelworks, effective utilization of the by-product gases and heat energy can realize energy savings and operational cost reduction. These by-products are converted and mixed by the energy plant in steelworks according to the various loads. It is possible to reduce operational costs and environmental loads by appropriately distributing the by-products according to the supply and demand balance. Therefore, optimal operational planning for energy plants is a very important task.

In order to generate optimal operational plans for energy plants, start-up/shutdown status (0/1: binary values) and/or input/output values (continuous values) of the facilities for each control interval should be determined using a plant simulator (Fig.1). Therefore, it has been formulated as a mixed-integer linear problem (MILP) and mathematical programming techniques such as branch and bound, decomposition method, and dynamic programming have been applied conventionally (Ravn, 1994; Ito, et al., 1994). However, the facilities may have nonlinear input-output characteristics practically and operational rules, which cannot be expressed as mathematical forms, should be considered in actual operation. Therefore, the problem should be formulated as a MINLP.

PSO is one of the evolutionary computation (EC) techniques (Kennedy and Eberhart, 1995). The method is improved and applied to various problems (Kennedy and Eberhart, 2001; Fukuyama, et al., 2000; Fukuyama, 2002; Yasuda, et al., 2006). The original method is able to handle continuous state variables easily. Moreover, it has been expanded in order to handle both continuous and binary/discrete variables for a MINLP (Fukuyama, et al., 2000).

This paper proposes an optimal operational planning system for energy plants in steelworks using particle swarm optimization. The proposed system is applied to an actual energy plant (Fig.2) with promising results.

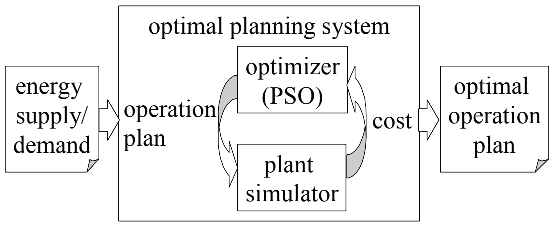

Fig. 1. Overview of the optimal operational planning system

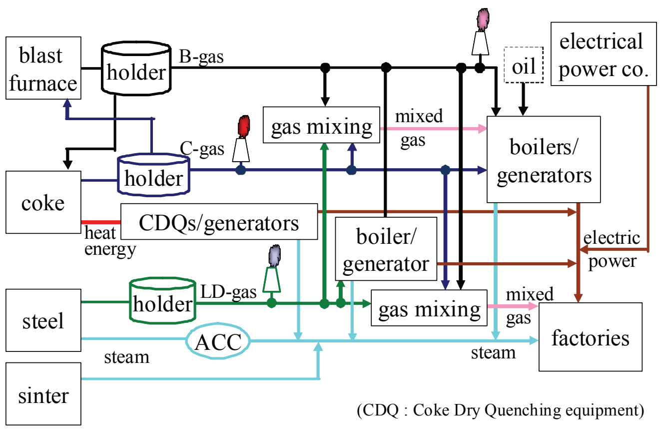

Fig. 2. Overview of the energy plant in the steelwork

2. PROBLEM FORMULATION

2.1 State Variables

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In the proposed system, the state variables can be selected from the following list. The state variables for 24 points of a day should be determined.

- ✓ input/output variables (by-product gases, electric power, steam) of each facility (gas mixing, boiler/generator, CDQ: Coke Dry Quenching equipment/generator) as continuous or discrete state variables
- ✓ start-up/shutdown status of each facility as binary (0/1) state variables

2.2 Objective Function

The objective function is to minimize the operational costs and/or the environmental loads of the day.

$$\min(\alpha C + \beta CO_2 + \gamma P) \tag{1}$$

where, C : total costs (electric power trading cost, fuel (oil/gas) trading cost, steam trading cost) of the day, CO_2 : total CO_2 emission, P : penalty functions, α,β,γ: weighting factors of each term.

2.3 Constraints

The following constraints can be considered directly or using penalty functions.

- ✓ Demand and supply balance: Summation of energies supplied by facilities such as electrical power, and steam should be equal to each corresponding load.
- ✓ Facility constraints: Various facility constraints including the boundary constraints (upper and lower bounds, equality and unequality constraints) with variables of each facility should be considered. Input-output characteristics of facilities should be also considered as facility constraints.
- ✓ Operational rules: Various operational rules, including which cannot be expressed as mathematical forms, should be considered. The up and down speed constraints of generators and boilers should be also considered.

3. PARTICLE SWARM OPTIMIZATION

The PSO is a population based stochastic optimization technique developed by Kennedy and Eberhart (Kennedy and Eberhart, 1995, 2001). The current searching points are modified using the following state equations.

$$v_i^{k+1} = wv_i^k + c_1 r_1 \times (pbest_i - s_i^k) + c_2 r_2 \times (gbest - s_i^k) \tag{2}$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{3}$$

where, v^i_k : velocity of particle i at iteration k, w : weighting function, c_i : weighting coefficients, r_i : random number between 0 and 1, s^i_k : current position of particle i at iteration k, $pbest_i$: position of the best evaluated solution so far of particle i, $gbest$: position of the best pbest of the swarm.

When all optional variables are assumed to be the state variables in the practical plants, the order of the problem exceeds a thousand. Therefore, the modified PSO algorithm has been applied in the proposed system. In the modified PSO, the swarm and the state variable vector are divided into several groups. When the state variables of one group are updated, the state variables of other groups are fixed to gbest or pbests. As results of preliminary studies, the modified PSO can generate better results than the original PSO for large scale problems.

4. NUMERICAL EXAMPLES

The proposed system has been applied to the actual energy plant (Fig.2). It has been applied to various unusual operating conditions such as start and stop of a blast furnace, and large steam or electric power loads. Table 1 shows reduced costs by the proposed system. All the values in table 1 are the relative reduced rate when the values of the actual operations by operators are assumed to be 100[%]. According to the results, the proposed system can generate better results than present actual operations.

Table 1. Reduced costs by the proposed system

unusual operating condition case #	1	2	3	4
reduced costs (ave.)[%]	1.5%	2.5%	1.0%	2.5%

5. CONCLUSIONS

This paper proposes the optimal operational planning system for energy plants in steelworks. The proposed system has been applied to the actual energy plant and the results indicate practical applicability of the proposed PSO based system.

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