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Fuzzy possibilistic modeling and sensitivity analysis for optimal fuel gas scheduling in refinery

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ABSTRACT

In refinery, fuel gas which is continuously generated during the production process is one of the most important energy sources. Optimal scheduling of fuel gas system helps the refinery to achieve energy cost reduction and cleaner production. However, imprecise natures in the system, such as prediction of production rate of fuel gas, prediction of energy demand of the equipments and cost coefficient in the objective function, make the deterministic optimization method which requires well-defined and precise data cannot be competent for the fuel gas scheduling problem. In this study, fuzzy possibilistic programming (FPP) method is proposed to deal with these imprecise natures by triangular possibility distributions. The fuzzy possibilistic model is transformed into usual mathematical model by definition of necessity measure and the α-level method. Although FPP models have been widely applied to modeling, few research works have been reported on the performance evaluation, namely sensitivity analysis, of these models. Marginal value analysis, which is always used to provide additional economic information, is proposed to give the sensitivity analysis in the paper. This method is demonstrated to be much more flexible than the simulation method. Particularly, the analytical method is adopted to examine how the imprecise natures in the fuel gas system affect the scheduling results.

1. Introduction

Refining process is one of the most energy-intensive industries, whose energy cost is the second-largest cost component after crude and intermediate products. Among all kinds of the consumed energy sources, fuel gas which is continuously generated during the production process contributes most of the primary energy source to the energy needs of the refinery. Furthermore, fuel gas can be converted into other forms of energy, such as steam, electricity and heat. Therefore, the effective scheduling of the fuel gas system plays a central role in energy cost reduction and cleaner production in refinery process.

Little research work has been reported on the optimal scheduling of the fuel gas system in refinery. It is always referred as an important part in the analysis of the whole refinery energy system. Frangopoulos et al. (1996) presented a method for the thermoeconomic operation optimization of a refinery combined-cycle cogeneration system. By the analysis of the interrelationships among various energy sources, such as fuel gas, fuel oil, steam and electricity, an energy system planning model was formulated. Nevertheless, the capacity of the fuel gas drum and the gas vessels was not considered because of the large time granularity. White (2005) proposed the concept of the fuel gas balance and recommended to model the planning model of the site-wide energy system integrating fuel gas, steam and electricity. Zhang and Hua (2007) embedded the Mixed Integer Linear Programming (MILP) model of utility system which included the fuel gas system into the plant-wide planning model for overall optimization and better energy efficiency, and the proposed approach was executed in an example provided by a real refinery. Li et al. (2006) developed a plant-wide multi-period planning model for a refinery complex. By considering the fuel oil and fuel gas produced in the refinery plant and the steam and electricity generated in utility plant, the interaction of utility plant and other plants in the complex is taken into account. Therefore, the plant-wide optimization can be achieved. Zhang and Rong (2008) proposed an MILP model for multi-period optimization of fuel gas system scheduling in refinery, and then gave a marginal value analysis of the system. Some suggestions are also made by the analysis to assist the engineering operation in refinery. Some research works related with the optimal scheduling of fuel gas system in iron- and steel-making process have been reported. Akimoto et al. (1991) proposed a multi-period MILP model which considered the drum level control and the optimal distribution of fuel gas in the power plant of steel works. Based on his research,

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Nomenclature

Sets

B	set of boilers
T	set of turbines
H	set of heaters
FG	set of fuel gas {LP gas, HP gas}
FO	set of fuel oil {fuel oil}

Indices

T	period (t=1, …, P)
I	boiler $i \in B$
J	turbine $j \in T$
K	heater $k \in H$
L	fuel gas $l \in FG$

Parameters

$\tilde{\omega}_L^l$	fuzzy penalty for shortage of fuel gas l, yuan/Nm^3
$\tilde{\omega}_H^l$	fuzzy penalty for emission of fuel gas l, yuan/Nm^3
$\tilde{\omega}_{\Delta L}^l$	fuzzy penalty for amount of fuel gas l below the normal capacity, yuan/Nm^3
$\tilde{\omega}_{\Delta H}^l$	fuzzy penalty for amount of fuel gas l above the normal capacity, yuan/Nm^3
ω_i^{FG}	penalty for change of fuel gas consumption in boiler i, yuan
ω_i^{FO}	penalty for change of fuel oil consumption in boiler i, yuan
ω_k^{FG}	penalty for change of fuel gas consumption in heater k, yuan
ω_k^{FO}	penalty for change of fuel oil consumption in heater k, yuan
C_{FO}	unit cost of fuel oil, yuan/t
C_{wat}	unit cost of fresh water, yuan/t
C_{elec}	unit cost of electricity, yuan/kW h
C_{LP2HP}	unit conversion cost of LP to HP gas, yuan/Nm^3
C_{HP}	unit cost of HP gas which is converted from the LP gas system, yuan/Nm^3
H_l	heat value of fuel gas l, MJ/Nm^3
H_{FO}	heat value of fuel oil, MJ/t
H_{stm}^i	enthalpy of steam generated by boiler i, MJ/t
H_{wat}^i	enthalpy of water consumed by boiler i, MJ/t
$H_{stm,CT}^j$	enthalpy of steam consumed by turbine j, MJ/t
$H_{stm,GT}^j$	enthalpy of steam generated by turbine j, MJ/t
$H_{wat,GT}^j$	enthalpy of water condensed by turbine j, MJ/t
η_B^i	efficiency of boiler i
η_T^j	efficiency of turbine j
η_H^k	efficiency of heater k
$V_l^{\min}$	lower bound for the capacity of fuel gas l, Nm^3
$V_l^{\max}$	upper bound for the capacity of fuel gas l, Nm^3
V_l^n	normal capacity for fuel gas l, Nm^3
$F_{stm}^{i,\min}$	minimum flow rate of steam generated by boiler i, t/h
$F_{stm}^{i,\max}$	maximum flow rate of steam generated by boiler i, t/h
$F_l^{i,\min}$	minimum flow rate of fuel gas l consumed by boiler i, Nm^3/h
$F_l^{i,\max}$	maximum flow rate of fuel gas l consumed by boiler i, Nm^3/h
$F_{FO}^{i,\min}$	minimum flow rate of fuel oil consumed by boiler i, t/h
$F_{FO}^{i,\max}$	maximum flow rate of fuel oil consumed by boiler i, t/h
$F_{stm,CT}^{j,\min}$	minimum flow rate of steam consumed by turbine j, t/h
$F_{stm,CT}^{j,\max}$	maximum flow rate of steam consumed by turbine j, t/h
$F_l^{k,\min}$	minimum flow rate of fuel gas l consumed by heater k, Nm^3/h
$F_l^{k,\max}$	maximum flow rate of fuel gas l consumed by heater k, Nm^3/h
$F_{FO}^{k,\min}$	minimum flow rate of fuel oil consumed by heater k, t/h
$F_{FO}^{k,\max}$	maximum flow rate of fuel oil consumed by heater k, t/h
$F_{LH,HG}^{\min}$	minimum flow rate of fuel gas in the compressor, Nm^3/h
$F_{LH,HG}^{\max}$	maximum flow rate of fuel gas in the compressor, Nm^3/h

Variables

C	total operation cost of the energy system
E_t^j	amount of electricity generated by turbine j at time t, kW h/h
$E_{grid,t}$	amount of electricity bought from outside grid at time t, kW h/h
E_t^k	amount of heat generated by heater k at time t, MJ/h
$\tilde{E}_{Delec,t}$	fuzzy prediction of demand amount of electricity at time t, kW h/h
$\tilde{E}_{Dheat,t}^k$	fuzzy prediction of demand amount of heat from heater k at time t, kW h/h
$\tilde{F}_{LG,g,t}$	fuzzy prediction of flow rate of LG gas generated by production system at time t, Nm^3/h
$\tilde{F}_{HG,g,t}$	fuzzy prediction of flow rate of HG gas generated by production system at time t, Nm^3/h
$F_{LG,c,t}$	flow rate of LG gas consumed by the whole refinery at time t, Nm^3/h
$F_{HG,c,t}$	flow rate of HG gas consumed by the whole refinery at time t, Nm^3/h
$F_{LG,HG,t}$	flow rate of fuel gas from LP gas drum to HP gas vessels at time t, Nm^3/h
$F_{FO,t}^i$	flow rate of fuel oil consumed by boiler i at time t, t/h
$F_{l,t}^i$	flow rate of fuel gas l consumed by boiler i at time t, t/h
$F_{stm,t}^i$	flow rate of steam generated by boiler i at time t, t/h
$F_{wat,t}^i$	flow rate of water consumed by boiler i at time t, t/h
$F_{stm,CT,t}^{i,j}$	flow rate of steam from boiler i to turbine j at time t, t/h
$F_{stm,CPR,t}^i$	flow rate of steam from boiler i to production system at time t, t/h
$F_{stm,CT,t}^j$	flow rate of steam consumed by turbine j at time t, t/h
$F_{stm,GT,t}^j$	flow rate of steam generated by turbine j at time t, t/h
$F_{wat,GT,t}^j$	flow rate of water condensed by turbine j at time t, t/h
$F_{FO,t}^k$	flow rate of fuel oil consumed by heater k at time t, t/h
$F_{l,t}^k$	flow rate of fuel gas l consumed by heater k at time t, t/h
$\tilde{F}_{Dstm,B,t}$	fuzzy prediction of demand amount of steam from boilers at time t, t/h