CHEMICAL ENGINEERING RESEARCH AND DESIGN 86 (2008) 141–151

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An MILP model for multi-period optimization of fuel gas system scheduling in refinery and its marginal value analysis

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ARTICLE INFO

Article history:
Received 12 March 2007
Accepted 4 November 2007

Keywords:
Refinery
Fuel gas
Cogeneration system
MILP
Multi-period optimization
Marginal value analysis

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. A mixed integer linear programming (MILP) model for multi-period optimization of fuel gas scheduling is proposed in the paper. In this method, fuel gas is considered as the key energy source, while fuel oil and electricity as the secondary one. Site-wide fuel gas balance has been achieved by considering the storage ability of fuel gas system and the consumption of fuel gas both in cogeneration system and production system. The objective is to reach the minimum operation cost of the energy system by effective scheduling of the fuel gas system. Marginal value analysis, which provides additional economic information of the fuel gas system, is proposed in the paper. This analytical method is used to identify the system bottleneck and assist decision-making in the case study.

1. Introduction

Refinery 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.

In some refineries, unbalance between the amount of the production and consumption of the fuel gas occurs frequently because of the poor scheduling of the fuel gas system. This unbalance means excess or shortage of fuel gas in the low-pressure gas drum or the high-pressure gas vessels, which will cause an increase of the operational cost, pollution to the environment and even a threat to the safe production. In fact, once the prediction of the production of fuel gas has been given, this abnormal situation can be avoided by appropriately adjusting the supply of fuel gas to the users. As shown in Fig. 1, the users include the steam boilers in cogeneration system and the fired heaters in production processes.

Few research works have been reported on the optimal scheduling of the fuel gas system in refinery. However, it is 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. Davis (2004) and 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 MILP (mixed integer linear programming) model of utility system which included the fuel gas system into the plant-wide planning model for

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0263-8762/$ – see front matter
doi:10.1016/j.cherd.2007.11.002

Nomenclature

Sets

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

Indices

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

Parameters

C_{elec}	unit cost of electricity (yuan/kWh)
C_{FO}	unit cost of fuel oil (yuan/t)
C_{HP}	unit cost of HP gas which is converted from LP gas system (yuan/(N m^3))
C_{LP2HP}	unit conversion cost of LP gas to HP gas (yuan/(N m^3))
C_{wat}	unit cost of fresh water (yuan/t) (t/h)
$F_{FO}^{i,max}$	maximum flow rate of fuel oil consumed by boiler i (t/h)
$F_{FO}^{i,min}$	minimum flow rate of fuel oil consumed by boiler i (t/h)
$F_{FO}^{k,max}$	maximum flow rate of fuel oil consumed by heater k (t/h)
$F_{FO}^{k,min}$	minimum flow rate of fuel oil consumed by heater k (t/h)
$F_l^{i,max}$	maximum flow rate of fuel gas l consumed by boiler i (N m^3/h)
$F_l^{i,min}$	minimum flow rate of fuel gas l consumed by boiler i (N m^3/h)
$F_l^{k,max}$	maximum flow rate of fuel gas l consumed by heater k (N m^3/h)
$F_l^{k,min}$	minimum flow rate of fuel gas l consumed by heater k (N m^3/h)
$F_{LH,HG}^{max}$	maximum flow rate of fuel gas in the compressor (N m^3/h)
$F_{LH,HG}^{min}$	minimum flow rate of fuel gas in the compressor (N m^3/h)
$F_{stm}^{i,max}$	maximum flow rate of steam generated by boiler i (t/h)
$F_{stm}^{i,min}$	minimum flow rate of steam generated by boiler i (t/h)
$F_{stm,CT}^{j,max}$	maximum flow rate of steam consumed by turbine j (t/h)
$F_{stm,CT}^{j,min}$	minimum flow rate of steam consumed by turbine j (t/h)
H_{FO}	heat value of fuel oil (MJ/t)
H_l	heat value of fuel gas l (MJ/(N m^3))
H_{stm}^i	enthalpy of steam generated 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}^i	enthalpy of water consumed by boiler i (MJ/t)
$H_{wat,GT}^j$	enthalpy of water condensed by turbine j (MJ/t)
V_l^{max}	upper bound for the capacity of fuel gas l (N m^3)
V_l^{min}	lower bound for the capacity of fuel gas l (N m^3)
V_l^n	normal capacity for fuel gas l (N m^3)
η_B^i	efficiency of boiler i
η_H^k	efficiency of heater k
η_T^j	efficiency of turbine j
ω	penalty for unit emission of LP gas (yuan/(N m^3))
ω_H^l	penalty for emission of fuel gas l (yuan/(N m^3))
$\omega_{\Delta H}^l$	penalty for amount of fuel gas l above the normal capacity (yuan/(N m^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)
ω_L^l	penalty for shortage of fuel gas l (yuan/(N m^3))
$\omega_{\Delta L}^l$	penalty for amount of fuel gas l below the normal capacity (yuan/(N m^3))
ω_Δ	penalty for unit deviation from the normal capacity in LP gas drum (yuan/(N m^3))

Variables

$E_{Delec,t}$	demand amount of electricity at time t (kWh/h)
$E_{Dheat,t}^k$	demand amount of heat from heater k at time t (kWh/h)
$E_{grid,t}$	amount of electricity bought from outside grid at time t (kWh/h)
E_t^j	amount of electricity generated by turbine j at time t (kWh/h)
E_t^k	amount of heat generated by heater k at time t (MJ/h)
$F_{Dstm,B,t}$	demand amount of steam from boilers at time t (t/h)
$F_{Dstm,T,t}$	demand amount of steam from turbines at time t (t/h)
$F_{FO,t}^i$	flow rate of fuel oil consumed by boiler i at time t (t/h)
$F_{FO,t}^k$	flow rate of fuel oil consumed by heater k at time t (t/h)
$F_{HG,c,t}$	flow rate of HG gas consumed by the whole refinery at time t (N m^3/h)
$F_{HG,g,t}$	flow rate of HG gas generated by production system at time t (N m^3/h)
$F_{l,t}^i$	flow rate of fuel gas l consumed by boiler i at time t (t/h)
$F_{l,t}^k$	flow rate of fuel gas l consumed by heater k at time t (t/h)
$F_{LG,c,t}$	flow rate of LG gas consumed by the whole refinery at time t (N m^3/h)
$F_{LG,g,t}$	flow rate of LG gas generated by production system at time t (N m^3/h)
$F_{LG,HG,t}$	flow rate of fuel gas from LP gas drum to HP gas vessels at time t (N m^3/h)
$F_{stm,t}^i$	flow rate of steam generated by boiler i 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)