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A new coal gas utilization mode in China's steel industry and its effect on power grid balancing and emission reduction

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HIGHLIGHTS

- A new utilization mode of coal gases is proposed for steel industry.
- The economic benefit of the new utilization mode is analyzed.
- A simulation model of coal-fired power units is used.
- Coal savings and emissions reduction were evaluated.

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ABSTRACT

Inspired by energy storage systems for peak load shifting (PLS), this study proposes a PLS utilization mode of electricity-generating coal gas resources for the steel industry in China. The proposed mode can help the steel industry save electricity bills (2.4%) through the introduction of a time-of-use tariff. Data of a steel enterprise are used to prove the economic benefit of the coal gas utilization mode. Given that China produces more than half of converter steel of the total production worldwide, their coal gas resources are abundant. The PLS utilization mode will have a great effect on balancing the power grid. A simulated operation model for PLS coal-fired power units is used to calculate the energy conservation and emission reduction effect of coal-fired power plants under different scenarios. The annual coal savings are 1.7–3.1%, and the annual SO_2 and NO_X emission reductions are 2.9–12.4% and 44.6–14.1% of the total reduction amount of the steel industry in China, respectively.

1. Introduction

Increased peak demand in energy intensive industries may result in power outages during a peak period. The problem of load shedding also arises accordingly during an off-peak period [1]. One proposed solution for peak load shifting (PLS) is the use of energy storage systems, which refers to a process of converting electrical energy from a power network into a form that can be stored for converting back to electrical energy when needed [2]. Examples of which include pumped hydroelectric storage, compressed air energy storage [3,4], building thermal mass, thermal energy storage system, and phase-change material [5].

Given that time-of-use (TOU) electricity tariff rates are implemented as a viable load management technique to flatten the system load curve, demand-side management can bring economic benefits to industry sectors [6]. Steel industry [7] and electrolytic process industries [8] have got benefits from load management. The steel industry in China accounts for 15% of the total industry electricity consumption [9]; thus, the steel industry should control their electricity costs.

This study proposes a PLS utilization mode of electricity-generating coal gases in the steel industry in China, which gives a new utilization mode of energy resources and a new view for PLS method that focuses on energy resources.

At present, by-product coal gases are generated in the production processes in steel enterprises in China, and the energy management center of steel enterprise is responsible for ensuring the balance of coal gases; 50–80% of coal gases are generally used for heating, the remainder is used for electricity generation, and the surplus coal gases that cannot be consumed are released away

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Nomenclature

PLS	peak load shifting	PPP	peak power period
TOU	time-of-use	MPP	middle power period
LGD	Linz–Donawitz process gas	VPP	valley power period
COG	coke oven gas	PVR	peak–valley ratio
BFG	blast furnace gas		

[10,11]. In the PLS utilization mode, coal gases are not consumed immediately, but are stored in gas tanks and used intensively in the peak period of the power system. In this way, by-product gases are not used only as a fuel for heating and power generation but also as a type of PLS energy resource that can be used flexibly. In this study, the effects of PLS utilization mode of electricity-generating coal gases are evaluated by using the 2010 data of China. The effects are analyzed on the basis of the following aspects.

First, the proposed mode can provide steel enterprises with economic benefits and decreases or even eliminates the coal gas-releasing phenomenon.

Second, considering that China produced 57% converter steel of the world in 2010 [12], their coal gases are of huge amount and will have a significant effect on balancing the power grid of China.

Third, the influence of the proposed mode on the power industry is also considered. Coal-fired thermal power units in China, which account for approximately 70% capacity of the power grid [13], have to participate in PLS. Units participating in PLS have to change working load frequently or shutdown, and such a change will affect the economy, service life, and security of coal-fired power units [14,15]. A simulated operation model for PLS coal-fired power units is used to analyze the energy conservation and emission reduction effect of the coal-fired power plants.

Finally, the proposed mode can promote the policy implementation of the "Substitution of Small Units with Large Ones" [13] of China, which means to shutdown small and unefficient thermal power units and replace them with large and efficient units.

Although this study focuses on the PLS utilization mode of coal gases of the steel industry, it may be of inspiration for people working in other fields.

2. PLS utilization mode of electricity-generating coal gases

The electricity supply to electrical grids can be divided into several categories with different prices, such as base load power, peak load power, spinning reserve power, and regulation power [16]. According to the TOU electricity tariff system of China, a day is divided into peak power period (PPP; 8:00–12:00, 17:00–21:00), valley power period (VPP; 24:00–next day at 8:00), and middle power period (MPP; 12:00–17:00, 21:00–24:00) [17]; the electricity price of PPP is the highest. By implementing the PLS utilization mode of power-generating coal gas resources, enterprises should collect and store coke oven gas (COG) and Linz–Donawitz process gas (LDG) in the off-peak period (16 h) and use the stored COG and LDG to generate electricity in the peak period (8 h). In this way, steel enterprises can use more cheap electricity from power grid in the off-peak period and less expensive electricity in PPP. The PLS utilization mode of coal gas can provide steel enterprises with economic benefits.

The electricity provided by self-provided power plants of large- and medium-sized steel enterprises in China in 2008 accounted for 28% of their total electricity consumption [18], and this percentage will increase in accordance with China's steel industry development policy, which advocate steel enterprises with annual production above 5 million tons realizing electricity self-sufficiency [19]. The utilization of PLS mode in coal gases will accordingly be of vital importance.

2.1. Electricity generation mode of coal gases through PLS utilization

To implement the PLS utilization mode, we first should select an appropriate electricity generation mode for coal gases. In self-provided power plants in the steel industry in China, coal gas resources are presently mainly used to generate electricity by three means, namely, pure gas-fired boiler-steam turbine power generation, coal-gas mixed boiler-steam turbine power generation, and gas-steam combined cycle power generation [20].

Pure gas-fired boiler-steam turbine power generation units in China commonly have small boiler capacity and low thermal efficiency, i.e., only 25–30%. Their coal gas buffering capacity is also small. They are not suitable for the PLS utilization mode of coal gas resources to generate electricity [20].

Gas-steam combined cycle power generation has a high thermal efficiency, but the high thermal efficiency must rely on high power load. In case of load fluctuation, gas-steam combined cycle power generation units are unable to maintain high power generation efficiency. Steel enterprises generally consider gas-steam combined cycle power generation units "rigid" coal gas users and provide them with stable coal gas supply [21]. They also are not suitable for the PLS utilization mode of coal gas resources to generate electricity.

Coal-gas mixed boiler-steam turbine power generation units have a large installed capacity in China. Their power generation efficiency is 35–40%, which is obviously higher than that of pure gas-fired boiler-steam turbine power generation units. Coal-gas mixed boiler-steam turbine power generation units are mainly fueled with coal, and coal gases are complementary. They are reliable gas buffer users, and the mixed burning gases have an insignificant influence on power generation efficiency [20]. Therefore, they are a suitable system for the implementation of the PLS utilization mode of coal gas resources to generate electricity.

Steel enterprises in China mostly use the coal-gas mixed boiler-steam turbine power generation way to use coal gases to generate electricity. After some large steel enterprise practicing, the power generation efficiency of coal-gas mixed boiler-steam turbine power generation units remain 37.4% when blending 40% blast furnace gas (BFG). The average calorific values of the BFG, LDG, and COG of the steel industry in China are 3500, 7750, and 17,650 kJ/m^3, respectively [20]. Among BFG, LDG, and COG, BFG is the fuel with the poorest quality; if BFG can be burned well, no problem exists with the other two [22]. The power generation efficiency of the PLS utilization mode of coal gas resources is considered the average efficiency of coal-gas mixed boiler-steam turbine power generation units, which is 37.5%.

2.2. Coal gas resources used in the PLS utilization mode in the steel industry in China

Before evaluating the effect of PLS utilization mode, we should know the amount of electricity-generating coal gases in the steel industry in China. According to statistics data [23,24] of 2010,