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A joint scheduling method for multiple byproduct gases in steel industry

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ABSTRACT

Reasonable scheduling of the byproduct gases produced during steel making procedure is of significance to steel industry because it is helpful to save energy resources, raise economic profit, alleviate the environment pollution and ensure the safety of the production process. In this study, a causal-interval-reasoning (CIR)-based joint scheduling method is proposed for scheduling the multiple categories of byproduct gases. A causal reasoning model is constructed here to predict the gas tank level, in which not only a number of influence factors (i.e., the gas users) on the gas tanks but also the mutual influence of the online tanks are considered. The upper and lower limits of the prediction intervals (PIs) of each gas tank level are constructed based on the granularity partition of the samples and a particle swarm optimization is designed to determine the parameters of granularity. In order for the balance of the whole byproduct gas system, a four-layer causal network is established, in which the operational statuses of boilers, the heat quantity, the steam demand and the gas mixture proportion are all well involved. To further optimize the scheduling solutions, an evaluation index is accordingly proposed. The practical data coming from a steel plant are employed for the validation data experiments, and the human experience based approaches considering only one single category of gas are also conducted as comparable studies so as to indicate the superior performance of the proposed method. For the practical application, a scheduling software system is consequently developed and implemented based on the proposed method, which has been applied in this steel plant for more than 1 year.

1. Introduction

Byproduct gas is a kind of important secondary energy resources produced during steel making process, and its reasonable scheduling provides the advantages of raising economic profit, saving energy resources, keeping the safety of the production process and alleviating the environment pollution. There are three categories of gases involved in the byproduct gas system, i.e. blast furnace gas (BFG), coke oven gas (COG) and Linz Donawitz converter gas (LDG)), and the pipelines are arranged in a crisscross pattern in steel enterprise, which makes the system rather complex.

Considering that effective forecasting can provide positive help for the scheduling process, the existing studies on short or long-term prediction had been reported in literature. With respect to short-term prediction, an optimization method for the parameters of least squares support vector machine (LSSVM) was proposed in Tao, He, and Wang (2017) and Zhao, Wang, Pedrycz, et al. (2012). A multiple kernel learning model was presented in Zhao, Liu, Zhang, et al. (2012) to forecast the gas tank levels of energy system in steel industry. And, an echo state network was used in the prediction of telephone calls load presented in Bianchi, Scardapane, Uncini, et al. (2015). As for long-term prediction, a granularity-based long-term model was then constructed for the consumption of energy system in Yin, Jiang, Tian, et al. (2017) and Zhao, Han, Wang, et al. (2015). Also, a 'wavelet-gene expression' programming approach was employed in long-term stream flow prediction in Karimi, Shiri, Kisi, et al. (2016). However, the methods mentioned above concentrated on single value prediction, i.e., merely focusing on one category of byproduct gas, and deploying iteration mechanism on data samples construction. In such a way, the reliability of the forecasted results can hardly be guaranteed. Therefore, the interval prediction instead of the point-wise one was put forward to meet the practical requirements. For instance, a bootstrapping reservoir computing network ensemble was developed to predict a nonlinear time series reported in Sheng, Zhao, Wang, et al. (2013), and the prediction interval was constructed in Kavousi-Fard, Khosravi, and Nahavandi (2016) by a fuzzy-based framework for wind power forecasting. In addition, a prediction interval construction model combined a kernel-based method with wavelet technology was proposed in Antoniadis, Brossat, Cugliari, et al. (2016). Nevertheless, these approaches were

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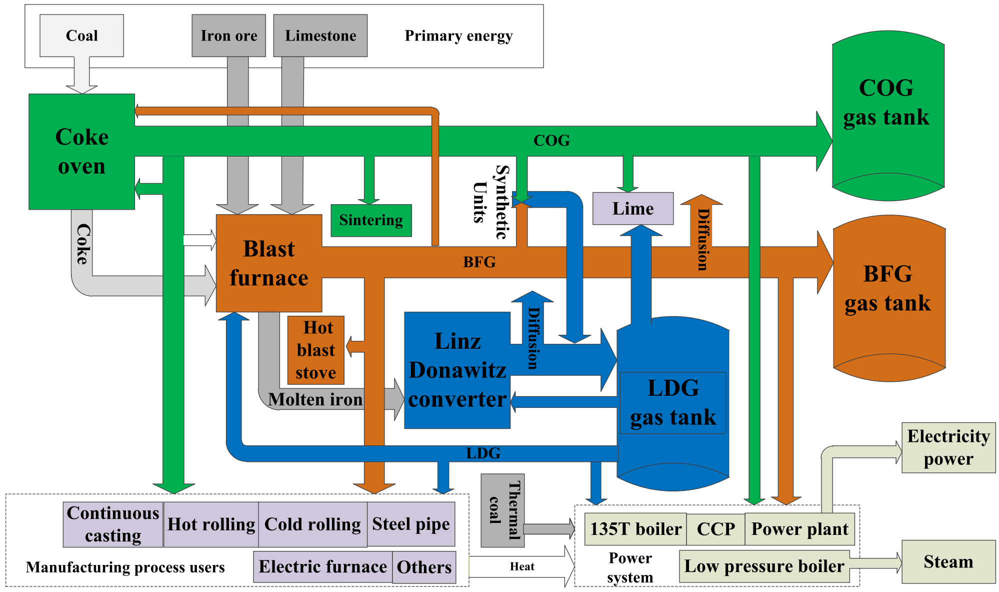

Fig. 1. Structure of the byproduct gas system.

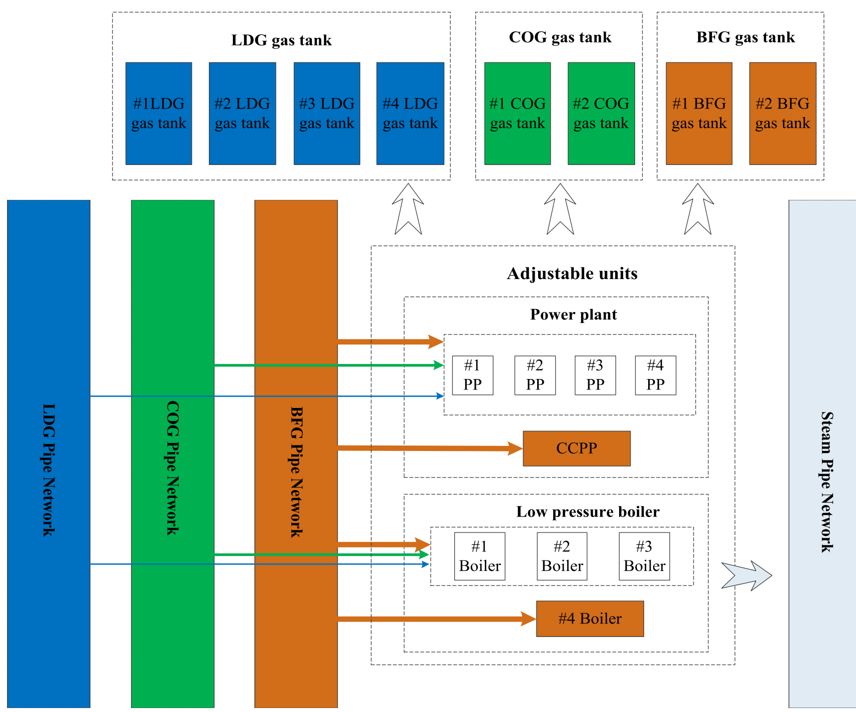

Fig. 2. Relationship between the schedulable units and the gas system.

also based on time series analysis, which ignored the multiple influence factors with respect to the prediction targets.

As for the byproduct energy scheduling, a two-phase method was proposed in Zhao, Liu, Wang et al. (2012), in which a Gaussian process-based echo state network was firstly established to predict the gas tank level, and then a certain heuristic scheduling method was developed for the COG pipeline network. The similar studies can also be found in Sun, Cai, and Song (2013), Yang, Cai, Sun, et al. (2017), Zhang, Zhao, Wang, et al. (2011) and Zhao, Wang, Sun, et al. (2014). In addition, a forecasting and scheduling approach was also designed in Han, Zhao, Wang, et al. (2016). For the oxygen and nitrogen systems in steel plant. However, these solutions only took single gas category as the target, which was under the assumption that the corresponding operation had no influence on the balance of other gas system. In practice, if the energy imbalance occurs in multiple pipeline networks, such methods will be however no longer applicable.

Causality approach is a class of modeling and analysis technique in highly consistent with human cognition originally established in Pearl (2009), in which a directed acyclic graph (DAG) was employed to denote the cause and the effect among variables. A typical application was to evaluate the facial attractiveness models as introduced in Chen and Zhang (2016), where the average causal effect was quantified. Besides, the causality modeling was also capable of being adopted to solve the problems of missing data preprocessing (Daniel, Kenward, Cousens, et al., 2012; Mohan, Pearl, & Tian, 2013; Ren, Drummond, Brewster, et al., 2016), knowledge discovery (Dai, Keble-Johnston, & Gan, 2012),