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Multi-Layer Encoding Genetic Algorithm-Based Granular Fuzzy Inference for Blast Furnace Gas Scheduling*

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Abstract: A timely and effective scheduling of byproduct gas system in steel industry is very significant for cost reduction and environment protection. In this study, a granular-based fuzzy inference model is proposed for blast furnace gas (BFG) scheduling, in which the fluctuation characteristics of the flow of the byproduct gas users is considered for unequal-length data partition, and the time warping normalization (TWN) is exploited to equalize the data segments into the granules with same length. By applying fuzzy clustering, the adjustment amount of each gas user and the system adjustment amount are granularized to the form of fuzzy sets. Furthermore, a fuzzy inference model is built up to describe the relationships between the two variables and thus establish the gas scheduling rules. To improve the precision of fuzzy inference, a multi-layer coded genetic algorithm is proposed to determine the prior's parameters including the major influential users and their corresponding clustering numbers. A case study applied in a steel plant in China demonstrates that the proposed scheduling model can guarantee a higher accuracy and make the operation of blast furnace gas system safe and stable.

Keywords: Steel industry, energy scheduling, information granularity, genetic algorithm, fuzzy inference

1. INTRODUCTION

Recently, energy scheduling is becoming more and more important for process manufacturing industry (Odgaard and Stoustrup, 2009). Steel industry generally accompanies with high-energy consumption and emissions, in which a main reason is the unbalance between the generation and the consumption of energy media. With the shortage of coal and petroleum, the efficient utilization of the byproduct gas is significantly crucial for steel production, which can not only reduce the economic cost, but also alleviate the environmental pollution (Zhang et al., 2011). To improve the utilized efficiency of the byproduct gas, the schedulers or operators of energy management center in steel plant have to adjust the consumption amount of the adjustable gas users real-time to balance its generation and consumption.

An optimal allocation strategy for gas balance was reported in Kim et al. (2003b), where a mixed integer linear programming (MILP) was developed for a higher economic benefits. Similarly, the MILP-based models were proposed again for the gas usage optimization and applied to the Kawasaki steel and the Tata Steel Company Ltd plant for validation respectively (Kim et al., 2002). Since the above MILP models fail to reflect the dynamic characteristics of the gas systems, they can only be applied for long-term scheduling, which performs poor demand for real-time scheduling. In addition, a heuristic algorithm was discussed in Kim and Han (2001) to optimize the gas allocation; and a scheduling model was established in Kim et al. (2003a) for an effective scheduling scheme by minimizing the emission of redundant gas. However, those two studies were completed based on the assumption that the dynamic relationship between the gas tanks level and the flow of gas users can be accurately identified, which is a rather difficult task because of the complexity of the transmission pipeline. As for the dynamic scheduling researches, a Bayesian networks-based modelling and reasoning method was developed in Zhao et al. (2014) to produce the scheduling strategies for a single gas user, which cannot deal with the circumstance of a large gas adjustment amount. Meanwhile, all of the above mentioned studies provide a limitative consideration within numeric data-based modelling and analysing rather than the mode of information granules. In such a way, the numeric data could not effectively reflect the fluctuation characteristics of the energy data in practical production process, which motivate this study to come up with a granular-based byproduct gas scheduling approach.

As for granular computing (GrC) -based model, information granules are commonly used instead of numerical data to reduce excessive detail information redundancy and provide a better insight into the essential characteristics of data (Yao et al., 2013). At present, there exist many researches on the GrC-based modelling. Chen and Su (2008) established a GrC model to induce the scheduling knowledge in dynamic manufacturing environments. A granular-based knowledge

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discovery method was reported in Wang et al. (2013), which was applied in the fault diagnosis of helicopter transmission system. However, the above studies intended to solve the imbalance distribution of sample data, which are not suitable for the energy scheduling in steel industry. As for the byproduct gas system, a granular computing-based method was proposed to carry out a long-term prediction for the energy flow (Zhao et al., 2015). Moreover, A GrC-based hybrid collaborative clustering was reported in Han et al. (2016) to complete a long-term prediction for multiple gas tank levels. However, the two studies paid more attention to the byproduct gas flow prediction that could be viewed as a partial task for the energy scheduling. As for the energy scheduling in practice, the operators usually tend to determine scheduling schemes according to the fluctuation characteristics of a number of essential gas users at a certain period of time, which can be viewed as a kind of information granularity and adopted for developing a more effective scheduling scheme.

Aiming at the evident demands on BFG system scheduling realized in steel industry, a granular fuzzy inference-based scheduling method is proposed in this paper to consider the fluctuation characteristics of the byproduct gas users, and partition the practical data in accordance with its actual production meanings. Here, the TWN is exploited to transform the unequal-length data segments into the granules with same length. By applying fuzzy clustering, the adjustment amount of each gas user and the system adjustment amount are granularized to the form of fuzzy sets. Finally, for the realization of BFG scheduling, a fuzzy inference method is reported to specify the system adjustment amount at the adjustment moment, and then accord with the current adjustable gas users' status to obtain the final energy scheduling scheme. In order to optimize the clustering numbers and to select the optimal subset of gas users which influential for the determination of system adjustment amount, a multi-layer coded genetic algorithm is proposed for the parameter optimization process.

This paper is organized as follows. In Section 2, a typical BFG system and its scheduling problem are briefly stated. The information granularity-based fuzzy inference approach is proposed in Section 3. Meanwhile, a multi-layer coding genetic algorithm is also presented in this section. As for a practical scheduling problem, a number of comparative experiments are carried out in Section 4 to illustrate the effectiveness of the proposed method. Finally, Section 5 draws the conclusions of this study.

2. PROBLEM STATEMENTS

The BFG system is a complex multi-input and multi-output system, which involves blast furnaces, transportation networks and a series of gas users. In a typical steel plant, four blast furnaces viewed as the generation units can supply to the transportation network on average 1.8 million cubic meters BFG per hour. The transportation system includes pipelines, mixing stations and pressure stations; and the gas users mainly comprise coking furnace, hot rolling plant, cold rolling plant, chemical products recovery (CPR), low pressure boiler (LPB), synthesis unit (SU) and the power generator. Since the hot blast stoves consume a large amount of BFG, and be switched continuously, the generated gas supplying to the transportation network will fluctuate frequently. In addition, some ill-conditioned states might occur in the production process, such as blast reduction, equipment parameters changes, etc. Both the fluctuations and the ill-conditions can break the balance of the BFG system, which lead to some economic loss and environment pollution. In order to maintain the stable operation of the system, the schedulers have to timely adjust the consumption amount of some users before the unbalance states appear. As follows, a practical scheduling process is described in detail. Fig. 1 shows the gas tank level tendency and the consumption flow of one adjustable user in a period of time. The positions marked by circles indicate that the scheduling operations are implemented to the BFG system. It is easily observed that the reason for the first scheduling operation is the tank level is approaching to the lower boundary, and the solution to make the level retrieve to the secure region is to reduce the consumption amount of the #1 power station. Similarly, when the tank level will drive up towards the upper boundary, the consumption amount of the power station is increased by the scheduler in order to reduce the impact on the tank. Currently, the expertise-based scheduling scheme is still the common-used approach in industrial practice to keep the operational balance of the BFG system and to reduce the economic loss. In such a way, the reliability and effectiveness of the expertise cannot be guaranteed due to the personal subjectivity. Therefore, it is required that the effective scheduling scheme of BFG system can be developed automatically to reduce the production cost, resources waste and alleviate the environment pollution.

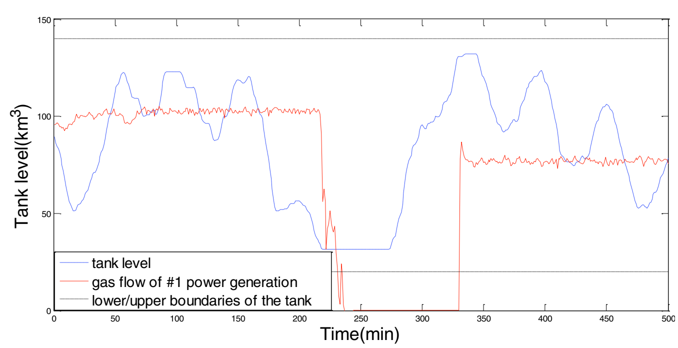

Fig. 1. The gas tank level and the corresponding gas flow of #1 power generation.

3. DYNAMIC SCHEDULING BASED ON GRANULAR FRAMEWORK

Since the fluctuation tendency of gas flow has a significant effect on the development of the scheduling scheme, the dynamic characteristics of the BFG data are generally considered by the schedulers. Information granularity compared to the numeric data can more effectively reflect the dynamic features of gas flow, thus a granular fuzzy inference-based scheduling method is proposed in this study. The architecture of the proposed approach is illustrated in Fig.