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An online case-based reasoning system for coal blends combustion optimization of thermal power plant

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ABSTRACT

Coal blending is becoming increasingly common as more and more off-specification coals are received in coal-fired power plants, given the present coal market in China. This situation requires optimization of the operating parameters for matching the varying coal properties. The motivation for such optimization includes confirming good performance of the units regarding the security, the economy and environmental protection. However, the current adjustments to operation of the plant rely mostly on human experience because of the imperfections of existing theoretical models for coal-blend combustion. In this paper, a Case-Based Reasoning (CBR) method providing online decision-making for optimization of coal-blend combustion was investigated using cases representing successful operation of the unit for specific coal blends and loads. A case base containing a wealth of knowledge about optimal operation modes was constructed from a large number of cases. The development process for the CBR system includes case design, case evaluation, case generation, case retrieval and case reasoning. Case evaluation focused mainly on heating surface security, output capability, slagging tendency, comprehensive fuel consumption and pollutant emissions. Five indexes were introduced to quantify the above characteristics based on actual combustion parameters. A case-generating algorithm employing an evolutionary strategy was proposed in which the case base evolves while retaining new cases. Two methods for measuring case similarity – termed entirely similarity and eigenvalue similarity – were used for case retrieval. Run-time optimization strategies were recommended by the case-reasoning model based on the current operating status. The CBR system using Browser/Server framework were successfully applied to a 600-MW power plant, which provided an opportunity for coal-blend combustion optimization.

Introduction

Coal provides more than two-thirds of the total power generated and will continue to be the dominant fuel for use in electricity production in China [1]. However, the uneven distribution of coal resources, market tightness and transportation difficulties force coal-fired power plants to fuel a variety of types of coal at most times. Safety, efficiency and pollutant emission standards of the boiler are hard to guarantee when the properties of the burning coal deviate from that of the designed coal. Consequently, coal blending and adjustment of the operations procedure are usually regarded as important ways to solve these problems. Generally speaking, the objectives of optimization are to achieve the best unit efficiency and the lowest pollutant emissions on the premise of safety. These objectives are very difficult to describe mathematically because they are affected by many strongly coupled factors, such as boiler load, coal properties, operation parameters and equipment conditions. Over the past ten years, many researches focused on the coal blends combustion performance and thermal power plant (TPP) optimization. Experiments, simulation or black-box models were usually employed as a main method. A previous study by Haas et al. [2] presented results on the combustion characterization of coal blends and found that the behavior of blends could not be predicted by the component coals using a additive rule. Qiu et al. [3] studied the mineral behavior during the coal blends combustion process and the determinants of the initial deformation temperature of coal blends. Arenillas et al. [4] carried out experiments in a drop tube reactor and concluded that accurate predictions of NOx emissions of blends cannot be made. However, the laboratory findings always could not be applied in actual directly. Field studies on specific boilers were sometimes more practical research method for coal blend combustion. Backreedy et al. [5] provided two prediction models of NOx and unburned carbon of coal blends. Liu et al. [6] carried out industrial experiments on a retrofitted down-fired 660-MW utility boiler and

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found optimal anthracite ratios under different conditions. Co-firing of coal-biomass was also investigated by many researches and the approaches proposed in these papers are also meaningful for coal blends combustion [7]. As the theoretical models of coal blends combustion was imperfect, simulations [8,9] especially the computational fluid dynamics methods, were widely used to study the combustion characteristics of coal blends. And neural networks which can be regarded as a black-box model were also important approaches in this field. Zhou's group [10–12] have done a lot of work on this method and achieved good results on the prediction and optimization of NOx emissions. An AOSVR model for boiler combustion optimization which can provide on-line prediction of NOx emissions was proposed by Si et al. [13]. Another model based ANN-GA [14] for optimization of a high ash coal-fired power plant presented can be used for on-line optimization when quick response was required. In these previous researches of TPP operation optimization, the influence of various coals was not fully considered in the models, which is actually a decisive factor. Optimization models established by experimental results or black-box methods are lack of generalization and cannot be applied in situations if the coal properties changes frequently. To solve this problem, power plants commonly use optimization or adjustment of pilot test results. However, effective adjustment strategies usually require a lot of test conditions and take long time.

On the other hand, modern TPPs have stored a large amount of historical data amassed by the Distributed Control System (DCS) and Supervisory Information System (SIS). For a specific unit, successful operating conditions and performance for certain coals and operation parameters can provide reliable experience. If a boiler has been running for a long period of time, this experience will constitute a very valuable case library that can provide guidance for most of the operating conditions of the unit, even while using different coal blends and under different load conditions. This idea presents a new approach called case-based reasoning (CBR) to provide operation optimization decisions.

CBR research dates back to the introduction of Schank's Dynamic Memory, which described a memory-based approach to reasoning [15]. Since then, CBR systems have been applied in various areas such as identification of failure mechanisms [16], fault diagnosis [17], bridge engineering [18], chemical process design [19], cancer treatment [20] and Natural language processing [21]. Xia et al. proposed a dynamic CBR method for process operation support systems [22]. Tsai et al. developed a CBR system for Printed Circuit Board (PCB) principal process parameter identification [23]. Gu et al. developed a case-based knowledge system for safety evaluation decision-making of thermal power plants with CBR-Grey case adaptation algorithms and application software developed with Delphi tools [24]. Yan et al. proposed an improved CBR method which combined with a group decision-making model, and applied it to fault prediction for a shaft furnace and achieved better results than traditional CBR [25]. Generally, case retrieval, reuse, revision and retention comprise the four main processes of a CBR system [26]. In this work, case generation is used instead of case retention; because the case base is initially empty, it is necessary to create new cases during the first step. Additionally, an evolutionary strategy is proposed and used as an alternative to the case revision process.

The remainder of this paper is organized as follows. Firstly, Section 'CBR method for TPP' introduces the process of coal blending in TPP and the flow of the proposed CBR method in detail. The case definition and description is mentioned in this section. Secondly, the evaluation method for cases, which is the most important procedure of CBR, is described in Section 'Case evaluation'. Then, Case-generating and case-retrieval algorithms are developed in Sections 'Case-generating method' and 'Case retrieval and reasoning' respectively. Finally, Section 'Implementation' introduces the system implementation and application examples. Conclusions of this work are presented in Section 'Conclusion'.

CBR method for TPP

Coal blending process in TPP

Thermal power plants use two methods of coal blending. The first involves blending outside of the boiler, which prepares blended coal in accordance with the requirements of the boiler at a specialized blending center. This method is conducive to the integrated dispatching of steam coals and can achieve high-precision blends. However, implementing this method requires acquisition of new machines, or renovation of existing facilities, which most power generation companies cannot afford. The second method to blend coal is through co-burning inside of the furnace (CCIF). In this method, different coals are first pulverized in different mills, then delivered to different layers of burners, and finally blended in the furnace through co-burning. This is the more convenient method of the two and is now widely used by many coal-fired power plants in China.

Comparing the two approaches above, blending coal outside of the boiler is not conducive to optimized combustion. However, CCIF can achieve specific settings for mills and burners depending on the different coals' properties, which can improve the comprehensive efficiency. Generally, a boiler is equipped with multiple sets of milling systems – as many as six sets in most power plants. When using CCIF, the coal supply scheme for bunkers or mills (mill-coal combinations) varies according to the blending ratio. Although the average coal properties are the same across different combinations, the distribution of different coals in the furnace may vary and lead to significant differences in the combustion atmosphere, the flow field, the temperature distribution, the combustion efficiency and the pollutant emissions. Hence, for certain coal-blend schemes and mill-coal combinations, the operating parameters need to be optimized to achieve the best combustion performance. So the purpose of this work is to indentify remarkable cases and establish a case library which can mine and store the operation optimization knowledge from different coal-blend combustion cases and to provide guidance to the operators when encountering a new similar problem.

As a supplement, in order to obtain the coal type on-line, a previous study on coal identification by monitoring coal bunkers was carried out. The outline of identification process is as follows. Firstly, A curve corresponding to the level and the amount in bunker was obtained through experiments. Secondly, Using the integral value of coal feeder amount and the on-line coal level obtained from SIS, the change of coal stratification in bunker was monitored based on the curve. Thirdly, coal type in mill was identified by the lower coal in the bunker. Finally, for the directed-injected pulverized coal feeding system which is widely used in TPP, the real-time coal into the furnace was determined according to the coal type in mills. In addition, to compensate for the error of this approach, a soft-sensing of coal moisture based on the heat balance equation was used to assist in identifying the coal in the mills.

Case feature interpretation

A CCIF case can be described as a set of parameters characterizing good safety performance, high combustion efficiency or lower pollutant emissions of the unit associated with a particular operating mode for a given load and type of coal blends. Given the complexity of the boiler operation, each case generates a large amount of data comprising a complete description of the CCIF process.