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Improved coal combustion optimization model based on load balance and coal qualities

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ABSTRACT

Combustion optimization by fine tuning combustion parameters of boilers can cut down NO_x emissions effectively with little cost. Coal qualities, which change from time to time, have great influences on NO_x emissions. However, the current NO_x reduction optimization model cannot handle with this problem well. What is more, the output load would deviate from the demand load as the boiler efficiency is also affected by the optimized manipulated variables (MVs). In this paper, an on-line method to calculate coal qualities based on reverse balance thermal efficiency model was integrated into the optimization model. Furthermore, a new constraint was added to the optimization model to meet the demand load. NO_x emission characteristics of some 600 MW capacity utility boiler were investigated. Fine selected MVs were taken as the inputs of support vector machines (SVM) and NO_x emission was taken as the output, respectively. Parameters of SVM were fine tuned by particle swarm optimization algorithm (PSO). Combustion optimization for the studied boiler was undertaken based on the proposed optimization model. Results showed that the new model can provide lower NO_x emissions and meet demand loads at the same time.

1. Introduction

As fossil fuels are the main primary energy all over world, nitrogen oxides (NO_x) emitted from power plants is an important pollutant to the ambient circumstance. Statistics shows that coal combustion emits about 7.7 million tons NO_x, about 70% of NO_x emissions, into the atmosphere, and leads to more than $13.3 billion losses every year in People's Republic of China [1]. NO_x emissions restriction will be stricter and stricter, posing a great challenge for researchers, engineers and operators.

There are three kinds of NO_x emissions during the coal combustion progress, namely fuel NO_x, thermal NO_x and prompt NO_x. Fuel NO_x is converted from fuel nitrogen and accounts for 60%–80% of the total NO_x. It is influenced by the oxygen concentration, combustion temperature and fuel properties [2]. Thermal NO_x accounts for 20%–30% of total NO_x and is mainly affected by temperature. This kind of NO_x increases as the combustion temperature increases first, then the emission decreases as NO_x decomposes fast in high temperature. Thermal NO_x also increases with oxygen concentration. However the flame would be cooled by oxygen if its concentration is too high. There is no complete theory for the formation mechanism of prompt NO_x. Fortunately, prompt NO_x is insignificant at the level of combustion temperature.

Low NO_x combustion technology is a popular method to cut down NO_x emissions, in which air and fuels are sent into the furnace in different layers. NH_3, C_mH_n and HCN are abundant in the downstream zone of the burners to form low oxygen reduction atmosphere. When combustion products go through this zone, part of the NO_x emissions would be reduced to N_2. Low NO_x swirl burners characterized by air/fuel classification and fuel reignition are both belong to this kind of combustion technology. Denitrification of the flue gas mainly refers to flue gas desorption technologies like wet denitrification and dry denitrification, which are commonly used in developed countries. Although the denitrification devices can reduce NO_x emissions to a large extent, costs of investment, operation and maintenance are too high [3]. Combustion optimization is a method to cut down NO_x emissions based on artificial intelligences [4]. It utilizes advanced computational intelligence algorithms and operation data or thermal adjustment test data to cut down NO_x emission. This method can cut down NO_x emissions effectively with little cost. Combined with the two

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Nomenclature

ABC	artificial bee colony
ACO	ant colony algorithm
ANN	artificial neural network
BPNN	back-propagation neural network
CEMS	continuous emissions monitoring system
DCS	distributed control system
DVs	disturbance variables
ELM	extreme learning machine
GA	genetic algorithm
GRNN	generalized regression neural network
HS	harmony search
MVs	Manipulated Variables
NO_x	nitrogen oxides
PSO	particle swarm optimization algorithm
RBFNN	radial basis function neural network
SVM	support vector machine

methods mentioned above, combustion optimization technology not only can help to meet the strict emission standards but also can reduce the costs of equipment investment, operation and maintenance to a great extent. Illinois power company [5] employed dynamic optimization method to achieve low NO_x combustion optimization and 20% NO_x emissions were cut down. G. S. Jing [6] proposed a combustion optimization framework for on-line applications based on improved artificial bee colony (ABC) algorithm. Results of a 600 MW utility boiler showed that the on-line optimization framework can provide reasonable optimal advices to operating engineers. T. Peng [7] introduced the novel extreme learning machine (ELM) model to model the NO_x emissions characteristics of a 700 MW coal-fired power plant boiler and used harmony search (HS) algorithm to optimize the manipulated variables (MVs) to realize NO_x emission reduction. 16.5% and 19.3% NO_x emissions reductions for two selected cases were achieved according to the simulation test.

Prediction model of NO_x emission is the base of combustion optimization. H. Zhou [4] predicted NO_x emission of a tangentially fired dry bottom boiler by artificial neural network (ANN) with some manipulated parameters as inputs and NO_x emissions as the output, respectively. Application results showed that the accuracy of prediction results was satisfying, while the prediction time was cut down greatly. C. Xu [8] changed the topology of back-propagation neural network (BPNN), and utilized it to predict the NO_x emissions of burners in different layers, providing the possibilities for further grasping the NO_x emission characteristics and optimizing manipulated parameters. Afterwards, radial basis function neural network (RBFNN) and generalized regression neural network (GRNN) [9] were introduced into the modeling of NO_x emissions characteristics. However, applications showed that these neutral networks have too many parameters to be set and would false in small sample cases. Besides, their structures are hard to be determined and troubled with over fitting and poor generalization. Fortunately, support vector machine (SVM) can overcome these defects. C. L. Wang [10] studied the influences of the SVM's parameters on the prediction accuracy of NO_x emissions. H. Zhou [11] introduced ant colony algorithm (ACO) to optimize the parameters of SVM, facilitating the parameter selection process and increasing the prediction accuracy. Y. B. Zhu [12] advocated that the quadratic programming method in SVM can be replaced by PSO and Quasi-Newton method. F. Q. Si [13] proposed a new method to eliminate the old samples for the on-line SVM to prevent the training samples from being limited to only a few operating conditions. Y. Lv [14] provided an integrated SVM for massive data cases. J. Smrekar [15] and L. Mika [16] studied on the selection of MVs affecting NO_x emissions by F-verification, K-fold cross-validation, and the sequential forward selection method, respectively.

Optimization of MVs is the core of low NO_x combustion optimization technology. Genetic algorithm (GA) was first introduced to the NO_x emission reduction area [17]. A swarm composed of several individuals evolved through coding operation, selection operation, cross operation and mutation operation to optimize MVs. Application results showed that NO_x emissions were reduced greatly. L. G. Zheng [18] improved ACO and applied it to NO_x reduction, cutting down NO_x emissions and strengthening the stability and robustness of optimization progress. Afterwards, he [19] compared ACO, GA, particle swarm optimization algorithm (PSO) in the application of some tangentially fired boiler in the aspect of solution quality, iteration times and computation time. ACO outperforms classical GA for the studied boiler and thought to be favorable to the development of the sophisticated combustion optimization software package. To accelerate the optimization speed, Y. P. Gu [20] got the optimized operation strategies based on GA first. Then she established fuzzy rules library based on the optimized results and recommended operation strategies based on this library. Recommended results and optimized results were close, while the computation time was reduced greatly.

Traditionally, MVs like secondary air distribution pattern, overfire air distribution pattern and nozzles' tilting angles are optimized in reasonable ranges to cut down NO_x emission, keeping the coal quantity and air quantity unchanged [17,19]. However, these MVs also have influences on the boiler's efficiency [21]. If the coal quantity and air quantity remain the same, the demand load cannot be satisfied.

Thermal power plants are market-oriented enterprises. In order to reduce the generation costs, they would choose low-grade coal or blended coal. Although traditional coal qualities analysis technologies have high analytical accuracy, they take too much time to analyze the results and contribute little to the real-time combustion adjustment and optimization. On-line analysis technologies like on-line microwave measurement of moisture, on-line dual-energy y-ray attenuation detection of ash, instantaneous y-ray detection of ash, carbon, hydrogen, oxygen, fast neutron activation technology to detect ash composition and sulfur content and rapid analysis of coal characteristics based on infrared measurement have made some progress. But the investments and maintenances of these technologies are expensive. H. Zhao [22] utilized the real-time operation data from DCS to calculate coal characteristics based on simplified counterbalance calculation model. Coal qualities have great influences on NO_x emissions characteristics. D. S. Sandro [23] pointed out that future work should include the variability of fuels, since the NO_x level is highly dependent on the type of fuel used. Coal qualities are often taken as factors of the prediction model of NO_x emissions characteristics. However, few works considering coal qualities in the optimization model have been done up to now.

This paper proposed a new NO_x emission optimization model considering the load balance and coal qualities. Related algorithms are introduced in section 2. Section 3 proposed a new optimization model for the NO_x emission reduction. Section 4 tested the NO_x emissions characteristics of some 600 MW capacity boiler and constructed prediction model of NO_x emission characteristics. Results and discussion were given in section 5. Finally, conclusions were given in section 6.

2. Prediction and optimization algorithms of NO_x emissions

SVM and PSO were utilized to model NO_x emission