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Online adaptive least squares support vector machine and its application in utility boiler combustion optimization systems

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ABSTRACT

Boiler combustion optimization is a key measure to improve the energy efficiency and reduce pollutants emissions of power units. However, time-variability of boiler combustion systems and lack of adaptive regression models pose great challenges for the application of the boiler combustion optimization technique. A recent approach to address these issues is to use the least squares support vector machine (LS-SVM), a computationally attractive machine learning technique with rather legible training processes and topologic structures, to model boiler combustion systems. In this paper, we propose an adaptive algorithm for the LS-SVM model, namely adaptive least squares support vector machine (ALS-SVM), with the aim of developing an adaptive boiler combustion model. The fundamental mechanism of the proposed algorithm is firstly introduced, followed by a detailed discussion on key functional components of the algorithm, including online updating of model parameters. A case study using a time-varying nonlinear function is then provided for model validation purposes, where model results illustrate that adaptive LS-SVM models can fit variable characteristics accurately after being updated with the ALS-SVM method. Based on the introduction to the proposed algorithm and the case study, a discussion is then delivered on the potential of applying the proposed ALS-SVM method in a boiler combustion optimization system, and a real-life fossil fuel power plant is taken as an instance to demonstrate its feasibility. Results show that the proposed adaptive model with the ALS-SVM method is able to track the time-varying characteristics of a boiler combustion system.

1. Introduction

Boiler combustion optimization techniques are amongst the most effective methods for energy saving and emission reduction in power plants. They are usually implemented by adopting advanced control algorithms and artificial intelligent technologies in a supervisory control system, which is functioning over the distributed control system (DCS) in a plant [1]. Compared with the traditional control system, a control system based on the boiler combustion optimization technique does not incur any extra costs for equipment modification, thus its relevant investment costs are rather small. Moreover, this technique has been improved to be rather effective, and has been widely applied around the world [2–6]. A regression model of the boiler combustion system plays an important role in the optimization system. Although first-principle models have been extensively studied, they are still not suitable for online uses due to the complex computation; thus the empirical model built by data-driven methods is more attractive. Typically, a regression model can be trained using historical operating data offline. However, the characteristics of a combustion system are unstable and time-varying, because of equipment ageing, modification, and soot or slag formation on heating surfaces. Then the initial model established based on the historical operating condition will be less accurate as time goes by, and the associated manipulated variables optimized based on the initial regression model will also be far from the optimum point. Therefore, it seems extremely demanding and meaningful to develop an adaptive boiler combustion model, for tracking the time-varying characteristic and for better results of this excellent optimization technique.

The least squares support vector machine (LS-SVM) is a special version of the support vector machine (SVM) proposed by Suykens and Vandewalle [7]. In contrast to the traditional artificial neural network, it can efficiently solve the problems of over-fitting, local minima, and others. Moreover, the topologic structure of the LS-SVM model is also legible, and it involves support vectors selected directly from the training set and a series of support values which indicate the influence degree of every support vector on the regression model. In addition, according to the KKT (Karush–Kuhn–Tucker) condition, the training process of the LS-SVM model can be accomplished by solving a linear system, which

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