OPTIMIZATION OF THE PLANT CONTROL SYSTEMS AT WILHELMSHAVEN POWER PLANT BASED ON COAL MILL MODELS AND STATE CONTROLLERS

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ABSTRACT

In the light of increasing renewable feed-in and challenging market conditions, flexibility requirements for hard-coal fired power plants become more important. The focus is on the capability for primary and secondary control response. In this work, a procedure has been developed using Kalman filters to smoothen stochastic oscillations of a Promecon coal dust mass flow measurement while capturing the dynamic behavior during steep load ramps. The filtered signal can be used to improve the performance of the power correction controller in the power plant.

A state controller with observer is proposed for this purpose, where the observer is corrected by the power output measurement and the coal dust mass flow measurement. Test results of the implementation in the control system at Wilhelmshaven power plant show promising behavior of the enhanced controller.

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INTRODUCTION

The intermittency in the German electrical grid due to renewable power generation is mainly compensated by hard coal fired power plants. This leads to increasing requirements for primary and secondary control reserve for these power plants (Hentschel 2017). Current control structures are typically based on standard PI controllers, simplified reference models and open-loop control for step load changes. These control concepts typically use constant parameters and cannot adapt automatically to new boundary conditions like new coal types or wear of the coal mill rollers.

Modern state controllers with observers can partly mitigate the time variance of the power plant and reduce the need for optimization of controller parameters, which is cost- and time-intensive. In coal fired power plants, the controlled section from inlet signal at the coal feeder to the output signal at the generator is long. The quality of the observer is therefore reduced. The additional measurement of a state variable in the middle of the controlled section would help to improve the quality of the observer.

Additional measurement of the coal dust mass flow downstream of the coal mill is a promising solution. However, this measurement is not easy and yields lot of stochastic oscillations. More precise coal mill models and the use of Kalman filters can smoothen the measurement signal without influencing the time response of the measurement. This article describes how Kalman filters are successfully applied to

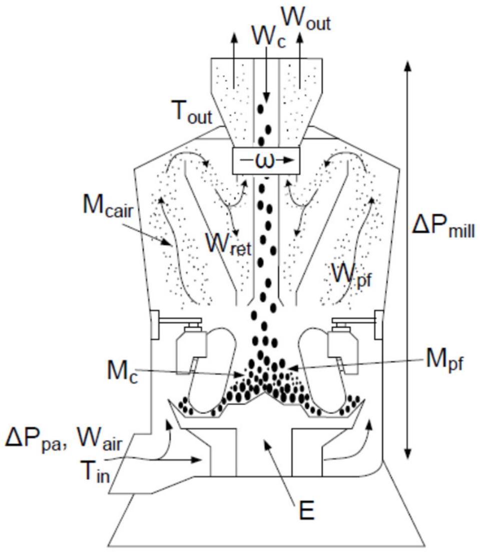

Figure 1: Hard coal mill and its internal coal storages (Niemcyk 2012)

optimize coal dust measurement signals based on Promecon measurement systems. In addition, new control concepts are discussed and the results of the practical implementation at Wilhelmshaven power plant are presented.

COAL MILL MODELS

Figure 1 shows the processing schematic of raw coal and coal dust in a coal mill. The raw coal falls in the middle of the mill plate. The coal is transported towards the outer edge of the rotating plate. In the middle of the plate, coal is grinded by the rollers. The primary air transports all coal upwards that falls over the edge of the plate, where heavy particles are thrown back to the plate. Smaller particles are directed upwards to the classifier. Very small particles are transported to the burners. All other particles are separated in the classifier and thrown back to the center of the plate. The separation grain size in the classifier is a function of the primary air volume flow.

The development of a new coal mill model is based on the complete dynamic power plant simulator of a commercial power plant and the comparison with its process data measurement. The basic idea is that the furnace, heat transfer and fluid flow can be modelled precisely since the plant geometry and process data measurements are available. E.g. heat transfer parameters can be optimized to meet the temperature measurements. The remaining variable to account for the dynamic behaviour of the power plant is the coal mill.

Figure 2: Optimization of the coal mill model

Figure 2 shows the principle of the optimization process. The simulation model has been developed in Apros simulation software, please compare also (Zindler 2016). Measured feeder inlet values are used as transient boundary condition of the model. The model response e.g. generator output is compared to the real measured generator output. The discrepancy is used to optimize the parameters of the mill model in an iterative procedure. Introducing a coal dust measurement downstream of the mill allowed to improve the optimization process. The mill model itself is a grey box model based on transient mass balances. However, the grain size distribution cannot be calculated so that the distributions in the mill are approximated by simplified relations. Details of the process are described in (Hentschel 2016).

FILTERING OF THE COAL DUST MEASUREMENT

Uniper has installed a Promecon coal dust mass flow measurement in Wilhelmshaven power plant to optimize the capacity for secondary control response. Figures 3 and 4 show the measurements of feeder speed and coal dust mass flow during a “double-hump” test. The coal dust measurement signal is clearly oscillating in a stochastic manner. The signal is therefore not suitable for control optimization in its original quality. The reason for the oscillation could not be identified.

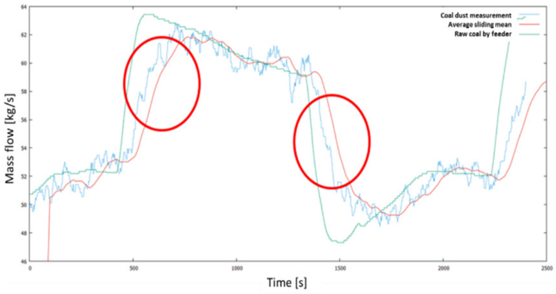

Figure 3: Measurements of a double-hump test and optimization of the oscillating coal dust mass flow measurement signal (blue) based on sliding average mean value (red) and first-order filter (green)

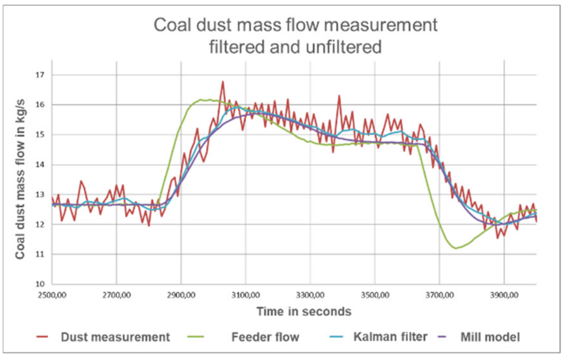

Figure 4: Test of the Kalman filter in Apros simulation software using real measurements

In order to make the coal dust measurement signal available to the control system, different filters have been tested. Figure 3 shows the filtered results based on average sliding mean value and on a first-order filter. In both cases the signal is smoothened, but the dynamic behavior is not accurately captured (particularly ramps). This signal is not suitable for the optimization of large load changes. A filter is required, which does not alter the dynamic behavior of the measurement signal. Uniper has developed a Kalman filter for this purpose.

KALMAN FILTER

The basic principle of a Kalman filter can be explained in two steps. Firstly, the coal dust mass flow is predicted or calculated based on the feeder speed, other boundary conditions and a mathematical model of the mill. The second step is a continuous correction of the model based on the measured coal dust mass flow. The signal influence can be weighted by parameters (Bruns 2016). For in-depth explanation of the Kalman filter, the interested reader is referred to the pertinent literature such as (Föllinger 2013, Lunze 2008).

Figure 4 shows the results of the Kalman filter based on the mill model. The feeder speed and the primary air flow are input signals of the model. The model is corrected continuously by the Promecon coal dust measurement. The signal is well filtered while accurately capturing the dynamic behavior of the measurement signal during a step load change. In this form, the signal is suitable as basis for control optimization.

Figure 5 shows the results of the Kalman filter implementation in the Siemens T3000 control system of Wilhelmshaven power plant, where the green curve is the Promecon coal dust mass flow measurement and the red curve is the filtered signal.

Figure 5: Implementation of the Kalman filter in Wilhelmshaven plant control system

The calculation precision of the control system is sufficiently high to implement the Kalman filter directly into T3000.

USE OF THE FILTERED SIGNAL FOR OPTIMIZED STATE CONTROLLER

The coal dust measurement can now be used for the optimization of the power correction controller. The controller is normally implemented as correction controller to the power set point. The corrected power set point is required in block control to calculate set points for further parameters like fuel mass flow, feed water mass flow or combustion air mass flow.

Figure 6 shows the simplified schematic of a power correction controller for a limited load range (Load-dependency of the parameters is omitted). In the upper section, the real power plant process is shown (orange colour), which can be divided into two parts:

1. Feeder and coal mill

2. Furnace, steam generator, turbine and generator

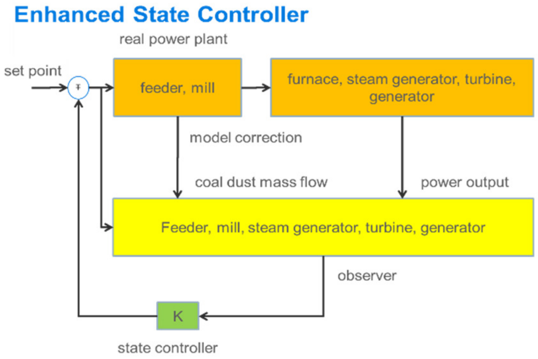

Figure 6: Use of the coal dust measurement to optimize secondary control quality

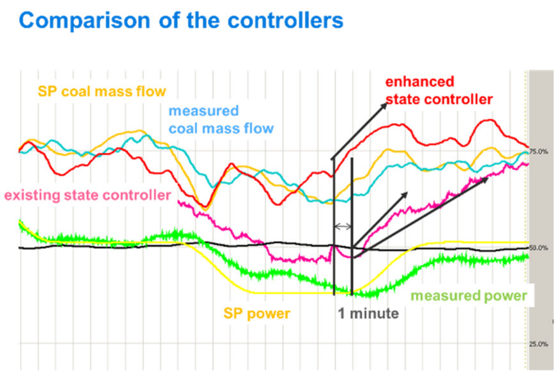

Figure 7: Comparison of a PI controller and the new state controller (Kühling 2017)

In the lower section, the observer is shown (yellow colour). The first part of the observer model describes the feeder and the coal mill, which is corrected by the coal dust measurement. The second part of the observer describes the furnace, the steam generator, the turbine and the generator, which is corrected by the power measurement. The state controller design is based on the merged observer. The main advantage of this approach is the reduced time delay before a discrepancy is identified by the correction controller, particularly in the coal mill (e.g. due to new coal types or mill roller wear).

Figure 7 shows a comparison of the existing state controller of the power plant and the enhanced state controller. Both controllers are implemented in the T3000 Siemens control system, where the existing state controller is in operation. The enhanced state controller is running in parallel. The results show that both state controllers have a qualitatively similar behaviour in operation. In the marked time period, the coal mass flow set point is increased by pilot control for a positive load change. The deviation between this set point and the coal mass flow measurement is readily considered by the enhanced state controller to increase the feeder speed, whereas the existing state controller is limited to the deviation between power set point and measured generator power. The control response time is thus reduced by approximately one minute.

By comparison, for secondary control response the target load must be achieved five minutes after the initial jump of the load set point, with limited overshoot and undershoot not permitted. The enhanced controller is thus a significant contribution to upgrade hard coal-fired power plants for secondary control response and to counteract grid intermittency due to renewable feed-in.

SUMMARY

In this work, a procedure has been developed using Kalman filters to smoothen stochastic oscillations of a Promecon coal dust mass flow measurement while capturing the dynamic behavior during steep load ramps. The filtered signal can be used to optimize the power correction controller of the power plant. The coal dust measurement is suitable to quantify the time variance of a coal mill due to different coal types or mill roller wear.

A state controller with observer is proposed where the observer is corrected by the power output measurement and the coal dust mass flow measurement. Real tests at Wilhelmshaven power plant have shown that the enhanced state controller reacts approximately one minute faster in case of an issue in the coal mill, resulting in increased capability and reliability of plant secondary control response.

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