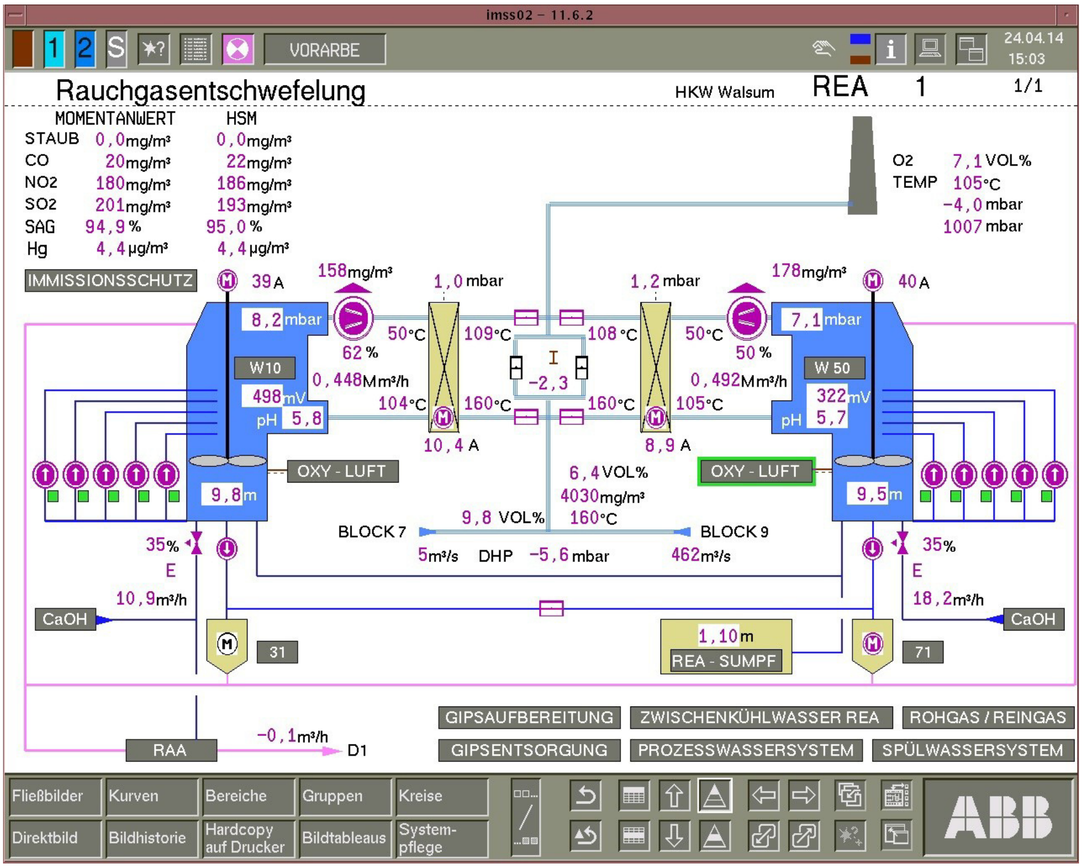
Improved FGD Operation Efficiency
with
Self-Tuning Predictive APC-Software

Dr. Volker Stephan, Christoph Möller
STEAG Energy Powitec GmbH, Germany

Dr. Peter Deeskow
STEAG Energy Services GmbH, Germany



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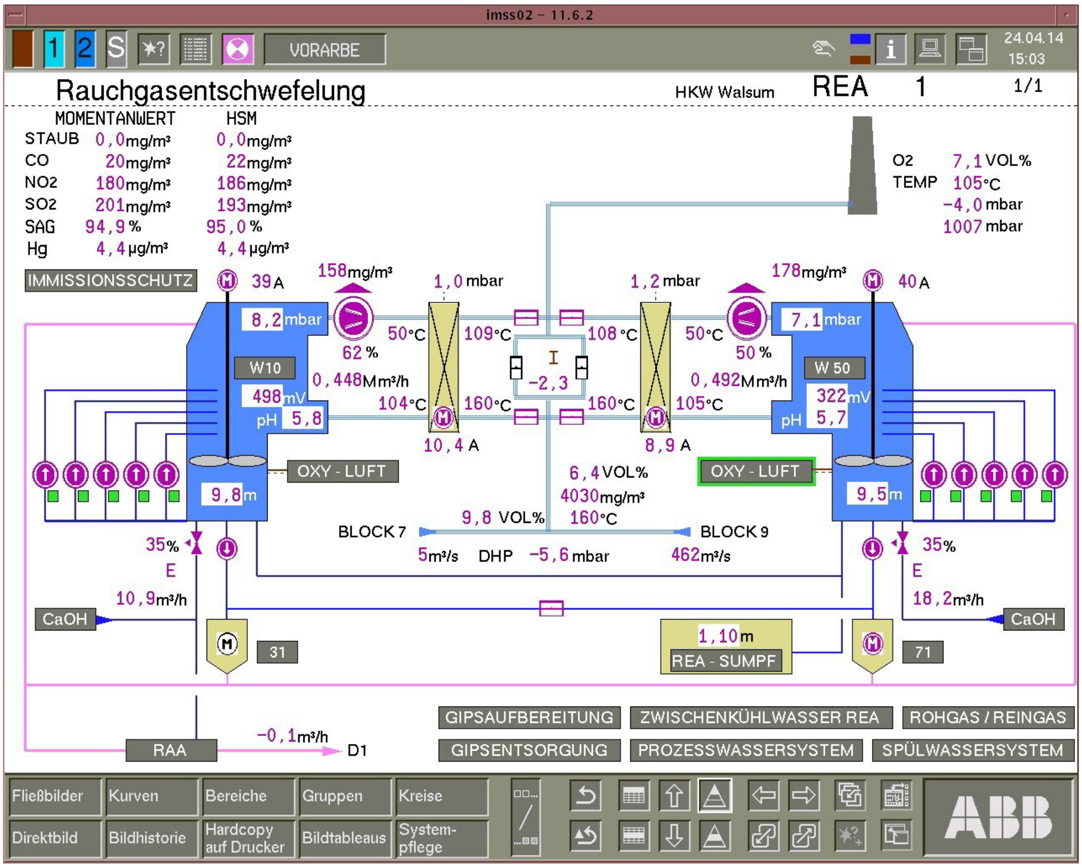
1 Motivation

Efficiency is a very common objective in today's power plant operation. Much work and effort are spent to optimize the combustion, heat transfer, heat recovery, turbine and generator performance. On the other side, every power station also has a considerable power consumption on its own. To minimize its own demands for electricity will also increase the power plants efficiency.

In this paper we will describe a new approach to optimize the FGD operation of the hard-coal fired 560MW power plant Walsum 9 in Germany. In this plant, a wet scrubbing flue gas desulfurization (FGD) is used, which consumes in average about 2.4MW of electricity, because considerable mass flows of the scrubbing reagent (limestone) need to be pumped to the spray nozzles usually located at different elevations in a vertical spray tower.

2 Problem Description

The flue gas desulfurization system (in German abbreviated "REA") in the Walsum 9 power station was originally built for sulfur removal of two blocks. It is a wet scrubber system that uses limestone solvent to absorb the SO_2. Its design for two blocks resulted in a very powerful and flexible structure featuring many degrees of freedom to operate that aggregate. As figure 1 shows, there are two independent desulfurization subsystems each featuring five pumps feeding the reagents into the SO_2 -absorber at five different elevations of spray nozzles.

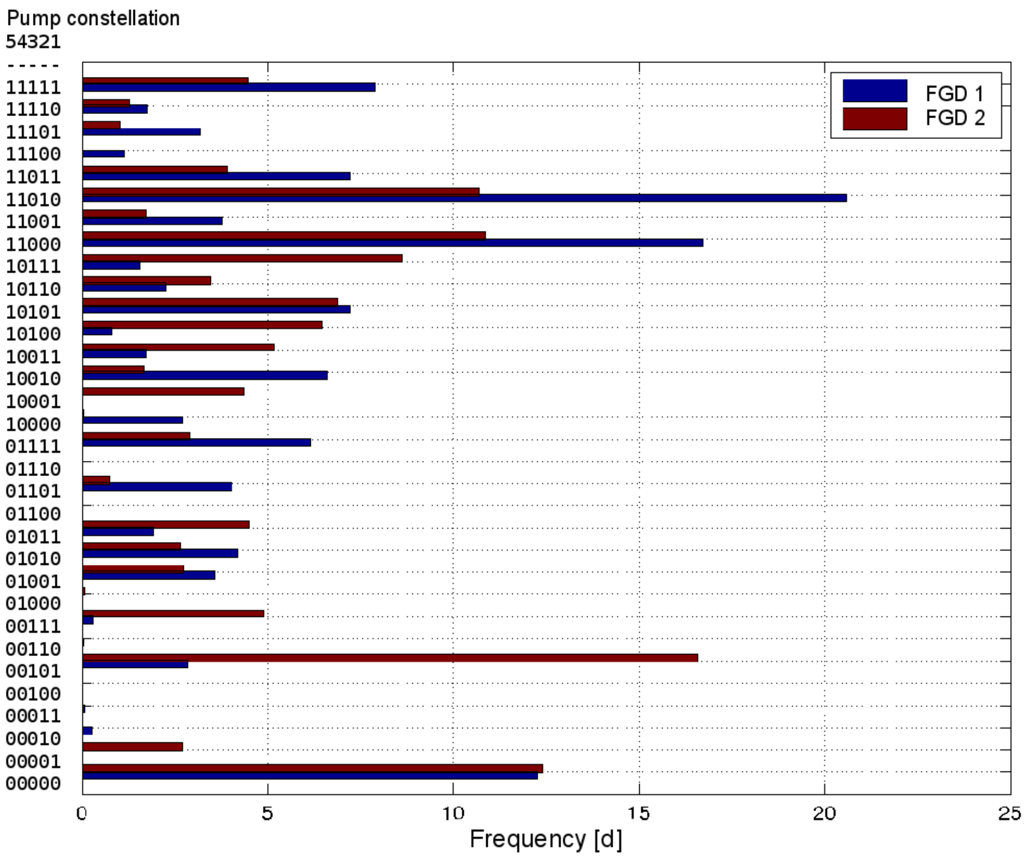


Drawing 1: Schematic view of the flue gas desulfurization at the Walsum 9 power station

The pumps can be either switched on or off, they do not allow any flow rate control. Due to different feeding elevations of the limestone solvent, these five pumps demand on one hand also diverse energy amounts and on the other hand show different SO_2 -absorbing rates. A drawback of that complexity is, that it can be operated in many different ways while fulfilling the legal limitations for sulfur emissions. Although many operation modes maintain the limits, there are significant differences with respect to energy consumption for all these modes.

Up to now, the selection of pumps to be activated is made by the operator. Furthermore, also the distribution of the flue gas flow between both FGD-subsystems is run manually. Because the operator is usually quite busy maintaining the legal limitations for all emissions as well as observing several other aggregates of the power station, there is not enough time left to optimize the pump selection with respect to both energy consumption and desulfurization efficiency. His task gets even more complicated due to varying coal qualities with changing sulfur contents and frequent load variations over time.

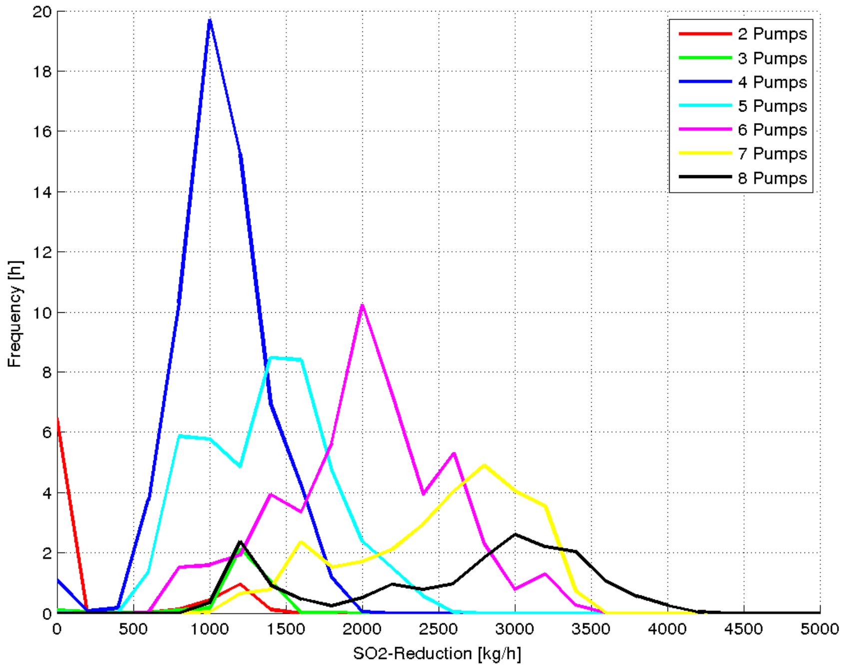
Figure 2 shows the frequency of all constellations of active FGD-pumps over a time range of about 4 months. For five pumps there are 32 different combinations possible. As to be seen, the operators chose almost all available constellations to maintain the legal limitations for sulfur emissions.



Drawing 2: Frequency of constellations of active pumps over four months.
The binary number code on the y-axis describes if the corresponding pump was active (1) or not (0).

Therefore, a control structure is required, which operates the flue gas distribution and the selection of active pumps in order to maintain the emission limits while minimizing the energy demand of the FGD.

To analyze the current mode of operation and to check, if there is any potential to improve the FGD, figure 3 shows the desulfurization rate for different numbers of active pumps. As to be seen, the same amount of reduced SO_2 has been achieved with many different numbers of active pumps. For instance there were 7 (yellow curve) or even 8 (black curve) pumps activated to reduce only smaller amounts SO_2 of where 3 (green) or 4 (blue) pumps would have been sufficient.



Drawing 3: Desulfurization performance for different numbers of active pumps

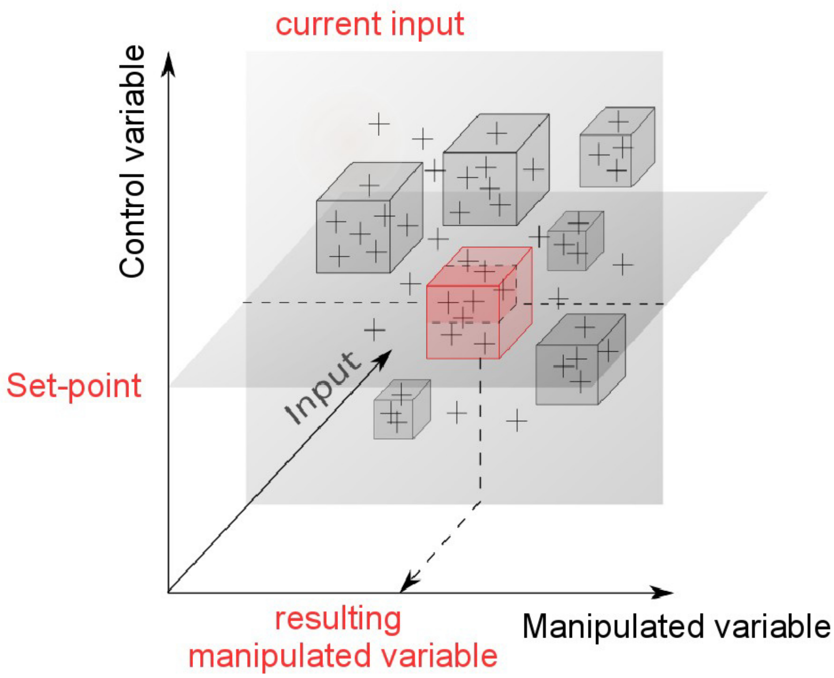
The other manipulated variables of FGD like the total limestone feed into the system, the pH-value or the oxydizing gas flow are intentionally not addressed in this paper.

3 Approach

Because of the time varying coal properties, there was no detailed knowledge available about optimal pump constellations for each load case and coal type. Therefore, we decided to apply a learning system, which automatically extracts optimal pump constellations from historical process data.

Clustering algorithms are well suited to compress high dimensional data and to extract relationships. After defining the relevant n channels to be processed by this clustering algorithm, each data point over time is treated as a point in a n -dimensional space. The clustering algorithm now compresses these data points by representing groups of very similar points by only a single representative. This way, the whole variety of observed situations can be memorized very efficiently.

Figure 4 shows in a schematic view the principal functioning of a clustering algorithm for only three variables, where one variable is the control variable (like SO_2-reduction), one is an independent input (like load case), and the third dimension is defined by a control variable (like pump constellation). As can be seen, each data point over time is marked as a "+" in this three dimensional space. In consequence, similar process situations will result in very close points in this input space. This spacial closeness will be detected by the clustering algorithm and groups of similar data points will be replaced by a representative illustrated as a box.



Drawing 4: Schemativ view of a clustering system. For details see text.

Once this clustering is done for a large set of historical data, the learned locations of the representatives are storing knowledge about the relationships of all clustered process variables.

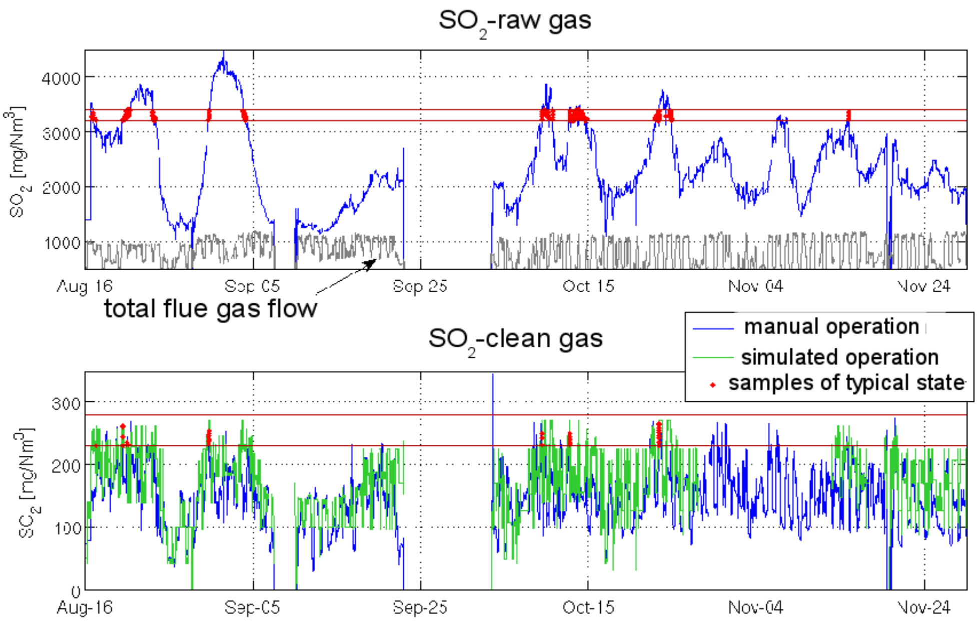
In the following, this knowledge can be used operate the FGD-system. Therefore, the desired set-points of all control variables together with the current values of the independend process variables are presented to the clusterer. Based on the locations of all representatives in the high-dimensional space the clustering algorithm can find those representatives that are matching these preconditions at best. If they are found, the corresponding manipulated variables of these representatives can be retrieved and used to decide which pumps to activate and which not.

In contrast to the very simple example illustrated in figure 4, the clustering algorithm to be used for the real plant operates in a much larger input space. There are for instance for each pump, for the flue gas distribution between both subsystems, for the plant load, for the energy demand, and last but not least for the required SO_2-reduction a separate input space dimension.

4 First Results

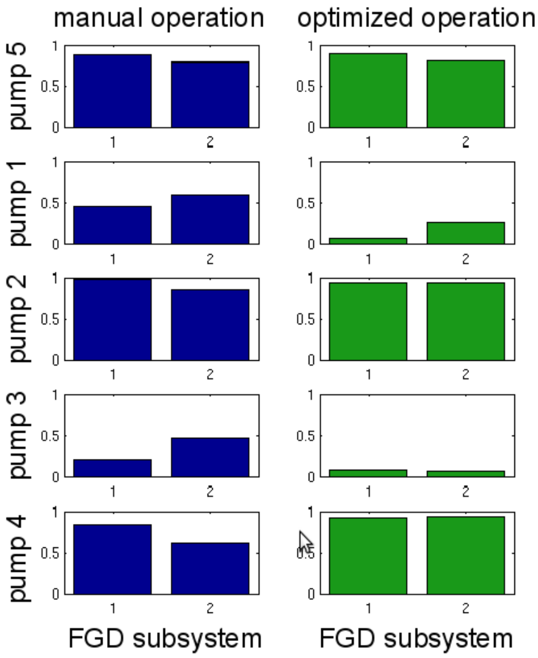
Figure 5 shows a comparison between real manual operation of the FGD system and the simulation of the operation based on the clustering algorithm over a time range of about four months. The upper diagram shows the plot of raw-gas SO_2-concentration along with the total flue gas flow. The total flue gas flow oscillates according to the daily load changes. Furthermore, also the SO_2-concentration in the raw gas shows slower, but significant changes over time, which are caused by changing coal types with different sulfur contents.

The lower diagram in figure 5 shows the SO_2-concentration in the clean gas, where the blue curve shows the real plot of manual operation and the green curve depicts the simulated clean gas sulfur content, if the optimized pump constellation would have been used. As can be seen, both curves remain clearly below the legal limit (300mg/Nm^3 daily average) for sulfur emissions. In comparison to the manual plot, the simulated versions tends to run with slightly higher SO_2-concentrations in the clean gas, because needless reductions are avoided to safe energy.



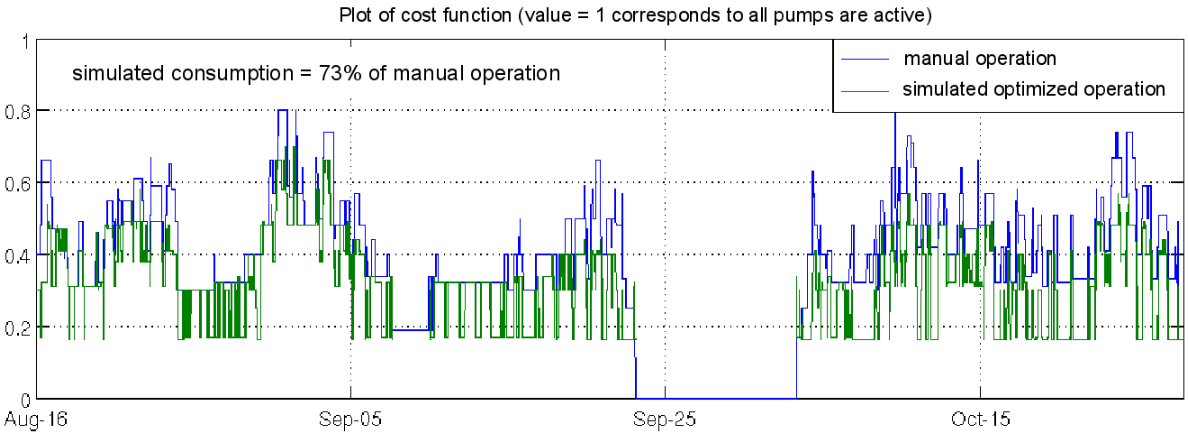
Drawing 5: Comparison of manual and simulated optimized FGD-operation

Another aspect becomes clear in figure 6, where the pump activation frequencies of manual and simulated optimized operation are compared. The activation frequencies for pumps 5, 2, and 4 do not differ much, but for pumps 2 and 3 there are noticeable differences. In optimized operation these pumps would be used much less than in manual operation.



Drawing 6: Pump activation frequency with manual and simulated optimized operation

This also indicates a reduction of energy consumption by an optimized pump activation pattern. To quantify the optimization potential for the clustering algorithm, we simulated its active pump pattern over a longer time range. Since each pumps feeds the reagent to different nozzle elevations, we also weighted each pump with its individual cost factor. Figure 7 shows a comparison of the sum of the weighted cost factors over time.



Drawing 7: Comparison of cost factors for active pump constellations for manual and simulated optimized FGD-operation.

As to be seen, the simulated optimized cost function is in many time periods less than the function of manual operation. In some time periods both plots are identical. This indicates, that no better pattern of active pumps could be found.

In total, the simulated optimized pattern exceeds only 73% of the cost function of manual operation. Thus about 27% of energy could be saved by application of optimal FGD-pump activation patterns.

Currently this clustering algorithm is commissioned in the plant and will be tested in the next months in detail.

5 Summary

In this paper an approach to reduce the energy consumption of the flue gas desulfurization system for the hard coal fired power station named Walsum 9 in Germany has been presented. The FGD-system features two independent FGD-subsystems with 5 pumps each. This high number of operation modes makes it for the human operator very complex to find optimal pump activation patterns, because each pump has an individual SO2-reduction efficiency and also a specific power consumption. Furthermore ongoing load demand changes as well as changing coal types with different sulfur contents make this challenging task even harder.

To optimize the operation of the FGD-system we proposed a clustering algorithm, who learns automatically from historical process data relationships between pump constellations, power consumption, reduction of sulfur emissions, plant load, and so on.

Based on that learned knowledge, the clustering algorithm can be used afterwards, to find for the current process situation an optimal constellation for active FGD-pumps, which keeps the legal limitations for SO_2 -emissions with the lowest energy demand of active pumps.

By simulation of optimized pump constellations a comparison to the manual operation could be done. It turned out, that about 25% of the currently used electrical energy for pump operation could be saved while keeping the limits for SO_2 -emissions. Since in normal operation about 2.4MW are required to operate the pumps, this corresponds to about 0.6MW.

The system it commissioned at the plant at the moment and will be tested in detail within the next months.

STEAG Powitec GmbH
Im Teelbruch 134b
45219 Essen
Dr. Volker Stephan

Phone: +49 49 152 0933 0601
E-mail: volker.stephan@steag.com
Internet: www.steag-powitec.com