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Predictive Diagnostics to Detect Faults and Problems in Power Plant Operation

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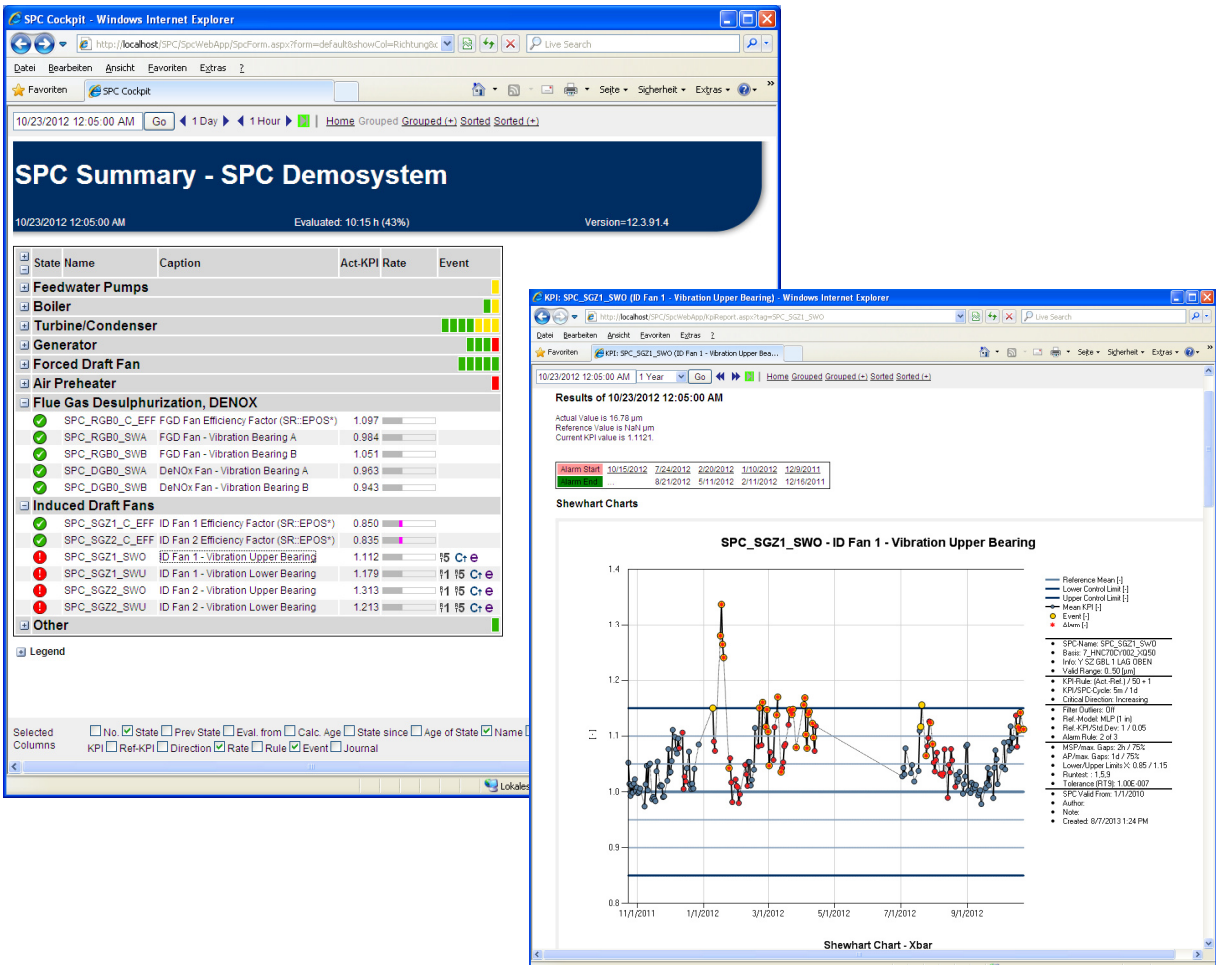

Created for the fair "POWER-GEN Brazil" and presented in the session 6 "Operation and Maintenance" on September 26th 2013 in São Paulo

1 Abstract

Power plants and their components are subject to continuous changes in their operational behaviors which, for instance, can be traced back to wear and tear or fouling. These changes regularly lead to undetected deteriorations of the degree of efficiency of the power plant or to seemingly sudden failures of components with economic consequences. In the past, methods of statistical process control (SPC) were developed in order to detect significant deviations of a process from its reference state early on. These methods have been used successfully in production control of homogenous goods for many years now. The monitoring of continuous power plant processes leads to special demands on the SPC method. Unlike in the production control of homogeneous goods, in which each feature is described by means of a fixed reference value, no fixed reference values exist for the technical power plant process. Therefore, for the qualitative description of power plant processes or components, standardized characteristic values, the so-called KPIs (Key Performance Indicators) should be set up. These KPIs depend only on the process quality and no longer on the mode of plant operation or on the ambient conditions. In this way, the SPC method can be used successfully as predictive diagnostic in power plant processes. Faults and problems that are developing can be detected early and reliably. The paper and the presentation will show examples of the described predictive diagnostic method.

2 The Purpose of Statistical Process Control in Power Plants and Industrial Facilities in brief

SR::SPC breaks down slow and long-term developments and sometimes overwhelming amounts of available operational data. At a certain notification frequency, e.g. once a day, SR::SPC actively notifies the operator without the hassle of false or too frequent alarms via regular e-mail or one HTML-overview on any intranet workstation with sufficient privileges. The appropriate notification frequency can be set according to the individual requirements.

Key Performance Indicators enable the operator to conveniently keep an eye on existing third-party systems (e.g. vibration sensors) or combine measurements to monitor condenser pressure, air preheater leakage etc.

An easy-to-use graphical user interface enables the operator to try additional KPIs on any available measurements and add those KPIs into the online system at no additional cost.

Satisfied customers use SR::SPC to

- increase transparency in terms of condition-based maintenance
- decrease response time to process quality degradation
- avoid unpredicted downtimes
- enable their trained staff to run data analyses and reports spontaneously

The software solution SR::SPC combines the classical approach of statistical analysis with reasonable additional tools such as neural networks, trend prediction and advanced data filtering for maximum usefulness.

3 An Example from Practice Illustrating the Difficulties in Plant Condition Assessment

Today, thousands of digital values can be organized in dozens of different views by the operating personnel.

Also, a common feature of modern distributed control systems (DCS) is that any measurements can be arranged in diagrams at will.

Sometimes the data of the last four to eight weeks is available, the older data is erased or compressed. In other cases timeframes of months or years can be shown.

What does that mean for the operating personnel at a power plant or industrial facility?

The following example is based on an analysis after the event. At the time of the event no permanent online assessment was conducted on the customer's premises.

In the following diagram (Fig. 2) we see data from two different vibration sensors on one forced draft fan. The horizontal axis shows months (March of the first year to February of the next year); the vertical axis shows millimeters per second as an indicator for the strength of the vibration.

The green line represents the warning limit that is configured in the DCS. If the warning limit is exceeded, power plant operators tend to pay closer attention to the component. That does not necessarily mean that there is an urgent danger or that damage occurs yet.

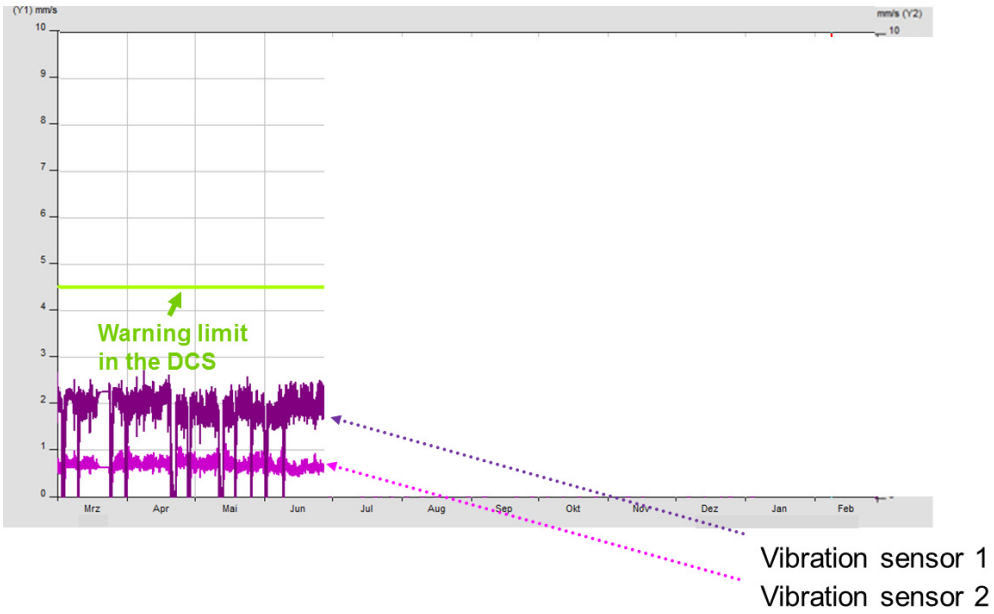

Fig. 1: Two vibration sensors on one forced draft fan

The time span from March to June does not show any significant vibrations. Since there are, as mentioned above, hundreds of measurements available to be monitored by the operating crew, nobody can constantly follow and analyze charts like the one in Fig. 1.

Under regular operating conditions, the staff might "know" the data from the last week or two by heart, so following time spans might be considered to determine whether the forced draft fan functions well or not:

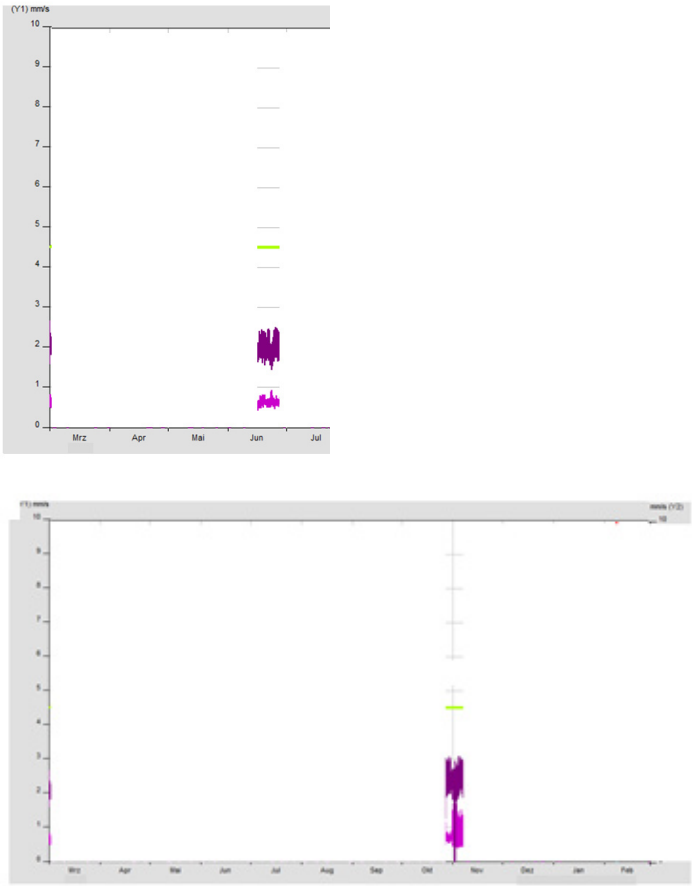

Fig. 2: The same measurements at different time periods

It can be observed that each of the different time periods seems to be unobjectionable; the operating staff might not be inclined to initiate further investigations.

The impression is very different as soon as the whole time period is considered as shown in Fig. 3:

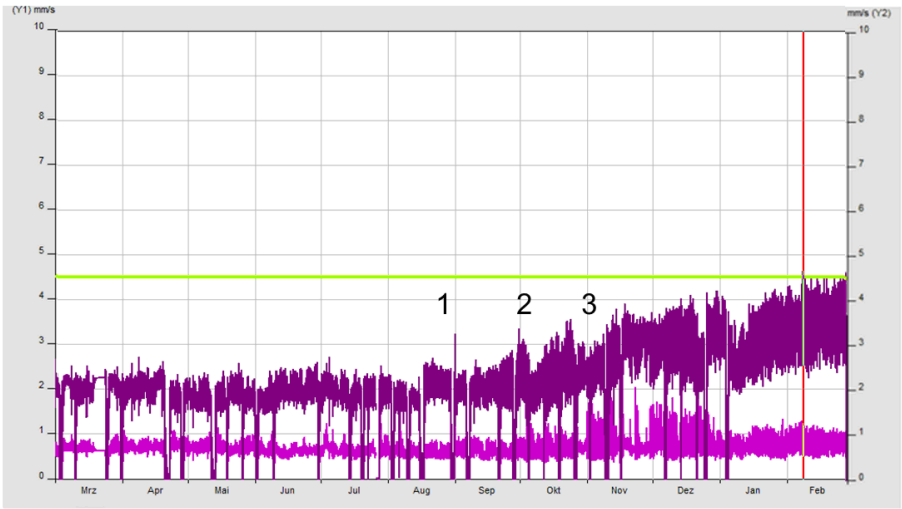

Fig. 3: Same data for the whole time period

During February of the second year the warning limit of the value of vibration sensor 1 eventually passed 4.5 mm/s and an alarm was set off in the DCS.

It turned out that the forced draft fan had to be balanced due to a creeping development of an imbalance. An early warning could have helped to reduce the danger of damages and unplanned shutdowns.

Could a more sensitive system have helped?

Simply reducing the warning limit to e.g. 2.5 mm/s would have produced numerous false alarms.

But are there any significant changes? Fig. 4 shows the result of a statistical analysis of the data of one sensor:

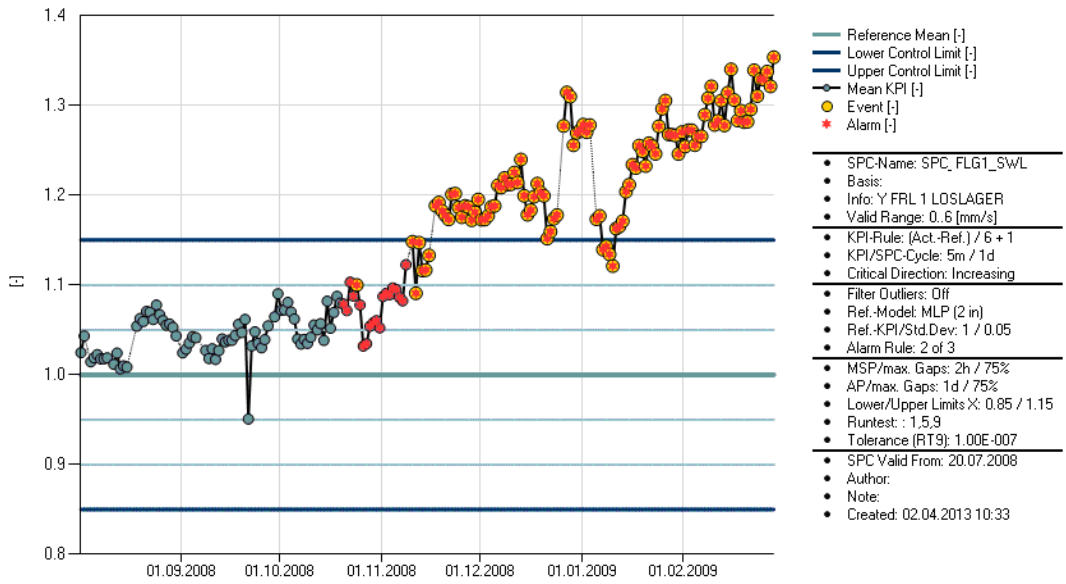

Fig. 4: Statistical analysis of the data

Based on “experience” (“the fan was in order during a specific period of time in the past”) which is modeled by a data-based neural network, an automatic system could have issued an early warning (between the numbers 2 and 3 in Fig. 3). Also, an early warning provides the chance of organizing the measure during times of planned shutdowns. No additional production downtimes are necessary, and it is much easier to allocate resources early on. Finally, an early procurement of spare parts often offers price advantages.

4 Approach: How does the Statistical Analysis work in a Continuous Process?

A software solution for a statistical analysis of power plant processes and industrial processes might conduct the following steps of analysis. The goal is to make use of available data in the DCS or data historian to identify whether the component is in a “good condition” - or if a current development is leading to a degradation of the component.

4.1 First Step: Raw Data

Statistical procurement of operational data starts with digitized measurements. Typically, they can be obtained easily via an interface to the DCS (OPC for example) or a data historian.

An example of raw data - the pressure drop of a flue gas desulfurization separator - is shown in Fig. 5:

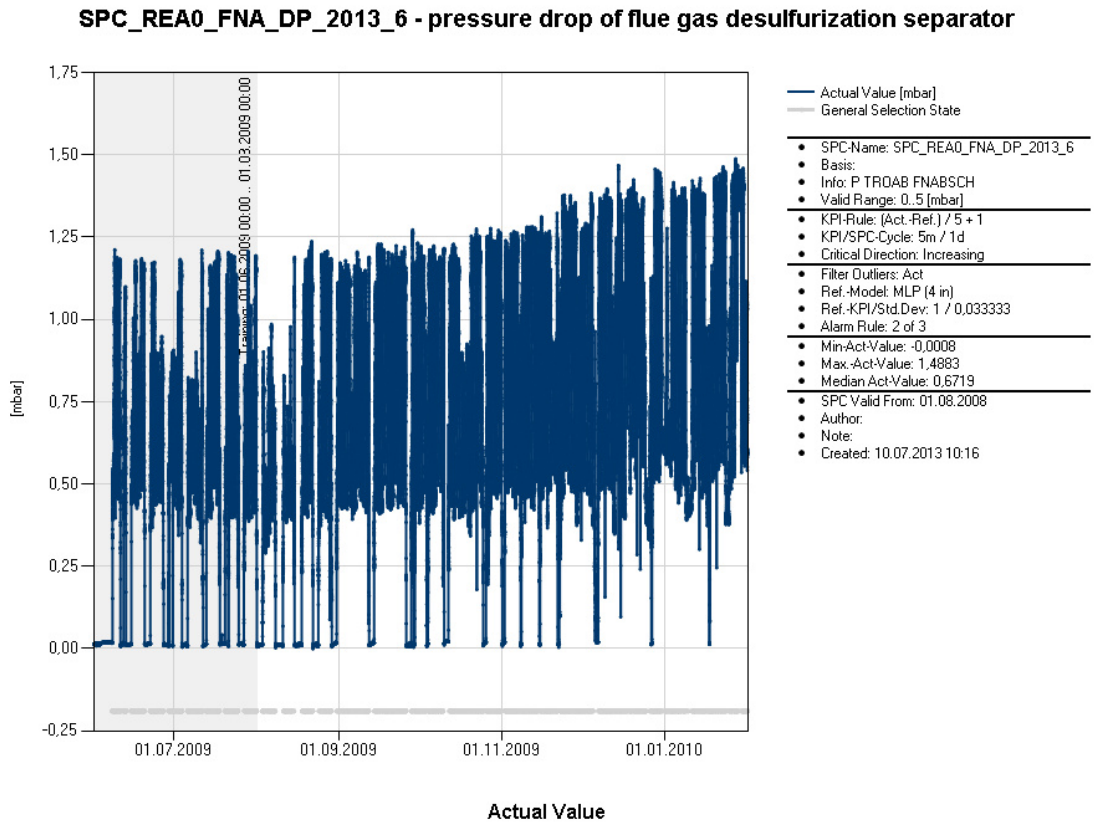

Fig. 5: Raw data imported from the DCS (actual value)

First, the raw digital data of a measurement will contain values of times which are irrelevant for a long-term analysis (e.g. periods of very low load, load changes, periods where the crew knows that there were irregularities / damages, outliers from faulty measurements, long-term shutdowns).

Please refer to Fig. 6 to see what it looks like in SR::SPC.

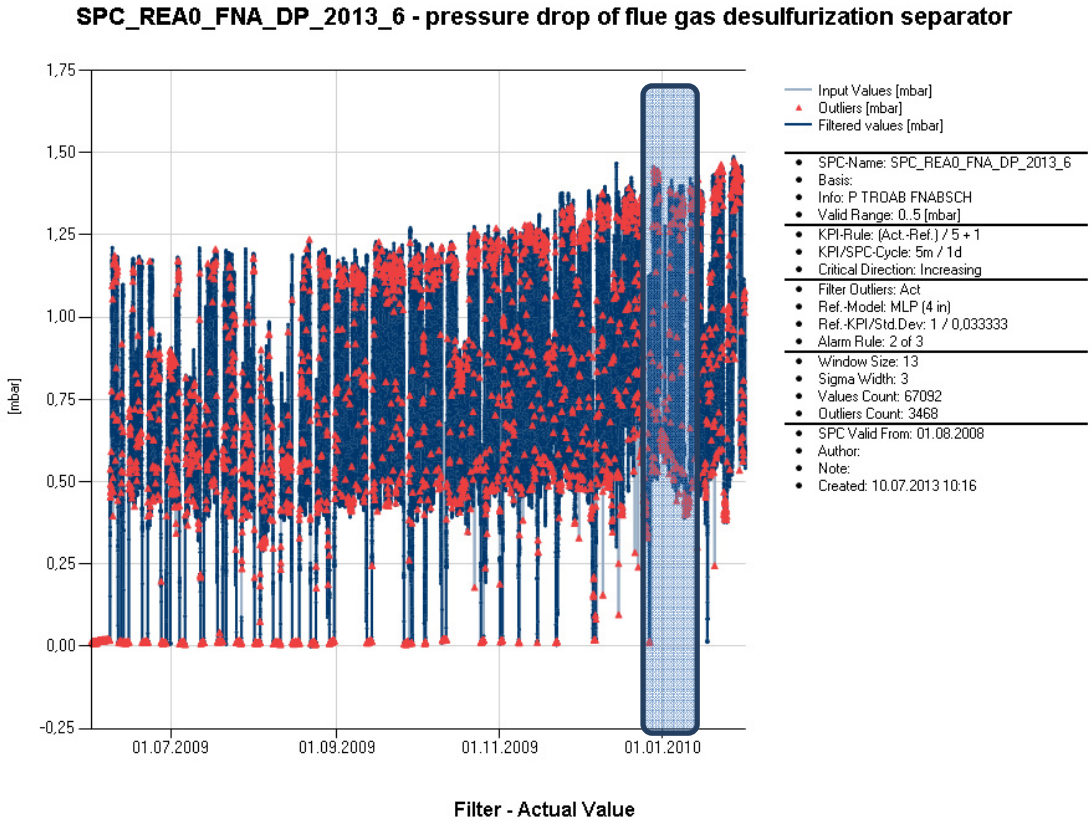

Fig. 6: Relevant data is prepared for further analysis

Fig. 6 shows the measured raw values for the pressure difference [mbar] as light blue lines, outliers as red triangles and the filtered values as dark blue lines. The area highlighted by theblue box will be analysed in more detail in Fig. 7.

Two different kinds of filters can be applied to focus on the relevant data:

1. Selection filter
2. Outlier filter

The selection filter defines which periods of time will not be evaluated. Times of unit shutdowns, extreme part-loads or - for a specific component - times when it was deactivated should not have an influence on a long-term statistical analysis. In SR::SPC, it is easy to define parameters to have the selection filter remove these time frames.

Additionally, the outlier filter identifies measured values which do not fit in with the other measurements in the context of the statistical analysis. For example, an O_2 measurement behind a coal-fired boiler might usually output 2-4 percent O_2 within the flue gas. In order to reduce fouling, that sensor is cleaned every few hours, and the content of O_2 might temporarily amount to 21 percent. This is a technically necessary process and should never lead to an alarm. To avoid misleading interference, the statistical outliers are discarded and will not be used for further evaluation. That approach helps to improve the quality of the analysis.

On a higher zoom level (Fig. 7) it is possible to verify the benefit of filtering outliers: all outliers were identified and only few non-outliers were eliminated. Due to the large amount of non-outliers, it does not do any harm to filter a few too many – as defined by the priority to avoid false alarms.

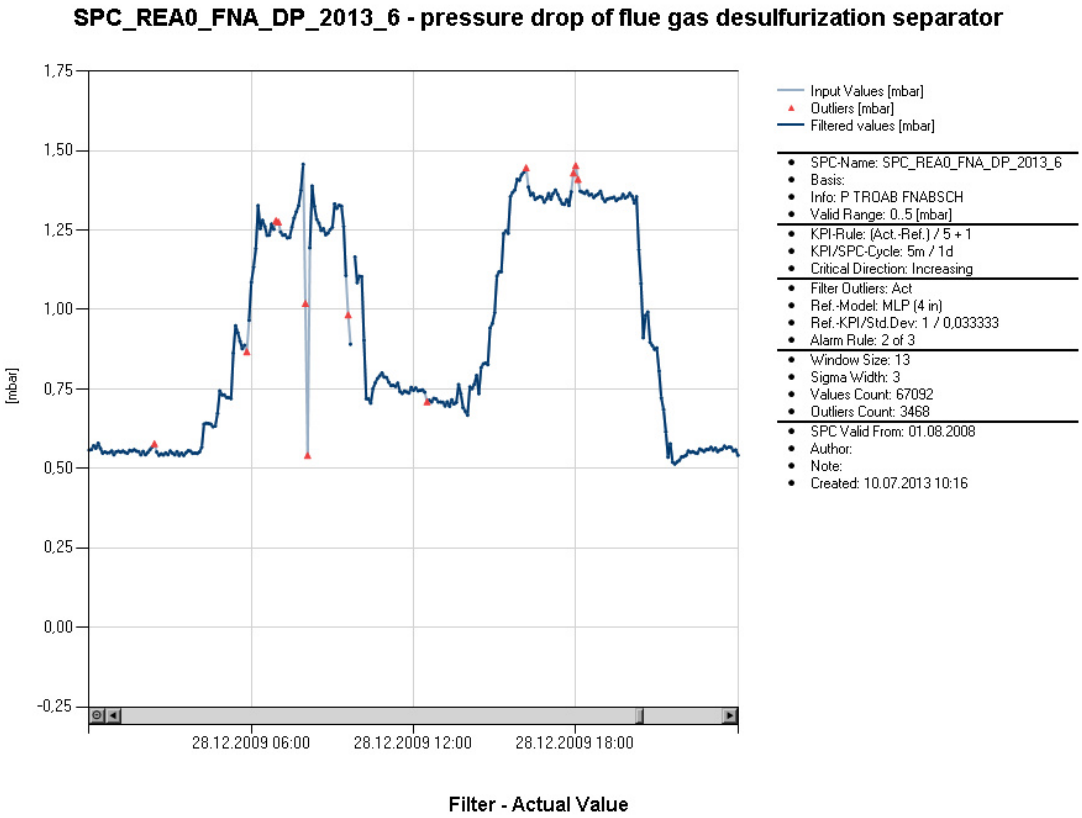

Fig. 7: Measured values, outliers and filtered values on a higher zoom level

For both filters the sensitivity can be configured according to the specific requirements by adjusting the parameters.

4.2 Comparison with a Reference Value / KPI

In plants, where base load scenarios with long periods of same output values prevail, experienced shift members can determine the quality of a measured value to some degree.

Additionally, there are other operators whose everyday business in their plant is defined by constant load changes. Therefore, these staff members experience a wide range of possible process values thus it is very hard to make an assessment which is true independently of the current load.

For both types of operators it makes sense to use a neutral point of reference in order to achieve the highest possible level of evaluation.

A good approach is to generate a reference value for the current load. This can be achieved by a physical approach (e.g. models according to the second law of thermodynamics) or based on operational data (e.g. neural networks).

There are different ways of combining the reference value and the actual value. The easiest way is a simple fraction (e.g. reference value / actual value); according to the specific requirements it is important to choose the appropriate way to link the values, while a division by zero etc. has to be avoided.

The goal is to calculate normalized Key Performance Indicators (KPI), i.e. independent of the current load, fuel quality and environmental conditions. An example can be seen in Fig. 8:

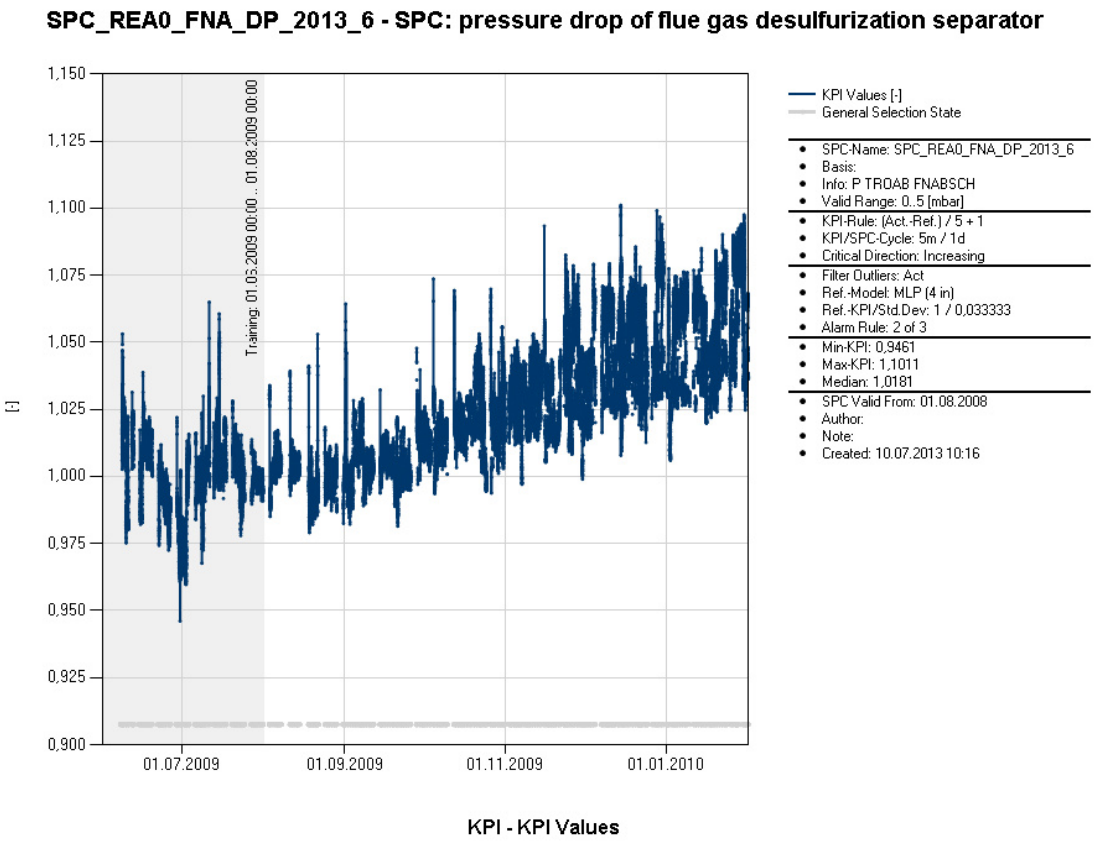

Fig. 8: SR::SPC creates normalized Key Performance Indicators

Please note that the vertical axis no longer represents millibars. Now, the vertical axis is dimensionless. As long as a measured value corresponds to the reference value, the KPI is close to one. Any changes can be spotted easily.

Compared to the data in Fig. 6 it is much easier for the operating staff to see long-term developments. But due to the numerous components on site it makes sense to run an automated analysis of the data.

4.3 Automated Analysis of the Data

To avoid false alarms, SR::SPC conducts different statistical evaluations of the KPIs. Measurements that report faulty data are identified, and statistically significant changes in the components are reliably detected.

The graph in Fig. 9 shows the KPI from Fig. 8 in an analyzed state.

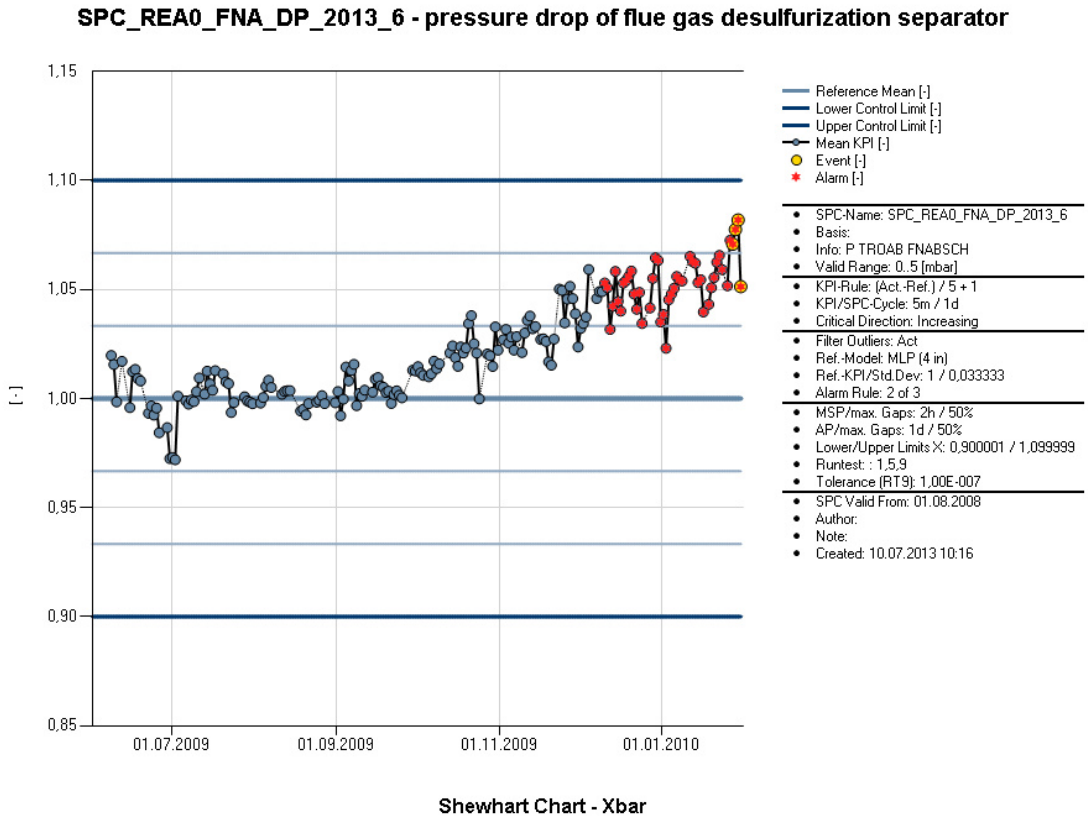

Fig. 9: SR::SPC uses means of statistical analysis to detect important changes automatically

According to the specific application for one KPI, different ways of analyzing the data can be used: first, statistical control charts (as shown in Fig. 4 and Fig. 9) can be applied. Secondly, additional statistical methods can analyze patterns and identify e.g. frozen measurements which otherwise would not raise any attention because often the last value was in between the alarm limits.

Different views and results are available and useful information can be sent via e-mail to the responsible employees automatically. It is also possible to output this information to the alarming function in the DCS.

4.4 Trend Detection and Prediction

To allow for a better quality of planning the work load, SR::SPC offers a prediction which, by extrapolation, forecasts the date when a limit (defined by the operating staff) will be reached. That makes sense for all long-term developments, e.g. air preheater fouling or worn off intake filters.

The trend detection and prediction has proven to be very helpful especially for recurrent measures (e.g. air preheater or filter cleaning), when a good knowledge of the upcoming jobs allows to carry out more tasks with own personnel and to reduce the amount of support by external companies.

In Fig. 10 the prediction of the latest date for a recurring measure was conducted and a planning time range of approximately six weeks was identified. This gives operating personnel the opportunity to make best use of planned shutdowns.

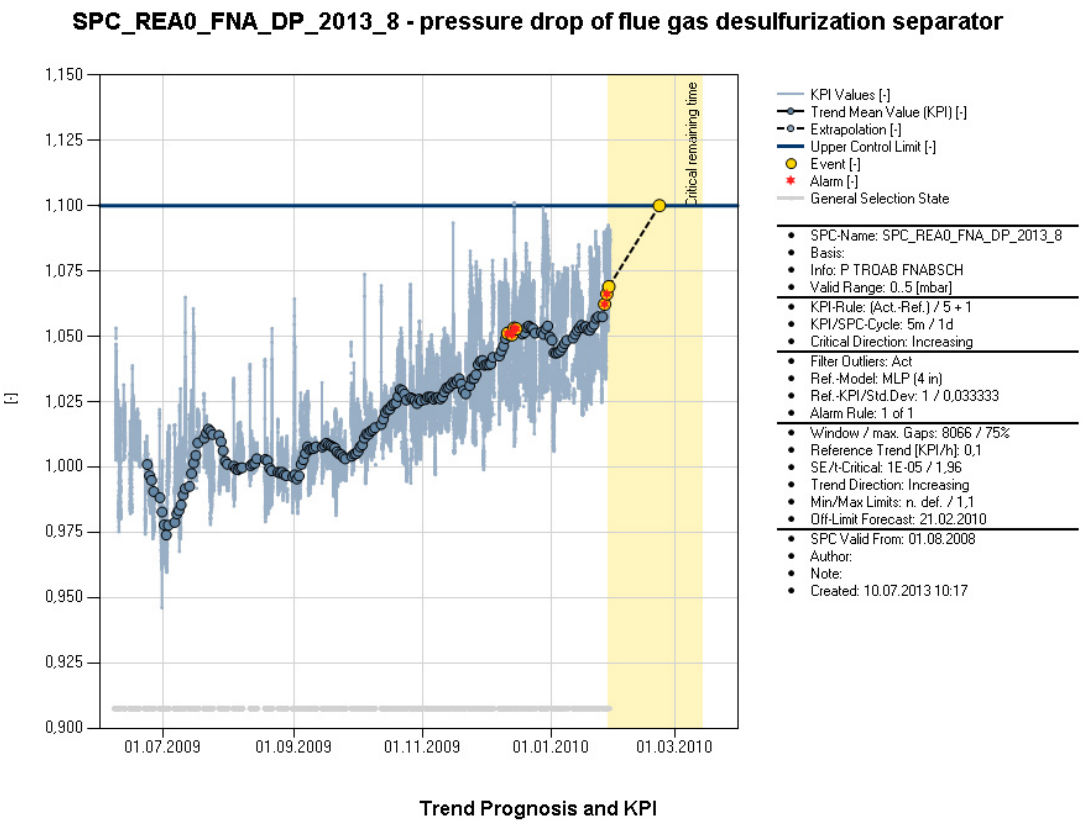

Fig. 10: SR::SPC detects trends and predicts the remaining time for reaction

5 Conclusion and Lookout

Modern DCS technology has brought plenty of advantages for power plant owners and operators. Tough market conditions, high demands with respect to operational safety and declining numbers of operating personnel, to mention only a few influences, have put high requirements on the staff.

5.1 Benefits and Scope of Application

Smart software systems can support the staff and ensure that the tremendous available possibilities can be used to prevent damages and efficiency leaks – promptly and even under hectic and stressful everyday working conditions.

Our experience has shown that the use of statistical methods is a highly efficient way of condensing operational data to reliable information on the condition of the components of the plant.

SR::SPC offers the opportunity to monitor different departments and production lines as well as several third-party systems in only one clearly laid out view. Without such a compiled view, often several different DCS, which are not interconnected, have to be used in parallel and it takes a lot of manual effort e.g. to compile reports for managerial or official purposes.

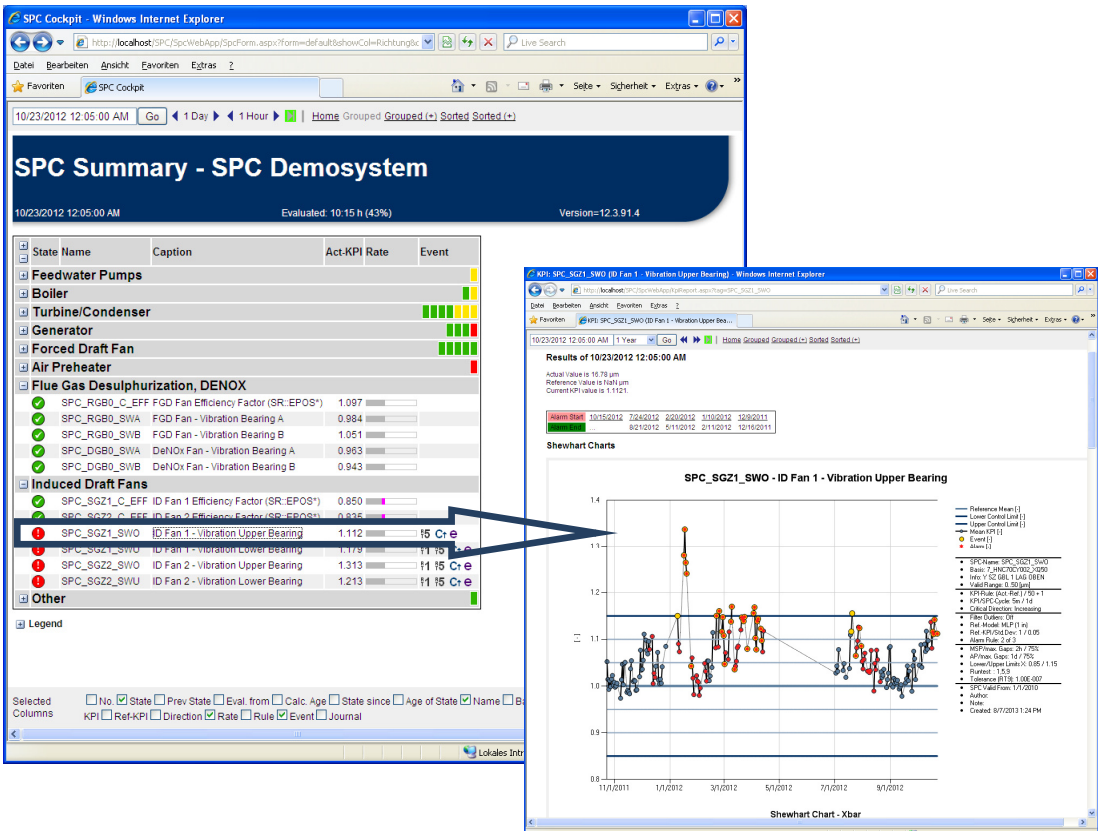

Fig. 11: SR::SPC Cockpit - all you need to know about the condition of your plant components at a glance (left), detailed reports are available by clicking on the respective KPI (right)

In Fig. 11 on the left hand side we see the plain traffic light color coding scheme, available in the internet browser (as far as user privileges are configured) and on the right hand side an example of the information sent automatically via e-mail in the case of a significant event.

5.2 Best-Practice Approach for Implementation

The best-practice approach is to start with the most important and tricky measurements or third party systems. Skilled project members from SES provide the customer with their experience from previous projects as well as in-depth knowledge of the software and the statistics it is based on.

In close cooperation with the experts from the customers' site, the first 10 to 20 KPIs are modeled and the system goes online.

After that first phase the experts from the customers' site obtain a one-day hands-on training and are able to service the system on their own and also to create new KPIs without any extra cost.

That way, the system is permanently enhanced, and after one year or two, some customers use SR::SPC to permanently monitor up to 150 KPIs, including KPIs for third-party systems.

5.3 Support from SES – Custom-Fit to meet the Customers' Requirements

How much the customer wants to do and can do on his own totally depends on him: as described above, the full maintenance and enhancement of the system can be done by the customer. What is more, STEAG Energy Services gladly offers a variety of support services ranging from a few hours of support per year to a full service which covers (remote access to the customers' server required):

- a regular analysis and interpretation of the customers SR::SPC system
- detailed evaluation
- contacting the customers' responsible persons on site by telephone or e-mail by the experts of SES to discuss the findings and possible causes.

If a customer wishes to make use of the full service, it is possible to have his system permanently monitored by trained ST professionals (process specialists, IT staff, and product specialists). A part of that central room can be seen in Fig.12.

Fig. 12: The central control room for STEAG power plants and customers' power plants for proactive monitoring of the systems

5.4 The Bottom Line

Finally, our internal and external customers' experience indicates that the saying "A small leak can sink a great ship" applies to modern power plants and industrial plants: to manage and master the new load and flexibility requirements, it is crucial to make use of all technical reasonable options as well as prevent unnecessary trouble, failures and downtimes.

The statistical approach and useful tools have been helping operators to maintain or extend their success.

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