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Definition and Verification of the Control Loop Performance for Different Power Plant Types

Market Analysis of Control Loop Performance Online-Monitoring Systems

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1 Introduction

There are several hundred control loops in each power plant. Performance of control loops directly affects the operability and profitability of power plants. To achieve optimum power plant performance, control loops should be operated as good as possible.

Control loops are tuned during initial commissioning. However, process characteristics change with time compared to original design. Power plant modifications, equipment wear, adding of new equipment, varying unit loads and operation modes contribute to degradation in the performance of control loops. As a result, performance of control loops deviates from its optimum. Poorly performing control loops can make a plant difficult to operate and may have several negative economic effects on power plant operation. In order to identify poorly performing control loops, control loop performance monitoring systems (CLPMSs) can be used.

A lot of control loop performance monitoring systems are actually available on the market. These systems automatically monitor control loops, identify and report which of these are performing poorly. The result of this assessment can be used by engineers to improve the critical control loops.

In this report, basic functions of control loop performance monitoring systems, some currently available control loop performance systems on the market and comparison of their features to the results of the VGB research project 331 are described. The information given in this report is based on the literature research, survey of vendors of monitoring systems and survey of operators who already use control loop performance monitoring systems in their power plants.

2 Basic Functions of CLPMSs

By means of control loop performance monitoring systems several hundred control loops are monitored at the same time. The monitoring can be performed online or offline. **Offline monitoring systems** analyze collected measurement data of a system not in real time but subsequently after data collection. **Online monitoring systems** analyze the measurement data in real time [9].

Online monitoring systems are suitable for the continuous monitoring of a system and the early detection of specification violations [9]. Operators who already use control loop performance monitoring systems in their power plants mentioned that the online evaluation of control loop performance doesn't take place synchronously. This means that such a system evaluates the performance of several control loops not at the same time, but one after another. Therefore, these systems cannot be used to identify relationships between different events in different control loops and to analyze these.

By means of offline monitoring systems by contrast, control loops are evaluated synchronously. Therefore, these systems are more suitable for the analysis of the measurement data as well as for the identification and analysis of relationships between different events in different control loops. However, the functionality of offline-monitoring systems is limited, since these don't provide any real time functions such as alarms, sending of e-mail in case of events, etc.

Control loop performance monitoring systems vary in the range of analysis they perform, their presentation of results, reporting features and data collection methods. However, all these systems have some similar basic functions that are shown in Figure 1 [3].

These systems provide the information about the operation of control loops on the basis of standard control loop signals such as manipulated variable, controlled variable and set point as well as some additional signals (e.g. control loop is in automatic or in manual mode) [4]. Therefore, one of the basic functions of control loop performance monitoring systems is the **collection of measurement data**. The method of data collection and the quality of collected measurement data have an essential influence on the results of control loop performance evaluation [7].

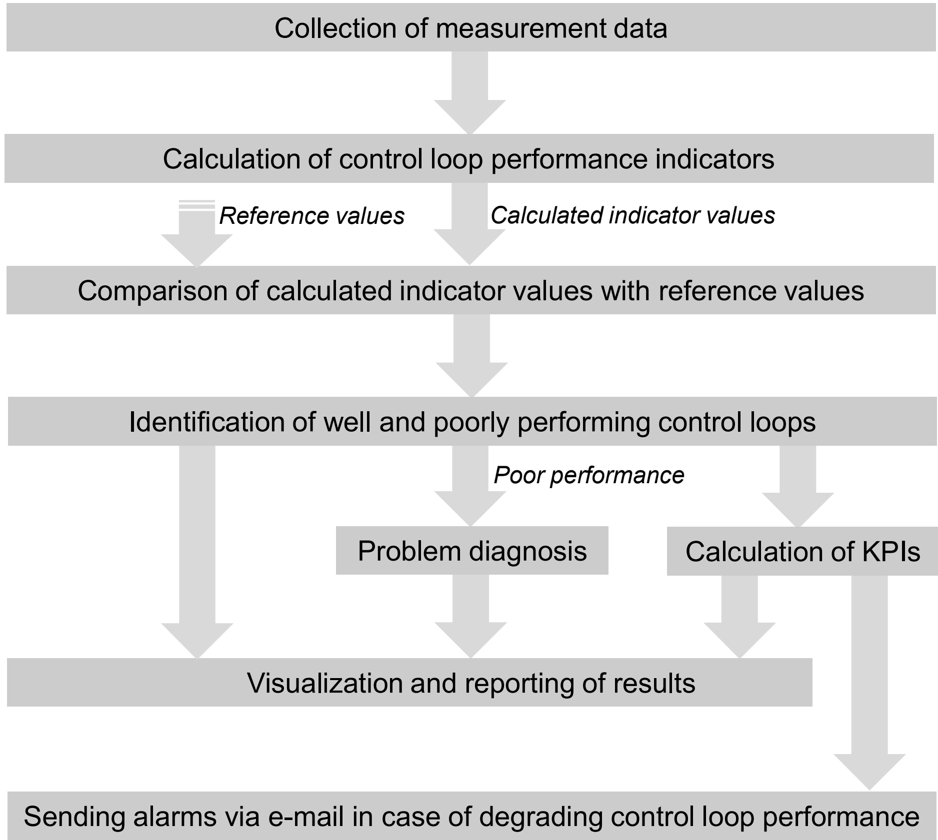

Figure 1: Basic functions of control loop performance monitoring systems

Different control loop performance indicators are used to quantify the performance of control loops. Exemplary **control loop performance indicators** are [3], [6]:

- Percentage of time the control loop is in automatic or in manual mode,
- Percentage of time the controller output is at its limits,
- Mean value of controller output,
- Tendency of control loop to oscillate,
- Standard deviation in error,
- Cumulative control valve travel per day,
- Number of direction changes in control valve travel per day,
- Number of process alarms generated by control loop and its associated process,
- Maximum deviation from set point,
- Noise of measurement data,
- Number of operator interventions,
- Number of alarms.

These indicators are not described in detail in this report, since their algorithms are not publicly available.

According to the statements made by operators who already use control loop performance monitoring systems in their power plants, the user can not configure individual control loop performance indicators in these systems.

Calculated values of control loop performance indicators can be compared to a threshold of proper control loop performance. The threshold of proper control loop performance is defined by engineers when a control loop is considered to be performing well. If violation of this threshold occurs during operation, the control loop is flagged as having bad performance. Hence, the assessment of control loop performance is based on the **comparison of calculated indicator values with their reference values**.

In the next step, calculated values of single indicators are combined to the **overall performance index** representing the total performance of a control loop. The total performance of a control loop is classified at least into two groups: good and bad. In this way proper and poor performing control loops are identified. **Proper performing control loops** require no further attention. **Poor performing control loops** should be investigated and improved [3].

Evaluation results of control loop performance are visualized in an intuitive way in the user interface of a control loop performance monitoring system. The **visualization of results** can take place in different ways, e.g. these can be visualized in form of a TreeMap as shown in Figure 2. In this example, control loop performance evaluation results of two power plant units “Rodenhuize” and “Ruien 3” are represented. Individual control loops of these power plant units are shown in form of quadrangles. The more important a control loop is the bigger is the quadrangle. The importance of control loops is user defined. Important control loops that are working poorly should be optimized first. Proper and poorly performing control loops can be identified by the colour of a quadrangle: proper performing control loops are represented in green colour and poorly performing control loops in red colour. White quadrangles represent control loops with medium performance.

Besides, the evaluation results can be visualized as a weekly or a monthly report in form of a bar graph as shown in Figure 3. This kind of visualization can be used to compare the evaluation results before and after control optimization or the evaluation results of different weeks/months with each other.

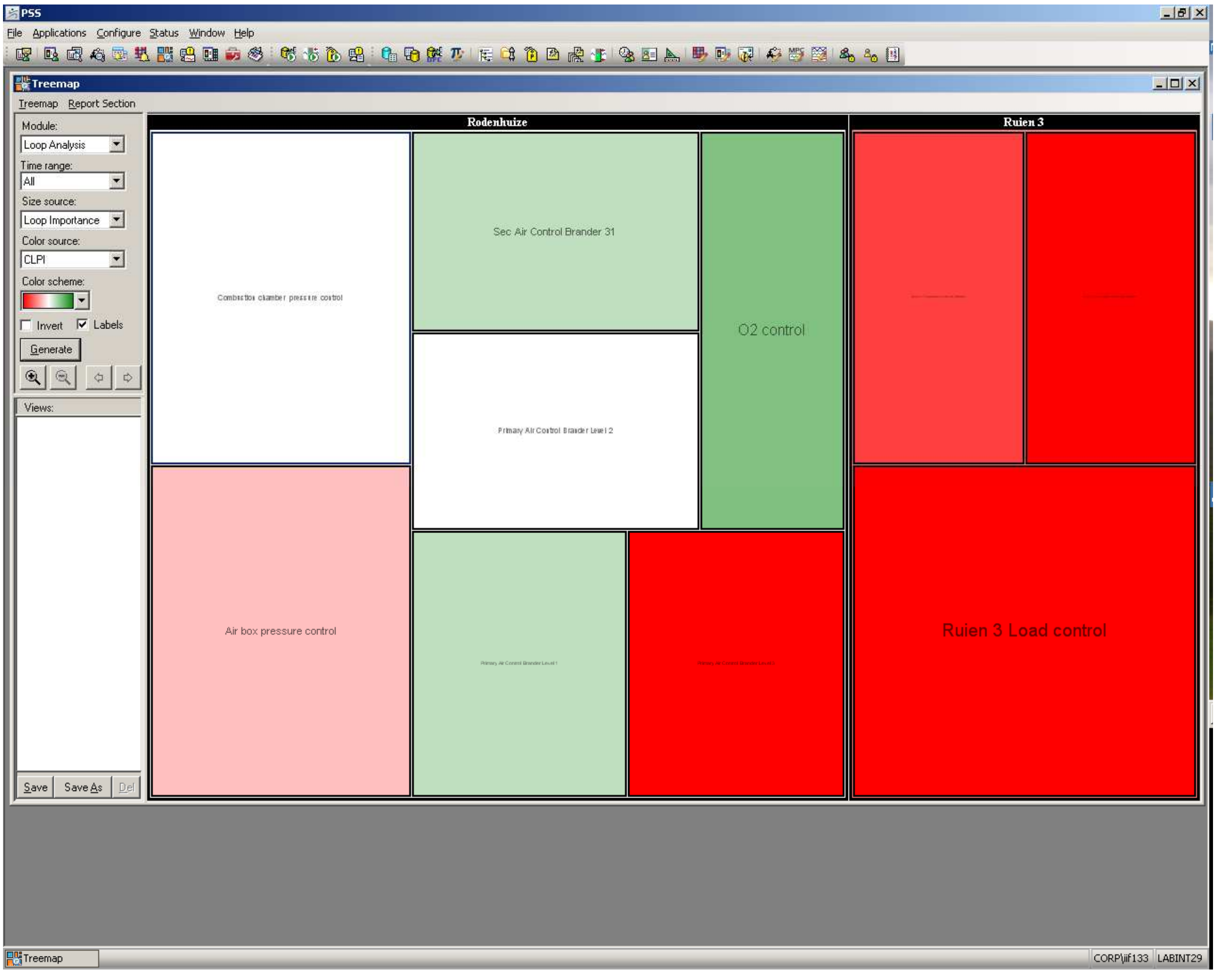

Figure 2: Visualization of evaluated control loop performance in form of a TreeMap (PSS) [3]

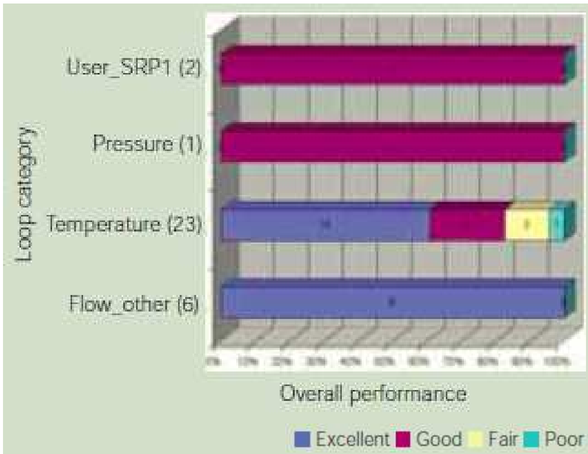

Figure 3: Visualization of evaluated control loop performance (LPM) [1]

Since each control loop under analysis can have different conditions, the assessment of control loops is condition-based. The **condition-based assessment** includes for example the information whether a control loop is in automatic or in manual mode, the percentage of time the controller output is at its limits, tendency of control loop to oscillate, etc. According to [2], [5], the most obvious and serious control loop problem is regular or persistent oscillations. Such behavior of control loops may have different reasons. Control loop performance monitoring systems provide a **problem diagnosis** of poor performing control loops. Examples for diagnosis given by a control loop performance monitoring system are:

- Oscillating due to aggressive tuning,
- Oscillating due to valve stiction,
- Controller output runs into limits,
- Sluggish tuning.

Moreover, some control loop performance monitoring systems provide **economic assessment**. Each control loop under analysis can be evaluated by means of indicators that are associated with economic factors or maintenance factors (e.g. after 1000 control valve operations its replacement is required).

The problem diagnosis can be visualized in user interface as shown in Figure 4. In this example, the left pane of the Loop Analysis Window allows viewing of different power plant units or groups of power plant units. As the power plant unit is selected, loop analysis of its control loops is given in the Loop Analysis List. This Loop Analysis List includes the name, importance, overall performance index, problem diagnosis, etc. of each control loop (see Figure 4).

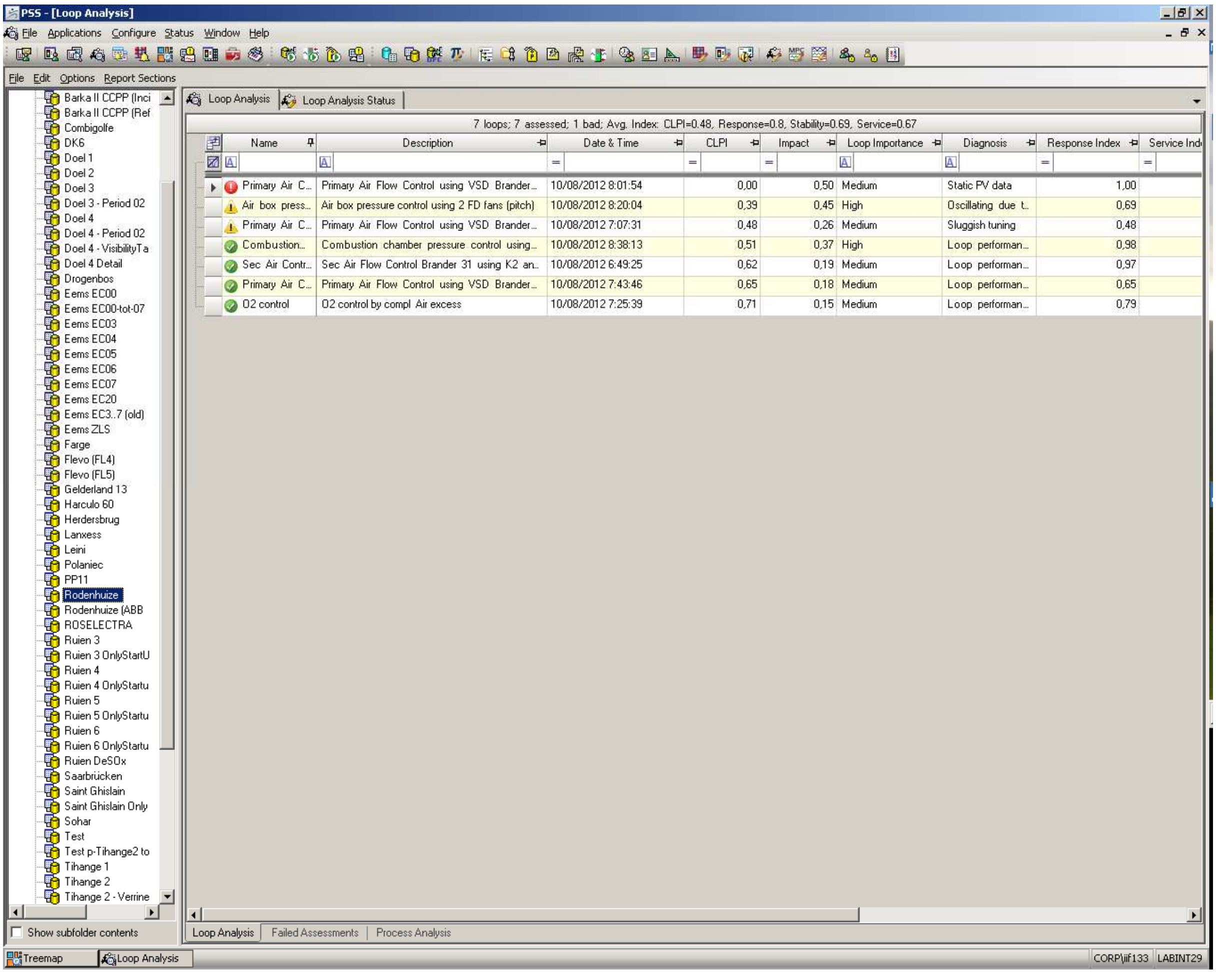

Figure 4: Visualization of problem diagnosis (PSS)

Control loop performance monitoring systems provide information not only about individual control loops, but also aggregated control loop performance indicators such as for example:

- The number of control loops in manual
- The number of oscillating control loops,
- The average performance index of all control loops.

Key Peformance Indicators (KPIs) can be used to represent these aggregated control loop performance indicators. KPIs can be visualized in the user interface of the control loop performance monitoring system in different ways (see Figure 5, Figure 6 and Figure 7).

Once KPIs are defined they are displayed in the Metrics Window (see Figure 5). The left pane of the Metrics Window allows viewing of all existing KPIs and KPI groups. In Figure 5 there are two KPI groups and multiple KPIs in each group. As the check boxes next to each KPI are selected, details for each KPI are displayed in the KPI Details Table and the KPI trends over time are displayed in a chart (see Figure 5). Icons next to each KPI in the KPI list indicate the KPI status as shown in Table 1.

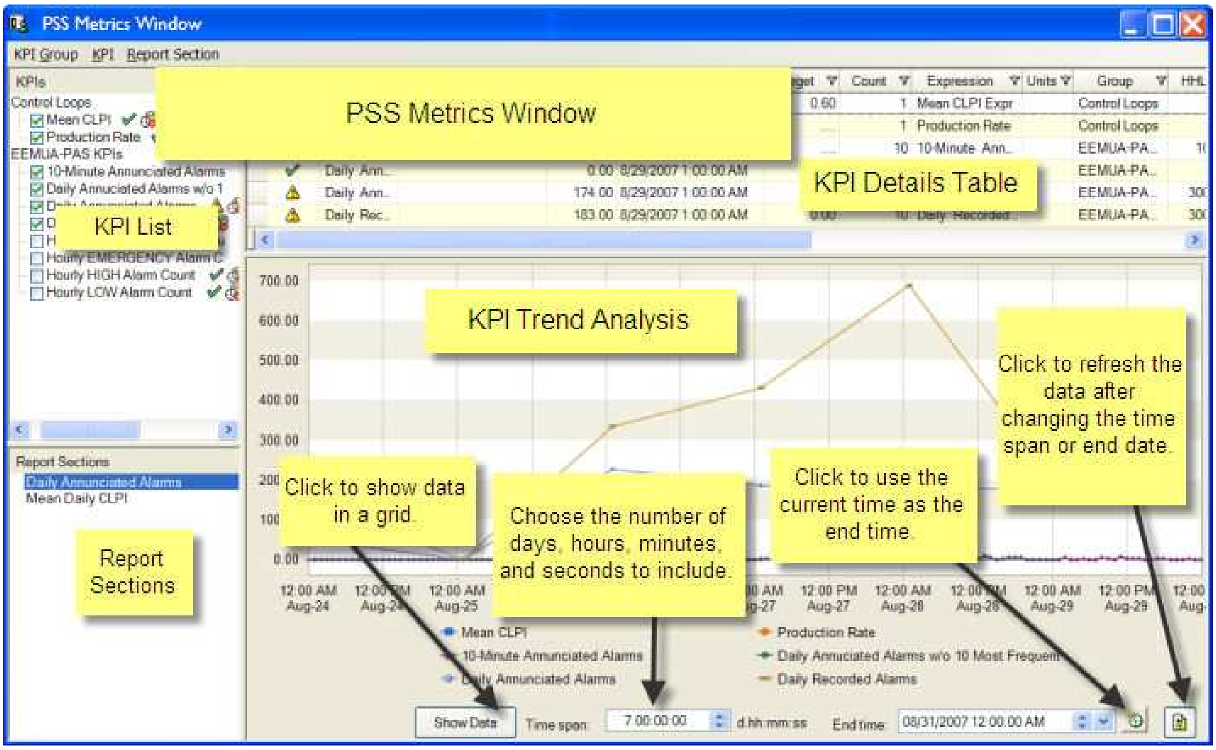

Figure 5: Individual parts of module for viewing KPIs (PSS)

Icon	KPI Status
	Scheduled execution of the KPI has been enabled.
	The KPI schedule is inactive.
	The KPI value is within the Target range.
	The KPI value is either in the High Limit or Low Limit range.
	The KPI value is either in the High-high Limit or Low-Low Limit range.

Table 1: Icons representing the status of KPIs

One or more KPIs can be selected in the KPI list for trending in the KPI Trend Analysis chart (see Figure 6). Each KPI selected from the KPI list is displayed as one line in the chart. This allows viewing of the KPI values over specified period of time. The Time span box and the End time box can be changed to show data from a different time period (see Figure 6).

Figure 6: Module for viewing KPIs (PSS)

Each KPI selected from the KPI list can be displayed in form of a bar graph over specified period of time (see Figure 7). For this representation, the target value of the selected KPI is defined and indicated by the green line (see Figure 7). Additionally, two further limits are defined (see Figure 7):

- High and low limits of the KPI, which are pictured with yellow lines and
- High-high and low-low limits of the KPI, which are pictured with red lines.

As long as the KPI value is within the target range, its bar is green. Green colour of a bar represents a good value of the selected KPI. As soon as the KPI value crosses the high limit or the low limit range, its bar is yellow. Yellow colour symbolizes a medium value of the KPI. As soon as the KPI value crosses the high-high limit or the low-low limit range, its bar is red (see Figure 7). Red colour symbolizes a bad value of the KPI.

Some control loop performance monitoring systems provide the automatically sending of alarms via e-mail to the responsible person, in case of degrading control loop performance (e.g. a KPI is not within the predefined limits).

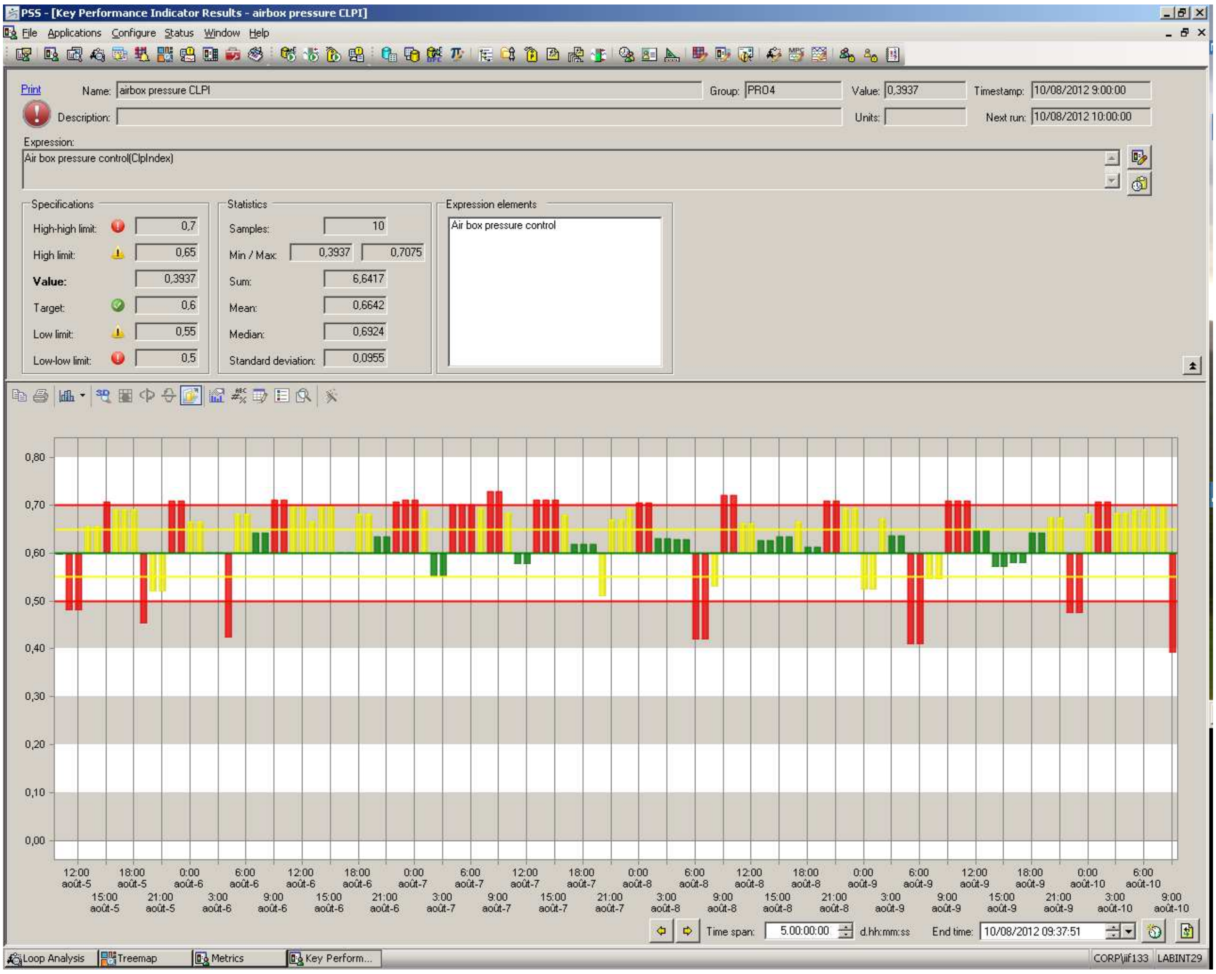

Figure 7: KPI in form of a bar chart (PSS)

3 Procedure for the first Application of CLPMSs

Control loop performance monitoring systems are available as online or offline tools and can normally be used independent from I&C-System installed in a power plant [7]. These systems consist of several components. To use such a system in a power plant it is necessary to install its different components in the first step (see Figure 8). After that all distributed components are to be connected and configured. According to the experience of the operators, who already use control loop performance monitoring systems in their power plants, these systems are sold as ‘plug and play’ products, but a solid effort is necessary for their installation and configuration. For the configuration [3], [7]:

- A database of control loops must be obtained and loaded into the software’s own database.
- Additionally to a list of control loops, the data connection points for the control loop’s set point, process variable, controller output, mode and PID-settings are needed.
- Additionally information such as the desired settling time, control objective, control strategy, type of process, etc. can be also needed.

It is preferable to load a database of control loops and to configure a control loop performance monitoring system automatically. Non-automatic system configuration can be difficult and error-prone. Incorrect configuration can lead to evaluation mistakes such as e.g. missing poor performance or false reporting of results [3].

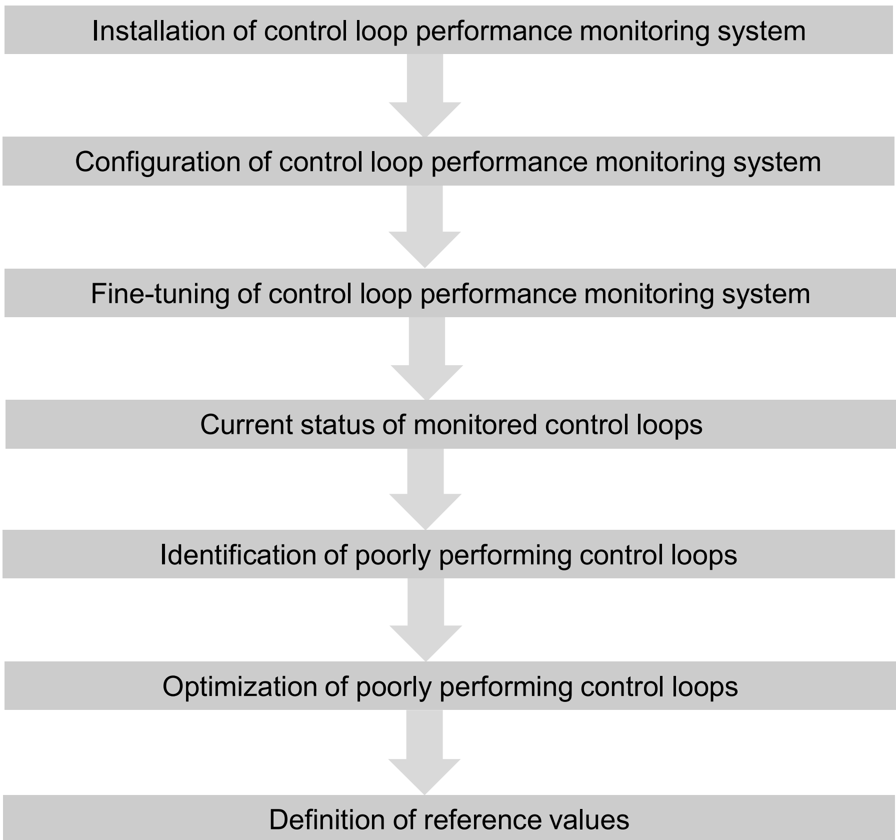

Figure 8: Procedure for the first application of a control loop performance monitoring system in a power plant and definition of reference values

After installation and configuration of control loop performance monitoring system, an overview of current status of all monitored control loops is given and poorly performing control loops can be identified. After the identification of poorly performing control loops their tuning and optimization must be executed. Once a control loop has been optimized and its performance is considered to be good, reference values for the evaluation of its performance can be defined. It is to be mentioned that control loop performance monitoring systems as a rule treat all control loops as single PID control loops. Some control loop performance monitoring systems provide a possibility to use the cascade control structure (e.g. PSS). Feed forward and other advanced control structures are not specially considered [3].

4 CLPMSs Available on the Market

The chemical, petro-chemical, pulp and paper industries were the first to apply control loop performance monitoring systems. More recently, there have been successful applications in power plants [2]. A lot of control loop performance monitoring systems from different vendors are currently available at the market. Exemplary control loop performance monitoring systems are:

- Loop Performance Manager - ABB,
- PID watch - AspenTech,
- SmartProcess™ LoopMetrics - Emerson,
- Loop Scout - Honeywell,
- Control Monitor - Control Arts,
- INTUNE+ - ControlSoft,
- Control Performance Monitor – Matricon,
- PlantState Suite (PSS) Alarm Management – Plant Automation Services (PAS).

On the basis of literature research and survey of CLPMSs' vendors, the following exemplary control loop performance monitoring systems were studied in detail in this research project:

- Loop Performance Manager - ABB,
- Smart Process™ LoopMetrics - Emerson,
- PlantState Suite Alarm Management - PAS.

A short overview on these systems is given in the following subchapters.

4.1 Loop Performance Manager (ABB)

Loop Performance Manager (LPM) is an offline-tool that is successfully used in several power plants. LPM provides following components for the analysis of control loop performance [10], [11]:

- Loop Tuning Tool,
- Loop Auditing Tool,
- Plant-wide Disturbance Analysis.

The first stage of **Loop Tuning Tool** is data collection. In the next step, the optimization algorithm computes the best control loop tuning parameters. After LPM has calculated the first set of tuning parameters, the user may fine-tune the results by adjusting the specifications using slider bars in the user interface.

Once control loops are well tuned, the objective is to monitor them and to maintain them at the optimum performance. For this **Loop Auditing Tool** is used. The functions of Loop Auditing are [10]:

- Periodic data collection for monitored loops,
- Calculation of control loop performance indicators,
- Archiving of evaluation results,
- Problem diagnosis.

Loop auditing begins with daily periodic data collection that operates in the background for up to 250 control loops per LPM server. After data collection is complete, the control loop performance indicators are computed and stored in the auditing data base. The audit reporting function generates configurable reports and then outputs the data as spreadsheet or HTML files on weekly and monthly basis. The reports contain quantitative information in form of calculated values of control loop performance indicators and qualitative information. The qualitative information includes problem diagnosis such as e.g. sluggish tuning, valve stiction and loop oscillation. Using the collected data, the user can create plots of indicators or on-demand reports. The reports enable the maintenance team to focus on the most important process control problems.

Plant-wide Disturbance Analysis gives the possibility to analyse collected measurement data, automatically detects available oscillations and helps to identify the localization of their root cause [5], [11].

4.2 Smart Process™ LoopMetrics (Emerson)

Smart Process™ LoopMetrics (Emerson) is an online-tool and can analyze control loop performance around the clock. It can be used nearly with any I&C-System installed in a power plant. This system is used successfully in several power plants. The features of Loop Metrics are [12]:

- PID Loop Tuning,
- Performance Monitoring,
- Diagnostics and assessment,
- Real-time event notification,
- Key performance indicator trending,
- Web-based performance reporting.

PID Loop Tuning computes the best control loop tuning parameters. The advisory adaptive tuning feature is designed for continuous background operation. It detects and logs abnormal process characteristics, such as controller output saturation, sluggish response to process changes or persistent oscillations.

During **Performance Monitoring** 80 available standard control loop performance indicators can continuously analyze each control loop through real-time moving window analysis and condition-based assessments. Condition-based assessment guarantees that only the right information is used in the analysis and the real-time moving window ensure that the analysis is based on the latest information.

Diagnostics and assessment include:

- Identification of poorly performing control loops,
- Comparison of current performance with reference values,
- Problem diagnosis with differentiation between hardware and tuning problems,
- Calculations of the economic impact of poor performance,
- Definition of key performance indicators (KPIs).

Real-time event notification automatically records an event (e.g. degrading plant performance or diminishing control loop health) and sends it via e-mail to the operator.

KPIs trending tool provides real-time tracking of plant and process KPIs.

Web-based performance reporting tool documents control loop performance, control loop health assessment and diagnosis, tuning, simulations, system configuration and communication status.

4.3 PlantState Suite Alarm Management (PAS)

PlantState Suite (PSS) Alarm Management is an online-tool and can be used nearly with any I&C-System installed in a power plant. PSS can be also used in offline modus but then with limited functionality, since in offline modus it doesn't provide any real time functions such as alarms, sending of e-mail in case of events, etc.

PSS is used successfully in several power plants. This system facilitates event analysis, documentation, rationalization, auditing and dynamic alarm management. It provides detailed analysis of real-time alarming including suppression of alarm floods, state-based alarming, alarm configuration and auditing [13]. The tools of PSS and their briefly description are shown in Figure 9.

Figure 9: Tools of PlantState Suite (PSS) Alarm Management

PSS provides automatically tuning of control loops and evaluation of control loop performance, by means of the tools TuneWizard and ControlWizard. This software includes all basic functions that are described in chapter 2.

According to the survey of the operators who already use PSS in their power plants, three KPIs are calculated by means of this system:

- The stability index,
- The response index and
- The service index.

The stability index represents the oscillation behavior of a control loop. For its calculation the process variable and the set point are concerned. The stability index of 0 indicates a pure sine wave, while 1 indicates random noise. Within the stability index calculation, PSS also determine the oscillation period, which can help to isolate the oscillation source during a deeper analysis.

The response index is calculated as a function of the difference between the settling time of the measurement data of a control loop and the desired settling time specified in the assessment properties section for this control loop.

The service index is based on the composition of the following control loop performance indicators:

- Noise of measurement data,
- Standard deviation in error,
- Alarm frequency,
- Number of operator interventions,
- Percentage of time the control loop spends in manual,
- Percentage of time the controller output is at its limits.

The control loop performance evaluation results are represented in the user interface of PSS in tabular and graphical format (see Figure 2, Figure 4 and Figure 6). Users may look into details of individual control loop performance, including time trends, statistical analysis, time-series analysis and correlation analysis [13].

Operators who already use PSS in their power plants mentioned that, the online evaluation of control loop performance by means of this system doesn’t take place synchronously. This means that, PSS evaluates the performance of several control loops not at the same time, but one after another. Evaluation results that can be seen at the user interface e.g. in form of a TreeMap represent the last evaluated performance of control loops. Operators also mentioned that, the offline evaluation of control loop performance by means of this system takes place synchronously.

5 Comparison of Analysed Information to the Results of the VGB Research Project 331

In this chapter features of control loop performance monitoring systems are compared to the methodology that was developed in the VGB research project 331 relating to such aspects as aim, procedure of control loop performance evaluation, distinction between different operation modes and unit loads, comparison of control loop performance of different power plants etc.

- *Aim*

On the basis of studied control loop performance monitoring systems, it can be observed that control loop performance monitoring systems monitor the performance of hundreds or thousands of control loops and are aimed to identify poorly performing control loops in a power plant. The signs of poor performance are frequent alarms, large number of operator intervention, manual control loop operation mode, controller output at its limits, etc. Therefore, the control loop performance evaluation by means of control loop performance monitoring systems is strongly focused on status of a control loop.

The methodology that was developed in the VGB research project 331 was aimed to assess how good is the performance of five most important control loops in a power plant. These control loops have a decisive influence on the economic efficiency of the power plant operation. These control loops were studied in detail and it was shown what influence their performance has on power plant efficiency, on the lifetime of thick-walled components and on the economic efficiency of the power plant operation. On the basis of these investigations meaningful control loop performance indicators were defined. Defined control loop performance indicators were classified depending on the control loop and requirements thereon. The control loop performance evaluation by means of this methodology is based on the calculation of these indicators. The results of the data evaluation are quantitative statements about how good is the control loop performance. Therefore, the methodology that was developed in the VGB research project 331 is aimed to assess how good is the performance of five most important control loops in a power plant.

- *Procedure of control loop performance evaluation*

The evaluation of control loop performance by means of control loop performance monitoring systems is based on the comparison of calculated indicator values with their reference values. Firstly, these reference values are defined by an engineer, when a control loop is considered to be performing well. Since, the definition of reference values is based only on a subjective opinion of a control engineer, it can be considered as a subjective definition. Secondly, the user gets as a result a qualitative statement whether the control loop performance is excellent, good or poor.

By means of the methodology that was developed in the VGB research project 331 the values of meaningful indicators are calculated. As a result the user gets a quantitative statement about how good is the control loop performance.

- *Distinction between different operation modes and units loads*

Control loop performance varies with unit load and operation mode. Due to this fact it is meaningful to distinguish between different operation modes and unit loads when defining control loop performance.

In control loop performance monitoring systems it is distinguished between three operation modes: start-up, shut down and ‘normal’.

In the VGB research project 331 such operation modes as start-up and shut down were not considered. However, concerning ‘normal’ operation it was distinguished between further operation modes such as:

- steady-state operation,
- frequency control operation,
- positive load changes,
- negative load changes, etc.

Besides, it was distinguished between different unit loads such as:

- full load operation,
- part load operation,
- low load operation.

Moreover, it was distinguished between different sizes of load changes and the range in which these take place (e.g. load change form full load to part load or full load to low load).

In the VGB research project 331 it was shown that control loop performance is different during different unit loads and operation modes and control loop performance indicators have different importance during different operating conditions [8]. Due to this fact, it is not enough to distinguish only between start-up, shut down and ‘normal’ operation modes in control loop performance monitoring systems, when defining and analysing control loop performance of a power plant. It is necessary to distinguish between operation modes and unit loads mentioned above in order to evaluate the control loop performance accurately and correctly.

Moreover, reference values for the control loop performance evaluation should be also defined depending on unit load and operation mode, because it is not meaningful to compare indicator values that were calculated during part load operation with reference values that were defined during full load operation.

However, control loop performance monitoring systems show control loop performance evaluation results for the latest data without distinction between different unit loads and operation modes. Due to this fact, it is not possible to compare control loop performance of a power plant during different unit loads and operation modes with each other by means of control loop performance monitoring systems. To make it possible, filtering and sorting of measurement data on unit load and operation mode should be done for the evaluation of control loop performance in power plants. Besides, reference values are to be defined depending on unit load and operation mode.

- *Comparison of control loop performance of different power plants*

Since, reference values defined in control loop performance monitoring systems are as a rule different in different power plants, it is difficult to compare the control loop performance of different power plants with each other. To enable this comparison, reference values are to be the same for all considered power plants.

- *Before-after comparison of control loop performance in a power plant after control optimization*

Reference values defined in control loop performance monitoring systems are as a rule the same before and after control optimization. Therefore, it is possible to compare the control loop performance evaluation results before and after optimization with each other.

The features of control loop performance monitoring systems that are based on analysed information are summarized in Table 2.

Features	Methodology that was developed in the VGB research project 331	Control Loop Performance Monitoring Systems
Number of control loops	5	>200
More than one control loop performance indicator	✓	✓
Different indicators have different importance during different unit loads and operation modes	✓	–
Evaluation of control loop performance by comparison of current indicator values with reference values	–	✓
Definition of reference values depending on unit load and operation mode	No reference values	–
Comparison of control loop performance during different unit loads and operation modes	✓	–[1]
Before-after comparison of control loop performance in a power plant after control optimization	✓	✓
Comparison of control loop performance of different power plants	✓	–[2]

✓ Available feature

– Not available feature

Table 2: Features of control loop performance monitoring systems

[1]To make it possible, reference values are to be defined depending on unit load and operation mode and control loop performance is to be evaluated depending on unit load and operation mode.

[2]To make it possible, reference values are to be the same for all considered power plants.

6 Summary

Well-configured control loop performance monitoring systems can provide users with useful information about poorly performing control loops and diagnosis why the performance is poor. Sluggish tuning, oscillations and controller output running into limits are examples of diagnosis given by a control loop performance monitoring system.

Besides, these systems can provide steps for validating the diagnosis and resolving the problem. Moreover, documentation of control loop performance and appropriate controller tuning settings can be used to see the effect of tuning changes on the control loop performance. Furthermore, it is possible to compare the control loop performance in a power plant before and after control optimization by means of these systems.

The results of control loop performance evaluation are visualized in user interface in a user-friendly way. The overview on performance improvement of all control loops is represented by KPIs. The success of control loop performance optimization is shown by single control loop performance indicators.

Hence, control loop performance monitoring systems help power plant’s employees and save them time.

By the evaluation of control loop performance it is important to distinguish between important and less important control loops. Important control loops that are working poorly should be considered first. Therefore, it is important for every control loop performance system to have a prioritizing tool.

Control loop performance monitoring systems treat as a rule all control loops as single PID control loops. Some control loop performance monitoring systems provide a possibility to use cascade control structure (e.g. PSS). Feed forward and other advanced control structures are not considered separately. This, bad data quality and incorrect configuration of control loop performance monitoring systems can lead to incorrect control loop performance evaluation and problem diagnosis.

Control loop performance monitoring systems show control loop performance evaluation results for the latest data without distinction between different unit loads and operation modes. This means, that reference values are defined and control loop performance is evaluated without distinction between different unit loads and operation modes. Due to this fact, it is not possible to compare the evaluation results of control loop performance in a power plant during different unit loads and operation modes.

Since, reference values are as a rule different in different power plants, it is difficult to compare the control loop performance evaluation results of different power plants with each other.

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