Control Loop Performance Monitoring in a Power Plant

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Abstract

Several control loop performance monitoring (CLPM) software products have become commercially available over the last decade. These products automatically and continuously monitor the performance of control loops. The software potentially identifies several aspects of poor control and generates a list of problem loops with diagnoses of the individual problems so that they can be attended to. Testing of CLPM software in a power plant has not been done formally, or at least has not been documented in a publicly accessible manner. It has therefore been unclear to what degree CLPM software would work and be beneficial to power plants. To address this uncertainty, Southern Company and EPRI launched a joint project to test one version of control loop monitoring software in a power plant; evaluating its capabilities and benefits. This paper describes the project, technology, and findings of the evaluation team.

Introduction

Control system dynamic performance is a critical determinant of a plant's performance and one that is often difficult to assess [1]. Power plant control systems must be performing well to obtain maximum performance, reliability, regulatory compliance, and safety from the plant. Poorly performing controls can cause operational difficulties that could have several costly side-effects including boiler oscillations, increased heat rate, accelerated equipment wear, increased emissions, slower load ramp rates, reduced generation capacity, steam temperature excursions, and unit trips following upsets.

To maintain optimum plant performance, control loop performance should always be kept at the highest possible level. This can be achieved only by monitoring loop performance and taking the appropriate corrective actions when poor performance is detected. However, the diagnosis and resolution of these problems are difficult, particularly in large and complex process facilities, like power plants.

CLPM products are said to mitigate this problem by automatically and continuously monitoring the performance of hundreds or thousands of control loops. The software potentially identifies several aspects of poor control and generates a list of problem loops with diagnoses of the individual problems so that these can be prioritized and corrected.

Testing of control loop performance monitoring software in a power plant has not been done formally, or at least has not been documented in a publicly accessible manner. It has therefore been unclear to what degree loop monitoring software would work and be beneficial to power plants. To address this uncertainty, Southern Company and EPRI launched a joint project to test one version of control loop monitoring software in a power plant; evaluating its capabilities and benefits. The software would be critically reviewed, to answer at least the following questions:

- Does the software work in the power plant's nonlinear and interactive control environment?
- Are the results accurate?
- Will it benefit a power plant, and how?
- Is it easy to use – can the intended users use it and understand the results it produces?
- Are there shortcomings and are they show-stoppers?

Background

Southern Company has done two other trials on control loop performance assessment solutions before embarking on this project. The first trial was completed around 2007 and used commercially available software. The second trial was completed around 2008 and used internally-developed algorithms. In both cases, the results were less than satisfactory due to a number of factors.

In both of the previous trials, the process data for the analyses was obtained from the process historian. The data was compressed data, sampled at ten-second intervals. The performance assessments were not accurate in many cases with the primary contributor determined to be data compression and relatively slow sampling rate. Another problem, which was associated with the commercially developed software, was that the software was developed to run on a single machine and the vendor had difficulty adapting it to the desired web browser (client-server) interface environment.

In 2009, Southern Company approached EPRI to collaborate on a third trial, also using commercial, externally-developed software. Alabama Power's Plant Gaston, located near Birmingham, Alabama, was selected as the pilot site for testing the technology. PAS' Loop Analysis software was believed to be reasonably representative of commercially available loop performance software and was considered sufficient for testing this type of technology in a power plant.

CLPM Software

Software Vendors

The loop monitoring solutions are available from DCS (distributed control system) vendors and 3rd-party software companies. The vendors and their products include:

- ABB – Loop Performance Manager
- AspenTech – PID Watch
- Capstone Technology – Control Loop Performance
- Control Arts – ControlMonitor
- ControlSoft – INTUNE+
- Control Station – Plant ESP
- Emerson – DeltaV Insight
- ExperTune – PlantTriage
- Honeywell – Loop Scout
- Matrikon (owned by Honeywell) – Control Performance Monitor
- PAS – Loop Analysis (formerly ControlWizard)
- RoviSys – rCAAM (RoviSys Control Assessment and Monitoring)

The products vary in the range of analyses they perform, their presentation of results, reporting features, and data collection methods, but they all aim to identify and report on poorly performing control loops.

High-level Functions

Although there are many differences in the features and presentation methods from one CLPM product to another, they all provide the following basic functions:

- Automatic collection of process data for analysis
- Assessment of the dynamic performance of control loops
- Diagnosing loop performance problems
- Representation of loop performance with a set of metrics
- Loop performance visualization tools or reports

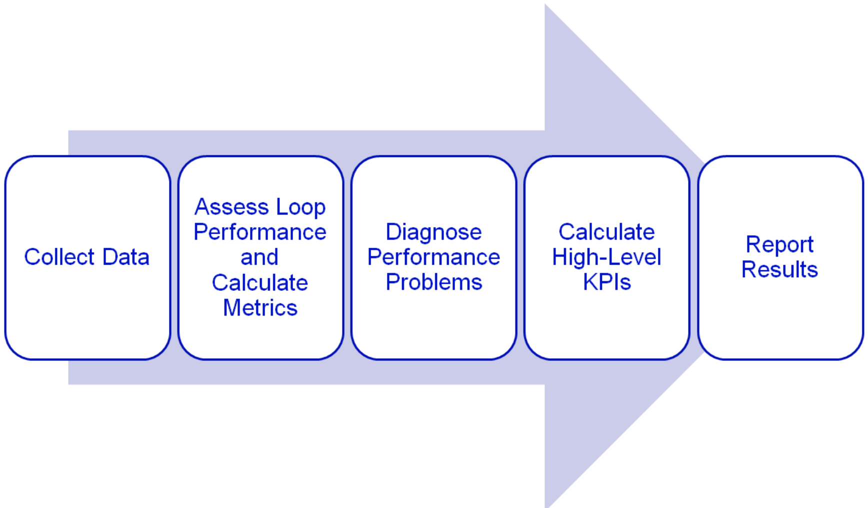

Figure 1 Steps in control loop performance monitoring.

Many of the CLPM products also provide one or more the following functions:

- Diagnosis of performance problems
- Guidance on corrective actions if performance problems are detected
- Tracking of changes in controller tuning parameters
- Identification of process models and recommending controller tuning settings
- Aggregation of loop performance metrics into high-level KPIs (key performance indicators)
- Analysis of multi-loop disturbances and oscillations with identification of the root cause

Data Acquisition

The first fundamental technical requirement for monitoring the performance of control loops is that of high-fidelity process data [2]. A good way of collecting process data for loop monitoring is through OPC DA (OPC: object linking and embedding for process control, DA: real-time data access), because it is supported by all modern control systems, and it gives the loop monitoring software the most control over sampling rate and data resolution. Careful consideration should be given to the rate at which loop performance assessment software acquires data from the data server so that the software does not overload the data server.

For this trial, the CLPM software collected data via OPC, although the software can also collect data from historians. Each DCS already had an OPC interface available, and collecting data via OPC ensured that the software acquired high-fidelity data. The software limits load on the data server through an adjustable “data throttle” setting. It then schedules periodic data collection for loops so that the rate of data collection does not exceed the throttle setting. Because data collection is not continuous, intermittent control problems might not be detected unless the data throttle is set high enough to allow continuous data collection. Other CLPM software reviewed either did continuous data collection or collected continuous periods of data from process historians.

Moving Data through Firewalls

To improve network security, most plants segregate process control computer systems and regular users into individual networks separated with firewalls. Process data has to flow from the process control network to the application servers, and client computers must have access to connect to these applications. Software vendors provide various data connectivity solutions to get process data to their application servers and application data to their users.

The software used for this project had a “data collector” component to collect process data from networks different from the one where the application server resides. It also had a “redirector” component that could be deployed on intermediary networks if necessary to connect clients and data collectors to the server across multiple firewalls.

Client-Server Architecture

Because control loop performance applications will most often have multiple users, it is essential that these applications have a client-server architecture. The server is responsible for collecting data, running the analyses, historizing the results, sending out scheduled reports, and delivering performance results on request from client applications. The client applications may be used by engineers, technicians, and managers distributed throughout the enterprise.

Web or Windows User-Interfaces

Most processing facilities require web browser access for viewing plant data and reports to minimize the need for software installations and upgrades on client machines. Modern, well-designed web applications provide virtually the same level of functionality users get from Windows applications and some software vendors provide only web interfaces for their applications.

The trial software provided both web and Windows user interfaces for viewing the output from the loop monitoring and KPI modules. The configuration functions had only a Windows interface.

Assessing Loop Performance

Loop performance should be assessed from various perspectives. For example, a control loop has to run in automatic control mode, be stable and responsive, and it must reduce process variability [4]. Loop performance from each of these perspectives should be calculated and expressed as a numerical value, or metric. Each metric can be compared to a threshold for proper loop performance. If one or more metrics exceed their threshold, the loop can be flagged as having poor performance and the offending metric(s) can indicate the reason. Maintenance or engineering staff can then attend to the problem.

Loop Performance Metrics

Some loop performance metrics are based on simple statistical calculations, while others require complex algorithms based on time-series and frequency-domain analysis. The following metrics are essential for assessing the performance of the control loop:

- Percentage of time the controller is not in its correct mode (or in manual)
- Standard deviation in error
- Tendency of loop to oscillate
- Controller responsiveness to set point changes and disturbances
- Percentage of time the controller output is at its limits

Several other metrics can provide useful additional information on the performance of the control loop, control valve, and measurement device, for example:

- Cumulative control valve travel per day (can be used for predictive maintenance)
- Number of direction changes in control valve travel per day
- Mean value of controller output (can be used to indicate oversized and undersized valves or incorrectly ranged transmitters)
- Measurement noise
- Maximum deviation from set point
- Number of process alarms generated by the control loop and its associated process
- Number of times the operator changed controller mode and/or output
- Number of tuning constant changes done on the controller

The software used on this trial used DCS event logs to determine percentage of time in manual, and the number of process alarms, operator changes, and tuning constant changes. The site did not have an OPC A&E (Alarms & Events) interface available for the trial; consequently the aforementioned metrics could not be calculated.

Composite Loop Health

Once the various individual metrics of control loop performance have been calculated, they should be combined into a single number representing the control loop health. In this way the performance of all loops can be compared, and the loops can be ranked in order of performance so that loops requiring attention are easy to find.

The loop monitoring software used for this project did the loop health composition in two phases. First it distilled the loop performance metrics down to three sub-indices and then combined these into one overall control loop performance index (CLPI).

Performance Classification

It is useful to classify control loops into groups, based on their overall performance. At minimum two groups are needed: Good and Bad. Loops in the Good category require no further attention, while loops in the Bad category should be investigated and improved. The software tested on this project had added two categories between Good and Poor called Fair and Questionable.

Problem Diagnosis

An important part of control loop performance monitoring is providing a diagnosis when poor performance is detected. Process control engineers and technicians can use the diagnosis to decide on the appropriate type of corrective action, like tuning or mechanical maintenance. It is advisable that the diagnoses have sliding scales of severity, much like the classification of loop performance described above. The software used for this project provided many diagnoses, including the following:

- Sluggish tuning
- Controller output runs into limits
- Large standard deviation in Error
- Excessive PV noise
- Oscillating due to aggressive tuning
- Oscillating due to valve stiction
- Oscillating set point
- Oscillating due to loop X (where X is the outer loop in a cascade arrangement)
- Loop performance is fair
- Loop performance is good

Guidance on Corrective Actions

If the diagnosis of loop performance problems is detailed enough, it should be possible for the assessment software to provide steps for corrective action. If tuning is the problem, the software should ideally provide appropriate tuning settings. However, tuning settings should only be provided if the software has an accurate process model, and obtaining an accurate process model from regular process data is quite a challenge.

The software used for this project provided detailed guidance on steps to verify the diagnosis and corrective actions to be performed. The software did not provide new controller tuning settings but many this and other vendors offer controller tuning software.

Support for Advanced Regulatory Control Strategies

Power plants use advanced regulatory control strategies much more than other large industries. These include cascade, feedforward, override, ratio control, gain scheduling, and linearization. It would be helpful if loop performance monitoring applications also evaluate the design of these control strategies and provide a more targeted corrective action. The software evaluated during this project did not support any advanced control strategies except cascade control.

Tracing Down Multi-loop Oscillations

It is often difficult to find the root cause of process oscillations on highly interactive processes [3]. There is a two-phased approach to this: first, all the loops affected by the oscillation must be identified, and then the foremost leading loop must be identified. The software tested on this trial provided a module called Process Analysis. This module featured an interaction matrix to show the degree of cross-correlation between measurements, power spectrum analysis plots indicating oscillation periods, and time-trends that can help a user identify the leading loop. The software did not have the ability to automatically identify all loops affected by an oscillation, nor could it automatically identify the leading loop.

User Interface

Loop performance analysis is very complex, and it is important that CLPM hide the complexity from the user. Loop performance results should be presented in a clear and intuitive way, with easy-to-use navigation and drill-down capabilities. Several task-oriented user interfaces with easy navigation between them and drill-down is ideal.

The software tested on this trial had four different user interfaces for presenting CLPM results and a multitude of user interfaces for diagnostics and configuration. The user interfaces for CLPM were:

1. A treemap with colored rectangles for displaying the performance (in color) and importance (in size) of loops in a hierarchical structure.
2. A grid for displaying all the metrics of all loops, and providing sorting and filtering capabilities.
3. A window to display the data used for an individual loop's performance assessment, as well as statistics and metrics.
4. A historical plot of loop performance and metrics over time.

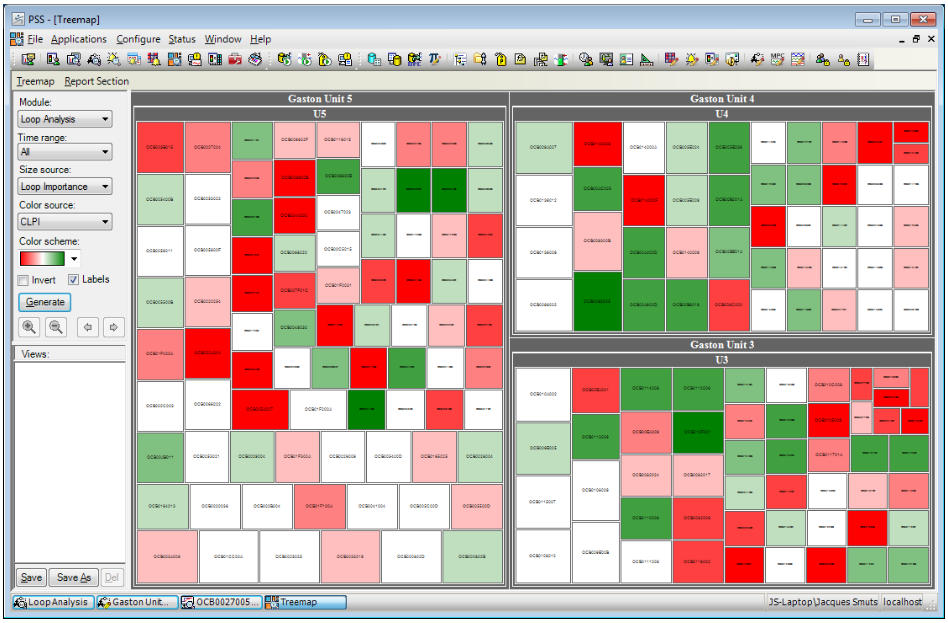

Figure 2 Treemap of control loop performance.

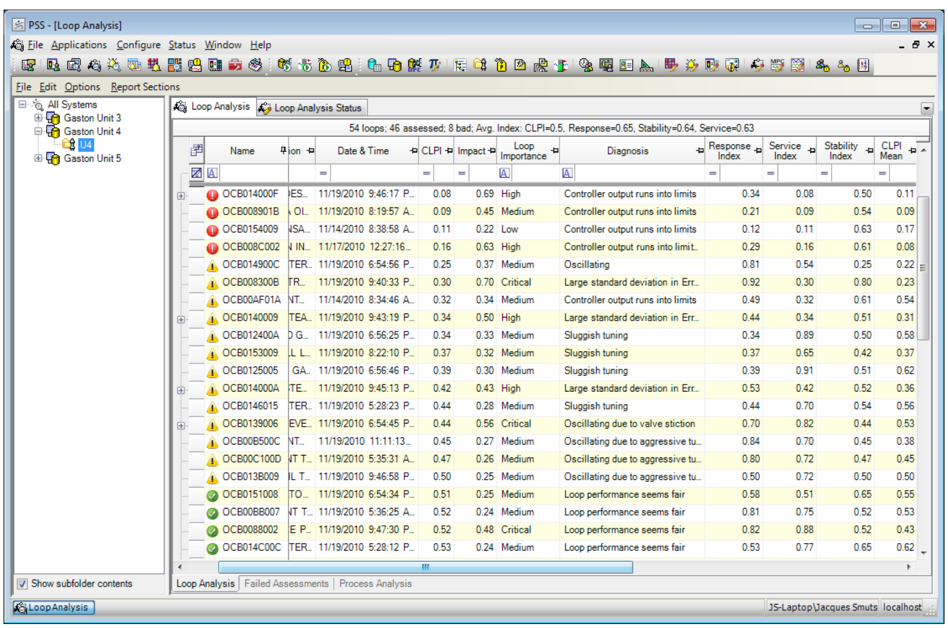

Figure 3 Table displaying the results of loop performance assessments.

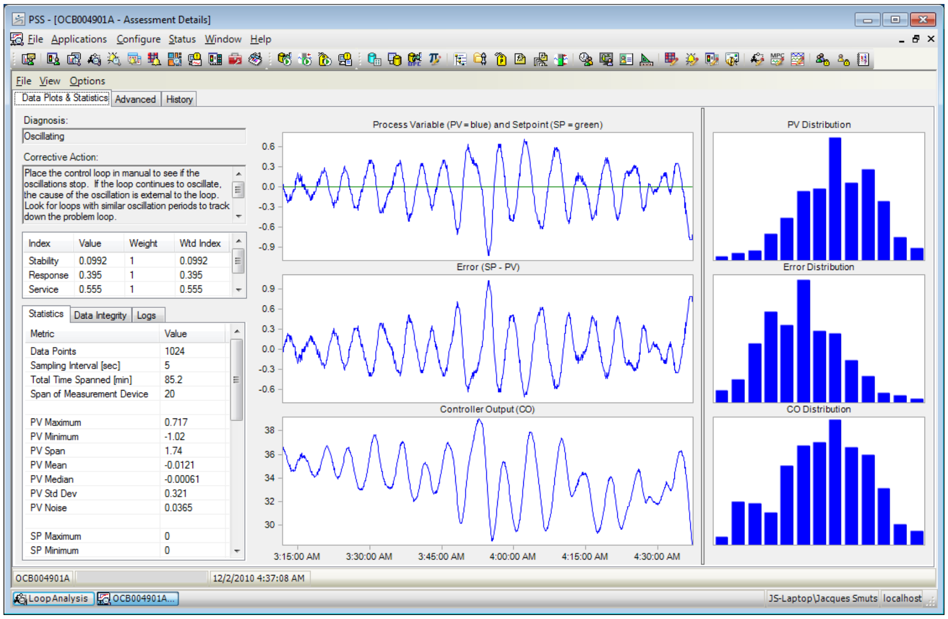

Figure 4 The software's data plots and statistics display.

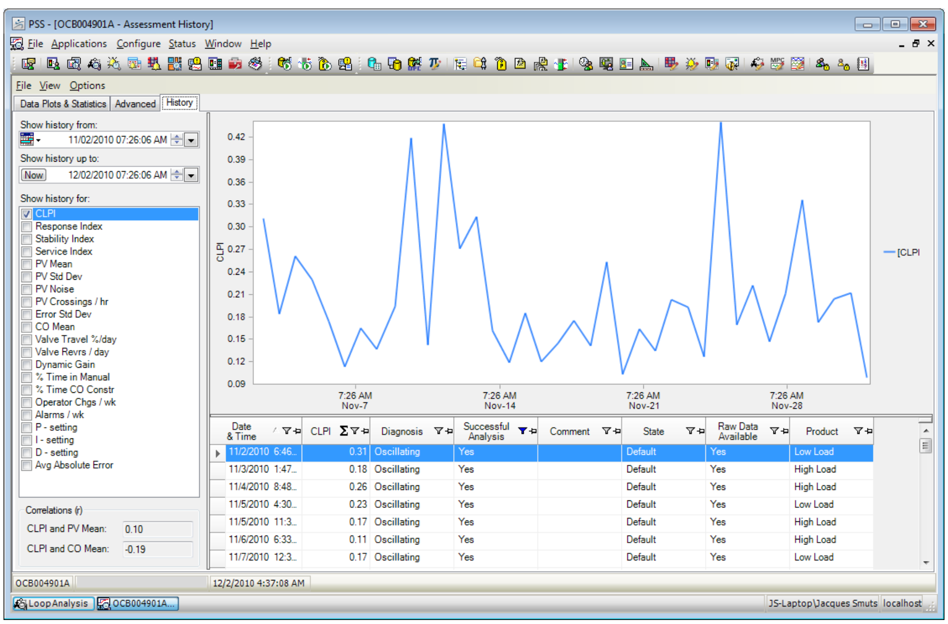

Figure 5 The software's loop performance history display.

Key Performance Indicators

The treemap and results table provide the user with a snapshot of the performance of individual control loops. However, for control loop performance monitoring it is useful to have aggregated loop performance metrics, for example the number of loops in manual, or oscillating, or the average performance index of all control loops. Key Performance Indicators (KPIs) can be used for this.

A KPI is a measurable indicator of a metric that indicates some aspect of plant performance, usually associated with a business driver. For control performance, KPIs can be a unit- or plant-level aggregation of the performance of individual control loops. The software tested during this project provided a module for defining, trending, and reporting KPIs. Although flexible, it was not very easy to configure KPIs.

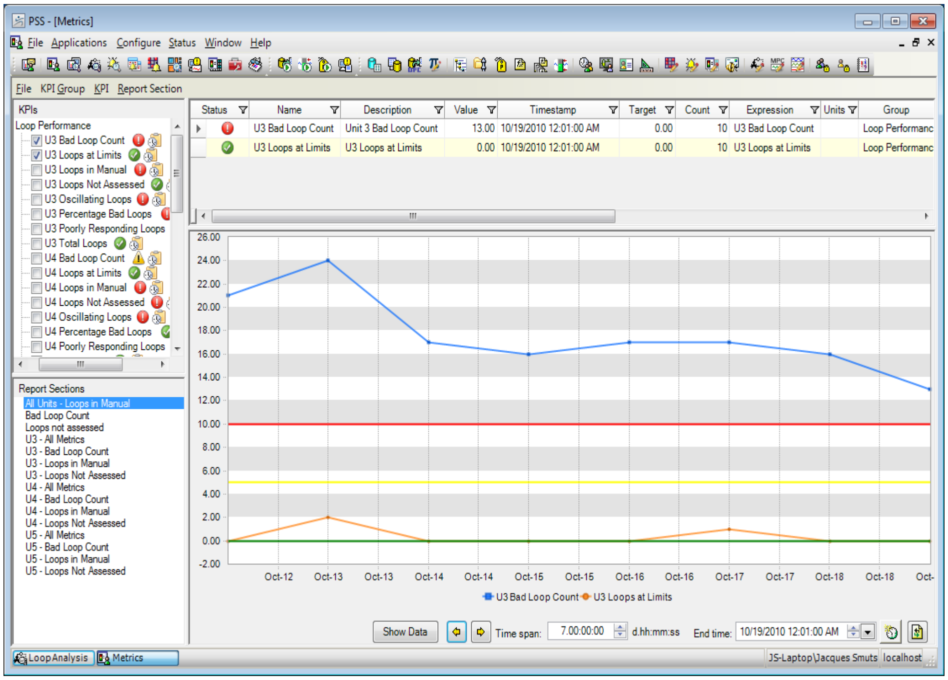

Figure 6 Module for viewing KPIs.

Reporting

Interactive use of loop monitoring software is essential for mining information through ad-hoc navigation, drill-down, data sorting, and custom filtering. For a periodic, routine overview of loop performance, targeted reports are far more efficient. Ideally, performance monitoring software should have pre-packaged reports, but it should allow customization of these reports and creation of new ones. The loop monitoring software evaluated through this trial did not have standard reports, but it did provide complete customization of the contents of a report, the delivery schedule, and list of recipients. Reports were transmitted via email.

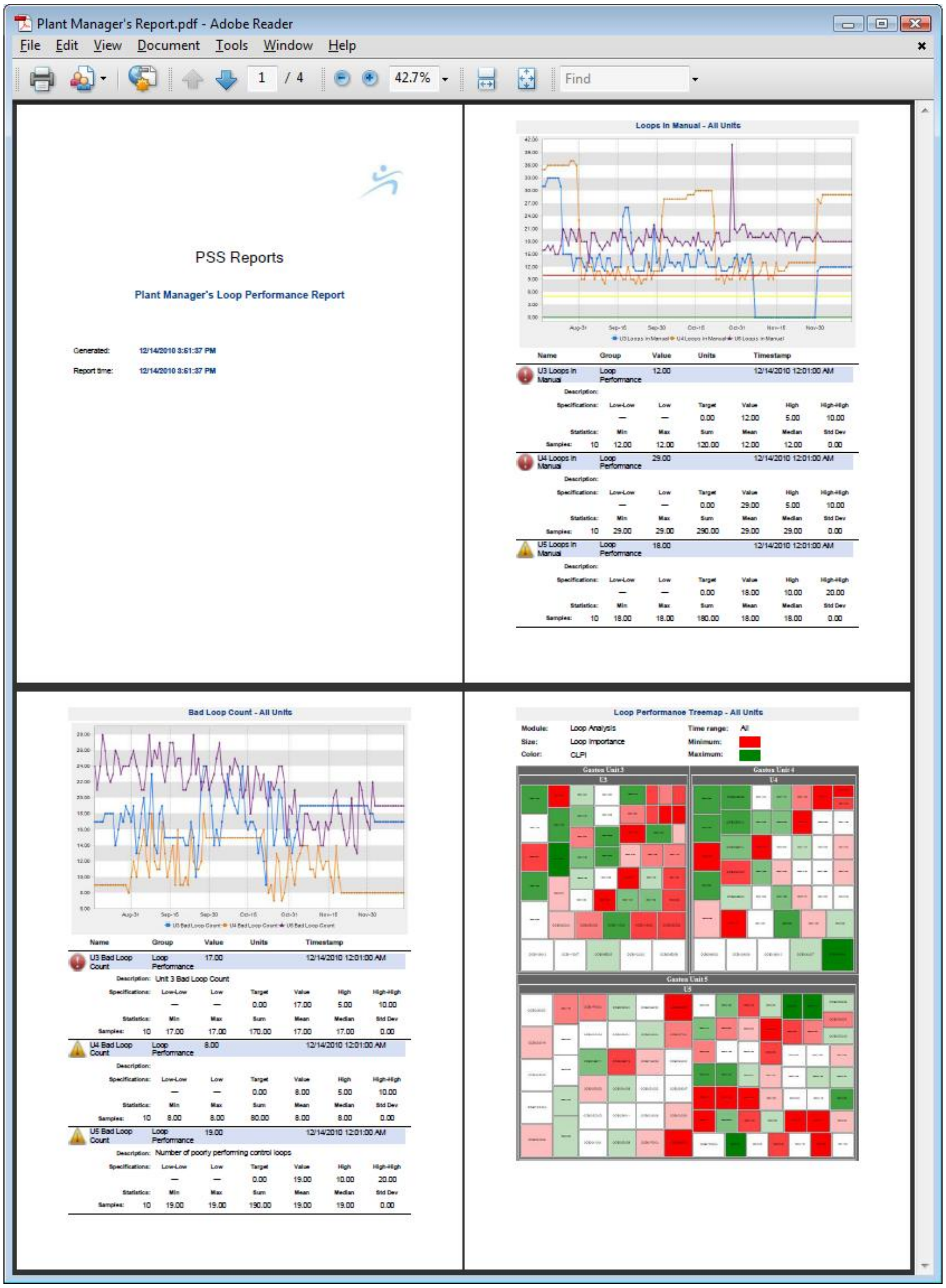

Figure 7 An example of a CLPM report.

Installation, Configuration and Evaluation

Installation

Multi-component software should come with an option-based installation program that allows the user to install different components of the CLPM system onto different machines and networks. After installation, communication must be established between all the distributed components. Both of these activities are quite specialized and it is recommended that the software vendor or an authorized agent install the software and establish communications. This is also the approach followed by the evaluation team in this project.

Configuration

Once the software has been installed, a database of loops present in the DCS must be obtained and loaded into the software's own database. In addition to a list of loops, the data connection points (OPC addresses) for the loop's set point, process variable, controller output, mode, and PID (proportional – integral – derivative) settings are needed. Additional information like the desired settling time, control objective, control strategy, type of process, etc. may also be needed.

This information can potentially be loaded into the software by configuring a spreadsheet with all the loops and importing this into the CLPM software, or the software can import the loop list directly from the DCS configuration files or database. The software used in the trial can import the configuration of many types of DCS, but not the Ovation DCS that the trial was run on. So the configuration was done in a spreadsheet that was then imported into the software. There was no known easy way to export a list of control loops from the DCS, so considerable effort was required to compile the spreadsheet.

Fine-tuning the Assessments

Initially, CLPM software does not understand the exact function, objectives, and limitations of each control loop. This can result in the software falsely reporting problems, or missing poor performance. To improve the accuracy of loop assessments, the software should provide adjustable parameters.

A person with a high level of technical expertise on control loops, the process being controlled, and the monitoring software is required for tweaking the assessment parameters until the system is properly set up and the results of the loop assessments are accurate for all loops. This person should be able to look at the loop assessment results and make a judgment on the accuracy of the analysis and the appropriate assessment parameter adjustments where needed. During this trial, a consultant that was intimately familiar with the design and operation of the software helped the evaluation team with adjusting the loop assessment parameters.

Once the loop assessment software has been tweaked, an instrumentation & control technician should be able to use the treemap to find problem loops, drill down to obtain the diagnoses and corrective actions, and use a tuning application to solve tuning problems, or submit a work order for other maintenance.

Evaluation of Results

The evaluation team met on a monthly basis to review the results of the loop assessments done by the monitoring software. All the loop assessments where the software indicated poor or questionable loop performance were reviewed. The evaluation team used the Treemap as a starting point for identifying loops with poor performance. From there they drilled down to the

Analysis Details page, and used history on past performance and DCS trends to support / discount the software's findings. Tweaking of the assessment parameters was done where necessary. It was found that after the necessary parameter adjustments have been done, the top-level loop assessments were mostly accurate, but the causes of oscillation (stiction, tuning, or externally caused) were not always correct.

Special issues for power plants

Power plants pose some unique challenges to the assessment of control loops. The biggest of these challenges, and the way the test software handled them, are discussed below.

Impact of Unit Load on Loop Performance

A control loop's performance may vary depending on unit load. This caused the historical assessments of many loops to flip between good and poor performance, and the diagnoses to flip between different problems. The team added unit load as a tag on each assessment so that filtering and sorting on unit load could be done. This helped with analyzing loop performance history of any single loop. However, the treemap and loop analysis results table did not support the concept of unit loads in an elegant way, because it showed only the result of the last assessment done on any control loop.

Many Cascaded and Non-simple PID Loops

The software treated all loops as single PID loops, with two exceptions. Cascade arrangements were indicated on the loop analysis results table, and if the inner loop oscillated because of its set point oscillating, the software did point the user to check the outer loop. Feedforward and other advanced control structures were not specially supported. Loop performance was viewed from a process variable perspective and poor control performance was flagged based on this alone.

Loop Interactions

Power plants have a significant number of interacting processes. Problems in one loop may be evidenced in several other loops. Oscillations in a power plant tend to be systematic instead of localized – that is, when something swings, everything swings. The evaluation team found that the Process Analysis module did not really help with tracking down the root cause of oscillations when multiple, interactive loops were oscillating simultaneously.

Changing Fuel Quality

When coal from different sources is used for fuel, the quality could vary over time. If the control system does not detect or infer these changes and compensate for them, they might affect performance of the boiler. The software did not have a feature to detect and/or diagnose changes in fuel quality. However, if loop performance deteriorated as a result of changes in fuel quality, the software would likely have indicated the poor performance of the affected control loops.

Mills in Service
Depending on unit load, one or more mills can be shut down. Steam temperature, throttle pressure, and possibly other control loops can be affected by the combination of mills in service. The software did not have a feature to record the mills in service at the time of loop assessments.

Nonlinearities
The software did not directly report on nonlinearities, although control loop history did show cross-correlation between loop performance and controller output / process variable. A high absolute value (more than roughly 0.67) for one or both of the cross-correlations could indicate process nonlinearity.

Pulverizer Degradation
Pulverizer performance is known to decrease over time, and control loop performance could be affected by this. The software did not have a feature to directly diagnose pulverizer degradation. However, if loop performance deteriorated because of pulverizer performance, the software would likely have indicated the poor performance of the affected control loops.

Startups, Shutdowns and Intermittently Operating Equipment
Power plants have several pieces of standby equipment (e.g. boiler feedwater pumps and turbine bypass systems), or equipment with intermittent operation (e.g. soot blowers). Loop assessment software must be able to detect the equipment state and assess the loop only if the equipment is operating. The tested software had the ability to inhibit loop assessments if the controller output was saturated at limits, or by using a custom expression. It also has a trigger feature that could ensure that loops are assessed when they come into service.

Benefits of Loop Performance Assessment Software
Several benefits may be reaped from using CLPM software in power plants.

Assisting Younger and Inexperienced Controls Staff
As older, experienced workers retire, they are inevitably replaced with younger workers having less experience. CLPM software can be a significant asset to less experienced process control engineers and technicians by differentiating between good and poor loop performance, and diagnosing the causes of poor loop performance.

Improving Work Efficiency and Saving Time
There are many ways in which loop performance assessment software improves work processes, raises efficiency, and saves time for experienced and inexperienced control engineers and technicians alike. These are described in more detail below.

Assessing Loop Performance Automatically

A typical coal-fired power plant has several hundred control loops. CLPM software assesses the performance of hundreds or thousands of control loops without the need for human intervention. The software can identify poorly performing control loops so that these can be attended to.

Prioritizing Bad Actors

A loop may be performing poorly, but if it is not an important control loop it should not be worked on if more important loops are also performing poorly. Loops that are important and also performing poorly should be worked on first. When CLPM software considers both the performance and the importance of control loops, it can provide a prioritized list of poorly performing loops.

Diagnosing Control Problems

CLPM software not only indicates which loops have poor performance, but it also gives a diagnosis of why the performance is poor. Sluggish tuning, oscillations, and controller output running into limits are examples of diagnoses given by the software.

Providing Guidance on Problem Resolution

CLPM software can provide steps for validating the diagnosis and resolving the problem. This is vital information for the non-expert.

Measuring Success of Control Improvement Projects

An essential aspect of any performance improvement initiative is the reporting and monitoring of key performance indicators. These are used to track progress toward goals, and to help establish overall project success. The metrics produced by CLPM software can be useful for evaluating the success of a control optimization project or loop tuning effort through a before-after comparison.

Keeping History on Performance and Tuning

CLPM software can maintain history on several aspects of control loop performance and controller tuning settings. These can be trended over time to see the effect of tuning changes on loop performance. It is helpful to see at what point in time the tuning settings were changed, what the old values were, what they were changed to, and what effect the changes had on loop performance, loop stability, standard deviation in error, etc.

Conclusions

Several conclusions were drawn from the evaluation of CLPM software at Plant Gaston:

1. System configuration can be difficult and error-prone if the control loop configuration cannot be obtained from the DCS in some automated way.

2. For the software to correctly assess performance and diagnose problems for all control loops, the loop assessment criteria have to be properly adjusted according to the loop service and control objectives.
3. After the system has been running for a few weeks, the loop assessments need to be reviewed and assessment criteria adjusted where necessary to improve analysis and diagnostic accuracy. This requires a vendor expert or consultant with intimate knowledge of the software and process control.
4. Some issues specific to power plants, like non-simple control loops and interactions, are not adequately addressed by the software.
5. Once the software has been properly configured, it can provide plant personnel with useful information on which loops perform poorly, and guide users through further problem diagnosis and correction.
6. Although it might be difficult to establish a dollar value for return on investment, there are many benefits associated with the information, analysis, and diagnoses provided by the software.
7. Pilot installation of the software is valuable in that it helps identify potential value and problems thus enabling more informed decisions before broader deployment.

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