Power Plant Control System Tuning

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BACKGROUND

Competition has forced power producers to operate their power plants more efficiently to be able to handle varying load conditions, provide fast load response and comply with stringent new emission standards. These sometimes conflicting goals are usually to be achieved with minimal capital expenditures. Tuning of the power plant control system has a direct impact on these aspects of plant operation and when done properly can assure significant improvements in productivity and reduction in costs.

The plant control system is really several different control systems including the boiler control system, turbine control system, fuel handling system, ash handling system and many other small control systems. Although all these systems are important, the one that usually has the largest impact on plant operation is the boiler control system. This system controls the combustion process and the primary steam temperature and pressure conditions. These areas have the greatest direct impact on plant performance, whether it is thermal performance, emissions compliance, or responsiveness. So if the control system does not do a good job of controlling these important parameters, the plant performance suffers.

Unfortunately, it is not easy to achieve excellent control system performance and as a result many plants today (and in years past as well) operate at less than their optimum performance. There are several possible reasons for poor control system performance including improper control strategy, inadequate field devices and improper control system tuning. This Technical Review will discuss the current state of control system tuning in the power industry, provide some guidance on how to improve it, and discuss what EPRI is doing to develop improved tools to assist plant personnel with control system tuning.

TUNING TODAY

A typical boiler control system consists of many control loops. Almost universally, a proportional-integral-derivative (PID) controller is used as the primary control algorithm. This is true regardless of whether the control system is a new distributed digital control system (DCS), an older analog electronic system or even a pneumatic system. In addition to the PID controllers, every boiler control system includes many other important functions to make the system work. Tuning a control system consists of adjusting many parameters within the control system to make the system compatible with the characteristics of the plant being controlled. Tuning usually implies matching the dynamics of the PID controllers to the plant dynamics, but actually many tuning adjustments involve no dynamics at all. Tuning includes adjusting PID controllers, steady state scaling of control system signals, and linearization of signals. Tuning does not involve making strategy changes in the system, but often minor changes are needed to improve the operation of the system.

In an ideal plant, the control system would have been properly tuned during the initial startup of the plant and nothing about the plant operation would have ever changed. In this case, the control system tuning would never need to be altered. Obviously, no plant is an ideal plant. In reality, the control system may not have been tuned properly during the initial startup, a new control system may have been installed because the old one was obsolete, the fuel for the plant may have changed, low NO_x burners may have been installed or myriad other things may have impacted the tuning of the control system. In reality, the control system will need to be tuned many times during the life of the plant.

There are literally hundreds of references available for control system tuning but boiler control system tuning continues to be a difficult process. Boiler control tuning is difficult for many reasons. The control strategy used in boiler control is more complex because the process being controlled has more interactions than many process control systems. For example, the tuning of the steam temperature control system can significantly impact the throttle pressure control system so this must be taken into account when tuning the steam temperature. Boilers change load more than most processes. Since very little electrical energy can be stored, the power generated must always equal the load. Because the load varies throughout the day, the power generated by plants must also vary throughout the day. Coal fired plants are particularly difficult to tune because the fuel characteristics are more variable and ash causes many disturbances inside the boiler. Pulverizers also add significant delays to the fuel flow response, which slows the overall boiler response. These and other factors make boiler control tuning difficult.

Most control systems in service today were tuned by the vendor's service engineer when the system was first installed. This is true for both new plant control systems and retrofit installations. In some cases, the plant personnel have done the original tuning on the control system but this is a little unusual. After the system has been tuned and accepted, it is turned over to the plant staff to maintain. There are many different approaches used to handle the control system maintenance but probably the most common arrangement is for the plant staff to perform most of the maintenance themselves and only use a vendor for special situations. Usually the plant staff will try to handle the tuning needs, but for particularly difficult situations a vendor would be used.

There are a couple of factors in place today which make tuning more of an issue than it was a few years ago. First, there are fewer expert tuners available today because many of the older ones have retired and there are few young ones to take their place. Most control system vendors still have one or two experts but there are not enough to go around. This means that control systems installed today are probably not as well tuned at initial startup as they were years ago. Another factor is that many plants are undergoing modifications for emission regulation compliance, such as, low NOx burner installation. Also many coal fired plants are switching fuels either for emission control (low sulfur coal) or for competitive reasons. Any of these changes can require retuning of at least part of the control system.

One positive aspect of tuning today is that all systems installed recently are digital systems, and as such they have no internal drift problems. This eliminates some tuning work, which once was required to compensate for calibration drift within the control system.

No systematic effort has been undertaken to fully assess the quality of control system tuning in the power industry today. EPRI's *I&C and Automation for Improved Plant Operations Target* has proposed a project for 2000 which will provide such an assessment. Control system performance data will be collected from many plants and the range of performance will be quantified. This will give researchers more insight into the magnitude of the tuning problem and allow the proper resources to be assigned to help solve it. A similar study in the pulp and paper industry, identified improper tuning as a major contributor to control system performance problems.

WHAT IS AVAILABLE TODAY TO IMPROVE TUNING?

There are several good resources available from EPRI and others to help improve your control system tuning. The resources include EPRI Tuning Guidelines, technical papers, books, training courses, computer programs, and consultants. A few of the resources are specific to the power industry, but many are generic for all process industries.

In 1993 EPRI issued a very useful report, *TR-102052, Tuning Guidelines for Utility Fossil Plant Process Control*. The report consists of 4 volumes, each for a different audience. Volume 1 is *Management's Guide to Tuning* which gives an overview of what tuning is about and suggestions for setting up a successful tuning program. It also discusses how to determine when tuning is required and when a control system problem is not related to tuning. Volume 2, *The Technician's Guide to Tuning*, provides information about PID controllers and several tuning methods, both empirical and mathematical. It also discusses tuning of cascade control loops and feedforward signals both of which are very common in boiler control applications. Several useful references are also provided for learning more about tuning. Volume 3, *The Engineer's Guide to Tuning*, gives a good introduction to boiler control strategies and provides specific instructions for tuning boiler control systems. It has many functional diagrams of typical control strategies. Volume 4, *Appendices*, contains some case study results and a glossary of terms. This four-volume report is one of the few resources which is specifically aimed at power plant control and is well worth reading and keeping as a reference.

ISA, The International Society for Measurement and Control, has published several good books on controller tuning, including: *PID Controllers: Theory, Design and Tuning*, by Karl Åström and T. Hägglund; *Tuning and Control Loop Performance*, by Greg McMillan; *Tuning of Industrial Control Systems*, by A. B. Corripio. Another good ISA book is *The Control of Boilers*, by Sam Dukelow. Although this is really not a tuning book, it contains a wealth of information about how boilers work and many examples of practical control strategies for them.

Literally hundreds of technical papers have been published in the last 20 years dealing with controller tuning and boiler control systems so it is not practical to list them here. One good place to look for papers is in the Proceedings of the Joint ISA POWID/EPRI Controls and Instrumentation Conference (and its predecessor the ISA Power Symposium) held annually. This conference is devoted to power industry topics and several good papers on control system tuning have been presented over the years. A couple of note are: *Aspects of Tuning a Boiler Control System - A Strategy for Optimization*, by Richard Morse et al, 1976; *A Guide to Boiler Control System Checkout and Start-up*, by Cyrus Taft and Gordon McFarland, 1991. Other good papers have been published by ASME, IEEE and IFAC.

Taft's Top Ten Tuning Tips

Cyrus Taft, Chief Engineer at the EPRI I&C Center has been tuning boiler control systems for over 20 years and offers his version of a Top Ten List.

10. Linearize the response of the final control elements using either linkage arrangement or function generators. I think linkage arrangement should be used to get the characteristic close to linear and then the function generator should be used for fine tuning.

9. Tune lower level control loops first but don't tune them too tight on the first go around. When higher level loops are tuned and put in automatic, you will probably get too much interaction.

8. Always tune the loop for at least a small amount of overshoot to a step change in setpoint. A common problem with tuning is too little gain. A sure way to avoid this is to keep increasing the controller gain until some overshoot is detected. If there is no overshoot, you know the gain is too low but you don't know how low it is. It could be very low. I recommend about 10%-20% overshoot for most loops. You can speed up your tuning by doubling the gain for each tuning cycle until overshoot occurs. Small changes in gain are usually insignificant. If you think the loop should have no overshoot, tune until you get some and then back off on the gain a little.

7. Make the process repeat itself before you stop tuning. There is considerable uncertainty in most boiler processes, so don't assume that the perfect response you just saw was because of your superb tuning ability. It may have had a little help from random luck.

6. Plot the steady state values of all the primary flows (steam, feedwater, fuel and air) at three or more loads between minimum and maximum. Scale the primary flow variables so they all agree at full load. Be sure that the plant is in a 'normal' operating condition when the data is collected. This will help keep all the major flow loops aligned throughout the load range and make the main feedforward action of the control system work much better.

5. Understand the process you are trying to tune. If you don't have a pretty good idea of how the process should behave, you will have a tough time deciding whether the control strategy you're using is suitable and whether tuning changes you make are really helping.

4. Before beginning, select the performance criteria you will use to evaluate the tuning. If you don't have a criteria in mind, how will you know when you are finished? The criteria I like best is to make the response as fast as possible while keeping the overshoot between 10% and 20%. Figure 1 shows a step response curve with about 10% overshoot. Other criteria you may choose include rise time, settling time, and offset. Remember that there are physical limitations in all control loops, so you can't arbitrarily specify a very fast response time if the process can not respond that fast.

3. Use derivative (or rate) action for slow responding loops. According to Greg McMillan, derivative action is the most underutilized tuning tool. Many think that derivative action decreases a loop's stability when in fact it does just the opposite. The problem with using derivative is that any noise on the process variable will be amplified by the derivative action and the final control element may become too active. Consider using filtering in the transmitter, if available, to reduce process noise.

2. Tune by introducing disturbances into the loop and not just by making setpoint changes. Most loops have different responses to setpoint changes than they do to disturbances. More loops are used for disturbance rejection than are used to follow a setpoint. Also introduce the disturbances in both directions because the loop's response may not be symmetrical.

1. Record all your changes and why they were made. Keeping good records of all tuning activities is very helpful for several reasons. Sometimes it takes days to really evaluate a tuning change over the entire load range and you may forget what you did or why if you don't write it down. Once you have a loop well tuned, you don't want to lose the tuning values just because someone comes in after you and changes the settings.

The EPRI I&C Center offers a training course, *An Introduction to Computer-Aided Power Plant Control System Analysis*. This course provides an introduction to the use of a software product named MATLAB and also discusses power plant control loop tuning techniques. The I&C Center also offers a course on *Boiler Controls and Burner Management Systems* which covers the steam generation process and the basic strategies used for its control.

ISA offers many courses on Process Control, Boiler Control, Controller Tuning and related topics. Although most of these courses are not directly aimed at the power industry, they still provide useful training on general control system tuning.

There are several computer programs available to assist with PID controller tuning. The EPRI I&C Center offers a program called the Control Maintenance Workstation (CMW). CMW extracts data from a plant DCS to monitor the control loop performance and provides several other tools to support better control system tuning. It has a module for PID controller tuning and one for evaluating the linearity of final control elements and other system functions. It also provides an instrument calibration database and includes an online version of the EPRI Tuning Guidelines mentioned above. Figure 2 is part of a CMW report showing a trend of one loop's performance over the past week.

There are other programs just for controller tuning. Some of these programs can be integrated with a commercial DCS system for added convenience. Most DCS systems also include a self-tuning PID controller as an option. All of these type programs can provide good tuning parameters in some situations. Many of the programs are limited to simple PID control loops and will not help much with cascade or feedforward applications which are common in boiler control systems. Most require an open loop step test be performed on the loop being tuned to provide the process characteristics for the tuning algorithm.

Finally, there are always consultants to help with boiler control tuning. The EPRI I&C Center can provide assistance with control system tuning as well as assessing control system performance.

WHAT IS NEEDED IN THE FUTURE TO IMPROVE CONTROL SYSTEM TUNING?

Although there are considerable resources available to assist with tuning today, much more could be done. EPRI is planning three activities for 2000 to help improve control system tuning. One is a training course at the I&C Center concerned specifically with boiler control system tuning. The second is a benchmark study of control system tuning throughout the power industry and the third is a study to assess the feasibility of developing a computer program to completely automate the boiler control tuning process.

The boiler control training class will be a three day class and will provide practical procedures and methods for tuning a complete boiler control system. It will present an hierarchical approach to the process and will discuss empirical and mathematical techniques with more emphasis on the empirical approach. Troubleshooting control loop performance will also be covered. The intended audience is control system engineers and technicians at plants who are responsible for control system tuning.

As mentioned above there is no definitive study of the state of control system tuning in the power industry today. Because of this it is very difficult to compare one plant's performance against the rest of the industry. This makes it troublesome to decide whether control system improvement projects are worthwhile. It may be that your unit is already performing at a high level compared to the rest of the industry and little performance improvement is likely. The study planned for 2000 will collect data from many units and categorize it by type and size of unit. Both subcritical and supercritical boilers will be included as will coal, oil and gas fired units.

The most ambitious project will be to develop a computer program to actually tune the entire boiler control system automatically. This is a very complex and challenging effort, so a feasibility study will be done first. The study will examine all the self-tuning controller work that has been done to date, which is considerable. Several recognized experts will then be interviewed to get their thoughts on the matter. Different approaches to the program will be considered including an expert system (or rule based) type, an analytical approach, and a neural network type system. If the result of the feasibility study is positive, then development of the program will be planned to start in 2001.

CONCLUSION

Because PID controllers remain the dominant control technology in boiler control systems today, tuning is an important topic for further study. Factors at work now, such as, increased competition and tighter environmental regulations place increased emphasis on proper control system tuning. There are many resources available to power industry personnel, from EPRI and others, to assist with control system tuning. But more needs to be done and EPRI will continue to take a leadership role by beginning new projects in 2000. The ultimate goal is to make it easier to tune power plant control systems, even to the point of totally automating the process, and thereby improve plant performance.

EPRI TUNING RESOURCES

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Tuning Guidelines for Utility Fossil Plant Process Control
Volume 1: Management's Guide to Tuning
Volume 2: Technician's Guide to Tuning
Volume 3: Engineer's Guide to Tuning
Volume 4: Appendices
TR-102052, March 1993

Control Maintenance Workstation
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EPRI I&C Center Training Courses
Contact Ken Brittain, EPRI Charlotte
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FIGURES

Figure 1. 10% Overshoot Step Response

LOOP4005 -- 4A Fuel Flow Control

QPI Average:	104.61
Minimum Loop Error:	-9.58
Maximum Loop Error:	4.03
Average Loop Error:	0.00
Zero Crossings/hour:	67.63

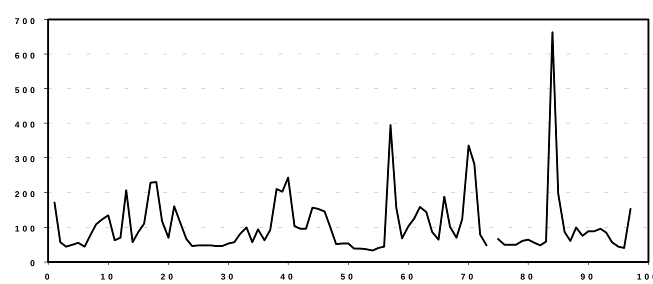

Figure 2. CMW Quality Performance Index Report

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EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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