Model Predictive Control Demonstration

Model Identification Testing and Simulation Results

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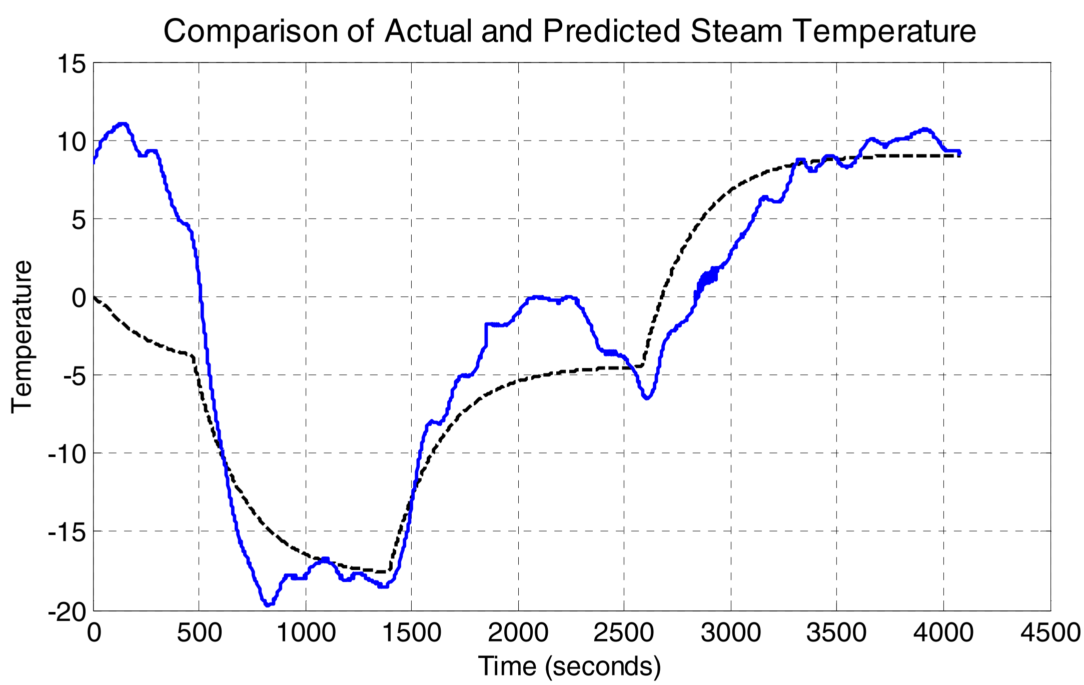

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Technical Update, March 2009

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PRODUCT DESCRIPTION

This report describes the first phase of a two-phase project to demonstrate an advanced control technique on a fossil power plant. The advanced control technique chosen for the project is model predictive control (MPC). Although MPC has been a commercially successful technique in many process industries, it has been used sparingly in the power industry even though industry-specific products are available. Although the Electric Power Research Institute (EPRI) has sponsored several advanced control demonstration projects in the past, this was the first project to use the MPC algorithm. Also new in this project is the fact that the model predictive controller is implemented in the distributed control system (DCS) control processor rather than in a separate application processor.

Results and Findings

A simple steam temperature control application has been designed for the model predictive controller and tested on a checkout simulator. The controller performance in the simulated environment was satisfactory based on preliminary test results. The model predictive controller also exhibited adequate robustness to process model changes in gain and time lag. One model predictive controller function that has not been verified yet is the ability to assume control from another controller with a smooth transition (bumpless transfer). Bumpless transfer is necessary when transferring from proportional integral differential (PID) control to MPC.

Tests have been conducted at the host plant to identify a model of the superheat steam temperature control process. Desuperheater spray control is the steam temperature control method used at the host plant. Due to seasonal demand, lack of availability of the host unit has delayed additional tests needed to identify disturbance models that are important to obtaining optimal performance with the MPC technique. These additional tests will be completed in subsequent project tasks, and the results will be documented in a final technical report.

Challenges and Objectives

The primary technical challenge in this project was to identify adequate models of the steam temperature process. There was considerable process noise identified in the steam temperature data, making determination of actual plant characteristics difficult. Once a good process model was obtained, the control design process was relatively straightforward, as was the addition of the new MPC algorithm to the existing temperature control logic.

The primary objective of this demonstration project was to determine whether advanced control techniques such as MPC can improve control system performance compared with conventional PID-based control. It is also important to determine whether the implementation of such advanced systems is too complex or expensive for everyday power plant use.

Application, Value, and Use

Advanced control techniques have shown the ability to improve control system performance in difficult power plant control loops. Their widespread use has been hampered by their cost and complexity. MPC is a more user-friendly type of advanced control than other methods and as such may be more readily accepted in the power industry. If this demonstration project is successful, it will encourage more use of advanced control, which will improve plant dynamic performance. Many power plants are still struggling with quantifying the value of improved dynamic response, but in competitive markets, the value is quantifiable. Also, as plants become more complex with extensive back-end emission control systems, it is important that the basic power island be well controlled at all times.

EPRI Perspective

EPRI's Generation Sector Instrumentation, Controls, and Automation for Improved Plant Operations Program has the objective to identify and demonstrate new methods and technologies to improve control system performance in fossil power plants. Although conventional PID-based control strategies are adequate for most boiler control applications, there are some difficult loops where PID does not perform well. The use of advanced control techniques has been studied by EPRI before, but the MPC method has not. Because MPC products are commercially successful, they are more fully developed than other advanced control systems. The particular system being demonstrated in this project is attractive because it operates in the DCS control processor along with the conventional PID control logic. This reduces cost and simplifies implementation, which should lead to more widespread use of the technology.

Approach

A host site was selected for the demonstration by the host utility. One reason that the host site was selected was related to current difficulty with the steam temperature control system. The main tasks of the first phase of this project were to design and implement the model predictive controller on a simulator for testing. Plant tests were performed to identify the process model needed by MPC technology. The simulator was a small DCS similar to that of the plant so that the test environment was as realistic as possible. In subsequent project tasks, after testing is completed on the simulator, MPC technology will be implemented in the real plant and tested. The existing PID control will also be available in the plant for comparison purposes. All results will be documented in a final technical report.

Keywords

Control system
Instrumentation and control
Model predictive control (MPC)
Proportional integral differential (PID)
Steam temperature control

ACKNOWLEDGMENTS

This project could not have been accomplished without the help of John Sorge, a research engineer from Southern Company. Additionally, EPRI recognizes the staff at the Gaston plant of Alabama Power Company (Southern Company) for allowing this project to be demonstrated on-site.

CONTENTS

1 INTRODUCTION

The Electric Power Research Institute (EPRI) has been researching advanced control technologies for many years [1,2]. When the research began, there were few, if any, commercially available advanced control solutions for the power industry. As a result, much of the early work was done with universities and involved evaluation of different control algorithms and their suitability for power plant applications. In the past few years, several major control system vendors have begun offering their own advanced control products usually based on the model predictive control (MPC) methodology. In 2007, EPRI arranged web casts by several commercial vendors of MPC technology to better understand the technology and its possible application to the power industry. The web casts were very informative and showed that MPC technology is very widely used in other industries but is still somewhat rare in the power industry. A brief summary of the web casts is provided in EPRI TR-1014237 [3].

After the MPC technology review was completed, Southern Company agreed to host a demonstration of MPC technology at one of their fossil power plants. The unit chosen for the demonstration was Alabama Power Company's Gaston plant unit 3, and the application was steam temperature control. The host unit has an Emerson Ovation control system, and Southern made arrangements with Emerson to use their Ovation Advanced Process Control Toolkit, which includes a model predictive controller.

This report describes the overall plan for the demonstration project and discusses progress to date with the model identification testing, model development, and simulator setup.

Demonstration Project Plan

The objective of the MPC demonstration project was to design and install an MPC system in a power plant application and compare its performance and usability with those of a conventional proportional integral differential (PID)-based control system. The project will be completed in two phases, with phase 1 encompassing the control design, implementation, and testing on a simulator and phase 2 involving implementation and testing in the actual plant.

Phase I: Controller Design, Implementation, and Testing on the Simulator

Task 1: Setup of the Ovation Simulator in the Southern Company DCS Laboratory

Southern Company set up a small Ovation DCS in their laboratory for use as a simulator on this project. The setup included assembling the correct hardware, installing the proper Ovation software, installing the Advanced Control Process Toolkit, and testing it all to ensure proper operation.

Task 2: Configure Conventional and Advanced Steam Temperature Control in the Simulator

The existing Gaston unit 3 steam temperature logic was configured in the simulator along with the connections required to interface with the new MPC blocks. Due to the different Ovation versions at Gaston and the simulator and because only a subset of the Gaston logic will be included on the simulator, the design was manually transferred to the Gaston system as opposed to copying the simulator logic sheets.

Task 3: Develop Steam Temperature Process Model and Install in the Simulator

A dynamic model of the steam temperature process was developed and installed in the simulator. The model was developed using system identification based on open loop and closed loop testing performed in the plant. Another project on automated control system tuning was also being conducted on Gaston unit 3 steam temperature control, and the intention was to reuse some of the test data from that project to identify a model for this project. The best approach for installing the model in the simulator was not determined ahead of time. One option was to implement it using the standard Ovation function blocks such as lags and gains. If the model was found to be relatively simple, this could be straightforward. Other options were also available, using the Advanced Control Process Toolkit or a special simulation processor.

Task 4: Design Model Predictive Controller

The MPC design was completed using the Advanced Control Process Toolkit. The outputs of the design process are the matrix coefficients required by the MPC function block. Engineering judgment was required in the design process to properly weight the loop errors and control actions to achieve the best overall performance. Real-world constraints were also factored into the design.

Task 5: Test Model Predictive Controller on the Simulator According to the Test Plan

Once the model predictive controller was implemented in the simulator, it was tested using both a formal test plan and *ad hoc* tests. A written test plan was prepared and approved by all parties. The test plan incorporated normal operating scenarios as much as possible. The purpose of the testing was to determine whether the model predictive controller provides better performance than the conventional PID controller. Performance measures include speed of response, stability, and robustness.

Task 6: Evaluate Test Results

The results of the simulator testing were evaluated by Southern Company to determine whether to proceed with the implementation of the model predictive controller in Gaston unit 3.

Task 7: Prepare Progress Report

This EPRI progress report was prepared in the first phase of the project.

Phase II: Implementation and Testing in Gaston Unit 3

Task 8: Install Ovation Advanced Control Process Toolkit in Gaston Unit 3

The Ovation Advanced Control Process Toolkit will be installed in the Gaston Unit 3 Ovation DCS. This may require a unit outage to do.

Task 9: Modify Steam Temperature Logic for Model Predictive Controller

The MPC function block will be installed in the DCS. The existing logic will be modified to interface it with the new model predictive controller. The configuration of the model predictive controller and the logic changes for the interface should be essentially identical to those tested on the simulator in phase 1.

Task 10: Test Model Predictive Controller

A new test plan will be developed for the plant testing. It will include closed loop step tests and load ramps if possible. Normal operation will also be included in the evaluation process.

Task 11: Prepare Final Report

A final project technical report will be prepared for publication.

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MODEL IDENTIFICATION TESTING

A model predictive controller uses a process model in both its design and operation. There are several possible methods for developing a model of the process being controlled, and for this project, the model will be developed based on actual plant test data. The technique is called *model identification* or *system identification* and is widely used in control system design and analysis.

Identification consists of plant testing, usually in open loop mode (control system in manual mode) but sometimes in closed loop mode. The input signal can be a simple step change or a more complex signal such as a series of steps or a sine wave. It is used to excite the system so that the natural characteristics of the system can be observed. Input and output data are collected during the test, and the data are analyzed using one or more computerized methods. Commercial software packages, such as Matlab, provide extensive tools for system identification. The methods can be parametric or nonparametric. When using a parametric method, the user must specify a model structure or possibly a family of structures. Each possible structure has one or more parameters associated with it, and the identification software attempts to find the set of parameters that allows the model to best fit the test data.

Plant and Process Description

Gaston unit 3 is a 250-megawatt (MW) unit that began operation in 1962. The boiler is a coal-fired Babcock & Wilcox drum type with front and rear wall burners. The fuel is provided by six ball and race pulverizers with gravimetric feeders. The turbine is a General Electric cross-compound type.

Superheat temperature is controlled by left- and right-side desuperheating sprays, and each desuperheater has two identical spray valves in parallel (Figure 2-1). The two valves are driven by the same controller, but the second valve does not begin opening until the first valve is 25% open. The boiler is equipped with two gas recirculation fans to control reheat temperature. The unit also has reheat spray valves, but they are no longer used.

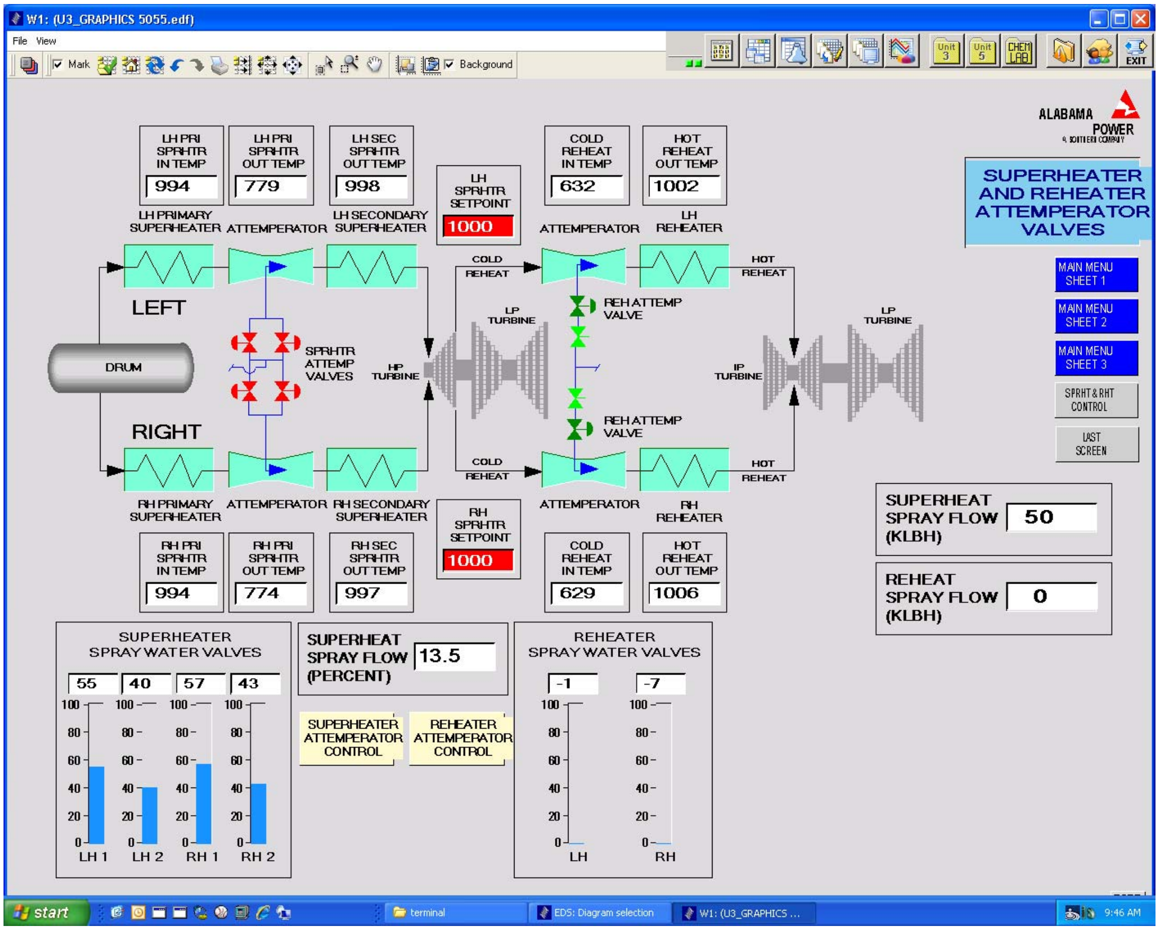

Figure 2-1
Process overview

The boiler control system is an Emerson Ovation system installed in 2007. The superheat steam temperature control strategy is a conventional cascaded control system using desuperheater outlet temperature for inner loop control and final steam temperature for outer loop control. No feedforward control is used. The reheat temperature control is also conventional with a single controller for both gas recirculation fans and inlet vanes. Normally the plant operates only one fan at a time, and the inlet vane position has a high limit of 40%.

One somewhat unusual control strategy in the unit is the fuel control. The fuel is controlled by changing the primary airflow to the pulverizers. This provides a quick response in the fuel to the furnace by delivering some of the pulverized coal inventory to the burners. The coal feeders are used to maintain the differential pressure across the pulverizer at a setpoint, which varies with primary airflow. This type of fuel control strategy was originally used when two-speed table feeders were supplied rather than variable-speed gravimetric feeders because, with table feeders, there is no direct measurement of fuel flow rate available.

Model Identification Tests

Tests were performed in the plant to produce data for identifying process models to be used in the MPC design. The identification tests consisted of a series of open loop step response tests of the superheat temperature controller output and the reheat controller output. In addition, other step tests on disturbance variables such as fuel flow, airflow, and steam flow were planned but not done during the testing described here. The complete test plan is included in Appendix A. Some modifications to the test plan were necessary during the tests to accommodate plant needs and scheduling constraints. Additional tests will be performed at a later date. A brief summary of the tests is provided here.

Tests were done on the superheat temperature control by placing the spray valve manual/automatic station in manual mode and making step changes in the spray valve position demand. There is one control loop for the left-side spray and one for the right side. Each side has two spray valves in parallel (Figure 2-2). The controller output drives both spray valves (Figure 2-3), one directly and one through a function generator. The function generator is set to begin opening the second spray valve at 25% demand and have it fully open at 100% demand. For the initial tests, the fuel and air control were kept in automatic mode, but the megawatt and throttle pressure control were placed in manual mode. In later tests, the fuel flow (primary air dampers) and airflow were also placed in manual mode. Tests were done on both the left- and right-hand sides with the unit at two different loads, 100% and 68%. It was not possible to do tests at minimum load because of the operating needs of the plant and time constraints. The step sequence (Figure 2-4) for the tests at 100% load was two steps up followed by two steps down. This allowed any hysteresis in the valve positions to be identified. The small spikes in the valve position data are caused by small disturbances in the valve positioner. The test sequence at 68% load was one step up and one step down because the hysteresis, if any, was already identified by the first tests. Similar step tests were done on the reheat control by stepping the gas recirculation fan damper demand down, up, and down again (Figure 2-5) at 68% load. It was not possible to do these tests at 100% load because the gas recirculation fan is not needed at full load.

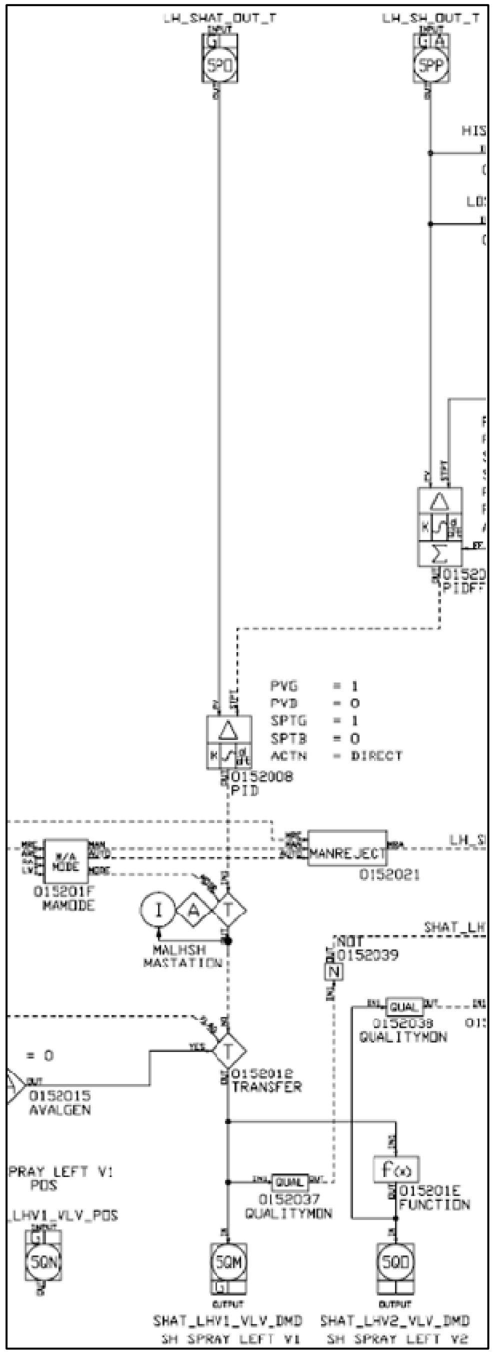

Figure 2-2
Section of superheat control schematic

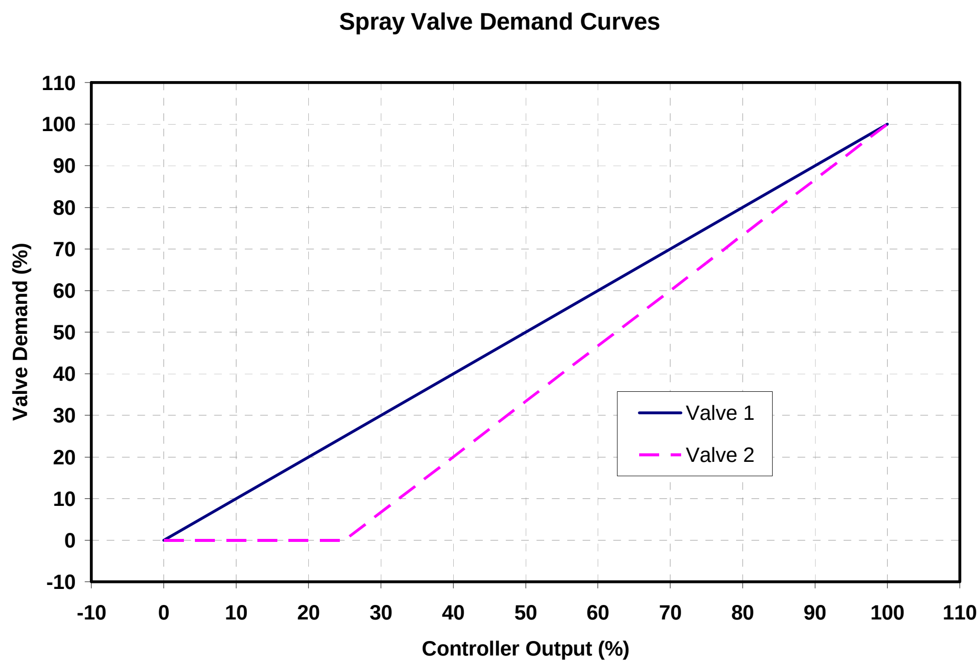

Figure 2-3
Superheat spray valve demand curves

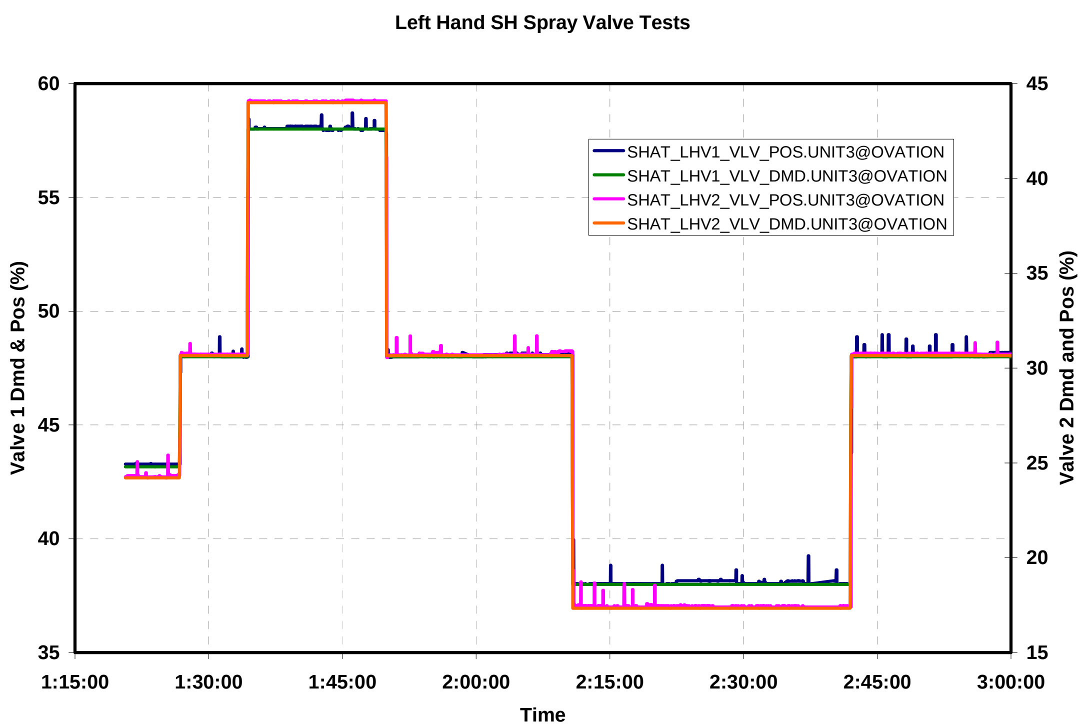

Figure 2-4
Left-hand spray valve test steps

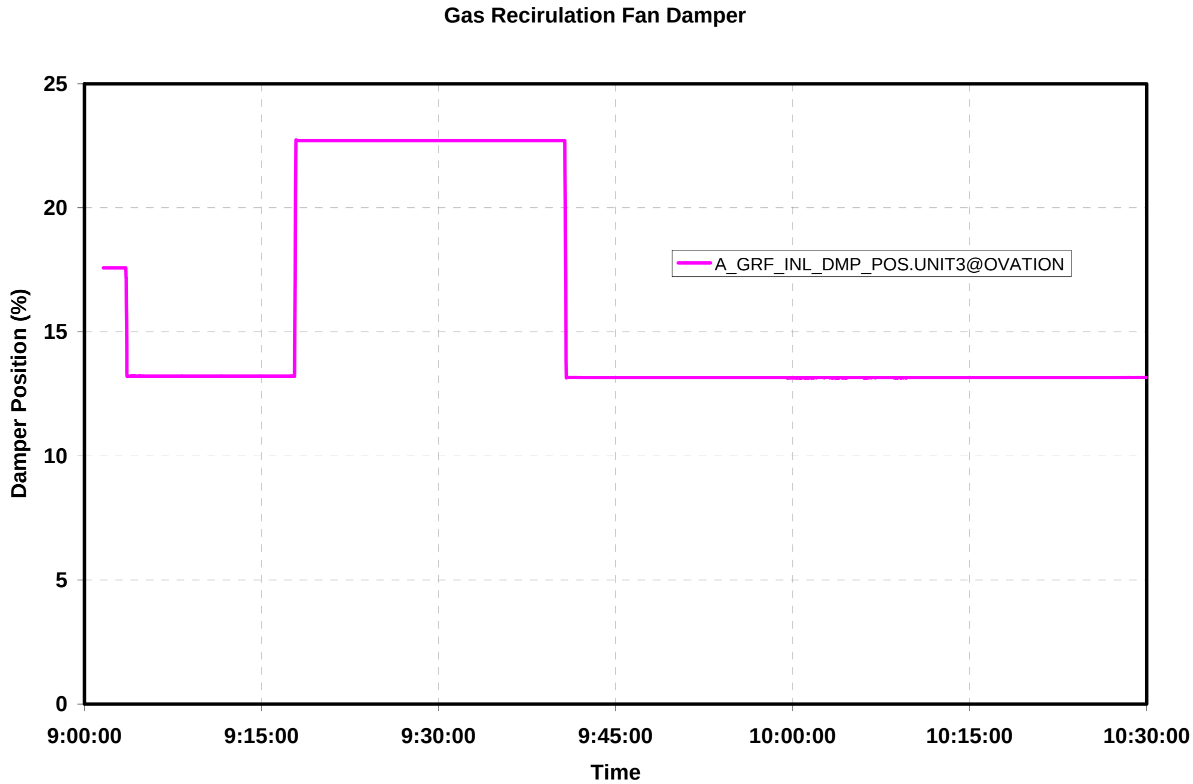

Figure 2-5
Gas recirculation fan step tests

Data from the test were collected in three different ways. An Ovation trend was configured with approximately 50 data points of interest. The trend was configured with a 1-second update rate and was saved as a tabular trend every 10 minutes. These tabular trend files are just text files in a space-delimited format and can easily be concatenated and loaded into Excel. The second collection method was through an overspeed protection controller (OPC) connection between the Ovation system and a notebook computer. OPC server software was already installed in the Ovation system and the Matlab OPC toolbox software was installed on the notebook. A small Matlab program was written to collect the same 50 points as on the trend also at a 1-second update rate. The last collection method was the plant archive system. The scan rate of most of the points of interest was changed to 1 second for some earlier tuning work on this loop. However, some of the points had larger deadbands than ideal for this type of testing, so these data were primarily used as a backup. Using three data collection methods was more than really necessary but did ensure that no test data were lost.

In addition to the open loop step response tests, several other closed loop response tests were also performed for other purposes. These additional test results may also be useful for identification and validation of process models.

In the second round of testing, several tests are planned to identify disturbance functions for other process variables such as fuel flow, airflow, gas recirculation fan, and turbine load.

Model Identification Results

Data from one of the spray valve step tests are shown in Figure 2-6. It is apparent that the steam temperatures are not very steady during the tests. After the first upward step, the final temperature actually goes up instead of down. The second step up and the first step down produce reasonable results, although at the end of the first step down, the final temperature is dropping instead of remaining steady. This unexpected behavior indicates that other disturbances are influencing the steam temperature. These disturbances persisted throughout the testing, and although attempts were made to identify the source of the upsets, it was never determined. The upsets also made the identification process more difficult.

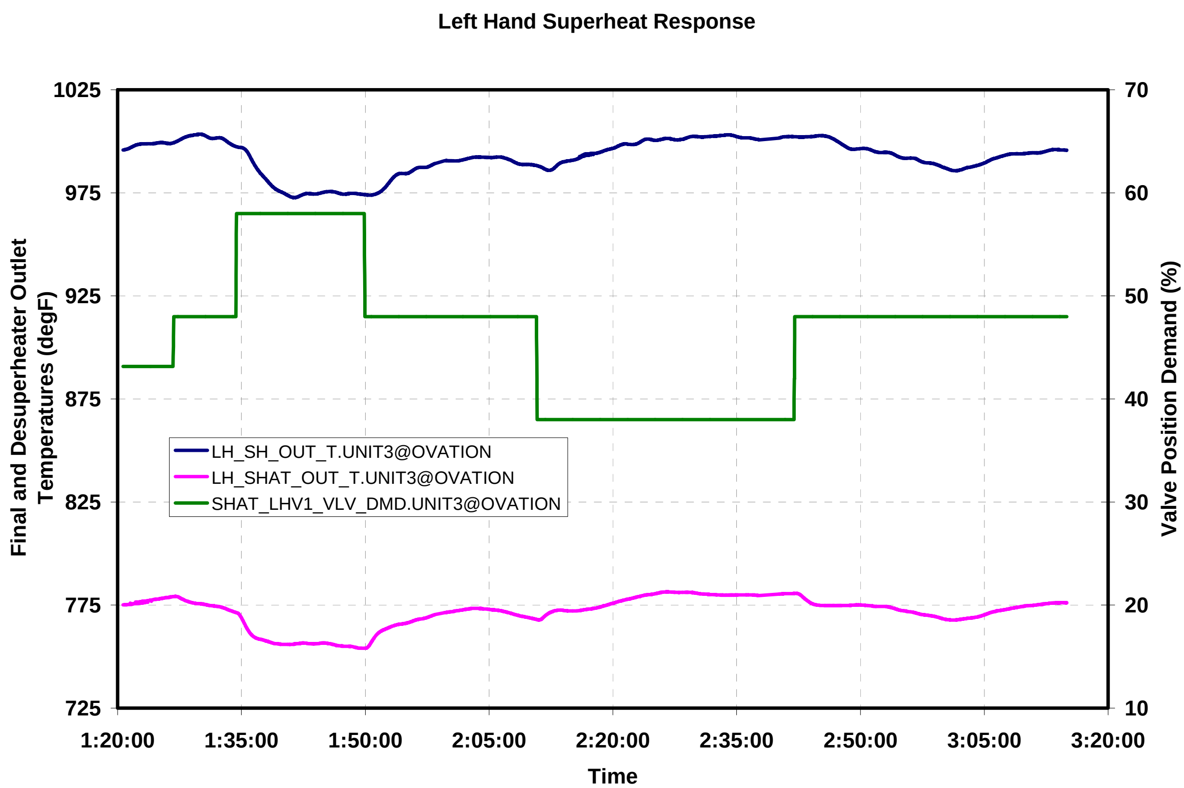

Figure 2-6
Final steam temperature and desuperheater outlet temperature responses to spray valve step changes

During the first round of testing, only the spray valve step response tests were performed. The data were first imported into Matlab and then into the Matlab System Identification Toolbox graphical user interface for system identification (Ident). The Ident graphical user interface provides a convenient interface for most of the Matlab system identification functions. The user may preprocess the data to remove means, designate one subset of the data for identification and another subset for validation, and select the model structure from several different types of models and other details. For this initial modeling effort, process model type was selected. The type selected was a first- or second-order plus deadtime model. An integrating type of model can also be specified. Both first- and second-order models were developed.

A comparison of the superheat steam temperature test data and the predicted data from one model is shown in Figure 2-7. The model shown here is a first-order with deadtime. The model parameters are a gain of −1.35, a time constant of 235 seconds, and a deadtime of 60 seconds.

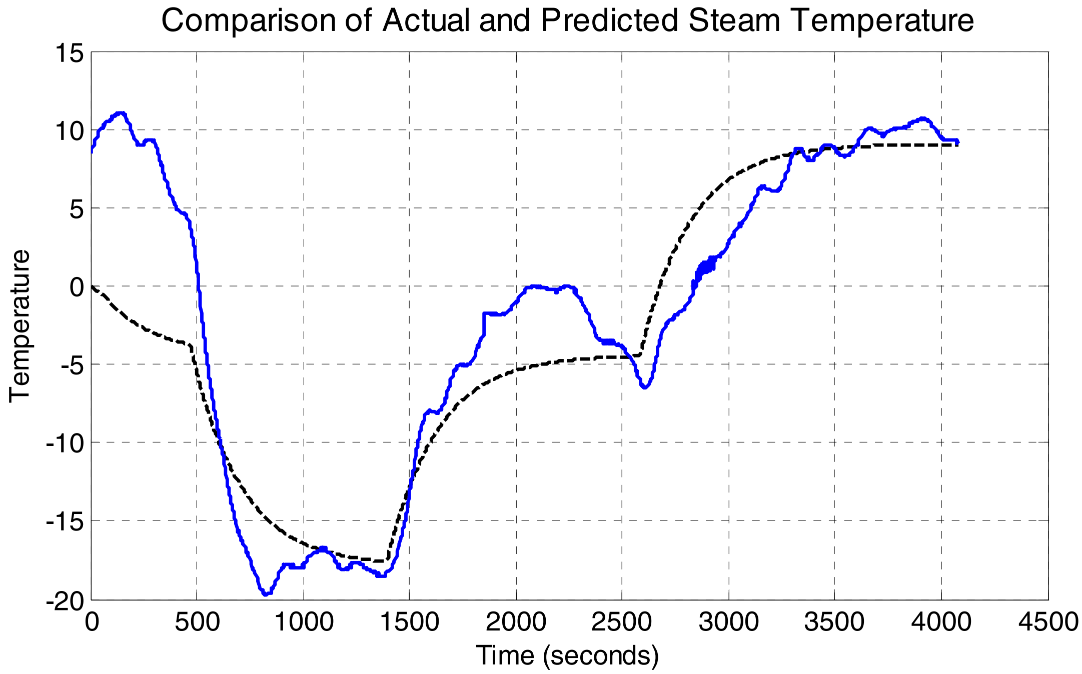

Figure 2-7
Comparison of test data (solid line) with model prediction (dashed line) for superheat temperature spray valve step test

3

MPC IMPLEMENTATION IN THE SIMULATOR

Simulator Description

The simulator used in this project is a small Windows-based Ovation system consisting of one nonredundant Ovation controller with no hard input/output system, one operator workstation, and one software server. The simulator is set up in Southern Company's DCS Laboratory in Birmingham, AL. The Ovation software for the simulator is version 5.4.

Installation of the Ovation Advance Process Control Toolkit

Before the Advanced Process Control Toolkit could be installed, the Ovation controller had to be upgraded from a standard controller to an advanced controller. This is simply a software upgrade, no new hardware was required. Although the upgrade and software installation process should have been relatively simple, it ended up taking several weeks to complete. Part of the problem was that some key personnel were not available at certain times, and there was some confusion about getting the proper license installed for the system. After the software was installed and the license was correct, the controller would still not execute a program, although it would accept downloads. The flash memory on the controller had to be cleared and reloaded to fix the problem. The simulator has operated without any problems since then.

Configuration of the Control System and Simplified Process Model

To test the integration between the existing PID-based control logic and the new MPC-based logic, it was necessary to install both sets of logic in the simulator.

Moving the Existing Steam Temperature Logic

The existing PID-based logic sheets were exported from the Gaston unit 3 control system and imported into the simulator. This worked but turned out to be a mixed blessing because all the point names associated with inputs and outputs were renamed by the Ovation Control Builder software when they were imported into the simulator system. Also, much of the existing logic was related to alarming or interlocks, which were not needed for the simulator testing. As a result, some of the existing logic was removed to simplify the configuration and the drawings. Also, new point names were assigned to the key inputs and outputs.

The existing logic had to be modified to accept the new model predictive controller logic and to interface with the simplified process model blocks. A selection switch was installed just upstream of the existing manual automatic station with one input to the switch coming from the PID-based control and the other input coming from the model predictive controller. The operator can use the switch to select which controller is in service at any time. Refer to Figure 3-1 for the superheater control logic implemented in the simulator.

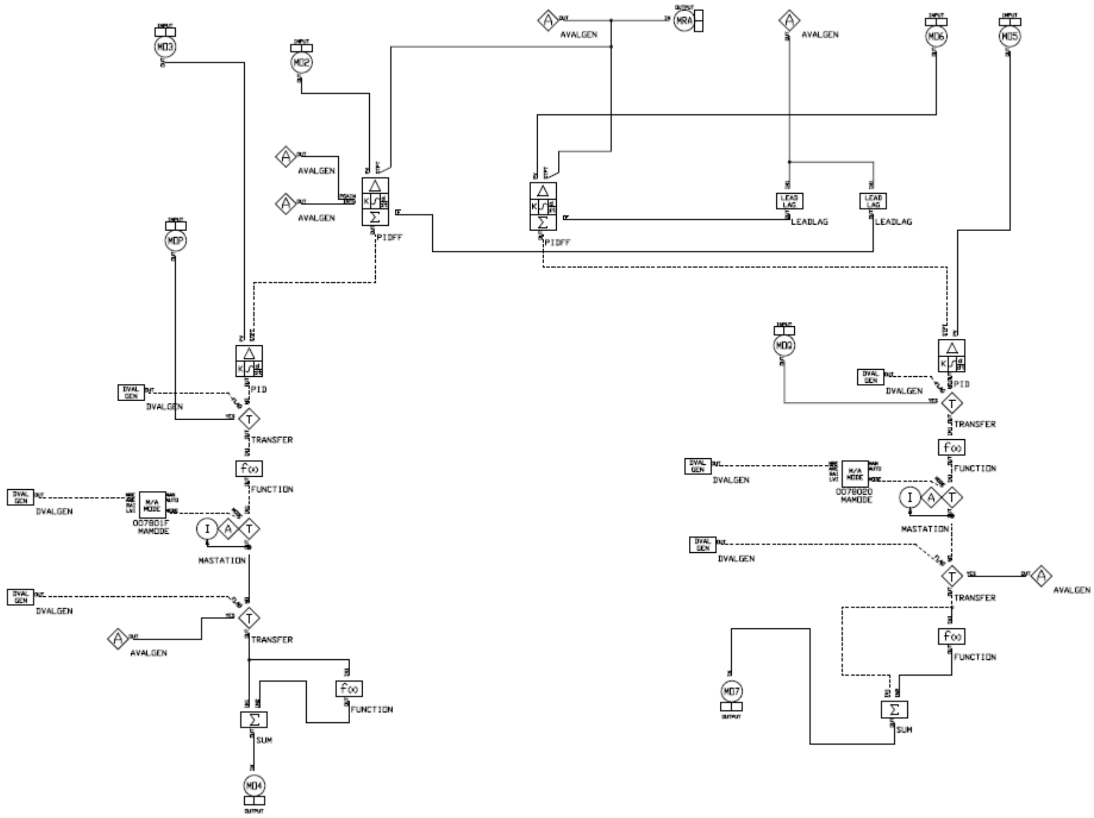

Figure 3-1
Superheater control logic implemented in the simulator

MPC Configuration

The model predictive controller is implemented in a single software block. It can have up to five manipulated variables, six control variables, and five disturbance variables. The block contains two primary functions. The prediction function computes the future behavior of the process based on the process model defined in the controller and the trajectory of the manipulated variable. The optimizer function finds the best trajectory of the manipulated variables to minimize a quadratic control cost function tuned by the user.

Because of the complexity of the MPC algorithm, a large number of parameters must be specified to configure the controller. As a result, it is not really practical to manually enter all the parameter values. The Advanced Control Process Toolkit includes a Model Builder program that produces a configuration data file that can be read by the MPC algorithm. The Model Builder program can identify a process model based on test data, or the user can enter a process model developed by another system such as Matlab.

The MPC algorithm has several parameters that can be adjusted by the user to improve the control response. The MPC algorithm operates with two different horizons, prediction and control. These are also referred to as the control variable horizon and the manipulated variable horizon, respectively. The prediction horizon is how far into the future the controller will compute the control variable response. The control horizon is the interval over which the manipulated variable trajectory will be optimized. The optimizer will find the manipulated variable trajectory, which minimizes the cost function over the prediction horizon. The prediction horizon should be set to the sum of the control horizon and the steady-state response time of the process. If the process can be represented by a first-order response plus a deadtime, then the steady-state response time will be approximately the sum of the deadtime and four times the time constant of the process. This ensures that the predicted process response will reach steady state within the prediction horizon. The MPC algorithm has a maximum control horizon of 10 steps to limit the computational load on the control processor. Also, the MPC algorithm does not necessarily run at the same cycle time as the regulatory control functions, with the cycle time selection of the MPC being dependent on the response time of the process. For this testing, the MPC controller cycle time was set to 10 seconds.

The user can also tune the controller by specifying relative penalties for control variable error and change in manipulated variable. If the response of one control variable is too sluggish, the user can assign a larger penalty to that control variable, which will alter the control design to tighten that variable's response. For a multivariable application, the weighting parameters are matrices. For a single-input, single-output system, the weighting parameter is a scalar. The control variable weighting matrix is called the Q matrix and the manipulated variable weighting matrix is the R matrix.

For the application in the simulator, the model predictive controller is configured with one control variable, one manipulated variable, and one disturbance variable. Consideration was given to using one MPC algorithm to control both the left- and right-side superheat spray valves, but there did not seem to be any compelling reason to use this approach. Additional disturbance variables will likely be added when additional plant testing is permitted and more disturbance data can be collected. Until then, the single disturbance variable will allow some testing of the MPC's disturbance rejection capabilities.

Consideration was also given to using the desuperheater outlet temperature in the model predictive controller, but it was not a control variable and would not work as a disturbance variable because it would be affected by the manipulated variable.

Simplified Process Model

A simplified process model was configured in the Ovation controller to verify the functionality of the model predictive controller and to provide an idea of how its performance compares with a PID controller (Figure 3-2). The process model included four first-order lag plus deadtime models. The four models are superheater outlet temperature, desuperheater outlet temperature, superheater disturbance, and desuperheater disturbance.

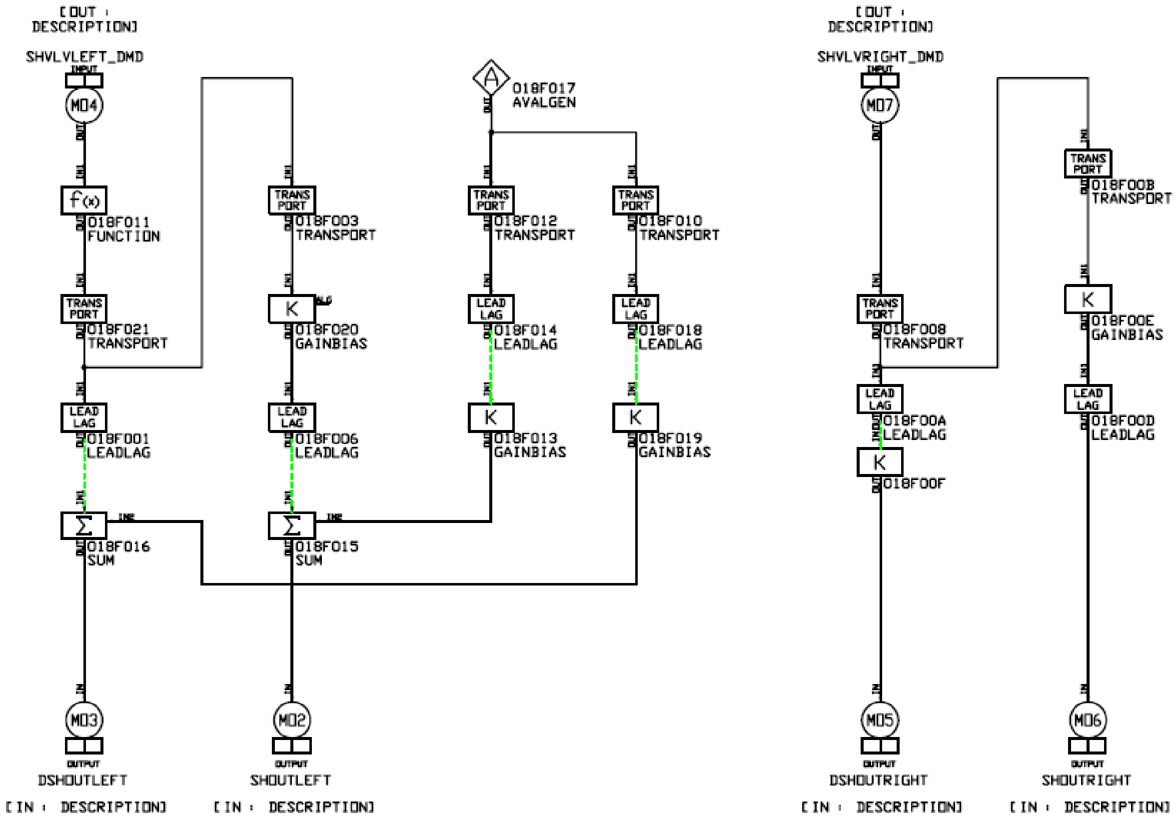

Figure 3-2
Simplified process model on simulator

The parameters for each of the models in this application are shown in Table 3-1. You may have noticed that the desuperheater outlet temperature model time constant is 90 seconds in Table 3-1. This is unusually long for this application, and the cause of this unusual response time is being investigated. A definitive answer has not yet been found.

Table 3-1
Simplified process model parameters

	SH Outlet	DSH Outlet	SH Disturbance	DSH Disturbance
Gain	−1.2	−1.1	1.0	0.5
Time constant	120 s	90 s	45 s	20 s
Deadtime	45 s	20 s	15 s	10 s

Notes:

SH means superheater; *DSH* means desuperheater.

4

SIMULATOR TEST RESULTS

The model predictive controller was implemented and tested on a simulator based on a DCS platform. The tests were intended to verify the functionality of the algorithm and provide some insight into the performance capabilities of the technique. The interface between the existing PID-based logic and the new MPC logic can also be verified. Performance comparisons between the PID control and the MPC were also included. Because the process model used in the simulator is quite simple, the precise performance of the model predictive controller cannot be determined by the simulator testing.

Test Procedure

Testing consisted of tuning tests, set point step response tests, disturbance rejection tests, and robustness tests. Table 4-1 lists all the tests that were or will be conducted on the simulator.

Table 4-1
Control system tests conducted on the simulator

Test Category	Test Description	Purpose
MPC tuning	Disturbance rejection, $R = 100$, $Q = 1$	Quantify effects of Q and R
MPC tuning	Disturbance rejection, $R = 10$, $Q = 1$	Quantify effects of Q and R
MPC tuning	Disturbance rejection, $R = 1$, $Q = 1$	Quantify effects of Q and R
MPC tuning	Disturbance rejection, $R = 1$, $Q = 10$	Quantify effects of Q and R
MPC tuning	Disturbance rejection, $R = 1$, $Q = 100$	Quantify effects of Q and R
PID disturbance rejection	Disturbance rejection	Comparison with MPC
MPC robustness	Disturbance rejection with process model time constant doubled	Comparison with PID
MPC robustness	Disturbance rejection with process model gain doubled	Comparison with PID
PID robustness	Disturbance rejection with process model time constant doubled	Comparison with MPC
PID robustness	Disturbance rejection with process model gain doubled	Comparison with MPC
MPC performance	Disturbance rejection using MPC controller with disturbance variable input	Assess benefits of including disturbance variables in model predictive controller
MPC performance	Set point step response	Performance assessment
PID performance	Set point step response	Performance assessment
MPC functionality	Tracking when PID in control	Verify bumpless transfer

Simulator Test Results

MPC Tuning Tests

The MPC algorithm uses a quadratic cost function for the optimization of the control trajectory. The cost function includes the control variable deviation from set point and the movement of the manipulated variable. Each of these terms has a weighting parameter associated with it that the designer can adjust to tailor the control response to the design specifications. The parameter associated with the control error is called the Q matrix and the parameter for the manipulated variable is called the R matrix. For this MPC testing, because the control is single input/single output, each parameter is a single number rather than a matrix. The impact of these matrices on performance is greatly affected by the scaling of the process variable. To better understand the impact of changing the weighting parameters, a series of tests were run in which the two weighting parameters were varied. The values ranged from $R = 100$ and $Q = 1$ to $R = 1$ and $Q = 100$. The results (Figure 4-1) show that the response gets faster as Q is made larger than R.

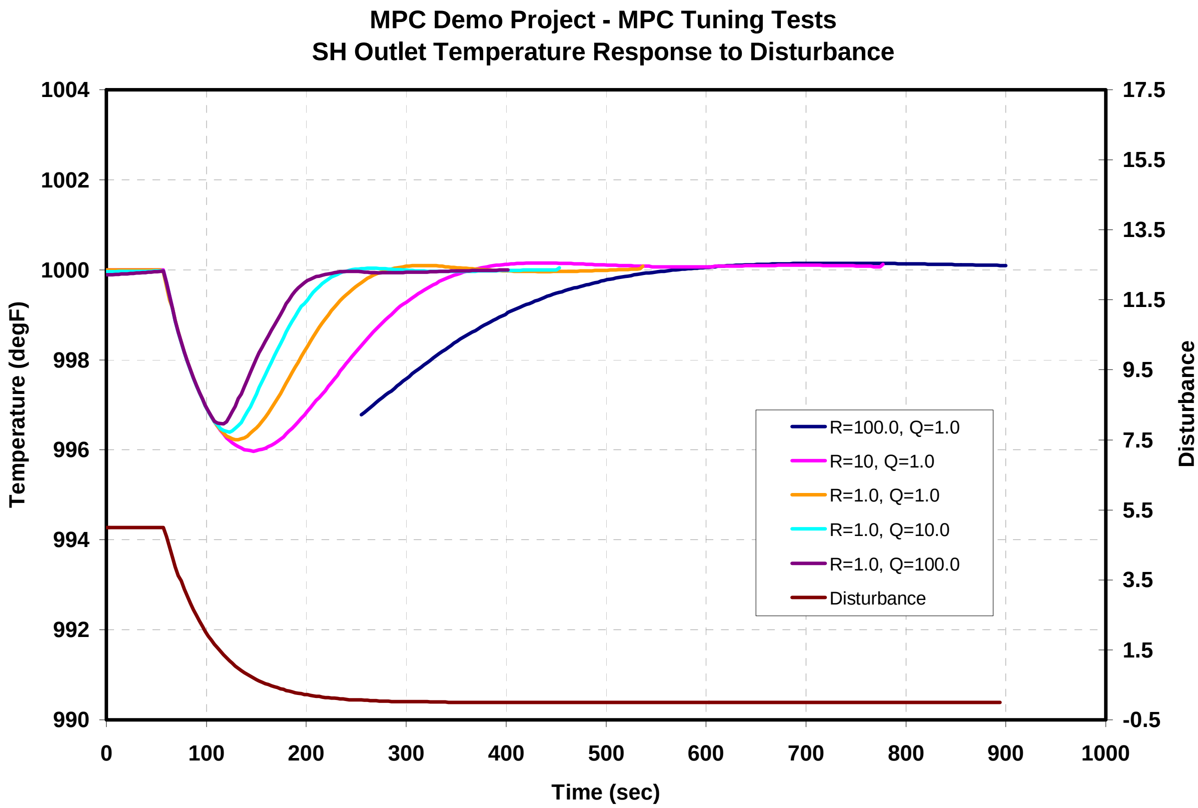

Figure 4-1
Disturbance rejection response of the model predictive controller as the weighting parameters *R* and *Q* are varied

When the response is the fastest, the manipulated variable is moving quite aggressively (Figure 4-2) and is probably faster than most plants would allow. For this reason, the tuning where *R* and *Q* were both 1.0 was used for the rest of the tests.

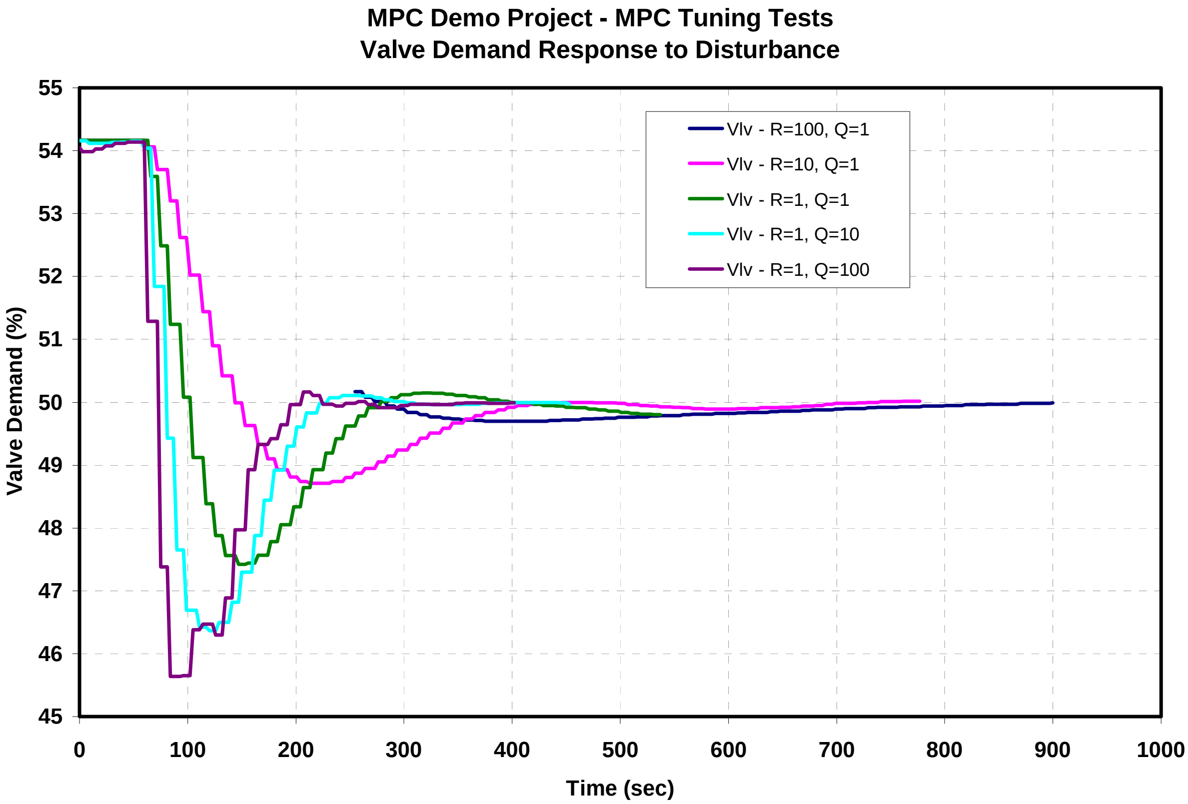

Figure 4-2
Manipulated variable movement during disturbance rejection as weighting parameters *R* and *Q* are varied

Disturbance Rejection Comparison

Disturbance rejection tests were run on the model predictive controller and the PID controller to compare performance (Figure 4-3). The weighting parameters for the model predictive controller were set at 1.0 for both *Q* and *R*. The outer loop PID tuning parameters were set at a proportional gain of 4.5 and an integral time of 30 seconds. The inner loop PID tuning parameters were a proportional gain of 30 and integral time of 4 seconds. As shown, at least for this condition, the model predictive controller was much more effective.

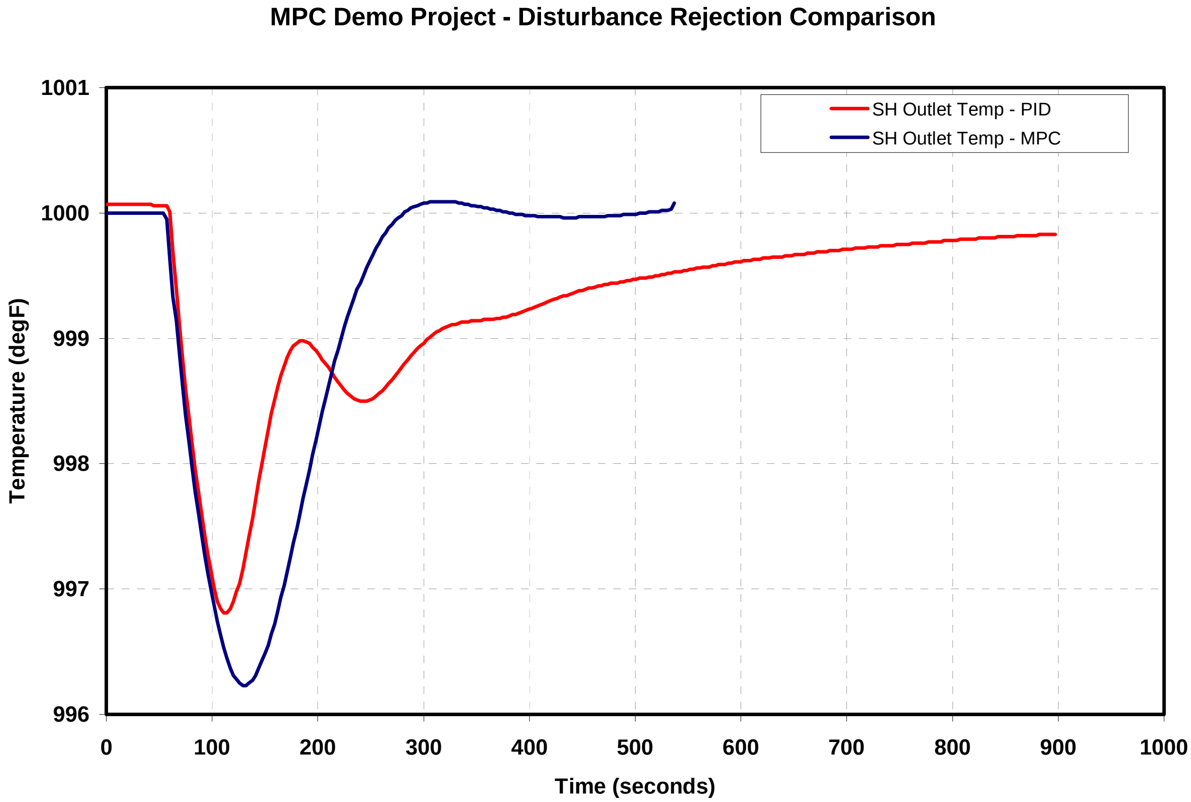

Figure 4-3
Comparison of MPC and PID disturbance rejection

Robustness Tests

Because power plant characteristics change over time, it is important that the plant's control system performance not degrade too much as a result of the plant changes. To investigate the robustness of the MPC algorithm and the PID controller disturbance rejection, tests were run in which the characteristics of the simplified process model were altered. For the first test, the time constant of the process model was doubled from 120 seconds to 240 seconds. In the second test, the process model gain was increased by 50% from –1.2 to –1.8. The results of the time response change tests (Figures 4-4 and 4-5) show that both controllers can tolerate these changes. The magnitudes of the disturbances are the same in both tests, only the directions are different. In fact, the performance of the PID controller is actually better when the time constant is increased. This is because the ratio of deadtime to time constant in the process decreases as the time constant is increased. The larger this ratio becomes, the more difficult it is for a PID controller to control the process. Both controllers can also tolerate the process gain change.

Summary of Simulator Tests

Testing on the simulator is intended to functionally test the MPC algorithm and its interface with the existing steam temperature control logic. It is not intended to be an exhaustive performance evaluation, although some insight into the MPC performance and tuning is obtained from the tests. A few additional simulator tests will be performed before the model predictive controller is installed in the plant. These will include the tracking ability of the model predictive controller when the PID controller is active and some more robustness tests.

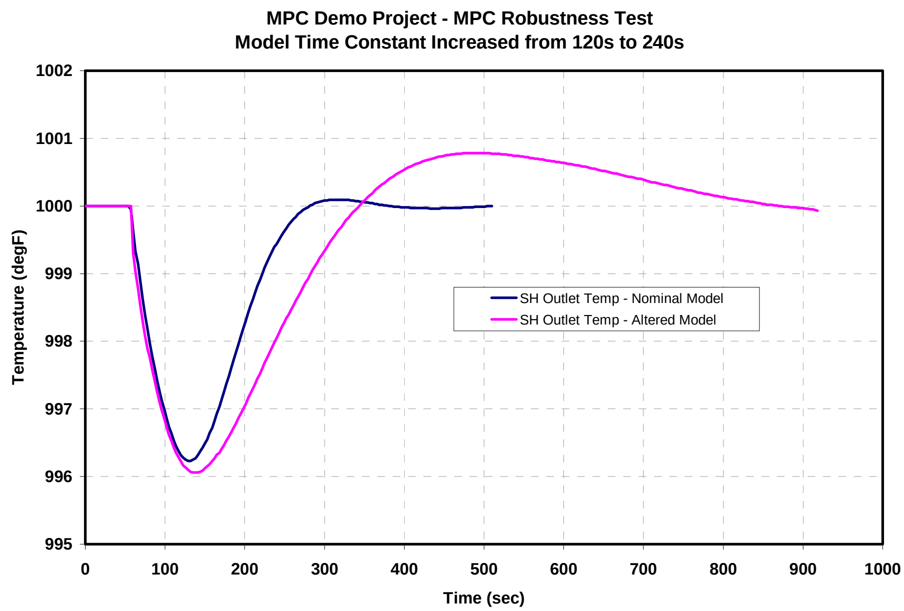

Figure 4-4
Model predictive controller performance during disturbance rejection with nominal and altered process models

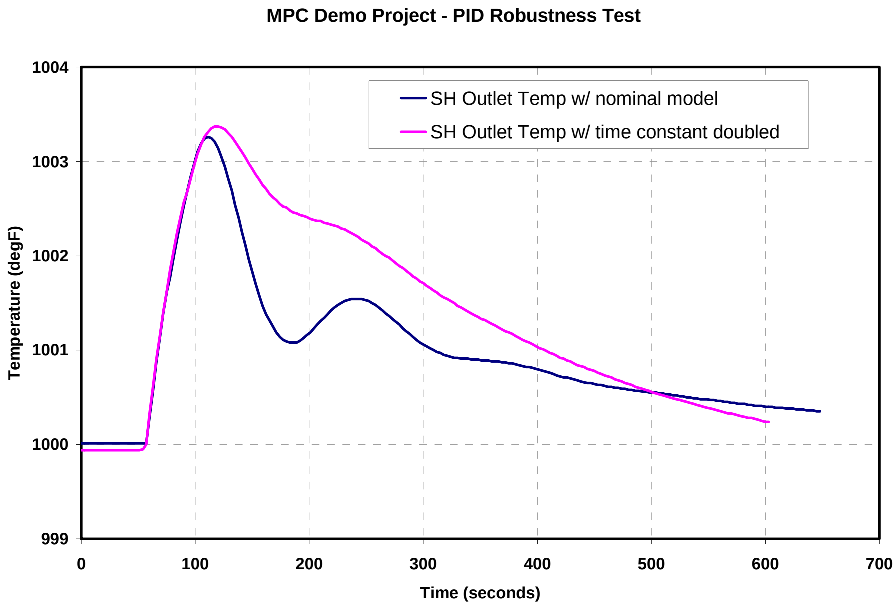

Figure 4-5
PID controller performance during disturbance rejection with nominal model and model with time constant doubled

5
CONCLUSION

A project to demonstrate a controller resident model predictive controller is under way at Southern Company. A series of tests were run on Alabama Power Gaston plant unit 3 to identify the superheat steam temperature response to spray valve changes. The data from these tests were used identify process models that will be used in the model predictive controller design process. A checkout simulator was developed using an Ovation DCS. The checkout simulator allowed the model predictive controller to be tested in a realistic environment to verify the functionality of the advanced system. Several tests were done to quantify the selection of weighting parameters for the MPC. Other tests were done to compare MPC performance with the conventional PID-based control system.

The controller resident MPC algorithm provides a less complex implementation than model predictive controllers, which require a special process for the operation. Although documentation is somewhat limited, the toolkit provided with the controller is adequate for design purposes.

In subsequent project tasks, after testing is completed on the simulator, the MPC will be implemented in the real plant and tested. The existing PID control will also be available in the plant for comparison purposes. All results will be documented in a final technical report.

6
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A
MODEL IDENTIFICATION TEST PLAN

Gaston Unit 3 Dynamic Response Test Plan

Background

Southern Company and EPRI are collaborating on a project to demonstrate the use of an advanced control method called MPC on a fossil power plant. The host site for the demonstration will be Alabama Power Gaston plant unit 3. The control application will be superheat and reheat steam temperature control using spray valves and gas recirculation. As the name implies, the MPC method uses a process model in its design. For this project, the model will be developed using system identification from data gathered from the actual plant. This test plan describes the testing necessary to produce the data required by the identification technique.

Test Description

When testing a process for model identification purposes, the process must be excited so that the inherent dynamic response of the system is exposed. It is also preferable to have the control system in manual mode so that the dynamics of the control system do not mask the dynamics of the process. Several types of excitation signals can be used for the testing, but simple step changes in the control actuator positions are the easiest to implement. Each actuator is stepped one at a time; thus, the effect of each is isolated from the others. Such tests are referred to as open loop step response tests. Because the dynamic response of the unit may change with load, it is desirable to perform the tests at nearly full load and also at a lower load, depending on the operating pattern of the unit. In this case, because the process being tested is steam temperature, the need for lower load tests will depend also on the ability of the boiler to make design steam temperatures at lower load. If the boiler cannot achieve design steam temperatures at lower load, then the testing is unnecessary.

Test Prerequisites

For the high-load test, the unit should be between 90% and 95% of full load and in a good steady-state condition. The unit should be off automatic generation control. The number/combination of mills in service should be consistent during the same-load test sequence.
The following control loops must be in manual mode:

- Superheat spray valves
- Gas recirculation fans
- Megawatt control
- Fuel flow control
- Airflow control

After the above control loops are placed in manual mode, the unit should be allowed to reach a good steady-state condition before beginning the tests. This will typically take about 30 minutes. If after 30 minutes, the unit has not reached a good steady-state condition, an attempt should be made to determine the cause of the continuing upsets.

The data archive system being used to store the data during the tests should be checked to ensure that each desired point is in the archive database and its storage parameters have adequate precision. Storage dead bands may need to be reduced during the tests to provide the desired precision in the stored data. Process data will be collected through a combination of the following mechanisms:

- OPC connection
- Manual log sheets
- Plant Aspen historian
- Fleetwide monitoring center Aspen historian
- Ovation tabular trends

Test Descriptions

Data points that should be collected for model identification are listed in Table A-1.

Table A-1
List of data points to be collected

Description	Ovation Name
Gross megawatts (MW)	TOTAL_MW
Throttle pressure	THROTTLE_PRESS
Throttle temperature (temp)	
Excess oxygen	SELECTED_O2
Steam flow/first-stage pressure	STEAM_FLOW
Primary air (PA) coal flow	PA_DMP_FUEL
Coal flow	OCB005B019-OUT
Airflow (total)	AIR_FLW_SUM
LH SH temp setpoint SP	OCB0152041-OUT
LH SH temp controller output (CO)	OCB0152009-OUT
LH SH temp process value (PV)	LH_SH_OUT_T
LH SH DSH temp SP	
LH SH DSH temp CO	OCB0152008-OUT
LH SH DSH temp PV	LH_SHAT_OUT_T
LH SH DSH spray valve 1 position	SHAT_LHV1_VLV_POS
LH SH DSH spray valve 2 position	SHAT_LHV2_VLV_POS

Table A-1 (continued)
List of data points to be collected

Description	Ovation Name
LH SH DSH spray valve 1 demonstration	SHAT_LHV1_VLV_DMD
LH SH DSH spray valve 2 demonstration	SHAT_LHV2_VLV_DMD
RH SH temp SP	OCB0152043-OUT
RH SH temp CO	OCB015200A-OUT
RH SH temp PV	RH_SH_OUT_T
RH SH DSH temp SP	
RH SH DSH temp CO	OCB015200F-OUT
RH SH DSH temp PV	RH_SHAT_OUT_T
RH SH DSH spray valve 1 position	SHAT_RHV1_VLV_POS
RH SH DSH spray valve 2 position	SHAT_RHV2_VLV_POS
RH SH DSH spray valve 1 demonstration	SHAT_RHV1_VLV_DMD
RH SH DSH spray valve 2 demonstration	SHAT_RHV2_VLV_DMD
SH spray flow	SH_SPRAYWTR_FLOW
RH temp SP	OCBSPREH-OUT
RH temp CO	OCB00D4002-OUT
RH temp PV	AVG_REHEAT
Gas recirculation damper position	A_GRF_INL_DMP_POS
Coal feeder A flow	A_FDR_FLOW
Coal feeder B flow	B_FDR_FLOW
Coal feeder C flow	C_FDR_FLOW
Coal feeder D flow	D_FDR_FLOW
Coal feeder E flow	E_FDR_FLOW
Coal feeder F flow	F_FDR_FLOW
Sootblower sequence (3-BLR-SB-RUN)	SB_RUN
Sootblower pressure	SOOTBLOWER_P
LH DSH SP bias	LHSPRAY_BIAS2
LH SH SP bias	LHSPRAY_BIAS1
RH DSH SP bias	RHSPRAY_BIAS2
RH SH SP bias	RHSPRAY_BIAS1

Test 1: High-load, right-hand (RH) superheat spray valve step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step RH superheat spray valve position up approximately 10% and wait 15 to 20 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step RH superheat spray valve position up approximately 10%.
3. Step RH superheat spray valve position down the same amount of the step up in 2.
4. Step RH superheat spray valve position demand down to the value before the test began.

Test 2: High-load left-hand (LH) superheat spray valve step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step LH superheat spray valve position up approximately 10% and wait 15 to 20 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step LH superheat spray valve position up approximately 10%.
3. Step LH superheat spray valve position down the same amount of the step up in 2.
4. Step LH superheat spray valve position demand down to the value before the test began.

Test 3: High-load gas recirculation damper step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step gas recirculation damper position up approximately 10% and wait 30 to 40 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step LH reheat spray valve position up approximately 10%.
3. Step LH reheat spray valve position down the same amount of the step up in 2.
4. Step LH reheat spray valve position demand down to the value before the test began.

Test 4: Low-load RH superheat spray valve step (optional)

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step RH superheat spray valve position up approximately 10% and wait 15 to 20 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step RH superheat spray valve position up approximately 10%.

Test 5: Low-load LH superheat spray valve step (optional)

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step LH superheat spray valve position up approximately 10% and wait 15 to 20 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step LH superheat spray valve position up approximately 10%.

Test 6: High-load gas recirculation damper step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step gas recirculation damper position down approximately 10% and wait 30 to 40 minutes for the response to complete. The step should be made by entering the new position demand digitally on the operator's console. This ensures a consistent rapid step change in position.
2. Step gas recirculation damper position up approximately 10% to return it to its original position. Wait 30 to 40 minutes for the response to complete.

Test 7: Airflow demand step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step airflow demand up approximately 3% and wait 30 to 40 minutes for the response to complete. The step should be made by entering the new demand digitally on the operator's console. This ensures a consistent rapid step change in demand.
2. Step airflow demand down approximately 3% to return it to its original position. Wait 30 to 40 minutes for the response to complete.

Test 8: Turbine valve step

Unit should be in steady-state conditions at a load between 90% and 95%.

1. Step turbine valve position demand up approximately 4% (~10 MW) and wait 30 to 40 minutes for the response to complete. The step should be made by entering the new demand digitally on the operator's console. This ensures a consistent rapid step change in demand.
2. Step turbine valve position demand down approximately 4% to return it to its original position. Wait 30 to 40 minutes for the response to complete.

Test 9: Closed-loop load ramp

For this test, all the control loops placed in manual before test 1 should be placed back in automatic mode.

1. Starting from a steady-state condition between 90% and 95% load, the unit should be ramped down at 2.5 MW/min to approximately 75% load.
2. The unit should be allowed to stabilize at 75% load for 30 minutes, and then the load should be ramped back up to its original load point at 2.5 MW/min.

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