

IMPROVED AVAILABILITY THROUGH EXTENDED RANGE CONTROLS

by

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ABSTRACT

Improved controls benefit power-plant availability through two primary paths: reduction of plant trips and life extension of critical components. Automatic controls generally are applied only at high plant loads - most units must revert to manual operation at low loads during startup and shutdown to maintain stable plant conditions. The application of model-based control and adaptive control algorithms extends the range of automatic control through these regions. These control algorithms can be readily implemented in distributed control systems, leading to improved availability, coupled with valuable fuel savings during startup.

INTRODUCTION

The improvement of power-plant control has been an ongoing effort since the introduction of central-station power plants. Performance history has established that poor control is a primary contributor to plant trips and premature equipment failures. Problems such as poor control of steam temperature have been plaguing the power industry. Steam temperature impacts the high-cost components of the power plant, including the superheaters, headers and turbines. Poor control of steam temperature can result in equipment life reduction and gross failures (1) and also plays a role in the problem of exfoliation (2).

Many utilities are upgrading to distributed control systems (DCS). However, most utilities have observed that an upgrade to new control hardware alone does not resolve the plant control problems. The control logic also must be enhanced to achieve control improvement.

Although models have been used for many years to evaluate and develop solutions to plant control problems, they could not be incorporated directly into the older pneumatic and analog control systems. With DCS, the direct application of model-based techniques is now practical.

This paper discusses Stone & Webster Engineering Corporation's (Stone & Webster's) model-based techniques for model reference feedforward (MRFF)

and adaptive control. These techniques were developed to solve client-specific control problems in applications where traditional controls could not suffice. They provide improved control over the entire load range and extend the range of automatic control to low load and startup.

EXTENDING AUTOMATIC CONTROL TO LOWER LOADS

Conventional automatic-control logic traditionally has been designed to provide responsive control at higher plant loads. At lower loads, control degrades due to changing plant-response characteristics. Large variations in plant parameters, and eventually unstable behavior (e.g., temperature oscillations), may result as the load is reduced, requiring a transfer to manual control. The control analyses conducted at Stone & Webster have identified the root causes of degraded control as: 1) poor performance of feedforward control; and 2) destabilizing control settings of feedback control.

Dynamic modeling, which has long been used as an analysis tool, resolves both of these control problems. First, MRFF has been developed, in which models provide precise feedforward signals. Second, models are used to adjust the settings for feedback control to maintain stable and responsive control over the entire load range.

MODEL REFERENCE FEEDFORWARD CONTROL

Stone & Webster has been extensively involved in the development of MRFF control algorithms, which were initially designed for an integrated boiler/turbine system. Specific algorithms have been designed for steam temperature control. These algorithms have been evaluated in a full plant simulation model and have been found to be extremely effective in reducing temperature transients.

A schematic of the modeled plant is presented in Figure 1. The dramatic improvements in temperature control, illustrated in Figure 2, are accomplished through the use of MRFF (see Figure 3).

The application of MRFF control is relatively straightforward. Potentially, any conventional feedforward signal can be directly replaced by an MRFF signal. The MRFF algorithm utilizes all relevant plant sensor signals and process models to develop a feedforward signal. This signal drives the final control element to maintain the process near setpoints. Feedback control is typically maintained to correct any residual offset of the process from setpoints.

The advantages of feedforward control are well established in the power industry. Many plant control systems have feedforward loops to provide



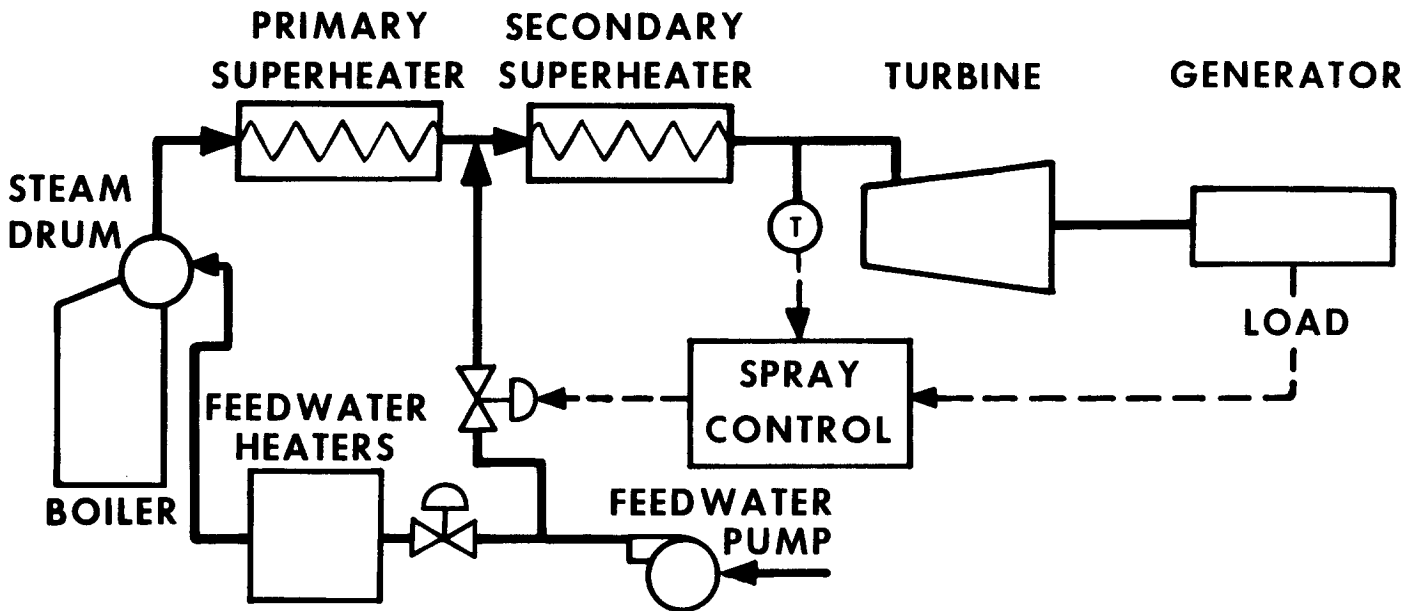


Figure 1--Process and instrumentation diagram.

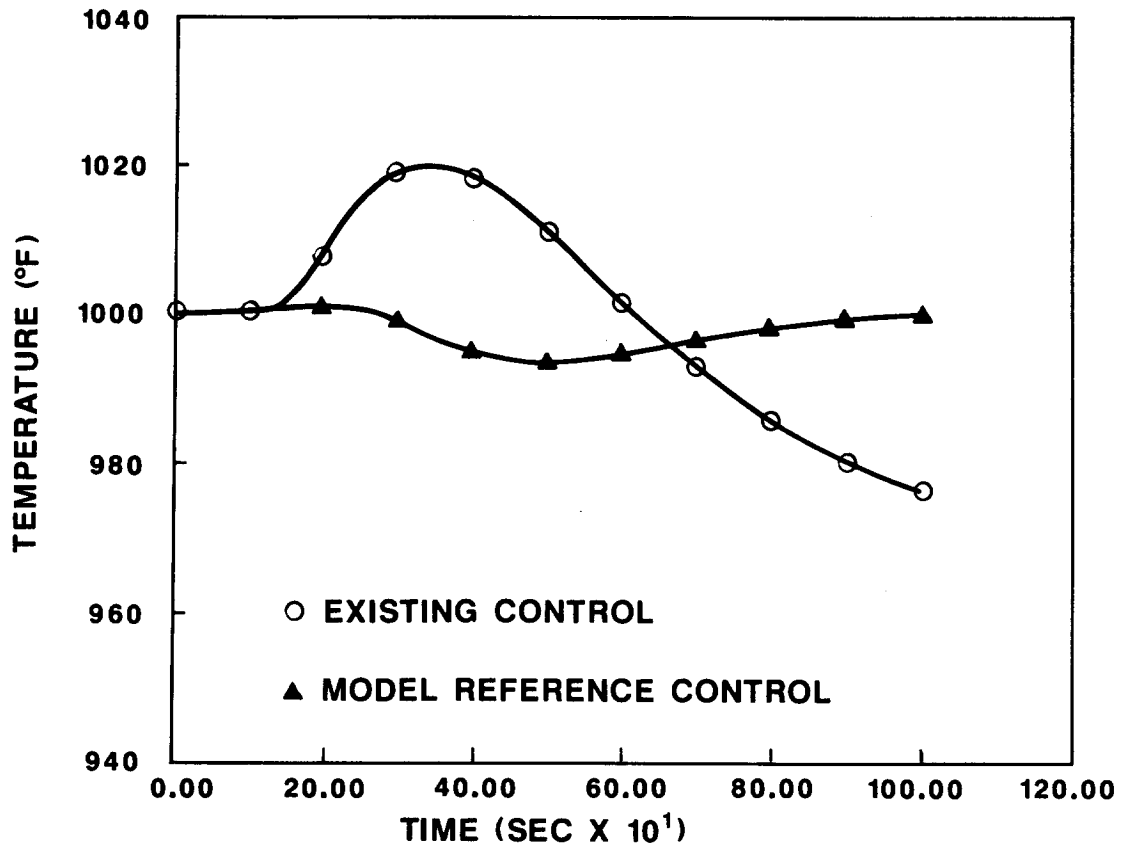


Figure 2--Alternative controls secondary superheat temperature.

some anticipatory signal to reduce process variations about the setpoints. The primary limitation of these traditional feedforward controls is that they are based on only a few sensors (typically one) and that relatively simple logic is applied. These limitations force the tuning of the control to be set for a typical operating scenario, which in turn limits the improvement in response and in the range of operation.

The ability of dynamic models to properly predict trends and provide reasonable predictions of process variables is the fundamental premise behind MRFF control. The system accesses all relevant data to predict the best control response to minimize deviations from process setpoints. The last step of achieving actual setpoints is left to feedback controls, which have well-established capabilities in correcting small offsets.

MRFF uses a modular modeling approach, in which each process or component is represented by a module and linked to other modules. Figure 4 illustrates the modules used to develop a feedforward signal for superheat spray control. Additional feedforward signals can be used by adding appropriate modules. Figure 5 illustrates the addition of MRFF to reheat spray control.

Another advantage of MRFF is the ease of tuning. The algorithms are based on engineering models and the contribution of each term can be readily calculated. The selection of tuning variables is based on the expected changes in the plant (e.g., the effect of soot on steam temperature control). The application of standard engineering equations and correlations separates this approach from black box controllers.

MRFF can be applied to virtually any system that has need of a feedforward index. These systems include the following:

- Steam temperature control
- Boiler firing control
- Steam turbine control
- Feedwater control
- Forced draft/Induced draft control
- Balance-of-plant controls (e.g., deaerator, heater, and condensor level)

Through the use of MRFF, a truly coordinated system control can be achieved. An integrated MRFF system, in conjunction with all relevant plant data, provides feedforward signals to each of the critical plant controllers, (see Figure 6). This approach provides for rapid plant maneuvering, while maintaining controllable parameters close to setpoints.

ADAPTIVE CONTROL

Adaptive control encompasses a wide variety of techniques. Two forms of adaptive control are discussed here: gain-scheduling proportional integral derivative (PID) controllers and self-tuning PID controllers. In conjunction with MRFF, either of these provides more than adequate control regulation.

Gain-scheduling PID controllers require an algorithm for the control settings. The development of this algorithm is based on the use of a model.

The development of the plant simulation model using a simulation language such as ACSL (4) provides the capability to perform frequency domain control analyses directly with ACSL or with add-on packages (e.g., CTRL-C (5)). Stone & Webster has extensively utilized the linear analysis capability of ACSL in support of simulation efforts. These analyses have been used primarily for stability assessment and controller gain selection. Generally, the best (or optimal) gain varies with the process throughput. By applying Root Locus or similar techniques, a method for gain selection at a particular operating point is established. By correlating the gain to an appropriate index (e.g., load demand), an adaptive control system is designed.

An adaptive control design of this nature can be combined with the MRFF approach to provide near optimal control. The adaptive portion of the control would ensure stable and responsive feedback control, while the MRFF would provide the anticipatory signal to limit the deviation from setpoints. It is anticipated that this control architecture can extend automatic control to the entire load range, including startup.

Self-tuning PID controllers differ from gain-scheduling PID controllers in regard to the control setting selection technique, in that self-tuning PID controllers use models on-line, in conjunction with the input and output measurements, to select stable and responsive control settings. The model is a general process model that is fairly representative of a broad spectrum of processes (6). The performance of a self-tuning PID controller should be comparable to that of a gain-scheduling PID controller.

IMPLEMENTATION IN A DCS

All modern DCSs consist of a conglomerate of microprocessor-based instrumentation that has as a minimum the following components:

- Input/Output subsystem
- Controller subsystem
- Video-display subsystem (operator/engineer)
- A computational resource

The controller subsystems that are available have a variety of algorithms that can range from simple Boolean logic to conventional PID loops to adaptive controllers. Some controllers' subsystems can provide programming capability in a high-level language.

The control engineer must configure the base regulatory control system in the controller subsystem, and also must make decisions as to where any supervisory control and/or computed algorithms will reside.

These decisions are dependent on the specific hardware proposed. Some vendors have controller subsystems that are limited by the number of analog outputs; others are limited by the number of calculations that can be provided at the controller levels. On the other hand, a device such as the "multifunction controller" (manufactured by Bailey Controls), can provide both the regulatory level control and the advanced control computations required. Also, the "application module"



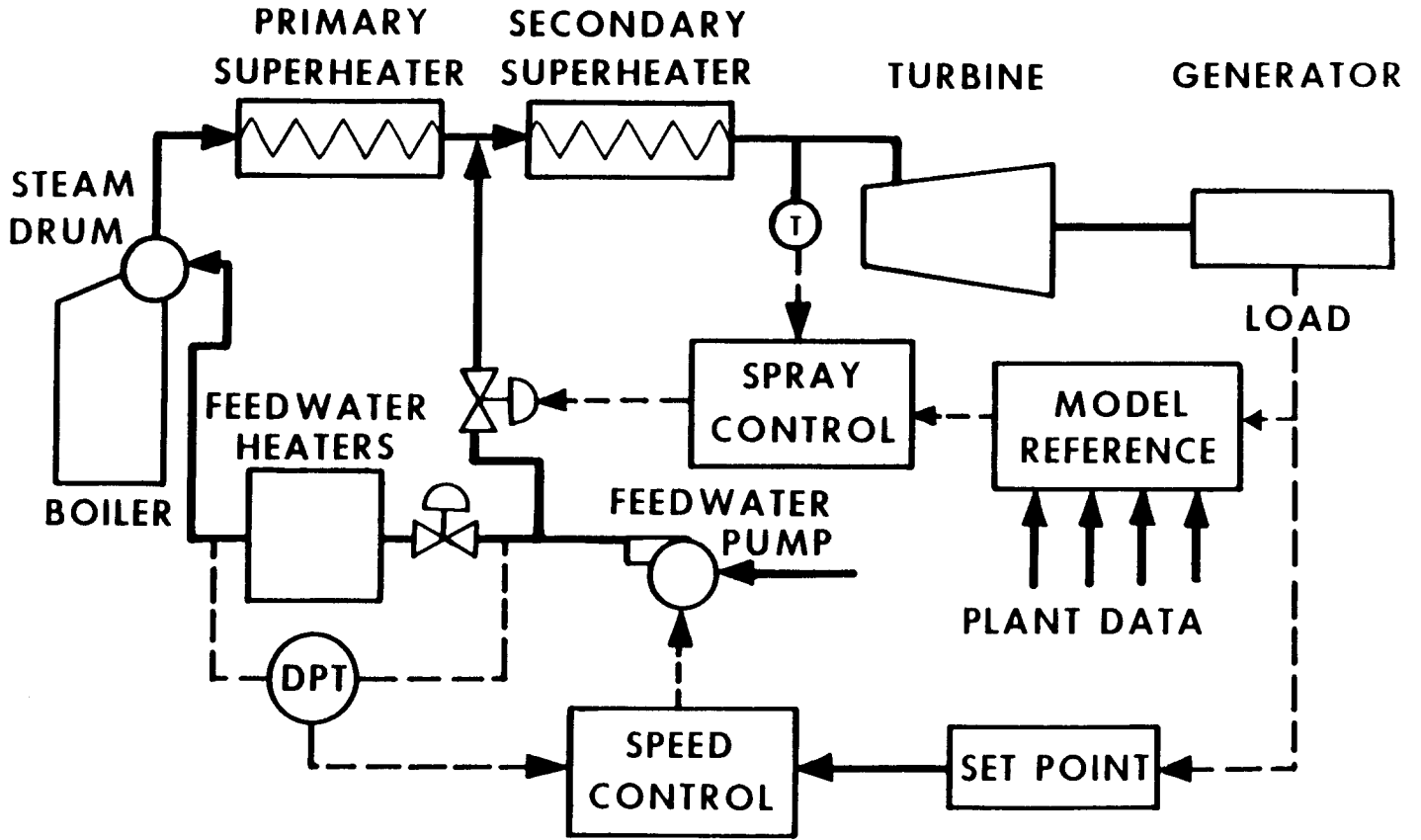


Figure 3--Application of advanced control.

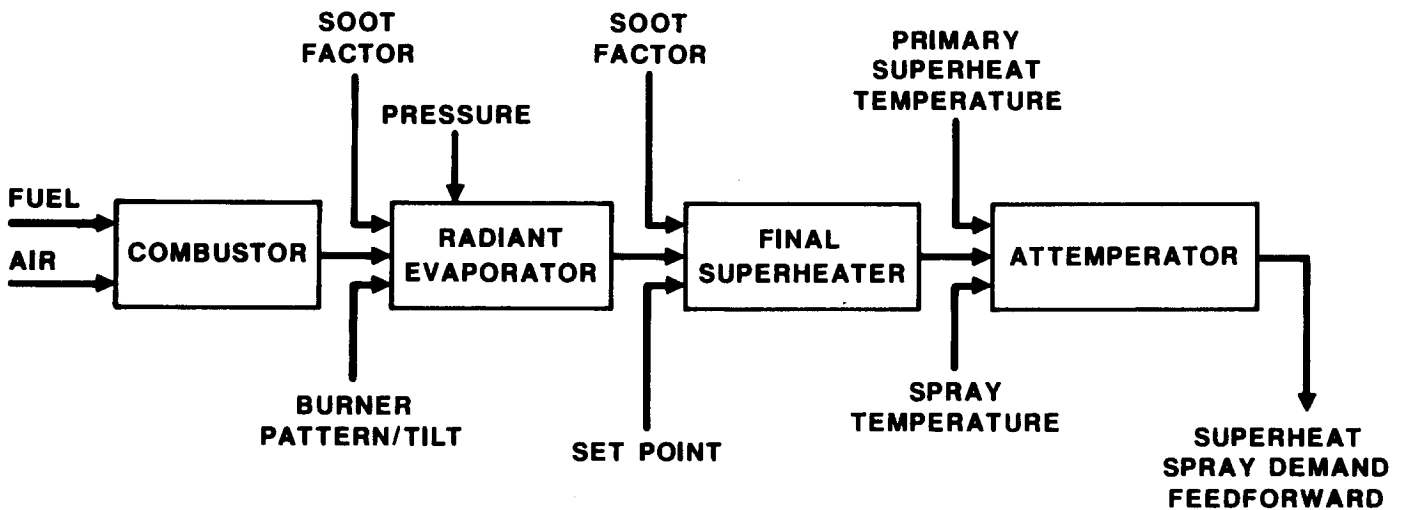


Figure 4--Modular structure of MRFF.

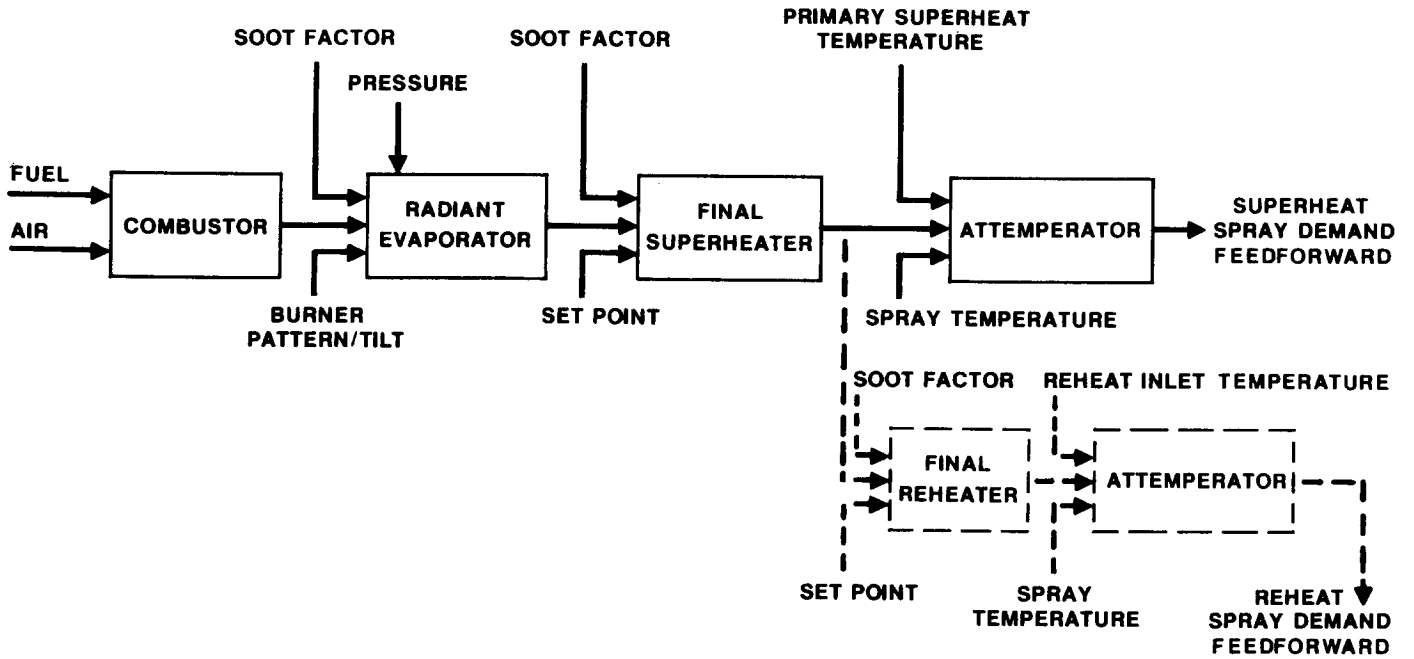


Figure 5--Addition of reheat spray MRFF.

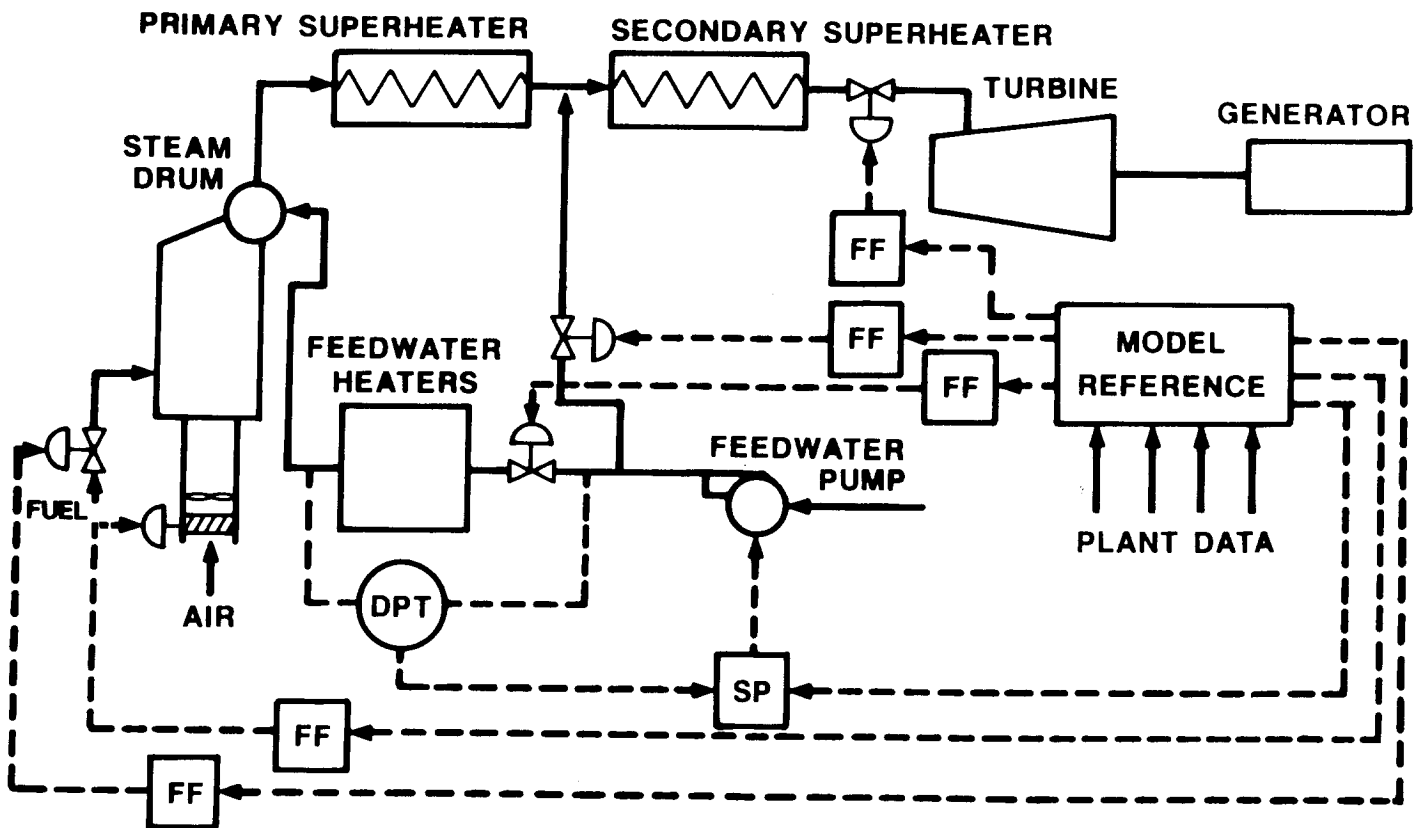


Figure 6--Multivariable MRFF control.

(manufactured by Honeywell Corporation), can reside in a local control network and readily provide the computed setpoints to any controller providing the regulatory control.

The "application module" features a full complement of control algorithms, as well as utility-type data points, such as timers, counters, flags, etc. In addition to standard, resident control algorithms, customer-generated control strategies can be programmed in a high-level control language.

As an example, Hitachi Ltd. offers a model-reference-type control for steam temperature regulation that is imbedded in the HIACS-3000 DCS (7). This system has been implemented in 19 plants in Japan to provide automatic control of steam temperature through the entire load range, including startup. Not only has the system been providing excellent temperature regulation over the entire load range, but it also is credited with providing substantial fuel savings through the reduction of startup times.

While the types of devices mentioned above are by no means the only ones with such capabilities, they are typical of the high level of functionality available in today's DCS.

CONCLUSIONS

Model reference feedforward and adaptive control algorithms provide the control tools to extend automatic control to lower loads and to startup. These control techniques can be readily implemented in today's DCS. Through improved

regulation, plant trips will be reduced and the life of costly plant equipment will be extended. Also, fuel savings can be achieved through faster startups and more responsive maneuvering. The net result is improved availability through extended range controls.

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