journal of dynamic systems measurement and control

discussion

On The Application Of Modern Control to Power Plants [1][1]

ASOK RAY.[2] The writer appreciates the important practical considerations suggested in the editorial [1]. But he cannot agree to the statement that the first-principle models, referred in the editorial, are too cumbersome for analytical control design. On the basis of a 14th order nonlinear dynamic model [2] (also reference [2] in the editorial) of a drum-type fossil-fueled power plant, linear optimal regulator theory was applied to design a physically realizable controller [3]; the results indicated that significant improvement could be achieved with respect to the existing conventional control system. This analytical technique has established a potential for controller design improvement of power plants, in general, and of drum-type units, in particular.

Control of once-through steam generators is recognized as a problem in the power industry [4]. In the present state of the art, modern control theory has a sound potential for improvement in controller design of once-through units, and requires state-space models. The 9th order first-principle model [5] (also reference [1] in the editorial) is believed to be suitable for a once-through subcritical steam generator controller design.

References

1 Smoak, R. A., "On The Application of Modern Control to Power Plants," *ASME* Journal of Dynamic Systems, Measurement, and Control, Vol. 98, No. 3, Sept. 1976, pp. 320–321.

2 Kwatny, H. G., McDonald, J. P., and Spare, J. H., "A Model for Reheat-Turbine-Generator Systems, Part II-Development," *Proc. 12th Joint Automatic Control Conference*, 1971, pp. 227–236.

3 McDonald, J. P., and Kwatny, H. G., "Design and Analysis of Boiler-Turbine-Generator Controls Using Optimal Linear Regulator Theory," *IEEE Trans.*, Ant. Contr. Vol. AC-18, No. 3, June 1973, pp. 202–209.

4 Nielsen, R. S., and Berkowitz, D. A., "Modeling and Testing Fossil-Fueled Generating Units," *Proc. 2nd Power Plant Dynamics*, Control And Testing Symp., Paper No. 6, Sept. 1975.

5 Ray, A., and Bowman, H. F., "A Nonlinear Dynamic Model of a Once-through Subcritical Steam Generator," *ASME* Journal of Dynamic Systems, Measurement, and Control, Vol. 98, No. 3, Sept. 1976, pp. 332–339.

Author's Closure

First I will deal with modeling and the design of regulators.

The practical analytical design tools available today require a linear model. The design reported in [6][3] is no exception. A linear model was derived from a nonlinear model to permit an analytical design of a control system.

The Cromby Model [7] was developed specifically to be used to design a control system (regulator). The plant was available for extensive testing prior to modeling. This testing indicated that the simplifying assumptions in the model were not incompatible with its intended use.

A control system was designed for this model using optimal control theory and compared with the existing control system which was supplied with the boiler in 1955. In addition, a coordinated control system such as is used in current practice was also placed on the model [8]. The system designed using quadratic regulator theory proved to be the best. It is not surprising that the coordinated control gave almost as much improvement over the 1955 single loop design.

There are several conclusions to be drawn. The most obvious is that the 1955 control system is far from optimum. In addition, optimal control theory designed a control system superior to a coordinated control system. It is not yet obvious that the modern design technique has enough advantages to allow it to displace the current practice. I believe that this will not happen until automated design becomes a consideration.

Neither of the control new systems described above were tested on the power plant, nor were they tested on a more detailed model which did not contain the simplifying assumptions of the Cromby model. Until this test has been performed, the process of modeling and control design has not been validated.

The first principle models described in the editorial are intended to be sufficiently detailed to permit their use in validating control designs in the wide variety of operating circumstances they will see on a real plant. To do this, all actuators will have to be modeled in addition to any mandatory base loop controls. The assumption of the Cromby model that the economizer and feedwater train may be neglected has not yet been justified. This can be done by experimenting on the plant or using a more detailed model. Since most of the plants of interest are being designed or under construction, I am driven to the conclusion that there is a need for high order, detailed, nonlinear models in addition to lower order linear and nonlinear models. I feel that our experience in power plant modeling is not adequate to insure that low order models will be adequate to their uses without a reference. In a few years this will probably no longer be necessary.

With regard to the control of once-through boilers, Ray's ninth order model [9] is of a steam generator for a nuclear power plant. Including the rest of the power plant will raise the order significantly. Babcock & Wilcox has a model of a nuclear power plant with two once-through steam generators modeled similarly. This is not a total plant model. Only the necessary elements of the power train are included and yet the order is about 100th.

Ray's model would not be satisfactory for a coal fired, supercritical, once-through boiler which is the plant which I feel can profit from the improved control which modeling will allow.

References

6 McDonald, J. P., and Kwatny, H. G., "Design and Analysis of Boiler-Turbine-Generator Controls Using Optimal

---

[1] Numbers 1–5 in brackets designate References at end of discussion.

[2] The MITRE Corporation, Bedford, Mass.

[3] Numbers 6–9 in brackets designate References at end of Closure.

Linear Regulator Theory," *IEEE Trans.*, Aut. Contr. Vol. AC-18, No. 3, June 1973, pp. 202–209.

7 Kwatny, H. G., McDonald, J. P., and Spare, J. H., "A Model for Reheat-Turbine-Generator Systems," *Proc. 12th Joint Automatic Control Conference*, 1971, 219–236.

8 McDonald, J. P., private communication.

9 Ray, A., and Bowman, H. F., "A Non-linear Dynamic Model of a Once-through Subcritical Steam Generator," ASME JOURNAL OF DYNAMIC SYSTEMS, MEASUREMENT, and CONTROL, Vol. 98, No. 3, Sept. 1976, pp. 332–339.

CALL FOR PAPERS

Fluid Control Systems Papers for WAM '78
San Francisco Hilton Hotel
Dec. 10–15, 1978

The Fluid Control Systems Panel of the Dynamic Systems and Control Division (formerly Automatic Control Division) is soliciting papers in fluid power and control for the 1978 WAM. Authors are invited to submit full length papers for presentation at the meeting. Papers in all areas of fluid power and control will be considered. Of special interest are papers related to "Measurement and Control Serving Mankind" which is the theme for the '78 WAM. Also, papers in the areas of fluid sensors, application in process control, and current needs in fluid control are of special interest.

Authors should submit five copies of their manuscript by April 1, 1978 to Dr. Karl N. Reid, School of Mechanical Engineering, Oklahoma State University, Stillwater, Oklahoma, 74074 (405) 624-5900. Authors also are encouraged to submit an abstract or indicate an intent to submit a paper. The abstract or intent should be submitted to Dr. Reid as soon as possible.

journal of dynamic systems, measurement, and control

forum

ARTICLES ON POWER PLANT CONTROL

On The Application of Modern Control to Power Plants

by Robert A. Smoak[1]

The subject of this editorial is "modern control" and its potential for application in the power industry. To be more specific, its application to the control of fossil boilers for central station power production. Some of my points also apply to nuclear power plants but the side issues are too complex to treat here.

I am writing this from the point of view of an engineer in an R&D laboratory. The lab serves a boiler manufacturer and a control vendor. I will try to describe the issues involved in using modern control as I see them.

If by "modern control" we mean the indiscriminant use of the quadratic regulator, I am opposed to it. Instead, let us define modern control as a collection of techniques developed since 1960. These methods address identification, estimation, and control. Modern control has acquired the reputation of being a cure looking for a disease. I want to rule this out and insist that it be the use of techniques developed to solve specific problems.

Modeling

The modern methods require a mathematical model for control design. The use of mathematical models for fossil power stations is growing but this technology is not widespread in the industry.

Models of interest for control work fall into two groups. The more detailed models usually contain 20 to 100 differential equations and a larger number of nonlinear algebraic equations [1, 2, 3, 4].[2] They are usually developed from first principles. These models are suitable for control validation but they are too cumbersome for analytical control design. All of the important nonlinearities can be included in a model of this type. Although these models are expensive to develop, adapting them to a similar plant is not difficult. Obtaining data for a model of this sort is usually only possible for the owner or manufacturer.

There is a definite need for low order models suitable for control design purposes. The Läubli-Fenton model [5] has been used in this country. The monograph by Eklund presents several boiler models [6]. The Dissertation by Park generates a model from measured data [7]. The paper by Thomas [8], et al., in this *Journal* makes a very real contribution in this area. Kerlin [9] discusses model validation, another important area. The lack of suitable models has acted as a barrier to the use of the modern methods in boiler control. This problem is being resolved now but not as quickly as we might like.

Regulators

The most obvious task of a boiler control system is to act as a regulator. In this mode, the control specifications are reasonably easy to define. These include control of generated power, steam temperature, furnace air flow, etc. They are technical specifications related to the performance of the unit. Modern control methods could be used to design the controls.

In addition to the system performance requirements, there are additional requirements on a control design. These requirements are related to being a product as opposed to a specific set of control hardware.

Identical units are uncommon. There are two main types of fossil boilers, the drum boiler and the once-through boiler. The expected operating mode of the boiler introduces further variations. Any control system design must be sufficiently flexible that a minimum of engineering is required to apply it to another unit of the same type.

Parameter variations are the rule, not the exception. Heat transfer surface fouling and variations in fuel characteristics are difficult to predict but it is certain that they will occur. Any control system must compensate for these variations.

Control system tuning is always a problem. It must be possible to gather data during unit startup and use these data to tune the control system.

A control system is sold to a customer. If the customer cannot maintain it, it will not be satisfactory. Any control system must be simple enough that utility personnel can be trained to operate and maintain it.

The current philosophy of plant design requires a manual control station ahead of each actuator in the plant. Exceptions are made but there is a definite pressure in this direction. The control system must still function correctly when an actuator is put under manual control.

In order for a manufacturer to change a product, there must be a reason to change. If modern control is to be used to design regulators for utility boilers, it must offer an improvement. The

---

[1] Babcock & Wilcox, Lynchburg Research Center, P. O. Box 1260, Lynchburg, Va.

[2] Numbers in brackets designate References at end of Forum.

analog control systems on drum boilers are sufficiently refined that a performance improvement will not be easy to obtain. The situation on once through boilers is less clear. Units have been built and tested which appear to have entirely satisfactory performance [10]. On the other hand, the IEEE System Operations Subcommittee stated in January that regulation of once through boilers is a problem [11].

Wide Range Dynamic Control

I believe that the place for the modern methods to contribute is in wide range dynamic control, particularly for once-through boilers.

The equipment associated with power production and distribution is tremendously expensive. Improved control systems can improve maneuverability and availability. Startup times for once-through units range from six to fourteen hours. Every boiler trip which is avoided raises the unit availability and reduces the necessary spinning reserve. Ultimately, improved boiler control reduces the capital investment required for a utility to meet demand.

There are two main areas where I feel substantial contributions can be made. The first is in the area of unit startup. Startup of once-through units is difficult. On coal fired units, it is usually not possible to start pulverizers during the pressurization ramp. Controls which would improve the quality of control during startup and extended the lower range of stable operation would be welcomed.

Units must occasionally reject load. If a boiler trip can be avoided on a load rejection, the unit can be returned to service quickly. On supercritical units, lifting the safety valves during a trip causes valve damage about 25 percent of the time. Repair of the safety valves extends a one shift outage to several days. With a differential fuel cost of 20 mils for a mine mouth plant versus replacement power, outages can cost several hundred thousand dollars per day. The incentive for improvement is obvious. Problems of this sort are suited to analytical methods.

Conclusion

If the modern methods are to gain acceptance in the power industry, they must solve real problems. By this, I mean they must solve problems that are not being solved by the current methods. Another solution to an already solved problem will never gain acceptance for a new technique.

References

1 Ray, A., and Bowman, H. F., "A Nonlinear Dynamic Model of a Once-Through Subcritical Steam Generator," published in this Journal pp. 332–339.

2 Kwatny, H. G., McDonald, J. P., and Spare, J. H., "A Nonlinear Model for Reheat Boiler-Turbine-Generator Systems," JACC Preprints, 1971.

3 Läubli, F., "Large Scale Boiler Simulation," *Proceedings of the Seminqr on Boiler Modeling*, The Mitre Corporation, November 6–7, 1975.

4 Flechsig, A., Jr., "A Digital Simulation of a Once-Through Supercritical Steam Generator," A Dissertation Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College, 1970.

5 Läubli, F., and Fenton, F. H., "The Flexibility of the Supercritical Boiler as a Partner in Power Systems Design and Operation," *IEEE Transactions*, PAS-90, No. 4, July - Aug. 1971.

6 Eklund, K., "Linear Drum Boiler—Turbine Models," Report 7117, November 1971, Lund Institute of Technology.

7 Chan Ung Park, "Parameter Identification of Low-Order Boiler Models for Dynamic Stability Analysis," A Dissertation Submitted to the Graduate Faculty at Iowa State University, Ames, Iowa, 1975.

8 Thomas, Y., "Analysis of a DDC Experiment Based on State Space Methods," et al., published in this Journal pp. 324–331.

9 Kerlin, T. W., "Dynamic Testing in Nuclear Power Plants for Model Validation," et al., this journal.

10 Durrant, O. W., "Operation of Once-Through Boilers During Electric Power System Emergencies," Presented at ISA Symposium on Power Instrumentation, Kansas City, Missouri, May 20, 1970.

11 Current Operational Problems—System Operation Subcommittee, Power System Engineering Committee, IEEE, Paper A 76 051-3, Presented at IEEE PES Winter Meeting, N. Y., Jan. 1976.

The Challenge of Reliability in Steam Turbine Control

By P. C. Callan[1]

Introduction

The history of steam turbine control goes back to near the turn of this century when the concept of using steam to turn a turbine and generator rotor combination to produce electrical power was first made economically practical. The control that was developed then, and which has been used with succeeding forms of improvement for the past 70 years, is the fly ball governor developed by Watt.

The essential concept of this governor is to control the position of the main stream inlet valves of the turbine in response to speed changes of the turbine. Increasing speed causes the valves to close, and decreasing speed causes them to open further. The term used for this control is speed regulation.

As steam turbines became larger, it became apparent that a new type of control would have to be developed. The need for this was caused by increased complexity, the need for faster control action, and the desirability of serving more functions with the control system. The result was the development of the electro-hydraulic control system.

The major turbine manufacturers in the United States put such a system into operation in the early 1960's. At first, it was essentially an electronic copy of the functions performed by the fly ball governor of the mechanical-hydraulic system. As time went on, it was found that additional functions could be performed quite readily using electronic networks. This resulted in adding to the functions performed, which in turn added to the complexity of the control.

Another aspect of the electro-hydraulic control system is the use of high pressure hydraulic fluid as the principal valve actuation power. This high pressure fluid is pressurized to between 1500 and 2000 psi. This results in smaller hydraulic actuators being required to move large steam inlet valves.

Operation of the new electronic networks with their added complexity, along with a hydraulic fluid system new to this industry, resulted in some very interesting reliability data. It was found that a very reliable system had been replaced by one much less reliable.

One measure of the reliability of steam turbine is forced outage rate. A *forced outage* is defined by the Edison Electric Institute as "The occurrence of a component failure or other condition which requires that the unit be removed from service immediately or up to and including the very next weekend." *Forced Outage Rate* is obtained by dividing the number of hours of forced outage by the total number of service hours plus forced outage hour since initial operation. To get percentage, this number is multi-

---

[1] Manager—EHC Design Engineering, Large Steam Turbine-Generator Department, General Electric Company, Schenectady, N. Y.