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OPERATOR SUPPORT THROUGH MODERN OPTIMAL ESTIMATION AND CONTROL

MASTER

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ABSTRACT

Applications of Modern Optimal Estimation and Control Theories are late in coming to the nuclear industry. This paper presents some features of the theories that might be exploited in nuclear systems applications. Activities at the Idaho National Engineering Laboratory relating to operator support using those theories are identified and some implementation challenges are discussed.

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1. INTRODUCTION

The past twenty years have seen intense activity in theory development and ingeneous applications of what is commonly termed "Modern Estimation and Control Theories". As used herein, this term will encompass such techniques as Box-Jenkins time series analysis, the Kalman filter and its extensions and variations, and conceptual duals of filtering techniques for the solution of optimal control problems[1]. Recent developments in fast, high capacity, low cost digital computing equipment intensified research in the applications area. In particular, engineers in the aerospace industry have applied the theories with impressive success to missile, aircraft, and satellite navigation problems. The literature increasingly reports applications of these techniques to chemical process control. Their implementation in major U.S. energy systems is currently nonexistent. However, since the pioneering efforts at the Halden Project, a number of papers have appeared that report possible applications to nuclear systems estimation and control problems; many of these reports describe supporting computer simulation studies. In the interest of ensuring a safe, reliable, economical supply of energy, this mounting evidence should not be regarded as being of academic interest alone. Therefore, the Idaho National Engineering Laboratory (INEL) has authorized its prime contractor, EG&G Idaho, Inc., to further investigate, develop, and plan for test implementation on the LOFT pressurized water reactor (PWR), applications of modern estimation and control theories. A number of these future applications are related to operator support in reactor surveillance and control.

2. GENERAL FEATURES

There are a number of general features of these theories that might beneficially be applied to nuclear systems problems.

2.1 On-Line Calculation

The amenability of some of these techniques to on-line calculation is an attractive feature. For example, the calculation of residuals and estimation error covariances is implicit in the Kalman filter. Analysis of these quantities could provide early indication of instrument drift and failure.

2.2 Optimality of Estimates

The optimality of estimates provided by the Kalman filter might be exploited to provide safe plant operation closer to limits. Operators could be provided with accurate histories of variables and accurate instantaneous time-rates of change of important plant variables. Fuel and clad temperatures might be estimated directly instead of being inferred from mathematically related variables.

2.3 Parameter Estimation

The extended Kalman filter might be applied to obtain on-line optimal estimates of system parameters that are currently either not provided to the operator, the control system, the plant protection system, or are provided in some off-optimal fashion. A few of these parameters are boiling water reactor (BWR) void fraction, temperature coefficients of reactivity, fuel and clad thermal conductivity, and heat transfer coefficients. Exploitation of this capability might lead to improved control and plant protection systems.

2.4 Prediction of Future States

Computer simulations could be devised to predict, from the latest actual data and hypothetical operator actions, future states of the plant. A state-variable predictor might be made an integral part of future plant protection systems.

2.5 Concentration of Modeling Efforts

The state-variable format and structure required for implementation of Kalman filter-based estimators, for control and/or plant protection system services, would force production of a unified, cohesive, plant model. This might provide more accurate information of overall system performance.

2.6 Determination of Measurements Requirements

The plant model could be used to put measurement system requirements on an analytical basis rather than an historical basis through observability studies performed on the model; that is, the information needed to accurately reconstruct the state of a system or subsystem at a particular time might be determinable.

2.7 Inherent Diversity of Measurements

The extended Kalman filter incorporates all the input measurements to obtain its estimate of each state and parameter. Therefore, it has a degree of independence from individual measurements. Filters have been devised which operate with limited loss of measurement inputs. This feature might be exploited to develop extremely reliable data acquisition systems.

2.8 Summary

From the preceding features of these theories, a number of areas of possible application for nuclear plant operator support can be listed. For example:

A. Improved control systems

B. Improved plant protection system (PPS) design

C. Instrument drift and failure detection

D. More believable, consistent information display

E. Inputs to a disturbance analysis system

F. Core surveillance system design

G. Fast-running prediction code development

H. Simulator development for realistic operator training

3. CURRENT INEL ACTIVITIES

Current INEL activities, in modern estimation and control, address a number of the preceding-listed areas. The remaining areas are in the planning stage. This section summarizes current efforts.

3.1 The Advanced Control/PPS Development Program

The purpose of this program is to investigate the utility of modern estimation and control theories to PWR control and plant protection system design. The tool used in the investigation is currently the INEL Hybrid Computer. The LOFT plant is simulated using two Applied Dynamics Inc. AD-5 analog units and one PDP-11/55 digital unit. The estimation and control algorithms[2] are being programmed on an additional PDP-11/55 unit. An all-digital simulation is planned for use in future studies.

Several control laws will be studied. The effectiveness of these laws and estimator algorithm performance will be judged under conditions of transient inputs and variations in process and measurement noise. Judgments will be based upon sensitivity, stability, and speed of operation of the experimental techniques in comparison to the current LOFT control and protection systems. Special attention is being given to steam-generator water level control[3] since this is a significant contributor to commercial PWR downtime.

Plans call for future implementation of the selected techniques in the LOFT experimental control room.

3.2 Instrument Drift and Failure Detection

The purpose of this project is to investigate the utility of the functional redundancy concept[4,5] to the design of an on-line digital instrument drift and failure detection system. Functional redundancy involves the use of dedicated observers in an n-out-of-m logic configuration.

The LOFT pressurizer has been selected as an example system. The pressurizer was selected because it is an important, yet relatively easy to model, PWR subsystem. System boundaries and instruments have been identified and test data from LOFT experiments are being collected for use in model development.

A simplified pressurizer model is being used for preliminary instrument failure detection algorithm development. This work is being done in conjunction with the University of Washington.

3.3 Nuclear Fuel Pin State and Parameter Estimation

This project[6] demonstrated that fuel and clad temperatures, cracked fuel thermal conductivity, clad thermal conductivity, and gap conductance could all be estimated from fuel and clad thermocouple measurements alone. Although not directly related to operator support, this project gives further evidence that on-line determination of important reactor physics parameters is feasible.

4. CHALLENGES

There are a number of challenges facing implementation of these techniques in PWR plant operator support systems.

4.1 Process Model Development

Process model development has been, and will continue to be, the crux of any control or estimation system design. There are two basic approaches to model development, modeling from physical first principles and empirical modeling from time series data. One reasonable approach is to base the model structure on physical principles and estimate unknown parameters from process data. Whichever approach is chosen, the model development phase of the system design will be one of the most difficult and time consuming tasks to be accomplished.

4.2 Computational Problems with High-Order Models

Three factors directly influencing on-line system performance are model order (and complexity), digital update time interval, and hardware configuration. Computer storage and computation time requirements increase exponentially with system order. Even off-line design computation becomes expensive for high-order systems.

4.3 Model Order Reduction

Model order reduction is the process of finding the optimum compromise between model simplicity and predictive ability. Order reduction may be approached on physical grounds or through modal analysis. Again, neither method is foolproof; a combination of the two is usually required.

4.4 Noise Characteristics Identification

Identification of process and measurement noise characteristics is a costly and time consuming exercise, often complicated by the lack of adequate measurements. Fortunately, estimator performance may not require accurate and complete knowledge of the noise sources, although this is problem dependent and requires careful consideration.

4.5 Determination of Operator vs Computer Functions

Primary factors influencing the allocation of tasks between the computer and the operator are task complexity and the time required for action. Objective criteria cannot always be applied here; thus, decisions are often based on subjective judgments of experienced operators and designers. In order to properly address man/machine task allocation in the design of future control rooms, human factors personnel must become more knowledgeable of reactor plant dynamics and new control and plant protection system concepts and capabilities.

4.6 Software Validation

The demonstration of reliability of hardware and software for accommodation of new digital systems for control and plant protection is definitely a challenge. However, it is probably no more formidable a challenge than reliability issues we presently face. A much more serious challenge is validation of software for new control and PPS applications. Software validation could be a problem that is not amenable to any mathematical approach. Ad hoc, incomplete, and difficult-to-justify procedures, may be all that will be available. Here is a situation where one man's program is another man's data. Validation software, for a very complex control program, could itself require validation, etc.

4.7 Licensing Criteria Development

Assuming that investigators are successful in overcoming the preceding challenges, regulatory agencies will be faced with the challenge of revamping current attitudes and requirements to produce guides for implementation of the new digital operator support systems on commercial plants. Many of the lessons learned, on the way to successful demonstration of these new systems, can be expected to be instrumental in overcoming this challenge.

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