CONF-890555--21

DE89 015695

APPLICATION OF ADVANCED TECHNOLOGY

TO

LMR CONTROL

by

R. W. Lindsay

EBR-II Division
Argonne National Laboratory
P.O. Box 2528
Idaho Falls, Idaho
83403-2528

Submitted for Presentation
at the
Seventh Power Plant Dynamics, Control
and Testing Symposium

May 15-17, 1989
Knoxville, Tennessee

* Work supported by the U.S. Department of Energy, Office of Nuclear Energy under Contract W-31-109-Eng-38.

APPLICATION OF ADVANCED TECHNOLOGY TO LMR CONTROL

R. W. Lindsay
Argonne National Laboratory
Experimental Breeder Reactor II Division
Box 2528
Idaho Falls, ID 83403

SUMMARY

Key issues must be resolved to preserve the nuclear option; including new considerations for safety, economics, waste, transportation, diversion, etc. The programs at the Experimental Breeder Reactor II (EBR-II) are now carefully focused to provide answers to the above concerns in connection with the Integral Fast Reactor program at Argonne. Safety features that are inherent in plant design, coupled with automating plant control to help achieve the above objectives are more than just an issue of installing controllers and exotic algorithms, they include the complete integration of plant design, control strategy, and information presentation.

Current technology development, both at Argonne and elsewhere includes efforts relating to the use of Artificial Intelligence, sensor/signal validation in many forms, pattern recognition, optimal control technologies, etc. The EBR-II effort is to identify needs, develop and/or adopt promising technologies, and integrate them into an operating power plant for proof of value. After they have proven useful at EBR-II, it is expected that they can be incorporated into advanced designs such as PRISM and/or included in backfit activities as well.

DISCUSSION

Development and integration of advanced control and display technologies for use in nuclear power plants in the U. S. is driven by several realities. Not the least of these realities is the fact that with all the U. S. plants aging, new equipment and systems must be backfit to the existing plants. It is a matter of great concern that original equipment replacement parts are not easily found, and, when compared to more modern technology, may not be desirable to use in any case. The digital revolution has matured to the point that it is widely used in process industries, but the U. S. nuclear community is, in reality, far behind in adapting the newer technology for plant use. One reason is that the regulatory process demands that new technology be proven to be at least as reliable as that which it replaces. While such reliability appears to be almost inherent in much of the digital control equipment, proof of reliability is not necessarily easy.

* Work supported by the U.S. Department of Energy, Office of Nuclear Energy under Contract W-31-109-Eng-38.

If it is assumed that digital systems will find their way into nuclear plant usage in the U. S., as indeed they are, then the way is also being opened to provide for the plant operators a far better interface, "smarter" control systems, and other helps that should materially improve reactor plant operation. Considerable effort is being expended to take advantage of the "new" capabilities although much of the work being done is still in the early stages of development.

The EBR-II reactor plant has a long history of operation. EBR-II first generated power in August of 1964 and has been in operation since then. The reactor is rated at 62.5 MWt, with electric output at 20 MWe. The reactor plant consists of three major systems, primary sodium, secondary sodium, and steam system. The primary system consists of the reactor, which is located in a large tank containing the sodium coolant (about 87 000 gallons), the two primary system pumps and the intermediate heat exchanger (IHX).

The secondary system is also a sodium system, obtaining heat at the secondary side of the IHX and transferring it through evaporators and superheaters to the steam system. The secondary system is rather unique with an electromagnetic pump providing the motive force for the sodium and acting as a "valve" for heat economy during plant shutdown.

Energy is transferred to the steam system in the steam generator assembly consisting of evaporators, a steam drum, and superheaters. Feedwater is supplied to the steam drum, then to the evaporators, and saturated steam from the steam drum to the superheaters. The steam then enters the turbine. The power-plant cycle is a conventional cycle except for the use of superheated steam rather than saturated as in the LWR case.

Over the years, the EBR-II plant has served many program missions from the initial proof of concept of a fast reactor power park: fuels and materials irradiation work, run beyond fuel cladding breach investigation, plant transients with failed fuel cladding research, plant dynamics testing, sodium handling technology, metallic fuels development, and plant controls and displays to name a few. The system has proven to be versatile and adaptable to these missions and during this time, the plant reliability has increased.

As a project which is devoted to the development and testing of advanced reactor plant concepts, the EBR-II facility has been and is now undergoing modifications to allow the testing of new digital components, software, and totally integrated systems. It is a matter of record that the same problems of backfit have arisen at EBR-II as at the commercial power plants. When replacements are required at EBR-II, it is the policy to upgrade with new, up-to-date systems and components to further facilitate testing and development work as well as to improve plant operations. The upgrades to EBR-II have provided a capability to further develop and test new, advanced technologies in an integrated fashion and on a complete power plant. To provide for data gathering, for example, the plant Data Acquisition System computer system was recently replaced and the capability increased.

Inherency and Control

Considerable progress has been made in understanding of plant dynamics that are inherent in the plant systems, and the interactions with the control systems at EBR-II. Tests (1) have been conducted that constitute the most stringent tests ever conducted for operational power plant systems. They include a loss of pumping power for the primary system with the reactor at full power and the normal automatic shutdown systems not active, and a second test wherein the secondary heat transport system was disabled to effect a loss of heat sink with the reactor again at full power and the normal automatic shutdown systems disabled.
Special safety considerations were provided for the tests.

In both cases, the reactor shut itself down due to features inherent in the system design, without any deleterious effects on the plant or the reactor, its structure or fuel. The bottom line of these tests, and others that have followed, wherein the plant has been subject to dynamic perturbations initiated in various areas of the plant, is that the total plant and its characteristics are well understood. With this validated knowledge of plant dynamics, a defendable integration of new technologies can be made. The use of a more patchwork approach would likely be doomed to failure.

As the EBR-II plant tests have been analyzed, it has become even more clear that there must be a careful integration between the plant systems design and the control systems. To illustrate, systems that are designed so that safety features are inherent in the system must not be compromised by an automatic control system which blindly insists on maintaining power even if the system has lost the cooling pumps.

With the above ideas in mind, the EBR-II staff has been working with a number of organizations whose interest is in the advanced control, display and diagnostics areas. Such groups as the University of Tennessee, Oak Ridge National Laboratory, Pennsylvania State University, MIT, Draper Laboratory, EG&G, NASA-Langley, General Electric, and numerous other commercial companies, etc., have worked or are working with EBR-II on various projects with the focus of developing, testing, and proving advanced control systems. This group represents a good cross-section of those who have expertise and interest in new and better control systems. The expertise of these organizations, coupled with the real-world capabilities at EBR-II have provided a unique focus that should result not only in success, but in a vast improvement in the way nuclear plants are designed and operated.

Controller Upgrades

Upgrades to instrumentation and control systems at EBR-II include the incorporation of commercial digital controllers in most of the major control areas, such as: control of the primary and secondary pumps, feedwater system, etc. The controllers can be networked together, and, in fact have been networked and controlled by a supervisory computer during plant dynamic testing. These controllers allow much greater flexibility in plant operation and testing than has been available in the past. The flexibility is in two forms: flexibility in reconfigurability of the control system, and flexibility in the dynamics allowed by the controller. Both of these features have been used during testing.

Diagnostic Development

In the past few years, a great deal of effort has been expended in the US and other countries on the development of computerized diagnostic systems. With all the effort, there are only a relatively few systems that are operational. The reasons are varied, but include that fact that while some diagnostic system concepts may be possible, they may not be practical in a real plant scenario. The reasons for the impracticality often are that many of the efforts at diagnostic development require far too much computer resource. It is true that computer hardware is becoming less expensive and much more powerful, but it is also true that many of the diagnostic efforts are not CPU efficient and the software is so complex that verification and validation issues prevent acceptance. In some cases, even supercomputers may not keep up with real-time requirements for diagnostics, display, and control work. Diagnostics very often competes for computer resources with display graphics and other software. It is sometimes not appreciated by developers that plant operators need most of their information in real-time. The information that is generated by such systems must be presented so that it is in the same time-frame and context as the other plant instrumentation.

EBR-II personnel have been involved in the development of diagnostic systems for several years, for example, working with contractors such as Westinghouse and now Penn State University on the DISYS (2) diagnostic program. In addition, much work has been done working with EI International, on pattern recognition techniques. At present, a pattern recognition system, the System State Analyzer (SSA) (3) is running on the plant at EBR-II. There are two SSA systems: the real-time SSA, which runs with 1 second updates, and the regular SSA which is used in a more "time relaxed" mode for longer-term surveillance. Pattern recognition is also showing its usefulness for sensor validation applications.

New Displays

More effective displaying of plant data in nuclear plants has been of considerable concern, especially since the TMI accident. With the advent of the computer, CRT displays have been proposed and used for display of system information. Advanced reactor concepts envision extensive use of CRTs. To date, display designs have usually not taken advantage of the capability of the computer. Significant strides in information presentation have been made at EBR-II based on the concepts and work of others(4,5,6) and adapted to EBR-II. The result is the first real-time, model based display incorporating the complete plant process as a Rankine cycle. This promising work will result in the development and testing of real-time plant displays that incorporate thermodynamic models of the plant operation. Rather than merely using the computer as a data collection and display device, at EBR-II, the computer is used to collect data, transform it into a real-time model of plant performance, and then to display it.

In addition, the coupling of display information with diagnostics is being pursued. It is likely that the alarm systems, as now used in nuclear plants, will disappear through integration of real-time diagnostics with the advanced graphical displays.

Fault-Tolerant Systems

There is a realization at EBR-II that fault tolerance is or will be required for many of the nuclear plant applications for safety as well as economic reasons. Proof of fault tolerancy is required for safety system applications. Work is being pursued to develop a methodology for formal proof of fault tolerancy for both software and hardware as a part of the EBR-II program. There is now a fault-tolerant computer at EBR-II which is undergoing testing at the same time that work is being done to prove the software integrity. The safety case is being prepared to defend the incorporation of the computer into a safety system in the EBR-II shutdown string. If this work is successful, it will chart the way for incorporation of computer systems into sensitive areas in nuclear plants.

CONCLUSIONS

The integrated approach to the development of advanced control and display systems for fast reactors and other systems has already provided many benefits at EBR-II. An up-to-date and flexible control system which provides the ability to test new ideas in the context of a complete power plant is an obvious benefit. The bottom line for a power plant is also benefiting as evidenced by the fact that the plant capacity factor continues to run greater than 70 percent, and, in fact has moved up to near 80 percent in recent years.

As new control systems and related concepts are proposed, an evaluation is made based on real plant needs and operating realities. Using an operating nuclear plant as the "forcing function" for development has caused more than one second look at technology which initially appeared desirable, but, which on closer examination is not feasible or is of questionable value.

Future plant tests, as now planned, along with new plant control and display equipment, coupled with advanced software will likely provide a demonstration of the first fully automatic nuclear power plant operation in the US. As this work progresses, close interaction with research partners is required to meet the goals of the advanced reactor control effort.

REFERENCES

1. H. P. Planchon, et. al. The Experimental Breeder Reactor-II Inherent Safety Demonstration edited by S. H. Fistedis, North-Holland, Amsterdam (1987).

2. A. M. Christie and R. W. Lindsay "The DISYS Real-Time Diagnostics/Control System and its Application to the EBR-II", Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Plenum Press, New York and London, 1988.

3. J. Mott, R. King, and W. Radtke, "A Generalized System State Analyzer For Plant Surveillance", Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Plenum Press, New York and London, 1988.

4. L. Beltracchi, "A Direct Manipulation Interface for Heat Engines Based Upon the Rankine Cycle", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-17, No. 3, May/June, 1987, pp. 478-487.

5. J. Rasmussen and K. J. Vicente, "Cognitive Control of Human Activities and Errors: Implications for Ecological Interface Design", Paper given at: The Fourth International Conference on Event Perception and Action, Trieste, Italy, August 24-28, 1987.

6. K. J. Vicente and J. Rasmussen, A Theoretical Framework for Ecological Interface Design, RISO-M-2736, August 1988.