N90-27293

A HYBRID APPROACH TO SPACE POWER CONTROL

E. W. Gholdston D. F. Janik K. A. Newton

Rocketdyne Division, Rockwell International
Canoga Park, California 91303

Abstract

Conventional control systems have traditionally been utilized for space-based power designs. However, the use of expert systems is becoming important for NASA applications. Rocketdyne has been pursuing the development of expert systems to aid and enhance control designs of space-based power systems. The need for integrated expert systems is vital for the development of autonomous power systems.

Introduction

The Rocketdyne Division of Rockwell International Corporation, Canoga Park, California, is pursuing research on space-based and lunar power systems design. Large scale power systems for NASA's future space and lunar missions pose significant challenges for autonomous control on-orbit. Conventional computer control techniques utilize highly structured algorithmic control code which can deal with a predetermined set of specific contingencies. In addition to control algorithms and power load flows, security analysis, system maintainability, and predictive simulations can also be used for power system control.

Conversely, expert systems and artificial intelligence technology offer great flexibility for control systems due to their response to unspecified situations. Research in the field of expert system applications for power systems is being pursued. However, acceptance and verification of these systems is an emerging discipline that does not have established criteria. Because expert systems may be less deterministic, control designs that depend solely on them may have reduced reliability. Integration of conventional control techniques with expert systems, or hybrid systems, could increase reliability of power systems utilizing this architecture.

Promising applications of hybrid systems include monitoring and diagnosing power systems. The potential use for hybrid systems is significant and offers great flexibility for system control. Additionally, challenges are introduced for development, test, and verification of expert control systems. This paper will describe research at Rocketdyne in the area of expert systems and hybrid systems.

Previous Research

Rocketdyne has been researching the development and integration expert systems for the evaluation of autonomous power applications. This research was conducted in the Space Power Electronics Laboratory (SPEL) facility at Rocketdyne. The SPEL contains a breadboarded space power distribution testbed where power system control methodologies can be evaluated.

Using the SPEL, development and testing of expert systems for hybrid computation has been explored. One expert system (ES) project concentrated on a single power switchgear component: a remote bus isolator (RBI) [3]. The ES developed could detect an anomaly within the RBI, based on power measurements of the component. From the resulting analysis, a single fault could be diagnosed for the RBI.

Building on this research, an expanded expert system effort was started [4]. Power hardware was added and diagnostic capabilities of the expert system were extended. The scope of the project was increased and new expert system development and interface environments were selected and used. This expert system, the Diagnostic Expert System (DES), diagnosed a larger component within the SPEL that was more complex than a single remote bus isolator (RBI): a power distribution control unit (PDCU).

The failures detected by this diagnostic system included short circuits, over-currents, loss of power, power surges, and loss of communication. The expert system integrated power system diagnosis with basic control algorithms.

While the capabilities for the DES were increased, there were problems during the development and execution. Accessing and converting the testbed measurements to an object-oriented structure resulted in timing problems. Additionally, not all knowledge acquired during the project was incorporated, due to the specific scope of the project. Expansion of DES needed to address additional fault diagnosis and detection, increased interactions with power system simulations, and study the effects of system loads and multiple failures.

Current Research

Based on the above assessments, the third expert system project was started at Rocketdyne, enhancing the capabilities of the DES. Increasing the scope over previous work was the first step of the project. The expert system's utility was also changed. This change was based on a recommendation that an expert system design relying solely on knowledge-base diagnoses would not be sufficient for intelligent implementation in a dynamic environment, such as a power system.

The expert system project would need commonality with existing or projected space-based power systems standards. For example, using an 80386-based computer would be more appropriate than using specialized artificial intelligence hardware. Because of emerging NASA software standards, integration with Ada control software needed to be explored and this priority maintained as the expert system developed. As expressed by current power system researchers, it will be a step-by-step approach to have expert systems be part of a closed loop control design for power systems [9]. Based on the above considerations, the enhanced expert system is called IPAC for Integrated Power Advisory Controller.

Facilities

For the development of IPAC, the SPEL testbed was used as shown in Figure 1. Two power sources, a simulated Photovoltaic source and Solar Dynamic source, produce single phase 440 volt electrical power distributed at a frequency of 20 KHz, which is being converted to dc.

Real and reactive programmable load elements are used to draw electrical power through the distribution grid enabling test engineers to emulate various user load profiles. The power distribution network is comprised of main bus switching units (MBSUs) and power distribution control units (PDCUs). The MBSU is an assembly used to supply electrical power to main

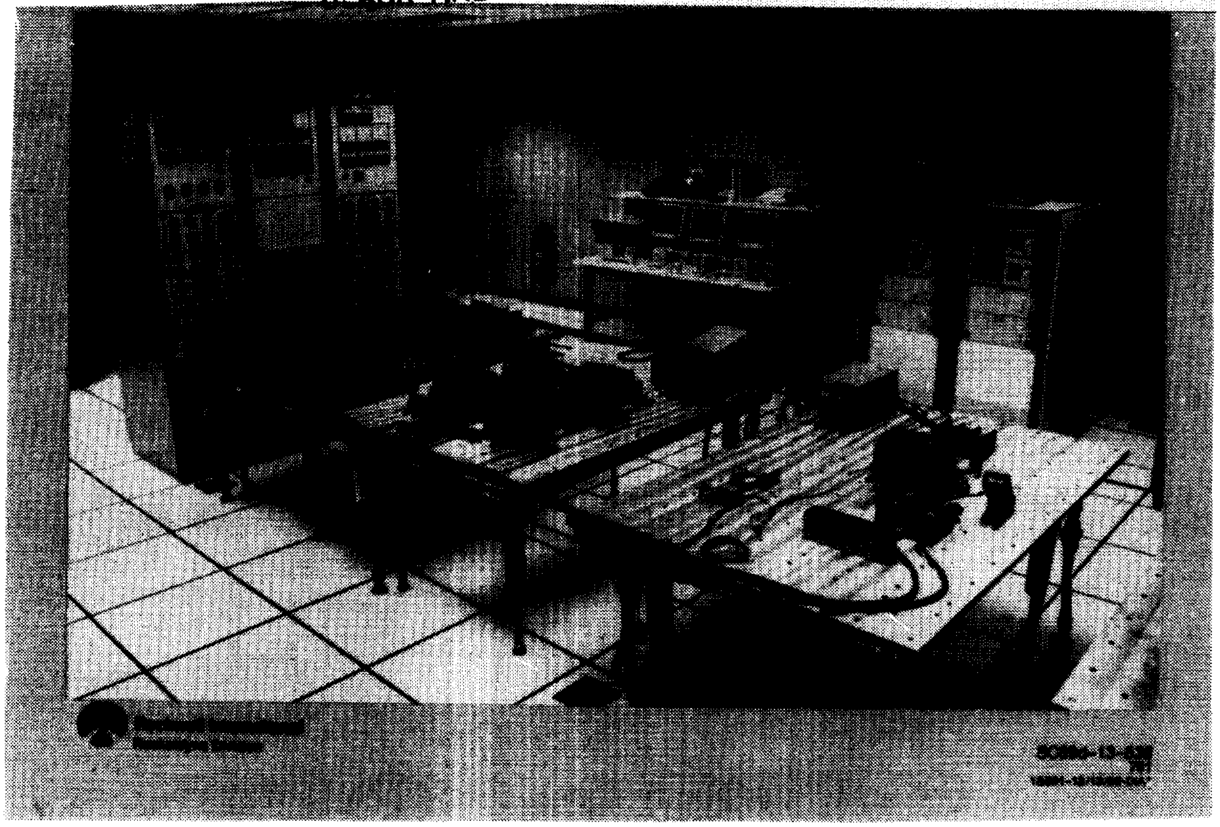

Figure 1. Electrical Power Testbed
in Space Power Electronics Laboratory.

feeder lines (power buses). The PDCU is an assembly used to distribute power directly to user loads. The fundamental building blocks for each of these assemblies are remote bus isolators (RBIs) and remote power controllers (RPCs).

The SPEL testbed was built using RBIs and RPCs. The current configuration divides the testbed into two sides representing the port and starboard sides of a space power system, with redundant power sources. This configuration is partitioned as shown in Figure 2 to distinguish outboard and inboard components. Outboard electrical components model distribution of electricity from the power sources to the first major switching assemblies. Inboard electrical components place distributed power into the feeder network.

Communication with components on the SPEL testbed is performed using a Mil-Std 1553 data bus. The component measurements transmitted are voltage, current, phase, temperature, and status. Due to power requirements of some NASA missions, the testbed is planned to be operated in parallel with a dc testbed. Changes to the dc testbed include new dc switchgear components and configurations.

Hardware and Software

The hardware used for IPAC, located in the SPEL, consists of a Compaq 386/20 personal computer and the SPEL testbed. The computer has 4 Megabytes of Extended Memory, a 60 Megabyte hard-disk, and a 80387 math co-processor. The computer has serial and parallel ports which can communicate with Mil-Std 1553 data bus and a RS-232 bus connected to the SPEL testbed. This computer hosts the expert system software, as well as the Mil-Std 1553 data communication software.

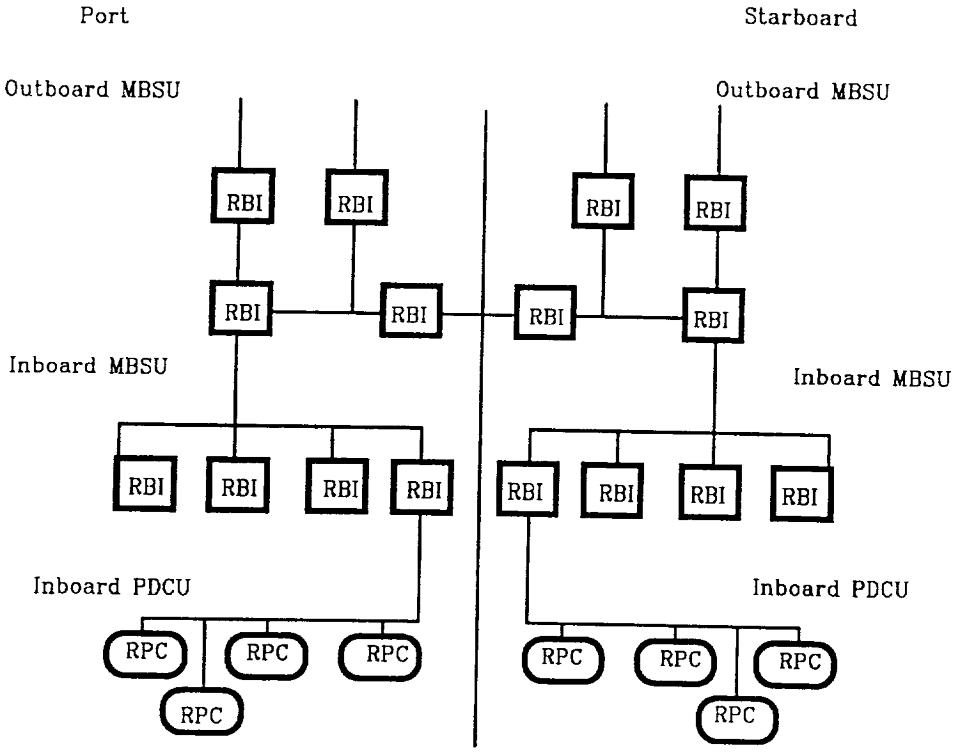

Figure 2. Testbed configuration.

Interacting with the SPEL is the expert system software. The expert system shell is Nexpert Object. This object-oriented environment is appropriate for dynamic representation of hierarchical power systems. An interactive graphical database program is the user interface for the expert system. This program, Ease +, can display dynamic updates of acquired data or consultation results. This interface reads data buffers generated by the component measurements on the SPEL testbed. An overview of IPAC's environment is shown in Figure 3.

Testing

To allow for increased capabilities for IPAC, knowledge acquisition using the SPEL testbed was started. The testing techniques are similar to ones used in previous research [4]. In particular, predictive indicators of faults are being assessed. The more accurately a fault can be defined, the better a power system may be utilized [7]. This philosophy translates to monitoring multiple points on a bus to detect variations within the power system. Basic diagnostics that were researched for a PDCU are now being applied to a MBSU. Switchgear interactions, load profiles, and multiple failures are being added to the test sequences. Some tests used last year are being conducted again to verify the results and look for additional indicators or responses.

A preliminary result from continuing knowledge acquisition reveals the testbed is governed by meta-knowledge that will be incorporated into the expert system structure. This knowledge consists of information that distinguishes which diagnostic or numerical methods programs or both should be used to check for anomalies. Constraint suspension models would indicate similar results, but these models address only functional representation [2]. IPAC's knowledge

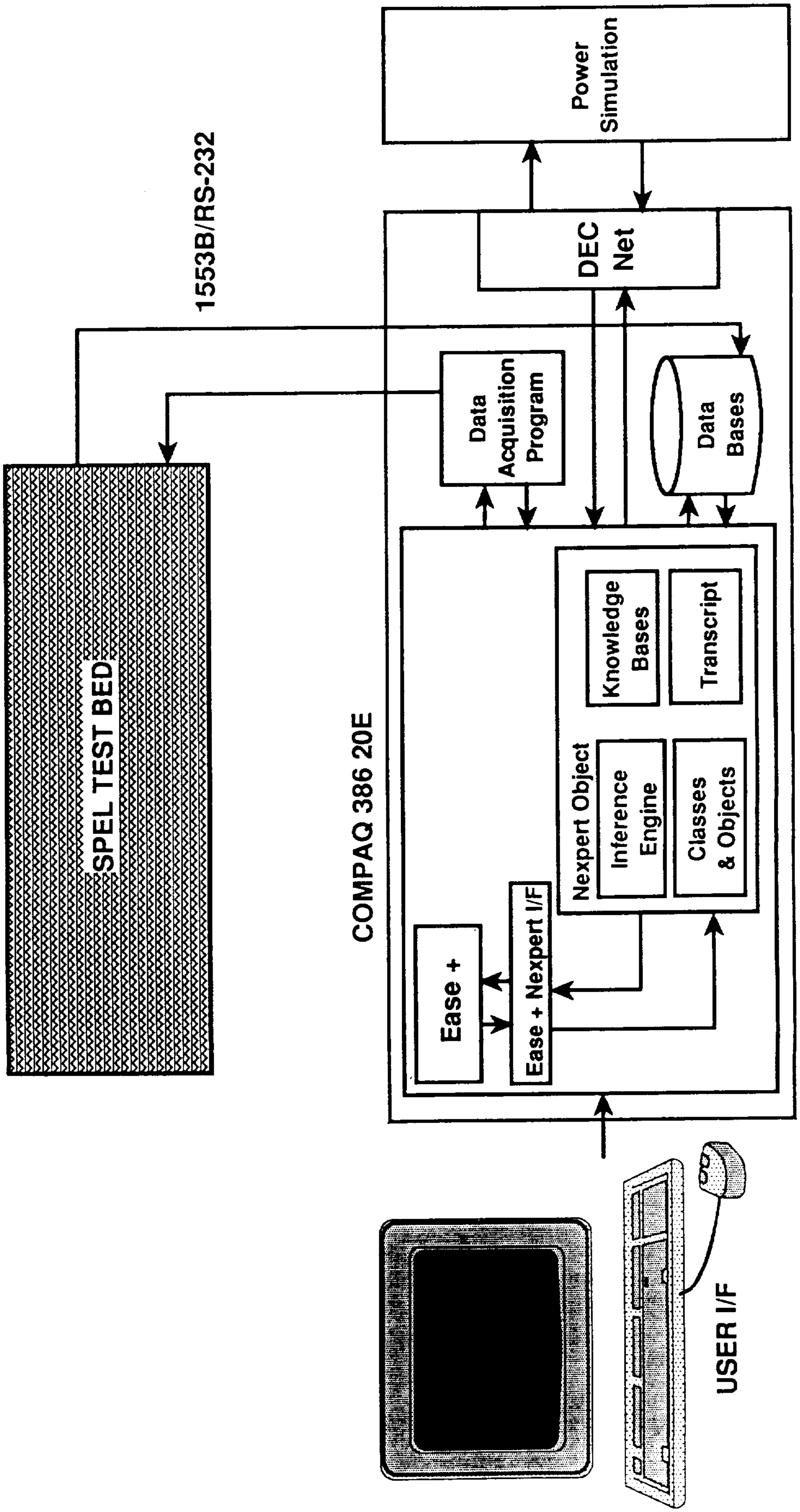

Figure 3. IPAC Environment.

is based on both functional and physical models. While similar research is being conducted at other facilities [6,8], IPAC is utilizing Rocketdyne's experienced power engineers and state-of-the-art facilities and technologies. These strengths are allowing IPAC to be developed and to evolve beyond expert system diagnostics to a total integrated power system environment.

Knowledgebase Structure and Development

To accommodate the growth in IPAC's knowledge, the structure and interactions of the DES knowledge base was changed. The DES used Ease+ only to access testbed measurements during execution, and then load the command knowledge-base. The command knowledge-base would then perform measurement validation and load appropriate knowledgebase(s) for various diagnoses and analyses (ie: communication failures, short circuits, degradation, etc.). This structure was not the most efficient for detecting some faults conditions on the testbed and for utilizing multiple knowledgebases.

IPAC's new structure alleviates these and other problems. First, the user is allowed to access three options for data during a session:

- Current testbed measurements
- Archived testbed measurements
- Simulation measurements

Data is continuously polled during a session. Depending on the option chosen, switchgear measurements will be accessed from the appropriate source and validation of these values will occur within the user interface software. This scheme is faster than using the knowledge-bases to check for correct values. While the data is being verified, critical conditions, such as short circuits, are being evaluated. This structure allows timely advisement to the user of critical problems. Once measurement validation is completed, appropriate knowledgebase(s) or programs will be loaded.

The knowledge-base(s) or numeric programs to be loaded are dependent on meta-rules within IPAC. These rules form a quasi-blackboard environment that accesses the modular programs. There are three classes of programs that can be accessed as shown in Figure 4: System Monitor, Fault Detection and Diagnostics, and System Simulation. The system monitor class contains trend analysis, component degradation, and numeric analysis programs. The fault detection and diagnostics system class contains expert systems that detect anomalies within the power system including the following:

- Communication failure detection
- Control power failure detection
- High Impedance detection
- Low Impedance detection

The system simulation module will be discussed below. Individual programs can be called from the quasi-blackboard. In the case of insufficient information, all programs will be run. Additionally, the quasi-blackboard environment can access archived data files and create new files for predictive simulations, access the SPEL testbed for testing and verification, and access the power system simulation.

When faults or possible problems are detected within the programs, advisory messages and reconfiguration suggestions are sent to the user, via the quasi-blackboard. Conflicting advice will be evaluated and adjusted by IPAC. The data is updated continuously throughout the user's session and the IPAC environment interacts with Ada control software to access the testbed.

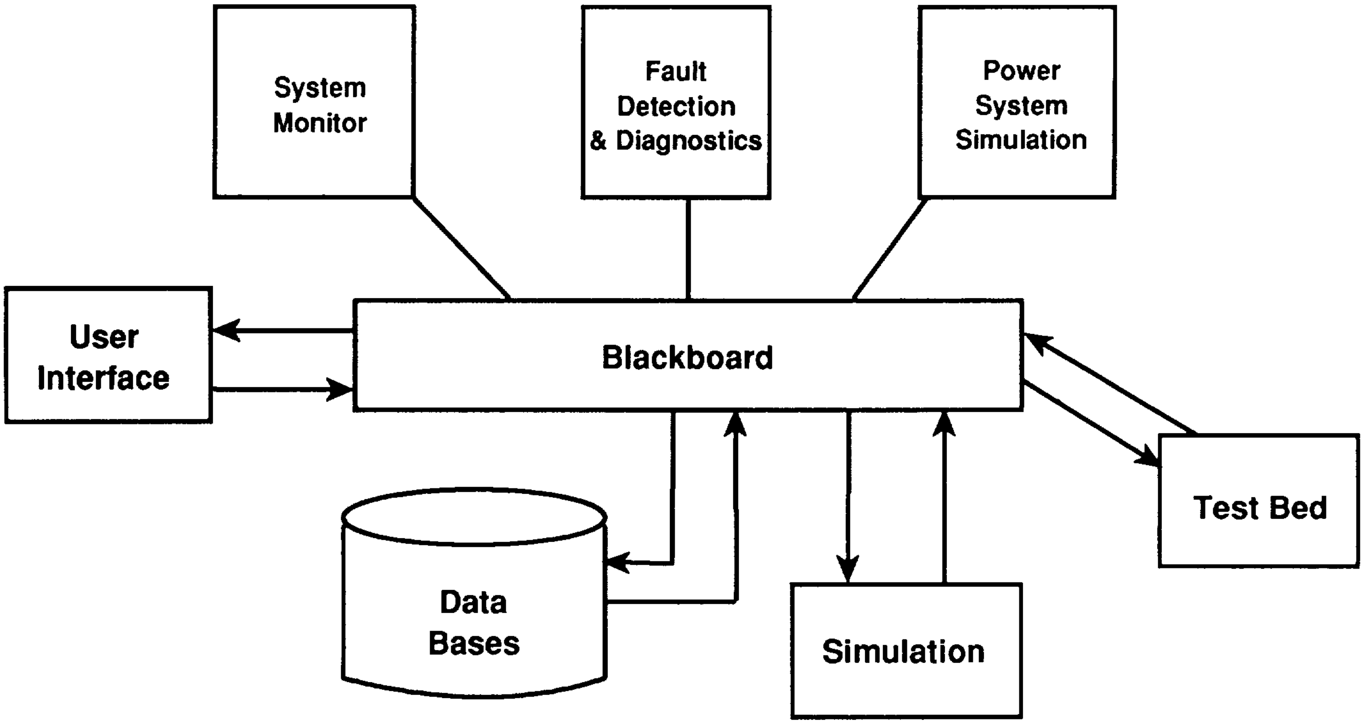

Figure 4. IPAC's Functional Environment.

Interaction with a Power Simulation

An option within IPAC is the ability to access a power system simulation. The IPAC interaction with a VAX-based power system simulation adds many capabilities to the overall program. Data from a simulation could be used as input to the diagnostic part of IPAC for monitoring and detection purposes. There has been research in the areas of power system simulation interaction with expert systems [1,5]. Additionally, interfacing with a UNIX environment, autonomous data reduction, and database protocol have been studied [9,10].

With these considerations in mind, the simulation interface to IPAC is being developed. As shown in Figure 3, a DECnet interface that will be used to access the simulation. Once the power system simulation is accessed, a power system scheduler and load flow can be executed. A template is available to specify the topology of the simulation including:

- Number of busses
- Bus connections
- Available power
- Number and type of loads

By employing the template and activating the simulation executive, a user could then receive power system information through databases. This information would include component measurements and failure modes that were detected. Power system scenarios on the simulator could be compared with data from the SPEL testbed and IPAC for evaluating predictive simulations. Work is continuing in this area.

Summary

The flexibility and adaptive diagnostic capabilities provided by an autonomous computer system, that combines classical control with artificial intelligence techniques, is being explored in the Rocketdyne SPEL. IPAC, the expert system portion of this hybrid environment, is being expanded as knowledge is gained on failure modes and hardware responses in the SPEL testbed. It is already emerging that the classical algorithms are superior in some categories of faults, while the heuristic rule base of IPAC appears better suited to others. As experimentation continues, both with real hardware and interactive simulations, the viability of this combined approach will be better determined. The results to date show considerable promise, and appear to offer a productive line of research.

References

1. Brady, M., G. E.Moody, and D. A. Scharnhorst, "A Symbolic Programming Approach to Intelligent Data Reduction," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., Vol. 1, August 1989, pp. 139-141.

2. Fesq, L. M. and A. Stephan, "On-Board Fault Management Using Modeling Techniques," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 225-230.

3. Gholdston, E. W., D. F. Janik, and G. Lane, "A Diagnostic Expert System for Space-Based Electrical Power Networks," Proceedings of the 23rd Intersociety Energy Conversion Engineering Conference, August 1988, Vol. 3, pp. 401-406.

4. Gholdston, E. W., D. F. Janik, and K. A. Newton, "A Hybrid Approach to Space Power Control Utilizing Expert Systems and Numerical Techniques," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, August 1989, Vol. 1, pp.

5. McKee, J. W., N. Whitehead, and L. Lollar, "Considerations in the Design of a Communication Network for an Autonomously Managed Power System," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 111-116.

6. Spier, R. J. and M. E. Liffring, "Real-Time Expert Systems for Advanced Power Control (A Status Update)," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 123-128.

7. Riedesel, J., "A Survey of Fault Diagnosis Technology," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 183-188.

8. Walls, B., "Exercise of the SSM/PMAD Breadboard," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 189-194.

9. Weeks, D. J. and S. A. Starks, "Advanced Automation Approaches for Space Power Systems," IEEE Computer Applications in Power, October 1989, pp. 13-17.

10. Wilhite, L. D, S. C. Lee, and L. F. Lollar, "Data Acquisition for a Real Time Fault Monitoring and Diagnosis Knowledge-Based System for Space Power System," Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, Washington, D. C., August 1989, Vol. 1, pp. 117-121.