AUTOMATION OF THE SPACE STATION CORE MODULE POWER MANAGEMENT AND DISTRIBUTION SYSTEM

David J. Weeks
National Aeronautics and Space Administration, NASA/MSFC
Marshall Space Flight Center, AL 35812

ABSTRACT

Under the Advanced Development Program for Space Station, Marshall Space Flight Center (MSFC) has been developing advanced automation applications for the Power Management and Distribution (PMAD) system inside the Space Station modules for the past three years. The Space Station Module Power Management and Distribution System (SSM/PMAD) test bed features three artificial intelligence (AI) systems coupled with conventional automation software functioning in an autonomous or "closed-loop" fashion. The AI systems in the test bed include a baseline scheduler/dynamic rescheduler (LES), a load shedding management system (LPLMS), and a fault recovery and management expert system (FRAMES). This test bed will be part of the NASA Systems Autonomy Demonstration for 1990 involving Ames Research Center, Lewis Research Center, Johnson Space Center, and MSFC. This demonstration will feature cooperating expert systems in various Space Station subsystem test beds. Earlier MSFC power system automation efforts contributing to the development of the SSM/PMAD include the Intelligent Data Reduction Expert (I-DARE), the Nickel-Cadmium Battery Expert System (NICBES), and the Autonomously Managed Power System (AMPS) including the fault diagnostic expert system, STARR. It is concluded that advanced automation technology involving AI approaches is sufficiently mature to begin applying the technology to current and planned spacecraft applications including the Space Station.

INTRODUCTION

One purpose of the Space Station advanced development program, implemented FY85-87, was to advance the state-of-the-art of various technologies to enable the development of the planned Station. The specific focus of the SSM/PMAD automation effort was to advance the Space Station Module (laboratory or habitation modules that the crew will live and work in) power system automation capability over previous manned spacecraft power systems [1,2,3].

The short-term objective of the work at MSFC is to develop ground-based knowledge-based systems integrated with actual electrical power system breadboards and test beds to demonstrate the viability of such advanced automation approaches for spacecraft on-board and ground support applications. It is envisioned that initially such knowledge-based systems would be employed as advisory systems in ground support station roles. When an appropriate confidence level in these systems is reached by program managers, advisory systems would next be employed on-board the spacecraft with the necessary hooks and scars to enable eventual direct control mode implementation. The long-term objective is to develop autonomous operation spacecraft electrical power systems.

In the Electrical Power Branch at MSFC, attention has been focused on comprehensive fault management and dynamic payload rescheduling activities. Comprehensive fault management includes identifying anomalies, diagnosing actual faults (hard and soft), recommending corrective actions for fault recovery, and autonomously implementing fault recovery actions. Dynamic payload rescheduling is necessary in order to operate a closed-loop autonomous electrical power system of significant size and complexity until a new spacecraft baseline schedule is developed and a loads event list is delivered to the power system.

When a fault develops (or begins to develop as an incipient failure) the system should be able to identify what is happening, locate the problem source, recommend actions to be taken, be able to actually implement those actions autonomously, evaluate the payload schedule for perturbations, and reschedule payloads in accordance with the current electrical power system configuration following recovery actions taken by the system. While hard short-circuits in the power system will be handled by the fast and smart switchgear to immediately protect the power system, open-circuits, resistive short-circuits, and impending faults will require intelligent systems to detect and isolate. An intelligent system should be capable of interacting with the power system by opening and closing various switches autonomously in order to narrow the list of malfunctioning component candidates to a minimum number. This implies that the system must know what switchgear it may open and close at any given time. At some point, the system may require a crew member to replace a suspect component to alleviate the problem or further narrow the suspect list. The intelligent system must also be able to discern a sensor failure from a power component failure. If a sensor is deemed to be malfunctioning, the system must inform the crew that the component should be replaced and that the system will ignore all data from that sensor until it has been informed by the crew that the sensor has been replaced.

The approach within the Information and Electronic Systems Laboratory at MSFC has been to start with well-defined, limited electrical power system applications as stand-alone systems. The next step was to integrate such applications with actual breadboards that are representative of flight systems. The current phase focuses on integrating these knowledge-based systems together and with conventional automation software.

Other research is being conducted in the area of intelligent data reduction for power system telemetry. Such data reduction is important because as much as 95 to 98% of the power system telemetry data at any given moment may be insignificant and manual data reduction is extremely people-intensive and often too late to avoid many problems. Incipient failure detection and other trends analysis for state-of-health monitoring would be greatly facilitated by on-board autonomous data reduction. Future plans involve the development of expert systems for battery management, trends analysis, and on-orbit replaceable unit (ORU) level failure forecasting.

The Electrical Power Branch at MSFC has been involved since 1984 with the development of expert or knowledge-based systems to facilitate the automation of electrical power systems. These knowledge-based systems include the Fault Isolation Expert System (FIES I and FIES II, managed by the Software and Data Management Division in 1982-84), the Space Station Experiment Scheduler (SSES), a fault detection/diagnosis/recovery expert system called STARR, the NICBES for the Hubble Space Telescope power system test bed, the SSM/PMAD system automation product which includes three AI systems [Fault Recovery And Management Expert System (FRAMES), Load Priority List Management System (LPLMS), and Load Enable Scheduler (LES)], the I-DARE, the cooperative expert system project for Scheduling And Fault Analysis/Recovery Integration (SAFARI), and some learning systems research. This paper will focus on the SSM/PMAD automation effort preceded by some discussion of the NICBES and I-DARE projects [4].

EFFORTS BENEFITTING SSM/PMAD

Two MSFC power system automation efforts involving AI are of particular interest to the SSM/PMAD automation effort. These are the NICBES and I-DARE projects.

NICBES

NICBES, the nickel-cadmium battery expert system, is integrated with the Hubble Space Telescope electrical power system test bed, featuring flight-type components. Implemented in PROLOG, the expert system resides on a PC/AT. A block diagram of NICBES and the test bed is given in Figure 1 [5].

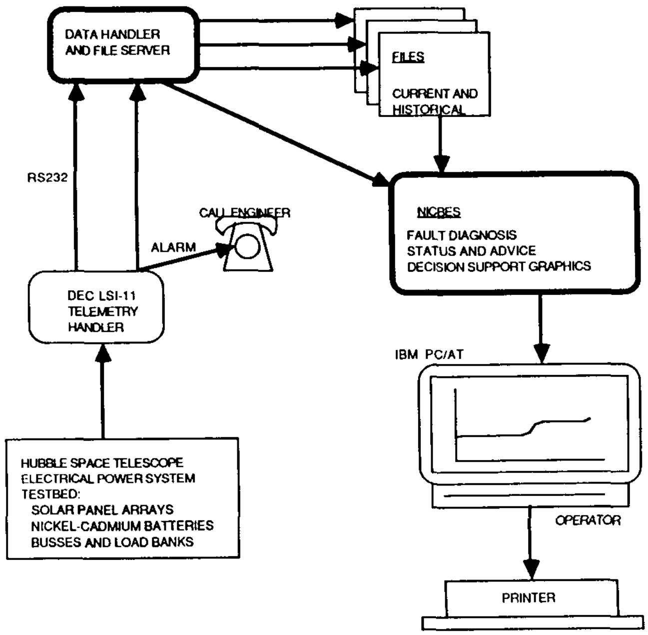

Figure 1. NICBES Functional Block Diagram

This test bed is operated continuously and automatically telephones the test bed personnel and manager at work and at home in the event of an anomaly. When these personnel arrive at the test bed site, they troubleshoot the system and take any steps necessary to restore the system to full operational status while protecting critical flight-type components in the test bed.

NICBES has three major functions in addition to the collection and storage of telemetry data from the test bed. The first function or mode is fault diagnosis. NICBES will independently verify the occurrence of an anomaly, identify the source of the anomaly, and recommend appropriate corrective actions.

The second mode is status and advice. NICBES will evaluate the status of each battery in the test (there are six, 23-cell flight-type batteries) and give advice concerning each battery. Where appropriate, graphs or histograms from the decision support system will be employed to support the advice given. Advice may also be sought on whether the battery is due for reconditioning, a change in workload, or a change in charging scheme.

The third mode is the decision support system which offers twelve plots for any of the six batteries in the system. These plots display summary data that the expert is accustomed to seeing and from which they can verify conclusions drawn by the expert system for the twelve previous simulated orbits.

NICBES is significant in that while only a prototype, it is the only expert system in NASA interfaced with a program-critical electrical power system test bed. The past year and a half of NICBES operation has driven out several features which are to be incorporated in the near future. These include the upgrading of the number of orbits of data handled from 12 to between 100 and 500; adding an explanation facility; employing a true multi-tasking operating system; and porting to a faster computer (80386 personal computer).

I-DARE

The intelligent data reduction expert system (I-DARE) is implemented on a Lisp workstation in Common Lisp. It is interfaced with the telemetry data stream from the Hubble Space Telescope power system test bed over dedicated lines to the electrical power systems test beds laboratory in another building and will autonomously reduce the data to the significant components. The concept of such data reduction is shown in Figure 2. Such data reduction is currently extremely slow and manhour intensive. This is a two year research effort with emphasis on emulating in an expert system the behavior of the test bed engineers in reducing the power system telemetry data to its significant components [8].

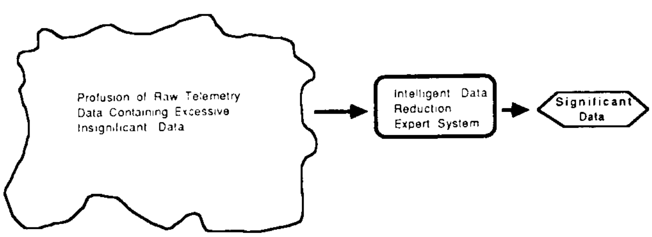

Figure 2. Intelligent Data Reduction Expert System

SSM/PMAD AUTOMATION

The Space Station advanced development breadboard for power system automation at MSFC is illustrated in Figure 3. The SSM/PMAD is a dual channel 20 kHz power system sized large enough to operate a substantial number of realistically sized loads simultaneously and autonomously. The architecture and functionality are based upon the requirements of a Space Station Core Module. Autonomy is pushed down to the lowest levels, the lowest level processors (LLP) located in the load centers and subsystem distributors. The Communications and Algorithmic Controller (CAC) implemented on a VME/10 mini-computer performs numeric computations, controls the breadboard communications (Ethernet and RS-422 serial data networks) and directs the LLPs. The breadboard includes three AI systems which function in a cooperative mode. These are the LPLMS, the LES, and the FRAMES [6].

LPLMS

The prioritization expert system is called the loads priority list management system (LPLMS) and keeps up with the dynamic priorities of all payloads while developing current global load shedding lists for the SSM/PMAD every 15 min in preparation for contingencies which necessitate load shedding. The global load shedding list is broken down by the CAC into local load shedding list for each load center/subsystem distributor. The LPLMS is implemented in Common LISP and resides on a LISP workstation.

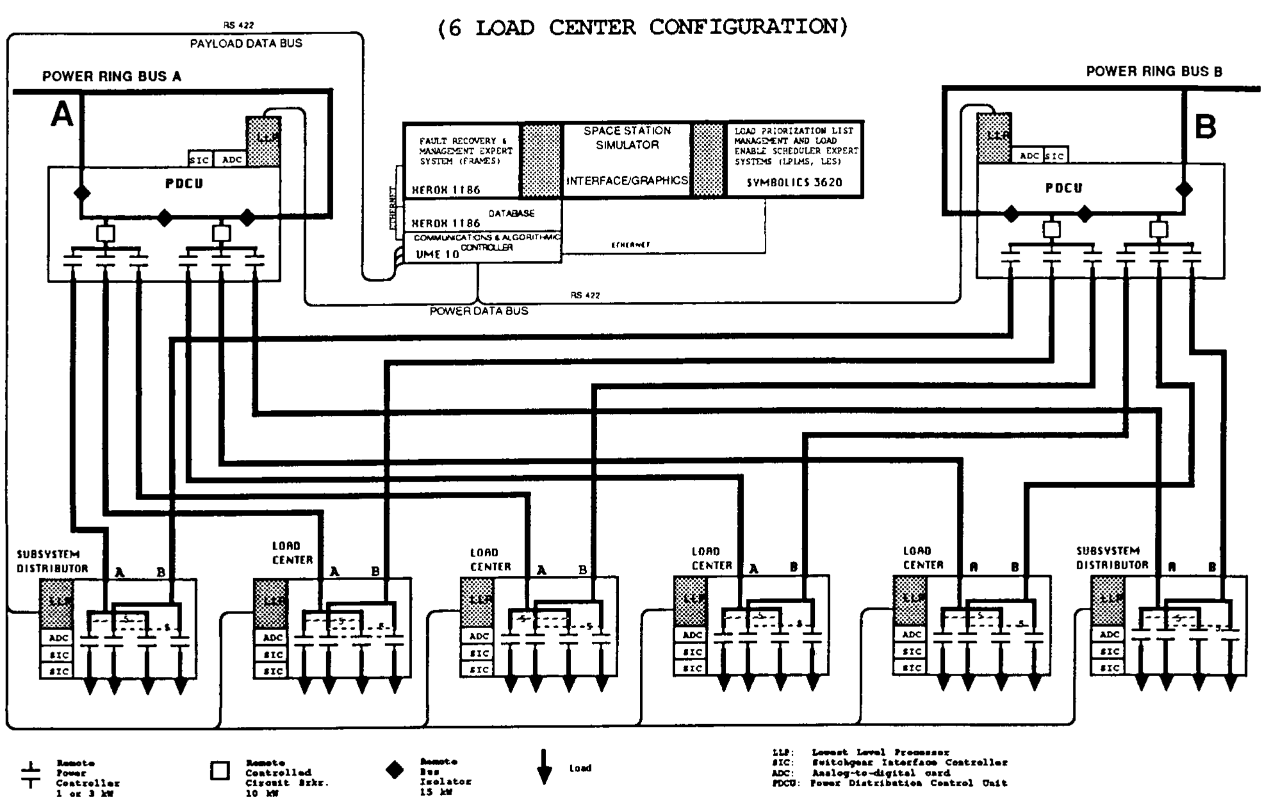

Figure 3. SSM/PMAD Block Diagram

ORIGINAL PAGE IS OF POOR QUALITY

LES

The scheduler expert system is called the load enable scheduler (LES) and schedules/reschedules the payloads for the Space Station module. LES is a special version of MAESTRO, the Martin Marietta IRAD AI scheduling effort. The baseline scheduling capability of LES generates a baseline schedule in the form of event lists which provide the SSM/PMAD test bed with operational scenarios. LES can handle hundreds of scheduling constraints. It can reschedule the loads in response to a reconfiguration of the SSM/PMAD (due to a fault, change in power allocation, or operator instructions) in as little as five minutes. This allows the SSM/PMAD to continue servicing loads in accordance with mission objectives and priorities the best that it can under deteriorating circumstances. This resource scheduler also resides on the Lisp workstation hosting the LPLMS and is coded in Lisp [7].

FRAMES

The fault recovery and management expert system (FRAMES) resides on a separate Lisp workstation and is implemented in the Common List Object System (CLOS). This expert system watches over the entire breadboard operation looking for anomalies and impending failures. The functionality of FRAMES actually extends to the lowest level processors and the smart switchgear with their associated controllers in the breadboard for comprehensive fault management of the entire breadboard.

FRAMES is responsible for detecting faults, advising the operator of appropriate corrective actions, and in many cases autonomously implementing corrective actions through power system reconfiguration. The expert system will carry out trends analysis seeking incipient failures and soft shorts as well as open circuits. Fast response remote power controllers (RPC) respond to the hard system shorts.

When a fault or anomaly occurs in this Space Station module power system breadboard, FRAMES detects, diagnoses, and recommends corrective actions (in the case of critical loads, it also autonomously performs corrective actions). Then the LES interface determines if a new payload schedule is necessary and if so, directs LES to reschedule the payloads. The LPLMS derives new load shedding lists from the new schedule and issues these lists to the CAC which develops local load shedding lists for LLPs in the load centers and subsystem distributors, thus completing the closed automation loop as illustrated in Figure 4.

SPECIFIC RESULTS

NICBES is employed daily and has proved to be a valuable aid to the Hubble Space Telescope power system breadboard personnel. Its major deficiency resides in the single tasking mode of the operating system on the PC/AT. An upgrade in progress will move NICBES to a 80386-based computer system. The revised NICBES will involve a multi-tasking operating system which will allow continuous data handling. It will increase the number of orbits data handling from 12 to between 100 and 500 while adding a natural language explanation facility. An editor to facilitate the rule base maintenance is also under development. Plans are now being formulated to develop another expert system for a new nickel-hydrogen battery test bed for the Hubble Space Telescope program.

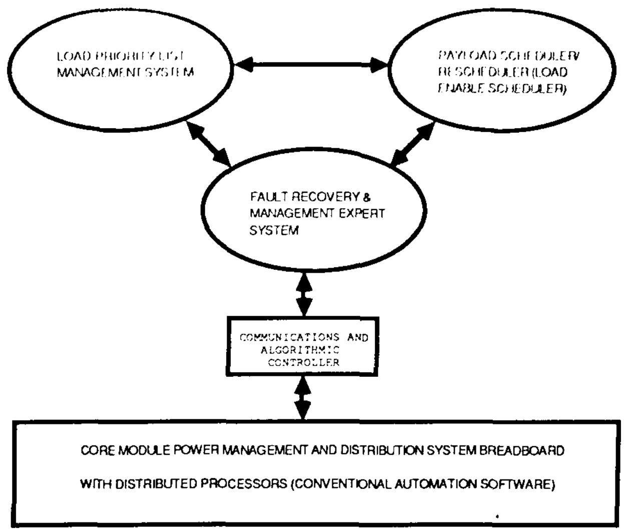

Figure 4. Closed-Loop Operation

I-DARE is a simple model at this point and will continue to be under development for the next year. The data link for the AI workstation is in place and intensive interviews with the domain experts (the data reducing engineers) have taken place. A prototype has been developed which does some telemetry transmission error detecting and reduces the actual telemetry data to a limited extent. The goal is to at least match human performance in this phase.

Prototypes of LPLMS, LES, and FRAMES have been completed. As this paper is being written, these systems are being integrated with one another and with the SSM/PMAD test bed hardware and conventional software. A full-up integrated test will be conducted at MSFC in August 1988. Work has already commenced on further development of the SSM/PMAD to support the 1990 NASA Systems Autonomy Demonstration featuring cooperating expert systems in Space Station subsystem test beds.

CONCLUSIONS

Artificial Intelligence systems will be employed in the automation of future spacecraft electrical power systems including the Space Station. Initially, these systems will serve in advisory roles primarily in the ground support stations with some limited advisory roles on-board manned spacecraft. The hooks and scars will be designed in place for these advisory systems to evolve to direct control implementation modes of operation. Initially, such control systems may be placed primarily in the ground support stations until program management, ground support personnel, and crew confidence is established to the point that they may be implemented on-board. On-board AI control systems will be implemented such that if the AI system fails, it will not cause a catastrophic situation but will instead allow the subsystem to continue operations in a less automated but safe fashion.

The eventual goal is completely autonomously operated spacecraft electrical power systems. Conventional automation software approaches have too many gaps to provide overall autonomy. Utilizing AI approaches allows for comprehensive fault management and dynamic rescheduling capabilities for the electrical power system. Autonomous intelligent data reduction will enable enhanced state-of-health monitoring and better trends analysis including incipient failure detection which will enable recovery actions to be taken in order to preclude an actual failure. Many of the approaches and techniques developed to support autonomous electrical power systems operation may also be utilized for other spacecraft subsystems as well.

ACKNOWLEDGMENTS

The author wishes to acknowledge the technical support of the knowledge-based projects discussed in this paper by the Martin Marietta Corporation, the University of Alabama in Huntsville, and the personnel of the Electrical Power Branch at MSFC. It is also acknowledged that the reverential awe of the Lord God is the beginning of all knowledge (Proverbs 7:1).

REFERENCES

1. Weeks, D. J., and Bechtel, R. T.: "Autonomously Managed High Power Systems," Proceedings of the 20th IECEC, Miami, FL, 1985.

2. Weeks, D. J.: "Application of Expert Systems in the Common Module Electrical Power System," SPIE Vol. 580 Space Station Automation, Cambridge, MA, 1985.

3. Weeks, D. J.: "Expert Systems in Space," IEEE Potentials, Vol. 6, No. 2, 1987.

4. Weeks, D. J.: "Artificial Intelligence Approaches in Space Power Systems Automation at Marshall Space Flight Center," Proceedings of the First International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Tullahoma, TN, 1988.

5. Kirkwood, N., and Weeks, D. J.: "Diagnosing Battery Behavior with an Expert System in PROLOG," Proceedings of the 21st IECEC, San Diego, CA, 1986.

6. Weeks, D. J.: "Artificial Intelligence and Space Power Systems Automation," Proceedings of the Third Conference on Artificial Intelligence for Space Applications, Huntsville, AL, 1987.

7. Geoffroy, A. L., et al.: "Power Resource Management Scheduling for Scientific Space Platform Applications," Proceedings of the 22nd IECEC, Philadelphia, PA, 1987.

8. Weeks, D. J.: "Space Power System Automation Approaches at the George C. Marshall Space Flight Center," Proceedings of the 22nd IECEC, Philadelphia, PA, 1987.