IN-20
46782
p. 22

NASA
Technical
Paper
3161

October 1991

Automating a Spacecraft Electrical Power System Using Expert Systems

L. F. Lollar

NASA

Automating a Spacecraft Electrical Power System Using Expert Systems

L. F. Lollar
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL PAPER

AUTOMATING A SPACECRAFT ELECTRICAL POWER SYSTEM USING EXPERT SYSTEMS

I. INTRODUCTION

The typical long-duration low-Earth orbit (LEO) spacecraft electrical power system (EPS) consists of an energy source, an energy storage element, a power management and distribution (PMAD) system, and loads. In the past, the majority of NASA's spacecraft have used solar energy sources, their energy storage elements have been batteries (usually nickel-cadmium (Ni-Cd)), their PMAD systems have been low-voltage dc (+ 28 Vdc) or 110 Vrms, 400 Hz ac, and the loads have totaled less than 10 kW. These spacecraft were typically payload-driven designs, and even small variations in payload would greatly affect the efficiency and maintainability of the EPS [1].

Future needs such as for Space Station *Freedom* (S.S. *Freedom*) and Moon/Mars missions will be on the order of tens of kilowatts to a few megawatts [2,3]. These new systems will contain increasingly more powerful and more complex elements. Energy sources could be concentrator solar arrays, solar dynamic, nuclear, or a combination. Energy storage, if separate from the source, could be advanced nickel-cadmium, nickel-hydrogen, lithium, or sodium-sulphur batteries, or advanced-momentum energy storage systems. The PMAD will require higher power and more efficient components as well as new EPS control technologies [2,4,5]. As a result of these new technologies and the increasing size, automating the EPS has become an enabling technology for future large spacecraft.

II. AUTOMATING THE ELECTRICAL POWER SYSTEM

After the final crew left on February 9, 1974, and Skylab, NASA's first space station, was powered down, the EPS was evaluated. In the conclusion of this evaluation, 10 recommendations for future spacecraft electrical power systems were presented. Seven of these recommendations can be resolved by automating the EPS [6]. Based on these seven recommendations and experience from other spacecraft electrical power systems, NASA and its industrial and university partners began to investigate automating a spacecraft's EPS.

The EPS is a natural candidate for automation. The EPS is of such complexity that any simplification can produce large benefits in cost and operation manpower reduction, yet it is of such simplicity that basic engineering concepts and experience can be translated into the hardware and software relatively easily. Many reasons exist for automating the EPS, two of the more significant are discussed in the following.

A. Critical for Some Future Missions

As NASA looks toward the 21st century, it has identified four mission goals to pursue: (1) enhanced capabilities for the S.S. *Freedom*; (2) a manned lunar colony; (3) the manned exploration of Mars and Phobos; and (4) a detailed study of the Earth from space. In order to meet the increased load demands, each of these four missions will require larger and more complex power systems. Because of this complexity, EPS automation will be required in order to control the system in real-time and to allow the crew to perform scientific experiments rather than devoting a lot of time to EPS operations.

In addition to these manned missions, NASA is designing new unmanned interplanetary satellites, similar to the Pioneer series. Because of the distances involved, these satellites will require large complex power systems with the ability to operate without man or ground support for minutes to hours. Thus, EPS automation will be required to meet these needs.

B. Reduced Operating Costs

One of the most valuable commodities on any space mission is crew time. On the order of $20,000 per manhour, having an astronaut observe a voltmeter or switch status is terribly inefficient and very expensive. Therefore, the ability of automation to reduce crew interaction with the EPS will allow the crew more time to monitor science and materials processing experiments which require his attention. Besides the crew, ground support personnel are an integral part of any space mission. They perform many functions including preflight checkout, postflight data reduction, and on-orbit operations. Automation techniques can aid in preflight checkout of the EPS by allowing a more friendly test computer user-interface, by being more flexible in failure mode testing, and by providing more detailed fault analyses. Postflight data analysis can be aided by data reducing programs.

Other cost reduction benefits from automation will be gained by a reduction of ground-based personnel during orbital operations. As noted earlier, Skylab was the first example of a near-utility type power system. Skylab's EPS required a two-person team working around the clock to monitor, plot, and analyze the power system and to make recommendations to the operations manager relative to EPS operation [8]. If this level of effort, without automation, were scaled to the size of S.S. *Freedom*, the EPS operation would become prohibitively expensive.

A further cost reduction can be realized through spacecraft weight savings. Using automation techniques, a spacecraft EPS can be designed to allow maximum use of the limited available power and energy. Solid-state circuit breakers and switchgear can be designed closer to their allowable operating ranges, thus providing smaller and lighter devices. Software techniques can be used to provide fault isolation and recovery, thus allowing for reductions in redundant hardware.

III. THE NEED FOR EXPERT SYSTEMS

If one accepts the need for power system automation, the next step is to establish the method(s). The early work (late 70's to early 80's) in automation concentrated primarily on the hardware with some

2

initial work on the level of and the complexity of the software that would be needed. These efforts produced many useful and necessary results, but newer technologies would be required to fully automate the EPS. Thus, as a part of the 1984–1985 effort to investigate automating the S.S. *Freedom* EPS, the role of expert/knowledge-based systems technologies in this area was evaluated.

As a result of this investigation, numerous functions in the EPS were determined to meet the necessary criteria to use expert/knowledge-based systems in their implementation. Some of these functions were power generation monitoring; energy storage management; fault detection, isolation, and recovery (FDIR); resource scheduling; and load management [7]. Each of these functional areas required decisions to be made with incomplete knowledge and/or a measure of uncertainty which meshed with the advantages of expert system technologies. In addition, this technology allows for flexible EPS development in order to establish the necessary algorithms needed for control. The remainder of this paper discusses some of the numerous expert/knowledge-based systems applied to the EPS domain.

IV. THE AUTONOMOUSLY MANAGED POWER SYSTEM

The first steps taken toward automating an EPS began in 1978 with the start of the autonomously managed power system (AMPS) program. The AMPS program was funded by NASA's Office of Aeronautics and Space Technology (OAST) through MSFC. The AMPS program was a three-phase program. The first phase was contracted to TRW and identified a reference photovoltaic EPS for a 250-kW class LEO satellite. The second phase developed the autonomous power management approach for the reference EPS using efforts at TRW and in-house MSFC. The third phase developed a breadboard test facility at MSFC to evaluate, characterize, and verify the concepts and hardware resulting from phases 1 and 2 and utilizing hardware developed under other OAST space power program initiatives.

At present, the AMPS test facility (fig. 1) features two power channels feeding three power busses which in turn provide power to a load simulator. The two solar array simulators are rated at 75 kW and 17 kW capacity, respectively, while the 168-cell high-voltage Ni-Cd batteries are rated at 180 Ampere-hours (Ah) and 55 Ah. The smaller battery is a flight-type battery retrieved from the Skylab project test bed. The load simulator consists of nine resistive loads and one dynamic load that consume a total of 24 kW of power when operated at 200 Vdc. Finally, four Motorola 68000 microcomputer-based controllers provide data retrieval and low-level decision making for the power system with a Sun 4/330-based host computer providing programmability and status display for flight power system simulations [9].

V. THE SPACE STATION MODULE/POWER MANAGEMENT
AND DISTRIBUTION TEST BED

Based on the results of AMPS, a project to investigate automation techniques appropriate to a large PMAD system such as will exist on S.S. *Freedom* modules was begun in 1984 at MSFC. With the support of Martin Marietta Space Systems Group, a 25-kW space station module/power management and distribution (SSM/PMAD) test bed was developed [10].
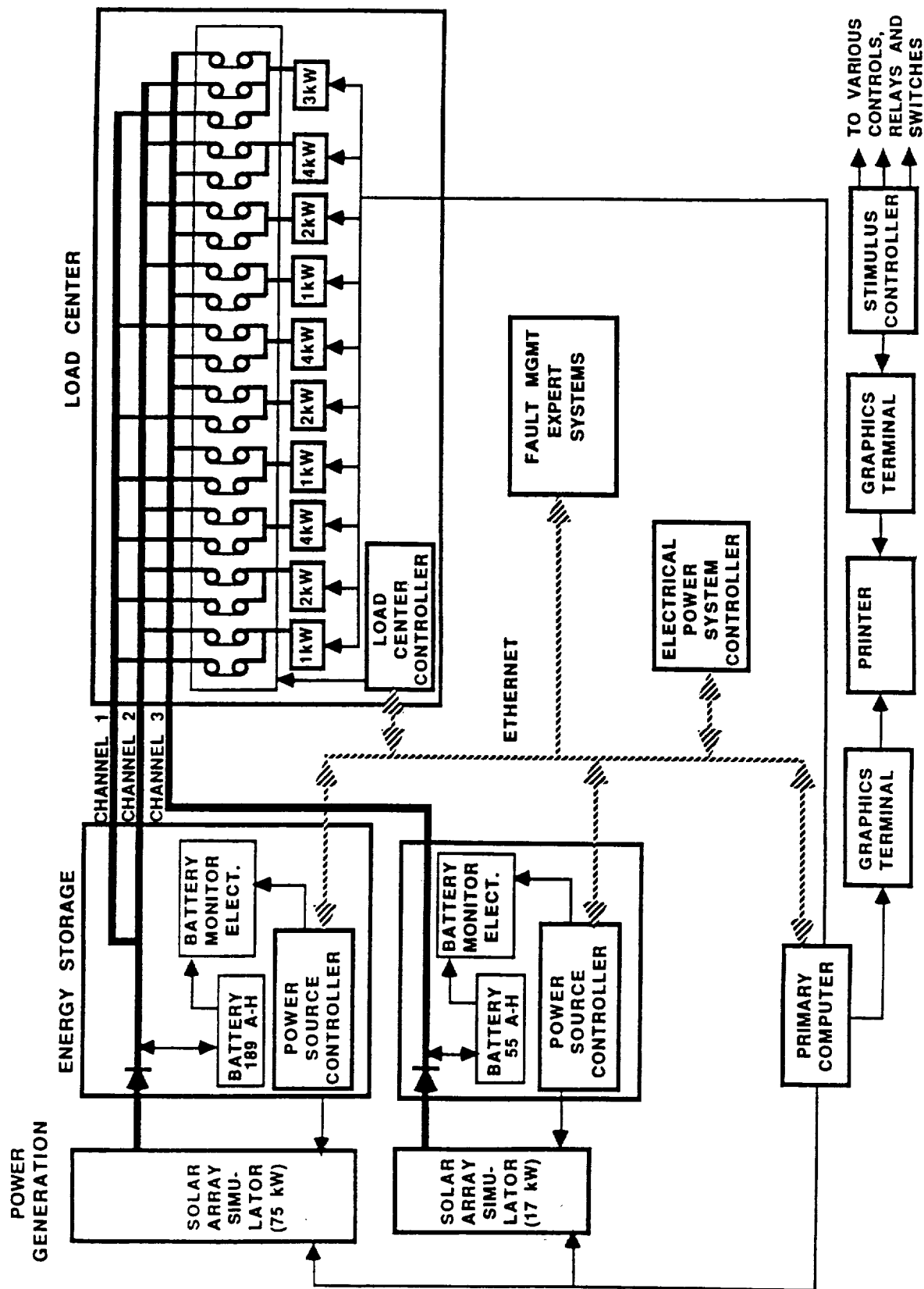
Figure 1. The autonomously managed power system (AMPS).

As figure 2 shows, this test bed hardware has two power distribution control units (PDCU's) and three load centers. The basic system design allows for two additional load centers. Further, the test bed includes remote bus isolators (RBI's), remote controlled circuit breakers (RCCB's), and remote power controllers (RPC's). Lastly, a lowest level processor (LLP) is included in each PDCU and load center. In the software area of the test bed, autonomy is pushed down to the lowest levels, specifically, to the LLP's and through the switch interface processors to the "smart" switchgear. Three artificial intelligence (AI) systems—the fault recovery and management expert system (FRAMES), the load priority list management system (LPLMS), and the master of automated expert scheduling through resource orchestration (MAESTRO)—reside above and communicate with the other processors through the communications and user interface (CUI) software [11]. The software will be described in more detail later.

VI. EXPERT SYSTEMS IN THE AUTOMATION TEST BEDS

A. AMPS Based

Two expert system projects have been based on the AMPS test bed. One is the power system fault detection and recovery expert system named STARR. Two is a real-time fault detection and advisory expert system named the autonomously managed power system expertise reinforcing expert system (AMPERES).

STARR is an object-oriented expert system featuring a parent object *SYSTEM for each of the five main objects (SA, SWITCH, BATTERY, DIST, LOADS) which correspond to the actual AMPS test bed subsystems. STARR was created using Intellicorp's Knowledge Engineering Environment (KEE) on a Xerox 1109 (Dandelion) AI work station. Figure 3 is a display of all the objects in the knowledge base and their inheritance hierarchy. STARR was interfaced to AMPS via the AMPS Ethernet local area network [12].

STARR proved to be a valuable first attempt at EPS fault detection and recovery using expert systems. However, the lack of speed of the Xerox 1109 and the KEE environment precluded fully implementing STARR in the AMPS test bed. These deficiencies led to the AMPERES project.

AMPERES is a real-time knowledge-based system which monitors the operational status of an EPS and provides fault diagnostic information. AMPERES uses the AMPS test bed at MSFC and is being developed by the University of Tennessee Space Institute (UTSI) [13].

AMPERES is composed of five major functional models to efficiently perform the necessary tasks (fig. 4). The fault monitoring and diagnosis task is decomposed into several subtasks, and each subtask is performed by a specialized module. The main controller module is a task-oriented inference engine which is organized and tuned to perform the given fault monitoring and diagnosis tasks. The status monitor module is responsible for assessing the current power system operational status. The fault diagnoser module is responsible for fault diagnosis and operator recommendations. The interface handler module is responsible for processing the various methods of input/output. The knowledge base (KB) module contains the necessary system information used to diagnose and monitor faults. Each module and submodule, except the natural language interface, the load of load schedule KB, and the statistic KB, has been initiated [13].
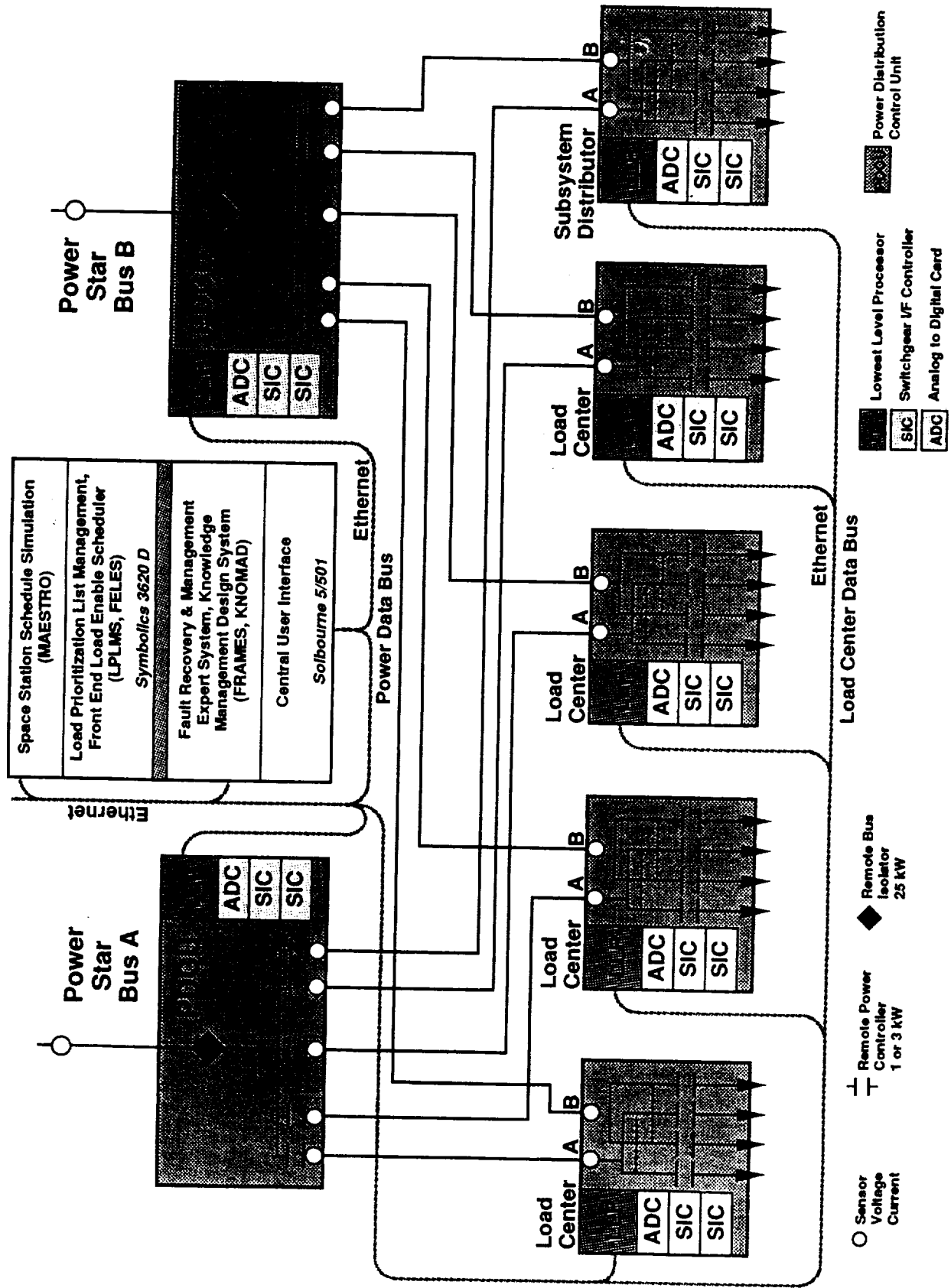
5

Figure 2. Space station module/power management and distribution system (SSM/PMAD).
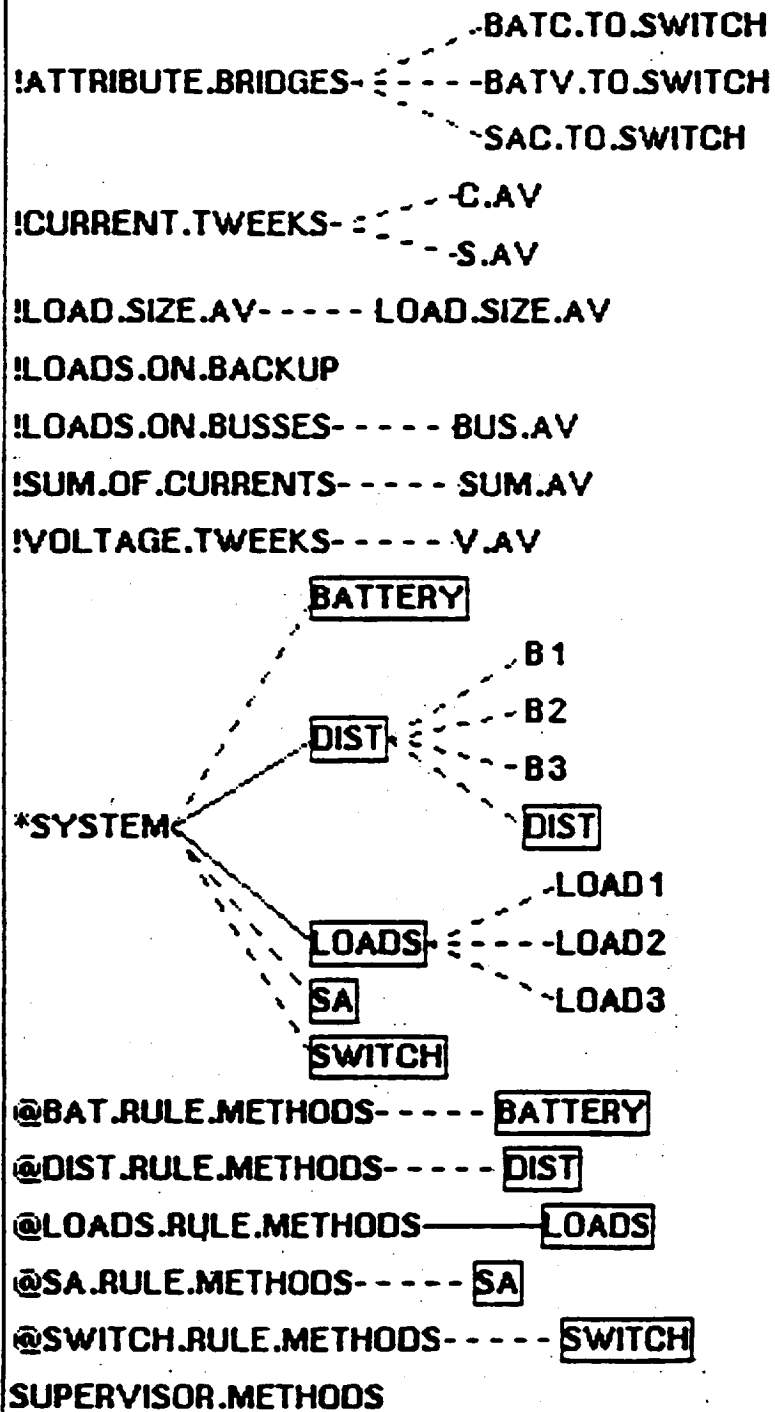
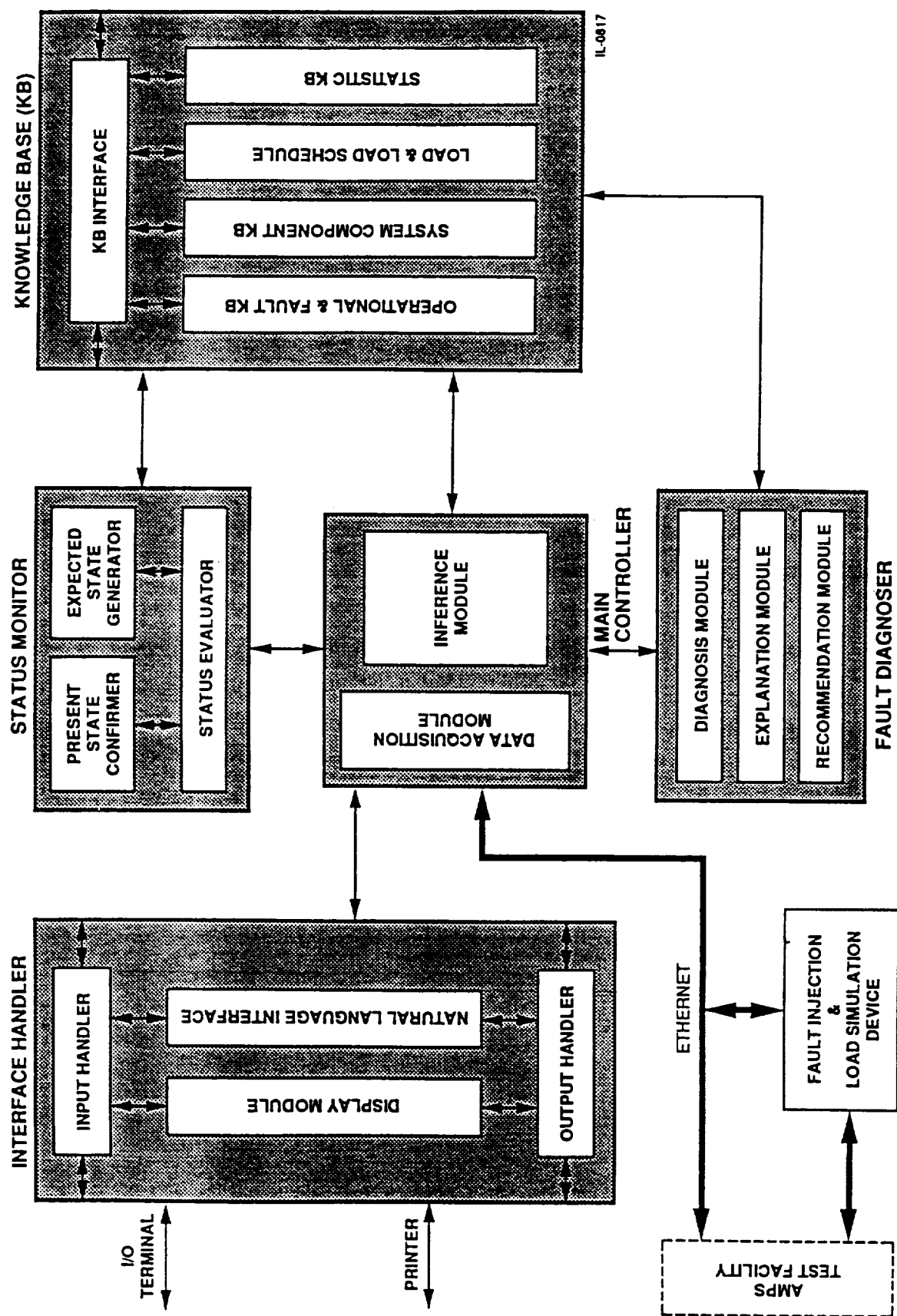Figure 3. Objects in the STARR expert system.

Figure 4. Autonomously managed power system extendible real-time expert system (AMPERES).

The knowledge base is structured using a component-centered approach. Each component in the AMPS test bed is represented as an object in AMPERES using the structure definition in common LISP. An ammeter representation is shown in figure 5. The information included in each component representation can be categorized into three groups: (1) the information about the component itself, (2) the functional environment of the component, and (3) the physical environment of the component. Fault monitoring and diagnosis knowledge is implemented in production rule forms (fig. 7) with the rule language being as close to natural language as possible which allows for ease of rule editing.

In order to perform prototype testing with AMPERES at UTSI, a single power channel AMPS load simulator was developed. The simulator consists of an IBM PC compatible computer with an Ethernet interface and an AMPS-type power channel with a fault injector. This simulator is then interfaced with a Sun 386i which houses AMPERES. Preliminary results with the simulator have been good, with the final goal of interfacing AMPERES with AMPS to be completed in early 1991.

B. SSM/PMAD Based System Software

The system software is distributed through several different types of processors and at different hierarchical levels. The LLP's are located at the level nearest the power hardware. The CUI software is notified of any anomalies by the LLP. FRAMES, MAESTRO, and LPLMS share the highest level of the hierarchy. Each step up this hierarchy reveals a decrease in speed (microseconds at the switchgear level, milliseconds to seconds at the LLP level, seconds to minutes at the AI level (fig. 6)) and an increase in sophistication [10].

The LLP's consist of Intel 80386-based computers and an Ethernet communication board. An LLP is located in each load center, subsystem distributor, and PDCU. Each LLP is responsible for controlling the switches associated with it and for keeping track of all the sensor readings and switch positions in its center. The LLP also executes scheduled changes in switch positions, sheds any loads which exceed their scheduled maximum, and switches redundant loads to their secondary bus if the load's primary source is interrupted. The LLP passes any or all of this information to the CUI software [10].

The CUI software is resident in a Solbourne 5/501 UNIX-based work station. The CUI software routes information to the various LLP's, controls LLP initialization, and serves as the man/machine interface for the entire system. Messages are passed from the three AI systems to the LLP's through the CUI via Ethernet communication links [10]. Figure 7 shows the top-level main screen of the user interface.

The FRAMES resides on the Solbourne 5/501 work station and is implemented in the common LISP object system (CLOS). This expert system watches over the entire EPS looking for anomalies and failures. FRAMES is responsible for detecting faults, advising the operator of appropriate corrective actions, and, in cases involving critical loads, autonomously implementing corrective actions through power system reconfigurations. FRAMES recognizes and adjusts to hard faults which the smart switchgear handles immediately, as well as handling soft faults, cascaded faults, and independent multiple faults [11].

The LPLMS resides on the Solbourne 5/501 work station and is implemented in LISP. The LPLMS keeps track of the dynamic priorities of all payloads while developing and downloading current load shedding lists for the LLP's every 15 min in preparation for contingencies which necessitate load

9

Component Representation and Its Environment

```
;-------------------- Ammeter Frame --------------------
(defstruct ammeter
  (component_id)
  (connect_terminal )
  (location)
  (one_of 'load_ammeter)
  (assoc_cb )
  (assoc_ms )
  (connect_load )
  (parent_ammeter )
  (children_ammeter )
  (assoc_voltmeter)
  (present_expected_range )
  (normal_expected_range )
  (present_value)
  (trend 'steady)
  '(faulty_state 'no)
  (signal_ckt )
  (graphics ))
```

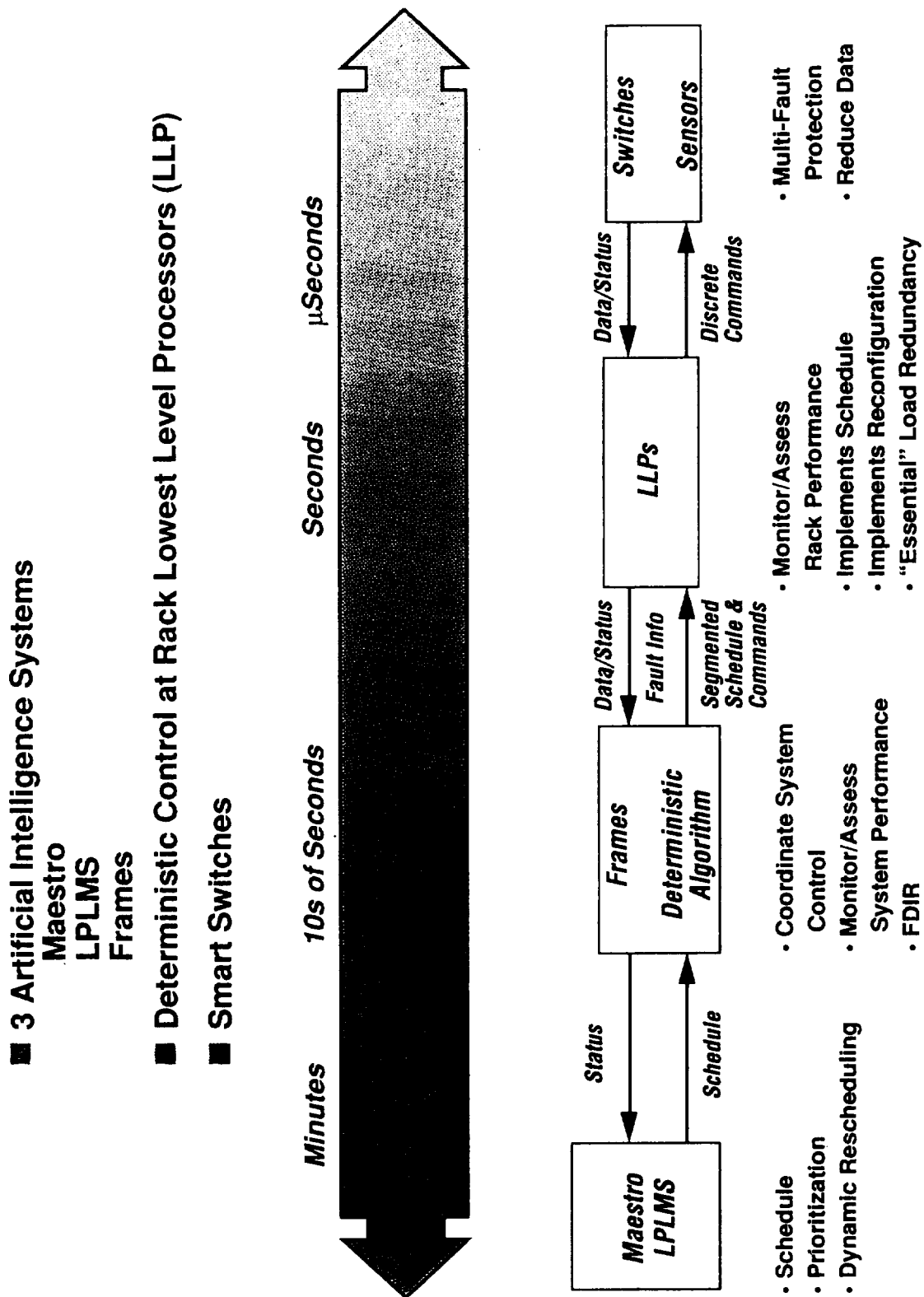Figure 5. Representation for an ammeter.

Figure 6. SSM/PMAD control diagram.

- 3 Artificial Intelligence Systems
  Maestro
  LPLMS
  Frames

- Deterministic Control at Rack Lowest Level Processors (LLP)

- Smart Switches

Minutes   10s of Seconds   Seconds   µSeconds

Maestro LPLMS

Status
Schedule

Frames
Deterministic Algorithm

- Coordinate System Control
- Monitor/Assess System Performance
- FDIR

Data/Status
Fault Info
Segmented Schedule & Commands

LLPs

- Monitor/Assess Rack Performance
- Implements Schedule
- Implements Reconfiguration
- "Essential" Load Redundancy

Data/Status
Discrete Commands

Switches
Sensors

- Multi-Fault Protection
- Reduce Data

- Schedule
- Prioritization
- Dynamic Rescheduling

11

Figure 7. The SSM/PMAD user interface (top level screen).

shedding. This way, load shedding is implemented quickly in each load center or subsystem distributor. The LPLMS maintains a real-time dynamic representation of all the module loads and relevant facts so that applicable rules can fire to reorder portions of the load shedding list as situations change. The loads in a laboratory module may have dynamic properties. A critical noninterruptible materials processing experiment involving crystal growth will undoubtedly have a different priority as it nears completion. Other factors may change priorities such as equipment malfunctions. An expert system such as the LPLMS is crucial in determining which loads must be shed in the event of perturbations to the available power. The LPLMS insures that critical loads not be shed unnecessarily [11].

MAESTRO resides on a Symbolics 3620D and is implemented in LISP. Special interfaces have been developed for MAESTRO which allow a great deal of flexibility in interactions with the scheduler. MAESTRO is a resource scheduler developed by Martin Marietta and can schedule and reschedule a number of payloads with various scheduling constraints. This AI system generates the baseline schedules for the EPS and accepts information from the other processors on when and how to reschedule module payloads. MAESTRO uses pieces of several AI technologies including object-oriented programming, heuristically guided search, activity library, expert functions, etc. MAESTRO schedules loads with regard to numerous resource constraints such as available crew members, supplies for payloads, interdependence of payloads, power profiles, and thermal status [11].

In order to efficiently operate these three expert systems together, a simultaneous multiagent knowledge manager function called the knowledge management and design (KNOMAD) system was designed and built. KNOMAD utilizes a distributed data base management function to provide a modified blackboard management capability. The KNOMAD architecture is layered as shown in figure 8. The central layer is the data base which provides a place for storing working memory data, for transferring and sharing data, and for storing long-term data. The data base is modular and may be implemented as a distributed data base. As a distributed data base, multiple cooperating knowledge agents,
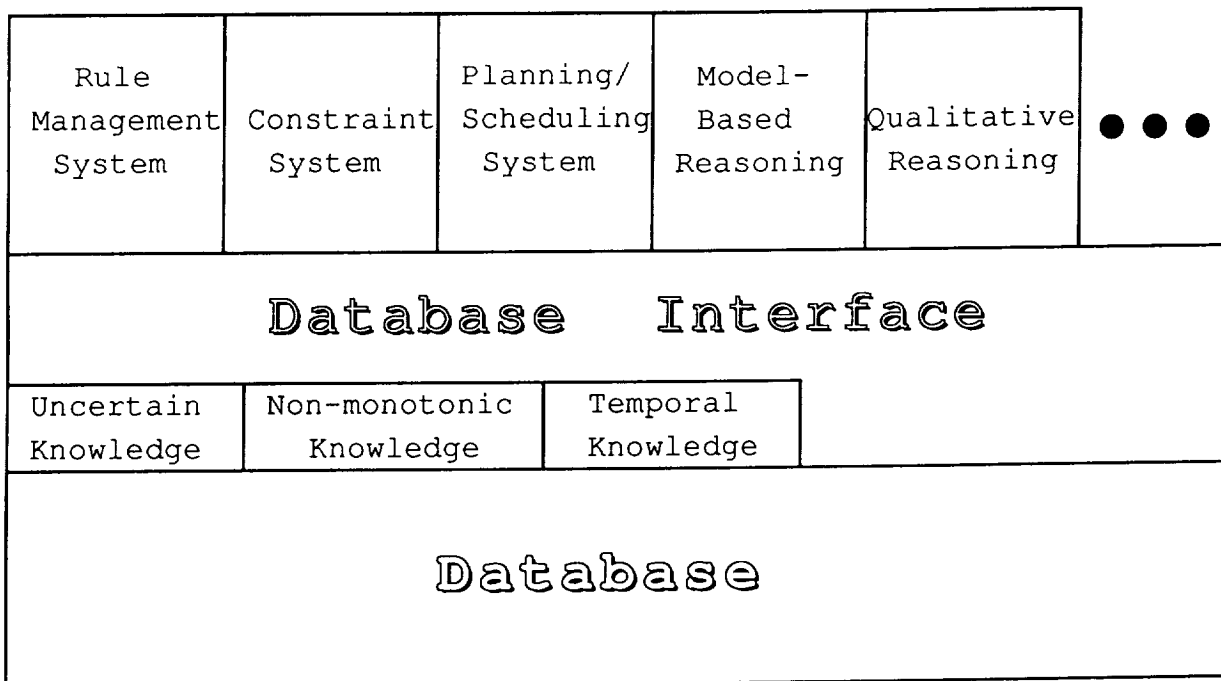

Figure 8. KNOMAD layered architecture.

each in different physical locations, could be supported. The next layer consists of an interface to the data base that provides a frame system for abstracting both data and procedure as well as a mechanism for storing simple facts. The top layer is the place where various tools are defined and implemented. All of the tools make use of the same data representation and thus easily share data across domains and functions [14]. FRAMES was implemented in KNOMAD in June of 1990 with LPLMS and a MAESTRO interface being implemented in April 1991.

C. Operation

The three AI systems interact such that when a hard fault occurs, the PMAD is immediately safed by smart switchgear in less than a microsecond. FRAMES recognizes the new configuration and decides if any other actions need to take place. FRAMES diagnoses the fault, recommends corrective action, and, where appropriate, autonomously implements the corrective action. If the system determines that the current loads schedule has been perturbated by the anomaly, MAESTRO is directed to reschedule the loads for the remainder of the crew period. The LPLMS then generates a new global load shedding list which is downloaded to the LLP's. A similar sequence autonomously occurs in the event of a soft fault (except the switchgear does not trip) or when new directions or power allocation levels are sent to the EPS (through the operator interface). The operator may also take manual control of the system at any time [11].

Before a planned system redesign (20 kHz, 208 Vac ring bus to a 120 Vdc star bus) was implemented, the system was exercised using a document called "SSM/PMAD Expository and Activity Plan" which contained a description of the tests required to demonstrate the operational capabilities of the SSM/PMAD software [15]. The test bed was subjected to approximately 30 different test scenarios. These are described in detail in reference 10. The tests were quite successful in pointing out the strengths and weaknesses in the system software.

After the initial system redesign was implemented, three of the test scenarios were repeated. These were a 1-kW hard fault, a 3-kW hard fault, and two 1-kW independent hard faults. Under the redesigned hardware and software, fault diagnosis speed increased from 5 min to 30 s for the first test, from over 10 min to about 1 min for the second test, and the last test which was not even possible with the old system took about 1 min to diagnose.

Recent advances in the CUI, the LPLMS knowledge base, and the MAESTRO interfaces have produced additional increases in diagnosis speed and system capabilities. During one demonstration, a 3-kW hard fault was injected into the system. The system responded by switching critical loads to their redundant buses in milliseconds, performing the correct fault diagnosis in tens of seconds, rescheduling two new loads, reprioritizing all of the remaining loads, and continuing normal operation. This entire process took less than 3 min.

D. Future Projects

At present, the SSM/PMAD breadboard is either fully autonomous or fully manual. This proves quite cumbersome especially during system troubleshooting or system parametric testing. Layers of intermediate autonomy will be developed so that the information contained in the system will be available at any level desired by the user.

Finally, the SSM/PMAD breadboard is intended to support the development of the PMAD system for the space station modules with Boeing Aerospace Company on a noninterference basis and, to test intersystem communications, the SSM/PMAD breadboard has been interfaced with the Lewis Research Center APS demonstration program. In order to support both of these requirements, the SSM/PMAD will be interfaced with the AMPS hardware to provide a more realistic source for the SSM/PMAD. The block diagram for this system, called the LASEPS, is shown in figure 9 and is described in detail in reference 16.
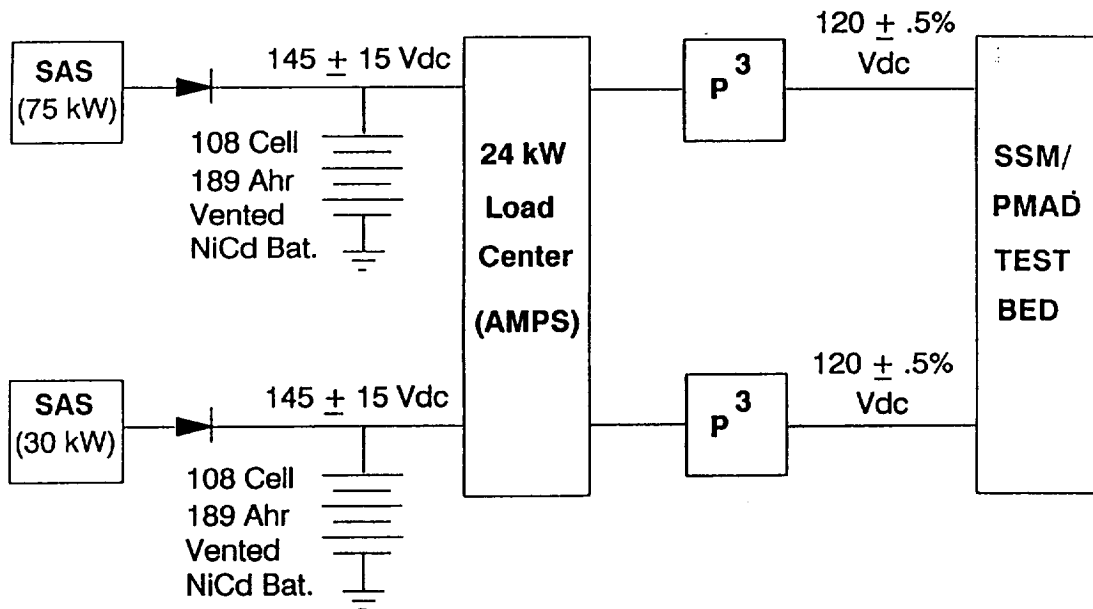

Figure 9. Large autonomous spacecraft electrical power system (LASEPS).

VII. CONCLUSIONS

This paper has described the various activities at NASA/MSFC for advancing the state-of-the-art in spacecraft electrical power system automation. Based on the AMPS and SSM/PMAD projects, a hierarchical approach of distributed processing is being developed. In addition, AI and in particular, knowledge-based systems, are proving to be invaluable in accomplishing tasks not possible with conventional software. Thus, NASA/MSFC is progressing toward the eventual goal of a totally autonomous power system (with human override).

REFERENCES

1. Brandhorst, H.W., Jr., and Faymon, K.A.: "Spacecraft 2000–The Challenge of the Future." Proceedings of the 21st IECEC, vol. 3, August 1986, pp. 1397–1400.

2. Barthelemy, R.R., Massie, L.D., and Borger, W.U.: "Military Space Power Systems Technology for the Twenty-first Century." Proceedings of the 21st IECEC, vol. 3, August 1986, pp. 1401–1404.

3. Mildice, Jim: "In Space, It's 20 kHz ac Power." Powertechnics Magazine, February 1989, pp. 29–32.

4. VanLandingham, E.E.: "The NASA Space Power Technology Program." Proceedings of the 21st IECEC, vol. 3, August 1986, pp. 1405–1410.

5. VanLandingham, E.E.: "Space Power Technology to Meet Civil Mission Requirements." Proceedings of the 23rd IECEC, vol. 3, August 1988, pp. 9–16.

6. Woosley, A.P.: "MSFC Skylab Electrical Power System Mission Evaluation." NASA TM X-64818, June 1974.

7. Britt, D.L.: "The Role of Expert Systems in Space Station Power Management." Proceedings of the 21st IECEC, vol. 3, August 1986, pp. 1776–1779.

8. Weeks, D.J., and Bechtel, R.T.: "Autonomously Managed High Power Systems." Proceedings of the 20th IECEC, vol. 1, August 1985, pp. 1.132–1.138.

9. Lollar, L.F., and Weeks, D.J.: "The Autonomously Managed Power Systems Laboratory." Proceedings of the 23rd IECEC, vol. 3, August 1988, pp. 415–419.

10. Walls, Bryan: "Exercise of the SSM/PMAD Breadboard." Proceedings of the 24th IECEC, vol. 1, August 1989, pp. 189–194.

11. Weeks, D.J.: "Space Station *Freedom* Advanced Development Project Plan for SSM/PMAD Automation." Internal NASA memo for contract NAS8-36433, February 1989.

12. Walls, B.K.: "Expert System for Fault Detection and Recovery for a Space Based Power Management and Distribution System." Proceedings of the 22nd IECEC, vol. 1, August 1987, pp. 668–671.

13. Lee, S.C.: "The Fault Monitoring and Diagnosis Knowledge-Based System for Space Power Systems: AMPERES." Phase I Final Report for university grant NAG8-721, The University of Tennessee Space Institute, November 1989.

14. Riedesel, J.D.: "Knowledge Management: An Abstraction of Knowledge Base and Data Base Management Systems." NASA Contractor Report 4273, January 1990, p. 3.

15. Miller, W.D., et al.: "Appendix X: SSM/PMAD Expository and Activity Plan." Space Station Automation of Common Module Power Management and Distribution Interim Final Report, Martin Marietta Aerospace Denver Astronautics Group, Denver, CO, February 1989, pp. X1–X31.

16. Hall, D.K., and Lollar, L.F.: "Development of an Automated Electrical Power Subsystem Testbed for Large Spacecraft." Proceedings of the 25th IECEC, vol. 1, August 1990, pp. 467–470.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1991	Technical Paper

4. TITLE AND SUBTITLE

Automating a Spacecraft Electrical Power System
Using Expert Systems

5. FUNDING NUMBERS

6. AUTHOR(S)

L.F. Lollar

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

M-670

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TP-3161

11. SUPPLEMENTARY NOTES

Prepared by Information and Electronic Systems Laboratory,
Science and Engineering Directorate.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified–Unlimited

Subject Category: 20

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Since Skylab, Marshall Space Flight Center (MSFC) has recognized the need for large electrical power systems (EPS's) in upcoming Spacecraft. The operation of the spacecraft depends on the EPS. Therefore, it must be efficient, safe, and reliable. In 1978, as a consequence of having to supply a large number of EPS personnel to monitor and control Skylab, the Electrical Power Branch of MSFC began the autonomously managed power system (AMPS) project. This project resulted in the assembly of a 25-kW high-voltage dc test facility and provided the means of getting man out of the loop as much as possible. AMPS includes several embedded controllers which allow a significant level of autonomous operation. More recently, the Electrical Division at MSFC has developed the space station module power management and distribution (SSM/PMAD) breadboard to investigate managing and distributing power in the Space Station "Freedom" habitation and laboratory modules. Again, the requirement for a high level of autonomy for efficient operation over the lifetime of the station and for the benefits of enhanced safety has been demonstrated. This paper describes the two breadboards and the hierarchical approach to automation which was developed through these projects.

14. SUBJECT TERMS

Automation, Spacecraft Power Systems, Expert Systems,
Space Station "Freedom" Power System, Distributed Knowledge
Bases.

15. NUMBER OF PAGES

24

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NASA-Langley, 1991
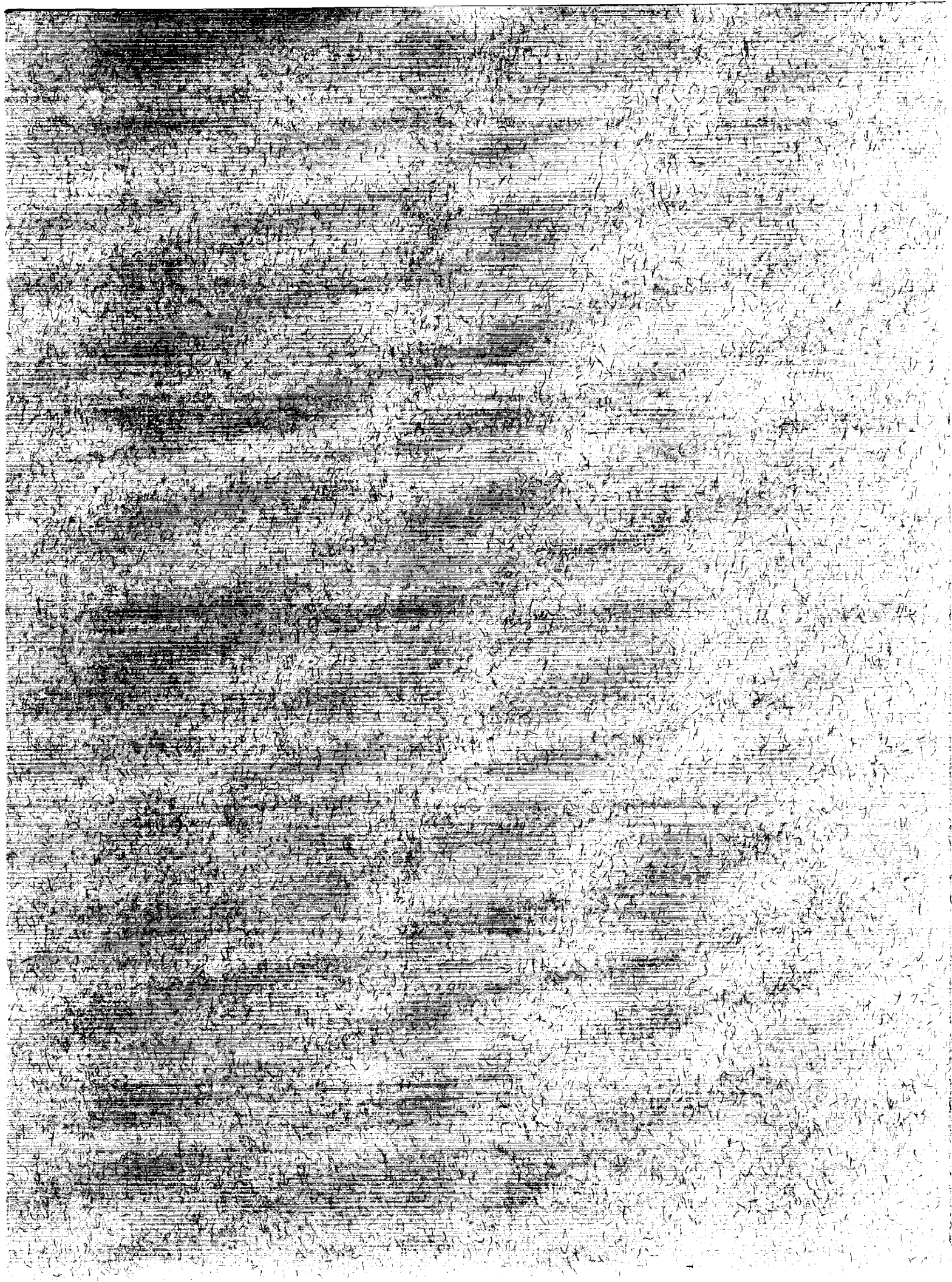
National Aeronautics and
Space Administration
Code NTT-4

Washington, D.C.
20546-0001

NASA

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Return