/N-33
117601
p-10

NASA Technical Memorandum 105842

Overview and Evolution of the LeRC PMAD DC Testbed

James F. Soeder and Robert J. Frye
Lewis Research Center
Cleveland, Ohio

(NASA-TM-105842) OVERVIEW AND EVOLUTION OF THE LeRC PMAD DC TESTBED (NASA) 10 p

N92-32867

Unclas

G3/33 0117601

August 1992

NASA

OVERVIEW AND EVOLUTION OF THE LeRC PMAD DC TEST BED

James F. Soeder and Robert J. Frye
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

Since the beginning of the Space Station Freedom Program (SSFP), the Lewis Research Center (LeRC) has been actively involved in the development of electrical power system test beds to support of the overall design effort. Throughout this time, the SSFP Program has changed the design baseline numerous times, however, the test bed effort has endeavored to track these changes. Beginning in August 1989 with the baselining of an all DC System, a test bed was developed which supported this design baseline. However, about the time of the Test Bed's Completion in December 1990, the SSFP was again going through another design scrub known as Restructure.

This paper describes the LeRC PMAD DC Test Bed and highlights the changes that have taken place in the Test Bed configuration and design resulting from the SSFP Restructure Exercise in December 1990. These changes have principally included the reduction of primary power channel size with an accompanying reduction in the size of various power processing elements. In addition to the scrubbing of the channel size, a substantial reduction was made in the amount of flight software with the subsequent migration of these functions to ground control centers. The impact of these changes on the design of the power hardware, the controller algorithms and the control software along with a description of their current status is presented.

An overview of the testing that has been conducted with the test bed during the last year is also highlighted. These tests include investigations of stability and source impedance, primary and secondary fault protection, and performance of a rotary utility transfer device.

Finally, information is presented on the evolution of the test bed to support the verification and operational phases of the Space Station Freedom Program in light of these restructure scrubs.

INTRODUCTION

Although the SSFP Program has gone through numerous design changes since its beginning, it still will be the largest power system ever flown in space. Furthermore, it will be built and evolved incrementally and be "utility like" in its ability to accommodate changing loads much like a terrestrial power system.

Finally, the system is characterized by its large numbers of power processing elements both in the source and distribution areas. Because of these unique characteristics, it is imperative that early experience be gained in the development and operation of systems of this type. Consequently, the Lewis Research Center in conjunction with its prime power system contractor, Rocketdyne, have had an aggressive test bed program underway since 1985. A detailed discussion of the history and the objectives of the Test Bed Effort at LeRC can be found in Reference [1].

KEY TEST BED OBJECTIVES

To evaluate the unique requirements posed by the power system for the SSFP Application the following set of key objectives were established:

Evaluate source / distribution system interaction with the solar array -- This testing addressees the high power level of the SSFP power system and the higher than normal impedance characteristics of the source system, to provide early evaluation of true end-to-end system performance and behavior.

Evaluate primary / secondary system protection concepts -- This testing addressees the protection of the high power primary system as well as examining the unique challenges associated with the "current limited nature" of the secondary distribution power processing elements.

Evaluate primary / secondary power quality and user load interactions -- This testing addresses the problems of conducted EMI along with the start-up, shutdown and interaction of user loads with the power distribution system.

Evaluate control concepts and Ada software performance -- This development and testing provides early programming and implementation experience with a real time distributed control system using the Ada programming language.

Generate early data to calibrate / validate system models and simulations -- This testing provides early data to anchor and refine component and system models and simulations.

TEST BED DEVELOPMENT APPROACH

The development philosophy of the PMAD DC Test Bed is to replicate a significant enough portion of the Space Station Freedom PMAD System to investigate issues such as system stability, power quality, faults protection, and distributed control concepts. The current PMAD system for the Manned Tended Configuration consists of two 9.375 kW nominal / 12 kW peak power channels which distribute solar array or battery power via a primary distribution system to a set of DC to DC Converter units (DDCUs) and finally through a set of switching assemblies (SPDAs and TPDAs) to the user. As the Space Station Freedom continues to be evolve to its Permanently Manned Configuration, four additional 9.375 kW Channels will be added to get to a 56 kW Space Station. Further information on the Space Station Power System Configuration can be found in Reference [2].

To develop a meaningful subset of the SSF electrical power system which can provide early test results and which can evolve as the SSF program matures, a phased development effort has been undertaken. In Phase A, a single end-to-end power channel of 9.375 kW nominal, 12.5 kW peak is being assembled using "hardware of convenience." Hardware of convenience is considered to be functionally equivalent to the hardware which will be eventually used on the Space Station but more readily available. In some cases, the hardware contains additional functionality which may not necessarily be in the final flight system but allows the evaluation of alternate design options. Currently the test bed program has completed the Phase A. In Phase B, the intent is to build a second power channel using copies of the breadboard hardware being built for the Space Station Freedom application.

TEST BED DESCRIPTION

Figure #1 shows a diagram of the PMAD DC Test Bed. Shown in the Diagram is the completed Phase A portion of the Test Bed as it currently exists with the restructure changes. The Phase B activity will add another channel similar to the one shown and is expected to be completed within the next calendar year. The test bed consists of two major elements, the power element and the control element.

TEST BED POWER ELEMENT

The source power for the test bed consists of an 82 string solar array switching unit which regulates the primarily bus to a nominal 160 Volts during solar insolation. The SSU regulates raw power either from the 35 KW LeRC Solar Array Field, or from the LeRC designed Solar Array Simulator. Further information on this simulator can be found in Reference [3].

The power from the SSU flows into the Direct Current Switching Unit (DCSU). This unit consists of switches called Remote Bus Isolators or RBIs for power switching and source protection as well as a large capacitor (4000uf) to provide primary bus stabilization. The DCSU directs the power into energy storage through two Battery Charge / Discharge Units BCDUs. The BCDUs provide regulated current and voltage to charge the batteries during insolation and regulate the primary bus voltage during eclipse. Power from the DCSU flows though a rotary power transfer device (roll ring) into a Main Bus Switching Unit (MBSU). The MBSU also contains Remote Bus Isolators (RBIs) which are used to enable and disable power to the DC to DC Converter Units (DDCUs), as well as provide primary source protection. The DDCUs provide the interface between the primary distribution system and the secondary. At the interface the DDCUs convert the voltage from the nominal 160 Volts on the primary to 120 Volts for use on the secondary. In addition, they provide EMI and grounding isolation between the primary and secondary distribution systems.

The power out of the DDCUs energies the secondary distribution system which contains the Secondary and Tertiary Distribution Units (SPDAs and TPDAs). The SPDA and TPDAs are made up of Remote Power Controllers (RPCs) that emulate the secondary and tertiary switching functions found inside a manned module. Finally, load converters (LC) which are DC to DC converters and provide constant power loads are used to exercise the test bed. It is expected that a majority of the loads on the Space Station will be of the constant power type. Currently, the test bed contains ten, one kW, 120 Volts to 28 Volt, load converters to provide loads of this type. These converters consist of a variety of different circuit topologies such as zero voltage switching, resonant and full bridge forward converters. These converters operate at a variety of switching frequencies and can therefore provide a realistic operating environment to test the system. Information on the characteristics and testing of these converters can be found in References [4-5].

IMPACT OF THE RESTRUCTURE CHANGES ON POWER ELEMENTS

The restructuring of the Space Station Freedom Program in December of 1990 had some profound effects on the Space Station as whole. Specifically, the overall size of the station was reduced which subsequently forced a reduction in the overall size of the power system from 75kW to 56kW. The result of this reduction in the overall size of the generation system was to reduce the channel size of the power system from 18.75kW to 9.375kW. Likewise, the ratings of the elements in the power distribution system were also reduced. Consequently, the DDCUs went from ratings of 12.5 KW to 6.25 KW and were required to allow unit parallelling to maximize the power utilization in the Laboratory Modules. Finally, the secondary switchgear ratings were reduced to reflect the reduction in the amount of power available in the secondary channels and the expected load mix.

The impacts on the Test Bed itself was to force a change in the DDCU and RPC Power Elements. In the case of the 12.5kW DDCUs, each one was composed of two 6.25kW Modules. Therefore, each DDCU could be separated into two units and appropriate parallelling circuitry added. Further information on these parallelling methods can be found in Reference [6]. In the case of the RPCs, the rating of the units were adjusted to reflect the revised ratings: 65, 12 and 4 Amps.

All of these modifications have been completed, the results of which are shown in the following summary of the Test Bed Power Components.

Test Bed Power Components

The principal characteristics of the key components in the Restructured Phase A Test Bed Configuration are as follows.

Solar Array Switching Unit (SSU) -- The SSU is a shunt regulator. It regulates the output voltage by shunting solar array strings to ground and passing the output of the other strings to the load

- o 32KW Total Power Capability
  - 82 Solar Array Strings
  - Each String 2.5 Amps at 160 VDC
- o Programmable Voltage, Current and Undervoltage Setpoints via Mil-STD-1553B Interface

Battery Charge / Discharge Regulator (BCDU) -- The BCDU controls the charge and discharge current and voltage to the batteries from the main power bus and visa-versa.

- o Topology -- Two Parallelled Bi-Directional 3.0 KW Buck / Boost Modules
- o Charge Mode
  - 120 to 157 Input Voltage
  - 90 to 130 Output Voltage
- o Discharge Mode
  - 75 to 150 Input Voltage
  - 120 to 157 Output Voltage
- o Mil-STD-1553B Interface for Data Monitoring and Commands

DC to DC Converter Unit (DDCU) -- The DDCU is a DC to DC Converter which converts the 160 VDC primary power to 120 VDC for the secondary distribution. In addition, it provides EMI isolation and grounding between the primary and secondary distribution systems.

- o Output power -- 6.25 kW (Nominal)
- o Topology -- One Resonant Modules
- o Input Voltage -- 125 - 170 VDC
- o Output Voltage -- 120 - 128 VDC +/- 1% Programmable
- o Efficiency full load -- 91 % (excluding control power)
- o Current Limit -- Programmable

o Parallelling Capability -- 3 Methods Switch Selectable
o Mil-STD-1553B Interface for Data Monitoring and Commands

Further Information on the SSU, BCDU and DDCU can be found in Reference [7].

Remote Bus Isolator (RBI) -- The RBI are hybrid switching devices which contain a relay in parallel with a solid state switch to control DC current. The RBIs are the primary components used to construct the MBSU and DCSU.

o 180 VDC 208 Amp Normal Operation
o 400 Amp Interrupt Capability
o 270 Volt / 208 Amp Dead Face Relay
o Supports Overcurrent and Differential Protection
o Settable Overcurrent Trip Points
o Different Devices can Support both Unidirectional and Bi-Directional Capability
o Mil-STD-1553B Interface for Data Monitoring and Commands.

Remote Power Controller (RPCs) -- The RPC are solid state devices which control DC Current and limit current during a fault. The RPCs are the primary components used to construct the SPDAs and TPDAs.

o Ratings
  - 4 Amps @ 120 Volts
  - 12 Amps @ 120 Volts
  - 65 Amps @ 150 Volts
  - 130 Amps @ 150 Volts
  - 150 Amps @ 150 Volts
o Overcurrent and Undervoltage Protection
o Settable Current Limiting
o Mil-STD-1553b Interface for Data Monitoring and Commands

Further Information on the RBI and RPC devices can be found in Reference [8].

TEST BED CONTROL ELEMENT

The test bed control systems consists of hierarchically networked computers which simulate the Electric Power System Controllers which will exist on the actual station. The control software includes a set of control algorithms along with utility communication software, all of which is programmed in Ada. The hardware, controller algorithms and software development are outlined below.

Test Bed Control Hardware

The controller hardware consists of an Operator Interface System or OIS which provides the operator with command and display capability. This computer communicates with the Power Management and Control Computer (PMC), which oversees the operation of the overall Test Bed. The PMC then communicates with the Photovoltaic Controller, or PVC, and the Main Bus Controller, or MBC, over an IEEE 802.4 communications network. The PVC and MBC are the next layer in the control hierarchy. The PVC controls, monitors and passes setpoints to the SSU, DCSU and the BCDU over a Mil-Std-1553b data bus. Likewise the MBC performs similar functions to the MBSU and the DDCUs.

Finally, the PMC communicates over a separate data link (802.4) to the Load Management Controller. The LMC provides the capability to communicate with the switches in the SPDAs and TPDAs as well as the load converters. The LMC functions, although not a LeRC Space Station Work Package (WP-04) responsibility, is required to address system level issues.

The control hardware for the test bed is characterized by the need to be cost effective but also be as compatible as possible with the control hardware proposed for the SSF. This led to the utilization of Compaq 386/20e PCs. These computers are based on the 80386 processor and have a 20mHz clock rate.

Test Bed Control Software

The test bed control software is divided into two major categories, the utility software and the algorithm software.

The design of the utility software provides the major communications for the test bed. The software is characterized by five major modules: 1) a Router which directs both inter and intra processor communication; 2) a Text Interface which handles communication between the system and user; 3) a Network Interface which handles communication between the distributed computer controllers over the 802.4 bus; 4) a Power Component Interface which handles communication between the controller and power components over the 1553B bus; 5) an Algorithm Interface which provides the test bed designer and developers with a uniform link to exercise various control algorithms; and 6) a data collection function which is used to collect periodic snapshots of data for use by various algorithms and for operator display. Using just the utility software the test bed can be run in what is know as manual mode via the operator inputing commands directly to the power components.

The test bed algorithm software consists of a series of functions that utilize the algorithm interface to facilitate the control of the test bed. When these algorithms are used, the test bed is considered to be in the Automatic Mode. In the automatic mode the operator has functions that provide for orderly start-up and shutdown of the test bed. In addition, the automatic mode has functions such digital filtering to smooth the sensed data, a state estimator to detect bad data, and fault detection algorithms to back-up the hardware fault protection system in the areas of overcurrent detection, undervoltage detection, and power interrupt detection. Further information on the design of the control system and software design can be found in References [9, 10, 11, 12]

IMPACT OF RESTRUCTURE ON CONTROL ELEMENT FUNCTIONALITY

With the exception of the start-up and shutdown functions, which are test bed specific, the use of the automatic mode functions for the on-board system is currently being assessed in light of the restructured program. The thrust of the restructure was to simplify all onboard systems to minimize the use of computing power on board the vehicle. This in turn translates into a savings in the amount of power required to run all of the station controls thereby providing more power for the users. In addition, considerable financial savings can be realized in the development of onboard software because of the simplified functions. However, many of the functions that have been scrubbed still have to performed, consequently, many of the control functions that were expected to be done on-orbit are being moved to the ground. Functions such as health monitoring, failure diagnostics, contingency analysis, load scheduling, and electrical power system state estimation are currently being planned for initial implementation in the ground based Space Station Freedom Control Center.

The impact of this change in development philosophy on the Test Bed has been to continue analytical efforts in the critical areas but to more closely examine how to best implement the final algorithms to closely simulate the current SSF development philosophy.

KEY TESTS PERFORMED

During the past year many tests have been performed using the Test Bed to generate data on systems behavior. These test have included evaluation of primary and secondary of the Test Bed using appropriate output and input impedance measurements. The measurements are evaluated relative to the Middlebrook Stability Criterion. Further information on these tests can be found in Reference [13].

Another series of tests that have been performed is to evaluate the primary and secondary protection systems implemented in the test bed. These tests have demonstrated the robustness of the Primary System and Secondary System trip characteristics. Further information on these tests can be found in Reference [14].

Finally, a series of tests was run with a developmental model Alpha Utility Transfer Assembly. The transfer assembly consists of a series of power and data roll rings which allow the transfer of same across a rotating interface on the Space Station Freedom Truss Structure. This rotating interface is necessary to keep the Space Station modules in an inertial mode relative to the earth and allow the pointing of the solar arrays at the sun throughout the insolation period of the orbit.
By conducting these tests using the test bed, it was possible to evaluate the device in a real system environment using real power sources, cable lengths, and loads. Results of the tests conducted proved to be very favorable. Further information on the test results can be obtained in Reference [15].

FUTURE TEST BED ROLES IN THE DEVELOPMENT OF SPACE STATION FREEDOM

As the Space Station Program approaches its CDR in the Mid 1993, its final design is being firmed up. A key area which still needs to be addressed is that of high risk or edge of envelop testing of the system to support the CDR activity. However, much of the initial testing to identify early system behavior is complete. In addition, other higher fidelity test beds will come on-line to support the final system verification. Therefore, supporting development test beds take on a different roles than earlier in the program.

Much work still needs to be done in defining the operational procedures for the electric power system and for planning the evolution of the power system throughout its 30 year lifetime. Because of this, a key activity in the upcoming months is to completely link the test bed control system with the LeRC Engineering Support Center to allow the investigation of the control system scrub on the operation of the overall power system. In addition, work is expected to continue on the use of advanced automation tools for power utilization scheduling, power system and power component failure diagnostics and battery management. Use of this work in advanced automation will greatly reduce the power system operational costs.

CONCLUSION

The PMAD Test Bed has been operational at the Lewis Research Center since the fall of 1990. During that time, substantial efforts have been made to continue to track the Space Station Program and to make hardware and software changes which will allow the Test Bed to functionally represent the current design. In addition, it has provided valuable test data and much useful information relative to the operation of high power DC power systems. It is expected that its usefulness will continue through subsequent years.

REFERENCES

[1] J.F. Soeder, R.J. Frye and Rudy Phillips, "The Development of Test Beds to Support the Definition and Evolution of the Space Station Freedom Power System, 26th IECEC Conference, Boston Massachusetts, August 4-9, 1991.

[2] Space Station Freedom Program Office, "Electrical Power System Architectural Control Document," SSP 30263.

[3] T. Vasek, "Development of a Single String Solar Array Simulator," IECEC-91, August 4-6, 1991, Boston, MA.

[4] R. C. Lebron, A.C. Oliver, and R.F. Bodi, "Test and Evaluation of Load Converter Topologies Used in the Space Station Freedom Power Management and Distribution Test Bed," IECEC-91, August 4-6, 1991, Boston Ma.

[5] R. C. Lebron, "Load Converter Interaction with the Secondary System on the Space Station Freedom PMAD DC Test Bed," IECEC-92, August 3-7, 1992, San Diego, Ca.

[6] D. K. Decker, "Operation of High Power Converters in Parallel," IECEC-92, August 3-7, 1992, San Diego, Ca.

[7] D. Decker and L. Inouye, "Multikilowatt Power Electronic Developments for Spacecraft," IECEC-91, August 4-9, 1991, Boston MA.

[8] R. Thorton and D. Fox, "Power Management Westinghouse and Distribution Equipment Developed for Space Applications," IECEC-91, August 4-9, 1991.

[9] A. Baez and G. Kimnach, "Description of the Control System Design for the Space Station Freedom PMAD DC Test Bed," IECEC-91, August 4-9, 1991, Boston, MA.

[10] K. Ludwig, M. Mackin, and T. Wright, "Description of a Real Time Ada Software Implementation of a Power System Monitor for the PMAD DC Test Bed. IECEC-91, August 4-9, 1991 Boston, MA.

[11] T. Wright, M. Mackin, and D. Gantose, "Development of Ada Language Control System for NASA Power Management and Distribution Test Bed," IECEC-89, August 6-11, 1989, Washington D.C.

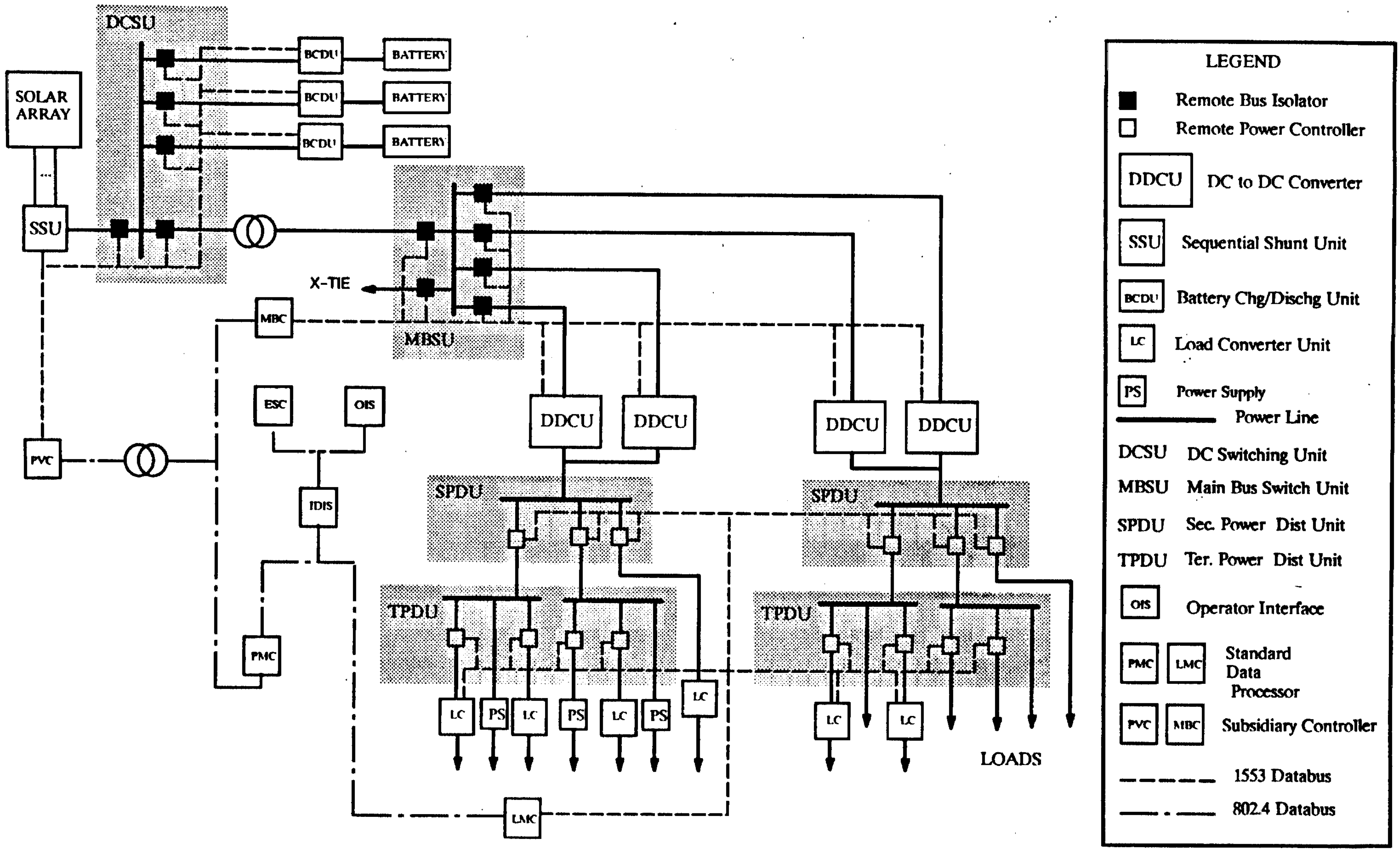
[12] G. L. Kimnach, and A. Baez "Power System Monitoring and Source Control of the Space Station Freedom DC Power System Test Bed,." IECEC-92, August 3-7, 1992, San Diego, Ca.

[13] R. M. Button, "Stability Testing and Analysis of the PMAD DC Test Bed For the Space Station Freedom", IECEC-92, August 3-7, 1992, San Diego Ca.

[14] R. Beach and G. Kubat, "Description and Evaluation of Protection System Concepts Developed for the PMAD DC Test Bed," IECEC-92, August 3-7, San Diego Ca.

[15] E. J. Yenni, "Electrical Characterization of a Space Station Freedom Alpha Utility Transfer Assembly," IECEC-92, August 3-7, San Diego, Ca.

Figure 1 POWER MANAGEMENT AND DISTRIBUTION SYSTEM



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Overview and Evolution of the LeRC PMAD DC Testbed

5. FUNDING NUMBERS
WU-474-42-10

6. AUTHOR(S)
James F. Soeder and Robert J. Frye

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-7285

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-105842

11. SUPPLEMENTARY NOTES
Prepared for the 27th Intersociety Energy Conversion Engineering Conference cosponsored by the ANS, SAE, ACS, AIAA, ASME, and IEEE, San Diego, California, August 3-7, 1992. James F. Soeder and Robert J. Frye, NASA Lewis Research Center, Cleveland, Ohio. Responsible person, James F. Soeder, (216) 433-5328.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 33

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***
Since the beginning of the Space Station Freedom Program (SSFP), the Lewis Research Center (LeRC) has been actively involved in the development of electrical power system test beds to support of the overall design effort. Throughout this time, the SSFP Program has changed the design baseline numerous times, however, the test bed effort has endeavored to track these changes. Beginning in August 1989 with the baselining of an all DC System, a test bed was developed which supported this design baseline. However, about the time of the Test Bed's Completion in December 1990, the SSFP was again going through another design scrub known as Restructure. This paper describes the LeRC PMAD DC Test Bed and highlights the changes that have taken place in the Test Bed configuration and design resulting from the SSFP Restructure Exercise in December 1990. These changes have principally included the reduction of primary power channel size with an accompanying reduction in the size of various power processing elements. In addition to the scrubbing of the channel size, a substantial reduction was made in the amount of flight software with the subsequent migration of these functions to ground control centers. The impact of these changes on the design of the power hardware, the controller algorithms and the control software along with a description of their current status is presented. An overview of the testing that has been conducted with the test bed during the last year is also highlighted. These tests include investigations of stability and source impedance, primary and secondary fault protection, and performance of a rotary utility transfer device. Finally, information is presented on the evolution of the test bed to support the verification and operational phases of the Space Station Freedom Program in light of these restructure scrubs.

14. SUBJECT TERMS
Space station power supplies; Test equipment

15. NUMBER OF PAGES
10

16. PRICE CODE
A02

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

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102