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Annual Progress Report on the Development of a 2 MW/10 Second Battery Energy Storage System for Power Disturbance Protection

*DOE Co-Op Agreement
#DE-FC04-94AL99852*

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January 29, 1996

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Appendix A System One Line Electrical Diagram

Appendix B System Container Structural Drawing

Abstract

Sandia National Laboratories (SNL), acting for the U.S. Department of Energy (DOE), contracts for and administers programs for the purpose of promoting the development and commercialization of large scale, transportable battery energy storage systems. Under DOE Co-Op Agreement No. DE-FC04-94AL99852, SNL has contracted for the development and delivery of an initial prototype 250 kW bridge that becomes an integral subsystem of a 2 MW/10 Second System that can be used by utility customers to protect power sensitive equipment from power disturbances. Development work includes field installation and testing of the prototype unit at a participating utility site for extended product testing with subsequent relocation to an industrial or commercial participating utility customer site for additional evaluation. The program described by the referenced document calls for cost sharing with the successful bidder and eventual title transfer to the participating utility. Prototype delivery is scheduled for January of 1996, with a period of two years allowed for field testing. A final report summarizing the test data with conclusions and recommendations is part of the contract.

Preface

Voltage sags and power outages that last on the order of cycles to several seconds are common on utility systems. These sags and outages are a result of normal utility switching associated with re-closer schemes, large starting currents required by certain types of equipment, or system faults and pose serious problems for many commercial power consumers with voltage sensitive loads such as process controls, hospital medical equipment, and other critical loads. These momentary disturbances can cause equipment shutdowns which may result in downtime, clean-up, and complete restart sequencing of manufacturing lines. A single disturbance may result in related costs of up to \$1 million.

This report outlines the development work of a 2 MVA battery energy storage system including the power conversion equipment (PCS) and a solid state power transfer switch to provide uninterrupted power to an industrial customer. The system will monitor the utility grid for disturbances, disconnect the critical load from the utility, and seamlessly reconnect reliable power to the load from the PQ2000 system control for the duration of the utility disturbance up to 10 seconds at a power level of up to 2 MVA. Upon verification that the utility is again stable, it then seamlessly returns the load to the utility. A one-line electrical diagram of the system is provided in Appendix A of this report.

This report summarizes project development work conducted between September 1, 1994, through August 31, 1995. Included in the development is system design, hardware component procurement for a 250 kVA battery module building block, battery module and system software development and battery module prototype testing. Actual work conducted and reported on is outlined in the Task List and Development Schedule provided in the Section 1.0 of this report.

1. INTRODUCTION

The concept of applying battery energy storage to resolve large scale industrial and commercial power management and power quality problems is not new. Government funded support for the development of a large scale, modular battery energy storage system was initiated in 1991, when the U. S. Department of Energy through Sandia National Laboratories issued a contract to Omnion Power Engineering Corporation to design and deliver an "AC battery" aimed at promoting battery energy storage for commercial applications. Work initiated by Omnion Power Engineering to refine and enhance system designs for this project led to the formation of strategic partnerships with key suppliers under the umbrella of a new corporate identity known as AC Battery Corporation.

AC Battery Corporation was organized expressly for the development and manufacture of large-scale, modular, turnkey battery energy storage systems as a successful bidder on a cost-shared, government funded project. Initial work conducted by AC Battery led to successful bidding on several follow-on projects requiring large capital development investment. The demand for capital investment led to the eventual purchase of AC Battery by General Motors in October of 1994.

Work performed under this contract was aimed at delivering a battery energy storage system designed to protect utility customers from the detrimental effects of power quality disturbances on power sensitive electronic equipment. AC Battery Corporation initiated development of a modular, transportable concept with Omnion Power Engineering Corporation supplying key power conversion technology and acting as a primary component and subsystem supplier.

1.1. Task List

The scope of work defined by the Project award was organized into several tasks with timelines for delivery established. The following task list was developed in conjunction with a Gantt Chart and used as a project management tool. The task list outlined below and schedule of deliverables was used to evaluate vendor delivery performance.

1.1.1. Task 1: Project Planning,

Input:	System abstract and completion of 250 kVA bridge development
Objective:	Fully define the deliverables in terms of hardware, performance, schedule, and documentation
	Develop system specification
	Develop project schedule
	Develop estimated costs
Output:	System specification document
	Project schedule

Cost breakdown
System one-line diagram

1.1.2. Task 2: Design of the System

Input: System specifications and one-line diagram
Objective: To develop component specifications to design control algorithms for:

- a. 250 kW module
- b. 2 MW container
- c. Static disconnect switch

To develop electrical schematics/bill of materials (BOM) and component layout drawings for:

- a. 250 kW module printed circuit (PC) boards
- b. 250 kW converter/charger power package
- c. 2 MW container control PC board
- d. Complete system

To develop mechanical drawings/BOM:

- a. 250 kW module
- b. 2 MW container
- c. 2 MVA static disconnect switch

To outline support documentation:

- a. Factory test plans
- b. Field test plan
- c. Operations and Maintenance Manual

Output: System schematic/BOM
Sub-assembly and PC board schematics/BOM
Artwork for PC boards
Control diagrams/flow charts or pseudo-code
Cabinet detail drawings
BOM for test equipment.
Outline for test plans and operations & maintenance manual

1.1.3. Task 3: System Design Review

Input: System design
Objective: To provide final technical review of concepts being implement
Output: Design approval

1.1.4. Task 4: Hardware Procurement

Input: Bills of Material
PC board artwork
Cabinet detail drawings
Component specifications

Objective: To identify competitive sources and purchase prototype 250 kW module components as specified by engineering
To manage the procurement so as to meet schedule demands

Output: All system component hardware

1.1.5. Task 5: Software

Input: System specification
250 kW module hardware design
2 MW container hardware design
Container control algorithm
Static switch control algorithm

Objective: To write the code to implement the control algorithms for the modules and container
The code will be detailed enough to enable testing of the hardware as the PC boards and modules are prototype

Output: Compiled code for each processor/computer in the system

1.1.6. Task 6: Prototype Test

Input: Components for a 250 kW module
Preliminary software
Assembly documentation
Test procedures

Objective: To build and test individual PC boards
To build and test a 250 kW converter
To build and test a 5 kW charger
To build and test an assembled 250 kW module as a stand-alone unit
To prototype and test a 250 kW, 10 second module including the static disconnect switch

Output: Hardware and software prototypes that prove the stand-alone and alternating current (AC) bus support concepts
Preliminary test data and summary of system performance
Completed PC board test procedures

1.1.7. Task 7: Design Modifications

Input: Test results and marked-up drawings from prototype testing

Objective: To implement design and documentation changes as necessary to allow procurement of components and production of seven additional 250 kW modules

Output: Updated schematics, BOMS, and mechanical drawings
Procurement listing of components for seven new 250 kW modules
Updated software

Field test procedures

1.1.8. Task 8: Manufacture Balance (7 Modules) of 2 MW/10 Second System

Input: Updated schematic, BOM, mechanical drawings
 Objective: Manufacture and test seven identical modules
 Package all modules in a system container (2 MW/10 Sec)
 Output: Completed, factory tested 2 MW/10 second battery energy storage system - PQ2000

1.1.9. Task 9: Field Test

Input: Field test procedures
 Objective: Actual site test over an extended period of time
 Collect performance data and analyze
 Output: Field test report

1.1.10. Task 10: Final Technical Report

Input: All documentation in Task 1 through Task 9
 Objective: Draft concise report of project and results
 Report will include drawings, procedures, test reports, and conclusion
 Output: Final technical report

1.2. Development Schedule and Status

Task	Total Hrs	Scheduled Start	Scheduled Finish	Status
PQ2000 Project	5240	10-03-94	11-20-95	
Task 1 Project Plan	360	10-03-94	11-02-94	Complete
Task 2 Design	1560	11-02-94	04-19-95	Complete
System Modeling	240	11-18-94	01-20-95	Complete
System Schematic/BOM	440	11-02-94	12-13-94	Complete
PCB Schematic/BOM	180	12-26-94	03-17-95	Complete
PCB Artwork	80	04-04-95	04-19-95	Complete
Control Diagrams	140	12-13-94	02-10-95	Complete
Cabinets	280	11-02-94	12-19-94	Complete
Outlines test, O&M	80	12-13-94	02-15-95	40%
Charger Assembly	120	11-28-94	01-25-95	70%
Task 3 Design Review	180	02-15-95	03-22-95	Complete
Task 4 Hardware Purchase	100	12-13-94	02-22-95	98%
Task 5 Software	300	12-28-94	03-27-95	
Static Switch	20	03-22-95	03-27-95	85%
Charger	120	12-28-94	01-20-95	90%
Controls	160	02-10-95	03-15-95	90%

Task 6 Preliminary	880	03-27-95	06-02-95	
Preliminary Product	680	03-27-95	05-18-95	Complete
Preliminary Test	200	05-18-95	06-02-95	88%
Task 7 Design Modifications	60	06-02-95	06-07-95	90%
Task 8 Final	940	06-07-95	07-28-95	
Final Production	300	06-07-95	06-16-95	80%
Factory Test	640	06-07-95	07-28-95	60%
Task 9 Field Test	420	08-15-95	10-18-95	
Task 10 Final Report	440	10-18-95	11-20-95	

Table 1. Development Schedule and Completion Status

2. DESIGN GOALS

The AC Battery PQ2000 Power Quality System has been designed to be an immediate-response, high-capacity, quick-discharge energy storage system that is capable of providing up to 2 MVA of clean power for up to 10 seconds and can switch sensitive industrial loads from utility service to full alternative, clean-power operation in approximately 1/4 cycle. The AC Battery PQ2000 Power Quality System is designed to operate as a voltage source supplying and maintaining all power levels up to a maximum rating of 2 MVA for 10 seconds.

One of the major goals of this project was to design and build the PQ2000 to meet the required performance specifications while utilizing only existing, state-of-the-art technology and current high-volume production components of proven reliability. The objective was to combine these technologies in unique fashion to produce a modular, fully self-supporting, self-sustaining, transportable battery energy storage package that could be completely factory assembled and tested before being transported to the customers site.

At this stage of the development process, it can be asserted that those objectives have been achieved. All components used in the fabrication of the AC Battery PQ2000 Power Quality System are commercially available from vendors serving other markets. These components are factory assembled and tested under rigorous quality control standards to create a fully operational, highly reliable, modular, battery energy storage system. No part of the system design or technology used is considered experimental, but the project is developmental.

2.1. System Design

The proposed AC Battery PQ2000 Power Quality System is comprised of three main components—the PQ2000 container, a 2 MVA Electronic Selector Device (ESD) with additional switchgear, and a 2 MVA/15 Second, 208/480 V isolation transformer. See Figure 1 through 3.

The PQ2000 System is modular by design. Unlike traditional battery storage systems that bus together numerous battery strings through specialized high-voltage DC switchgear and custom-built converters, the PQ2000 aggregates AC power from multiple

battery modules which are paralleled to achieve the desired system capacity. This modular, building-block approach gives the PQ2000 great flexibility in meeting system sizing and layout requirements.

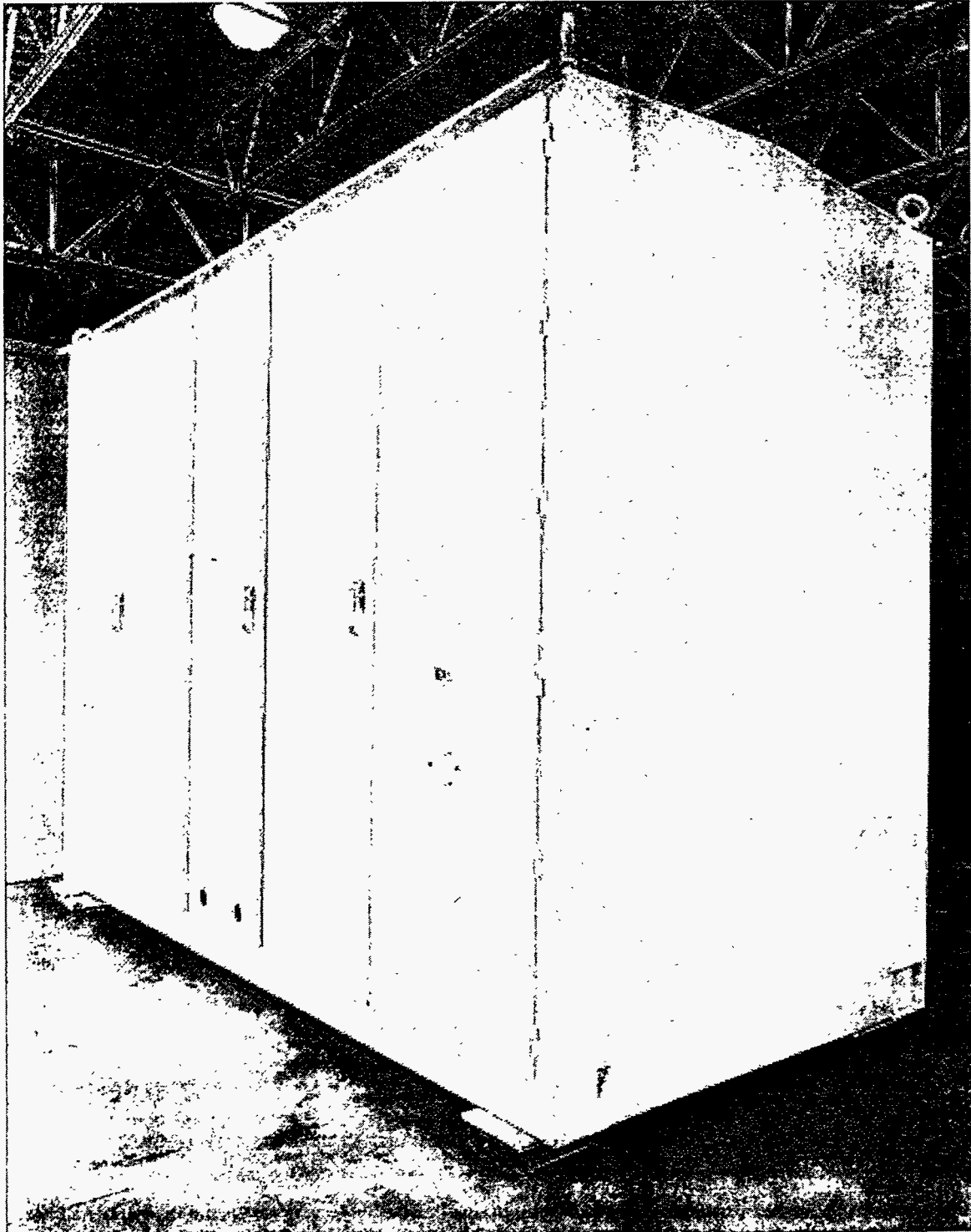


Figure 1. AC Battery PQ2000 System Container

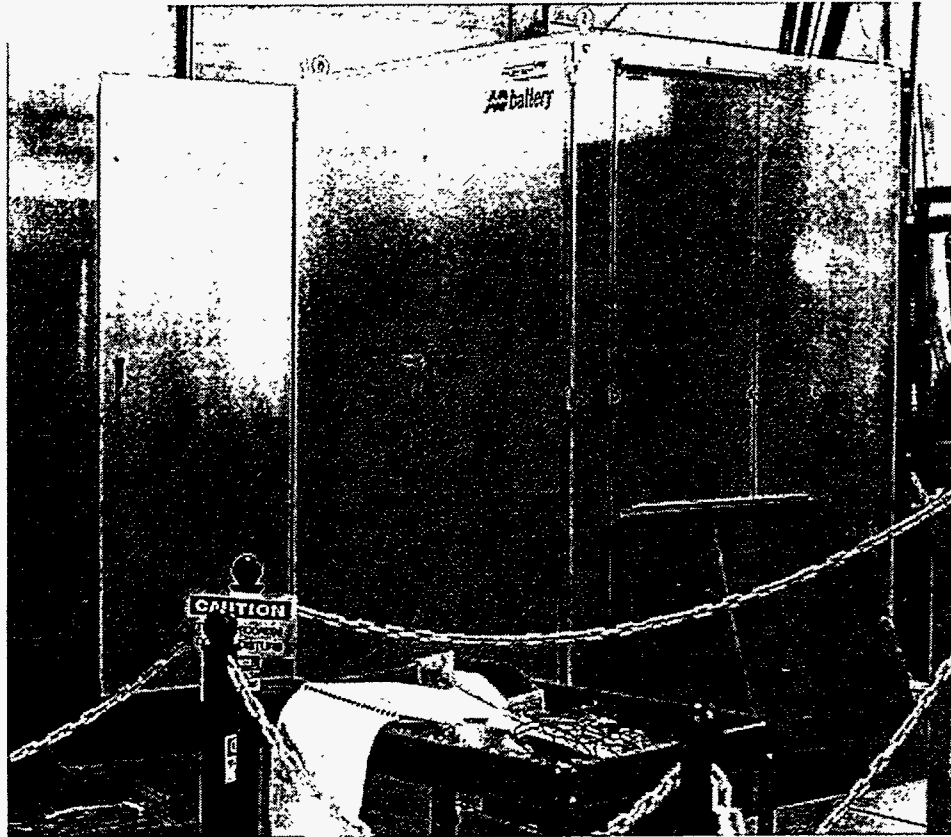


Figure 2. Static Automatic Transfer Switch



Figure 3. System Auto Transformer

The recommended installation site plan of the PQ2000 calls for an area of 1178 square feet. Eleven feet of access around the container is suggested for fork lift maneuvering to load and unload the battery modules. Clearance around the SATS and isolation transformer may be reduced, codes and other local restrictions permitting. See Figure 4 for a typical site layout plan.

Once activated, the PQ2000 Power Quality System is designed to operate automatically and not require attended operation.

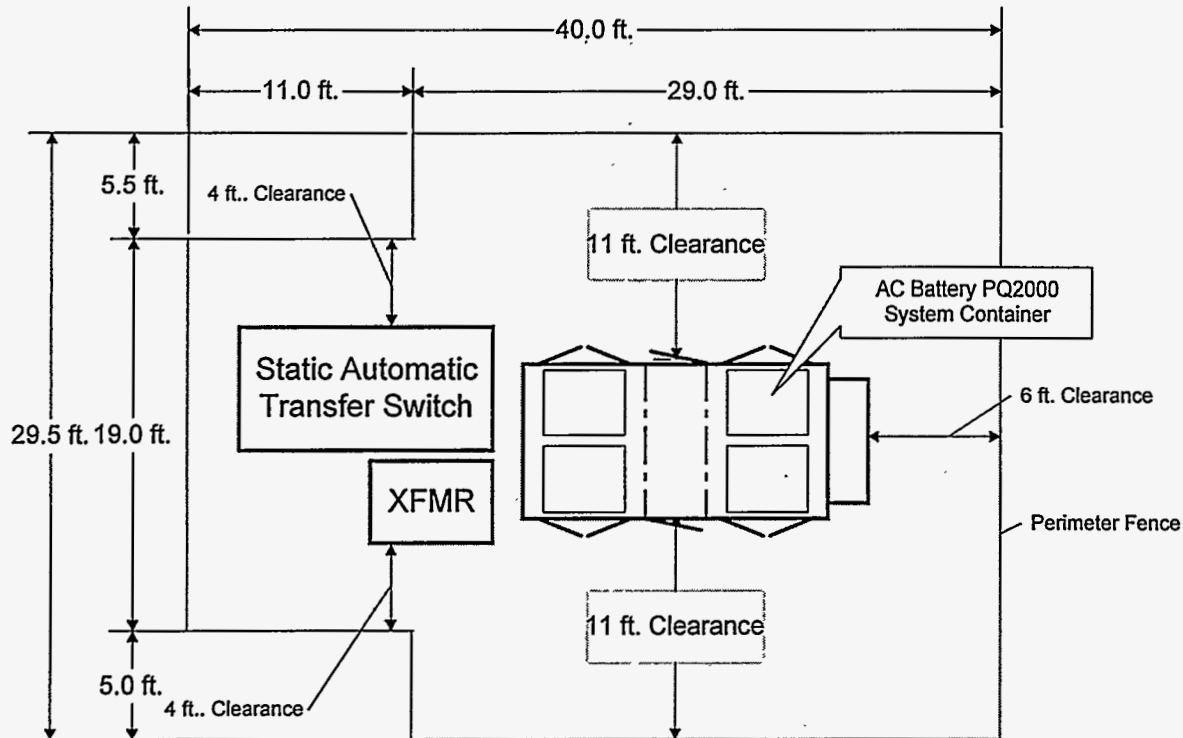


Figure 4. Typical AC Battery PQ2000 Site Layout Plan

2.2. Container Design

The system container had been designed to meet the requirements of a 20-year life cycle. The container features heavy gauge steel construction with tubular steel internal structural supports, and a corrosion resistant exterior enamel finish. Urethane foam is sprayed over all interior surfaces with the exception of the floor for insulation purposes. An internal enamel finish is applied to protect the internal container surfaces against any potential corrosive conditions.

A finite element analysis was conducted on the container design to ensure that the system will withstand the repeated lifting and moving stresses related to transporting the containers as well as seismic events up to zone 4.

The container design includes provisions for mounting up to eight (8) AC Battery Modules, hydrogen venting system, system monitoring, HVAC equipment, and microprocessor based System Control. The PQ2000 system container is designed to be mounted outdoors in ambient conditions from -20°F to 120°F and 0 to 100% humidity. The container is insulated to R-4.0. A structural drawing of the system container is provided in Appendix B of this report.

2.2.1. Physical Structure

The AC Battery System Container measures 15' long, 7.5' wide, and 11' high and weighs approximately 42,000 pounds when prepared for shipment. The container is shipped on a lowboy, flatbed trailer. Preparation of the container for shipment

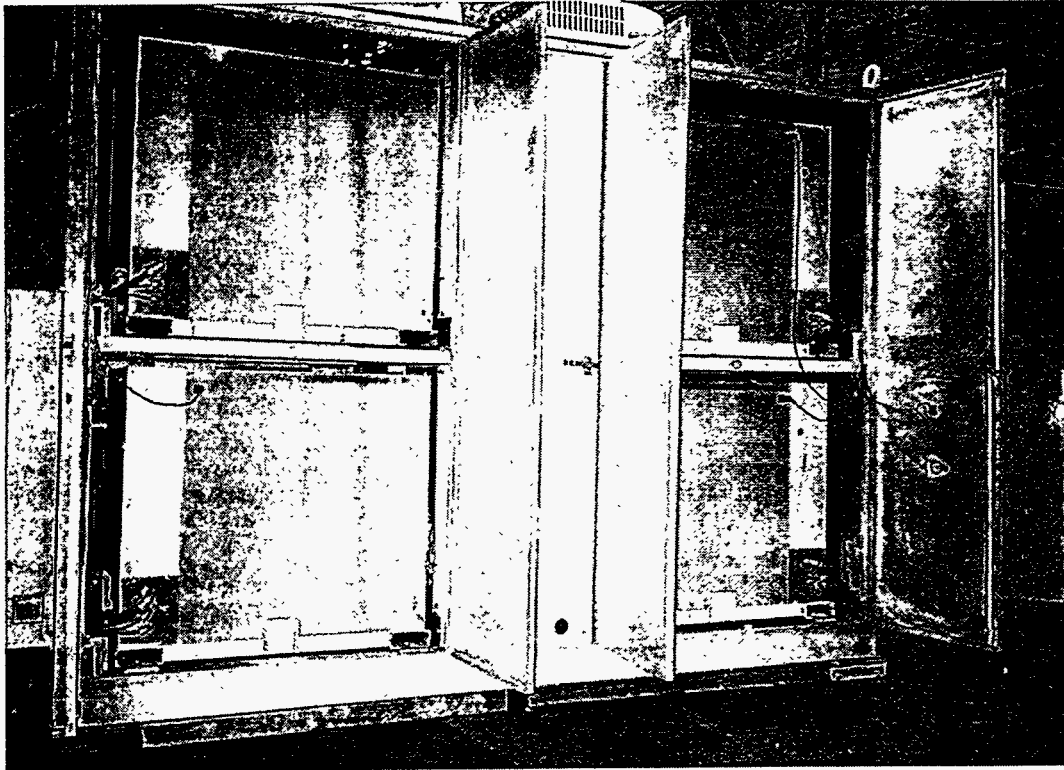


Figure 5. AC Battery System Container with Doors Open

includes removal and stowage of the rooftop mounted HVAC units. The battery modules remain inside the container during shipment.

The system container has two (2) sets of double doors for removing and replacing modules and two (2) electrical compartment access doors. Security provisions include key locks on the container access doors and panels. Figure 5 shows the container with the doors open. Figure 6 shows a forklift truck loading a module into the container.

The container door frames are sealed with weather stripping for protection against contamination from the elements. The container has been designed to withstand

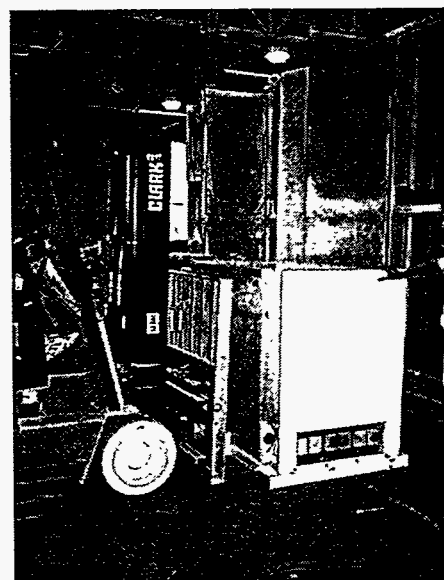


Figure 6. Forklift Loading of Battery Modules

shock and vibration to 5 g's and is rated for use in seismic 4 zones.

Passive input filters protect the Static Automatic Transfer Switch (SATS) against electrical input surges. Three rows of "capacitor banks" are mounted on the outside of the container. The "cap bands" are pictured in Figure 7.



Figure 7. AC Battery System Container with "Cap Banks"

2.2.2. Power Distribution

The AC Battery PQ2000 Power Quality System is modular in its power distribution wiring design. Each individual battery module has its own separate inverter bridge, battery charger and onboard microprocessor for data acquisition. The AC output of each module is wired in parallel with the other battery modules where total system output is aggregated. Aggregating power output on the AC side of the power converter made it possible to eliminate high voltage DC switchgear and build system capacity by adding battery modules as required.

Special high voltage cables are run strung in an overhead bundles to the individual modules. See Figure 8. Cam-loc style connectors are used for easy connect/disconnect. Each of the three phases of power output from all modules is individually fused. A bank of fuses is mounted in the center electrical control cabinet.

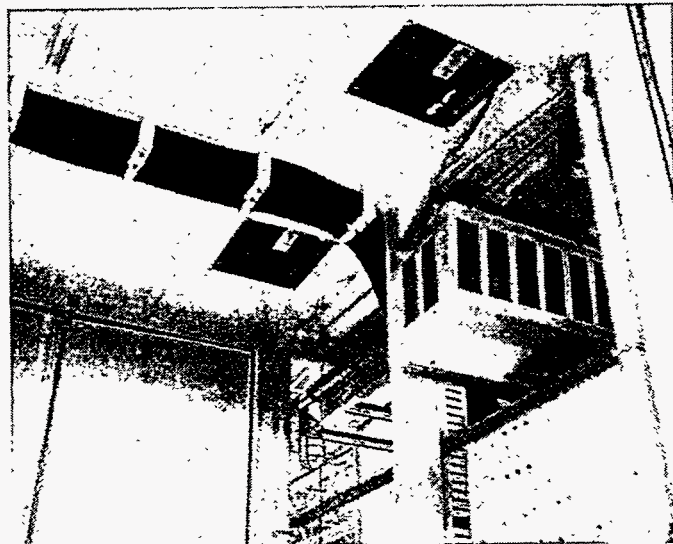


Figure 8. System Container Power Wiring

Figure 9 shows one of the current transformers used to sense the current output of each phase of the aggregated output of the system. Insulated power cables with cam-loc connectors are used at the AC Battery Module connections while insulated bolt-lugged connectors are used for terminations at the power bus, isolation transformer, and SATS. Connections to the

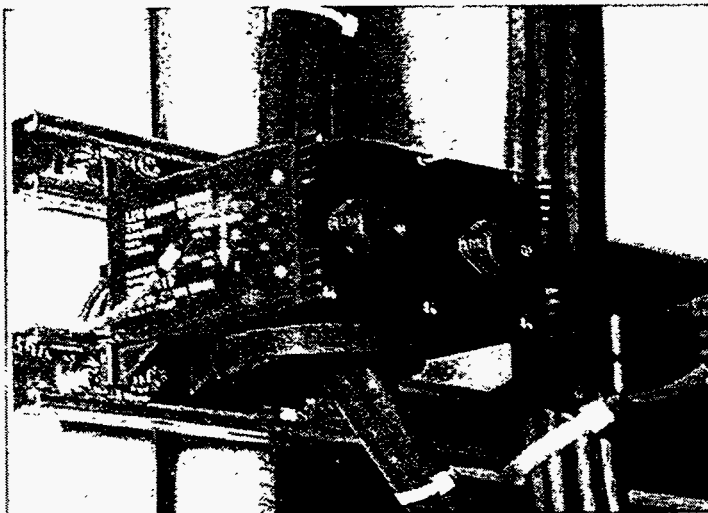


Figure 9. Power Wiring Current Transmitter

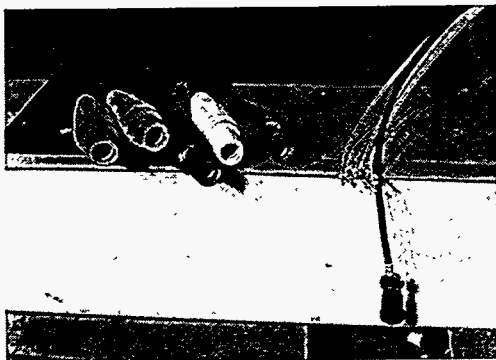


Figure 10. System Power Cable Cam-Loc Connectors and Fiber Optic Cables

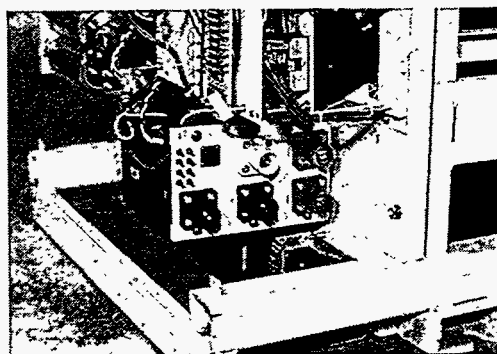


Figure 11. Cam-Loc Cable Connector Panel on System Battery Module

customer's 480 VAC switchgear are also made using insulated electrical cables with bolted-lugged connections. Connecting power cables will be run in conduit from the container to the SATS, isolation transformer, and the customer's switchgear. Figure 10 shows the cam-loc connectors and Figure 11 shows the mating connector panel on the battery module.

2.2.3. Module Interface

Fiber optic cables are used for signal communications from the master system control and the module controllers. The computerized master control sends scaling commands via fiber optics to each battery module inverter bridge.

The AC Battery PQ2000 Master Controller provides control and data acquisition for the system container and battery modules. It controls the eight (8) battery modules to operate and function together as a unified voltage source.

2.2.4. Auxiliary System Hardware and Power System

In the design of the AC Battery PQ2000 System, an Auxiliary Power System is used to power all auxiliary support systems and the master control computer. Power for the Auxiliary Power System is derived from the 208 VAC power bus within the system container. The components of the Auxiliary Power System are located inside of the center section of the AC Battery System Container. The Auxiliary Power System connects the 208 VAC power bus to an AC fused disconnect. The AC fused disconnect then, in turn, supplies a single-phase 10 kVA, 208:240/120 V Auxiliary Power Transformer. The 120 VAC single-phase output from the secondary of the Auxiliary Power Transformer then feeds the Auxiliary Power System distribution panel through a 50-amp main circuit breaker provided with the panel. Figure 12 to the right shows the fuse panel inside the center control cabinet. The respective auxiliary loads are fed through separate circuits from the Auxiliary Power System distribution panel.

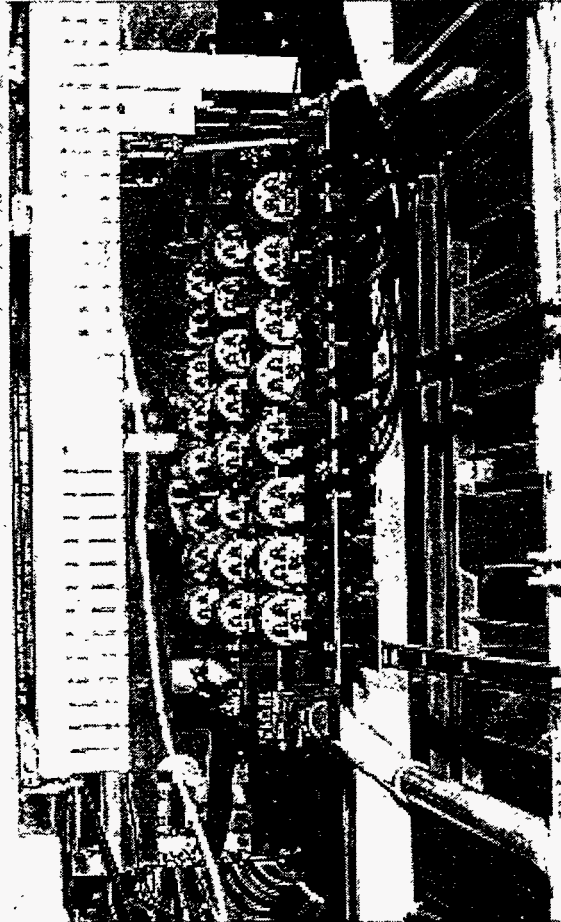


Figure 12. Fuse Panel Inside Center Electrical Compartment

Auxiliary Power System loads include:

<u>Qty</u>	<u>Description</u>	<u>Load (Watts)</u>
4	Air Conditioners	2200/ea.
1	Heater	6000
1	H ₂ Sensor	6
1	H ₂ Blower	40

1	Air Curtain	125
2	Lights on Switches	100/ea.
4	Auxiliary Power Outlets	600/ea.
1	Auxiliary Power to the AC Battery System Modules (8)	200
1	Control Power plus Other Miscellaneous Loads	3000
1	System Control Computer	200

2.2.5. Protective Controls

The AC Battery PQ2000 System PCS includes self-protective and self-diagnostic features to protect itself from damage in the event of a component failure or the excursion of operating parameters, which may be to internal or external causes beyond a safe or expected range. Error messages are displayed on an LCD display inside the center electrical control cabinet. Figure 13 below shows the LCD panel used by authorized service personnel to assist with maintenance troubleshooting.

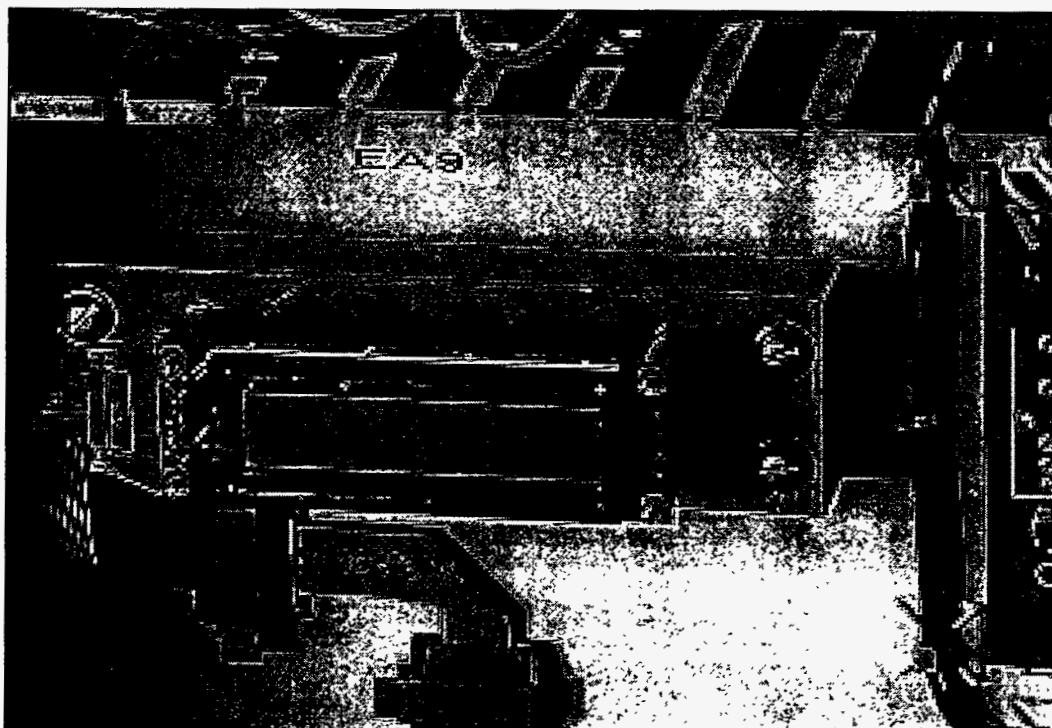


Figure 13. PQ2000 Control System LCD Display

2.3. Module Design

The eight (8) battery modules contained in the AC Battery PQ2000 system container each house forty-eight (48) individual 12 volt batteries arranged in four (4) "rack 'n stack" trays. The four (4) trays are secured to a base which is configured for lifting with a fork lift truck. Figure 14 to the right shows a photograph of the modular "rack 'n stack" assembly (less the bridge assembly) mounted in the system container.

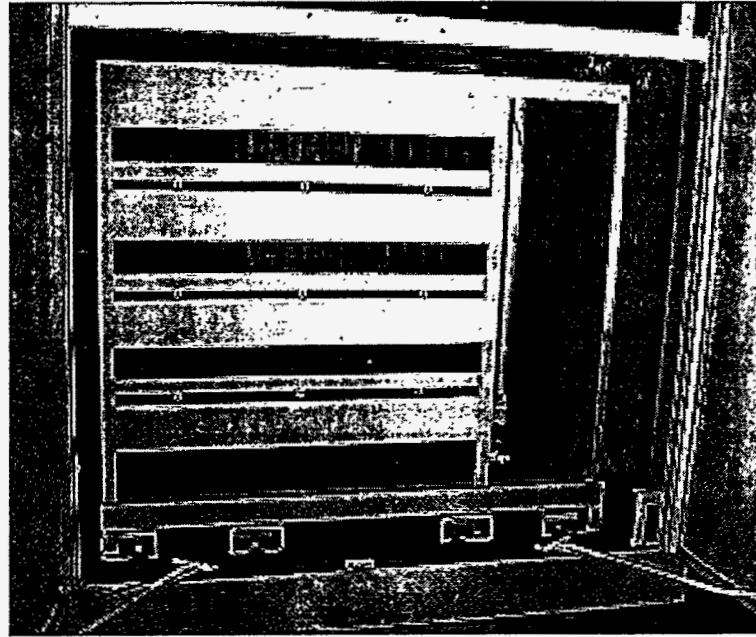


Figure 14. PQ2000 System Battery Module

2.3.1. Chassis

The chassis has been constructed such that the module can be disassembled easily to permit removal of the batteries for replacement. The inverter bridge is mounted on a separate assembly subpanel on one end of the module as shown

2.3.2. Battery Trays

Each module tray accommodates 12 batteries. See Figure 15. The batteries are held in place by compression packing between the trays. As an extra precaution, the bottom of each tray has been designed with a pan to hold a liquid volume equivalent to the amount of battery acid in a single battery.

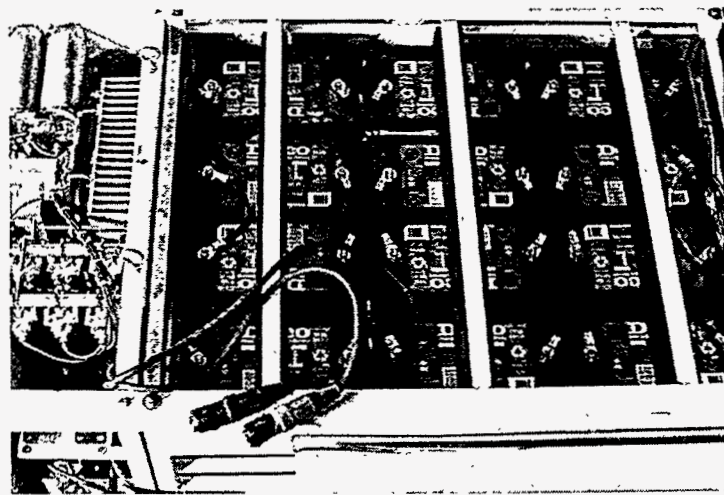


Figure 15. Top View of PQ2000 Battery Module

2.3.3. Inverter Bridge Mounting

Pictured in Figure 16 is a battery module with the three-phase inverter bridge assembly mounted. The bridge assembly in the photograph is undergoing testing prior to final assembly.

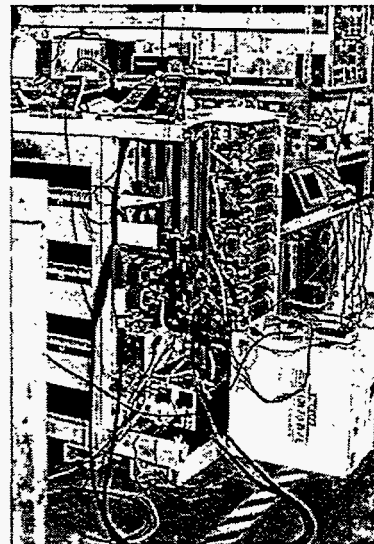


Figure 16. PQ2000 PCS Panel Under Test

2.4. PCS Design

The AC Battery PQ2000's PCS is comprised of eight (8) individual inverter bridges located on each of the eight (8) battery modules. The outputs of all eight (8) distributed inverter bridges are combined and collectively controlled to produce a single, unified voltage source. Each bridge consists of six (6) 1200 amp, 1200 volt, single Insulated Gate Bipolar Transistors (IGBTs) configured in a conventional three-phase bridge arrangement.

The AC Battery PQ2000 Power Quality System's Power Conversion System (PCS) provides the interface between the AC Battery PQ2000's DC battery system and the AC system, and provides for charging and discharging of the batteries. The PCS, in conjunction with the AC Battery PQ2000 System Master Control, is capable of automatic unattended operation.

2.4.1. Power Circuitry

Input to and output from the AC Battery PQ2000 Power Quality System is 480 VAC, 60 Hz, three phase and is connected to the distribution feeder through a 480 V Static Automatic Transfer Switch (SATS).

2.5. Static Automatic Transfer Switch (SATS) and Isolation Transformer

The Static Automatic Transfer Switch (SATS) measures 12'L x 5.2'W x 7.5'H and weighs approximately 7000 pounds. The isolation transformer measures 36"L x 48"W x 53"H and weighs approximately 2400 pounds.

3. OPERATION

The AC Battery PQ2000 Power Quality System is designed to operate as a voltage source supplying and maintaining all power levels up to a maximum rating of 2 MVA for 10 seconds. The output of all eight (8) AC Battery Modules housed inside the system container are combined

into a unified voltage source. The AC Battery PQ2000 Power Quality System will eliminate the potential effects of switching transients, voltage sags, and outages that may interrupt the Customer's manufacturing line, data processing, or other critical operations.

When a line disturbance is detected on the utility, the AC Battery PQ2000 Power Quality System will transfer power sensitive, electronic loads to the battery system and isolating them from the utility supply. While the AC Battery PQ2000 Power Quality System is operating and supplying power to critical bus loads (which conceivably could include an entire facility), the PQ2000 will operate at the utility frequency last monitored before the disturbance. The AC Battery PQ2000 Power Quality System will continuously monitor the utility to detect when the disturbance has cleared. When the utility is within normal tolerance and synchronized for 2 seconds, the AC Battery PQ2000 Power Quality System will reconnect the critical load to the utility. If for some reason the utility returns and is not in phase with the AC Battery PQ2000 Power Quality System, the AC Battery PQ2000 Power Quality System will first synchronize its output with the utility before allowing a transfer back to the utility supply.

If the utility does not return to nominal within the specified 2 MVA/10 second operating discharge time for the AC Battery PQ2000 Power Quality System, the AC Battery PQ2000 Power Quality System will transfer the load back to the utility. If the AC Battery PQ2000 Power Quality System has expended its available charge or has reached the thermal limits of operation, the AC Battery PQ2000 Power Quality System will, through self-monitoring, shutdown to protect its internal components.

The AC Battery PQ2000 Power Quality System is designed for complete automatic and unattended operation. External monitoring of the AC Battery PQ2000 can be accomplished through the use of a modem as outlined in other sections of this report. Local monitoring is annunciated on the LCD located inside the system container.

Charging of the AC Battery PQ2000 Power Quality System can be completed within 8 hours or less—depending upon the depth of discharge and total energy expended. Each battery module is designed with a separate 4 kW, 5 A @ 800 VDC battery charger to provide for charging and equalizing the batteries. The batteries contained in the battery modules automatically recharge after each discharge. No floating charge is required or provided for the batteries. A biweekly equalizing charge for the batteries is programmed to take place during off-peak hours. The eight (8) battery modules housed in the system container will be independently charged and controlled at the same time for the duration of their charge cycle. The charging algorithm provided has been specifically designed for maximizing the efficiency of the charge cycle to restore the state-of-charge of the AC Battery Modules after discharge.

3.1. Safety

Safety systems included in the design of the AC Battery PQ2000 include a hydrogen gas detection and ventilation system, an integral smoke detector, and an acid spill containment area as standard features. See Figure 17.

The hydrogen gas ventilation system is a forced air system that evacuates any hydrogen gas generated during charging through a network of tubing which runs from each battery in every battery module to one of four, two (2) inch PVC pipes running vertically in the system container. These pipes are vented to the outside and are connected to a common plenum equipped with a blower that pulls air through the pipes. The hydrogen sensor is mounted near the ceiling inside the system container

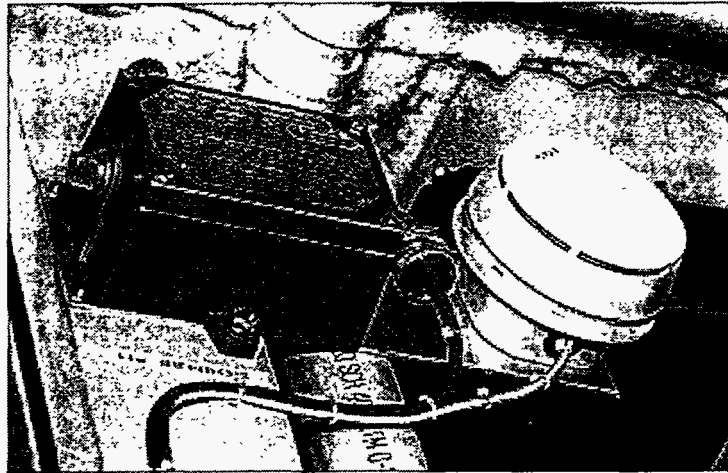


Figure 17. PQ2000 System Smoke and Hydrogen Detectors

If smoke or hydrogen gas is sensed, the AC Battery PQ2000 has been programmed to shutdown and announce an ALARM on both the local and remote SCADA System displays. The smoke detector is mounted near the ceiling inside the system container and is used to detect the presence of smoke which may have been generated from any type of combustion inside of the container.

As previously described, each of the eight (8) battery modules is comprised of four (4) vertically stacked trays of batteries. Each tray has a molded plastic liner which holds the individual batteries in place and provides the first level of acid spill containment. The molded tray design provides an effective containment system for acid spills equivalent to the volume of one battery on a per tray basis. For containment of larger acid spills, the second level of acid spill containment is provided at the bottom of the system container. See Figure 18. The system container floor area is constructed of sheet steel that is covered with a minimum 15 mils of sprayed on ethylene methacrylic acid copolymer making it resistant to sulfuric acid.

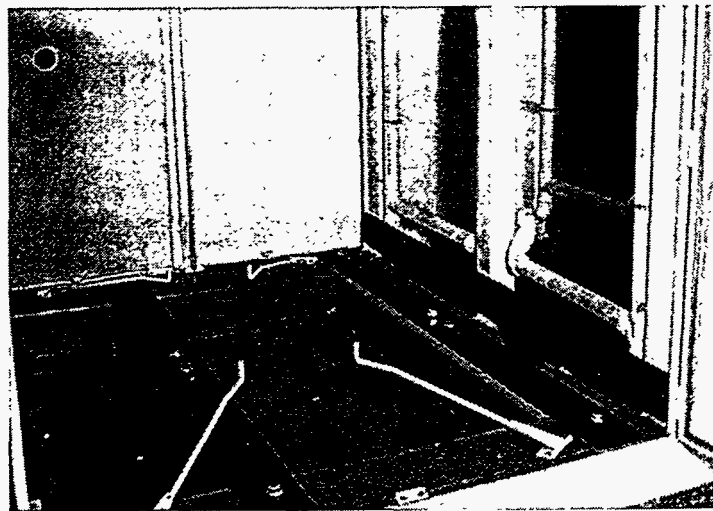


Figure 18. Container Acid Spill Containment Area

Additional safety features include protection from unauthorized entry into the container (door interlock), four fire extinguisher access ports on the container doors, frequency synchronization errors, low utility line frequency, voltage out-of-range, battery Over temperature, and container abnormal operating temperature.

4. SUMMARY

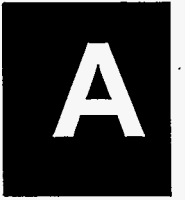
4.1. Progress to Date

As of the end of August, 1995, fabrication of the AC Battery PQ2000 Power Quality System was largely complete with subassembly testing underway. Fabrication of the container was completed and the bridges were under test. Delays to the project schedule of approximately one month were estimated due to unanticipated delays in delivery and extended testing of the static switch.

4.2. Work to be Completed

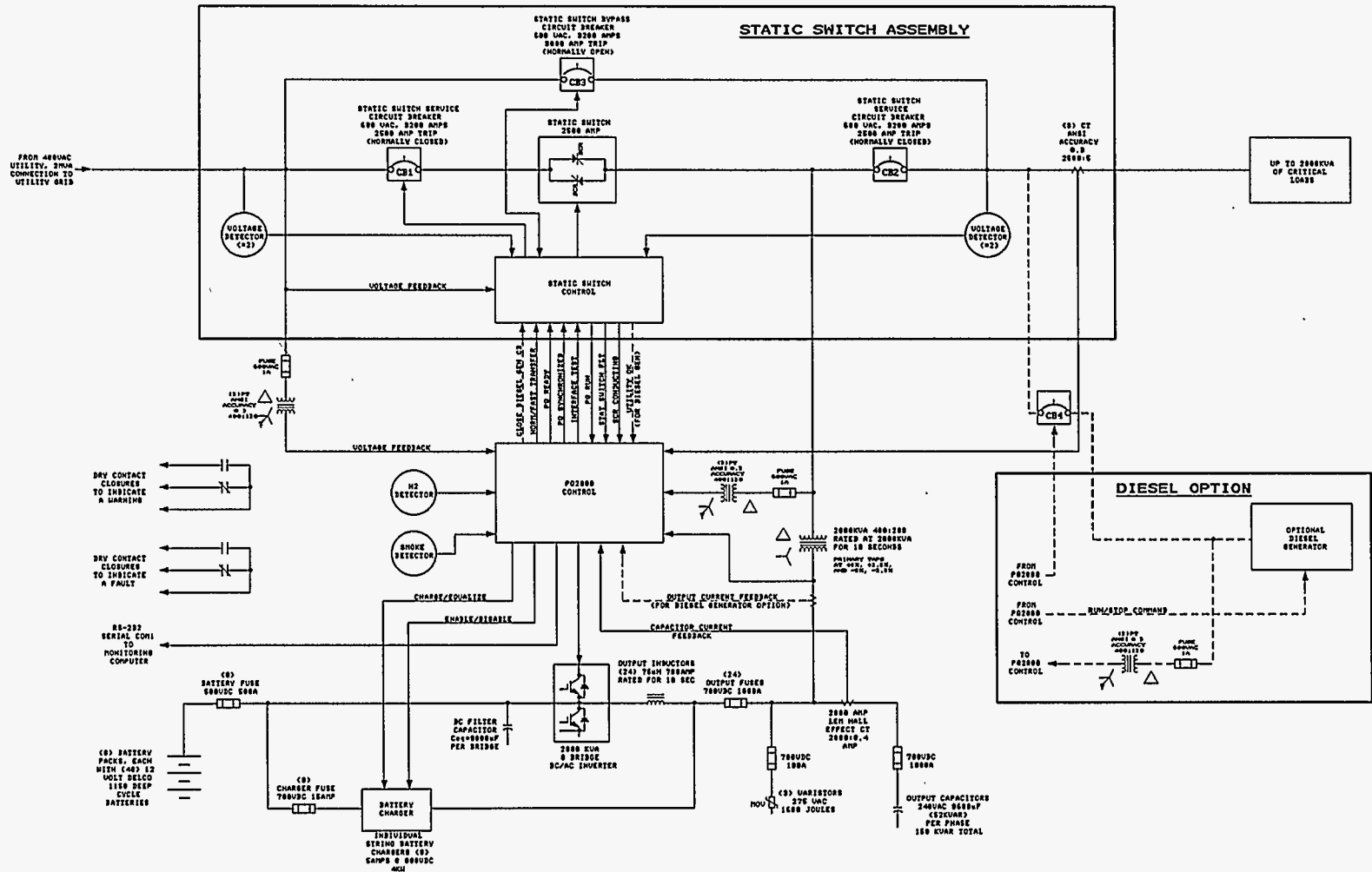
Final component testing of the bridge assemblies needs to be completed as does full system integration and final testing. No problems are anticipated at this point. It is expected that final fabrication, integration, and system testing will begin immediately after component testing has been completed in October, 1995. It is estimated that Factory Acceptance Testing will commence and conclude around end of December, 1995.

Documentation support for the PQ2000 System is an ongoing project. Testing protocols for final subassembly testing have been developed, but full system Operation & Maintenance Manuals will yet need to be written. However, preliminary manuals will be ready in time to send to the field along with the first PQ2000.



APPENDIX A

ONE-LINE DIAGRAM
PQ2000 AC BATTERY 2MVA POWER QUALITY SYSTEM
2MW FOR 10 SECONDS = 20MJ

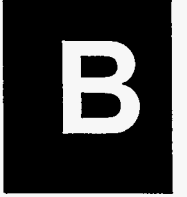


REFERENCE DRAWINGS

1. PQ2000 THREE LINE AND CONTROL SCHEM (4 SHEETS) --- 1224-1

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SYSTEM ONE-LINE DRAWING PQ2000 FOR AC BATTERY	
PAGE: SHEET 1 OF 1	NO. 1224-1



APPENDIX B

