DOE/AL/99852--T2

Final 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

December 11, 1996

Omnion Power Engineering Corporation
P.O. Box 879
2010 Energy Drive
East Troy, Wisconsin 53120
414-642-7200

TABLE OF CONTENTS

Abstract 1
Preface 2

1. INTRODUCTION 3
  1.1. Task List 3
    1.1.1. Task 1: Project Planning 3
    1.1.2. Task 2: Design of the System 3
    1.1.3. Task 3: System Design Review 4
    1.1.4. Task 4: Hardware Procurement 4
    1.1.5. Task 5: Software 4
    1.1.6. Task 6: Prototype Test 5
    1.1.7. Task 7: Design Modifications 5
    1.1.8. Task 8: Manufacture Balance of 2 MW/10 Second System 5
    1.1.9. Task 10: Final Technical Report 5
  1.2. Development Schedule and Status 6

2. DESIGN GOALS 6
  2.1. System Design 7
  2.2. Container Design 8
    2.2.1. Physical Structure 9
    2.2.2. Power Distribution 10
    2.2.3. Battery Module Interface 11
    2.2.4. Auxiliary System Hardware and Power System 11
    2.2.5. Protective Controls 12
  2.3. Module Design 13
    2.3.1. The Battery 13
    2.3.2. PCS and Inverter Bridge Design 15
  2.4. Electronic Selector Device (ESD) Design 15
  2.5. Engine Generator Interface Option 17
  2.6. Isolation Transformer Design 17

3. COMPONENT PHYSICAL SPECIFICATIONS 17
  3.1. Container Specifications 17
  3.2. Module Specifications 18
  3.3. Electronic Selector Device Specifications 18
  3.4. Isolation Transformer Specifications 18

4. SYSTEM OPERATIONAL SPECIFICATIONS 18

5. SYSTEM AUXILIARY LOADS and LOSSES 19
  5.1. System Container Component Loads 19
  5.2. ESD Component Loads 19
  5.3. Expected System Losses 19

6. SYSTEM OPERATION 20
6.1. ESD Sensing 20
6.2. ESD Control 20

7. FACTORY TESTING 21
7.1. Electronic Selector Device Tests 22
7.2. Isolation Transformer 22
7.3. Main System Container 22
7.3.1. Battery Modules 22
7.3.2. System Control 23
7.3.3. Auxiliary Subsystems 23
7.4. System Discharge Testing 23
7.5. Test Results Summary 24

8. SUMMARY AND CONCLUSIONS 25

List of Tables and Figures

Table 1. Project Development Schedule 6

Figure 1. PQ2000 System Components 7
Figure 2. Typical AC Battery PQ2000 Site Layout Plan 8
Figure 3. Cutaway View of Container 9
Figure 4. Forklift Loading of Battery Modules 9
Figure 5. Cap Bank Without Covers 10
Figure 6. System Container Power Wiring 10
Figure 7. Cam-Loc Connectors on Power Cables and Fiber Optic Cables 10
Figure 8. Cam-Loc Power Cable Connector Panel on System Battery Module 10
Figure 9. Power Wiring Current Transmitter 11
Figure 10. Fuse Panel Inside Center Electrical Compartment 11
Figure 11. PQ2000 Control System LCD Display 12
Figure 12. PQ2000 System Battery Module 13
Figure 13. Top View of a PQ2000 System Battery Module 13
Figure 14. The Delco 1150 PQ2000 System Battery 14
Figure 15. Graph of Consecutive Discharge Performance of the Delco 1150 Battery 14
Figure 16. PQ2000 PCS 15
Figure 17. ESD with Doors Open and Subpanels Removed 15
Figure 18. Original ESD Sensing and Switching Timing Diagram 16
Figure 19. ESD Setpoints Mapped over CBEMA Guidelines for Process Controller Power Supplies 20
Figure 20. Voltage Interruption on One Phase of the Utility and Load Pickup by the PQ2000 24
Figure 21. Synchronous Transfer Back to the Utility 24
Figure 22. Battery Cycle Life Plotted as a Function of Depth of Discharge 25

APPENDICES

Appendix A. Drawings, Sketches and Diagrams

System Block Diagram .... AC Battery Sketch; (No Dwg. Number)
System One Line Electrical Diagram .... AC Battery Dwg. 100001; Sheet 1 of 1
System Container Structural Drawing .... AC Battery Dwg. 100002; Sheet 1 of 1
PQ2000 Test Installation Diagram .... AC Battery Dwg.; PQ-TEST.VSD

Abstract

Voltage sags, swells and momentary power interruptions lasting on the order of a few cycles to several seconds are common disturbances on utility power distribution systems. These power disturbances are a result of normal utility recloser switching activity due in part to distribution system short circuits from natural causes such as lightning, small rodents, traffic accidents that down power poles, and current overloads initiated by certain types of industrial equipment such as large horsepower motors with high inrush currents.

Whatever the cause, power disturbances pose serious problems for many industrial and commercial customers with critical, voltage sensitive equipment. Faults can interrupt a manufacturing process, cause PLC's to initialize their programmed logic and restart equipment out of sequence, create computer data errors, interrupt communications, lockup PC keyboards and cause equipment to malfunction. These momentary disturbances result in billions of dollars of lost productivity annually due to downtime, clean-up, lost production and the loss of customer confidence in the industrial or commercial that provides the service or product.

This report describes prototype development work for a factory assembled 2 MW/10 Second Battery Energy Storage System (BESS). The system design includes 1) a modular battery energy storage system comprised of several strings of batteries—each string provided with an integral Power Conversion System (PCS), 2) an Electronic Selector Device (ESD) comprised of a solid state static switch with sensing and power switching controls, and utility interconnection termination bus bars, and 3) a separate isolation transformer to step-up PCS output voltage to interface directly with the distribution transformer serving the industrial or commercial customer.

The system is designed to monitor the utility distribution system voltage for voltage sags, swells, and momentary interruptions, switch the customer's critical loads from utility power to the energy stored in the systems batteries and provide up to 2 MVA until the disturbance clears or up to 10 seconds—the design limit of the system. Once the ESD sensing circuits have confirmed that the utility is again stable, it seamlessly returns the critical load to the utility. A one-line electrical diagram of the system is provided in Appendix A of this report.

Preface

Sandia National Laboratories (SNL) implements the Energy Storage Systems Program established by the U.S. Department of Energy (DOE). SNL works closely with private industry to analyze, develop, test and facilitate the transfer of technology to enable energy storage systems to become a viable utility resource by the end of the decade. This report describes the design development of a 2 MW/10 Second Battery Energy Storage System (BESS) under DOE Cooperative Agreement No. DE-FC04-94AL99852. Funding for the actual fabrication of the 2 MW/10 Second BESS was provided under separate contracts between Omnion Power Engineering Corporation, AC Battery Corporation and Pacific Gas & Electric Company (PG&E).

Additionally, a significant portion of the BESS subsystem design and development was preceded with another related contract issued by Sandia National Laboratories for the development and delivery of a prototype power conversion system (PCS). Design of the PCS called for a thermally constrained 250 kVA bridge assembly consisting of an Insulated Gate Bipolar Transistors rectifier, a 4 kW charging circuit and control hardware. The 250 kVA bridge assembly was intended to become an integral subsystem of the 2 MW/10 Second system developed under the DOE Cooperative Agreement.

This report details only the BESS design development funded under the DOE Cooperative Agreement. Reports on the design and development of the 250 kVA bridge assembly and the field installation and testing of the 2 MW/10 Second BESS by PG&E at their Modular Generation Test Facility (MGTF) are governed by separate Omnion contracts and not detailed herein. However, the scope of the entire BESS project required close coordination between DOE, SNL, PG&E and AC Battery Corporation. AC Battery Corporation was formed by Omnion as part of the commercialization plan required to meet tenants of the Cooperative Agreement.

This time frame summarized by this report encompassed development work conducted between September 1, 1994 (date of signed Cooperative Agreement) and August 31, 1995 (date of final deliverables—design summary, drawings, description and final specifications with initial factory testing results). Included in the scope of development is system definition and design, hardware procurement (funded by PG&E), battery module and system software development, battery module prototype testing and initial design modifications.

Actual work conducted and reported on is outlined in the Task List and Development Schedule provided in the Section 1.0 of this report. The Task List and Development Schedule is meant to satisfy the requirements of both DOE and PG&E. Elements of this report are intended to meet only the items within the scope of the DOE Cooperative Agreement. Actual delivery of the 2 MW/10 Second BESS prototype was made to PG&E in March 1996.

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 voltage disturbances that affects 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, Bills 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
Subassembly 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 Materials
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 prototyped

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 of 2 MW/10 Second System

Input: Updated schematic, BOM, mechanical drawings

Objective: Manufacture and test seven (additional) 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

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

1.1.9. 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

Task	Total Hrs	Started	Completed
PQ2000 Project	**5240**	**10-03-94**	**12-11-96**
Task 1 Project Plan	360	10-03-94	12-30-95
Task 2 Design	1560	11-02-94	09-11-95
System Modeling	240	11-18-94	01-20-95
System Schematic/BOM	440	11-02-94	12-13-94
PCB Schematic/BOM	180	12-26-94	07-15-95
PCB Artwork	80	04-04-95	07-15-95
Control Diagrams	140	12-13-94	02-10-95
Cabinets	280	11-02-94	07-30-95
Outlines test, O&M	80	12-13-94	11-20-95
Charger Assembly	120	11-28-94	09-01-95
Task 3 Design Review	180	02-15-95	03-22-95
Task 4 Hardware Purchase	100	12-13-94	02-22-95
Task 5 Software	300	12-28-94	07-30-95
Static Switch	20	03-22-95	07-30-95
Charger	120	12-28-94	01-20-95
Controls	160	02-10-95	03-15-95
Task 6 Preliminary	880	03-27-95	06-02-95
Preliminary Product	680	03-27-95	05-18-95
Preliminary Test	200	05-18-95	06-02-95
Task 7 Design Modifications	60	06-02-95	06-07-95
Task 8 Final	940	06-07-95	03-14-96
Final Production	300	06-07-95	10-26-95
Factory Test	640	10-23-95	03-14-96
Task 9 Field Test	420	05-01-96	ongoing
Task 10 Final Report	440	03-14-96	12-11-96

Table 1. Project Development Schedule

2. DESIGN GOALS

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 customer's site. Other desirable design characteristics of the PQ2000 BESS included:

(a) a multi-megawatt capacity

(b) capability of many discharges over life
(c) a discharge capacity in terms of seconds
(d) high efficiency and an economic life cycle cost
(e) a compact footprint (high kW/ft^2)
(f) a self-contained, outdoor enclosure
(g) a sensing and transfer time ≤ 1/4 cycle

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.

The AC Battery PQ2000 Power Quality System design was intended to be a high-capacity, short-duration standby power (voltage) source capable of delivering up to 2 MW of clean electrical power to voltage sensitive loads for up to 10 seconds. The goal was to effectively switch electrical loads from a "disturbed" utility service in approximately 1/4 cycle, incorporate continuous monitoring of the utility service line and switch back after 10 seconds—or less, if the voltage disturbances have cleared. Once activated, the PQ2000 Power Quality System was intended to operate automatically and not require attended operation.

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 208/480 VAC Isolation Transformer rated 2 MVA for 10 seconds. The three elements of the system are shown in Figure 1.

The PQ2000 System is modular by design and contains eight independent functioning battery modules.. 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 improved flexibility to meet system sizing and layout requirements.

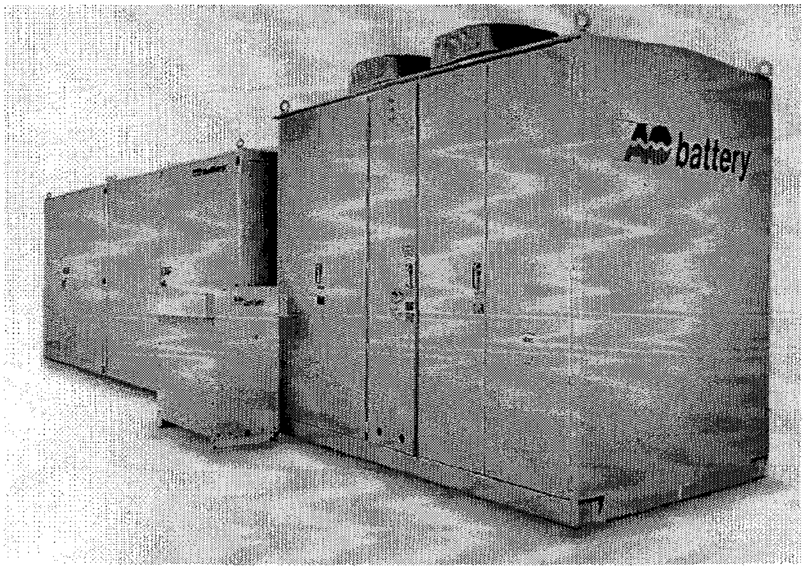


Figure 1. PQ2000 System Components

AC output from the system was specified to have a voltage THD of less than 5%, a transfer time of approximately 2 milliseconds, and the capability of performing 2 ten second discharges within a time interval of approximately 20 minutes. Dial-up telemetry with remote diagnostic capability were also specified.

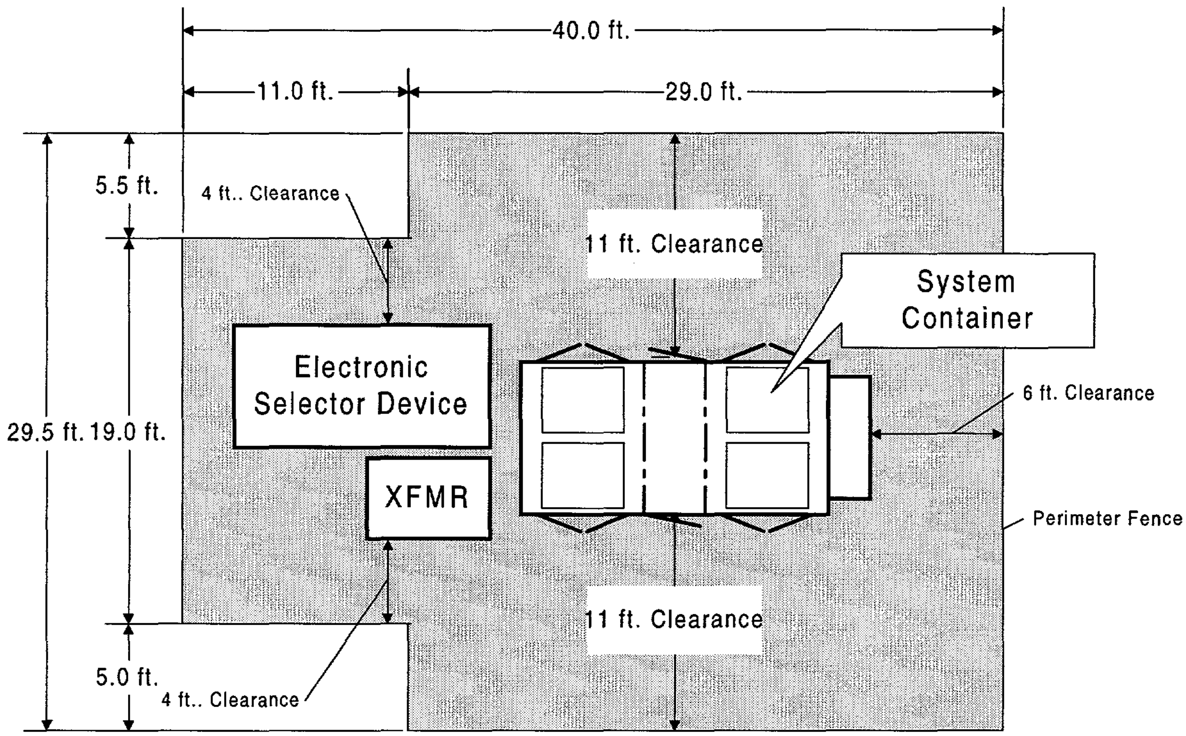


Figure 2. Typical AC Battery PQ2000 Site Layout Plan

The recommended installation site plan of the PQ2000 calls for a rectangular area roughly 30 feet by 40 feet, however, other site configurations can be accommodated. Eleven feet of access around the container is suggested for fork lift maneuvering to load and unload the battery modules. Clearance around the ESD and isolation transformer may be reduced, codes and other local restrictions permitting. See Figure 2 for a typical 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 a hydrogen venting system and free hydrogen detection system, smoke detector, HVAC equipment for internal container temperature control and a microprocessor based control system. 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 R4.0. A structural drawing of the system container is provided in Appendix B of this report.

2.2.1. Physical Structure

The PQ2000 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 includes removal and stowage of the rooftop mounted HVAC units. The battery modules remain inside the container during shipment.

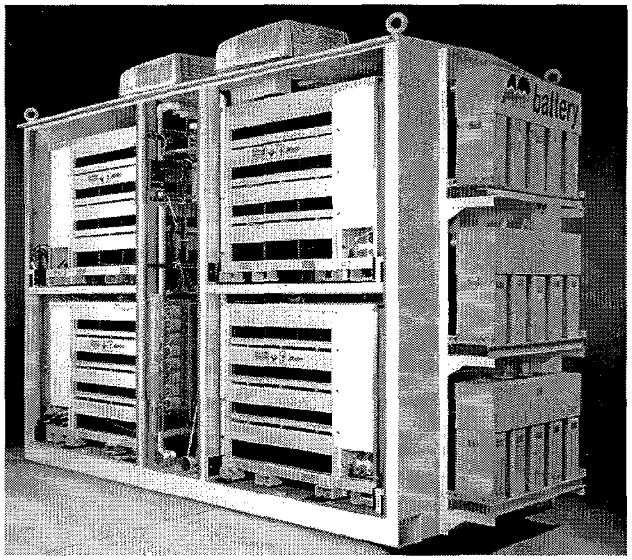


Figure 3. Cutaway View of Container

The system container has four (4) 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. A forklift truck is required for loading modules into the container. Figure 3 shows a cut away view of the container with all battery modules loaded in place. Figure 4 shows loading of the battery modules.

The container door frames are sealed with weather stripping for protection against contamination from the elements. The container has been designed to withstand shock and vibration to 5 g's and is rated for use in seismic 4 zones.

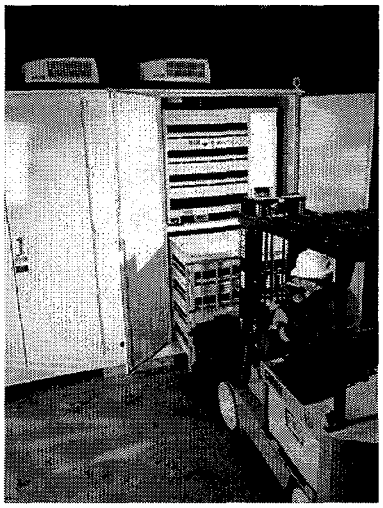


Figure 4. Forklift Loading of Battery Modules

Passive input filters protect the Electronic Selector Device (ESD) against electrical input surges. Output filtering is accomplished by three rows of "cap (capacitor) banks" mounted on the outside of the container as pictured in Figure 5. Removable protective covers are installed prior to shipping to the field.

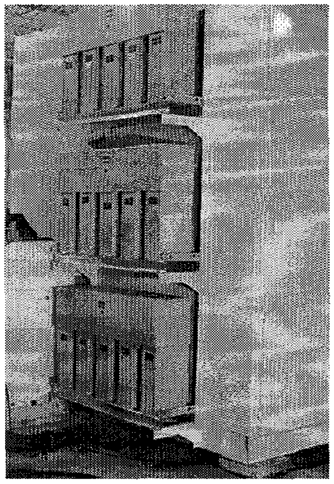


Figure 5. Cap Bank Without Covers

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 6. Cam-loc style connectors are used for ease and speed of connection and disconnection. The cable connectors and module termination panel are shown Figure 7 and Figure 8.

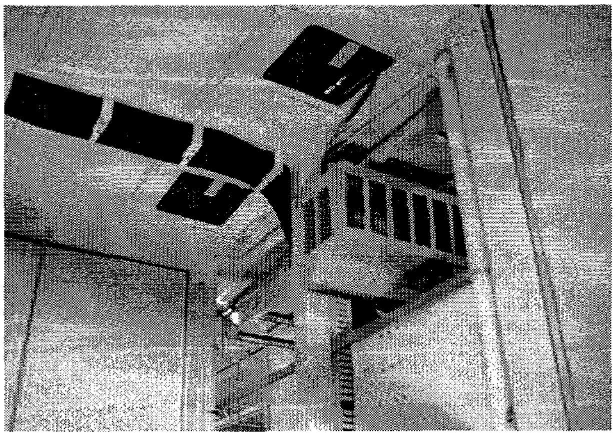


Figure 6. System Container Power Wiring

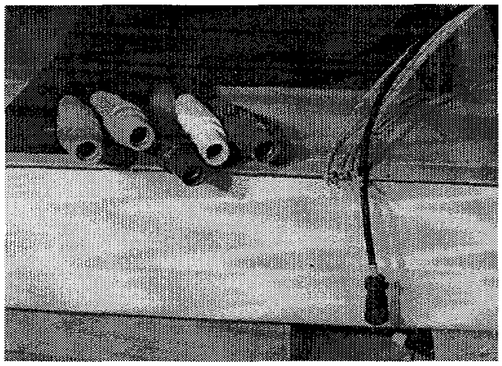


Figure 7. Cam-Loc Connectors on Power Cables and Fiber Optic Cables

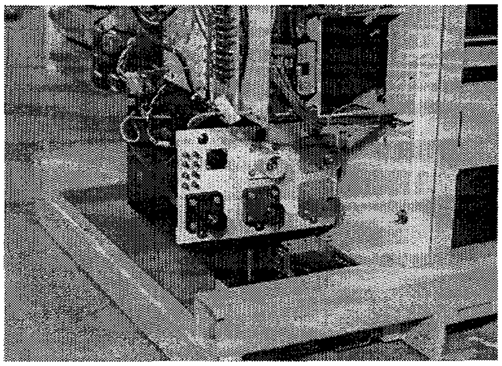


Figure 8. Cam-Loc Power Cable Connector Panel on System Battery Module

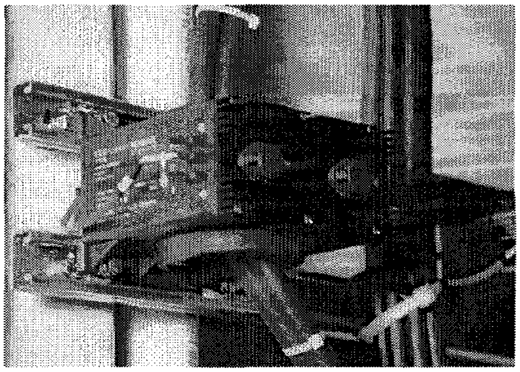


Figure 9. Power Wiring Current Transmitter

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 9 shows one of the current transformers used to sense the current output of each phase of the system. While insulated power cables with cam-loc connectors are used at the AC Battery Module connections, insulated bolt-lugged connectors are used for terminations at the power bus, isolation transformer, and ESD. Connections to the 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 ESD, isolation transformer, and the customer's switchgear.

2.2.3. Battery 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

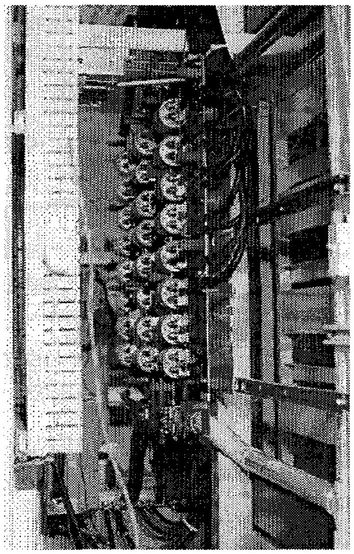


Figure 10. Fuse Panel Inside Center Electrical Compartment

The components of the Auxiliary Power System are located inside of the center electrical section of the container. The Auxiliary Power System provides single phase power to all auxiliary support systems and the master control computer. Auxiliary Power is derived from one phase of the 208 VAC power bus via a 10 kVA power transformer. The 208 VAC bus connects the outputs of all battery modules to the 208/480 VAC output isolation transformer. The 208 VAC bus always remains powered—either by the utility supply on the output side of the static switch or by the output of the battery modules when the system is in the discharge mode. The 208 VAC bus can be de-energized by opening the input circuit breaker to the static switch and by ensuring that the System Control is not in a discharge mode. The Auxiliary Power System is protected by an AC fused disconnect located on the main AC Power Fuse Panel shown in Figure 10. A block diagram and a one-line electrical system drawing are included in the Appendix of this document.

An integral part of the 208 VAC power system is the battery charging system. Each battery module PCS is designed with a built-in battery charger rated at 4 kW. Stepped down power to recharge the batteries is supplied by the utility supply through the 208/480 VAC power transformer and regulated by control signals from the PQ2000 System Control Computer.

Auxiliary Power System loads include:

Qty	Description	Load (Watts)
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 11 shows the LCD panel used by authorized service personnel to assist with maintenance and troubleshooting.

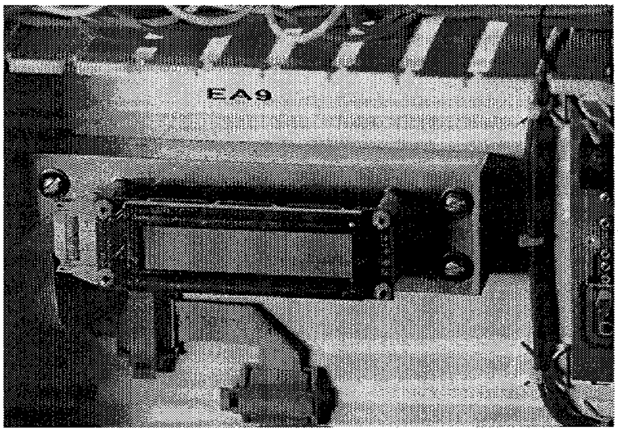


Figure 11. PQ2000 Control System LCD Display

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 forklift truck. Figure 12 shows a photograph of the modular "rack 'n stack" assembly with the PCS shroud cover in place.

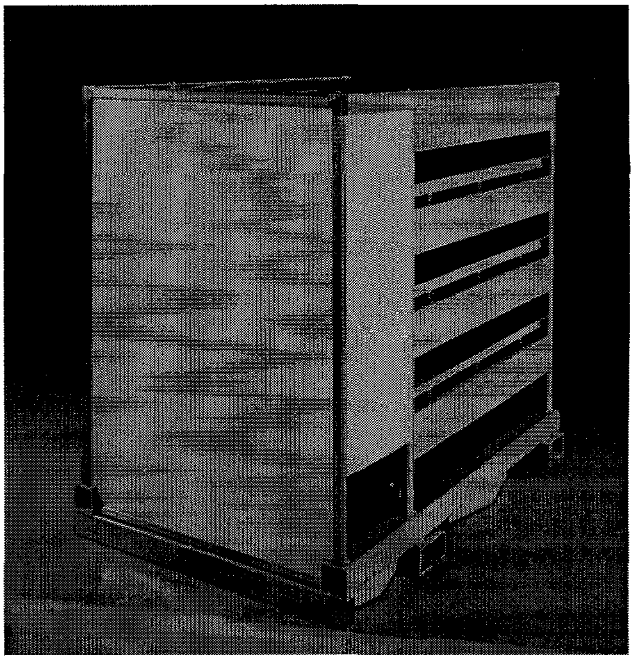


Figure 12. PQ2000 System Battery Module

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 in Figure 13. Each module tray accommodates 12 batteries. The batteries are held in place by compression packing between the trays as illustrated by Figure 13. 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.

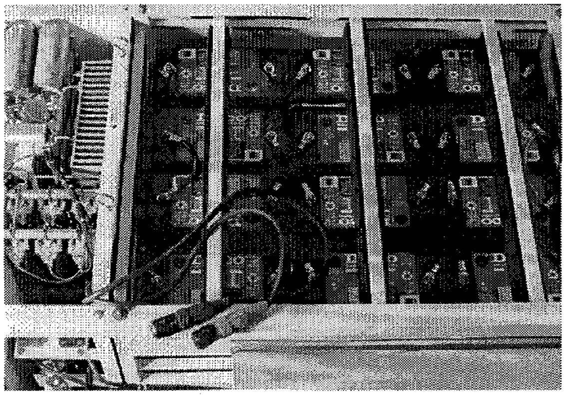


Figure 13. Top View of a PQ2000 System Battery Module

2.3.1. The Battery

A key element in the PQ2000 development is the effective matching of the strengths and limitations of the flooded lead acid battery with the requirements demanded by the application. More than two years of exhaustive applied research and development has led to an integrated approach for collectively controlling and regulating factors affecting battery cycle life and discharge performance referred to by AC Battery Corporation as Advanced Battery Management. Restricting operation of the battery to a well defined performance regime optimizes battery performance and has lead to predictability of battery life and service requirements. It is this predictability that increases system availability and reliability.

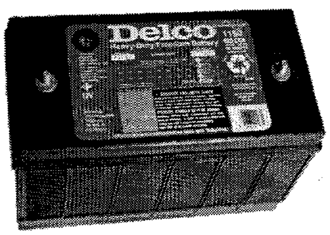


Figure 14. The Delco 1150 PQ2000 System Battery

The battery selected for use in the PQ2000 is the Delco 1150. The Delco 1150 is a high power "SLI" battery—a battery designed for starting, lighting and ignition of heavy duty truck engines. It is a maintenance-free, flooded, lead-acid battery. The Delco 1150 has been in high volume commercial volume production since 1981 and has an excellent performance history. Its high-energy design is capable of multiple, successive discharges over a short period of time (i.e., minutes), without requiring a complementary recharge cycle. It is expected to deliver in excess of 2500 cycles over the life of the battery. Battery operational life is expected to be in the 5 to 7 year range given the application and the duration and frequency of occurrence of voltage sags and momentary outages in a real world application.

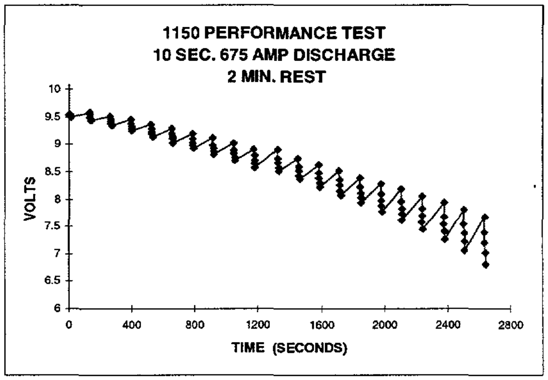


Figure 15. Graph of Consecutive Discharge Performance of the Delco 1150 Battery

The algorithm used for recharging the batteries was developed as a result of a program initiated by Delphi Energy and Engine Management Systems to provide additional technical battery performance data relative to its cycle life and the relationship between 1) depth of discharge, 2) rate of discharge, 3) amp-hour rating of the battery, 4) regulation of discharge limits for nameplate rating, and 5) identification of methods to maximize battery life. It was found that battery discharge performance and cycle life could be significantly extended by using a combination of constant voltage and constant current pulses to recharge the batteries.

2.3.2. PCS and Inverter Bridge Design

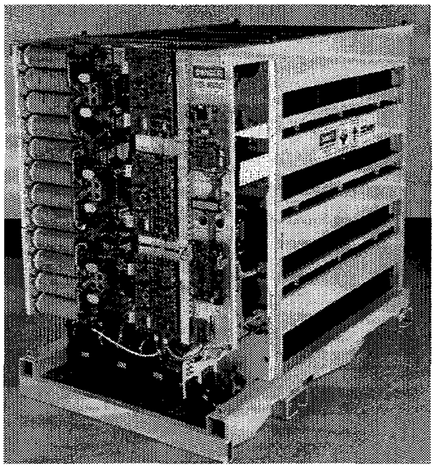


Figure 16. PQ2000 PCS

The AC Battery PQ2000's Power Conversion System (PCS) is comprised of eight (8) individual bridge assemblies and a PCS panel located in the center section of the container. Each bridge assembly consists of six (6) 1200 amp, 1200 volt, single Insulated Gate Bipolar Transistors (IGBTs) configured in a conventional three-phase bridge arrangement. Each converter bridge also contains a battery charger, IGBT firing logic circuits, analog data monitoring and data interface. The data interface and IGBT firing logic circuits receive information from the PQ2000 System's microprocessor based PQ2000 Control through fiber-optic cables. The microprocessor based PQ2000 Control is the principle controller for the PQ2000 System Container and interfaces with the PQ2000 System ESD. The outputs of all eight (8) distributed inverter bridges are combined and collectively controlled to produce a single, unified voltage source.

Pictured in Figure 16 is an installed bridge on a battery module with protective covers removed. The PQ2000 PCS provides the interface between the DC battery system and the AC system and controls charging and discharging of the batteries. The PCS, in conjunction with the PQ2000 System Master Control, is capable of automatic unattended operation.

2.4. Electronic Selector Device (ESD) Design

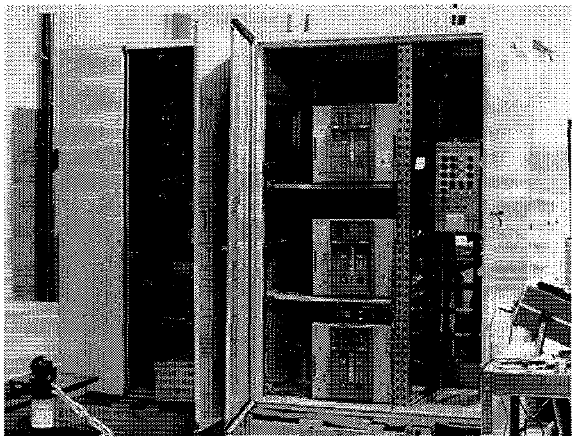


Figure 17. ESD with Doors Open and Subpanels Removed

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 Electronic Selector Device (ESD). The switch includes input, output and bypass circuit breakers, SCR (thyristor) AC switches, HVAC, monitoring and controlling computer and bussing for landing the connecting cable lugs. Computer control components are located in the cabinet on the left and the switchgear on the right.

The ESD 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. The specifications for the AC Battery PQ2000 System Electronic Selector Device are:

(a) 2500 A, 480 V, 3-phase, 3 wire plus ground

(b) 2 source inputs: (1) utility supply; (2) PQ2000 System Container

(c) Sense and transfer in 1/2 cycle or less

(d) Fiber-optic interface to PQ2000 Master Control

(e) Manual and automatic bypass modes

(f) Automatic restart

(g) Silicon Controlled Rectifiers (SCRs) rated to 110%

(h) Overtemperature and overcurrent protection

(i) NEMA 3R (outdoor) enclosure

An RMS voltage sensing algorithm is factory programmed into the PQ2000 System ESD and is not field adjustable. When a disturbance has occurred, the ESD will transfer the critical load to the PQ2000 System if the *PQ Ready* control signal from the PQ2000 Master Control is present. Switching criteria is listed below.

(a) Ramp-up time from Standby to Full Load: .... ≤ 2.5 ms

(b) Synchronization:
1. Slip frequency matching .... 0.1 Hz or less
2. Voltage matching .... ± 10% or less
3. Phase angle acceptance .... ± 5 degrees or less

(c) Transfer time to return to utility supply .... 2 seconds (out of synchronization)
0.2 seconds .... (synchronized)

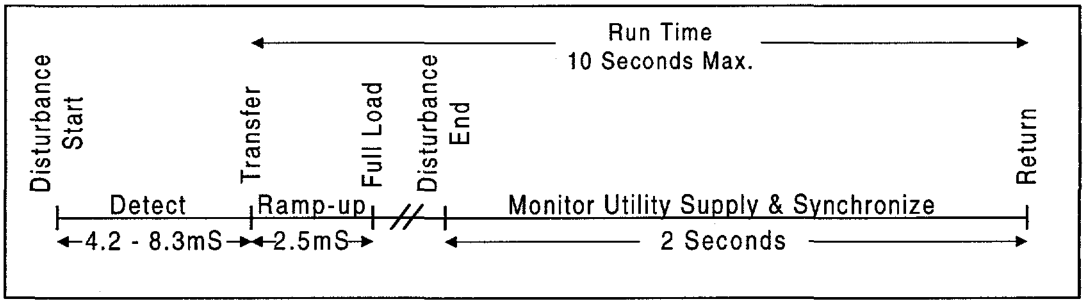


Figure 18. Original ESD Sensing and Switching Timing Diagram

2.5. Engine Generator Interface Option

The Cooperative Agreement calls for a system design that will support an engine generator interface as an option. This feature will allow the customer to address disturbances and interruptions lasting longer than 10 seconds in duration.

When a fault or disturbance on the utility occurs, the critical load is transferred to the PQ2000 System as previously described. Two (2) seconds into the disturbance, the PQ2000 Master Control sends a *Run* command (control signal) to the engine generator. A 2-second time delay is used because many faults will clear in that time frame reducing the number of engine generator starts required. In 10 to 15 seconds after the *Run* command, the engine will spin up to speed. Once up to speed, the PQ2000 System will synchronize with the generator output. Once synchronized, the PQ2000 System will match generator voltage and transfer the load to the engine generator. When operating in this mode, the PQ2000 Master Control and ESD Control will be continuously monitoring the utility.

If the PQ2000 System ESD is open for more than two (2) minutes, the ESD Control will open CB1 to isolate any possibility of feeding power from the diesel generator into the utility supply. When the ESD Control senses that the utility supply has returned to nominal, the ESD Control will send a control signal to the PQ2000 Master Control to synchronize the output of the PQ2000 System to the diesel generator and switch the critical load back to the PQ2000 System. The PQ2000 Master Control will then synchronize the output of the PQ2000 System with the utility and switch the load back to the utility. Synchronization for transfer back to utility is always controlled by the PQ2000 System Master Control.

2.6. Isolation Transformer Design

The PQ2000 System is designed with a 2 MVA/10 Second, 208/480 VAC, 3 phase isolation transformer to step-up and connect the 208 VAC, 3-phase output from the PQ2000 System Container to the 480 VAC, 3-phase utility supply and critical load. The continuous rating of the isolation transformer is 200 kVA. The transformer was configured with a Wye wiring configuration to match the installation requirements of the PG&E Modular Generation Test Facility.

3. COMPONENT PHYSICAL SPECIFICATIONS

3.1. Container Specifications

(a) Size .... 15'L x 7.5'W x 11.1'H

(b) Weight .... 42,000 lbs gross (est.)

(c) Construction .... Welded Structural Frame/Sheet Steel Walls

(d) Subframe .... Suitable for Transportation by Truck

(e) Access Doors .... Hinged for Battery Installation and Service

(f) Access to HVAC, Power Connections, and
System Control .... Hinged Doors and Removable Panels

(g) Exterior Surfaces.. Vandal Resistant

(h) Finish .... White Enamel Interior with Ultraviolet Resistant Exterior

(i) Shock and Vibration Resistance .... to 5 g's

(j) Insulation Factor.. R-4.0

3.2. Module Specifications

(a) Size...56"L x 39"W x 51"H

(b) Weight...3,600 lbs.

(c) Capacity...250 kW/250 kVA

(d) Batteries per module 48

(e) Battery Model...Delco 1150

3.3. Electronic Selector Device Specifications

(a) Size... 12'L x 5.2'W x 7.5'H

(b) Weight...9000 lbs (est.)

3.4. Isolation Transformer Specifications

(a) Size...36"L x 36"W x 53"H

(b) Weight... 2400 lbs gross (est.)

4. SYSTEM OPERATIONAL SPECIFICATIONS

The expected maximum achievable ratings for the PQ2000 System are tabulated as follows:

(a) Maximum kW Output...2000 kW

(b) Maximum kVA Output...2000 kVA

(c) Power Factor Range ....0.7 Lead or Lag to Unity

(d) Maximum Duration of Consecutive Discharges w/o Recharge............. 10 Seconds

(e) Recharge Time to 90% State of Charge (SOC) 10 sec. discharge .... 30 min.

(f) Recharge Time to 100% SOC (from 90%) for 10 sec. discharge .... 1 Hour

(g) Operating Voltage Range... 480 VAC_{rms} ± 10%

(h) Maximum PQ2000 Output V_{THD} .... Under 5% for Load I_{THD} ≤ 20%

(i) Maximum PQ2000 Output I_{THD}...N/A - Voltage Source

(j) Maximum AC Current .... 3403 A_{peak}

(k) Maximum Current Imbalance 30%

(l) PQ2000 Module Overvoltage Trip ....790 VDC

(m) PQ2000 Module Maximum DC Equalization Voltage...................................770 VDC

(n) PQ2000 Module Maximum DC Charge Voltage..750 VDC

(o) PQ2000 Module Nominal Battery Voltage .... 576 VDC

(p) PQ2000 Module Minimum Battery Voltage .... 360 VDC

(q) PQ2000 Module Under-Voltage Trip .... 360 VDC

(r) PQ2000 Module Nominal DC Current
with 2 MW Load .... 765 ADC @ 408 VDC

(s) PQ2000 Module Maximum DC Current
with 2 MW Load .... 868 ADC @ 360 VDC

5. SYSTEM AUXILIARY LOADS and LOSSES

PQ2000 System auxiliary equipment loads are listed as follows:

5.1. System Container Component Loads

Qty	Description	Rated Load (watts)
4	Air Conditioners	2200/ea.
1	Heater	6000
1	H2 Sensor	6
1	H2 Blower	40
1	Air Curtain	125
2	Lights on Switches	100/ea.
4	Auxiliary Power Outlets	600/ea.
1	Auxiliary Power to PQ2000 Modules (8)	200
1	PQ2000 System Monitoring Computer	200
1	Control Power plus Other Misc. Loads	3000

5.2. ESD Component Loads

Qty	Description	Rated Load (watts)
1	Control Power	500
1	Blowers	960
2	Air Conditioners	2280/ea.

5.3. Expected System Losses

Qty	Description	Loss
1	Electronic Selector Device (ESD) (continuous)	1%
1	Capacitor Bank (non-continuous)	150 watts
1	Power Conversion System (PCS) (non-continuous)	10%
1	Isolation Transformer, Wire plus Other Misc. (non-continuous)	10%

Note: Maximum continuous loss of the PQ2000 System is expected to be less than 33 kW (20 kW for the ESD plus and another 13 kW for parasitic losses attributed to the container operating system and auxiliary loads.)

6. SYSTEM OPERATION

6.1. ESD Sensing

Setpoints for switching from utility to stored battery energy was based upon the upper and lower limits defined by the Computer Business Equipment Manufacturers Association (CBEMA). A graph of the selected setpoints is provided illustrating the recommended guidelines for process controller power supply design for voltage supply sensitivity. Overlaid on the upper and lower limits for Type 1 and Type 2 Process Controllers are the setpoints for the PQ2000 System ESD.

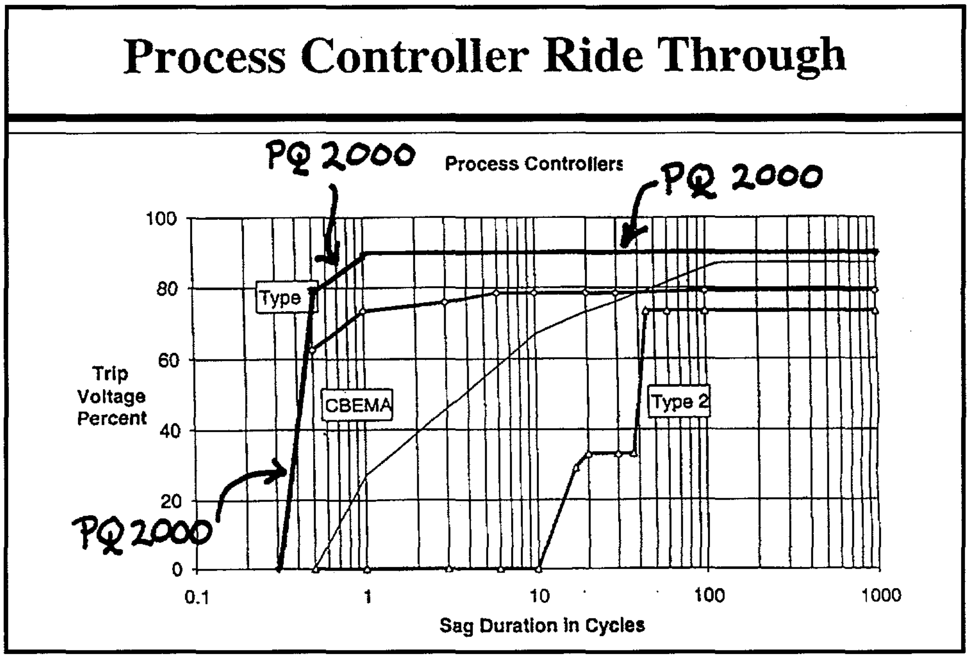


Figure 19. ESD Setpoints Mapped over CBEMA
Guidelines for Process Controller Power Supplies

The ESD senses the phase-to-phase voltage from the A to B and B to C and compares the expected voltage against a template value in a lookup table. Voltage measurements are made approximately 80 times a cycle. The ESD tracks the measured values and stores a moving window of values. If the measured voltage does not match the expected value within a small tolerance for the length of the cycle window, the ESD interprets the information as a voltage disturbance and switches the connected critical loads to battery power. Phase detection is also sensed by the ESD. Phase synchronization is coordinated by the ESD control computer before retransferring the load back to utility power.

6.2. ESD Control

A simplified block diagram of the PQ2000 is provided for the reader in Appendix A of this document. In normal operation, the ESD input circuit breaker CB1 and output circuit breaker CB2 are closed, and the bypass circuit breaker CB3 is open. While the utility is operating within its normal acceptable range, the critical load is supplied by the utility through CB1, the ESD, and CB2. The PQ2000 Master Control and ESD Control are constantly monitoring the utility supply voltage and load current.

When a line disturbance is detected on the utility, the ESD Control will transfer the critical load from the utility to the PQ2000 System provided the PQ2000 Master Control is sending a *PQ Ready* control signal to the ESD Control at the time of the line disturbance. The PQ2000 Master Control will not transmit a *PQ Ready* signal if any of the following fault conditions are present:

(a) load overcurrent,
(b) smoke/fire,
(c) disable operate,
(d) cleared capacitor bank fuses,
(e) hydrogen, or
(f) voltage regulator fault.

While the PQ2000 System is operating and supplying the critical load, it will operate at the utility frequency last monitored before the disturbance. The PQ2000 Master Control and ESD Control continuously monitor the utility to detect when the disturbance has cleared. When the utility is within normal tolerance and synchronized for 2 seconds, the ESD Control then removes the *PQ Run* signal and reconnects the critical load to the utility. If the utility returns out of phase with the PQ2000 System, the PQ2000 Master Control will first synchronize the output of the PQ2000 System before sending a *PQ Synchronized* signal to the ESD Control to transfer the load back to the utility supply.

If the utility supply does not return to nominal within the 10 second discharge operating time limit for the PQ2000 System, or the PQ2000 System has expended its available charge because of discharging to service subsequent events, or has reached a system thermal operating limit, the PQ2000 System will shutdown to protect its components. The PQ2000 Master Control will remove its *PQ Ready* control signal to the ESD Control signaling that it should transfer the critical load back to the utility supply from the PQ2000 System.

An option considered for future development at the time of development but not included here is the capability to operate in conjunction with an engine generator to allow servicing interruptions longer than 10 seconds in duration. Termination bus bars for connection to an engine generator are provided in the ESD. ESD Control outputs and software programming are not part of this contract.

7. FACTORY TESTING

Prior to initiation of any major component testing, individual components and subassemblies were visually checked and tested against a pre-established test card profile. The results were verified and recorded. Any engineering modifications required to certify compliance with design specifications were completed prior initiation of major component testing and load testing of the completed system. A list of test categories for the three major component assemblies is provided below. Overall system testing was completed in early 1996 and a final PQ2000 Factory Test Report completed March 12, 1996. Transfer of ownership of title for the PQ2000 prototype system occurred upon on PG&E's written acceptance upon completion of factory testing. Detailed results of factory testing are the domain of AC Battery Corporation and PG&E—owner of the system hardware. Certification of compliance to original design specifications is provided in this document to meet the requirements of deliverables as stated in the Cooperative Agreement.

Factory system testing of the PQ2000 prototype was conducted on a reduced load basis utilizing a resistive load bank rated 300 kVA. An electrical diagram of the test setup is included in the Appendix. Additional dynamic testing of the PQ2000 prototype will be conducted at PG&E's MGTF. That testing will include full load testing with passive resistive and reactive loads, resistive and rotating machine loads, ASD, resistive and various single phase and electronic loads. Extended field testing and long-term monitoring of system performance is not included here as it is beyond the scope of the deliverables under the Cooperative Agreement.

7.1. Electronic Selector Device Tests

(a) visual inspection for proper power, input, output and control wiring against certified assembly drawings

(b) visual inspection for foreign material

(c) DC Hi-Pot testing of all three phases to ground

(d) high current limit testing of SCRs

(e) input/output phase verification

(f) fiber optic communications and control function

(g) power verification and heat run testing under load

(h) enclosure temperature regulation function

(i) system alarm sensing and automatic component failure detection

(j) V-detect alignment for phase detection, timer and trip settings

(k) proper control, auto restart and transfer function

7.2. Isolation Transformer

(a) visual inspection

(b) polarity verification

(c) resistance to ground

(d) hi-pot tests

(e) turns-ratio testing (no load)

(f) voltage and current testing under load

7.3. Main System Container

7.3.1. Battery Modules

(a) visual inspection for proper power, input, output and control wiring against certified assembly drawings

(b) DC hi-pot tests and capacitor voltage sharing/leakage

(c) fiber optic communications interface, control signal functionality

(d) IGBT (inverter) switching

(e) battery charging, battery charger operation and software algorithm functionality

(f) voltage and current regulation

7.3.2. System Control

(a) master control computer

(b) fiber optics communications interface

(c) analog and utility interface through Electronic Selector Device

(d) voltage and current regulation

(e) capacitor bank fuse detector clearing

(f) software self-diagnostics

(g) alarm warning and logging function

(h) remote data acquisition and telemetry and auto-paging function

(i) operator monitoring computer interface

7.3.3. Auxiliary Subsystems

(a) hydrogen detection system

(b) smoke detection system

(c) enclosure HVAC temperature control

7.4. System Discharge Testing

(a) utility voltage sensing

(b) disturbance detection

(c) transfer switching

(d) synchronization for return to utility

(e) heat run testing under partial load

(f) battery recharge performance

(g) alarm detection and warning

(h) automatic shutdown and restart function

(i) multiple discharge runs under varying loads, conditions and discharge durations

7.5. Test Results Summary

The PQ2000 has demonstrated its ability to effectively detect and eliminate voltage sags, swells and momentary outages. As utility service voltage exceeds a deviation threshold limit, the system's Electronic Selector Device (ESD) executes the transfer to battery power. As illustrated by Figure 20, the PQ2000 is capable of switching to stored battery energy in approximately 1/4 cycle. The top waveform displays the recorded voltage between the A and B phases of the customer's electrical load. Sensing and transfer time is measured at 3.8 ms. The bottom waveform shows the recorded voltage and momentary outage that has occurred on the utility supply line. The time to ramp the output load voltage up to the expected utility supply voltage was measured at 1.6 ms.—making the total event 5.4 ms. in duration or 1/240th of a second.

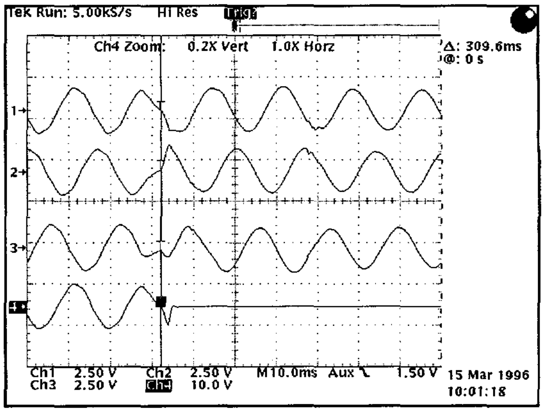


Figure 20. Voltage Interruption on One Phase of the Utility and Load Pickup by the PQ2000

Transfer back to utility power, illustrated by Figure 21, occurs after the disturbance has cleared and the system has synchronized phase with the utility. A 2 second delay before switching back to utility service is incorporated into the system's control program to prevent excessive transfer oscillation between the utility and battery power. If the disturbance has not cleared after 10 seconds, the system will shutdown or execute a transfer of the critical load to a standby engine generator, if that option has been specified.

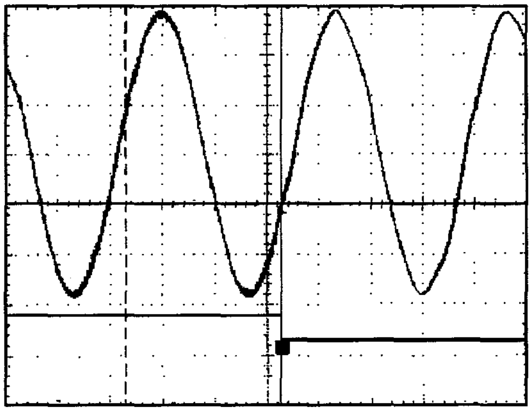


Figure 21. Synchronous Transfer Back to the Utility

The current system has been validated for 10 seconds of continuous or cumulative cycle runtime without a complementary recharge. Calculations and testing show that a 10 second discharge of the battery at the full rated output of the PQ2000 consumes less than 4% of its charge. The high power, short duration discharge capability of the Delco 1150 battery make it highly suitable for the PQ2000 application.

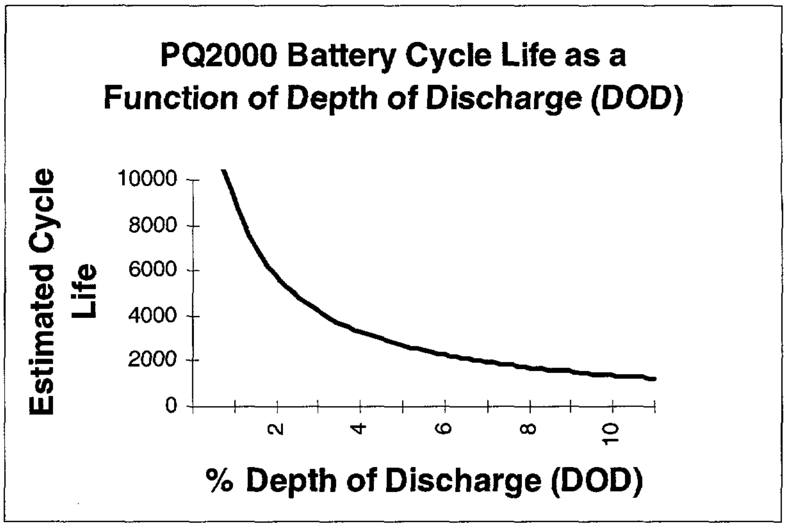


Figure 22. Battery Cycle Life Plotted as a Function of Depth of Discharge

Figure 22 shows estimated battery cycle life as a function of depth of discharge. Given the application, duration, and expected frequency of voltage sags and momentary outages in real world applications, the Delco 1150 is expected to provide in excess of 3000 cycles over an expected life of more than 5 years. Limiting discharge time to 10 seconds balances depth of discharge with cycle life expectations and thermal load limits of the system. The 10 second limit more than matches the application requirements while substantially improving battery cycle life and discharge performance.

A battery recharge cycle is initiated immediately after each discharge event. Battery modules are simultaneously but independently recharged using the proprietary algorithm designed specifically to maximize charge cycle efficiency for the Delco 1150. Lab tests conducted on individual batteries have shown that battery cycle life nearly doubled as a result of using the new algorithm and contributed substantially to eliminating electrolyte stratification.

A major factor governing battery recharge time is depth of discharge. Each second of discharge at 720 amps requires approximately 2 1/4 minutes of recharge to restore the battery to 90% of its predischarge potential. Up to one additional hour is needed to restore the remaining 10% of the battery's potential for a continuous, full 10 second discharge. Recharging may, however, be interrupted by a requirement to service another disturbance.

8. SUMMARY AND CONCLUSIONS

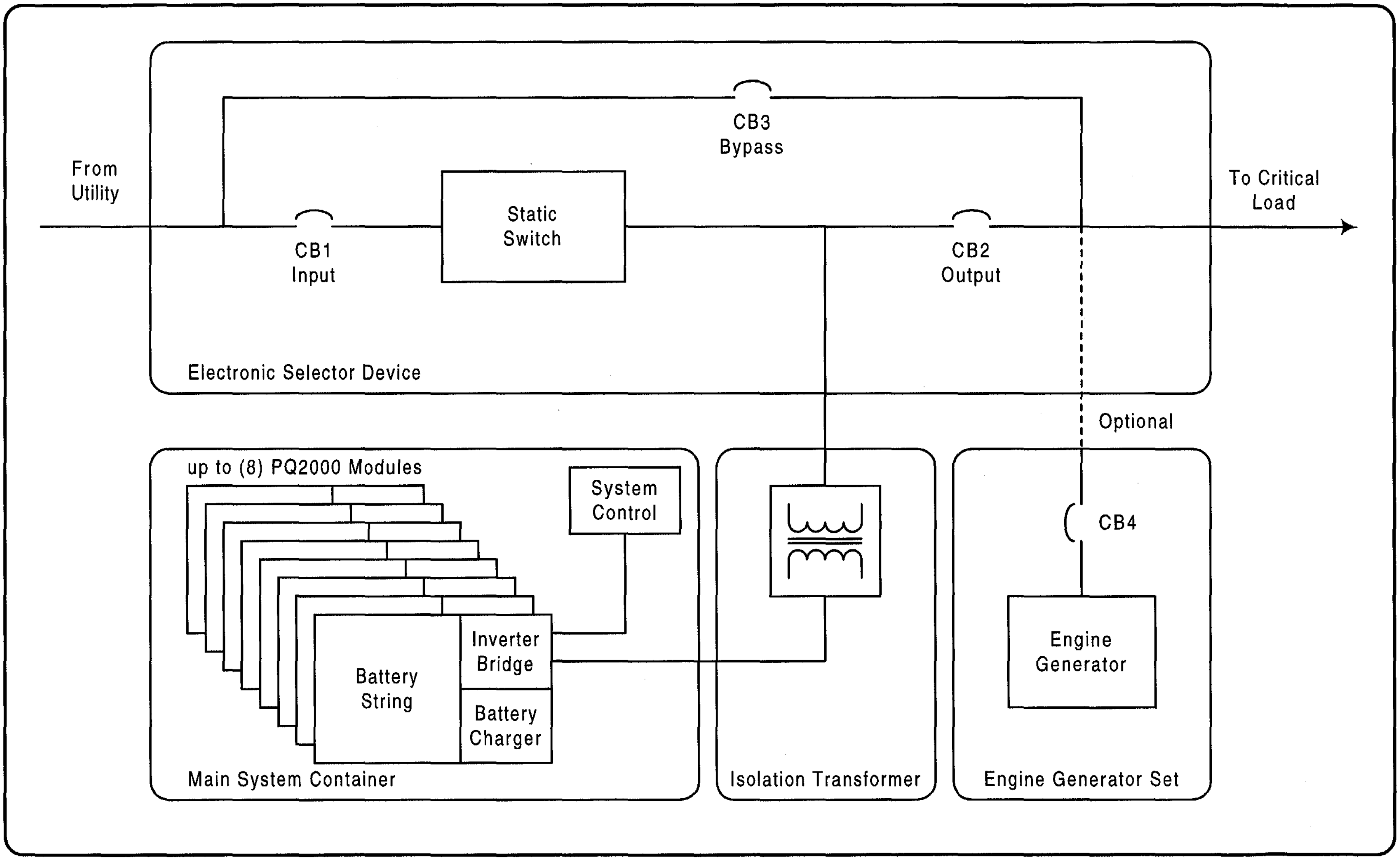
Based on the initial design specifications outlined at the outset of the project, factory testing of the PQ2000 Power Quality System is considered a success. The PQ2000 demonstrated that it has met the project functional design objectives while incorporating all the outlined engineering mechanical design characteristics previously delineated. The next step in the commercialization of the PQ2000 Power Quality System is to conduct extensive field testing and long-term monitoring of the system at PG&E's MGTF, evaluate the PQ2000's performance in light of the dynamic tests subjecting the system to real world disturbance conditions that could not be duplicated or created at the factory and making whatever design and control adjustments are necessary to mitigate voltage sags, swells and momentary interruptions in severe operating environments.

The use of a high production volume, flooded, lead-acid battery in the AC Battery PQ2000 is proving to be a cost effective solution for eliminating momentary voltage sags, swells and interruptions. The fully integrated battery energy storage technology of the PQ2000 provides convincing evidence that the flooded, lead acid battery can effectively protect critical loads from power disturbances. The high cost of production losses and lost productivity resulting from power disturbances provide incentive and justification for its use.

The microprocessor based control and advanced IGBT (Insulated Gate Bipolar Transistor) technology used for switching and power conversion permit high switching frequencies that yield higher efficiency with low output distortion.

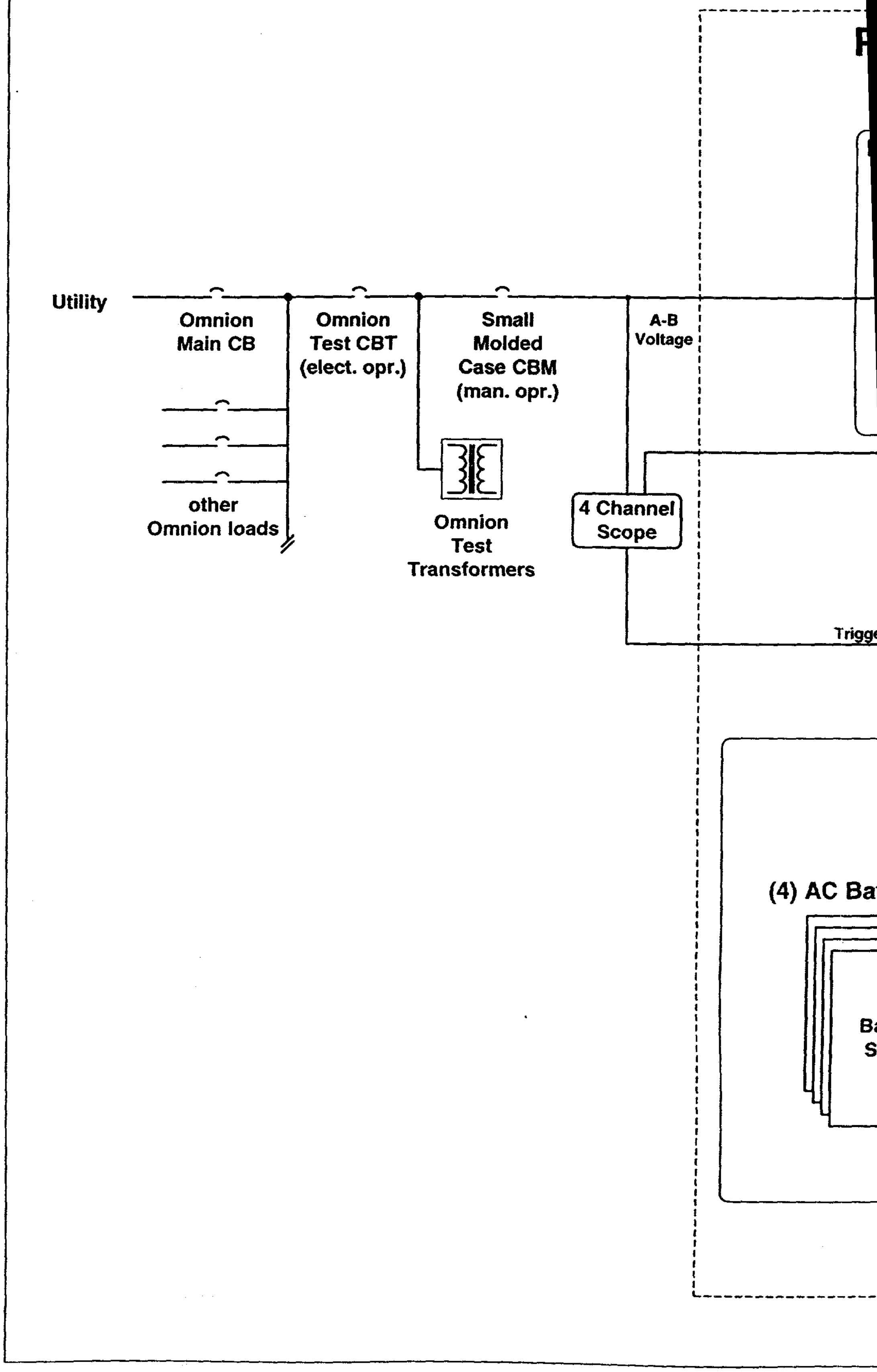
The PQ2000 utilizes proven technology and highly reliable commercially available components. Indications from the market are that the PQ2000 is a cost effective, commercially viable energy storage method. The system features less than 1% continuous operating loss, and less than 20 kW of intermittent operating subsystem parasitic loss. Little annual maintenance is projected and the unit is expected to have a very competitive total life-cycle cost.

The design configuration of the PQ2000 possesses several significant competitive features not characteristic of conventional battery systems and other competing technologies. The design utilizes mature technology and high volume production components to reduce component lead time and cost while improving system reliability and lowering project risk. It offers high power with extended ride-through including the ability to bridge successive recloser operations—outperforming competing technologies. The standby design of the PQ2000 effectively isolates batteries from the detrimental effects of continuous DC ripple charging, does not require watering and agitation of the batteries, can be located outside in a relatively compact area. The system design features excellent recharge capability and extended battery cycle life. Low parasitic operating losses coupled with a highly efficient static switch gives the PQ2000 a comparatively low economic life cycle cost. The PQ2000 is demonstrating that a factory assembled and tested battery system can improve product quality while reducing installation time and cost. It's compact, highly transportable outdoor enclosure significantly adds to siting flexibility and broadens the scope of battery energy storage.

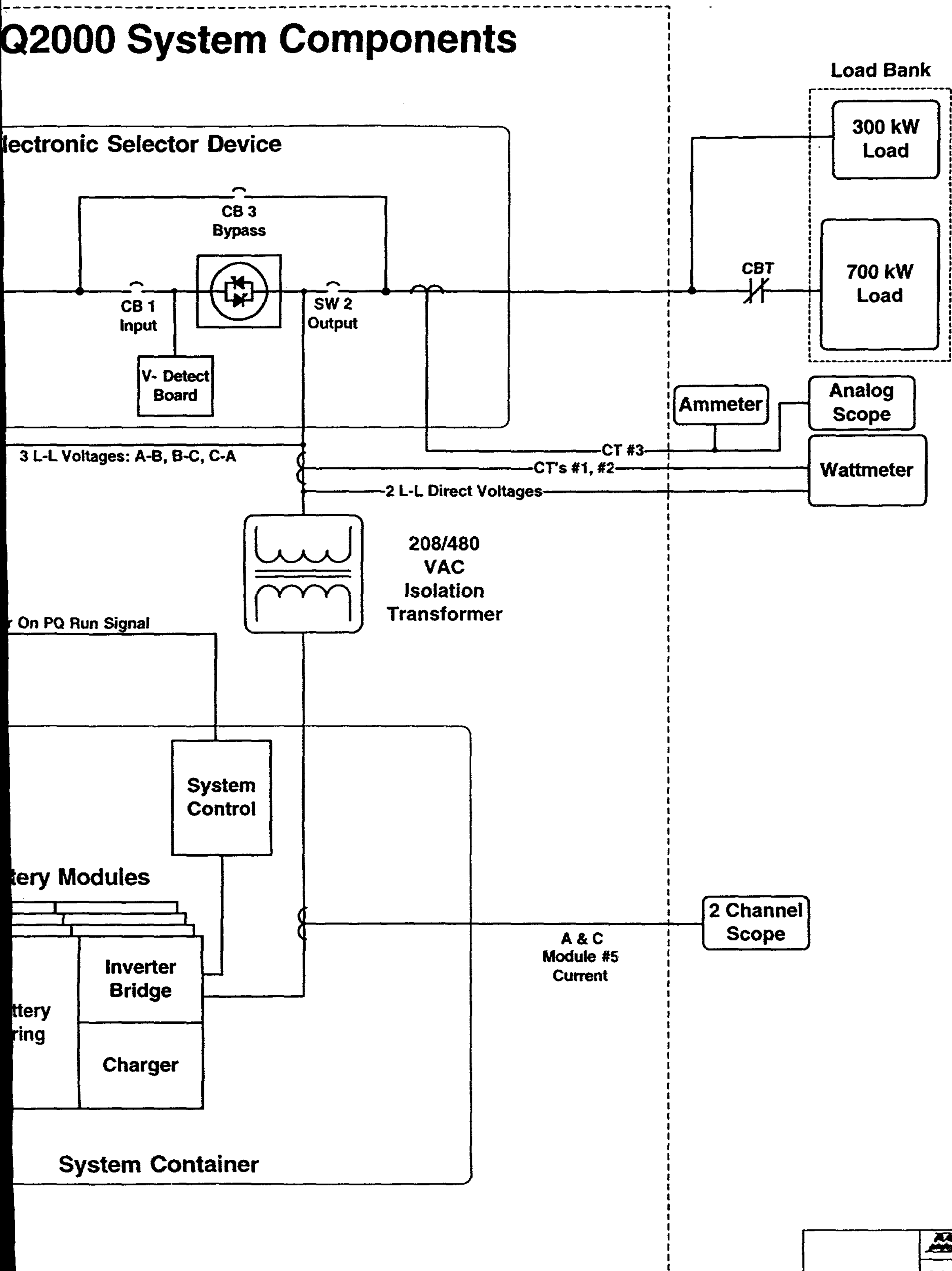


AC battery	AC Battery Corporation Subsidiary of General Motors East Troy, WI 53120		
Scale:	Date: Aug. 28, 1995	Drawn by: WN	
Title: PQ2000 One-Line Block Diagram			
Page: Sheet 1 of 1	Dwg. No. NONE	Rev: 1	

PQ2000 Sy


Utility
Omnion
Main CB
Omnion
Test CBT
(elect. opr.)
Small
Molded
Case CBM
(man. opr.)
A-B
Voltage
other
Omnion loads
Omnion
Test
Transformers
4 Channel
Scope

stem Test Setup One-Line

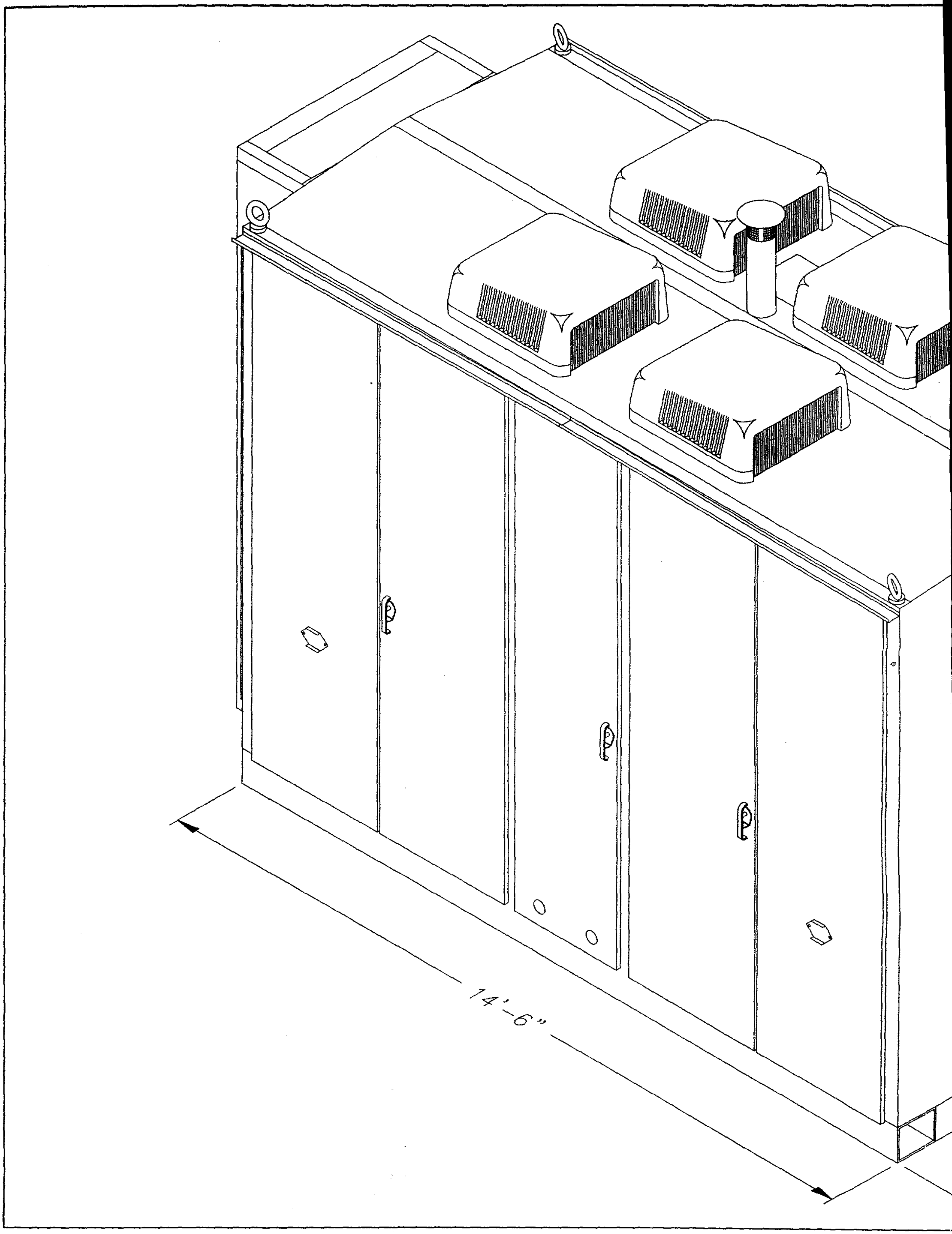


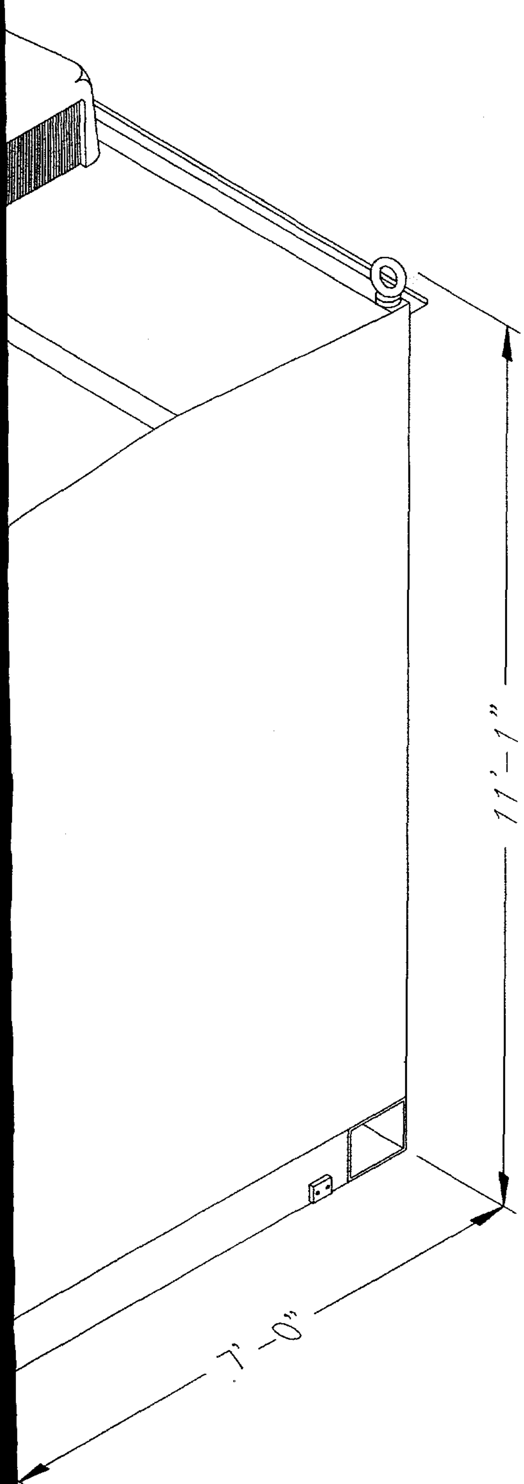
AC Battery Corporation

PQ2000 System Test Setup Drawing
for Factory Acceptance Testing

FILENAME: PQ-TEST.VSD

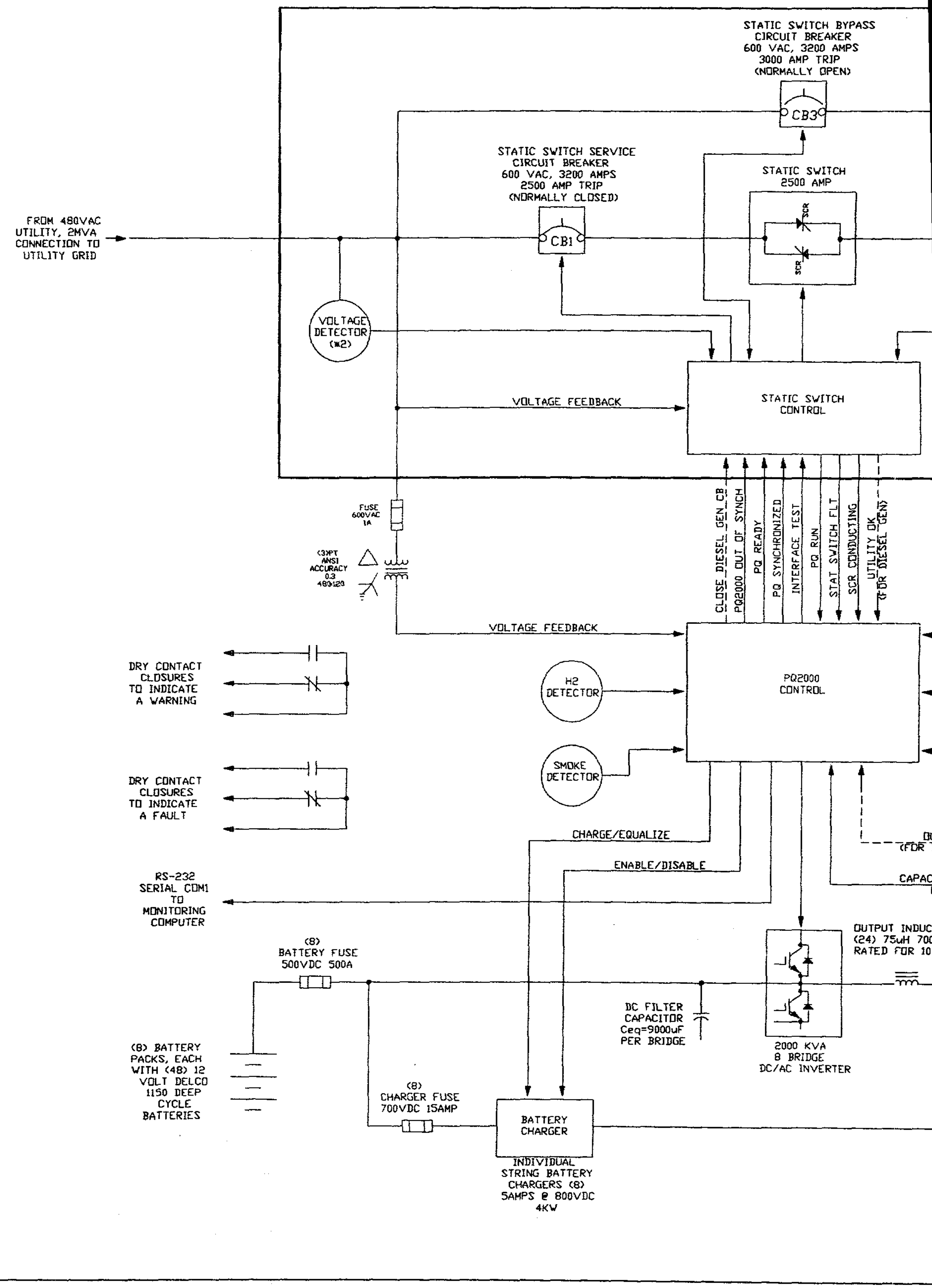
SHEET 1 OF 1

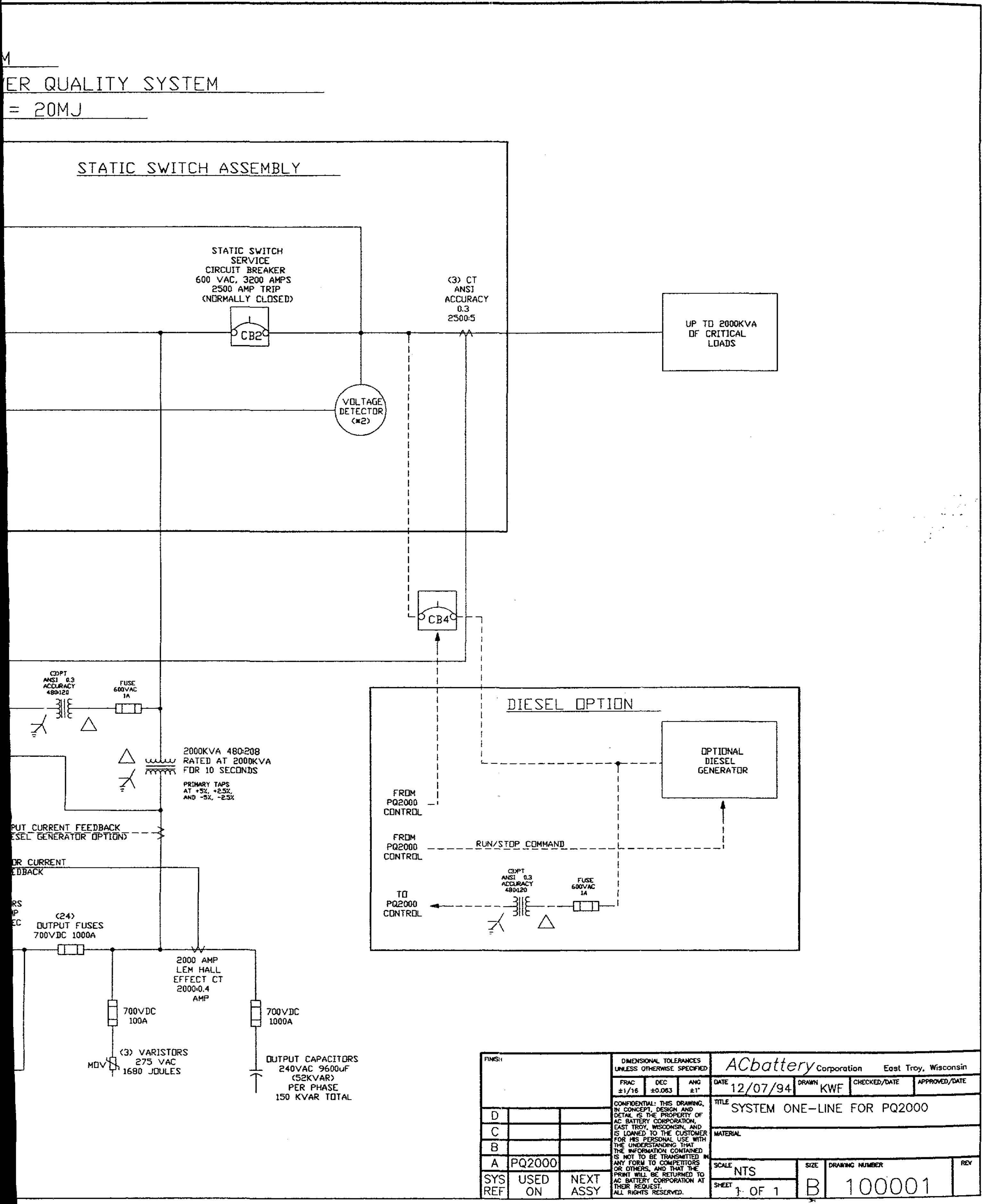

14'-6"



FINISH			DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED FRAC ±1/16 · DEC ±0.063 · ANG ±1°	ACbattery Corporation · East Troy, Wisconsin DATE 01/03/95 · DRAWN KWF · CHECKED/DATE · APPROVED/DATE
D				TITLE SYSTEM CONTAINER FOR PQ2000
C				MATERIAL
B				
A	PQ2000			SCALE NTS · SIZE B · DRAWING NUMBER 100002 · REV
SYS REF	USED ON	NEXT ASSY		SHEET 1 OF 1

ONE-LINE DIAGRA
PQ2000 AC BATTERY 2MVA PO
2MW FOR 10 SECONDS




M
ER QUALITY SYSTEM
= 20MJ
STATIC SWITCH ASSEMBLY
STATIC SWITCH SERVICE CIRCUIT BREAKER 600 VAC, 3200 AMPS 2500 AMP TRIP (NORMALLY CLOSED)
CB2
(3) CT ANSI ACCURACY 0.3 2500:5
UP TO 2000KVA OF CRITICAL LOADS
VOLTAGE DETECTOR (*2)
CB4
(3)PT ANSI 0.3 ACCURACY 480:120
FUSE 600VAC 1A
2000KVA 480:208 RATED AT 2000KVA FOR 10 SECONDS
PRIMARY TAPS AT +5%, +2.5%, AND -5%, -2.5%
PUT CURRENT FEEDBACK
ESEL GENERATOR OPTION)
OR CURRENT
EDBACK
RS
P
EC
(24) OUTPUT FUSES 700VDC 1000A
2000 AMP LEM HALL EFFECT CT 2000:0.4 AMP
700VDC 100A
700VDC 1000A
(3) VARISTORS 275 VAC 1680 JOULES
MOV
OUTPUT CAPACITORS 240VAC 9600uF (52KVAR) PER PHASE 150 KVAR TOTAL
DIESEL OPTION
OPTIONAL DIESEL GENERATOR
FROM PQ2000 CONTROL
FROM PQ2000 CONTROL
RUN/STOP COMMAND
TO PQ2000 CONTROL
FINISH
DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED
FRAC ±1/16
DEC ±0.063
ANG ±1°
CONFIDENTIAL: THIS DRAWING, IN CONCEPT, DESIGN AND DETAIL IS THE PROPERTY OF AC BATTERY CORPORATION, EAST TROY, WISCONSIN, AND IS LOANED TO THE CUSTOMER FOR HIS PERSONAL USE WITH THE UNDERSTANDING THAT THE INFORMATION CONTAINED IS NOT TO BE TRANSMITTED IN ANY FORM TO COMPETITORS OR OTHERS, AND THAT THE PRINT WILL BE RETURNED TO AC BATTERY CORPORATION AT THEIR REQUEST. ALL RIGHTS RESERVED.
ACbattery Corporation East Troy, Wisconsin
DATE 12/07/94
DRAWN KWF
CHECKED/DATE
APPROVED/DATE
TITLE SYSTEM ONE-LINE FOR PQ2000
MATERIAL
D
C
B
A PQ2000
SYS REF
USED ON
NEXT ASSY
SCALE NTS
SIZE B
DRAWING NUMBER 100001
REV
SHEET 1 OF 1