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Three-Phase Power Conversion System for Utility-Interconnected PV Applications

Phase I Technical Progress Report, 1 October 1995 - 17 April 1997

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East Troy, Wisconsin

National Renewable Energy Laboratory
1617 Cole Boulevard
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A national laboratory of
the U.S. Department of Energy
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PREFACE

This is the Annual Report on technical progress for Phase I of a two-phase effort to make advancement in three major areas of Three-phase utility interconnected, photovoltaic power conversion: cost, reliability, and performance. It summarizes work performed from October 1, 1995 to April 17, 1997 under DOE/NREL subcontract #ZAF-5-14271-02.

The following personnel at Omnion have contributed to the efforts covered in this report.

David Porter	Hans Meyer	William Leang	Kevin Dennis
Peter Keck	Jeff Cutberth	Candace Porter	Robert Massey
Deanna Tracy	Mark Haug		

In addition, Omnion has been supported by the following personnel from SST.

Depak Divan	Trevor Grant	Ian Wallace	Glen Luckjiff
Robert Schneider	Nasser Kutkut		

Support was also received from Wayne Hunnicutt, Mechanical Engineer.

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SUMMARY

Omnion Power Engineering Corporation (Omnion) has completed Phase I of a two-phase sub-contract under the auspices of the U.S. DOE PVMaT project.

The objective of this contract is to make advancements in three major areas of three-phase utility interconnected, photovoltaic power conversion: cost, reliability, and performance. The total manufacturing cost of a nominal 100-kilowatt power conversion system (PCS) will be reduced from approximately $0.50/watt to $0.25/watt when built in production lots of 100 units. A design goal of 40,000 hours mean time between failures (MTBF) has been established for this development. Using soft-switching technology, three performance goals have been established to 1) improve converter efficiency from 95.5% to 96.5%, 2) meet FCC regulations for conducted and radiated electromagnetic interference, and 3) reduce audible noise to below 60 decibels.

Under Phase I, the following was accomplished:

- An advanced product specification was drafted to guide prototype design and development.
- Field failure data with Omnion's hard-switched IGBT technology hardware was analyzed to better understand where design improvements were needed.
- Product specifications were presented and reviewed with key customers/users.
- A working product specification was drafted to serve as a baseline in the development of the new power conversion system.
- The core resonant converter technology was developed in conjunction with Soft Switching Technologies Corp. (SST).
- A 100-kilowatt prototype power conversion system was designed.
- A prototype system package was designed.
- Interaction with vendors to optimize component selection and specifications was initiated.
- Preparation of design documentation was initiated.
- The prototype core resonant converter was built, and preliminary testing was initiated.
- Assembly of a 100-kilowatt prototype power conversion system was initiated.

These accomplishments will provide the framework for the completion of Phase I, and the smooth transition into Phase II of the contract.

The work undertaken in Phase I has demonstrated the potential of the soft switching resonant DC link (RDCL) inverter and its application to three-phase utility interconnected photovoltaic power conversion system. The RDCL inverter has demonstrated its advantage over hard switching PWM inverters in terms of efficiency and audible noise. With proper package design and manufacturing process design and implementation, the RDCL power conversion system has the potential to be low cost, reliable, and with superior performance.

1.0 INTRODUCTION

1.1 Background and Goals

This Phase I Technical Progress report covers the work performed by Omnion Power Engineering Corporation (Omnion) for the period October 1, 1995 to March 31, 1997 under DOE/NREL Subcontract ZAF-5-14271-02 entitled "Three-Phase Power Conversion System for Utility Interconnected PV Applications".

The goal of the Omnion contract is to make advancements in three major areas of three-phase utility interconnected photovoltaic power conversion: cost, reliability, and performance. In keeping with this goal, Omnion will:

1) Improve its power conversion system manufacturing processes. This will be accomplished by facilitating the flow of materials and components to the assembly line, incorporating jigs and fixtures to ease product handling and implementing semi-automated product testing. The concept of using production cells will be investigated and adopted as appropriate. These improvements address reliability, efficiency, electromagnetic interference and audible noise.

2) Reduce manufacturing cost. This will be accomplished by refining product specifications in conjunction with its customers, designing a standard "point design" product, and careful packaging engineering.

3) Lay the groundwork for increased production. This will be accomplished by minimizing production labor content, automating test functions, and instituting manufacturing processes to minimize material handling.

Under this effort. Omnion will make significant improvements in cost, reliability and performance of its power conversion products representing a very high return on investment in this work. Omnion will also work toward PVMaT goals of developing quality assurance and Environmental Safety and Health programs.

1.2 Task Descriptions

The contract consists of two one-year phases. During the first phase, Omnion will develop the specifications, then design and build a prototype 100-kilowatt, three-phase power conversion system (PCS), tentatively called the Series 3400. Also during Phase I, this PCS will be tested and product specifications finalized. These developments will be conducted in three tasks, described below.

Task 1 – Specification Development
Under this task. Omnion will prepare an advanced product specification with input from customers, certification laboratories and other standard-making entities. Field experience gained to date with related products will be analyzed for its relevance to product specifications. The result of this task will be a working advanced product specification to be used as a benchmark during the balance of the development effort.

Task 2 – Prototype Design and Fabrication
Under task 2, Omnion will develop, fabricate, and test a prototype PCS based on the product specification developed in Task 1. This will be accomplished in nine sub-tasks.
The result of this task will be a fully tested and documented advanced PCS.

Task 3 – Customer/User Demonstration and Review
Omnion will demonstrate operation of the prototype to the customer/user group at Omnion's facilities upon completion of factory testing. At the conclusion of the demonstration, all participants will review and critique the baseline product specification developed in Task 1. The result of this task will be an informed customer/user group and a list of possible areas for improvement.

In Phase II, Omnion will finalize the revised and repackaged design for the 100-kilowatt PCS product. Omnion will also conduct tests on modified manufacturing equipment, and conduct a pre-production run of the prototype Series 3400 100-kilowatt, three-phase PCS.
At the conclusion of Phase II, Omnion will have a production-model power conversion system submitted for UL certification. This PCS will meet the requirements for utility-interconnected PV and offers reduction in costs with improved performance. In addition, Omnion will develop an Operation and Maintenance Manual (O&M) for the new PCS. These developments will be conducted in four tasks, described below.

Task 4 – Preproduction Power Conditioning System Development
Under task 4, Omnion will incorporate changes in Task 3 in the PCS product and specification. The result of this task will be a revised and repackaged design.

Task 5 – Test Procedures and O&M Manual
Under task 5, Omnion will refine product test procedures and draft a comprehensive Operation and Maintenance Manual. The result of this task will be a user-friendly O&M Manual and full product test procedures.

Task 6 – Manufacturing Development
Under task 6, Omnion will design and develop the manufacturing Process for the product, including development of suitable jigs and fixtures for assembly and test. The result of this task will be a documented manufacturing process, including functional supporting manufacturing equipment.

Task 7 – Fabricate and Test Preproduction Model
Under task 7, Omnion will assemble and test two units to verify the design of both the product and the manufacturing process. The result of this task will be a demonstrated 100-kilowatt, three-phase PCS and manufacturing process with final product submitted to a certification entity.

2.0 TASK EFFORTS AND ACTIVITIES

Significant progress has been made in Phase I. Discussion will be focused on the two main tasks of Phase I: specification development and prototype design and fabrication.
The deliverables specified in Phase I have been delivered. Some Phase I deliverables have been included in this report in the figures and Appendix.

2.1 Task 1 Specification Development
The goal of this task is to develop an advanced product specification with input from customers, certification laboratories and other standard-making entities. In the performance of Task 1, Omnion completed the following milestones and deliverables:

m-1.1.2a	Initiated lower-tier subcontract with SST
m-1.1.3a	Complete resonant power module specification in conjunction with SST.
m-1.1.1	Complete development of draft product specifications.
m-1.1.2	Complete failure analysis of all Omnion 3-phase IGBT units deployed since 1990.
m-1.1.3	Complete customer review and comment on draft specifications with eight customers/users.
m.1.1.6	Complete draft working product specifications.
m-1.1.8	Complete Task1.
D-1.1	summary report of field failure experience.
D-1.2	Final draft of product specifications.

A project start-up meeting was held on October 4, 1995 with NREL and Sandia personnel at Omnion's facilities.

Specification for the core resonant converter was developed in conjunction with SST. Product specifications for the PCS were also developed. Representative Omnion product specifications and specifications from recent major procurements (PVUSA, Team-Up, and Sacramento Municipal Utility District (SMUD)) were collected to serve as references. A draft 100-kilowatt PCS specification based on Omnion Series 3200 and 1996 draft Team-Up power conversion specifications was completed in January 1996. Review and comments from the Technical Monitoring Team prior to our presenting this to key customers/users were requested and received.

Review of the product specification with key customers/users was initiated. Omnion sales/marketing and engineering personnel conducted these interviews. To facilitate presenting the design and focusing the reviewer's attention on specific features, three documents were provided to each reviewer: 1) A system one-line drawing (see Figure 1), 2) A system specification (see Appendix A), and 3) A matrix comparing the specification requirements of recent industry procurements (see Appendix B). The specification comparison matrix included the most recent SMUD three-phase specification, the most recent Team-Up specification, Amoco Enron's draft specification and Omnion's single-phase series 2400 product specification. Walking each reviewer through the matrix and referring to the

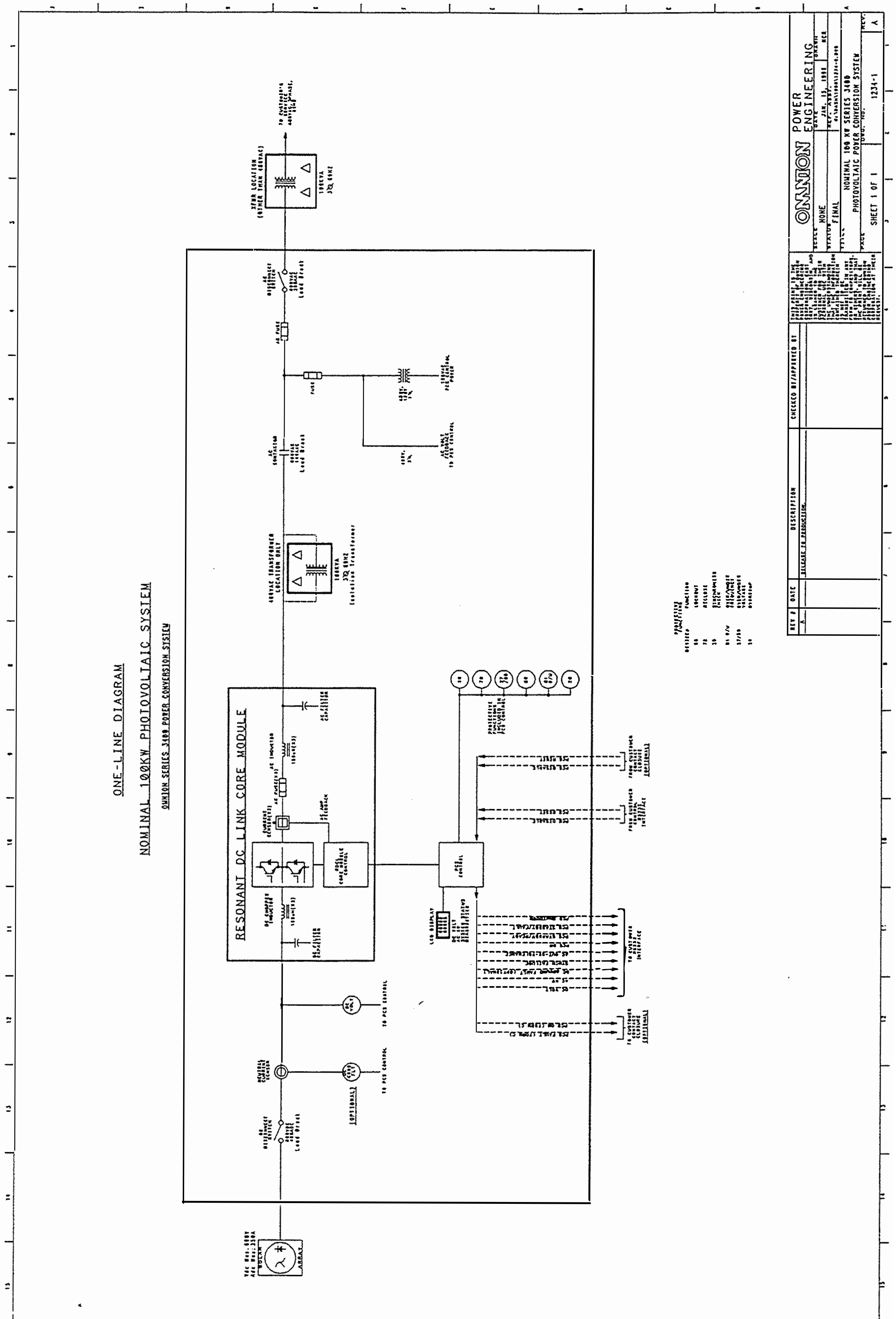

Figure 1: Series 3400 One-line Diagram

one-line diagram or system specification when necessary proved to be an efficient method for obtaining detailed input. Each interview lasted between two and three hours. Comments from each reviewer were shared with the design team. Customer/user feedback (See Appendix C) regarding features and qualities were incorporated in the PCS specification.

A review and analysis of field failures experienced with Omnion's Series 3200 hard-switched IGBT product was initiated in March and completed in June 1996. The analysis showed most failures were due to components and some failures were site related. Recommendations to the design team were to develop a standard product, incorporate into a design that minimizes components and interconnections, and develop better production standards and test plans. Proper identification of past problems was helpful in solidifying the design of the Series 3400 product.

During the month of January 1997, Omnion participated in the UL industry work group to draft the IEEE1741 standard for PV inverters. In addition, Omnion participated in the IEEE work groups of SCC21 and IEEE929. The information gathered at these meetings will be used in conjunction with the customer/users reviews for determining improvements to the product. Omnion will compare the product design with these standards.

2.2 Task 2 Prototype Design and Fabrication

The goal of this task is to develop, fabricate and test a prototype PCS based on the product specification developed in Task 1. The following were accomplished during Task 2:

m-1.2.7a	Demonstrate core module high power operation at SST.
m-1.3.1a	Complete deployment of core module at SST.
m-1.3.2a	Complete prototype power conversion system design.
m-1.2.3	Complete prototype power conversion system packaging.
m-1.3.4a	Complete final bill of material and component specification for prototype.
m-1.3.5a	Complete assembly of 100-kW 3-phase PCS prototype.
D-1.3	Sample photo of prototype system packaging.
D-1.4	Final bill of material.
D-1.8	SST delivers core module to Omnion.

The core resonant converter was developed in conjunction with SST. SST has developed soft switching technologies covered by several issued and pending international patents. The soft switching resonant DC link (RDCL) core module represents the first commercially-viable high-performance inverter which may be a replacement for hard switching PWM inverters. It also solves some problems such as derating at high switching frequency and EMI, that are associated with hard switching PWM inverters. RDCL inverters use IGBT's under zero voltage switching conditions at a link frequency of 70 kHz to realize superior performance than hard switched inverters, and at a price which is competitive with PWM inverters. Unlike in PWM inverters, no derating is required for these high switching frequencies, and higher inverter efficiency is obtained. In sinusoidal output applications, very low voltage THD can be obtained with small output filters. The inverter output also features very low and controlled dv/dt (<500V/μs), and very low EMI on the input and output terminals of the inverter. This offers the possibility of meeting the European IEC 1000 standard on conducted EMI with a significant cost advantage.

A draft Resonant Power Module specification was prepared and forwarded to SST. The draft specification was reviewed in detail with SST personnel and then updated to serve as a working specification. A breadboard core module was designed and tested by SST at full voltage and current in December 1995. SST then shifted their focus to designing of final control boards and the prototype. The core resonant converter printed circuit board features were reviewed SST personnel in January 1996 to confirm adequacy and to assure compatibility with Omnion's master control functions. Particular attention was paid to interface specifications. During the development phase of the core resonant converter, monthly progress review meetings were held with SST personnel.

Midway through the development of the core resonant converter, SST ran into a serious problem with respect to clamp IGBT failure. SST personnel and the device manufacturer were puzzled by the failures since the device appeared to operate within specifications. Efforts to solve this obstacle resulted in a two-month delay in SST's schedule. Core module performance testing remained on hold while the clamp problem was being worked on. The clamp problem was finally solved in May 1996. It appeared that the clamp IGBT failure was due to internal oscillation on the gate. After this obstacle, work at SST progressed normally. A prototype core resonant converter was delivered by SST in September of 1996 (See Figure 2).

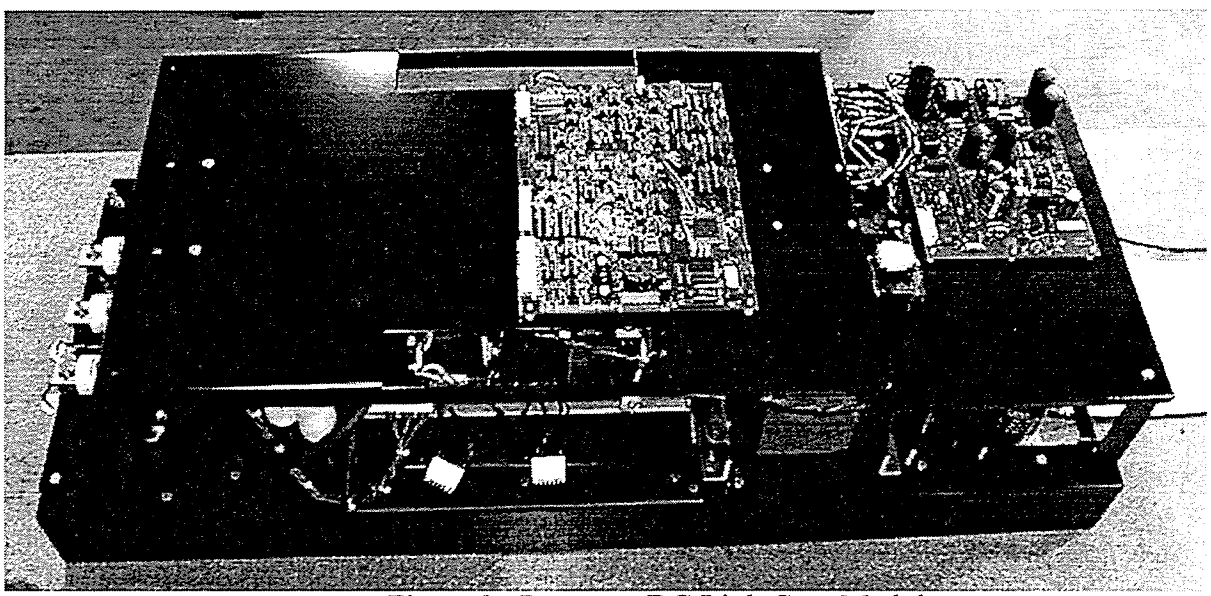

Figure 2. Resonant DC Link Core Module

SST started the development of the DC/DC converter, the "front end" of the core resonant converter, in September 1996. This DC/DC converter is used to step up the photovoltaic array voltage to the level that the core resonant converter needs to produce the appropriate AC voltage to the utility grid. A trade-off analysis was conducted to arrive at the final converter topology and a schedule for fabrication and test was developed. A prototype DC/DC converter is scheduled for delivery to Omnion in April 1997.

Design work was initiated on the Analog Interface printed circuit board in January and completed in December 1996. The prototype Analog Interface Board is shown in Figure 3. This board is used to convert high voltage signals to logic levels for input to the Master Control board. Work was also initiated in January on the system schematic and bill of materials.

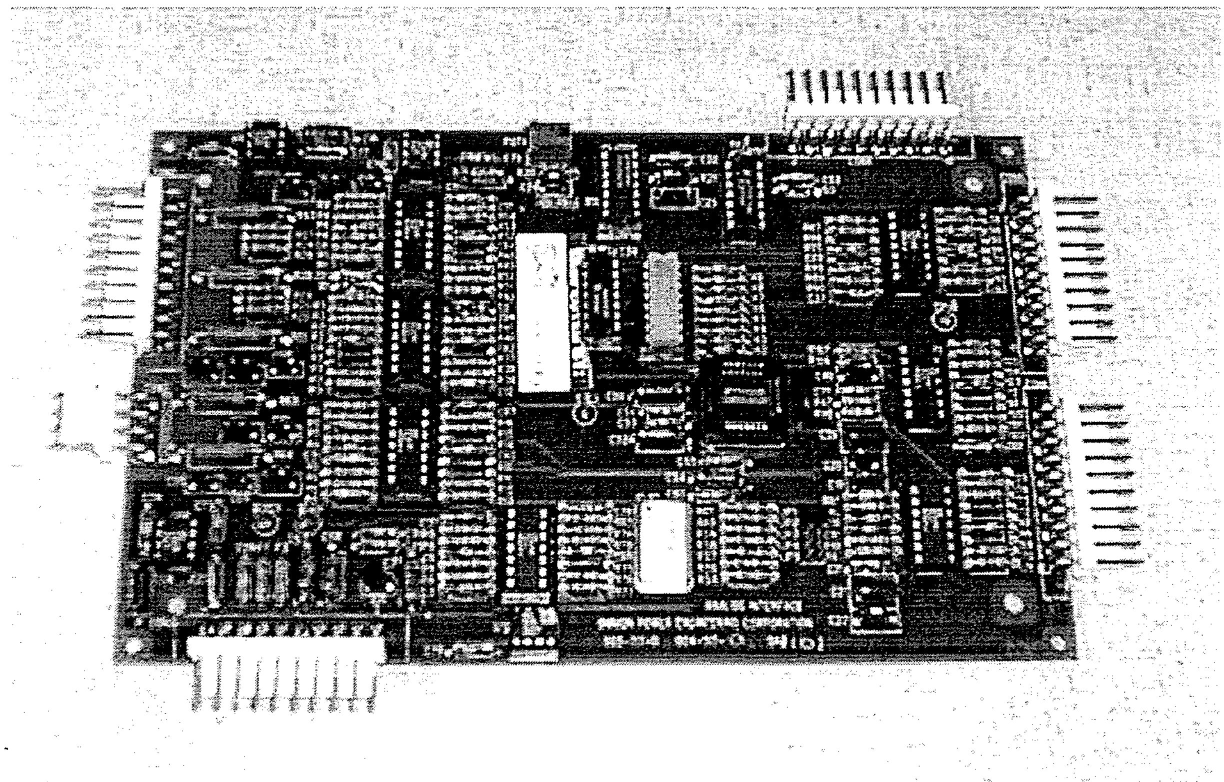

Figure 3. Analog Interface Board

Work on the Master Control printed circuit board was initiated in February and completed in September 1996. The prototype Master Control Board is shown in Figure 4. The Master Control is responsible for overall system control and, specifically, control of the core resonant converter module. Preparation of test procedures for the Master Control printed circuit board was initiated in June. A state diagram was prepared to facilitate writing of the software. Software design was initiated in September.

The prototype bill of material was released by engineering in June. In stock materials were staged while other items were given to purchasing for procurement.

System packaging work was initiated in February 1996. Packaging, control design, and core resonant converter module design are all highly interrelated, and therefore require some level of simultaneous consideration. Progress made at SST on the final packaging of the core resonant converter module enabled Omnion to move forward with system packaging in August. A modular T-slotted aluminum frame system, with aluminum side panels, was selected to readily permit optimization of component location within the enclosure. A preliminary cabinet layout (See Figure 5) was completed in September.

A quality audit on the core resonant converter was conducted by Omnion's quality assurance personnel in September. The report was shared with SST to enable improvements to be implemented on future units.

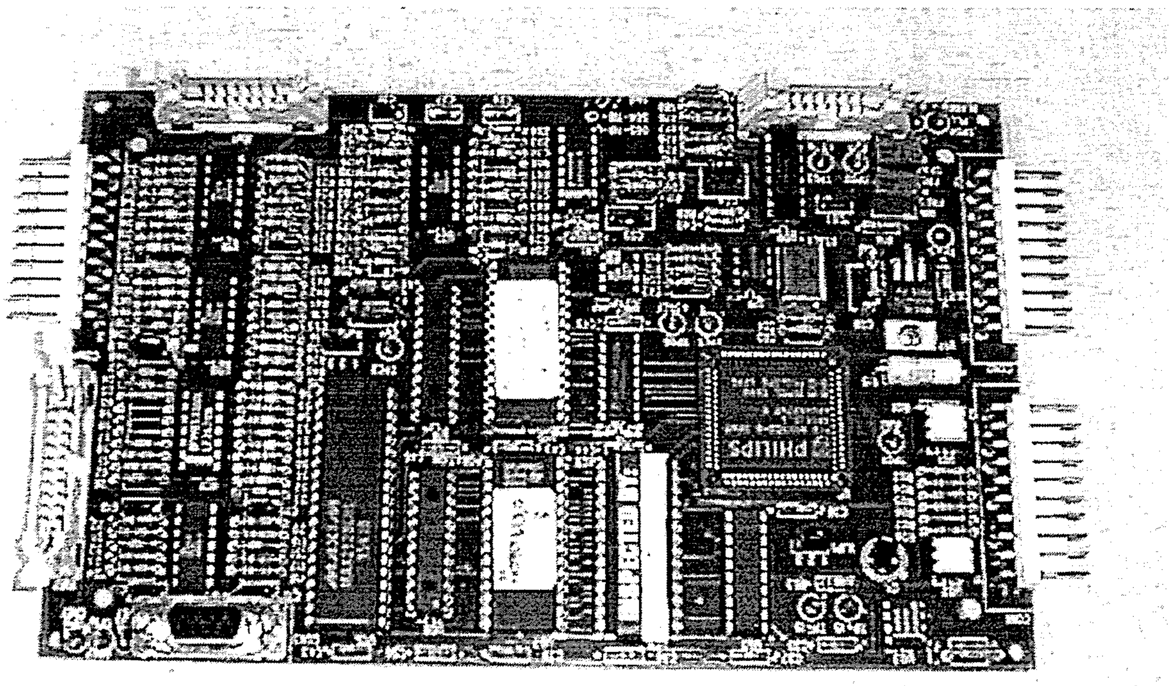

Figure 4. Master Control Board

The core resonant converter module received from SST was tested in October. It was operated in parallel with Omnion's utility service to ensure proper functioning. It performed well in all respects.

Design of a test fixture for the PCS control boards was initiated in December 1996. Software was written for the test fixture to verify the functionality of the controls. All the main system boards were tested in January 1997 using the completed test procedures. System tests started in February upon the completion of the system software and system test procedure. The majority effort of the software was to implement and debug the communication between different system control boards. This was completed in January 1997 along with all the fault handling routines, anti-islanding routine, and sequencing routines.

Fabrication of the prototype PCS (See Figure 6) was completed in February 1997 and the system test was initiated. Preparation was made for the design of an additional test fixture that will be used as the main power source for power testing. Additional software routines including DC voltage monitoring, automatic power tracker, reference waveform generation and other system interfaces were completed in February.

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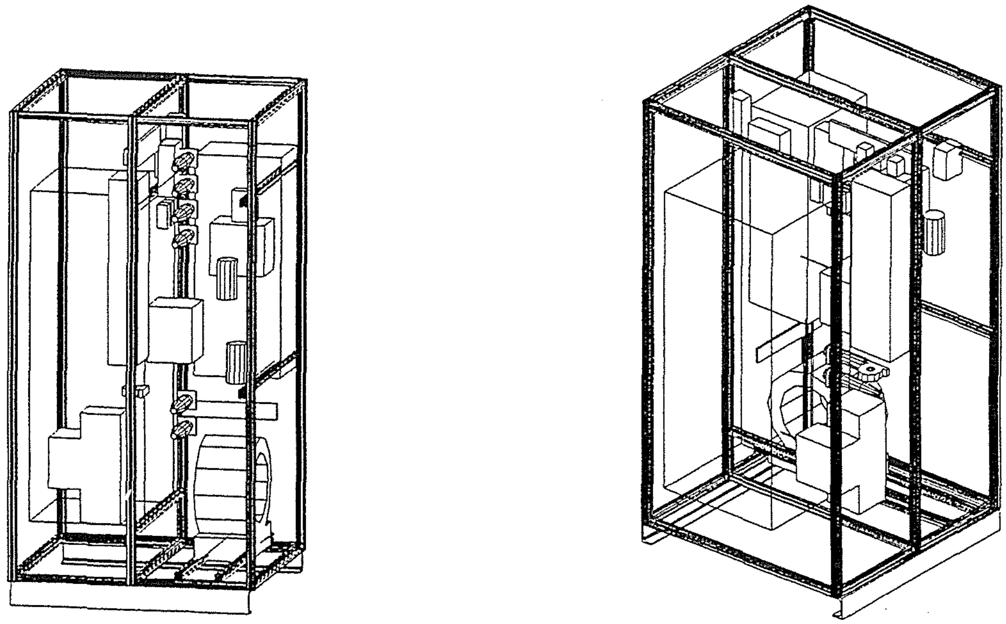

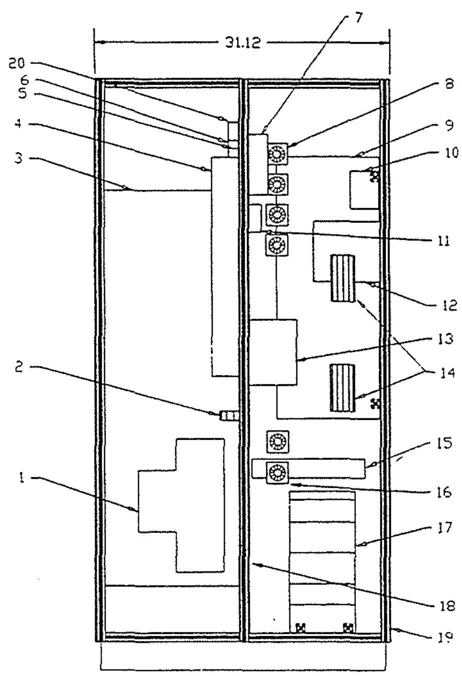

COMPONENTS LIST

ITEM	NO. REQD	DESCRIPTION
1		POWER CIRCUIT
2		CURRENT SENSOR
3		CORE MODULE
4		OUTPUT CAPACITOR
5		POWER SUPPLY
6		TERMINAL STRIP
7		FUSE HOLDER
8		CAMLOCS A.C.
9		OUTPUT REACTOR
10		SOFT START
11		FUSE HOLDER
12		CONTACTOR
13		CONTROL TRANSFORMER
14		SURGE PROTECTOR
15		DC BUSS
16		CAMLOCS D.C.
17		BOOST REACTOR
18		SUBPANEL
19		FRAME
20		OUTPUT FILTER
21		
22		
23		
24		

REV	DATE	DESCRIPTION	DRAWN	CHECKED	APPROVED
A	10/09/96	ADDED COMP LIST & CALLOUTS, DIMS	WEH		

OMNION POWER ENGINEERING

SCALE: -/- DATE: 09/09/96 DRAWN: WEH
STATUS: LAYOUT CHECKED: --- APPROVED: --
TITLE: CABINET - 3400, LAYOUT
SHEET: -OF- DWG. NO.: H34CAB REV.: A

Figure 5. Series 3400 Cabinet Layout

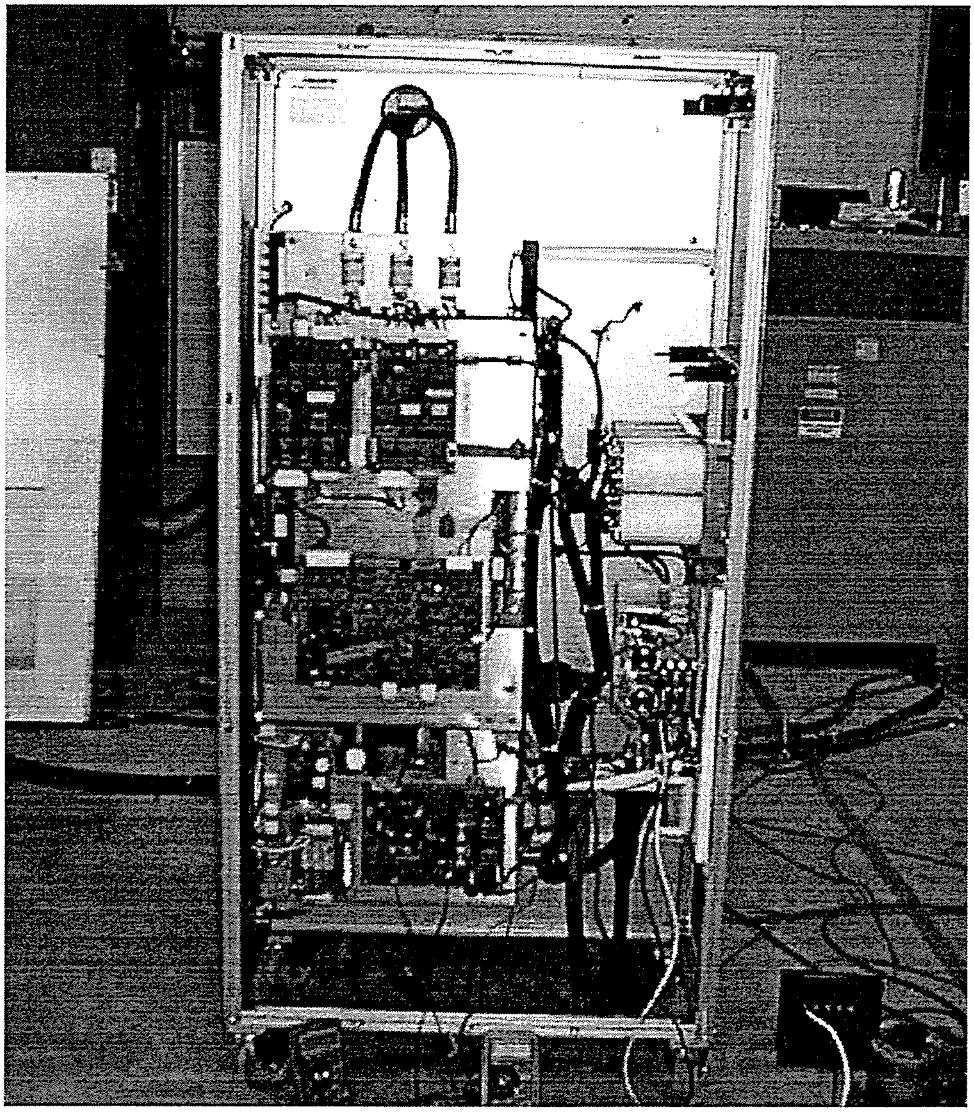

Figure 6. Prototype Series 3400 PCS

In March, the prototype PCS was running as a utility grid connected system in excess of 70 kW. A maximum core resonant converter efficiency of 97.7% was obtained, and a graph is shown in Figure 7. Additional testing will be conducted using the DC/DC converter along with the core resonant converter module. Issues which have slowed progress include a protective function coordination within the core resonant converter module itself, which resulted in the unit shutting down; some communication assumptions between the core module and the master system controls, which results in loss of communication under certain conditions; some incorrect gains in the control loops, which caused instability at certain power levels and the implementation of the handheld pendant control interface. All issues were resolved with the exception of the handheld pendant, which is expected to be completed in April 1997.

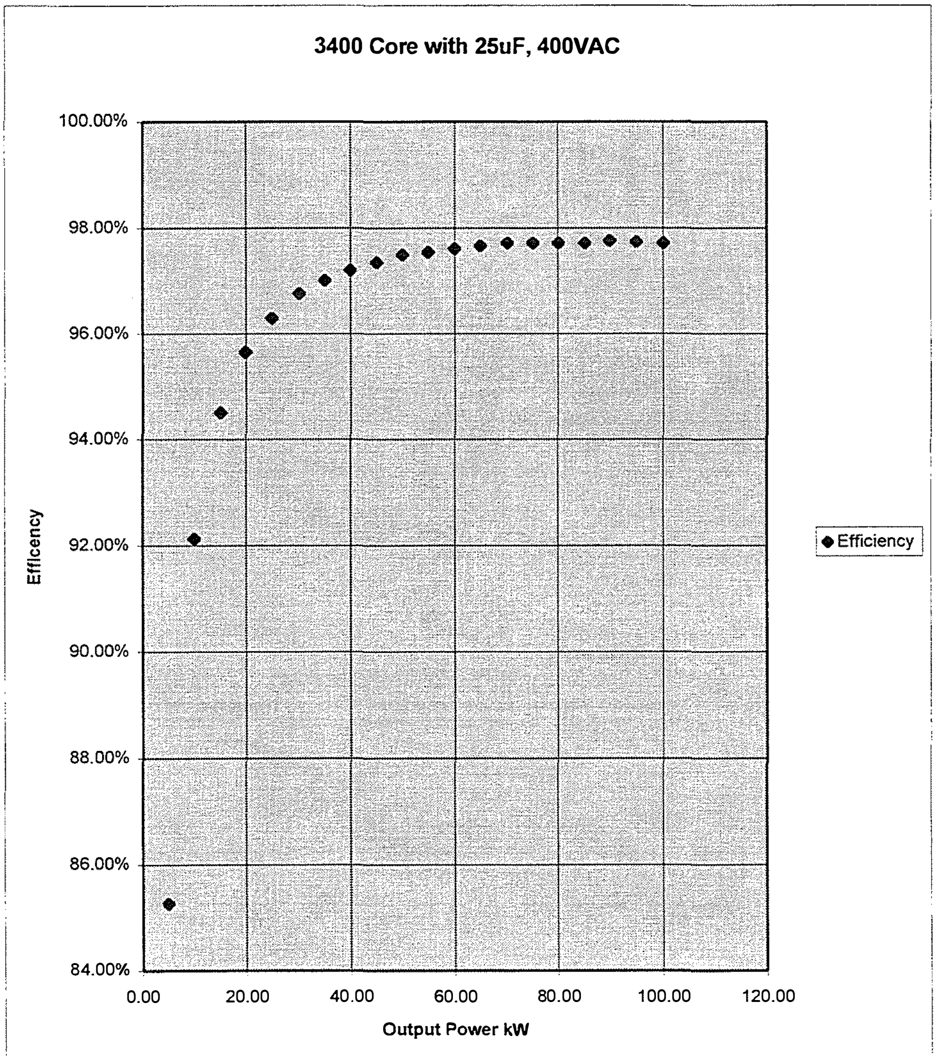

Figure 7. Resonant Converter Efficiency

2.3 Task 3 Customer/User Demonstration and Review

Under Task 3, Omnion will demonstrate operation of a prototype PCS to its customer/user group. At the conclusion of the demonstration, this customer/user group will review the product specification. The following milestones are scheduled to be completed by April 1997.

m-1.4.2	Complete 100-kW PCS prototype demonstration to customer/user group.
m-1.2.	Complete development of test procedures for the 100-kW PCS.

Final schedule has been determined and the demonstration and review was conducted on April 16, 1997 at Omnion's facilities. The PCS was brought up to full operating condition for the demonstration. After the demonstration, a design review was conducted with the customer/users group. The outcome of this review has provided Omnion with valuable insight in the development of this PCS. Inputs from the group will be incorporated in the final revision of the PCS specifications.

2.4 Phase II Pre-production Model Development

Phase II of this project was reviewed with the Technical Monitoring Team on April 17, 1997. With TMT approval, Phase II will be moving forward upon the completion of Phase I.

3.0 CONCLUSIONS

Significant progress has been made in Phase I of this contract. The emphasis of efforts in the remaining Phase I tasks is to focus on the review process with the customers/users group, and continued development of the DC/DC converter. This valuable input will be a main driving force in finalizing the Series 3400 specification for the pre-production model to be procured under Phase II. In Phase II, Omnion will refine the design and packaging of the Series 3400; implement manufacturing processes to reduce labor content and materials cost, and produce two production models with UL certification. The Series 3400 will be able to meet the requirement for utility interconnected PV and offer reduction in cost with improved performance.

APPENDIX A

Preliminary Series 3400 Specification
Document #900986-4

OMNION POWER ENGINEERING CORPORATION

OMNION SERIES 3400 NOMINAL 100 KW PCS SPECIFICATION

Document #900986-4
April 15, 1997

This document represents specifications for an Omnion Series 3400 nominal 100 kilowatt utility interconnected power conversion system for use with a photovoltaic array.

1.0 Codes and Standards

1.1 The quality of the equipment and services supplied shall be controlled to meet the guidelines for engineering design included in the standards and codes listed below. In case of conflict, this specification shall govern.

- National Electrical Code - NFPA 70-1996
- National Electrical Safety Code - ANSI C2-1993
- IEEE 928-1986 Recommended Criteria for Terrestrial PV Power Systems
- IEEE 929-1988 Recommended Practice for Utility Interface of Residential and Intermediate PV Systems
- IEEE 519 - 1992 Guide for Harmonic Control and Reactive Compensation of Static Power Controllers
- ANSI/IEEE C37 - 1986 Circuit Breakers, Switchgear, Relays, Substations and Fuses
- ANSI/IEEE C57-1986 Distribution, Power and Regulating Transformers
- ANSI/IEEE C37.90 Surge Withstand Capability of Electronic Equipment
- FCC Part 15, Subpart A and Subpart B for Conducted/Radiated Electromagnetic Interference and Compatibility
- UL 1741 Certification of Utility Grid Interactive Photovoltaic Inverters

2.0 Environment

2.1 The power conversion system (PCS) shall be capable of operating in the following environment:

2.1.1 Temperature Range: -22 to +131°F (-30 to 55°C)

2.1.2 Humidity: 0 - 100%

2.1.3 Storage Temperature Range: -40 to 150°F

3.0 DC Electrical Interface

3.1 A plus (+) and minus (-) cable shall be brought from the photovoltaic (PV) array to the power conversion system (PCS). The PCS power circuitry shall cause the PV array source circuit to be solidly grounded at its negative cable.

3.2 Input parameters to the PCS shall be:

Minimum Operating Voltage: 200 VDC
Nominal Operating Voltage: 420 VDC
Maximum Operating Voltage: 600 VDC
Maximum Power Tracking Range: 200-600 VDC
Maximum Open Circuit Voltage: 600 VDC
Nominal Operating Current: 250 ADC
Maximum Operating Current: 350 ADC
Maximum Ripple Voltage: 2% RMS from 30% to 100% of Rated Output

Note: Input voltage less than 300 VDC will result in power rating reduction.

3.3 A no-load break disconnecting means shall be provided via quick connect camlock connectors. Signage will be provided in a visible location indicating the connection is not opened under load.

4.0 Power Conversion System

4.1 System Configuration

4.1.1 A single power conversion system capable of serving a nominal 100 kW PV array shall be supplied. See Attachment I. The PCS converter output parameters shall be:

Operating Voltage: 400 VAC ±10%
Number of Phases: Three
Frequency: 60 Hz
Nominal Operating Current: 145 AAC
Maximum Operating Current: 145 AAC
Output Power Rating (Nominal VAC): 100 kWAC
Output Power Rating (+10% of Nominal VAC): 110 kWAC
Output Power Rating (-10% of Nominal VAC): 90 kWAC

4.1.2 The PCS converter shall be self-commutated utilizing insulated gate bi-polar transistors in a soft switching circuit topology suitable for meeting the specifications delineated herein at low cost and with high reliability.

4.1.3 The PCS converter shall be supplied in a single outdoor enclosure. See Attachment II. Installation shall be the responsibility of others.

4.1.4 An outdoor pad mounted, dry-type isolation transformer shall be supplied to match the converter output voltage to the utility voltage. A +5% and -5% voltage tap will be provided on the primary winding of the transformer. The transformer output parameters shall be:

Operating Voltage: 480 VAC ±10%
Output Winding: Delta
Number of Phases: Three
Frequency: 60 Hz
Nominal Operating Current: 120 AAC
Maximum Operating Current: 130 AAC

4.1.5 A no-load break disconnecting means shall be provided via quick connect camlock connectors. Signage will be provided in a visible location indicating the connection is not opened under load.

4.2 Operating Characteristics

4.2.1 The PCS shall include the following four modes of operation:

Mode 1: Shutdown - AC contactor open. Control system power shall remain energized. Operator cycle Enable/Disable (local or remote) required before operation may resume.

Mode 2: Standby/Fault - AC contactor open. Control system power shall remain energized. PCS shall go to the Standby/Ready mode when the fault condition has been cleared.

Mode 3: Standby/Ready - AC contactor open. PCS shall begin operation when all starting conditions have been met.

Mode 4: Run - AC contactor closed and available power flowing from the PV array to the utility service.

Mode 4 above may include additional sub-modes and sequences as deemed necessary by Omnion.

4.2.2 The PCS shall as a minimum be able to accomplish the following functions:

a) Shutdown - The PCS shall open its AC contactor under the following conditions and remain in the Shutdown mode until a local or remote cycle of the Enable/Disable is initiated:

- PCS Disable commanded

b) Standby/Fault - The PCS shall open its AC contactor under the following conditions:

(i) PCS Faults – The PCS will remain in the Standby/Fault mode for a minimum of 5 minutes or as long as the fault condition is present prior to automatically advancing to the Standby/Ready mode.

- PCS Over-Temperature Indication
- DC Ground Fault Indication *(Optional)*
- Bridge Fault
- Synchronization Error

(ii) Utility Faults

- Utility Over or Under Voltage -- The PCS shall go to the Standby/Ready mode when the utility voltage has returned to within limits for two minutes.

- Utility Over or Under Frequency -- The PCS shall go to the Standby/Ready mode when the utility voltage has returned to within limits for two minutes.

- Loss of Utility -- The PCS shall go to the Standby/Ready mode when the utility voltage has returned to within limits for two minutes.

c) Standby/Ready - The PCS shall open its AC contactor under the following condition before automatically restarting after an appropriate time delay when all starting conditions have been met:

Insufficient Solar Power -- Power available from the PV array is insufficient to supply the tare losses of the system. The PCS control shall prevent excessive cycling during nightly shutdown or extended periods of insufficient irradiance.

d) Run - In this mode the PCS shall operate normally.

4.3 Protection Features

4.3.1 The PCS shall include appropriate self-protective and self-diagnostic features to protect itself and the PV array from damage in the event of PCS component failure or from parameters beyond the PCS's safe operating range due to internal or external causes. The self-protective features shall not allow signals from the PCS front panel or from remote customer inputs to cause the PCS to be operated in a manner which may be unsafe or damaging.

4.3.2 The PCS when operating in parallel with the utility service shall be capable of interrupting line-to-line fault currents and line-to-ground fault currents. Faults due to malfunctions within the PCS shall be cleared by the PCS protective devices and not by the site utility service protection device.

4.3.3 The PCS control shall incorporate Omnion's standard Utility Protection. The PCS shall go to the standby/fault mode anytime the utility voltage exceeds +10% of nominal for 0.5 seconds or -10% of nominal for 5 seconds (factory set points). The over/under voltage set points and time delays shall be field adjustable via the use of the optional pendant controller and the RS232 port. Up to two sets of values for each parameter may be programmed.

4.3. The PCS control shall incorporate Omnion's standard Utility Protection. The PCS shall go to the standby/fault mode anytime the frequency exceeds

61 Hz for 0.25 seconds or falls below 58.5 Hz for two seconds (factory set points). The over/under frequency set points and time delays shall be field adjustable via the use of the optional pendant controller and the RS232 port. Up to two sets of values for each parameter may be programmed.

4.3.5 Temperature sensors shall be incorporated in the power bridge within the PCS. The PCS shall alarm and go to Shutdown when an over-temperature condition is detected. (This fault condition is a lockout mode fault.)

4.3. An early warning power bridge over-temperature signal is used to drop the PCS output power to 75% of rated.

4.3.7 The PCS shall alarm and go to Standby/Fault in the event of a bridge fault condition.

4.3.8 The PCS shall alarm and go to Standby/Fault in the event synchronization is not achieved. PCS shall attempt to synchronize continuously.

4.3. The PCS shall have provisions for prevention of reverse power flow.

4.4 Instrumentation & Control

4.4.1 Pushbuttons or select switches located in the control access compartment of the PCS enclosure shall be provided for the following functions:

- Enable/Disable
- Manual/Automatic (Constant Voltage/MPT, optional)
- Remote control disable

4.4.2 The PCS shall be capable of completely automatic operation, including wake-up, synchronization and shutdown and shall be capable of being Enabled/Disabled by using the local On/Off button, or via the remote RS232 control.

4.4.3 The PCS shall be capable of tracking the maximum power point of the PV array.

4.4.4 The following remote signals shall be accepted by the PCS via the RS232 port (see Attachment III):

- PCS Disable/Enable (On/Off)

4.4.5 The following local indication shall be provided:

- PCS On
- Percent Operating Power Level Indication

All information provided via the RS232 will be available locally through the
use of the optional hand held pendant.

4.4.6 The following remote signals shall be provided via dry contacts (Optional):

- PCS Standby/Fault or PCS Shutdown
- PCS On

4.4.7 The following remote signals shall be received via dry contacts (Optional):

- PCS Disable

4.5 System Performance

4.5.1 The PCS and transformer tare losses when in the shutdown or standby modes, exclusive of any auxiliary power usage, shall not exceed 40 watts. (Transformer is off at night, control power remains energized-- 480 VAC configuration only.)

4.5.2 The PCS efficiency measured at its input and output terminals shall be equal to or greater than the values given below when operating at nominal rated input and output voltages:

% Nominal Output	Measured System Efficiency
0	40*
25	90% (est.)
50	94% (est.)
75	95% (est.)
100	95% (est.)

*Watt losses in Standby/Shutdown modes.

4.5.3 The PCS power factor measured at the system's AC interface when in the unity power factor mode of operation shall be greater than .95 (lagging or leading) when operating above 20% nominal rated output.

4.5.4 The PCS generated harmonics measured at the system's AC interface when operating at nominal rated power shall not exceed a total harmonic current distortion of 5% or a single frequency current distortion of 3% when the 1st through 50th integer harmonics of 60 Hz are considered.

4.5.5 The PCS shall meet FCC Part 15, Subpart A and Subpart B with regards to conducted and radiated electromagnetic emissions.

4.5.6 The PCS shall operate at rated power with an audible noise level of less than 60 db excluding the transformer.

4.6 Construction

4.6.1 PCS wiring shall be bundled, laced or otherwise laid in an orderly manner. Wiring, devices, and test points shall be permanently labeled or color coded to be easily identifiable for maintenance. PCS internal wiring shall have flame retardant insulation -- PVC shall not be used. Wires shall be of sufficient length to preclude mechanical stress on terminals. Wiring around hinged panels or doors shall be extra flexible and shall include loops to prevent mechanical stress or fatigue.

Conductors shall be copper with NEMA Class B or C stranding for fixed wiring and with extra flexible stranding (Class K stranding or an approved equivalent) for movable wiring such as across hinges for devices or panels having rotatable mountings. Solid wire shall not be used.

Insulations and jackets shall be flame retardant and self-extinguishing and shall be capable of passing the flame test of IEEE Standard 383, except coaxial and triaxial cable insulation.

Shielded wire makeup shall consist of two, three or four twisted, insulated No. 20 AWG or larger conductors within a common conductive shield with drain wire and an overall jacket. The twist of the conductors shall be to a lay of 1-1/2 to 2-1/2 inches.

Wiring for main power circuits shall be terminated with compression-type terminal connectors. Connectors shall be uninsulated, teardrop, crimp-type. These wires shall be terminated at molded screw type terminal blocks with terminal marking strip and washer-head or binder-head screws or approved equal. Terminal blocks shall be accessible for future additions and/or testing while the equipment is energized. Terminal blocks shall be protected from the environment.

4.6.2 Not more than two wire leads shall be terminated under one terminal.

4.6.3 Conductors shall be continuous from termination to termination.

4.6.4 The PCS shall include ground lugs for equipment grounding and photovoltaic array circuit grounding. The DC circuit ground shall be a solid, single point ground connection in accordance with NEC 690-42.

4.6.5 All exposed surfaces of ferrous parts shall be thoroughly cleaned, primed, and painted or otherwise suitably protected to survive for the 20 year design life of the system.

4.6.6 Outdoor enclosures shall be weatherproof and dustproof and shall have provisions to prevent moisture condensation, entrance of rodents and entrance of insects into air intake/exhaust ports.

4.6.7 Components mounted inside of enclosures shall be clearly identified with suitable permanent designations that shall also serve to identify the items on drawings provided.

4.6.8 The PCS shall include the necessary heating and cooling requirements to insure prevention of condensation and overtemperature. No air conditioners or external air shall be used to insure the proper temperature range of the controls.

4.6.9 The PCS shall be designed for pad mounting and shall include mounting rail so as to maintain the bottom surface of the enclosure a minimum of two inches above the pad surface.

4.5.10 The PCS shall include dead front access compartments for the following areas:

- Local controls/Indication
- DC power connections
- AC power connections
- Remote control interconnections

4.7 Optional Equipment and Features

4.7.1 RS232 Interface - PCS operational status and remote customer interfacing can be supplied using an Omnion supplied RS232 communications protocol.

- Omnion supplied pendant for hand held local communication and programming device.

4.7.2 DC Disconnect Switch - A load break DC disconnect switch may be supplied to isolate the PCS converter from the PV array for servicing purposes. The disconnect switch shall be capable of being padlocked and shall contain visible break contacts. The disconnect shall be supplied loose for customer installation.

4.7.3 AC Disconnect Switch - An AC disconnect switch may be supplied to isolate the PCS converter and transformer from the utility service. The disconnect switch shall be capable of being padlocked and shall contain visible break contacts. The AC disconnect shall be supplied loose for customer installation.

4.7.4 DC Ground Fault Detection, Interruption and Array Disable: The PCS will alarm and go to the Standby/Fault Mode upon detection of excessive PV array ground current. The trip level is field adjustable in the range of 2 to 10 ADC via the RS232 interface. The PCS shall contain a means of interrupting the ground fault current through the disconnection of the known ground and disable the array via open circuiting the array.

4.7.5 PV String Current Monitoring – Current monitoring of a single PV string will provide the customer with additional information on string and array performance. This information will be made available via the RS232 interface.

4.7.6 PV String Power Monitoring – Power monitoring of the PV input will provide the customer with additional information on the PV input performance. This information will be made available via the RS232 interface.

4.7.7 DC Combiner Section – A DC Combiner Section may be added to accommodate multiple monopole source circuit inputs. The Combiner Section shall provide accommodation for terminating up to ten source circuits and include fusing on up to ten positive inputs.

4.7.8 A convenience receptacle may be supplied and be rated 15 amps, 120 VAC.

4.7.9 A backup protective function system may be provided for redundant monitoring for O/U voltage and frequency on the AC line and will have the capability of being field adjustable.

4.7.10 The PCS may be provided with the necessary space (h x w x d tbd) for insertion of revenue metering equipment. This area will be physically isolated from all other areas of the PCS. Revenue meter equipment to be supplied and installed by customer.

4.7.11 Customer contact closure control.

Status:
- PCS Fault
- PCS On

Control:
- PCS Disable

5.0 Factory Testing

5.1 The PCS shall be tested to demonstrate operation of its control system and its ability to be automatically synchronized and connected in parallel with a utility service prior to its shipment to the site.

5.2 Operation of all control, protective, and instrumentation circuits shall be demonstrated by direct test if feasible or by simulating operating conditions for all parameters that cannot be directly tested.

5.3 Factory testing shall include a burn-in test. For this test, the PCS shall be operated at full rated power output through one continuous 8-hour period.

6.0 Operation and Maintenance Manual

6.1 One copy of a detailed Operation and Maintenance (O&M) Manual shall be submitted. One of these copies shall be suitable for reproduction. The manual shall contain the following descriptive material:

- Site storage and handling instructions.
- Installation requirements.
- Electrical and Mechanical installation diagrams.
- Operation of the PCS.

- Maintenance requirements and schedules, including instructions on how to perform all required work.

- An electrical single line drawing delineating major components and their ratings.

- Enclosure outline drawings.

- Recommended spare parts list.

ATTACHMENT III

Parameter	Instrument or Transducer Type	Quantity (Signals)	Signal Level	Accuracy
Remote PCS Disable/Enable			1	RS232 ---
Remote PCS Disable/Enable (Optional)		1	Dry Contact	
PCS On		1	RS232	---
PCS Standby/Ready		1	RS232	---
PCS Standby/Fault		1	RS232	---
DC Ground Fault (optional)		1	RS232	---
PCS Shutdown		1	RS232	---
DC Voltage		1	RS232	1.0%
AC Kilowatt		1	RS232	3.0%
DC Current(optional)		1	RS232	---
DC Kilowatt(optional)		1	RS232	---
PCS Standby/Fault or Shutdown (optional)		1	Dry Contact	
PCS On (optional)		1	Dry Contact	

APPENDIX B

Three-Phase UI/PV PCS Specification Comparison
Document #901021-2

THREE PHASE UI/PV PCS SPECIFICATION COMPARISON

DOCUMENT #901021-2
April 15, 1997

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
1.1	National Elec Code	S	S	S	S	S
	National Elec Safety	S	S	S	S	S
	IEEE 928-1986	S	S	S	S	S
	IEEE 929-1988	S	S	S	S	S
	IEEE 519-1992	S	S	S	S	S
	ANSI/IEEE C37-1986	S	S	-	S	S
	ANSI/IEEE C57-1986	S	S	-	S	S
	ANSI/IEEE C37, 90	S	S	-	S	S
	FCC Part 15, Subpart A, Subpart B	S	S	S	S	S
	Insulated Cable Engineers Assoc. Standards (ICEA)	-	S	S	-	-
	UBC - Uniform Building Code -1995 (Seismic Loads)	-	S	S	S	-
	NEMA 3 or Equiv. for Outdoor Enclosures	-	S	S	S	-
	OSHA Directives	-	S	S	S	-
	ANSI/ASCE 7-88	-	S	S	S	-
	UL, ETL	S	-	S	-	S
	Local Codes & Standards	-	S	S	-	-
	IEC Standards	-	-	-	S	-
	ISO Standards	-	-	-	S	-
	NFPA Standards	-	-	-	S	-
2.11	Temperature Range Oper	-20 to 131°F	18 - 111°F	-	28 - 122°F	-5 to 115°F
	Temperature Range Storage	-40 to 150°F	-	-	-	-

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
2.1.2	Humidity	0 to 100%	0 to 100%	-	27 - 84%	0 to 100%
3.1	DC Interface	2 Wire	2 or 3 Wire	2 or 3 wire	?	3 Wire
	Grounding	Neg Leg	Neut or Neg Leg	Neut or Neg Leg	?	Neut Leg
3.2	Input Voltage	200-600 VDC	600 VDC Max	600 VDC Max	?	360-600VDC
	Input Current	0-350 ADC	500 A Max	500 A Max	?	0 -18 ADC
	Max Ripple	2% RMS	-	-	?	3.5% RMS
4.1.1	Nominal Output	100 kVA	-	-	-	6 kVA
	Nominal Output Voltage	400 VAC	Not Specified	Not Specified	Not Specified	120 VAC
	Voltage Tolerance	"10%	"10%	+6, -14%	"5%	"10
	Frequency Tolerance	+1, -1.5 Hz Programable(opt)	+1, -1.5 Hz	+1, -1.5 Hz	+1.5, -2.9 Hz (50 Hz)	+1, -1.5 Hz
	Max Operating Current	145 AAC	-	-	-	-
4.1.3	PCS Enclosure	Outdoor/Wall/ Pad	Outdoor	Outdoor	Outdoor	Outdoor
4.1.4	DC Disconnect	0	S	S	S	-
	Load Break	0	0	0	0	-
	Visible Break	S	S	S	S	-
	Lockable	0	0	0	S	-
	Non-load break (quick connect)	S				

Ref	Description		3400	SMUD	Team-up	Amoco Enron	2400
4.1.5	AC Disconnect		0	S	S	0	-
		Fused	0	0	0	0	-
		Load Break	0	0	0	S	-
		Visible Break	S	S	S	S	-
		Lockable	0	S	S	S	-
		Non-load break (quick connect)	S				
4.1.6	Output Transformer						
		Enclosure	Outdoor/Pad	Outdoor	Outdoor	Outdoor	-
		Output Voltage	480 VAC	Match Utility	?	12.47 kV	-
		Output Winding	Delta	-	?	Delta	-
		Max Current	130 AAC	-	?	-	-
4.2.2a	Shut Down						
		Remote Disable	S (RS232)	S	S	-	-
		Emergency Stop	-	S	S	S	-
		Lockout Mode Fault	-	S	S	-	S
4.2.2b	Standby/Fault						
		Over-Temperature	S	-	-	-	S
		DC Ground Fault	0	-	-	S	S (BB)
		Bridge Fault	S	-	-	-	S (BB)
		Logic Power	0	-	-	S	S (BB)
		Synchronization	S	S	S	S	S
		O/U Voltage	S	S	S	S	S
		O/U Frequency	S	S	S	S	S
		Loss of Utility	S	S	S	-	S
		Over Power	-	-	S	-	S (BB)

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
4.2.2c	Standby/Ready Insufficient Solar	S	S	S	S	S
4.2.2d	Run	S	S	S	S	S
4.3.1	Fail Safe	S	S	S	S	S
4.3.2	Fault Clearing	S	S	S	S	S
4.3.3	O/U Voltage	+10%/0.5 S -10%/5 S	+6% -14%/5 S	+6% -14%	±5% -	±10% -
	Field Adjustable	S(2 set points) via pendant/RS232	S	S	S	S
4.3.4	O/U Frequency	61 Hz/0.25 S 58.5 Hz/2 S	61 Hz/.255 58.5 Hz/25	61 Hz/.255 58.5 Hz/25	51.5 Hz 47.1 Hz	61 Hz 58.5 Hz
	Field Adjustable	S(2 set points) via pendant/RS232	S	S	S	S
4.3.5	Over Temperature	Bridge	Bridge	Bridge	-	Bridge
4.3.6	Over Temperature	75% De-Rate	Shutdown	Shutdown	-	Shutdown
4.3.7	Bridge Fault	S	-	-	-	S
4.3.8	Loss of Synchronization	S	S	S	S	S

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
4.4.1	LCD Display	O RS232/pendant				
	AC kW	-	S	?	?	S
	VDC	-	S	?	?	S
	Mode	-	S	?	?	S
	Bridge Fault	-	S	?	?	S
	Sych Error	-	S	?	?	S
	Utility Out-of-Tolerance	-	0	?	?	S
	Over Temp	-	S	?	?	S
	Ground Fault	-	S	?	?	S
4.4.2	Controls					
	Emergency Stop	-	-	S	S	-
	Reset	-	S	S	S	S
	On/Off	S	S	S	S	S
	Man/Auto(const volt)	O	-	-	-	-
	Remote disable	S	-	-	-	S
4.4.4	Maximum Power Tracking	S	S	S	S	S
	Anti-Islanding Prot.	S	S	S	-	S
4.4.5	Remote Control (RS232)					
	Disable	S	S	S	S	-
	Reset	-	S	S	S	S
	Local Disable	S	S	S	S	-
	ON/OFF	S	-	-	-	-

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
4.5.1	Tare Losses (Standby/Shutdown)					
	PCS	40 W	-	-	-	<15 W
	480 V transformer	0	-	-	-	-
	12 kV transformer	?	-	-	-	-
4.5.2	Efficiency (PCS & Transformer)					
	25	90%	?	?	>92%	95.3%
	50	94%	?	?	>92%	95.9%
	75	95%	?	?	>95%	95.5%
	100	95%	?	?	>95%	95.4%
4.5.3	Power Factor	".95 > 20%	".95 > 20%	-	.8 lag - .95 lead	±.95 > 20%
4.5.4	Harmonics (Current)	5%/3% < 50th	5%/3%	See IEEE 519-1992	IEEE 519-1992	<5% >30%
	(Voltage)	-	5%/1%	-	-	-
4.5.5	FCC Part 15~~A~~ Sub A/B	S	S	S	S	S
4.6.1	Construction					
	No PVC	S	S	S	-	S
	Class K Stranding	S	S	-	-	S
	Flame Retardant (IEEE383)	S	S	-	S	S
4.6.2	Max Two Leads/Terminal	S	S	-	S	S
4.6.4	Single Point Ground	S	-	-	S	S
4.6.5	20 Yr. Paint	S	S (30 Yr. Paint)	-	30 Yr. Life	S

Ref	Description	3400	SMUD	Team-up	Amoco Enron	2400
4.6.6	Outdoor Enclosure	NEMA 3R	S	S	S	S
	Dust Proof	S	S	S	S	S
	Rodent Proof	S	S	S	S	S
	Insect Proof	S	-	-	-	-
	Mount rails	S	-	-	-	-
	Dead front access(ctl/pwr)	S	-	-	-	-
4.6.7	Component Identification	S	S	S	S	S
	120 VAC, 20 A Outlet	O	0	-	-	-
4.6.8	PV string current monitoring	O	-	-	-	-
4.6.9	PV string power monitoring	O	-	-	-	-
4.6.10	DC combiner	O	-	-	-	-
4.6.11	Backup protective functions	O	-	-	-	-
4.6.12	Revenue metering compartment	O	-	-	-	-
4.6.13	Time stamped events/storage	-	-	-	-	-
4.7.4	DC Ground Fault	O	-	-	-	S
		0/2-10A	?	?	Field Adjustable	0.5 A
		0/0,1-1A	?	?	-	-
6.1	O&M Manual	S	S	S	S	S

APPENDIX C

PVMaT/OPEC Series 3400 Customer Review Matrix
Document #901096

PVMAT/OPEC SERIES 3400 CUSTOMER REVIEW MATRIX
Document #901096

COMMENT		NUMBER OF OCCURENCES
ELECTRICAL CONFIGURATION		
1.	Optional ADC, kWDC	2
2.	Locate control power connection to line side of main fuse	2
3.	Add DC blocking diode for prevention of reverse power flow	2
4.	Multiple fused source circuit inputs	1
5.	PCS output 480 VAC transformerless	3
6.	Transformer configuration Wye-Wye	1
7.	Contactor between negative and ground (disrupt ground)	1
8.	Load break DC disconnecting means	3
9.	Load break AC disconnecting means	3
10.	Label non-load break disconnect (not operate under load) -load break not necessary (AC/DC)	3
11.	DC disc open positive only (ground fault protection)	2
12.	Add manual control of AC contactor	2
13.	Metering socket integral to AC disconnecting means	2
14.	Transformer taps if not 480 VAC transformer	1

COMMENT		NUMBER OF OCCURENCES
PROTECTIVE FUNCTIONS		
1.	Interrupt and alarm DC ground fault	2
2.	Detect DC ground fault no interrupt	1
3.	Islanding protection - one second adjustable	1
4.	Anti-islanding Protection UL Certified	1
5.	DC injection protection	1
6.	Protective functions classified as industrial grade	1
7.	Independent detection/backup scheme for islanding protection	1
8.	O/U voltage, +6, -14% standard	1
9.	O/U frequency, +1, -1.5 Hz standard	1
10.	Adjustable set points (level, time) -qty. two for each parameter with factory default	2
11.	Adjustable set points -no instantaneous, 1 trip	1
12.	No lockout mode faults (equipment/safety only)	3
13.	No baseball faults (equipment/safety only)	3
14.	Two-minute delay on retry	1
15.	Five-minute delay on retry	1
16.	Lockout on OT and DC ground fault only	1
17.	Three tries and lockout - yes	1
18.	Logic power fault not necessary	2
19.	Self test scheme	2

COMMENT		NUMBER OF OCCURENCES
PERFORMANCE/OPERATION		
1.	Bridge 75% de-rate on over-temperature—yes	2
2.	Bridge 75% de-rate on over-temperature not useful	1
3.	FCC Part A and Part B vs. just Part B	3
4.	FCC 15, Subpart J	1
5.	Lower minimum DC operating voltage (300 VDC present)	5
6.	Identify power rating at -10% and +10% utility line in spec	2
7.	Audible Noise level 52 dbA or less	1
8.	Audible Noise level same as pad mount transformer	1
9.	Audible Noise level same as present hard switching	1
LOCAL CONTROL		
1.	On/Off control only (no ESTOP, reset)	4
2.	LCD display/Power level indication only	1
3.	LCD (MMI) necessary	1
4.	LCD remove and pendant substitute	2
5.	Local single fault indicator only (no remote DAS)	1
6.	Add selector for manual mode (constant voltage)	1

COMMENT		NUMBER OF OCCURENCES
REMOTE COMMUNICATIONS		
1.	RS232 local disable via disconnecting	2
2.	Modem with RS232 or other -accommodate multiple drops -longer distance -protocol	4
3.	Communication multiple units addressing (?RS485)	2
4.	Software to support protocol	2
5.	Add instrumentation standard (i.e., SAMI)	1
6.	Event storage, time stamped, 5-10 events, 10 cycle prior, 20 cycle after	1
7.	DAS built in (kWHR, temp, irradiance, DC/AC voltages/currents power factor)	1
8.	Baseball faults, call in diagnostic	1
9.	Remote restart	4
10.	Remote programmable parameters	1
11.	Add auxiliary dry contacts for shutdown	1
12.	No dry contact closures	1
13.	No remote DAS	1

COMMENT		NUMBER OF OCCURENCES
PACKAGING/ENCLOSURE		
1.	Physical Protection - Utility grade	1
2.	Insect entrance prevention – standard	1
3.	Isolate inside air from external (i.e., external heatsink)	2
4.	No Air conditioners	2
5.	Convenience outlet	1
6.	No filters	2
7.	Strip heater	2
8.	No flat bottom for ground mounting	2
9.	No user changeable parts	2
10.	User interface via dead front control	2
11.	Access panel for connections only (RS232, power)	2
12.	Access panel for controls	2
13.	Space for revenue metering package	1
14.	UBC if wall mounted	1
15.	NEMA 3R enclosure	1
Modularization design (inverter, interconnects, disconnect switch)	-built in disconnect switches with barrier	1
17.	Add storage temperature range to specification	1
18.	Make maximum operating temperature 131 degree F	2
19.	Wall mountable	1

COMMENT		NUMBER OF OCCURENCES
MISCELANEOUS		
1.	O&M manual less than 5 pages (not service manual)	2
2.	Timing to market – short	1

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13. ABSTRACT *(Maximum 200 words)*

This report describes work performed by Omnion Power Corporation under Phase I of a two-phase subcontract. During this phase, Omnion researchers: designed an advanced product specification to guide prototype design and development; analyzed field failure data with Omnion's hard-switched Insulated-Gate Bipolar Transistor technology hardware to better understand where design improvements were needed; presented and reviewed product specifications with key customers/users; drafted a working product specification to serve as a baseline in developing the new power conversion system; developed the core-resonant converter technology in conjunction with Soft Switching Technologies Corp.; designed a 100-kW prototype power conversion system; designed a prototype system package; initiated interaction with vendors to optimize component selection and specifications; initiated the preparation of design documentation; built the prototype core-resonant converter and initiated preliminary testing; and initiated the assembly of a 1-kW prototype power conversion system. This work has demonstrated the potential of the soft-switching resonant DC link (RDCL) inverter and its application to a three-phase utility-interconnected PV power conversion system. The RDCL inverter has demonstrated its advantage over hard-switching pulse-width modulated inverters in terms of efficiency and audible noise. With proper package design and manufacturing process design and implementation, the RDCL power conversion system has the potential to be low-cost and reliable with superior performance.

14. SUBJECT TERMS	15. NUMBER OF PAGES
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