March 2000 • NREL/SR-520-27982

Subcontractor Report

Cost Reduction and Manufacture of the SunSine® AC Module

Phase I Annual Report
21 April 1998 — 31 October 1999

Dr. Edward Kern and Greg Kern
Ascension Technology
A Division of Applied Power Corporation
Boulder, Colorado

National Renewable Energy Laboratory

1617 Cole Boulevard
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NREL Technical Monitor: H. Thomas

Prepared under Subcontract No. ZAX-8-17647-03

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1.0 Executive Summary

This report summarizes the progress made by Ascension Technology in Phase I of the Cost Reduction and Manufacturing Improvements of the SunSine AC Module. This work was conducted under NREL subcontract No. ZAX-8-17647-03. The project is a two-phase effort consisting of investigations into improving inverter packaging, soft switching, circuit optimization, design for manufacturing, manufacturing processes and pilot production manufacturing. Significant cost reduction and performance improvements have been achieved in Phase I.

The main goal of this project was to reduce cost and improve the manufacturability and reliability of the SunSine AC module, which consists of a SunSine inverter mounted on a PV laminate. This work has also boosted the performance and enhanced marketability by adding customer-valued features. Ascension Technology is accomplishing these advancements by cost reductions or design modifications in the following areas:

- Die-cast aluminum enclosure and base plate;
- Soft switching for cost reduction and efficiency gains;
- Circuit board and component optimization for performance gains and size reduction;
- Streamlined inverter assembly & automated production testing;
- Streamlined inverter/module assembly and test; and
- Conduit-ready version and versions for export markets.

As a result of the effort in these areas, Ascension Technology's objectives are to achieve the following:

- 40-50% reduction in inverter manufacturing costs,
- 40% reduction in inverter size from 169 to 100 square inches;
- 4% increase in peak inverter efficiency from 87 to 91% at full power;
- UL listing, FCC certification, and export safety and emissions requirements;
- establish a production capability of 5,000 SunSine inverters/year through manufacturing improvements and production line design improvements;
- less than 1 failure per 1,000 units at time of installation/turn-on;
- a 5 year warranty; and
- a rating of 250 W_{ac} at PTC for the SunSine AC Module Rating.

Accomplishments during Phase I includes:

- **SunSine® AC Module costs have been reduced enough that we expect to be able to reduce our suggested list price by 3.00 $/W_{ac}$ STC!**
- successful implementation of soft-switching
- power circuit board sized reduced 53%
- power circuit board component count reduced 34%
- total inverter parts count reduced 49%
- anticipated inverter manufacturing cost reduced 57% on a $/W_p$ rating
- transformer efficiency improved 1.4%
- inverter efficiency improved 4.7% to 91.0% at 275-W_{ac}
- we have decided to eliminate burn-in testing from the production process, removing a major bottleneck in production capacity, the remaining bottleneck in production capacity will be final assembly. Our target capacity will be 5,000 units per year.
- before we remove burn-in from the production process, we will use the Burn-In Test Station to verify production boards meet specifications
- software and hardware for the Burn-In Test Station has been completed to a level suitable for testing production boards.

- conformal coat process was successfully tested using the HAST test process
- a prototype casting was developed which is actually slightly larger than the original casting. By going through this design and prototyping process we have learned what is really important in the product design and will do one more revision of the design in Phase II to achieve a much smaller casting.
- we have learned how to design and create prototype aluminum castings at a moderate cost.
- potential export markets have been identified, including safety and emissions requirements.
- we have decided to focus on getting the product ready for U.S. and Canadian markets first, and will address international markets second.
- the inverter has been designed so that it may be easily modified to work in international voltage and frequency versions.

2.0 Background

Ascension Technology (AT) first began development of the module-scale inverter in 1991. When integrated with a large PV module, the inverter produces utility-compatible ac power without any balance of system issues or overhead. The module-scale inverter is the AC PV Module's user interface, eliminating system-integrator compromises between module and inverter specification and eliminating user access to live dc voltages. Restricted access to the DC voltages provides enhanced safety during installation, service and operation of PV systems. The first prototypes were developed and tested under research funds from the New England Power Service Company and Sandia National Laboratories.

During this subcontract, Ascension Technology, a division of Applied Power Corporation, addressed the PVMaT goals of manufacturing improvements directed toward innovative, low-cost, high-return and high-impact PV products.

Ascension Technology began this subcontract with NREL in April 1998 with goals to reduce significantly the cost of the SunSine inverter, enhance its performance, and streamline and expand the manufacturing process. The primary goal was to reduce costs, thereby allowing the units to be sold at a lower price. Secondary goals were to enhance performance and improve marketability by adding features that customers require or desire. Finally, Ascension Technology has worked to increase their manufacturing capacity, to allow higher volumes and lower costs as the market expands.

3.0 Phase I Tasks

The following is a summary of the Phase I Tasks for this project. The project consists of two phases. Phase I comprises Tasks 1 through 5. Phase II comprises Tasks 6 through 9. At the time of this report, Tasks 1 through 5 have been completed.

3.1 Task 1 - Power Electronics Improvements

Soft switching is a widely accepted class of switch-mode power circuit design techniques used to reduce losses and device stresses incurred during switch transitions and to reduce electromagnetic emissions. Passive or active elements may be used to reduce either the voltage across a switch during a switch transition, called Zero Voltage Switching (ZVS), or the current through a switch during a switch transition, called Zero Current Switching (ZCS). While the extra circuit elements necessary to achieve soft-switching impose extra cost and electrical losses, these are usually offset by increased reliability due to lower operating temperatures, reductions in heat removal, less EMI filtering hardware, and decreased component stresses. It is noted though, that some soft-switching approaches actually increase component stresses. The details how soft switching is implemented in the new SunSine inverter will not be presented in this report. Only enough data is presented to show that the method is working.

Before we can explain the need for soft switching, we must first explain the overall topology of the SunSine inverter. The inverter is actually a combination of two power converters in series. The first converter is a dc/dc converter with high bandwidth output current control. This is a buck converter consisting of C1, Q1, D1 and L1 seen in Figure 1. Q1, the main switching MOSFET is pulse width modulated (PWM) to control the output current of L1 to match a half-sinewave reference signal. The PWM signal switches Q1 at about 100 kHz and is considered a self-commutated converter. Accurate high bandwidth control of L1 current is what allows the unit to achieve low harmonic distortion in the inverter output current. The exact switching frequency has not been chosen and will be optimized for EMI and efficiency performance later in the testing process of Phase II. The switching frequency will be somewhere between 50kHz to 200kHz. Many commercially available inverters do not have such high bandwidth control and will have difficulty meeting the new IEEE-P929 and UL 1741 harmonics requirements at the high order harmonics. These requirements become mandatory for the production of listed inverters in the U.S. November 7, 2000.

The second converter in the SunSine inverter is a current fed H-bridge dc/ac converter. MOSFETs Q2,Q3,Q4 & Q5 comprise this converter. Switching of the H-bridge MOSFETs is controlled by a voltage sensing and frequency detect circuit. This circuit has a logic level (0 or 5V) output depending on the polarity of the utility voltage waveform. The output changes state at the zero crossing of the voltage waveform. This circuit is designed to minimize the impact of multiple zero crossings and noise from the utility voltage. This signal controls operation of the H-bridge MOSFETs, hence this part of the inverter is line-commutated. The H-bridge MOSFETs are also controlled by a second signal, a shutdown signal from the microprocessor. The microprocessor can shutdown operation of MOSFETs Q1..Q5 in microseconds.

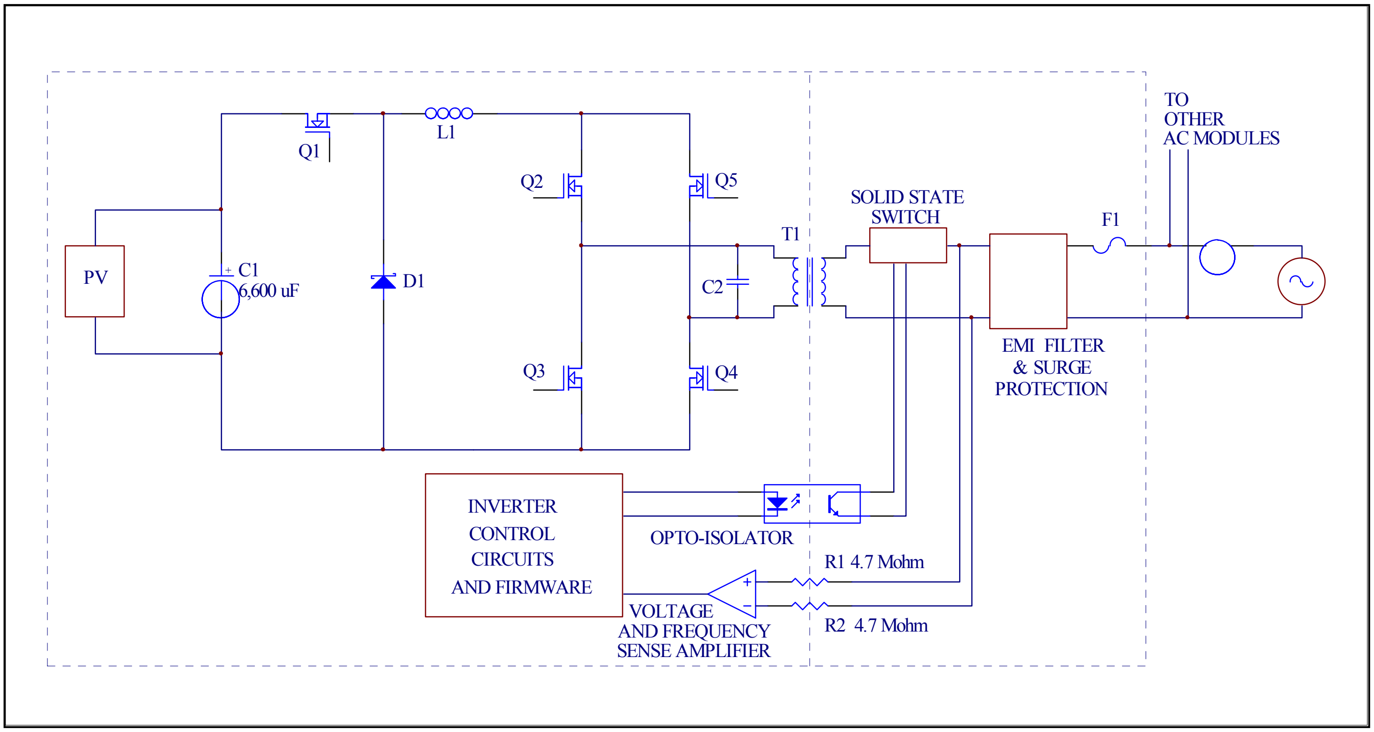

Figure 1. SunSine AC Module Power Topology

The output of the H-bridge dc/ac inverter is connected to a filter capacitor, C2. The voltage at C2 is a nominal 24Vac. Transformer T1 is a 60-Hz, (or 50-Hz for international versions) 24:120 volt transformer, designed and tested for isolation up to 4,000 V_{ac}, and provides isolation between the PV input circuit and the ac output circuit of the inverter. In series with the transformer output is a solid state relay, isolated from the low voltage control circuits by an optoisolator rated for 5,300 V_{ac} isolation. The purpose of the solid state relay is to provide a second means of inverter shutdown and to remove power from the transformer at night. Otherwise, standby losses of the transformer at night would be about 3.0 W_{ac} continuous.

On the utility side of the solid state relay is the connection for voltage and frequency sensing. This is done through a high input impedance differential amplifier. The input impedance of 4.7 megohm is sufficient to meet UL isolation requirements between the PV input and the ac output of the inverter. The resistors are rated for 2,500 V_{ac} continuous operation.

Next is the EMI filter and surge protection components. These components filter conducted emissions from entering or exiting the inverter and are generally effective in the frequency range of 150 kHz to 30 MHz Also included is surge protection to minimize the probability of conducted line surges damaging or affecting inverter operation.

Finally, each inverter is fused, F1, to prevent any component failures from affecting the rest of an AC module system. The only time F1 would open is due to component failure in the inverter. The fuse, F1, is not accessible or serviceable.

So where does soft switching come in? Soft switching is used when Q1 turns on. A special circuit is used to control the voltage across Q1 so that Q1 turns on with zero voltage switching, ZVS. Figure 2 shows the voltage that controls operation of the MOSFET, Vgs Q1, and the voltage across the MOSFET output, Vds Q1. This ZVS technique is achieved by an auxiliary circuit that draws the main voltage across the switch (Vds) down to zero before the control signal (Vgs) is activated.

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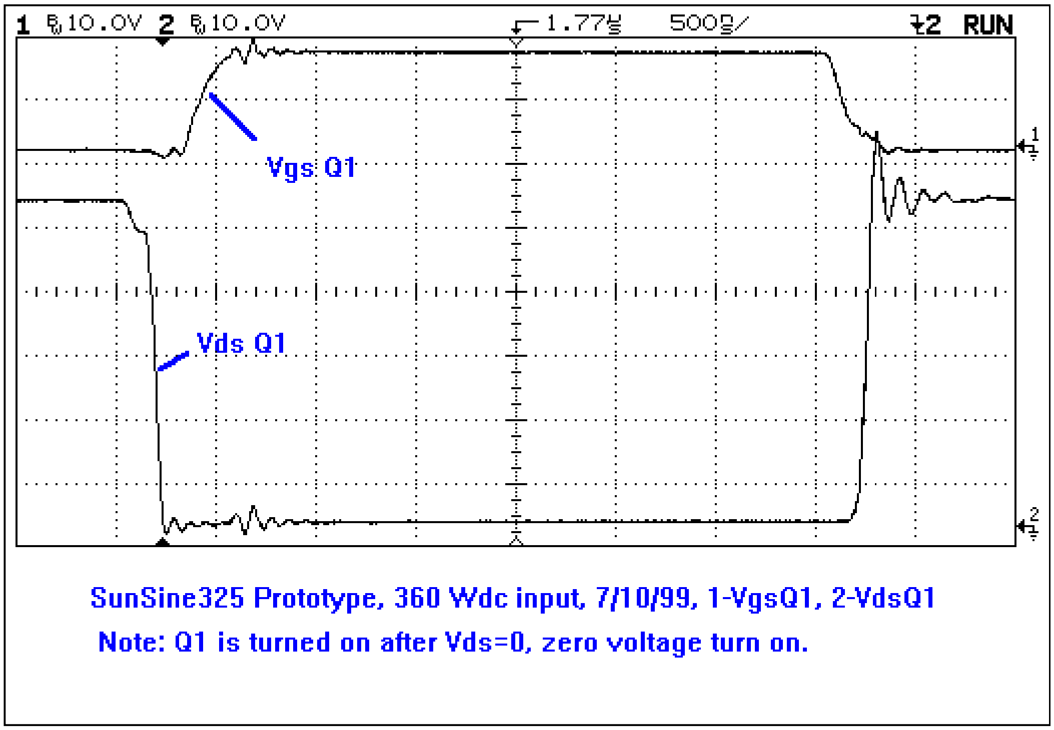

SunSine325 Prototype, 360 Wdc input, 7/10/99, 1-VgsQ1, 2-VdsQ1

Note: Q1 is turned on after Vds=0, zero voltage turn on.

Figure 2 Transistor waveforms during soft switching (V_{gs} is the control signal, V_{ds} is the voltage across MOSFET Q1. "SunSine325" is the company's internal name for this new product.

Figure 2 also shows the turn-off transition of Q1. The current waveform is not shown in Figure 2. If it were it would show that Q1 was already off during the turn-off transition. Extra capacitance has been added to the circuit to slow down this transition, to prevent electromagnetic interference that can be generated by steep dv/dt waveforms.

Task 1 deliverables completed:

D-1.3 Report summarizing rationale for selection of soft-switching approach and prototype performance results.

Task 1 results summary:

- successful implementation of soft-switching

3.2 Task 2 – Circuit Board Optimization

The circuit board was also optimized. The basic circuit was redesigned such that most of the circuit elements were available as standard products from multiple vendors, and more in line with other production activities being conducted by Ascension Technology. This has the effect of reducing part prices.

The redesign process has made extensive use of surface mount technology (SMT) components. These parts are less expensive, better for use in automated assembly lines, and take up less room on the board. The new inverter uses 88% surface-mount components. The presence of large components in the inverter dictates some manual insertion during assembly, but this has been minimized in the new design.

3.2.1 Inverter Circuit Improvements

Reducing the size of the main circuit board was a major goal of this task. The redesign was conducted by test and analysis of the circuit, and improvements in component quality and control technique. Numbers that summarize the results of this work can be seen on Table 1, and a picture of the old design next to the new board appears in Figure 3. The reduced size of the circuit board will help to reduce the size of the enclosure casting as well. Summary numbers for the inverter are presented in Figure 4.

Table 1. Comparison of Circuit Board and Casting Versions

Component	*Original SunSine300*	*New SunSine*	*% reduction*
Casting Cost (estimated production cost)	1.00x	0.20x	80%
Board Size	89.9 in^2	42.0 in^2	53%
Circuit Board Component Count	282	187	34%

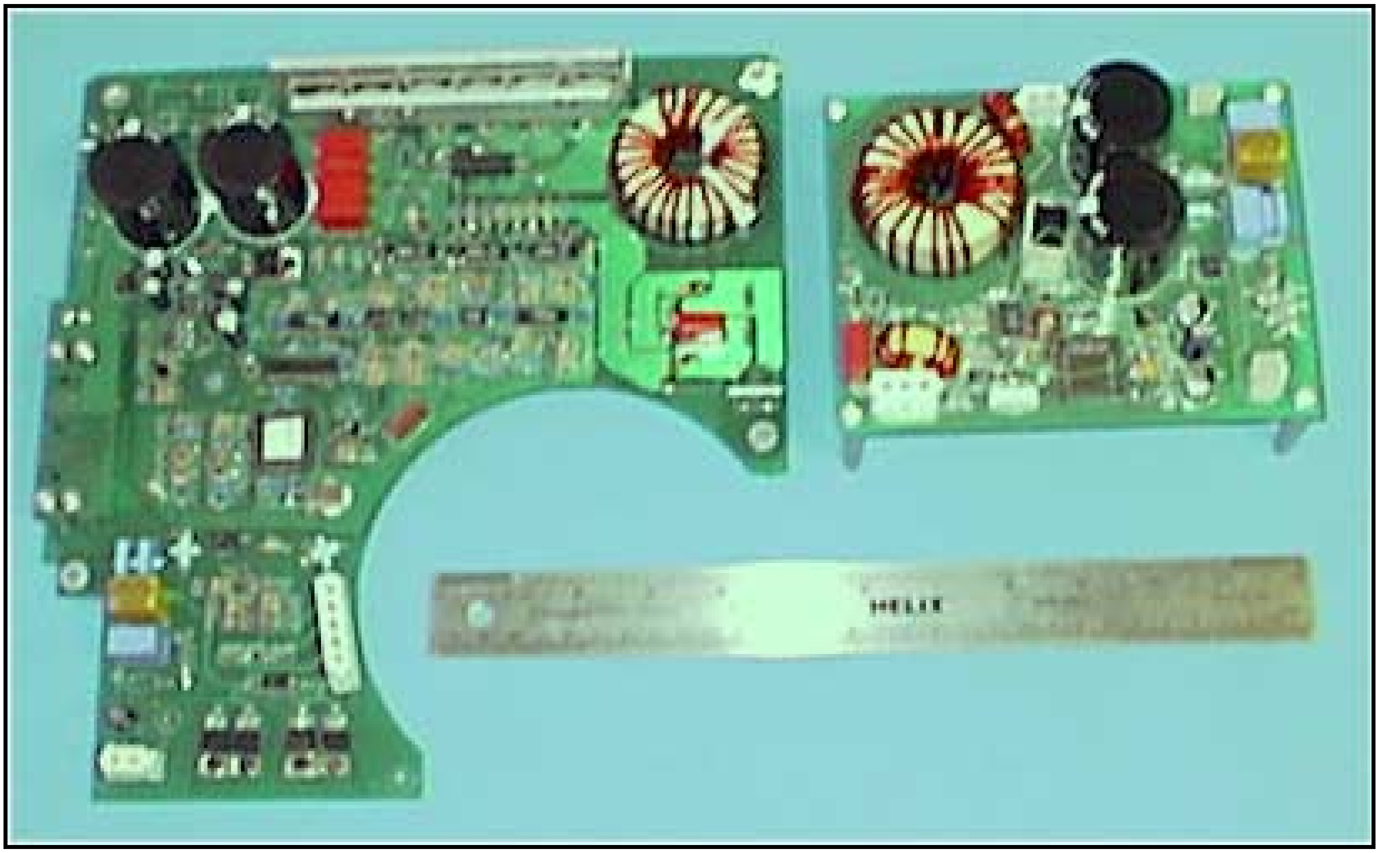

Figure 3. Circuit Board Area of old and new SunSine Inverter board. This photo is intentionally lacking detail to prevent competitors from seeing details of the designs.

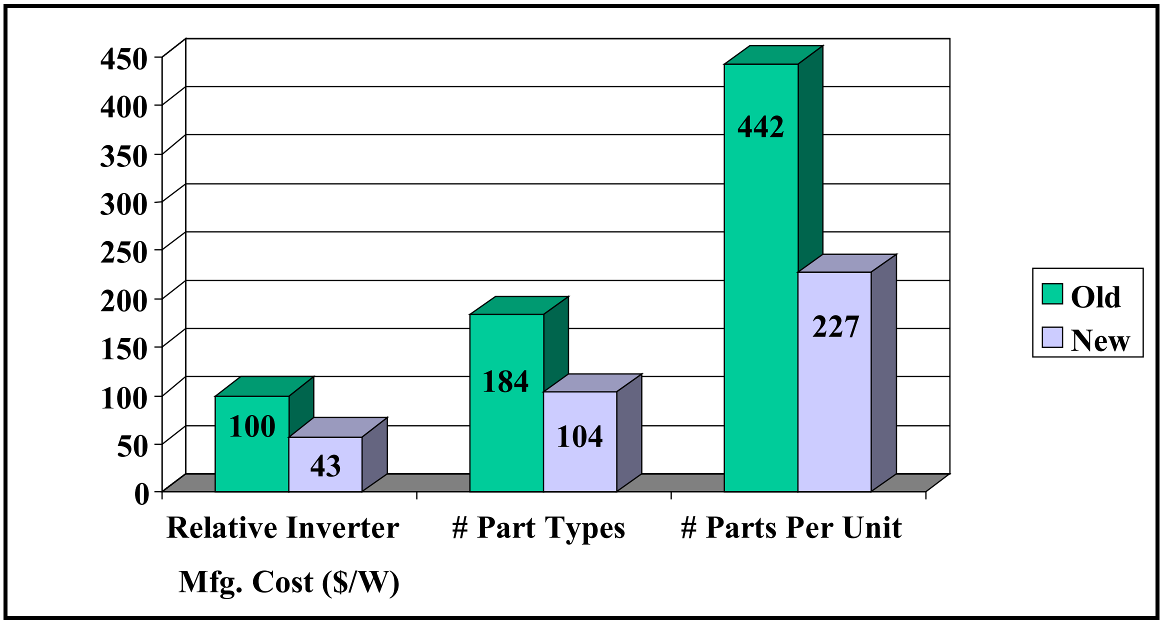

Figure 4. Inverter cost and parts count reductions

3.2.2 Capacitor Lifetime Estimates

One of the failure modes in dc/ac inverters can be failure of the electrolytic storage capacitors. These capacitors are used to filter the difference between the dc-input power and the ac output power, as well as to reduce ripple current from switching operation of the converter. These capacitors contain a liquid electrolyte, which evaporates over time. The rate of evaporation is a function of capacitor temperature. A rudimentary model of capacitor temperature versus ambient temperature, wind speed and POA irradiance has been constructed. Data from one year of operation of a single axis tracking system in Tempe, Arizona was used as input to the model to determine how much capacitor life was used up per year of operation. Based upon this preliminary model, various capacitors were evaluated to determine what kind of life we could expect in this environment. Our goal is to achieve a capacitor lifetime of 20 years. Based upon this goal, a specific capacitor type was selected for this inverter. Using the model and the specific data of the capacitor, a capacitor lifetime of 23.62 years is expected in an application such as mentioned above. Locations where temperatures and average irradiance are lower can expect longer lifetimes for the capacitors.

During Phase II, data will be collected on actual capacitor temperatures during testing at the NREL Outdoor Test Facility. This data will be used to update the model mentioned above to ensure a capacitor lifetime of 20 years. The model will then be applied to data from other locations to determine how capacitor lifetime varies as a function of location.

3.2.3 Transformer Improvement

As part of the improvement process, the transformer was redesigned. The new transformer exhibits higher fixed losses leading to a lower efficiency at low power, but lower conduction loss than the old transformer. The result is that the inverter will obtain higher efficiency at high power ratings. This is summarized in Figure 5. The crossover point of the two curves is near the 50% rating point for the inverter. The effects of this change on energy production will vary from site to site, but clearly the new transformer will allow the ac module to achieve a higher output rating at STC and PTC conditions. These are the ratings at which customers make their purchasing decisions.

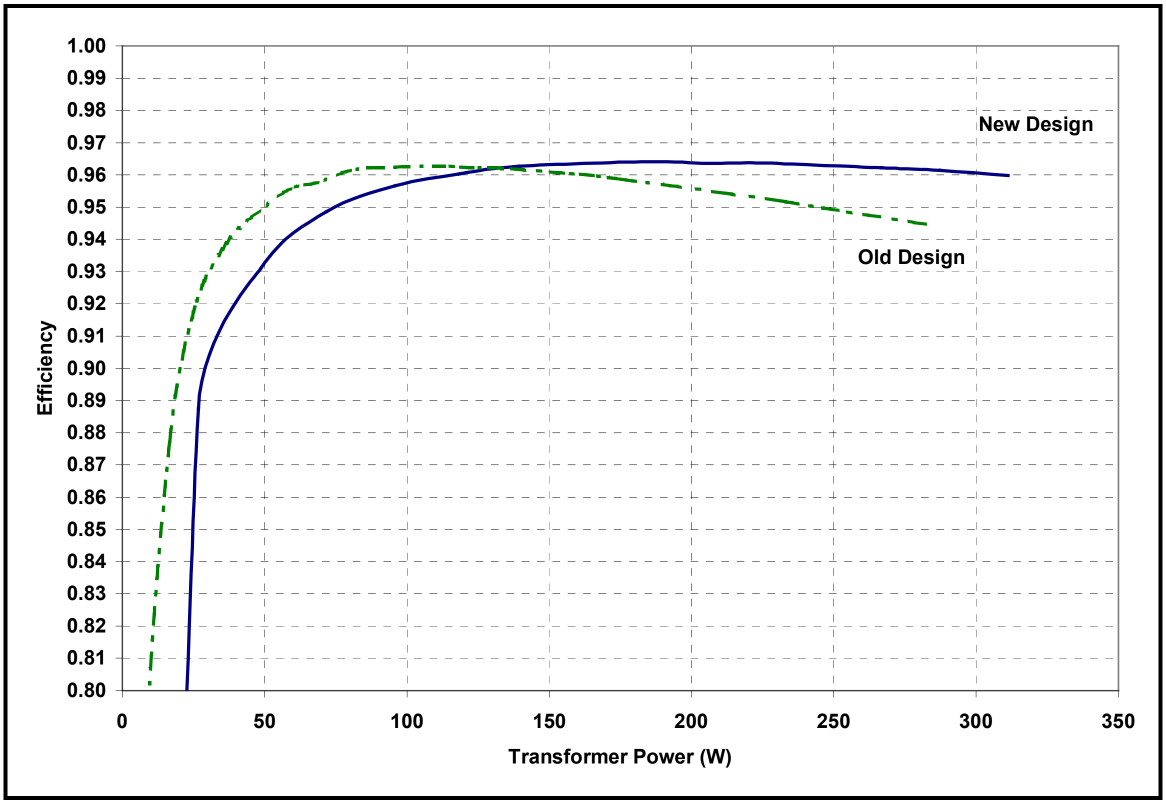

Figure 5. Old and New Transformer Efficiency

The new transformer design is simpler, maintains nearly the same dimensions as the old design and while heavier by about 2 pounds boasts a temperature rise characteristic reduced by 37%. At 275 Wac output, the new transformer increases inverter efficiency by about 1.4%.

3.2.4 Inverter Efficiency

It is difficult to separate out the impact soft switching has on inverter efficiency versus other changes that have been incorporated into the inverter design. Therefore, we will show the results of inverter efficiency testing which include all of the design changes to date.

A test of inverter efficiency was performed on the new SunSine inverter, Rev. 3, and the old inverter, a production unit of the SunSine300. The efficiency of each unit was measured from zero to full output power at a fixed input voltage of 51.0 volts. This voltage corresponds to the maximum power voltage of the PV laminate at STC conditions. These two inverter versions were tested with exactly the same test setup so that a comparison of efficiency could be as accurate as possible.

One reason for doing a comparison is that there is some uncertainty in the absolute accuracy of our test setup. Measurement of efficiency is rather difficult to do with absolute precision. The test equipment, however, is very good at producing repeatable results. It is estimated that the absolute precision of the efficiency measurement is +/- 2.0%. This is shown in the error bars in Figure 6.

At 275 Wac, the new inverter design is 4.7% more efficient than the SunSine300 inverter. At 300 Wac, this difference increases to 5.2%. This increase in performance at the higher power levels is achieved with some loss of efficiency at the lower power levels. The increase in efficiency has been achieved through changes in the transformer design, the implementation of soft switching in the power conversion stage and in a reduced number of components needed for EMI reduction. Note that at 275 Wac, the new transformer is 96.2% efficient. This means that at 275 Wac, the rest of the inverter, the power electronics, is 94.6% efficient!

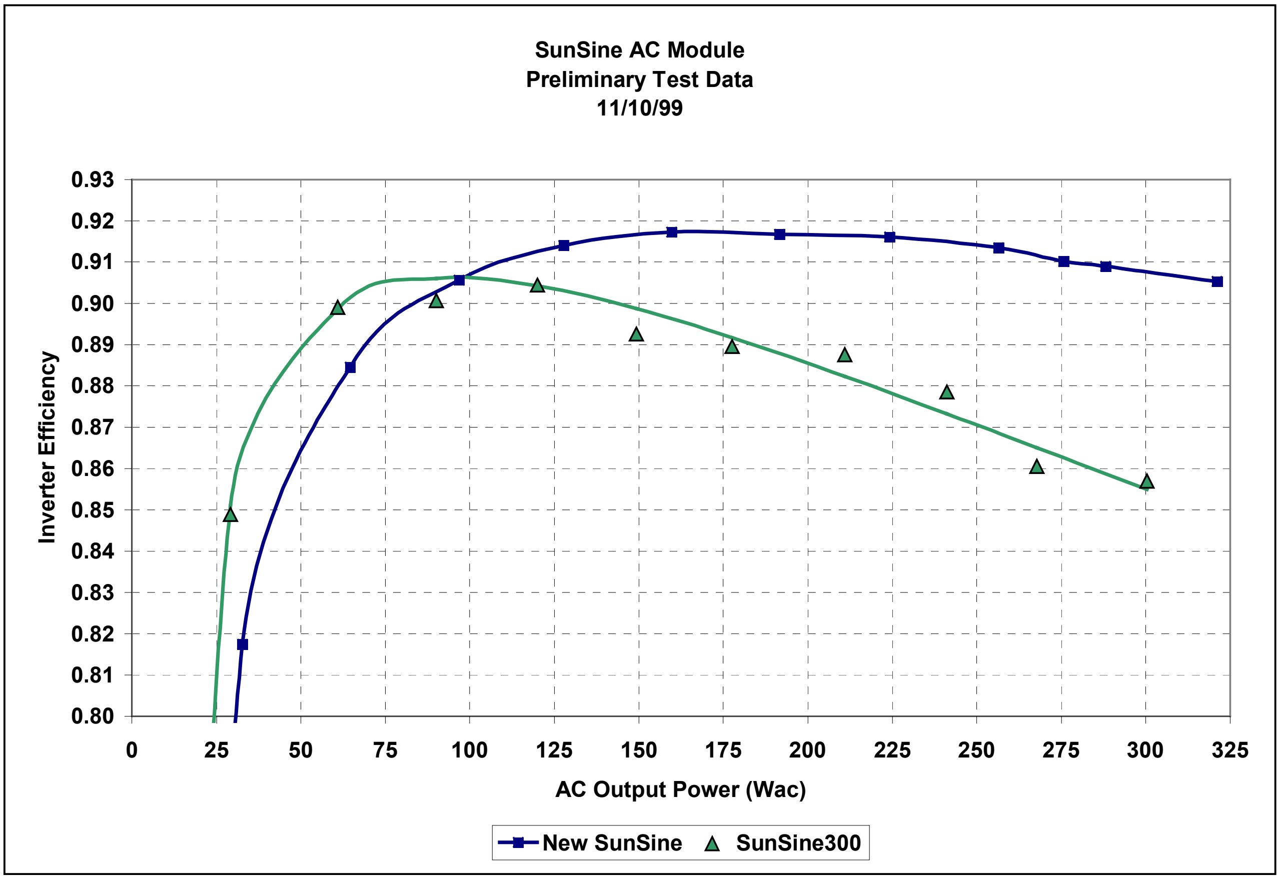

Figure 6. Comparison of inverter efficiencies: SunSine300 and the new SunSine.

Task 2 deliverables completed:

D-1.7 Prototype ac module for performance testing.

Task 2 Results Summary:

- power circuit board sized reduced 53%
- power circuit board component count reduced 34%
- total inverter parts count reduced 49%
- anticipated inverter manufacturing cost reduced 57% on a $\$/W_p$ rating
- transformer efficiency improved 1.4%
- inverter efficiency improved 4.7% to 91.0% at 275-W_{ac}

3.3 Task 3 – Manufacturing Process Improvements

Burn in testing, involving full-power operation for hours at a time to identify infant mortality, is being used less and less in modern production lines. If it can be eliminated from the production process, there will be savings in production cost for each unit, and every cost saving measure possible will be exploited in order to gain and maintain a competitive standing.

The Burn-in Test Station (BITS) will be used to conduct functional tests on 100% of the inverters coming out of pilot production. The purpose of this is to verify that production can meet the performance goals without burn in testing. When a sufficient number of inverters have passed BITS testing with no defects, we will discontinue BITS testing from the production process.

The BITS system is partially completed at this point, a picture of the computer controls appears in Figure 7.

Figure 7. Burn-In Test Station (BITS) computer controls

The power portion of the BITS was built at Omnion and will be shipped to Ascension Technology for production. A photo of the BITS test platform is shown in Figure 8.

Figure 8. Burn-In Test Station (BITS).

Inverter assembly has been simplified as well. There are fewer parts involved and hence fewer manual operations. Connectors are easier to access during assembly due to the new orientation of the circuit board. Thread-forming screws are used to eliminate machining operations in the casting and to eliminate the need for thread-locking hardware or compounds. The heat sink interface between the power semiconductors and the casting has been simplified to use far fewer components as well and requires a less labor to achieve.

Meetings were held with critical component vendors and production management to review the first prototype of the new inverter. These meetings generated very good feedback to the design process and the majority of the issues raised are being address to make the unit as easy as possible to manufacture. A review of the documentation needed to support manufacturing was also conducted. A plan has been developed to ensure proper manufacturing documentation is prepared and maintained.

A review of an automatic dispensing conformal coat process was conducted. A sample inverter, coated using this method, was subjected to a Highly Accelerated Stress Test, HAST. In this test, the unit is subjected to 110 °C temperature at 85% relative humidity for 200 hours. This test is conducted with power applied to most of the electrical circuits. Testing with electrical bias applied to the parts is considered to be an important factor in the test. The purpose of the test is to accelerate aging effects on the inverter components. When the unit was returned from the test it was found to still be operational, with no significant defects in the unit.

Since this conformal coat test was conducted, we have decided to change our approach in packaging the inverter. We will no longer use conformal coating of the main circuit board, but rather will encapsulate the circuit board in part of the die-cast housing.

3.3.1 Production Capacity

Burn-in testing has been identified as the bottleneck in the production process. Our original goal was to increase the throughput of burn-in testing from 2,500 units per year to 5,000 units per year by automating the BITS. We have since decided that we should aim for elimination of burn-in testing all together, but before we do that we need to make sure our production process is stable and catches all of the possible defects that burn-in testing would catch anyway. What is the impact on production capacity?

The PV modules come from ASE Americas, where they will soon have a production capacity of 20,000 300W modules per year. The circuit boards come from a contract manufacturer who has multiple lines, and each line could produce about 500 boards per day (estimated). At a capacity factor of 0.80 this would be 100,000 units per year with one line fully dedicated to the product. This assumes burn-in testing is not required. The die cast contractor will be able to fabricate between 250 to 500 units per day, so this represents a capacity of 50,000 to 100,000 units per year. So by choosing our critical component vendors wisely, we are able to avoid bottlenecks in our supply chain.

This leaves final assembly as the bottleneck to production capacity. At 5,000 units per year, this comes down to 100 units per week as a target final assembly rate. This rate seems achievable and we will know for sure what capacity we can achieve later in Phase II of this project.

Task 3 deliverables completed:

D-1.1 Report summarizing planned process modifications and anticipated improvements.

Task 3 Results Summary:

- We have decided to eliminate burn-in testing from the production process, removing a major bottleneck in production capacity, the remaining bottleneck in production capacity will be final assembly. Our target capacity will be 5,000 units per year.
- Before we remove burn-in from the production process, we will use the Burn-In Test Station to verify production boards meet specifications
- Software and hardware for the Burn-In Test Station has been completed to a level suitable for testing production boards.
- The conformal coat process was successfully tested using the HAST test process.

3.4 Task 4 – Smaller Packaging for SunSine Inverters

The original enclosure used for the inverter was from a low-yield sand casting process. As motioned in section 3.1, the new circuit board permits the design of a smaller casting, and the cost of the previous casting inspired the search for a better process. A new vendor has been found, working from a die-cast process that promises higher yields and lower cost. Higher tolerances and better surface finish quality are also improvements available from the die-cast process. Figures 9 and 10 show the old and new prototype castings.

The prototype casting developed during phase I is much larger than the final version will be. This is because our initial approach in designing the casting was to see if we could use the same design for multiple product versions. Those versions would have included products for U.S. and international markets, ac module and string inverter applications, and 320-W_{ac} and 500-W_{ac} ratings. After the prototype was completed we realized that there would be significant penalties for trying to design one casting for so many product versions. That, combined with our decisions on export markets, has led us to focus on the domestic ac module. The next and final casting design will be optimized to take advantage of the much smaller circuit board design. The final casting size is expected to meet our size reduction goal of 40%.

During this design process we have improved our ability to generate casting prototypes. A design firm and prototype casting vendor has been contracted who can produce the design drawings and prototypes with very good quality and turn around. A stereo lithography prototype of the design was made and provided to a prototype casting vendor who fabricated several prototype castings in aluminum. The prototype castings are made in a process that is fast and reasonably close to what can be done in die casting at a moderate cost. The purpose of making such prototypes will be to prove out the packaging concept for thermal, structural, watertight integrity and other UL and performance related issues.

Figure 9. Picture of a prototype SunSine Inverter Assembly. Note that there is plenty of room for size reduction. The wiring compartment on the bottom will also be removed from the final design.

Figure 10. SunSine Inverter Assembly, Old and New Prototype side by side.

Task 4 deliverables completed:

D-1.2 Summary of enclosure design specifications and relative improvments.
D-1.6 High quality digital photographs of enclosure prototype.

Task 4 Results Summary:

- A prototype casting was developed which is actually slightly larger than the original casting. By going through this design and prototyping process we have learned what is really important in the product design and will do one more revision of the design in Phase II to achieve a much smaller casting.
- We have learned how to design and create prototype aluminum castings at a moderate cost.

3.5 Task 5 – Export Versions of the SunSine AC Module

The purpose of this task was to determine if there are appropriate export markets for the new SunSine AC Module. If so, to determine the requirements for selling into those markets. The markets considered include, the United States, Canada, China, Europe, the United Kingdom, Australia, and Japan.

The requirements for the U.S. and Canada are very similar. Both operate at 120V 60Hz. Listing for safety is required and can be done through Underwriters Laboratory (UL). The listing marks are UL and UL-C. FCC Class B is the required level of EMI protection. Interconnect requirements are set by the new IEEE Standard 929-2000.

The requirements for selling products in China are somewhat difficult to meet. They typically require a high degree of in country content in products sold in their markets. Direct import of inverters or ac modules into China would be difficult to develop. Interconnect voltage and frequency is typically 220V 50Hz.

Europe includes Austria, Denmark, Germany, Italy, the Netherlands, Portugal, and Switzerland. The interconnect voltage is typically 230V 50Hz. Europe is marked by intense local competition and widely varying interconnect standards. Tens of inverter manufacturers exist competing for market share. For this reason, this would be a difficult market to penetrate. For example, Germany requires a specific impedance detection method for anti-islanding protection. This method would be quite costly to implement and would only be applicable to Germany. There is also some question as to how long this method will be required as the international community attempts to harmonize interconnection standards. It would be prudent to wait until harmonization of these standards is completed before attempting to enter European markets. UL is working to harmonize UL 1741 with the European standards. At present, CE marking is required for safety and EN 55022 also known as CISPR 22 B, is required for EMI protection.

The United Kingdom and Australia have similar requirements as Europe. Their interconnect voltage is 240V, 50Hz. In the U.K., CE marking is required and C-tick is required in Australia for safety. EN 55022 applies to EMI protection in the U.K. and Australia. So the safety and EMI requirements are similar to Europe.

Japan has been very proactive with respect to grid-tied PV. The interconnect voltage in Japan is 100V 50/60Hz. Half of the island operates at 50 Hz and the other half at 60 Hz. An ac module introduced into Japan should allow operation at either frequency. The transformer used in the U.S. version can also work in Japan without modification. The maximum output current of the ac module would remain the same but this means the maximum output power would have to be reduced. Fortunately there is sufficient headroom in the inverter design to allow this. The SunSine AC Module could be derated for operation in Japan to a maximum output of 275 W_{ac} which corresponds to the STC rating of the unit. Other specifications would be slightly modified due to normal operation at a lower voltage. The benefit is that the same hardware could be used for both Japanese and U.S. markets. The only difference would be in the programmable setpoints programmed into the unit.

During the course of Phase I we have decided to focus on U.S. markets. To optimize the product for our own domestic markets. Attempting to design one product for world markets at this point would impose added cost to units sold in the U.S. and slow down getting the new product into production. Only after establishing a solid customer base in the U.S. and increasing market share of domestic grid tied PV markets will we consider export markets.

Task 5 deliverables completed:

D-1.4	Outline of manufacturing process documentation.
D-1.5	Powerpoint presentation summarizing markets surveyed, market requirements, and performance specifications.

Task 5 Results Summary:

- Potential export markets have been identified, including safety and emissions requirements.
- We have decided to focus on getting the product ready for U.S. and Canadian markets first, and will address international markets second.
- The inverter has been designed so that it may be easily modified to work in international voltage and frequency versions.

4.0 Future Work and Developments for Phase II

4.1 Task 6 – Design for Die-Cast Enclosure and Base Plate

The die-cast enclosure design will be finalized for production. The final design can not be made until the inverter circuit design is more stable and further along in testing. The results of task 4 will be modified to achieve a smaller casting footprint on the PV module. The production processes for manufacturing our die-cast housing will be set up and an initial run of units will be made to support the pilot production run.

4.2 Task 7 –Integration, Testing and Listing / Certification

The results of tasks 1 through 5 will be combined to achieve a final inverter design. The design will undergo UL, HALT, EMC, surge and immunity testing. Based on the results of that testing, the design will be modified one final time so that the unit may meet the following criteria.

Table 2. SunSine AC Module Test Specifications
UL 1741, Safety
IEEE Standard 929-2000, Interconnect
NY State NYSERDA, Interconnect
IEEE-C62.41-1991, Surge Testing
IEEE-C62.45-1992, Surge Testing
TUV Q_{ht}, Reliability
FCC Class B, EMC
CISPR 22B, EMC & Immunity

4.3 Task 8 – Pilot Production Manufacturing Assessment

A pilot production run of 110 units will be conducted to assess the cost reductions and manufacturability of the new SunSine AC Module. Data will be collected from the production run using the BITS and other processes. One of the major goals of this task will be to determine if burn-in testing can be eliminated from the production process without detrimental impact on product quality or reliability.

4.4 Task 9 – Manufacturing Test Fixture Development

Test fixtures for testing boards in production will be developed to verify component stuffing, conductivity, calibration, and IEEE 929 voltage and frequency test requirements. We believe that with proper production testing we can eliminate the need for burn-in testing. Manufacturing process documentation will also be completed.

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13. ABSTRACT *(Maximum 200 words)*

This report summarizes the progress made by Ascension Technology in Phase I of the Cost Reduction and Manufacturing Improvements of the SunSine® AC Module. This work, conducted under NREL subcontract, is a two-phase effort consisting of investigations into improving inverter packaging, soft switching, circuit optimization, design for manufacturing, manufacturing processes, and pilot production manufacturing. The objective of this subcontract is to significantly reduce the cost of the SunSine® inverter, enhance its performance, and streamline and expand the manufacturing process. During Phase I, the soft-switching topology was designed, then refined to meet stringent cost and performance goals. This design resulted in improved performance, smaller overall footprint, and reduced costs. The aluminum inverter housing was redesigned, and the decision was made to conformal coat the circuit boards, which was verified through the HAST (Highly Accelerated Stress Testing) method. Potential international markets were identified, and the inverter is designed to be easily modified to meet the requirements of other countries.

Significant cost reduction and performance improvements have been achieved in Phase I, and accomplishments during Phase I include:

! SunSine® AC Module costs have been reduced enough that we expect to be able to reduce our suggested list price by 3.00 $\$/W_{ac}$ STC;
! successful implementation of soft-switching;
! power circuit-board size reduced 53%;
! power circuit-board component count reduced 34%;
! total inverter parts count reduced 49%;
! anticipated inverter manufacturing cost reduced 57% on a $\$/W_p$ rating;
! transformer efficiency improved 1.4%; and
! inverter efficiency improved 4.7% to 91.0% at 275 W_{ac}.

14. SUBJECT TERMS
photovoltaics ; Photovoltaic Manufacturing Technology ; PVMaT ; modules ; module manufacturing ; SunSine® ; cost reduction ; inverter ; soft switching

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