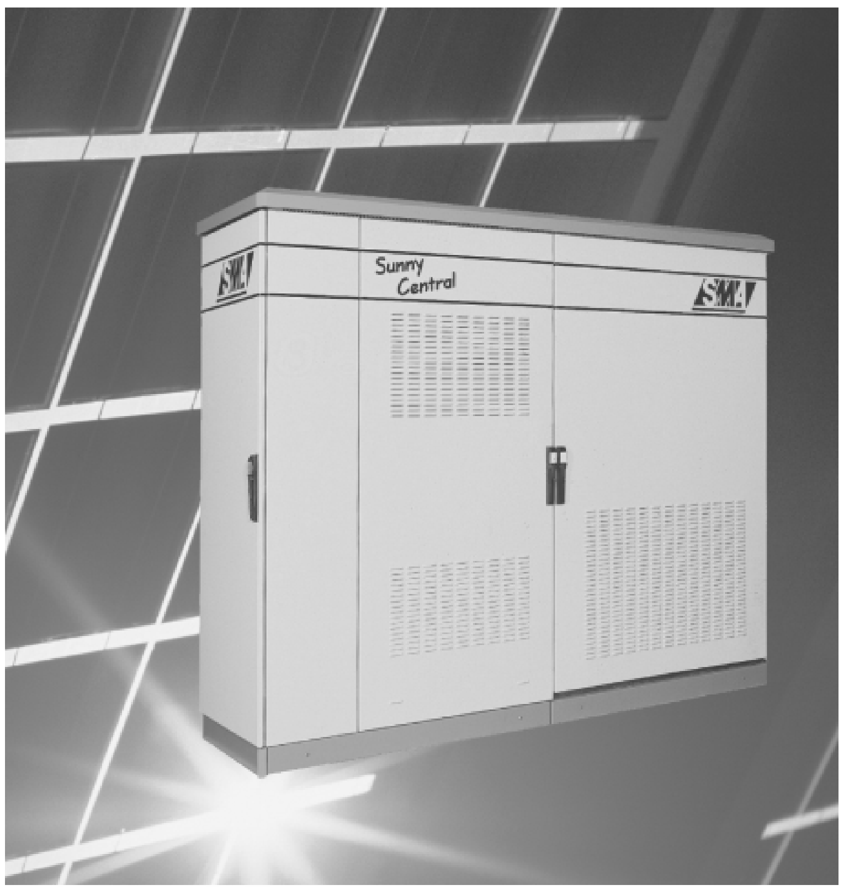
White Paper

Advantages of the Sunny Central 125 kW Grid-Tied PV Inverter



Overview

SMA America previewed the Sunny Central (SC) 125 kW, grid-tied, photovoltaic (PV) inverter at the UPEx 2003 trade show in Austin, TX. Since then, SMA America has received many inquiries regarding the availability (beginning of 2004) and functionality of this new model and what its advantages are over other inverters available today. This white paper answers these and other frequently asked questions by describing the Sunny Central's advanced functionality.

Background

In Europe, the grid-tied PV market consists almost exclusively of small residential and commercial systems comprising string inverters. In this market, there is occasionally a demand for a larger, 'central' inverter. To meet this demand, SMA Germany introduced the Sunny Central family for the European market. This family of inverters is available in 60, 90, 150, 200, 250, 400, and 500 kW models. Last year, SMA America requested a similar inverter designed specifically for the US market. SMA Germany, in collaboration with SMA America, adapted the European Sunny Central inverter designs and developed the US Sunny Central 125 to meet US market and regulatory requirements.

The following is a list of the major advantages that the Sunny Central has over other central, grid-tied, PV inverters available in the US:

- Isolation transformer is integrated within the inverter enclosure
- Total energy production is increased by greater than 3%
- Inverter energy efficiency increased by 5% compared to inverters with external isolation transformers
- Includes Sunny Boy Control Plus advanced data-acquisition and control system, which is compatible with all SMA communication products
- Complies with FCC-A noise-emission standard, which is required for all US installations
- Rugged stainless-steel and aluminum enclosure
- NEMA4 (sensitive electronics) and Nema3R (magnetics) outdoor rated
- Advanced Maximum Peak Power Tracker (MPPT) algorithm

Integrated Isolation Transformer

Because NEC690-5 requires that PV arrays be electrically grounded, galvanic isolation between the PV DC and utility AC power systems is necessary. The Sunny Central accomplishes this with a high-efficiency, 480 Vac, WYE transformer for interconnection with common, 3-phase utility services. The transformer is mounted within the main enclosure to allow the inverter to control and disconnect it when there is no PV-array power. Other large PV inverters also require an isolation transformer, but only the Sunny Central has one built into the control system. With other inverters, the isolation transformer must be specified and purchased separately. While acquiring a suitable isolation transformer may seem like a simple task, high-efficiency, 480 Vac, WYE transformers are not common in the utility industry. They are available only as custom-built units, which means that long lead times, high initial cost, and installation costs must also be considered. Installation may require pouring an additional concrete pad, running large conduit between the inverter and the transformer, pulling large-gauge wire, and a master electrician to wire everything together and to the utility grid while maintaining proper phase rotation. The additional time and cost required for specification, procurement, installation and the resulting schedule impact are factors that must also be considered.

Increased High-Efficiency Energy Production

When the isolation transformer is installed as a separate unit that is not controlled by the inverter system, it is energized 24 hours per day. Losses through an unloaded isolation transformer at night are quite large, as shown in the following example.

> **Note:** In response to a paper written in behalf of Xantrex by BEW Engineering, this section has been modified. The BEW paper makes the case that a utility customer is not responsible for paying for VAR current caused by reactive loads such as isolation transformers. This is not entirely true. Many customers are charged for VAR consumption, depending on the customer's utility rate structure. This is very common with industrial and commercial accounts, which already have large VAR loads. These customers also happen to be the most common customers for large grid tied PV.
>
> The BEW paper illustrates that real power (Watts) consumed by the idle isolation transformer of the Xantrex inverter is trivial on a cost-of-energy basis. Unfortunately, this also illustrates that the value of the energy produced by a PV system is trivial, and a PV system is not a sound economical decision.
>
> SMA America takes the other side of this argument. We believe PV power has great value. Most customers decide to install PV systems to offset their energy usage. These customers are often billed at a high rate tier, with time-of-use and VAR surcharges. Choosing a PV system that actually consumes more energy when it is not running seems counter-intuitive to us. This energy loss and hit to system efficiency is completely unnecessary and must be considered financially when choosing an inverter.
>
> **First, let's look at this from a simple, non-analytical point of view. What is better: To consume large amounts of energy by not disconnecting the PV system transformer at night, or disconnect it and not waste that energy? This is the basic issue, and the correct answer is obvious. Bottom line: A PV system is sized by the KW the customer wants to generate to offset loads and/or feed back to the grid.**

In the following examples we have used data from the BEW/Xantrex paper for the PV100-208 to keep the comparisons in these examples the same.

Example #1: Overall Inverter and Transformer Efficiency

This example considers the impact of transformer losses on the inverter efficiency value. Inverter efficiency is a major factor when considering a PV inverter. In California, the CEC uses the manufacturer's stated efficiency to determine the dollar amount of the system rebate they will pay. Unfortunately, the CEC trusts the manufacturer to provide this number. In the case of the Xantrex PV Series inverters, this number is listed at 96% efficient. This is the peak efficiency of the inverter alone at 75% of rated power. The required isolation transformer is not included in this value. Since a transformer is required with every PV Series inverter installation, the efficiency of the transformer should be included in the stated efficiency value. Most manufacturer's include the transformer in their efficiency number, which makes their inverters look worse than PV Series. This issue has been known for some time, and we believe Xantrex is intentionally taking advantage of the CEC program. There needs to be a level playing field and a standard for determining efficiency of inverters qualifying under CEC and other state incentive programs.

Furthermore, the Xantrex PV Series data sheet lists the family of inverters (and specifically the PV100) at 95% peak efficiency, and 93% peak efficiency with the isolation transformer included. We do not know why there is a discrepancy between their published data sheet and the CEC efficiency number. The Xantrex document also acknowledges that there are additional losses caused by the isolation transformer.

Assumptions:

- Transformer efficiency at 75% (75kW) of full load: 97.8% or 1650 Watts (from the transformer manufacturer)
- Inverter efficiency: 95% (from Xantrex PV Series published data sheet)

$$\frac{1.65kW}{75kW} = 2.2\% \ \textit{transformer loss (or 97.8\% efficient)}$$

$$\textit{Total Efficiency}:$$

$$95\% * 97.8\% = 92.9\% \ \textit{inverter and transformer operating efficiency}$$

Considering this additional efficiency loss on the system, the inverter operating efficiency with transformer is now approximately 93%.

Now, let's calculate what this does to the California CEC rebate. This comparison assumes a $7.00 per watt system install cost and a 50% rebate. At 96% and 93%:

$$100kW \times \underline{\underline{0.96\,eff}} \times \$7.00 = \$672{,}000$$

$$\$672{,}000 \times 50\% = \$336{,}000 \ \textit{rebate}$$

$$100kW \times \underline{\underline{0.93\,eff}} \times \$7.00 = \$651{,}000$$

$$\$658{,}000 \times 50\% = \$325{,}500 \ \textit{rebate}$$

$$\$336{,}000 - \$325{,}500 = \$10{,}500 \ \textit{rebate difference}$$

The question that should be asked is: Should the California rate payers be responsible for paying this $10,500 difference?

Example #2: Impact of Nighttime Tare Losses on Total Inverter Energy Efficiency

Since the transformer consumes energy every night, transformer nighttime tare losses should also be included in the inverter efficiency value.

Assumptions:

- Inverter and transformer efficiency is assumed constant at 92.9% (from Example 1). Actual average inverter efficiency will be lower, as inverters are less efficient at low power.
- Typical site solar-insolation level: 5 sun-hours per day. This is the equivalent number of full-power hours of sun on a fixed-plane-mounted PV array. Even though the sun energizes the PV array approximately 10 hours per day, it does not energize the PV array to full power during most of that time, because the sun is not shining perpendicular to the PV modules.
- No-load inverter and transformer losses: 1090 Watts (from BEW/Xantrex paper, also typical of an 80° C rise, copper wound, 480 Vac, 112.5 kVA isolation transformer)
- Inverter shut-down time: 13 hours per day (from BEW/Xantrex paper)
- Inverter peak AC power output: 100 kW
- Installed cost of PV: $7.00 per Watt

Transformer nighttime kWHr losses:

$$1090\,W \times 13\,Hrs = 14.2\,kWHrs$$

Typical daily kWHr production (rated inverter power times hour of operation less the transformer efficiency):

$$100kW \times 5\,Hrs \times 0.978 eff = 489 kWHrs \;\; per \;\; day$$

Resultant total kWHrs per day less nighttime tare losses:

$$489\,kWHr - 14.2kWHr = 474.8\,kWHrs$$

Total daily energy efficiency of the PV100-208 with nighttime tare losses included:

$$\frac{14.2kWHr}{474.8kWHr} = 3.0\% \;\; system \;\; energy \;\; loss \;\left(or \;\; 97\% \;\; efficient)\right)$$

$$Total \;\; Efficiency:$$

$$92.9\% * 97\% = 90.0\% \;\; total \;\; daily \;\; system \;\; energy \;\; efficiency$$

90% is the total inverter system efficiency when all inverter related losses are considered across a typical solar day. This value is quite a bit lower than the CEC value of 96%.

Now, let's consider how this affects the California CEC rebate. This comparison assumes a $7.00 per watt system install cost and a 50% rebate. At 96% and 90%:

$$100\ kW \times \underline{\underline{0.96 eff}} \times \$7.00 = \$672,000$$

$$\$672,000 \times 50\% = \$336,000\ \ rebate$$

$$100 kW \times \underline{\underline{0.90\ eff}} \times \$7.00 = \$630,000$$

$$\$630,000 \times 50\% = \$315,000\ \ rebate$$

$$\$336,000 - \$315,000 = \$21,000\ \ rebate\ difference$$

This makes the additional California rebate quite large because of inadequate inverter efficiency numbers. Should the California rate payers be responsible for paying this $21,000 difference as well?

Example #3: Equivalent Installed PV Cost to Offset Nighttime Transformer Losses

The big question is how much it will cost to install additional PV panels to offset the nighttime losses of the isolation transformer? Most PV systems are initially designed to generate a specific number of kWHrs per year. The losses from the isolation transformer must be considered in the initial system design; otherwise, the system will not produce as much energy as was originally expected. Bottom line: A PV system is sized by the KW the customer wants to generate. Ignoring nighttime transformer losses will lead to an underperforming PV system, and a disappointed customer.

Assumptions:

- Installed cost of PV: $6.30 per Watt. This is the cost for installing the PV panels alone. Inverter and AC installation costs are estimated at 10% of the total system cost or $0.70 per watt, and are not included in this example.
- Typical site solar-insolation level: 5 sun-hours per day.

From Example #2, 3% of the energy (14.2kWHrs) produced by the PV system is consumed by the isolation transformer each night. If you were to enlarge the PV array to make up for the lost energy, it would cost:

$$\frac{14.2\,kWHrs}{5\,Hrs} \times \$6.30 = \$17,892 \text{ cost of PV to offset transformer losses}$$

The additional costs to upgrade the inverter and energy-delivery system to compensate for the additional energy are not factored into this amount. Not only does a PV system with a Sunny

Central inverter produce significantly more energy throughout a 24-hour day, but the installation cost to produce the same amount of energy is also dramatically lower. This savings could also be considered an additional rebate on the inverter.

Integrated Data-Acquisition System

Every Sunny Central inverter is shipped with a Sunny Boy Control Plus (SBC+) monitoring and data-acquisition system installed in the user-interface enclosure as standard equipment. The system is modified with special software for additional control and protection of the Sunny Central inverter.

Real-time operating parameters for each Sunny Central inverter are viewable on the SBC+'s 4-line, liquid-crystal display. The SBC+ also includes separate PC and external display interfaces. Remote communication is available by adding an analog modem. Ethernet ports will also be available.

The SBC+ can be configured to store individual and cumulative PV-plant data in user-defined, averaged time intervals (DAS). It is capable of storing 100,000 data points between downloads. The total storage duration varies with the averaging period and the number of data points (channels) stored. Data in the SBC+ is overwritten in a first-in-first-out (FIFO) manner.

The SBC+ also has two user-programmable, signal-level, dry-contact relay outputs. These can be programmed to change state if a fault or system warning occurs, or they can be set to be dependent on an operating parameter threshold (e.g., power output).

The SBC+ is equipped with additional analog and digital ports for external sensors and internal data logging functions:

- 5 user-defined analog inputs (e.g., irradiance, temperature sensor, shunts, etc.)
- 2 PT100 temperature inputs
- 1 dry-contact output for failure indication

The SBC+ may also be used to adjust certain system operating parameters.

SMA Net Communication Protocol

The communication protocol used in the SC and SBC+ is the same protocol used in all other SMA products. This means Sunny Boy inverters can be included on the same communication bus with the SBC+. The SBC+ can share a common communication bus with up to 50 other SBC+ devices (50 other Sunny Central or Sunny Boy inverters). SMA America strongly recommends using an RS485, drop-network communication bus, although powerline can be used with proper line couplers, traps, and filters. However, powerline is prone to external interference, which is especially common in industrial and commercial environments.

FCC-A Noise Emissions Compliance

The Sunny Central is certified and compliant with the requirements of Federal Communications Commission Part 15, Subpart B for Class A digital devices. The FCC considers inverters to be unintentional radiators. This standard applies to all residential and commercial applications and requires inverters to limit both conducted and radiated radio frequency emissions. In the past, the US photovoltaic industry has largely ignored this Federal requirement. Failure to comply with FCC requirements creates a significant liability risk for the system integrator. If a device has not been certified and is found to be in violation of FCC Part 15, the first remedy is to require the system operator to cease operation. The system must then be brought into compliance before it is allowed to resume operation. Compliance testing in the field is extremely difficult, expensive, and time-consuming. In contrast, inverters that have been tested and certified are allowed to continue to operate while other remedies are explored.

Rugged Construction

The Sunny Central's enclosure and hardware are constructed from stainless steel and aluminum. The enclosure is also powder coated to provide an additional level of protection in the harshest of environments. The enclosure is a DIN rack system that provides strength and modularity while ensuring that the cabinet remains square and properly aligned. All access doors are can be locked with the keys provided with the unit; the doors are easy to operate and never need to be aligned.

Every wire inside the Sunny Central is banded with a locator number. Every component is labeled with an identifier referencing it to the schematic. Every control wire is terminated with a ferrule crimp lug to insure component connections remain tight and secure.

Poor crimp connections are the main cause of thermal failure and fire in power electronics. To prevent these types of failures, SMA does not use welding wire and crimp lugs anywhere in the power path. All power conductors are laminated bus wire, reducing the number of connections and failure points in the power path. The bus wire is connected directly to the component tabs, so there is no crimping, no heat shrink tubing, and no melting and dripping insulation from overheated lugs. Bus wire prevents another major cause of catastrophic failures by remaining rigid for life. It never sags, thus preventing contact with surfaces and sharp edges that can cause the insulation to cold-flow and allow metal-to-metal contact and catastrophic failure.

NEMA4/3R Outdoor Rated Enclosure

The Sunny Central's enclosure is divided into three compartments: The user-interface, power-electronics, and magnetics compartments. Both the user-interface and power-electronics compartments are fully sealed from the outside elements to an NEMA4 equivalent. Heat generated by the power-electronics components is transferred to the outside environment by means of a temperature-regulated, air-to-air heat exchanger. This ensures that the internal cabinet temperature remains cool for the sensitive control electronics and prevents dust, debris, humidity, insects, and rodents from entering and compromising sensitive electronics. The less-sensitive magnetics compartment is protected to a NEMA3R equivalent. Cool outside air is pulled into the magnetics enclosure by means of a series of three temperature-regulated fans that turn on only when needed. The Sunny Central is perfectly suited for installation in harsh outdoor environments.

Advanced Peak Power Tracker

The Sunny Central inverter incorporates the same advanced Maximum Peak Power Tracker (MPPT) that's been proven throughout the world in over 100,000 Sunny Boy inverters. This MPPT is historically the most accurate and stabile in the industry, thus providing maximum capture of available solar power.

Convenient User Interface Enclosure

The user-interface enclosure is conveniently located on the left side of the Sunny Central inverter. It contains the SBC+ data-acquisition system, PC interface, AC and DC-disconnect switches, main and control-power circuit breakers, analog and digital I/O interface, PV-input terminals, and AC utility-interconnection terminals. Everything is clearly labeled and easy to access. There are provisions for AC and DC-conduit entry from the bottom or the rear of the interface enclosure. Up to four parallel conductors may be connected to each PV terminal.

Availability

The SC125 is currently undergoing UL1741 evaluation. SMA America expects completion in March 2004. First shipments are also scheduled for March 2004. Please contact SMA America for further information.

Contact Information

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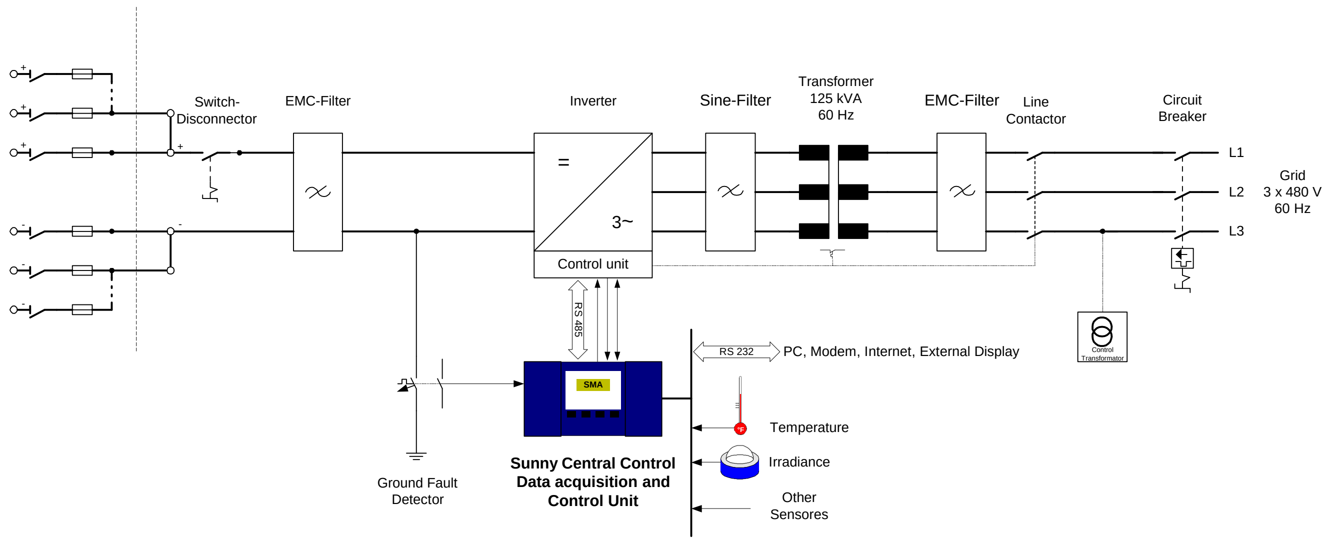
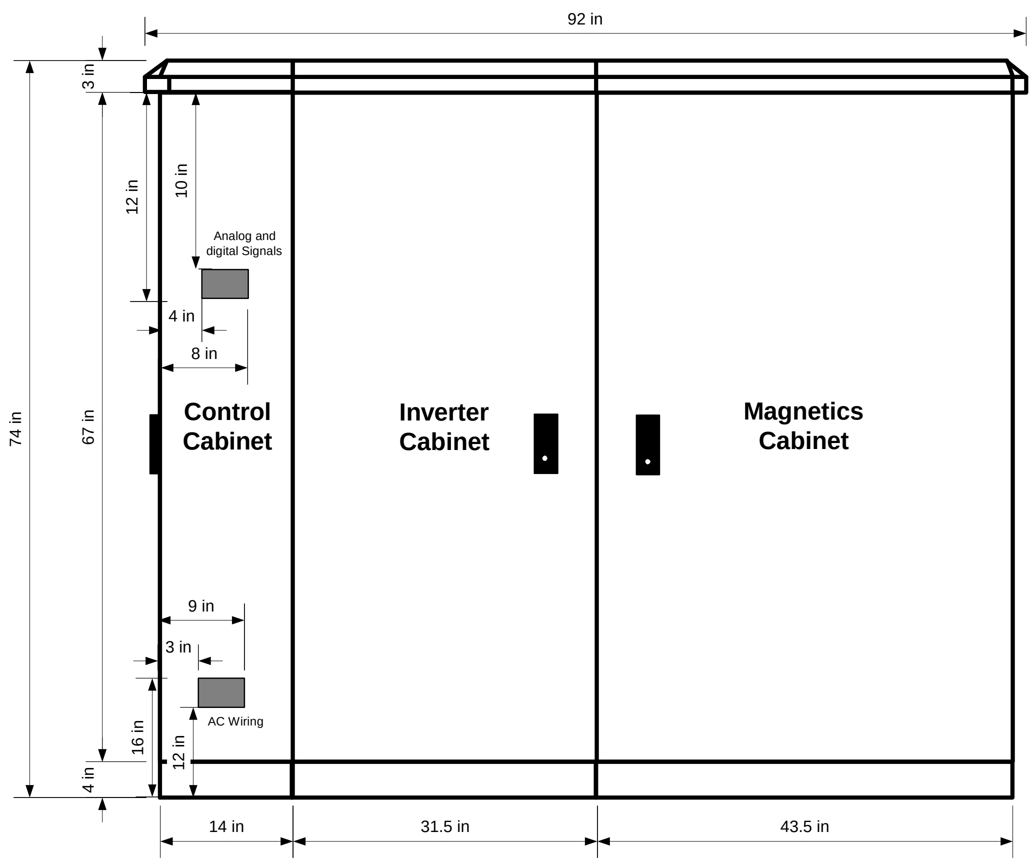
Technical Specifications

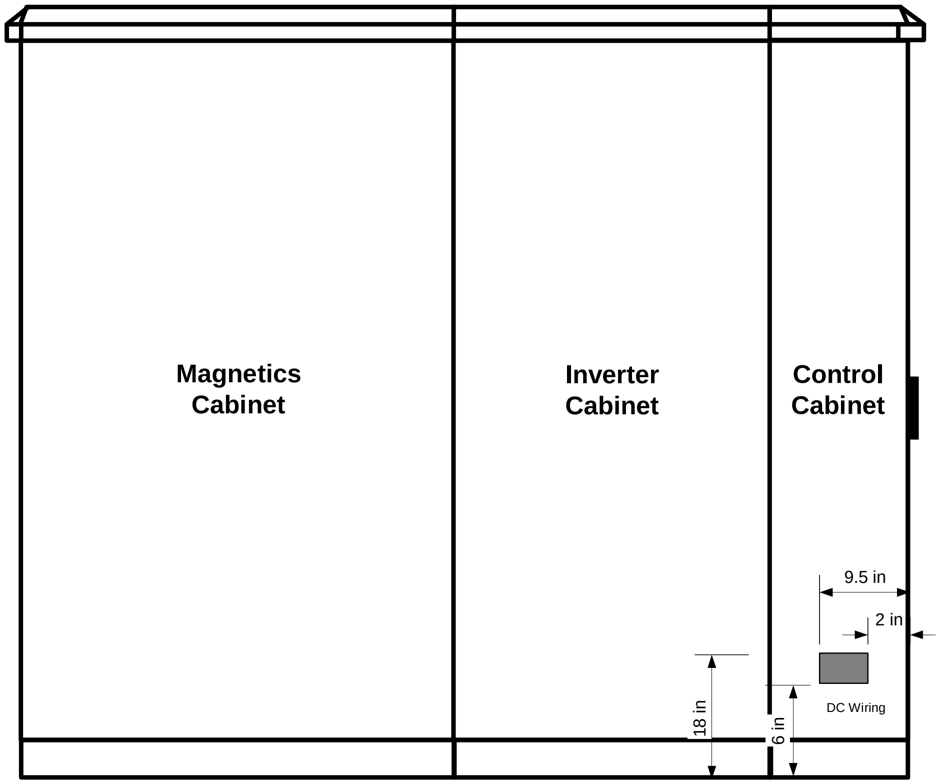
Inverter Technology	True sine wave, current source, high frequency PWM
AC Input Voltage	422 - 528 Vac (480 Vac nominal)
AC Input Frequency	59.3 - 60.5 Hz (60 Hz nominal)
DC Input Voltage	275 - 600 Vdc
Peak Power Tracking Voltage	275 - 600 Vdc
Nominal AC Power Output	125 kW (at 45 °C)
Maximum AC Output Current	180Aac
Current THD	Less than 4%
Power Factor	Unity
Peak inverter efficiency	95.7% (including grid transformer, with fans off) 95.7% (including grid transformer, with fans on)
Cooling	Forced-fan cooling with optional sealed heat exchanger
PV Start Voltage	300 Vdc (adjustable)
Maximum DC current	420 Adc
DC Voltage Ripple (peak to peak)	< 3%
Power consumption	110 W standby
Ambient temperature	–25°C +50°C
Enclosure	Bridge NEMA 4 Main enclosure NEMA 3R, powder coated, stainless steel and aluminum
Size	2350 W x 1800 H x 600 D mm (93 W x 71 H x 24 D in.)
Weight	1500 kg (3300 lbs)
Certifications	FCC part 15 compliant IEEE 519/929 compliant

Block Diagram



Dimensions




Magnetics Cabinet
Inverter Cabinet
Control Cabinet
9.5 in
2 in
DC Wiring
18 in
6 in

Revision History			
Rev. No.	**Date**	**By**	**Reason**
1.0	March 4, 2003	Kent Sheldon	Original draft
1.1	July 15, 2003	Mike Brazil	First edit
1.2	August 1, 2003	Kent Sheldon	Second edit
1.3	August 15, 2003	Kent Sheldon	Third edit
1.4	August 17, 2003	Mike Brazil	Fourth edit
1.5	September 1, 2003	Kent Sheldon	Final release edits
1.6	February 19, 2004	Kent Sheldon	Transformer calculation updates
1.7	February 25, 2004	Kent Sheldon	Update efficiency calc’s with Xantrex data
1.8	March 3, 2004	Kent Sheldon	Technical data update and minor calculation correction.

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