Chapter 8

Inverters

Definitions and Terminology ● Types and Applications ● Functions and Features ● Selection and Sizing ● Monitoring and Communications
Overview

- Defining the purpose for inverters in PV systems and other applications.

- Identifying basic electrical properties, waveforms and their characteristics relative to inverter design and operation.

- Explaining the basic types of inverter circuit designs and their components.

- Understanding the differences in operating principles and specifications for stand-alone and interactive inverters.

- Identifying key specifications and ratings for interactive inverters required for systems design and installation.
Inverters are used in PV systems to convert direct current (DC) power from batteries or PV arrays into alternating current (AC) power.

Other inverter applications include:
- Fuel cells
- Wind turbines and microturbines
- Variable-frequency drives
- Uninterruptible power supplies
- Electronic ballasts and induction heaters
- HVDC power transmission
Inverters are used in PV systems to convert direct current (DC) power from batteries or PV arrays into alternating current (AC) power.

The first inverters/converters used motor-generator sets, but were costly, heavy and inefficient.

Modern inverters use solid-state designs and microprocessor controls to produce high quality AC power very efficiently.
Basic electrical properties and principles are fundamental to understanding how inverters are designed and operate, including:

- Direct current and alternating current
- Waveform types and parameters
- Power and energy
- Ohm’s law
- Single-phase and three-phase power
- Resistive and reactive loads
- Real, apparent and reactive power
- Power quality
Direct current (DC) is a unidirectional flow of electrical charge that does not vary in polarity between positive and negative values over time.

Solar cells and batteries are examples of DC devices.
- Most electronic circuits also operate on DC power.

DC circuits are defined by a positive and negative polarity, or poles. Electrons flow in one direction.
Alternating Current (AC)

- Alternating current (AC) is an oscillating flow of electrical charge that periodically changes direction over time.

- In an AC circuit, the two poles alternate between negative and positive, continually reversing direction of the electron flow.

- The changing polarity of AC over time is what distinguishes it from DC.
A waveform is a graphical representation of how electrical properties vary over time, for example with current and voltage.

Current and voltage for both DC and AC circuits can be mathematically described by their waveform.

A periodic waveform repeats itself at regular intervals.

A cycle is a complete waveform set that repeats itself over time.
DC Waveforms

- Full wave rectifier
- Half wave rectifier
- Battery

Time >
AC Waveforms

- Sine Wave
- Modified Square Wave
- Square Wave

Time >
A sine wave is a periodic waveform commonly associated with rotating generators and AC power systems.
AC Waveform Properties

At frequency of 60 Hz, period is 1/60 sec (16.67 msec)

Voltage

Time = 0

Amplitude (peak)

One Cycle = 360 deg or 2π radians of phase angle

Peak to Peak

170 V peak

120 V rms

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Frequency

- Frequency is the number of alternating current waveform cycles that repeat in one second, expressed in units of hertz (Hz).

- The frequency of the U.S electric grid is maintained at 60 Hz, while 50 Hz is used in Europe and Asia.

- Frequency establishes the speed of AC motors and generators, and a critical parameter in synchronizing electrical utility systems.

- The period is the time it takes a waveform to complete one full cycle before it repeats itself.
  - Period is the inverse of frequency.
Peak and RMS Voltages

Sine wave has \( V_{\text{peak}} = V_{\text{RMS}} \times \sqrt{2} \)

Square wave has \( V_{\text{peak}} = V_{\text{RMS}} \)

One cycle: 360°
True RMS Meters

Fluke 179

Fluke 337

Fluke 87V
Resistive Circuits

Phase angle between current and voltage waveforms equals zero, and power factor equals unity.

One cycle: 360°

Voltage

Current

Power

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Inductive Circuits

One cycle: 360°

Positive >> << Negative

Voltage
Current
Power

Phase angle between current and voltage waveforms greater than zero, power factor is less than unity.

Positive power consumed by load

Negative power returned to source

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Inductive Circuits

Animation

current
voltage
AC loads are designed to operate at prescribed voltage, phase and frequency.

Power quality are effects that alter a nominal waveform characteristics, including:

- Power factor
- Voltage regulation (sag and surges)
- Frequency regulation
- Voltage and phase imbalance
- Harmonic distortion
Oscilloscopes and Power Quality Analyzers

Fluke 190 ScopeMeter®

Fluke 43B Power Quality Analyzer

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Harmonics

Time > 3\textsuperscript{rd} harmonic 5\textsuperscript{th} harmonic

Fundamental frequency

Combination of fundamental & 3\textsuperscript{rd} and 5\textsuperscript{th} harmonic
Power and Energy

- **Power is the rate of transferring work or energy**, and analogous to:
  - An hourly wage ($/hr)
  - Speed of a vehicle (mi/hr)
  - Water flow (gal/hr)

- **Energy is the total amount of work performed over time**, and analogous to:
  - Income earned ($)
  - Distance traveled (mi)
  - Water volume (gal)
Power and Energy

- Electrical power is expressed in units of watts (W).
  - 1 megawatt (MW) = 1,000 kilowatts (kW) = 1,000,000 watts (W)

- Electrical energy is expressed in units of watt-hours (Wh).
  - 1 kilowatt-hour (kWh) = 1000 Wh

\[ E = P_{avg} \times t \]

where

- \( E \) = energy (Wh)
- \( P_{avg} \) = average power (W)
- \( t \) = time (hrs)
Ohm’s law defines the relationships between voltage, current and resistance in electrical circuits.

By definition, a current of one ampere passing through a resistance of one ohm results in a potential difference of one volt.
- 1 Volt = 1 Amp x 1 Ohm

Ohm's law can be expressed in various forms:

- \[ V = I \times R \]
- \[ I = \frac{V}{R} \]
- \[ R = \frac{V}{I} \]

where
- \( V \) = voltage (V)
- \( I \) = current (A)
- \( R \) = resistance (Ω)
In DC circuits, electrical power is equal to the product of the voltage and current:

- Power (W) = Voltage (V) x Current (A)

Power can be calculated in different ways using Ohm’s law:

\[
P = V \times I \\
P = I^2 \times R \\
P = \frac{V^2}{R}
\]

where

- \( P \) = power (W)
- \( V \) = voltage (V)
- \( I \) = current (A)
- \( R \) = resistance (Ω)
Ohm’s Law Wheel

<table>
<thead>
<tr>
<th>Voltage (volts)</th>
<th>Resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{V}{I} )</td>
<td>( \frac{P}{V} )</td>
</tr>
<tr>
<td>( \frac{P}{I} )</td>
<td>( \frac{I^2}{R} )</td>
</tr>
</tbody>
</table>

- Voltage: \( V \)
- Resistance: \( R \)
- Current: \( I \)
- Power: \( P \)
The calculation of real power in AC circuits takes into account the phase angle difference between the current and voltage waveforms.

In AC circuits, the product of RMS voltage and current is called apparent power:

\[ \text{Volts} \times \text{Amps} = \text{Apparent Power (VA)} \]

Power factor is the ratio of real power to the apparent power and equal to the cosine of the phase angle:

\[ \text{PF} = \cos \theta \]

In 3-phase circuits:

\[ P = V \times I \times \cos \theta \times \sqrt{3} \]

where

- \( P \) = power (W)
- \( V \) = voltage (V)
- \( I \) = current (A)
- \( \theta \) = phase angle (deg)
- \( \cos \theta \) = power factor (0-1)
Power Triangle

Apparent Power, $S$ (volt-amperes, VA)

Reactive Power, $Q$ (volt-amperes reactive, VAR)

True Power, $P$ (watts, W)

\[ S = \sqrt{P^2 + Q^2} \]
Transformers are used in PV inverters to convert AC voltage from one level to another and to isolate the DC input from and AC output.
Transformers

- The turns ratio is the ratio of the number of coils in a transformer’s primary and secondary windings, and defines the ratio of primary and secondary voltages.

- For an ideal transformer, the ratio of the currents in the primary and secondary circuits is inversely proportional to the turns ratio.

\[
\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}
\]

where
- \(N_1\) and \(N_2\) = number of turns in primary and secondary windings
- \(V_1\) and \(V_2\) = voltage in primary and secondary windings
- \(I_1\) and \(I_2\) = voltage in primary and secondary windings
Autotransformers can be used to adjust inverter AC output voltage from one level to another, but provide no isolation because they use the same winding.

Primary: 240 V
Secondry: 208 V
Types of Power Systems

- Single-Phase Systems
  - Spilt-phase systems are commonly used for residential and small commercial electrical services derived from a single-phase source.

- Three-Phase Systems
  - Wye “Y” or “star” configuration
  - Delta “Δ” configuration

An understanding of different types of electrical services and their compatibility with inverter output specifications is an important aspect of designing and installing grid-connected PV systems.
Single-phase power sources have only one voltage waveform.

Split-phase power systems are single-phase power systems providing multiple load voltages by center-tapping distribution transformers.
Three-Phase Power

Phase angle between voltage waveforms in 3-phase motors and generators is 120 degrees.

At 60 Hz = 1 cycle takes 1/60 second
**Wye “Y” Configuration**

- Phase and line currents are always equal.
- For a balanced load, the line voltage between any two phases is equal to the phase voltage $\times \sqrt{3}$.

![Diagram of a Wye Configuration with labels and connections: A, B, C, L1, L2, L3, N, 120 V, 208 V, I_A, I_B, I_C, I_N. The diagram illustrates the currents and voltages in a Wye configuration with 4-Wire, 120V/208V.]
**Delta “Δ” Configuration**

- Line voltage and phase voltages are equal.
- For a balanced load, the line current is equal to the phase current \( \times \sqrt{3} \).
Wye and Delta Configurations

4-Wire, 120208 V - Wye “Y”

3-Wire, 240 V Delta “Δ”
A high-leg delta configuration center taps one winding for a ground and neutral connection, providing 120 V and 240 V single-phase and 240 V three-phase.
Three-Phase Power

Animation
Inverters produce AC power output from DC power input using different circuit designs and components.
Switching Elements

Metal-Oxide Field-Effect Transistors (MOSFETs)

Thyristors and Silicon Controlled Rectifiers (SCRs)

Insulated Gate Bi-polar Transistors (IGBTs)
Switching Control

- **Line-commutated inverters** use an external source, such as the utility grid to trigger switching elements and synchronize their output.
  - Used for grid-connected inverters only.

- **Self-commutated inverters** control switching elements and regulate their waveform output with internal software and controls.
  - Used for stand-alone or interactive inverters.
H-Bridge Inverter

H-Bridge Square Wave Inverter

Positive (+)

Negative (-)

DC input

AC output

1

2

3

4
H-Bridge Square Wave Inverter

For 60 Hz, 1 cycle is \( \frac{1}{60} \)th second, switching occurs every \( \frac{1}{30} \)th second.

Switches 1 and 4 closed, 2 and 3 open

Switches 1 and 4 open, 2 and 3 closed

DC input (blue line)

AC output (red line)

\( \wedge \) Positive

\( \wedge \) Negative

Current

0

One cycle

Time >>
H-Bridge Inverter

H-Bridge Square Wave Inverter

DC input

Positive (+)

Negative (-)

AC output

Animation
This H-bridge inverter converts 12 VDC into a 120 VAC square wave using a transformer with a 10:1 turns ratio.
Push-Pull Modified Square Wave Inverter

- Positive (+) input
- Negative (-) input
- Current flow with SW1 closed, SW2 open
- Current flow with SW1 open, SW2 closed
- Shorting winding
- AC output

SW1

SW2

Transformer
Low-frequency inverter designs use an H-bridge or push-pull inverter circuit, and the resulting AC output is stepped up to higher voltages through a transformer.
PWM control regulates the RMS voltage output by varying the width of the output signal depending on peak voltage available from the source.
Multistage Low-Frequency Inverters

Multistage inverter designs use parallel circuits to synthesize true sine waves.
Pulse-width-modulation (PWM) control is used to simulate multi-step AC sine waves by superimposing square waves of varying amplitude and width.
High frequency inverters use DC-DC converters and smaller transformers, resulting in highly efficient and lightweight designs.
Types of PV Inverters

- **Stand-Alone Inverters**
  - Operate from batteries and supply power independent of the utility grid.

- **Utility-Interactive or Grid-Connected Inverters**
  - Operate from PV arrays and supply power in parallel with the utility grid.

- **Bi-Modal or Battery-Based Interactive Inverters**
  - Operate as diversionary charge controllers, and produce AC power output to regulate PV array battery charging when the grid is energized.
  - Transfer PV system operation to a stand-alone mode and provide backup electric power to critical loads when the utility grid is not energized.
Stand-Alone & Interactive Inverters

Stand-Alone Operation with Battery as DC Power Source

- Battery
- Stand-Alone Inverter
- AC Load

AC load is limited by inverter power rating

Interactive Operation with PV Array as DC Power Source

- PV Array
- Interactive Inverter
- Utility Grid

PV array size is limited by inverter power rating
Stand-Along Inverters

- Stand-alone inverters use batteries for DC power input
  - PV arrays or other DC sources are used to charge the battery independently.
  - Common DC input voltage 12 V, 24 V and 48 V for residential application, up to 480 V for industrial applications.

- Supply power to AC loads isolated from the grid; inverter power rating dictates maximum AC load.

- Often include battery charger function for utilizing an independent AC input source (e.g., generator or grid)
  - Can not synchronize with and feed power back into the grid.

- Output power rating must be at least equal to the single largest connected load [NEC 690.10].
Stand-Alone Inverters

PV Array → Charge Controller → DC Load

Battery

Stand-Alone Inverter/Charger

AC Load

AC Source (to Charger Only)
Stand-Alone Inverters
Interactive inverters use PV arrays for DC power input, and supply synchronized AC output power in parallel with the utility grid.

Site AC loads may be served by the inverter output, utility or both. Excess power not needed by local loads flows to the grid.

- Power ratings limit the size of the connected PV array; output is independent of loads.

All listed interactive inverters produce utility-grade sine wave output and include anti-islanding safety features to de-energize inverter output to the grid upon loss of grid voltage.
Utility-Interactive Inverters

- PV Array
- Interactive Inverter
- Load Center
- AC Loads
- Electric Utility
Types of Interactive Inverters

- **Module-Level Inverters**
  - 200-300 W, includes AC modules and micro inverters integral to or installed at the PV module level.

- **String Inverters**
  - 2-12 kW, designed for residential and small commercial applications using 1-6 series-connected PV array source circuits.

- **Central Inverters**
  - 30-50 kW up to 500 kW, designed for commercial applications with homogeneous arrays.

- **Utility-Scale Inverters**
  - 500 kW to 1 MW, designed for solar farms.

- **Bimodal Inverters**
  - 2-10 kW, battery-based interactive inverters that provide grid backup to critical loads.
Module-Level Inverters

- AC modules are factory-integrated PV modules with interactive inverters.

- Micro inverters are similar in concept but are separate equipment.

- Typically 200-300 W rated maximum AC output (approx. PV module size).

- Used primarily for residential and small commercial applications, and can achieve greater energy harvest from partially shaded and multi-directional arrays.
String Inverters

String inverters are small inverters in the 1 to 12 kW size range, intended for residential and small commercial applications.

- Generally single-phase, usually limited to 1 to 6 parallel-connected source circuits, or “strings”.
- Some integrate source circuit combiners, fuses and disconnects into a single unit.
Central inverters start at 30-50 kW up to 500 kW, and interconnect to 3-phase grids.

- Best suited for homogeneous PV arrays having all the same modules and source circuit configurations, and aligned and oriented in the same direction with no shading.
Most commercial PV inverters up to 500 kW installed on public and private properties are interconnected to the grid at service voltages less than 600 VAC.

- These systems must comply with NEC requirements and use listed inverters and other equipment.
- PV arrays are less than 600 VDC.

Large inverters 500 kW to 1 MW and higher used in PV power plant installations are interconnected to the grid at distribution voltages up to 38 kV.

- For utility-controlled sites, certain variances with the NEC and product listing requirements may apply.
- PV arrays may operate up to 1000 VDC.
Utility-scale inverters use higher DC input and AC output voltages to reduce losses, and the size and costs of the conductors and switchgear required.
- DC input from PV arrays 900 to 1000 VDC
- AC output to grid at distribution level voltages up to 35 kV.

Packaged systems include inverters, transformers, switchgear, climate-controlled enclosure and mounting platform as a pre-engineered unit.
Bimodal Inverters

- Bimodal inverters use batteries for DC power input and may operate in either interactive or stand-alone mode.

- In interactive mode, the inverter produces AC power output in proportion to PV array production, while maintaining a prescribed maximum battery voltage.

- Upon loss of grid voltage, the inverter automatically transfers to stand-alone mode, and powers backup loads isolated from grid.

- Bimodal inverters may also include load control, battery charging, and generator starting functions.
Bimodal Inverters

Backup AC Loads

Critical Load Sub Panel

Bimodal Inverter/Charger

Primary AC Loads

Main Panel

PV Array

Charge Control

Battery

Electric Utility

Bypass circuit

AC Out

AC In

DC In/out
Inverter Selection

- Selecting and specifying the best inverter for a given application involves considering the system design and installation requirements.
  - Inverter specification sheets are critical.

- Inverter selection is often the first consideration in system design, and based on:
  - The type of electrical service and voltage.
  - Anticipated size and locations of the array.

- For interactive inverters, optimal DC ratings for the PV array are 110-130% of the inverter maximum continuous AC power output rating.
Stand-alone and interactive inverters have similar but different specifications due to their different application.

Standard specifications for all types of inverters include:

- AC output power ratings
- DC input voltage
- AC output voltage
- Power conversion efficiency
Interactive Inverter Specifications

- **DC Input**
  - Maximum array voltage (open-circuit, cold)
  - Recommended maximum array power
  - Start voltage and operating range
  - MPPT voltage range
  - Maximum usable input current
  - Maximum array and source circuit current
  - Ground fault and arc fault detection

- **AC Output**
  - Maximum continuous output power
  - Maximum continuous output current
  - Maximum output overcurrent device rating
  - Power quality
  - Anti-islanding protection
Interactive Inverter Specifications

- **Performance**
  - Nominal and weighted efficiencies
  - Stand-by losses (nighttime)
  - Monitoring and communications interface

- **Physical**
  - Operating temperature range
  - Size and weight
  - Mounting locations, enclosure type
  - Conductor termination sizes and torque specifications
  - Conduit knockout sizes and configurations

- **Other Features**
  - Integral DC or AC disconnects
  - Number of source circuit combiner and fuse/circuit ratings
  - Standard and extended warranties
**Inverter Standards**

- **UL Std. 1741 Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources**
  - Applies to both stand-alone and interactive inverters.

- **IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems**
  - Applies to interactive inverters and systems.

- **National Electrical Code (NEC), NFPA 70**
  - Applies to all inverters and PV system installations.
Both stand-alone and interactive inverters are rated for their maximum continuous AC power and current output over a specified temperature range.

Inverter power ratings are limited by the temperature of their switching elements. Larger inverters use cooling fans.

- Stand-alone inverters limit power output by disconnecting AC loads when their maximum DC input current is exceeded.

- Interactive inverters limit their maximum power output by tracking the PV array off its maximum power point.
Inverter Power Ratings

Stand-Alone Operation with Battery as DC Power Source

Battery → Stand-Alone Inverter → AC Load

AC load is limited by inverter power rating

Interactive Operation with PV Array as DC Power Source

PV Array → Interactive Inverter → Utility Grid

PV array size is limited by inverter power rating

Vs.

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For stand-alone inverters, the DC input voltage is based on a nominal battery voltage:
- Inverters less than 1 kW may use a 12 V battery, while large inverters use a nominal DC bus voltage of 24 V, 48 V or higher.

For interactive inverters, the DC input voltage covers a wide range (usually over 200 V) that permits the connection of different voltage arrays operating under a wide temperature range.
- String sizing is used to match the array voltage and size to the inverter DC input requirements.

The AC output voltage for all inverters is based on common electrical system configurations and ANSI standards.
Inverter efficiency varies with power level, input voltage and temperature, among other factors.

Inverter efficiency is calculated by the AC power output divided by the DC power input:

\[
\eta_{inv} = \frac{P_{AC}}{P_{DC}} = \frac{5700}{6000} = 0.95 = 95\%
\]

where
\[
\eta_{inv} = \text{inverter efficiency} \\
P_{AC} = \text{AC power output (W)} \\
P_{DC} = \text{DC power input (W)}
\]
Inverter efficiency testing is conducted over a range of operating voltages and power levels.
All interactive inverters employ maximum power point tracking (MPPT) functions to extract maximum output from PV arrays.
- Some inverters use MPPT at the source circuit or subarray level to maximize array output.

MPPT is not usually incorporated in battery-based inverters, although some charge controllers provide MPPT functions.
Most interactive inverters allow configurations for grounding either the positive or negative pole of the PV array.

- Performance enhancements are achieved with certain PV modules using a ground reference (SunPower).
Grounded vs. Ungrounded Arrays

- The grounding method for PV arrays affects the design of inverter switching, as well as overcurrent protection and fault detection for the system.

- All U.S. inverters prior to 2010 use a grounded DC current-carrying conductor from the array (positive or negative).

- Ungrounded PV arrays are permitted by the NEC, and can help facilitate fault detection within the array. Special requirements apply to these inverters and systems.
Bipolar inverters use two monopole PV subarrays for DC input, with a positive and negative pole, and a center tap ground.

- 1200 VDC maximum voltage to inverter bus.
- +600 VDC and -600 VDC PV output circuits referenced to ground.
- Conductors and equipment need only be rated for 600 V if the PV output circuits for each monopole arrays are run in separate conduit.
Interactive PV inverters from 700W to 500 kW

Stand-alone inverters 5 kW

www.sma-america.com

SMA America Family of Inverters
Sunny Boy 2000HFUS / 2500HFUS / 3000HFUS

- Residential string inverter
- 2-3 kW AC output
- Integrated DC disconnect
- Positive or negative ground
- Indoor and outdoor rated
- High-frequency, lightweight
- 10 year standard warranty
# Sunny Boy 2000HFUS / 2500HFUS / 3000HFUS

<table>
<thead>
<tr>
<th>Feature</th>
<th>SB 2000HFUS</th>
<th>SB 2500HFUS</th>
<th>SB 3000HFUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended max. PV power (modules at STC)</td>
<td>208 V 2500 W</td>
<td>208 V 3125 W</td>
<td>208 V 3750 W</td>
</tr>
<tr>
<td></td>
<td>240 V 600 V</td>
<td>240 V 600 V</td>
<td>240 V 600 V</td>
</tr>
<tr>
<td>Max. DC voltage</td>
<td>600 V</td>
<td>600 V</td>
<td>600 V</td>
</tr>
<tr>
<td>PV voltage range, MPPT*</td>
<td>175 V - 480 V</td>
<td>215 V - 480 V</td>
<td>220 V - 480 V</td>
</tr>
<tr>
<td>DC Minimum Start Voltage</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Max. input current</td>
<td>12.2 A</td>
<td>12.4 A</td>
<td>14.8 A</td>
</tr>
<tr>
<td>Number of MPP trackers / max. number of strings (parallel), extendable</td>
<td>1 / 2</td>
<td>1 / 2</td>
<td>1 / 2</td>
</tr>
<tr>
<td>Nominal AC power / max. AC power</td>
<td>2000 W / 2000 W</td>
<td>2500 W / 2500 W</td>
<td>3000 W / 3000 W</td>
</tr>
<tr>
<td>Max. output current</td>
<td>10.0 A / 8.5 A</td>
<td>12.0 A / 10.4 A</td>
<td>14.4 A / 12.5 A</td>
</tr>
<tr>
<td>Nominal AC voltage range</td>
<td>183 V - 229 V</td>
<td>183 V - 229 V</td>
<td>183 V - 229 V</td>
</tr>
<tr>
<td>Nominal AC voltage / automatic grid type detection</td>
<td>208 V &amp; 240 V / ●</td>
<td>208 V &amp; 240 V / ●</td>
<td>208 V &amp; 240 V / ●</td>
</tr>
<tr>
<td>THD of grid current</td>
<td>&lt; 4%</td>
<td>&lt; 4%</td>
<td>&lt; 4%</td>
</tr>
<tr>
<td>AC grid frequency: nominal / range</td>
<td>60 Hz / 59.3 - 60.5 Hz</td>
<td>60 Hz / 59.3 - 60.5 Hz</td>
<td>60 Hz / 59.3 - 60.5 Hz</td>
</tr>
<tr>
<td>Power factor (cos ϕ)</td>
<td>0.99 at nominal power</td>
<td>0.99 at nominal power</td>
<td>0.99 at nominal power</td>
</tr>
<tr>
<td>Max. efficiency*</td>
<td>&gt; 95.5%</td>
<td>&gt; 95.5%</td>
<td>&gt; 95.5%</td>
</tr>
<tr>
<td>CEC*</td>
<td>≥ 95%</td>
<td>≥ 95%</td>
<td>≥ 95%</td>
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Inverters: 8 - 85
## Sunny Boy 2000HFUS / 2500HFUS / 3000HFUS

<table>
<thead>
<tr>
<th>Feature</th>
<th>SB 2000HFUS</th>
<th>SB 2500HFUS</th>
<th>SB 3000HFUS</th>
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<tbody>
<tr>
<td>Certification*</td>
<td>UL1741, UL1998 IEEE 1547</td>
<td>UL1741, UL1998 IEEE 1547</td>
<td>UL1741, UL1998 IEEE 1547</td>
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<tr>
<td>DC reverse polarity protection</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>AC short-circuit protection</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Dimensions [W x H x D] in inches</td>
<td>13.7 x 28.6 x 7.2</td>
<td>13.7 x 28.6 x 7.2</td>
<td>13.7 x 28.6 x 7.2</td>
</tr>
<tr>
<td>Packing dimensions in inches</td>
<td>17.7 x 23.6 x 15.7</td>
<td>17.7 x 23.6 x 15.7</td>
<td>17.7 x 23.6 x 15.7</td>
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<tr>
<td>Weight*</td>
<td>&lt; 50 lbs</td>
<td>&lt; 50 lbs</td>
<td>&lt; 50 lbs</td>
</tr>
<tr>
<td>Operating temperature range (CEC)</td>
<td>-13 °F to 113 °F</td>
<td>-13 °F to 113 °F</td>
<td>-13 °F to 113 °F</td>
</tr>
<tr>
<td>Consumption: (standby) operation / night</td>
<td>&lt; 5 W / ≤ 0.25 W</td>
<td>&lt; 5 W / ≤ 0.25 W</td>
<td>&lt; 5 W / ≤ 0.25 W</td>
</tr>
<tr>
<td>Topology</td>
<td>HF-transformer</td>
<td>HF-transformer</td>
<td>HF-transformer</td>
</tr>
<tr>
<td>Cooling concept*</td>
<td>TBD</td>
<td>OptiCool</td>
<td>OptiCool</td>
</tr>
<tr>
<td>Installation location: indoor / outdoor (NEMA 3R)</td>
<td>●/●</td>
<td>●/●</td>
<td>●/●</td>
</tr>
<tr>
<td>Graphic display</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Interfaces: Bluetooth® / RS485</td>
<td>●/O</td>
<td>●/O</td>
<td>●/O</td>
</tr>
<tr>
<td>Warranty: 10 years / 15 years / 20 years</td>
<td>●/O/O/0</td>
<td>●/O/O/0</td>
<td>●/O/O/0</td>
</tr>
</tbody>
</table>
- 3 to 8 kW single-phase string inverters.
- Integrated load-break rated DC disconnect with fused combiner.
- Tower configuration allows 6 inverters to connected to 3-phase systems.
SMA Sunny Boy 6000US
Configurations and Label

AC power, voltage and current ratings

DC voltage and current ratings

Locations and configuration for GFID fuse and array grounding.

Listed interactive inverter
SMA Sunny Boy 6000US
Wiring Terminals

GFID and grounding configuration

DC input terminals

AC output terminals

© 2012 Jim Dunlop Solar
SMA Sunny Boy 6000US
Internal Components

- DC input capacitors
- Monitoring display
## Sunny Boy Specifications

### 5000 US / 6000 US / 7000 US

<table>
<thead>
<tr>
<th>Input Data (DC)</th>
<th>Sunny Boy 5000US</th>
<th>Sunny Boy 6000US</th>
<th>Sunny Boy 7000US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended Max. PV Power (Module STC)</td>
<td>6250 W</td>
<td>7500 W</td>
<td>8750 W</td>
</tr>
<tr>
<td>Max. DC Voltage</td>
<td>600 V</td>
<td>600 V</td>
<td>600 V</td>
</tr>
<tr>
<td>Peak Power Tracking Voltage</td>
<td>250 – 480 V</td>
<td>250 – 480 V</td>
<td>250 – 480 V</td>
</tr>
<tr>
<td>DC Max. Input Current</td>
<td>21 A</td>
<td>25 A</td>
<td>30 A</td>
</tr>
<tr>
<td>Number of Fused String Inputs</td>
<td>3 (inverter), 4 x 15 A (DC disconnect)</td>
<td>3 (inverter), 4 x 15 A (DC disconnect)</td>
<td>3 (inverter), 4 x 15 A (DC disconnect)</td>
</tr>
<tr>
<td>PV Start Voltage (adjustable)</td>
<td>300 V</td>
<td>300 V</td>
<td>300 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output (AC)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Nominal Power</td>
<td>5000 W</td>
<td>6000 W</td>
<td>7000 W</td>
</tr>
<tr>
<td>AC Maximum Output Power</td>
<td>5000 W</td>
<td>6000 W</td>
<td>7000 W</td>
</tr>
<tr>
<td>AC Nominal Voltage / Range</td>
<td>183 – 229 V @ 208 V, 211 – 264 V @ 240 V, 244 – 305 V @ 277 V</td>
<td>183 – 229 V @ 208 V, 211 – 264 V @ 240 V, 244 – 305 V @ 277 V</td>
<td>183 – 229 V @ 208 V, 211 – 264 V @ 240 V, 244 – 305 V @ 277 V</td>
</tr>
<tr>
<td>AC Frequency / Range</td>
<td>60 Hz / 59.3 – 60.5 Hz</td>
<td>60 Hz / 59.3 – 60.5 Hz</td>
<td>60 Hz / 59.3 – 60.5 Hz</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.99 @ nominal power</td>
<td>0.99 @ nominal power</td>
<td>0.99 @ nominal power</td>
</tr>
</tbody>
</table>
### Sunny Boy Specifications

#### 5000 US / 6000 US / 7000 US

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>5000 US</th>
<th>6000 US</th>
<th>7000 US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Inverter Efficiency</td>
<td>96.8 %</td>
<td>97 %</td>
<td>97.1%</td>
</tr>
<tr>
<td>CEC Weighted Efficiency</td>
<td>95.5 %</td>
<td>95.5 % / 95.5 % / 96 %</td>
<td>95.5 % / 96 % / 96 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical Data</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions W x H x D in Inches</td>
<td>18.4 x 24.1 x 9.5</td>
<td>18.4 x 24.1 x 9.5</td>
<td>18.4 x 24.1 x 9.5</td>
</tr>
<tr>
<td>Weight / Shipping Weight</td>
<td>141 lbs / 148 lbs</td>
<td>141 lbs / 148 lbs</td>
<td>141 lbs / 148 lbs</td>
</tr>
<tr>
<td>Ambient Temperature Range</td>
<td>-13 to +113 °F</td>
<td>-13 to +113 °F</td>
<td>-13 to +113 °F</td>
</tr>
<tr>
<td>Power Consumption: standby / nighttime</td>
<td>&lt; 7 W / 0.1 W</td>
<td>&lt; 7 W / 0.1 W</td>
<td>&lt; 7 W / 0.1 W</td>
</tr>
<tr>
<td>Topology</td>
<td>Low frequency transformer, true sinewave</td>
<td>Low frequency transformer, true sinewave</td>
<td>Low frequency transformer, true sinewave</td>
</tr>
<tr>
<td>Cooling Concept</td>
<td>OptiCool, forced active cooling</td>
<td>OptiCool, forced active cooling</td>
<td>OptiCool, forced active cooling</td>
</tr>
<tr>
<td>Mounting Location In-/Outdoor (NEMA 3R)</td>
<td>Included/Included</td>
<td>Included/Included</td>
<td>Included/Included</td>
</tr>
</tbody>
</table>
## Sunny Tower 36 / 45

<table>
<thead>
<tr>
<th>Input Data (DC)</th>
<th>Sunny Tower 36</th>
<th>Sunny Tower 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Recommended Array Input Power (DC @ STC)</td>
<td>45.0 kW</td>
<td>52.5 kW</td>
</tr>
<tr>
<td>Max. DC Voltage</td>
<td>600 V</td>
<td>600 V</td>
</tr>
<tr>
<td>Peak Power Tracking Voltage</td>
<td>250 - 480 V</td>
<td>250 - 480 V</td>
</tr>
<tr>
<td>DC Max. Input Current</td>
<td>150 A</td>
<td>180 A</td>
</tr>
<tr>
<td>DC Voltage Ripple</td>
<td>&lt; 5%</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Number of Fused String Inputs</td>
<td>24 x 15 A (AC/DC disconnect)</td>
<td>24 x 15 A (AC/DC disconnect)</td>
</tr>
<tr>
<td>PV Start Voltage (adjustable)</td>
<td>300 V</td>
<td>300 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output Data (AC)</th>
<th>Sunny Tower 36</th>
<th>Sunny Tower 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Nominal Power</td>
<td>36.0 kW</td>
<td>42.0 kW</td>
</tr>
<tr>
<td>AC Maximum Output Power</td>
<td>36.0 kW</td>
<td>42.0 kW</td>
</tr>
<tr>
<td>AC Maximum Output Current (per phase @ 208, 240, 277 V)</td>
<td>100 A, 87 A, 44 A</td>
<td>117 A, 101 A, 51 A</td>
</tr>
<tr>
<td>AC Nominal Voltage / Range</td>
<td>183 - 229 V @ 208 V</td>
<td>183 - 229 V @ 208 V</td>
</tr>
<tr>
<td></td>
<td>211 - 264 V @ 240 V</td>
<td>211 - 264 V @ 240 V</td>
</tr>
<tr>
<td></td>
<td>244 - 305 V @ 277 V</td>
<td>244 - 305 V @ 277 V</td>
</tr>
<tr>
<td>AC Frequency / Range</td>
<td>60 Hz / 59.3 Hz - 60.5 Hz</td>
<td>60 Hz / 59.3 Hz - 60.5 Hz</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.99 @ nominal power</td>
<td>0.99 @ nominal power</td>
</tr>
</tbody>
</table>
## Sunny Tower 36 / 45

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Sunny Tower 36</th>
<th>Sunny Tower 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Inverter Efficiency</td>
<td>97 %</td>
<td>97.1 %</td>
</tr>
<tr>
<td>CEC Weighted Efficiency</td>
<td>95.5 % @ 208 V, 240 V 96 % @ 277 V</td>
<td>95.5 % @ 208 V 96 % @ 240 V, 277 V</td>
</tr>
</tbody>
</table>

### Mechanical Data

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Sunny Tower 36</th>
<th>Sunny Tower 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions W x H x D in inches</td>
<td>43.3 x 70.5 x 39</td>
<td>43.3 x 70.5 x 39</td>
</tr>
<tr>
<td>Weight / With 6 Inverters</td>
<td>330 lbs / 1176 lbs</td>
<td>330 lbs / 1176 lbs</td>
</tr>
<tr>
<td>Shipping Weight in lbs.</td>
<td>500 lbs / 1388 lbs</td>
<td>500 lbs / 1388 lbs</td>
</tr>
<tr>
<td>Ambient Temperature Range</td>
<td>-13 to +113 °F</td>
<td>-13 to +113 °F</td>
</tr>
<tr>
<td>Power Consumption: standby/nighttime</td>
<td>&lt; 42 W / 0.6 W</td>
<td>&lt; 42 W / 0.6 W</td>
</tr>
<tr>
<td>Topology</td>
<td>Low frequency transformer, true sinewave</td>
<td>Low frequency transformer, true sinewave</td>
</tr>
<tr>
<td>Cooling Concept</td>
<td>OptiCool, forced active cooling</td>
<td>OptiCool, forced active cooling</td>
</tr>
<tr>
<td>Mounting Location Indoor/Outdoor (NEMA 3R)</td>
<td>included/included</td>
<td>included/included</td>
</tr>
</tbody>
</table>
SUNNY CENTRAL 250U / 500U

- 250 kW and 500 kW AC power output.
- 97% weighted efficiency with integrated isolation transformer.
- Graphical LCD interface.
- Optional combiner boxes.
- Install indoors or outdoors.
# Sunny Central 250U / 500U

## Input data
- Max. PV power (recommended): 295 kW
- DC voltage range MPPT: 330 V - 600 V
- PV start voltage (Configurable from 300 - 600 V): 400 V
- Max. permissible DC voltage: 600 V
- Max. permissible DC current: 800 A
- Number of DC inputs / connection point: 6 / DC fuse

## Output data
- Nominal AC output power: 250 kW
- Operating grid voltage: 480 V WYE / Δ
- Nominal AC current: 300 A (at 480 V)
- AC frequency (nominal): 60 Hz
- Power factor: > 0.99
- Harmonic distortion of grid current: < 5%
- Power consumption:
  - Internal consumption in operation: < 1000 W
  - Internal consumption in Standby: < 69 W

## Mechanics
- Width / height / depth (in): 110 / 80 / 33
- Weight: 4200 lbs

## Efficiency
- Peak efficiency: 97.5%
- CEC weighted efficiency: 97.0%
- Euro-Eta: 96.6%

## Permits
- Certificates: UL 1741, UL 1998, IEEE 1547
- EMC: FCC Part 15 Class A
- Ambient conditions:
  - Ambient temperature: -4 °F to 113 °F
  - Max. Temperature for fuse: 113 °F
  - Enclosure: NEMA 3R
  - Rel. humidity: 15% ... 95%

---

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Inverters: 8 - 96

---

SMA
500 kW high-frequency design, lower weight.
Sample System Diagram

SUNNY CENTRAL 500HE-US

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Satcon PowerGate Plus Inverters

- 30 kW to 1 MW inverters for commercial, utility scale and hybrid off-grid applications.

- [www.satcon.com](http://www.satcon.com)
# Utility-Scale Inverters

## Satcon Prism Platform

## 1MW MV System Electrical Specifications

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Array Configuration</td>
<td>Positive Ground</td>
</tr>
<tr>
<td></td>
<td>Negative Ground</td>
</tr>
<tr>
<td>Maximum Array Input Voltage</td>
<td>600 VDC</td>
</tr>
<tr>
<td>Input Voltage Range (MPPT, Full Power)</td>
<td>320 – 600 VDC</td>
</tr>
<tr>
<td>Maximum Input Current</td>
<td>1628A (per 500kW)</td>
</tr>
<tr>
<td>Combiner Option</td>
<td>60 inputs total (max) per 1 MW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter Output Voltage Range</td>
<td>200 VAC delta – 176 – 220 VAC</td>
</tr>
<tr>
<td>Transformer – HV Rating and Winding Configuration</td>
<td>To be specified by customer</td>
</tr>
<tr>
<td>Output Frequency Range</td>
<td>59.5 Hz – 60.5 Hz</td>
</tr>
<tr>
<td>Max Inverter Output Current per Phase</td>
<td>1443A (per 500kW)</td>
</tr>
<tr>
<td>Inverter CEC-Weighted Efficiency</td>
<td>97%</td>
</tr>
<tr>
<td>Transformer Representative Efficiency</td>
<td>&gt; 99% @ 50% Load</td>
</tr>
<tr>
<td>Maximum Continuous Output Power</td>
<td>1,000 kW</td>
</tr>
<tr>
<td>Default Power Factor</td>
<td>&gt;0.99 (Adj. 0.80 leading, -0.80 lagging)</td>
</tr>
<tr>
<td>Harmonic Distortion</td>
<td>&lt;3% THD</td>
</tr>
</tbody>
</table>

## Temperature

- Operating Ambient Temperature Range (Full Power): -20°C to +50°C

## Dimensions and Weight

- Shipping Dimensions: 22’ 2” L x 8’ 5” W x 8’ 7” H
- Weight: 28,000 lbs
Interactive PV inverters from 2-12 kW

IG Plus units have separable wiring compartment and inverter power stage, includes internal DC disconnect and source circuit fuses.

High frequency, multi-stage design and smaller transformers yield low weight, 95%+ efficiency

www.fronius.com
### Fronius IG Plus

#### Output Data

<table>
<thead>
<tr>
<th>INPUT DATA</th>
<th>Fronius IG Plus</th>
<th>3.0-1 уни</th>
<th>3.8-1 уни</th>
<th>5.0-1 уни</th>
<th>6.0-1 уни</th>
<th>7.5-1 уни</th>
<th>10.0-1 уни</th>
<th>11.4-1 уни</th>
<th>11.4-3 Delta</th>
<th>12.0-3 WYE277</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended PV-Power (Wp)</td>
<td></td>
<td>2500-3450</td>
<td>3200-4400</td>
<td>4250-5750</td>
<td>5100-6900</td>
<td>6350-8600</td>
<td>8500-11500</td>
<td>9700-13100</td>
<td>9700-13100</td>
<td>10200-13800</td>
</tr>
<tr>
<td>MPPT-Voltage Range</td>
<td></td>
<td></td>
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<tr>
<td>DC Startup Voltage</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Input Voltage (at 1000 W/m²)</td>
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<td></td>
<td></td>
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<tr>
<td>14°F (-10°C) in open circuit operation</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal Input Current</td>
<td></td>
<td>8.3 A</td>
<td>10.5 A</td>
<td>13.8 A</td>
<td>16.6 A</td>
<td>20.7 A</td>
<td>27.8 A</td>
<td>31.4 A</td>
<td>31.4 A</td>
<td>33.1 A</td>
</tr>
<tr>
<td>Max. usable Input Current</td>
<td></td>
<td>14.0 A</td>
<td>17.8 A</td>
<td>23.4 A</td>
<td>28.1 A</td>
<td>35.1 A</td>
<td>46.7 A</td>
<td>53.3 A</td>
<td>53.3 A</td>
<td>56.1 A</td>
</tr>
<tr>
<td>Admissible conductor size (DC)</td>
<td>No. 14 - 6 AWG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Number of DC Input Terminals</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Current per DC Input Terminal</td>
<td>20 A; Bus bar available for higher input currents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>OUTPUT DATA</th>
<th>Fronius IG Plus</th>
<th>3.0-1 уни</th>
<th>3.8-1 уни</th>
<th>5.0-1 уни</th>
<th>6.0-1 уни</th>
<th>7.5-1 уни</th>
<th>10.0-1 уни</th>
<th>11.4-1 уни</th>
<th>11.4-3 Delta</th>
<th>12.0-3 WYE277</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal output power (P&lt;sub&gt;AC_nom&lt;/sub&gt;)</td>
<td></td>
<td>3000 W</td>
<td>3800 W</td>
<td>5000 W</td>
<td>6000 W</td>
<td>7500 W</td>
<td>9995 W</td>
<td>11400 W</td>
<td>11400 W</td>
<td>12000 W</td>
</tr>
<tr>
<td>Max. continuous output power</td>
<td></td>
<td>3000 W</td>
<td>3800 W</td>
<td>5000 W</td>
<td>6000 W</td>
<td>7500 W</td>
<td>9995 W</td>
<td>11400 W</td>
<td>11400 W</td>
<td>12000 W</td>
</tr>
<tr>
<td>104°F (40°C) 208 V / 240 V / 277 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating AC voltage range (default)</td>
<td>208 V</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
<td>211 - 264 V (-12 / +10 %)</td>
</tr>
<tr>
<td>Max. continuous output current</td>
<td>208 V</td>
<td>14.4 A</td>
<td>18.3 A</td>
<td>24.0 A</td>
<td>28.8 A</td>
<td>36.1 A</td>
<td>48.1 A</td>
<td>54.8 A</td>
<td>31.6 A*</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>240 V</td>
<td>12.5 A</td>
<td>15.8 A</td>
<td>20.8 A</td>
<td>25.0 A</td>
<td>31.3 A</td>
<td>41.7 A</td>
<td>47.5 A</td>
<td>27.4 A*</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>277 V</td>
<td>10.8 A</td>
<td>13.7 A</td>
<td>18.1 A</td>
<td>21.7 A</td>
<td>27.1 A</td>
<td>36.1 A</td>
<td>41.2 A</td>
<td>n.a.</td>
<td>14.4 A*</td>
</tr>
<tr>
<td>Admissible conductor size (AC)</td>
<td>No. 14 - 4 AWG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. continuous utility back feed current</td>
<td></td>
<td>0 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nominal output frequency</td>
<td></td>
<td></td>
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<td>Operating frequency range</td>
<td></td>
<td></td>
<td>59.3 - 60.5 Hz</td>
<td></td>
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<td></td>
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<tr>
<td>Total harmonic distortion</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 3 %</td>
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<tr>
<td>Power factor</td>
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</table>

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Inverters: 8 - 103
## Fronius IG Plus General Data

<table>
<thead>
<tr>
<th>GENERAL DATA</th>
<th>Fronius IG Plus</th>
<th>3.0-1 UNI</th>
<th>3.8-1 UNI</th>
<th>5.0-1 UNI</th>
<th>6.0-1 UNI</th>
<th>7.5-1 UNI</th>
<th>10.0-1 UNI</th>
<th>11.4-1 UNI</th>
<th>11.4-3 Delta</th>
<th>12.0-3 YWE27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Efficiency</td>
<td>96.2 %</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>95.0 %</td>
<td>n.a.</td>
</tr>
<tr>
<td>CEC Efficiency</td>
<td>208 V</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>95.0 %</td>
<td>95.5 %</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>240 V</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>96.0 %</td>
<td>95.5 %</td>
<td>96.0 %</td>
<td>95.5 %</td>
<td>96.0 %</td>
<td>95.5 %</td>
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<tr>
<td></td>
<td>277 V</td>
<td>95.5 %</td>
<td>95.5 %</td>
<td>96.0 %</td>
<td>96.0 %</td>
<td>96.0 %</td>
<td>96.0 %</td>
<td>96.0 %</td>
<td>96.0 %</td>
<td>n.a.</td>
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<tr>
<td>Consumption in standby (night)</td>
<td>&lt; 1 W</td>
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<td></td>
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</tr>
<tr>
<td>Consumption during operation</td>
<td>8 W</td>
<td>15 W</td>
<td>22 W</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Cooling</td>
<td>Controlled forced ventilation, variable fan speed</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>Enclosure Type</td>
<td>NEMA 3R</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Unit Dimensions (W x H x D)</td>
<td>17.1 x 24.8 x 9.6 in.</td>
<td>17.1 x 36.4 x 9.6 in.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17.1 x 48.1 x 9.6 in.</td>
<td></td>
</tr>
<tr>
<td>Power Stack Weight</td>
<td>31 lbs. (14 kg)</td>
<td>57 lbs. (26 kg)</td>
<td>82 lbs. (37 kg)</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Wiring Compartment Weight</td>
<td>24 lbs. (11 kg)</td>
<td>26 lbs. (12 kg)</td>
<td>26 lbs. (12 kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Admissible ambient operating temperature</td>
<td>-4 °C...122°F (-20 °C...+50°C)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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## PROTECTION DEVICES

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<tr>
<th>Fronius IG Plus</th>
<th>3.0-1 UNI</th>
<th>3.8-1 UNI</th>
<th>5.0-1 UNI</th>
<th>6.0-1 UNI</th>
<th>7.5-1 UNI</th>
<th>10.0-1 UNI</th>
<th>11.4-1 UNI</th>
<th>11.4-3 Delta</th>
<th>12.0-3 YWE27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground fault protection</td>
<td>Internal GFDI (Ground Fault Detector/Interrupter); in accordance with UL 1741-2005 and NEC Art. 690</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DC reverse polarity protection</td>
<td>Internal diode</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Islanding protection</td>
<td>Internal; in accordance with UL 1741-2005, IEEE 1547-2003 and NEC</td>
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<td></td>
<td></td>
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<tr>
<td>Over temperature</td>
<td>Output power derating / active cooling</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Inverters: 8 - 104
Interactive inverters can usually handle PV array DC power input levels 110-130% or more of the continuous AC output power rating.

- Inverters thermally limit array DC input and power tracking at high temperatures and power levels.

Array voltage requirements are critical:

- Voltage must be above the minimum inverter operating and MPPT voltage during hottest operating conditions.
- Voltage must not exceed 600 VDC or the maximum inverter operating voltage during the coldest operating conditions.
Interactive inverter manufacturers offer online string sizing tools to determine the appropriate PV module configurations for their products.

- Inverter specifications define the operating limits for PV array DC current, voltage and power.
- PV module specifications and site temperature extremes are used to estimate the range of array voltage and power output for specific series and parallel module configurations appropriate for the inverter.
String Sizing

Inverter MPPT Range

DC Input Operating Range

PV Array IV Curves at Different Temperatures

Current

Voltage

Array voltage decreases with increasing temperature

STC

-50°C

25°C

0°C

-25°C

Inverters: 8 - 107
## SMA String Sizing Software

### Design Options

**Please Select an Inverter**
- SB 6000U (240)

**Please Select a PV Manufacturer**
- SolarWorld

**Please Select a PV Module**
- SW 175 mono

### Inverter Data

- **Design Irradiance (W/m²):** 1000
- **Pgac (W):** 6000
- **Pdcmx (W):** 6400
- **Idc Max (A):** 25
- **Vdc Max (V):** 600
- **Vmp Max (V):** 550
- **Vmp Min (V):** 250
- **Vmin (V):** 234

### Module Data

- **Module Pnom (W):** 175 W
- **Voc (V):** 44,4 V
- **Vmp (V):** 35,8 V
- **Isc (A):** 5,30 A
- **Imp (A):** 4,89 A

**Temperature Coefficient of Voltage:** - 0,33 %

**Temperature Coefficient of Current:** + 0,36 %

**Temperature Coefficient of Power:** - 0,3 %
SMA String Sizing Software

Mounting Method

Please select the mounting method for the array:

- Mounted flat against the roof

Temperature Data

If you do not know the hottest and coldest ambient temperatures that you should select for your area please enter the 5-digit postal ZIP code of the address of the installation here:

Select the coldest record low ambient temperature when sunlight will be on the array:

-13 °F

Select the hottest average high ambient temperature when sunlight will be on the array:

104 °F

Results

<table>
<thead>
<tr>
<th>1 string configurations</th>
<th>2 string configurations</th>
<th>3 string configurations</th>
<th>4 string configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 in series</td>
<td>8 in series</td>
<td>8 in series</td>
<td>8 in series</td>
</tr>
<tr>
<td>9 in series</td>
<td>9 in series</td>
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<tr>
<td>10 in series</td>
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</tr>
<tr>
<td>11 in series</td>
<td>11 in series</td>
<td>11 in series</td>
<td>11 in series</td>
</tr>
</tbody>
</table>

Get Sizes  Clear  Print Results  Predicted Outputs
### Predicted Results from String Sizing V 6.0

#### 1) Estimated PV Array Maximum Open Circuit Voltage vs. Low Temperature (°C/°F)

<table>
<thead>
<tr>
<th># of Modules</th>
<th>-40°C (-40°F)</th>
<th>-35°C (-31°F)</th>
<th>-30°C (-22°F)</th>
<th>-25°C (-13°F)</th>
<th>-20°C (-4°F)</th>
<th>-15°C (5°F)</th>
<th>-10°C (14°F)</th>
<th>-5°C (23°F)</th>
<th>0°C (32°F)</th>
<th>5°C (41°F)</th>
<th>10°C (50°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>324</td>
<td>319</td>
<td>315</td>
<td>310</td>
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<td>302</td>
<td>297</td>
<td>293</td>
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<td>284</td>
<td>280</td>
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<tr>
<td>7</td>
<td>377</td>
<td>372</td>
<td>367</td>
<td>362</td>
<td>357</td>
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<td>347</td>
<td>342</td>
<td>336</td>
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<td>326</td>
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<td>402</td>
<td>396</td>
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<td>485</td>
<td>479</td>
<td>472</td>
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<td>459</td>
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### 2) Estimated PV Array Minimum Open Circuit Voltage vs. High Temperature (°C/°F)

<table>
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<th># of Modules</th>
<th>5°C</th>
<th>10°C</th>
<th>15°C</th>
<th>20°C</th>
<th>25°C</th>
<th>30°C</th>
<th>35°C</th>
<th>40°C</th>
<th>45°C</th>
<th>50°C</th>
<th>55°C</th>
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### 3) Estimated PV Array Minimum Peak Power Voltage vs. High Temperature (°C/°F)

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<th>15°C</th>
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4) Estimated Inverter Maximum Output Power vs. High Temperature (°C/°F)

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<th># of Modules</th>
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<th>20°C</th>
<th>25°C</th>
<th>30°C</th>
<th>35°C</th>
<th>40°C</th>
<th>45°C</th>
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### SMA String Sizing Software

**Predicted Results**

#### 5) Estimated Inverter Maximum Output Power vs. Low Temperature (°C/°F)

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## SMA String Sizing Software Predicted Results

6) Estimated PV Array Maximum Output Power vs. High Temperature (°C/°F)

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All interactive inverters included integral monitoring and communications interfaces to record, display and retrieve key operating and performance information, including:

- DC input operating parameters (array voltage, current and power)
- AC output parameters (grid voltage, current and power)
- Energy production (daily and cumulative)
- Fault conditions and error codes

Data and operating status may be indicated on inverter panel and/or retrieved remotely through communications interfaces.

- Additional sensors for temperatures and solar radiation may be added to some inverters and aftermarket monitoring systems.
## Sunny Communication

### Solar System Data Technology

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<thead>
<tr>
<th>Inverter Type</th>
<th>Transmission Method</th>
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- **Sunny Webbox**: Data logging with a web interface to Sunny Portal. The portal is a solution for remote data transmission to large systems with the option to use external services.
- **Sunny Control Plus**: The solution for data logging for small to large systems with options to connect external services.
- **Sunny Beam**: Wireless monitoring of your Sunny Boy solar system's performance data.
- **Sunny Data Control**: The software solution for displaying data on your PC from Sunny Boy Control, Sunny Beams or Sunny Boy inverters directly.
String Inverter Manufacturers

- **Fronius USA:**
  - IG Plus 3 to 12 kW

- **KACO new energy:**
  - 1.5 to 5 kW

- **Motech: PVMate**
  - 2.7 to 5.3 kW

- **Power One:**
  - 3 to 6 kW

- **PV Powered:**
  - 1.1 to 5.2 kW

- **SMA America:**
  - 700W to 7 kW

- **Solectria Renewables:**
  - 1.8 to 5.3 kW

- **Xantrex Technology:**
  - 2.7 to 5 kW
Large Inverter Manufacturers

- Advanced Energy
- Fronius
- Ingeteam
- Kaco new energy
- Power-One
- PV Powered
- Satcon Technology
- Schneider Electric
- Siemens Industry
- SMA Solar Technology
- Solectria Renewables
Inverters are used in PV systems to convert DC power from batteries or PV arrays into AC power suitable for loads.

Different components and circuitry are used in various inverter designs.

Stand-alone inverters operate from batteries and supply AC power to dedicated loads off-grid.

Interactive inverters operate from PV arrays and produce AC power to interface with the utility system. Types of interactive inverters include module-level, string, central, utility-scale and bimodal inverters.

Most inverters incorporate monitoring and communications functions to record and display system operating parameters, fault conditions and performance information.
Questions and Discussion