Detailed Inverter Specifications, Testing Procedure, and Technical Approach and Testing Application Requirements for the Little Box Challenge

Introduction

Thank you for your interest in the Little Box Challenge. You may have seen a brief description of the inverter prize specifications needed to win on the www.littleboxchallenge.com website. This document is a more in-depth description of those specifications, along with some information regarding how the inverters will be tested. Your inverter must conform to the form factor, connector and safety requirements listed in this guide in order to be considered for testing, so please read these instructions carefully. Also included in this document are the requirements for what must be submitted for the Technical Approach and Testing Application document to be submitted on or before **July 22, 2015**. The legally binding terms and conditions for the competition are found on the registration page. These must be carefully read and agreed upon before entering the competition.

Questions about this document can be submitted by filling out the form on the FAQ section of the www.littleboxchallenge.com website. As described on the site, any question that is answered will be reproduced on the site, without identifying the asker, and posted in a pdf for everyone to see in order to ensure fairness for all competitors.

This document may be modified periodically to reflect questions/clarifications cited on the website or to reflect updated information and testing procedures. Anyone registered for the competition will receive an email indicating that there is a revised version.

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High Level Prize Specifications

The winning inverter will be the unit which achieves the highest power density, i.e. fits in the smallest rectangular enclosure, while meeting the following specifications under testing for 100 hours. A panel of judges will determine which inverters have met the specifications (e.g. if any deviations are substantial enough to warrant a disqualification) and may request further testing at their discretion based on the data gathered. In the event of a tie on volume, efficiency will be used to determine the grand prize winner.

Parameter	Requirement	Comment
Maximum load	2 kVA	Load will be adjusted so that at most 2 kVA is sourced at 240 V RMS AC output at 60 Hz
Power density	> 50 W/in^3	In accordance with maximum load and volume requirements
Volume	< 40 in^3	Require rectangular enclosure, max dimension 20 in., min 0.5 in.
Voltage input	450 V DC, 10 Ω Resistor	See voltage source description
Voltage output	240 +/- 12 V AC	Single phase. See description below
Frequency output	60 +/- 0.3 Hz	Single phase
Power factor of load	0.7-1	Leading and lagging, load description below
Voltage output THD+N	< 5%	Total harmonic distortion + noise
Current output THD+N	< 5%	Total harmonic distortion + noise
Efficiency	> 95 %	Measured by weighted average at different loads - a variation on the CEC method, see section below
Input ripple current (120 Hz)	< 20 %	Measured as $I_{peak\text{-}peak}/I_{average}$ from a 450 V supply in series with a 10 Ω resistor
Input ripple voltage (120 Hz)	< 3%	Measured as $V_{peak\text{-}peak}/V_{average}$ from a 450 V supply in series with a 10 Ω resistor
Maximum outer inverter temperature	< 60 °C	Tested at 15 °C - 30 °C ambient. Any point that may be touched from the outside must be < 60 °C
Electromagnetic compliance	FCC Part 15 B	See section below
Maximum current on chassis ground connection	< 5 mA	Measured directly, or as the difference in current between the AC hot and neutral wires

Detailed Requirements and Testing Procedure

Volume and Enclosure Requirements

The inverter must be contained within a rectangular metal enclosure with a volume of less than **40 inches^3**. It is to your advantage to make each face of the enclosure flat, since any bulging on a face will result in an increased assessment of the relevant dimension of height width or depth as shown in Figure 1. The volume will be calculated as if it were a rectangular prism with HxWxD, thus any deviation from being flat will substantially increase the volume attributed to the device.

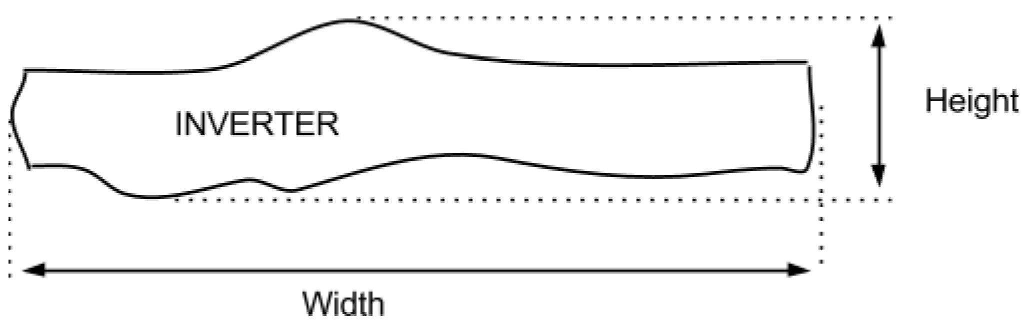


Figure 1: Inverter cross-section to illustrate calculation of height and width (depth calculated similarly)

The maximum dimension may not exceed **20 inches** and the minimum dimension may not be less than **0.5 inches**. The dimensions of the enclosure will be measured with digital calipers to a precision of **0.05 inches.** The bottom of the inverter must be large enough (each dimension **>= 1 inch.**) to accommodate the four support posts described in the Maximum Exposed Outer Device Temperature section below.

Openings in the enclosure are permitted (e.g. for the exit and strain relief of the AC, DC and ground wire connections, as well as holes to permit air to enter and exit for cooling purposes). Any opening in the enclosure must be finger safe, i.e. must not allow a cylinder of diameter ⅛” or greater to pass through it. Any mesh used should be recessed to fit within the rectangular enclosure. A protruding mesh will add to the effective dimension of the rectangular enclosure, thus increasing the assessed volume of the device.

The volume of the wires and strain relief exiting the enclosure will not be counted towards the total volume of the enclosure.

Voltage Input

The inverter will be tested using a near ideal voltage supply set at **450 V**. This power supply will be floating. Its positive terminal will be connected to a **10 Ω** wire wound resistor which will in turn be connected to the positive DC input terminal of the inverter. The voltage source will be very close to ripple free.

Voltage Output

The voltage output must be **240 V** RMS single phase AC, within a **+/- 12 V** band. After a transient change in the load the voltage should return to within acceptable bands in **0.1 seconds** or less and not leave the band again until the next load change. The voltage will be measured at the output of the inverter to ensure it remains within acceptable bands.

Frequency Output

The frequency output must be **60 Hz** single phase AC, within a band between **59.7 to 60.3 Hz**. After a transient change in the load the frequency, if it changes, should return to within the acceptable band in **0.1 seconds** or less and not leave the band again until the next load change. The frequency will be measured at the output of the inverter to ensure it remains within acceptable bands.

Load Profile

The inverter will be tested under dynamic load conditions. The load will be provided by an electronic load bank which can switch in and out a series of linear reactive, inductive and capacitive loads in small (**< 50 VA**) increments. The maximum load will be **2 kVA**. The power factors will vary between **0.7 and 1**, leading and lagging. The load change profile will be similar to that seen in a residential setting, although only using linear loads. Entrants can expect the load to vary between **0** and **2 kVA** with individual load jumps as high as **500 VA,** and the load may change as frequently as once every **second**.

Total Harmonic Distortion + Noise

Total harmonic distortion plus noise (THD+N) is a measure of how much the output of the inverter varies from an ideal sine wave at the primary frequency (60 Hz). The measurement for voltage THD +N is defined as:

$$V_{THD+N} = \frac{\sqrt{\sum_{i=2}^{i=\infty} V_i^2 + V_{Noise}^2}}{V_1} \qquad (1)$$

Where V_1 is the amplitude of voltage at the fundamental frequency (at 60 Hz) and $V_i = V_2, V_3, V_4\ldots$ are the amplitudes of the harmonics. V_2 is the amplitude at 120 Hz, V_3 at 180 Hz, V_4 at 240 Hz and V_n being the amplitude at $n \times 60$ Hz. V_{Noise} is the RMS value of the noise (e.g. all components not at a multiple of the fundamental) within the measurement bandwidth.

Similarly, the current THD+N is defined as:

$$I_{THD+N} = \frac{\sqrt{\sum_{j=2}^{j=\infty} I_j^2 + I_{Noise}^2}}{I_1} \qquad (2)$$

Where I_1 is the amplitude of current at the fundamental frequency (at 60 Hz) and $I_i = I_2, I_3, I_4\ldots$ are the amplitudes of the harmonics. I_2 is the amplitude at 120 Hz, I_3 at 180 Hz, I_4 at 240 Hz and I_n being the amplitude at $n \times 60$ Hz. I_{Noise} is the RMS value of the noise (e.g. all components not at a multiple of the fundamental) within the measurement bandwidth.

Both V_{THD+N} and I_{THD+N} must remain below **5%** at all load levels. The THD+N will only be measured during steady state operation at different loads. During any change in load, transient behavior and THD measurements will be ignored for **1 second** prior to the load change and **1 second** after the load change.

Efficiency

The inverter must demonstrate an efficiency of > **95** %. The efficiency is defined as:

$$Efficiency = \frac{AC\ Power\ Output}{DC\ Power\ Input} \qquad (3)$$

and will be determined by measuring the input voltage and current and output voltage and current, using the real component of the power at the fundamental frequency.

Efficiency measurements will be taken using a variation on the California Energy Commission (CEC) efficiency determination method. The inverter efficiency will be determined by taking measurements at 6 different load levels as shown in **Table 1**.

Output AC Power Level	10% (200 VA)	20% (400 VA)	30% (600 VA)	50% (1 kVA)	75% (1.5 kVA)	100% (2 kVA)
Weighting Factor	0.04	0.05	0.12	0.21	0.53	0.05

Table 1: Weighting Factors for CEC efficiency calculation

In the CEC efficiency method these measurements are taken at three different voltage levels. Unlike the CEC method, the voltage of the DC input in this competition will be tied to the power output since we are using a voltage source + resistor setup, as described in the Voltage Source section. Therefore, each part load measurement will take place at a single input voltage. Each of the measurements will be taken using a **purely resistive load.** The measurements will be taken at different times during the dynamic load tests with the loads specified above. Each inverter will have the same load profile applied for the tests and efficiency calculation.

In addition to the requirements listed above - the inverter must also have an efficiency of > 95 % at full 2 kVA load. The reason for this is so that a team cannot use a forced convection or otherwise parasitic means of cooling only when operating at or near full load, thus obscuring the parasitic cooling method's effect on efficiency.

Input Ripple Current and Voltage

The input ripple current and voltage limits are dependent on the voltage source configuration being used to test the device. Participants must plan and test their designs accordingly. The input ripple current (I_{Ripple}) is defined as:

$$I_{Ripple} = \frac{I_{Peak-Peak}(@\ 120\ Hz)}{I_{Average}} = \frac{I_{Max} - I_{Min}(@\ 120\ Hz)}{I_{Average}} \tag{4}$$

Similarly. the voltage ripple (V_{Ripple}) is defined by:

$$V_{Ripple} = \frac{V_{Peak-Peak}(@\ 120\ Hz)}{V_{Average}} = \frac{V_{Max} - V_{Min}(@\ 120\ Hz)}{V_{Average}} \tag{5}$$

The definition of $I_{Peak-Peak}$ *(@ 120 Hz)* and $V_{Peak-Peak}$ *(@ 120 Hz)* is shown in Figure 2. As illustrated, the peak to peak value is taken of the envelope of the 120 Hz oscillations (which are not necessarily perfect sinusoids) and narrow spikes or deviations at higher frequencies do not count in the measurement.

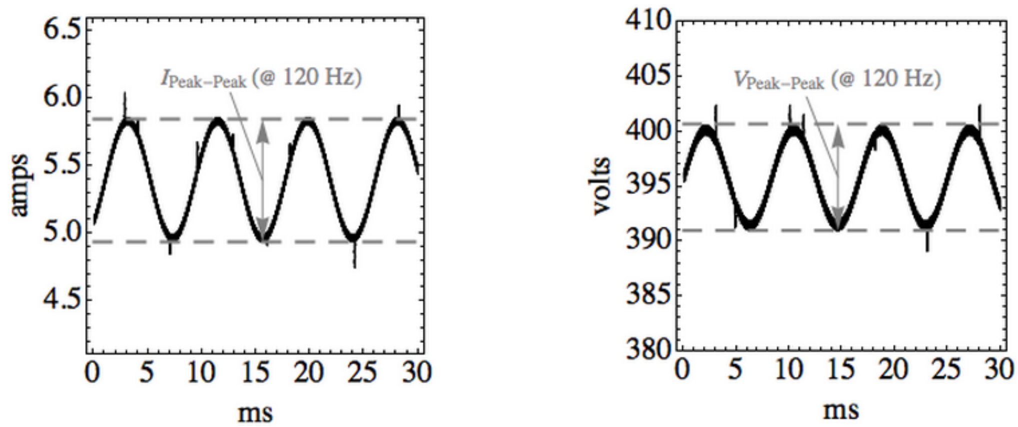


Figure 2: Demonstration of definition of $I_{Peak\text{-}Peak}$ *(@ 120 Hz)* and $V_{Peak\text{-}Peak}$ *(@ 120 Hz)* for the ripple current and voltage measurements

Both the current and voltage ripple will be measured between the positive and negative DC input terminals of the inverter, on the inverter side of the **10 Ω wire wound** resistor.

The limit for the input ripple current is $\boldsymbol{I_{Ripple}}$ **< 20%** at all load levels. Because the voltage and current relationship is set by the (near) ideal voltage source set at **450 V** in series with a **10 Ω** wire wound resistor, the corresponding V_{Ripple} follows from the allowable I_{Ripple} and requires $\boldsymbol{V_{Ripple}}$ **< 3.0%** (allowing for some additional losses in the system) at all load levels.

Maximum Exposed Outer Device Temperature

The device must be constructed such that all finger-accessible locations stay below **60°C**. We will test this through a combination of thermal (IR) imagery and placement of thermocouples. For our definition of finger-accessible, see the enclosure definition above.

Note that it is not sufficient merely to ensure that all finger-accessible device *surfaces* stay below **60°C**. We may also measure the temperature a thermocouple reaches in a finger-accessible location that is not on a device surface (e.g., just above a heat vent).

The placement of the thermocouples will be similar across all devices, but testers may also vary their placement looking for “hot spots”. Temperature measurements of openings on the enclosure for cooling, such as holes or a mesh to allow for air to enter and exit, will be taken using thermocouples as a reading using IR cameras may show the temperature of the internal sections of the inverter. The thermocouples will be small enough and placed in such a way as to not meaningfully impede airflow in and out of holes in the enclosure.

The ambient temperature of the testing environment will remain between **15 °C and 30 °C**. There are no requirements for the temperature reached by components within the enclosure. The bottom side of the inverter (the side to be parallel to the floor of the testing lab) will be supported on four posts, 1 on each corner, **1 inch high**, and with a top area which makes contact with the bottom of the inverter of dimensions **0.5x0.5 inches.** There will be no significant heat conducted through these posts.

Electromagnetic Compliance

The device must conform to FCC Part 15 B rules in the "unintentional radiators" category. More information about FCC Part 15 B requirements can be found in the Electronic Code of Federal Regulations and elsewhere.

The FCC Part 15 B compliance will be tested at certified electromagnetic compliance (EMC) testing laboratory in the United States near the testing facility. More details regarding the EMC testing facility will follow during the competition in an updated version of this document.

Due to the difficulty of reaching compliance with FCC Part 15 B, especially with prototypes, we encourage you to submit your inverter for testing even if it may not reach full FCC Part 15 B compliance. In the event that no inverters reach full FCC Part 15 B compliance, the judges may do a relative comparison of EMC performance between inverters and still award the prize.

Ground Current Limit

As described in the grounding, safety and connections section below, there will be a wire connecting the chassis of the inverter to earth ground in the testing laboratory. The current flowing across the wire to ground cannot exceed **5 milli-Amps** at any time during the testing. The current flowing across the wire to ground will be established either by measuring the current on the ground chassis connection directly, or by measuring the difference in current between the hot and neutral or hot 1 and hot 2 AC output connections.

Grounding, Device Connections and Safety Requirements

Grounding

The inverter does not need to provide galvanic isolation. The DC supply will be floating. In order to accommodate the most prevalent grounding conventions around the world, two different grounding configurations are permissible. ***The grounding configuration that the team wishes to use must be specified both during the Technical Approach and Testing Application Submission and during the submission of the inverter itself.*** No preference will be given to entries based on the requested grounding configuration.

Grounding Configuration 1: 240 V split phase configuration

The grounding configuration for the 240 V split phase configuration is shown in Figure 3.

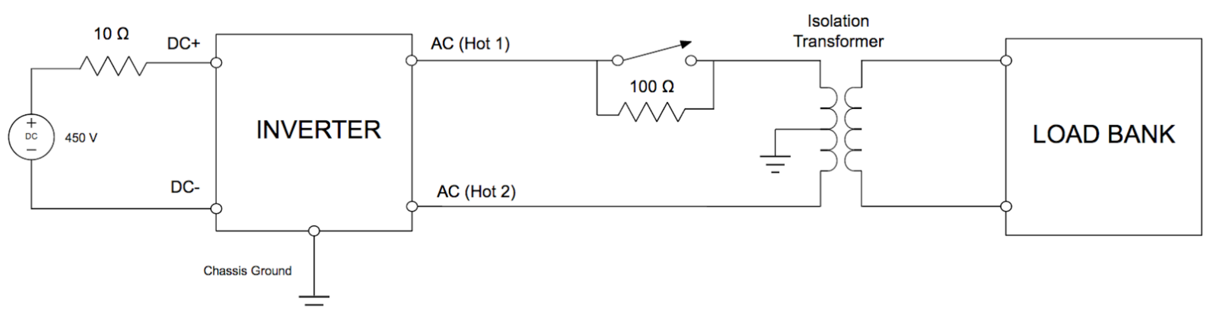


Figure 3: 240 V split phase grounding configuration

In this configuration, the 240 V RMS AC output of the inverter is between terminals designated AC (Hot 1) and AC (Hot 2). These terminals connect to each other through an isolation transformer whose other coil is connected to the AC load bank that will apply the load profile as discussed in the load profile section. The isolation transformer is center tapped on the inverter side and connected to ground. This has the effect of fixing both of the AC (Hot 1) and AC (Hot 2) lines to be 120 V RMS to ground, 180 degrees out of phase, similar to what would be found in a North American household.

The purpose of the 100 Ω resistor and switch on the output of the AC (Hot 1) is to limit the inrush currents into the transformer upon start up. The switch will be left open for a period of **10 seconds** upon start up, and then will be closed.

A separate wire is required to connect the chassis of the inverter to earth ground. The resistance between this wire, as measured in the **chassis ground receptacle on the NEMA 6-15 connector**, and the metal enclosure on the inverter must be < **1 Ω**.

The voltage and current measurements taken to measure efficiency and other parameters will be taken on the inverter side of the transformer to ensure that any transformer losses do not adversely affect the results.

Grounding Configuration 2: 240 V to ground configuration

The grounding configuration for the 240 V to ground configuration is shown in Figure 4.

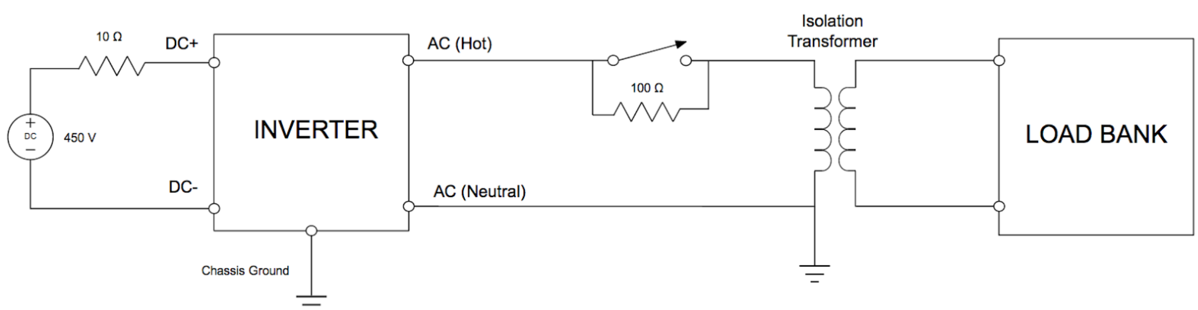


Figure 4: 240 V to ground grounding configuration

In this configuration, the 240 V RMS AC output of the inverter is between terminals designated AC (Hot) and AC (Neutral). These terminals connect to each other through an isolation transformer whose other coil is connected to the AC load bank that will apply the load profile as discussed in the load profile section. One side of the isolation transformer is connected to ground. This has the effect of fixing the AC (Hot) to be 240 V RMS to ground and the AC (Neutral) to be held at ground, similar to what would be found in a European and other households around the world.

The purpose of the 100 Ω resistor and switch on the output of the AC (Hot) is to limit the inrush currents into the transformer upon start up. The switch will be left open for a period of at **10 seconds** or more upon start up, and then will be closed.

A separate wire is required to connect the chassis of the inverter to earth ground. The resistance between this wire, as measured in the **chassis ground receptacle on the NEMA 6-15 connector**, and the metal enclosure on the inverter must be < **1 Ω**.

The voltage and current measurements taken to measure efficiency and other parameters will be taken on the inverter side of the transformer to ensure that any transformer losses do not adversely affect the results.

Device Connections

It is the responsibility of the competitor to wire the device exactly as specified below. Any damage or decrease in performance that results from improper wiring will be the responsibility of the competitor and not that of either the testing facility or Google.

The device submitted for testing must be a rectangular metal enclosure with 5 wires exiting from it. Each of the wires must have a diameter of **10 AWG**, a length of between **10-12 inches** and have adequate strain relief.

On one of the upright/vertical faces perpendicular to the testing surface, two DC connections wires must exit the enclosure, one designated “DC+” and the other marked “DC-”. The DC+ connection must be a red wire, the DC- must be a black wire. The red DC+ wire must connect to a **red Anderson power products** PP75 DC connector, the black DC- wire must connect to a **black Anderson power products** PP75 DC connector**.** The red DC+ connection will be attached to the positive terminal of the power supply, on the other side of the **10 Ω wire wound** resistor. The black DC- connection will be connected to the negative terminal of the power supply. The two Anderson power products PP75 connectors should not be glued, stuck, or otherwise permanently fastened together.

On the upright/vertical face opposite and parallel to the face with the DC wires exiting, two AC wire connections and one chassis ground connection must exit the enclosure. The chassis ground wire must be a **green wire**.

For the **240 V split phase** configuration, one wire should be designated “AC (Hot 1)” and must be **a blue wire**, and another should be designated “AC (Hot 2)” and must be a **brown wire**. For the **240 V to ground** configuration one wire must be designated as “AC (Hot)” and must be a **blue wire**, and another should be designated as “AC (Neutral)” should be a **white wire**.

These three wires must be connected to a **Female NEMA 6-15** AC electrical connector. The connections on the Female NEMA 6-15 AC electrical connector will be dependent on the grounding specification chosen: 240 V split phase configuration, or 240 V to ground configuration.

NEMA 6-15 connections for grounding configuration 1: 240 V split phase

The two AC connections and the chassis ground connection must be attached to the **Female NEMA 6-15** connector in the following way: when looking straight ahead into the outlets of the connector, with the single semi-circular flattened opening oriented towards the bottom and the two flat rectangular openings above it equidistant on either side, the AC (Hot 1) wire must be connected to the left rectangular outlet, the AC (Hot 2) wire must be connected to the right rectangular outlet and the chassis ground connection must be connected to the semicircular and flat outlet on the bottom. This is shown in Figure 5.

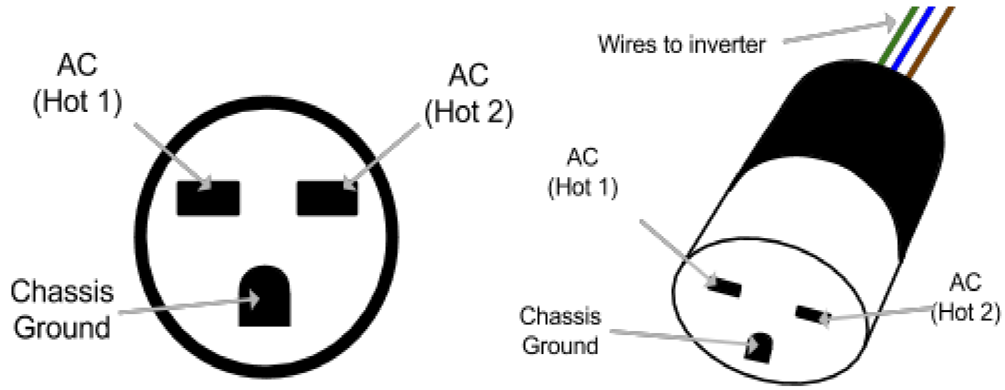


Figure 5: AC and chassis ground connection requirements on female NEMA 6-15 connector i the **240 V split phase** configuration

The AC (Hot 1) and AC (Hot 2) pins will be connected on either side of a center tapped transformer to ground, as shown in Figure 3. The other side of the transformer will be connected to a programmable load bank and the chassis ground will be connected to earth ground as shown in Figure 3.

<u>NEMA 6-15 connections for grounding configuration 2: 240 V to ground</u>

The two AC connections and the chassis ground connection must be attached to the **Female NEMA 6-15** connector in the following way: when looking straight ahead into the outlets of the connector, with the single semi-circular flattened opening oriented towards the bottom and the two flat rectangular openings above it equidistant on either side, the AC (Neutral) wire must be connected to the left rectangular outlet, the AC (Hot) wire must be connected to the right rectangular outlet and the chassis ground connection must be connected to the semicircular and flat outlet on the bottom. This is shown in Figure 6.

The AC (Hot) and AC (Neutral) pins will be connected to either side of the isolation transformer as shown in Figure 4 and the AC (Neutral) will be connected to earth ground.

Safety Requirements

On/Off Switch, LED indicator and Turn on Delay

The device must have a clearly labelled on/off toggle switch on the enclosure. When the toggle switch is in the off position, no voltage or current is to be present on the AC side even when the DC side is live.

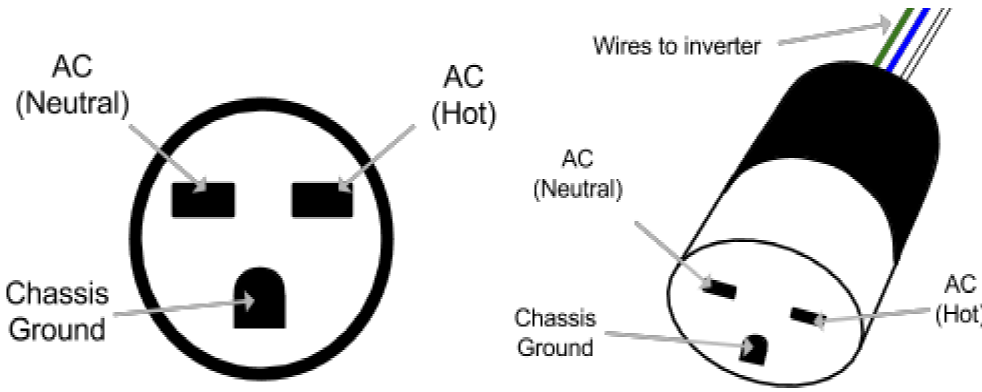


Figure 6: AC and chassis ground connection requirements on female NEMA 6-15 connector i the **240 V to ground** configuration

When the switch is in the on position, the device must detect that there has been a voltage of > **300 Volts** for at least **5 seconds** before outputting to the AC side. There should be no voltage or current output on the AC side until this time.

When there is live voltage on the AC side, a green indicator light located next to the on/off switch should be illuminated. When there is no voltage on the AC side, the LED should be off.

Fuse Configuration for Testing Setup

In order to protect both the inverters being tested and the equipment being used for the test, the following fuses will be used at the different locations in the testing setup:

- Between the resistor at the output of the voltage supply and the positive DC+ terminal of the inverter: 10A, 500VDC slow blow fuse.
- Between the negative terminal of the power supply and the negative DC- terminal of the inverter: 10A, 500VDC slow blow fuse.
- Between the the AC (hot) or (hot 1) terminal of the inverter and the AC (hot) or (hot 1) input to the isolation transformer: 12A, 240VAC, slow blow fuse.
- Between the the AC (neutral) or (hot 2) terminal of the inverter and the AC (neutral) or (hot 2) input to the isolation transformer: 12A, 240VAC, slow blow fuse.

These fuses are not to be provided by the contest participants. They will be incorporated into the test setup. Their values are included so that participants will understand what circumstances may lead to a blown fuse.

Further Inverter Self Protection Measures

[To be included by testing partner in updated version of this document]

Technical Approach and Testing Application Requirement

In order for their inverter to be considered for testing, the teams must submit a technical approach and testing application document on or before **July 22, 2015**. Those registering for the competition will receive more information by email about the submission guidelines in early 2015. This application will be reviewed by a panel of judges and no more than **18 finalists** will be selected for testing, and a chance to win the **Grand Prize of $1 million.** The criteria by which the submissions will be evaluated is:

- Did the teams adequately and clearly present the high level overview of the approach they were taking, meeting all the requirements for content listed below?
- Did their approach make sense in terms of being able to achieve what they claim?
- Did they submit the required data and safety information required in the testing application?
- Did that data validate the performance they are claiming?
- For the technical approach and testing applications that meet all of the criteria above, is the team claiming to achieve one of the 18 highest power densities of all the qualifying applicants?

Teams meeting all of these requirements will be invited to bring their inverters in person to the testing facility in the United States in October 2015.

Technical Approach Document

In order to be considered for testing, participants in the competition must submit a technical approach document not to exceed **4** pages. This document should describe at a high level what approach and innovations the team are using to achieve the high power densities claimed for their inverters. In addition, a **1** page appendix with biographical information about the key members of your team must also be included.

The purpose of this document is twofold. First, it will allow a panel of judges to assess the likely viability of your inverter design and decide whether the submission should qualify as a finalist for testing. Second, a subset of the technical approach documents submitted will be made public by Google so that the world may see the new techniques and innovations which are now making these high densities possible.

The level of detail required in the technical approach document is meant to be high level and not divulge any trade secrets. The content and descriptions of the device should be comparable to a short IEEE paper meant to explain conceptually how a new device can work without revealing all the details about the exact values of components used, nor going into details about the control algorithms and other more detailed aspects. General content guidelines include:

- Power density achieved: the volume of the rectangular enclosure used and thus the resulting power density achieved at a load of 2 kVA should be specified.
- Switch level schematics: schematics should be detailed enough to reveal what general topology is being used, but not include every passive component or other circuit detail.
- Order of magnitude passive component values: For passive components which typically take up a large volume, or are otherwise critical to the the conceptual design of the circuit, an order of magnitude value for what was used (e.g. 10s of microfarads vs. 100s of microfarads) is acceptable.
- Order of magnitude frequency values: For switching frequencies used in creating an alternating current output from a direct current through a pulse-width modulation or other technique, specifying the order of magnitude of frequency used (e.g. 10s of kilohertz vs. 100s of kilohertz) is acceptable.
- Semiconductor device type(s): Participants should specify the type of semiconductor switching devices that they are using (e.g. silicon, gallium-nitride, silicon-carbide, etc.). Participants may or may not specify the vendors and providers of these semiconductor switching devices at their discretion. The same is true of any novel passive components used.

Participants are free to include more detail than this at their discretion. The technical approach document should describe any and all of the key innovations beyond the current state of the art which enabled the inverter to achieve these high power densities. In addition to any general content about the innovations used, they **must provide clearly indicated sections** on what innovations they have used to confront the following challenges to increasing inverter power density:

- **120 Hz input current/voltage ripple requirement:** The typical solution to minimize the input current ripple on the DC side of the inverter, which is detrimental to the operation of PV, battery and other systems, has been to include large amounts of energy storage in the form of often unreliable, large volume electrolytic capacitors. Participants must describe what means that have used to meet the input ripple current/voltage requirements while minimizing the volume required.

- **Miniaturization of components for DC-AC conversion:** The typical methods of switching a fixed voltage DC signal into AC, such as pulse-width modulation (PWM), require the use of passive components to smooth square wave pulses into a sine wave with minimal harmonic distortion. The energy storage requirement, and thus the size, of these passive components can diminish as the frequency of these square wave pulses is increased. These higher frequencies may now be attainable either through the use of wide bandgap semiconductors such as Gallium Nitride (GaN) and Silicon Carbide (SiC), or through new topologies using traditional silicon semiconductors. Participants must elaborate on which of these methods, or others, they have used to minimize the size of the DC-AC switching components, and why it is the preferred solution for achieving high power densities. They may also include any advances in the passive components themselves.

- **Thermal management:** The amount of heat generated by the system will decrease as the efficiency of the system increases, but even at the required efficiency of **> 95%** at full load a 2 kVA inverter can generate up to 100 Watts of heat which must be dissipated in order to prevent an unacceptable temperature rise. The higher the power density of the inverter, the less surface area is available for this heat to be dissipated across.

  The local thermal management requirements in the system may be relaxed by using devices (e.g. wide bandgap semiconductors) that can operate reliably at elevated temperatures. New passive or active thermal management approaches may be used to manage the heat that does get generated and distribute it evenly across the surface area of the enclosure to avoid the presence of hot spots above 60°C. The technical approach document must describe what innovations in thermal management are being used to achieve the required specifications at these high power densities.

- **Electromagnetic Compliance (EMC):** The possible use of higher frequencies, new components in a smaller form factor offers both challenges and opportunities for limiting both the conducted and radiated electromagnetic interference within acceptable limits for FCC Part 15 B compliance . Participants must describe the steps taken to limit the electromagnetic interference of the device while consuming the minimum possible volume.

Biographical information appendix (maximum 1 page): In addition to the technical material listed above, competitors must submit a 1 page appendix with brief descriptions of the key members of your team. This must contain one to two paragraphs per team member with information on their professional and academic background, beginning with the team's point of contact. Descriptions should be similar to what would be found at the end of an IEEE paper in a journal such as "IEEE Transactions on Power Electronics". Photos are optional.

The technical approach document should conform to the following formatting guidelines:

- Must be written in english
- Must have the team name and registration code clearly indicated at the top of the first page of the document
- Use 8.5 x 11 inch page size
- Minimum 12 point font for body text
- Minimum 9 point font in figures, tables and captions
- Minimum 1 inch margins on all sides
- Not exceed 4 pages in length + 1 page biographical appendix
- Citations are welcome, but entrants should not expect judges to do a thorough examination of several citations to evaluate the merit of the approach

Technical approach documents which simply refer to the content of external citations without briefly explaining their content and specific relevance to the high power density inverter application are frowned upon and may result in a disqualification from being a finalist for testing.

Testing Application

A testing application document must be submitted alongside the technical approach document. This document presents data taken by each team on their inverters as a proof of their viability, along with a safety questionnaire needed for testing. A template of the testing application is included in Appendix A of this document. Participants do not need to follow the exact color/formatting scheme listed but should follow the general guidelines and provide the data in a very clear, legible format. Failure to do so may result in disqualification. The safety questionnaire will be provided in an updated version of this document to be posted during the competition.

The testing application consists of:

- **Maximum 1 page - Technical specification sheet**: In this document, competitors will list the performance of the inverter they themselves have measured on the following metrics while testing their inverter on a 2 kW purely resistive load at 240 +/- 12 V AC output. The inverter should be run for long enough to allow it to reach thermal equilibrium prior to these measurements being taken.

  As described above, the inverter should be tested while receiving an input from a 450 V near ideal power supply in series with a 10 Ω wire wound power resistor.

  The specifications measured and reported should be:

  - Grounding specification: The team must specify if their inverter is to be tested in the “240 V split phase” configuration or “240 V to ground” configuration. See the grounding section above for more details
  - Maximum load tested (must be 2 kVA or above, corresponding to ~28.8 Ω load at 240 V AC)
  - Volume of the rectangular enclosure ($inch^3$)
  - Dimensions of rectangular enclosure (LxWxH, inches)
  - Resulting power density at 2 kW load ($watt/inch^3$)
  - DC voltage mean input (volts)
  - DC current mean input (amps)
  - AC voltage RMS output (volts)
  - AC current RMS output (amps)
  - DC to AC efficiency (%)
  - Voltage total harmonic distortion+noise (%)
  - Current total harmonic distortion+noise (%)

- Input ripple current (%) $I_{peak\text{-}peak}/I_{average}$ (@ 120 Hz)
- Input ripple voltage (%) $V_{peak\text{-}peak}/V_{average}$ (@ 120 Hz)
- Maximum temperature reach by the enclosure (°C)
- Ambient temperature of testing environment (°C)

These should be organized in a table as shown in the example in Appendix A.

- **Maximum 2 pages - Waveform screen captures:** Participants must provide sample waveform images of the DC input and AC output of their inverters at full output on a purely resistive load. The waveform traces should be taken with a sampling rate of at least **10 kHz.**

  - Each image should be between 4-5 inches in width and 3-4 inches in height. There should be 1 trace per image (current or voltage) for a total of 4 images, 2 on each page.
  - DC input waveforms: Must show between 4-6 60 Hertz cycles of both input current and voltage at full load with clear indication of the voltage and current divisions. This corresponds to a 66-100 millisecond oscilloscope trace.
  - AC output waveforms: Must show between 4-6 60 Hertz cycles of both input current and voltage at full load with clear indication of the voltage and current divisions. This corresponds to a 66-100 millisecond oscilloscope trace.

- **Maximum 2 pages - Extended device testing:** Participants must provide a plot of 1 second measurements of the following quantities over the course of 3 hours of testing and two different load conditions: 2 kVA pure resistive load, and 1 kVA pure resistive load.

  - DC voltage mean input (volts)
  - DC current mean input (amps)
  - AC voltage RMS output (volts)
  - AC current RMS output (amps)
  - Each image should be between 4-6 inches in width and 1-2 inches in height. There should be 1 trace per image (current or voltage) for a total of 8 images, 4 on each page

- **Maximum 2 page: Device pictures:** The participants must submit 3 pictures of the inverter to be submitted for testing.

  - A picture from the top of the device with the enclosure removed. The entirety of the device must be within the bounds of the picture. The top level circuit components should be visible. This is only used to establish that you have an actual viable device for testing. This picture should be between 4-6 inches in both width and height.

    - A picture with the enclosure in place, taken from the top. The wires exiting the device and the proper connectors (NEMA 6-15 and Anderson Power Products PP75 per instructions above) must be clearly visible. A measuring tape or ruler should be present in the picture, with the markings legible, for scale and to validate the dimensions stated. This picture should be between 4-6 inches in both width and height.
    - A picture of the device with the enclosure in place taken from the side. A measuring tape or ruler should be present in the picture, with the markings legible, for scale and to validate the dimensions stated. This picture should be between 4-6 inches in both width and height.

- **Maximum [X] pages: Safety questionnaire (to be provided by testing partner in updated version of this document).** Participants must answer the questions relating to safety and hazardous materials information needed to conduct the testing at the testing facility.

Appendix A: Testing Application Template/Example

Testing Application: Technical Specification Sheet

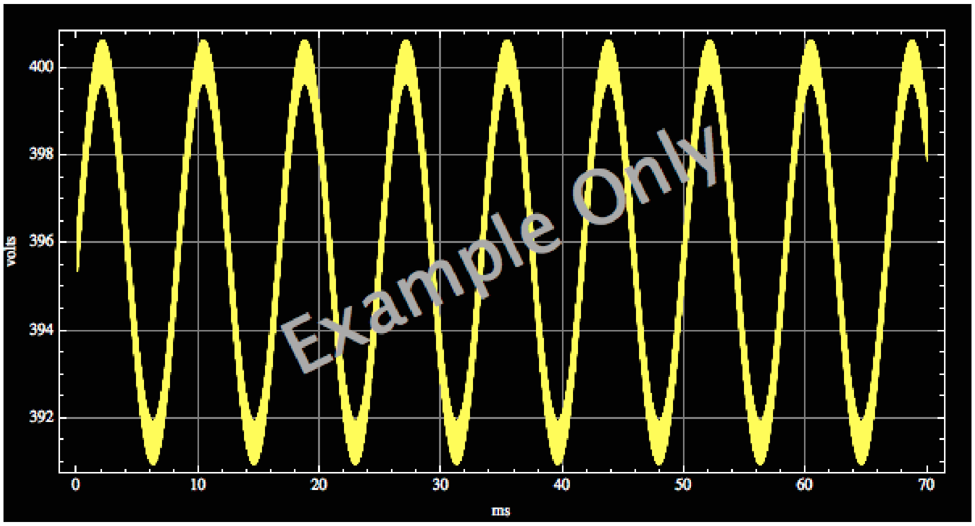
Team Name: Template Team	**Registration Code:** ****-*********-******

Parameter	**Value *(Template Example Only!)***
Grounding Configuration	240 V to ground
Maximum load tested	2.06 kVA / 28 Ω
Volume of the rectangular enclosure	35 in^3
Dimensions of rectangular enclosure	7 inch x 5 inch x 1 inch
Resulting power density at 2 kW load	57.1 W/in^3
DC voltage (RMS) input	395.8 V
DC current (RMS) input	5.4 A
AC voltage (RMS) output	240.2 V
AC current (RMS) output	8.6 A
DC to AC efficiency (CEC Method)	95.5%
Voltage total harmonic distortion + noise	4.4 %
Current total harmonic distortion + noise	4.4 %
Input ripple current	16.1%
Input ripple voltage	2.2%
Max Temperature of Enclosure	56°C
Ambient Temperature of Test	28°C

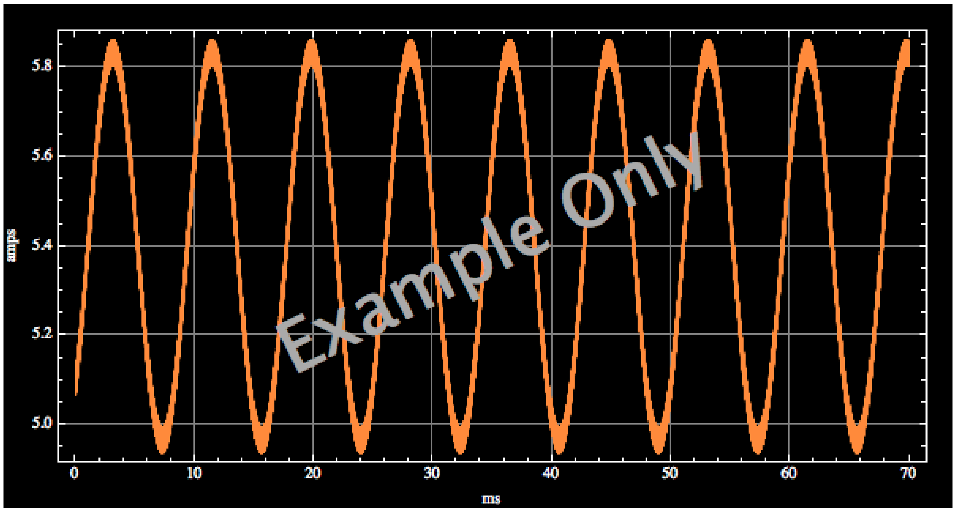
Testing Application: Waveform Screen Captures

Team Name: Template Team	**Registration Code:** ****-*********-******

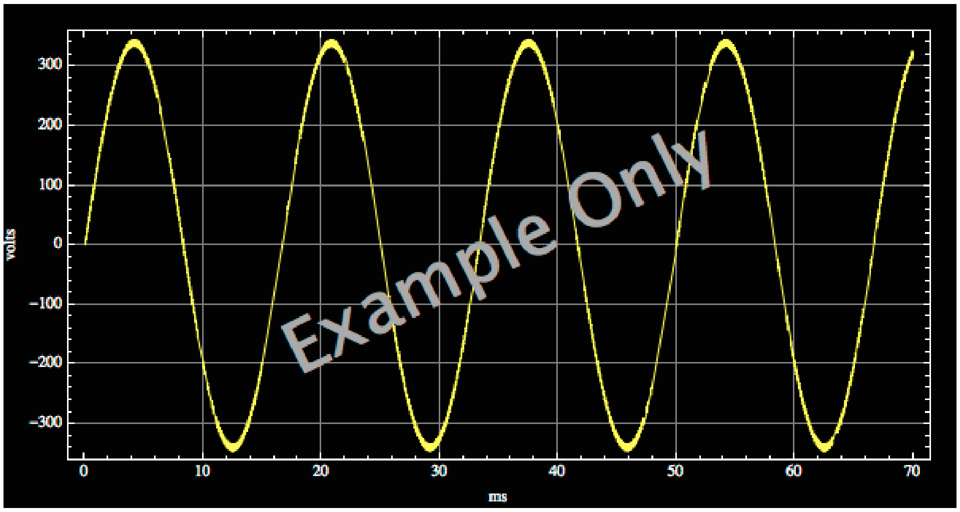
DC Input Voltage



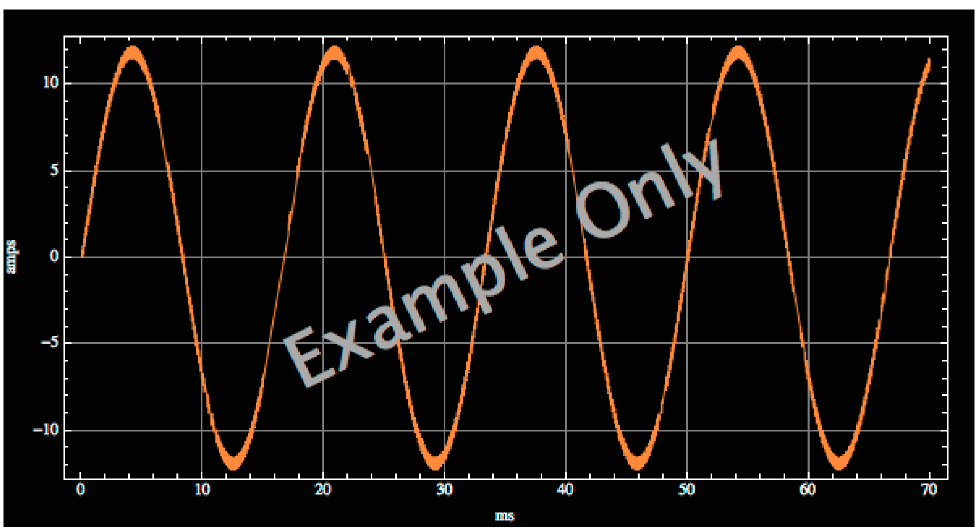
DC Input Current



AC Output Voltage



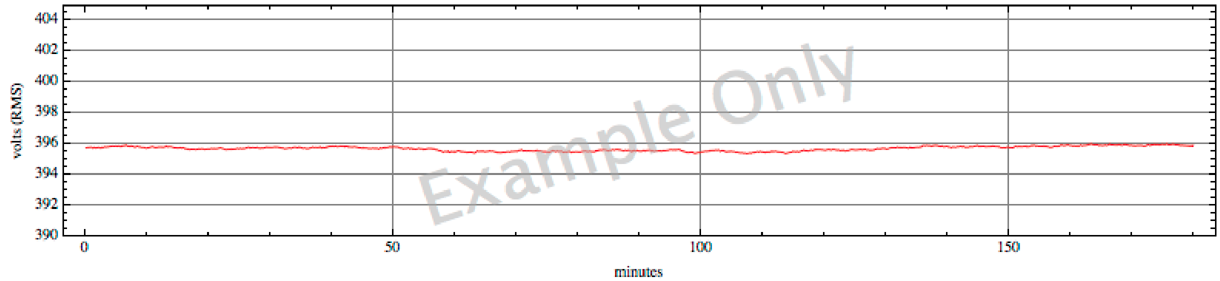
AC Output Current



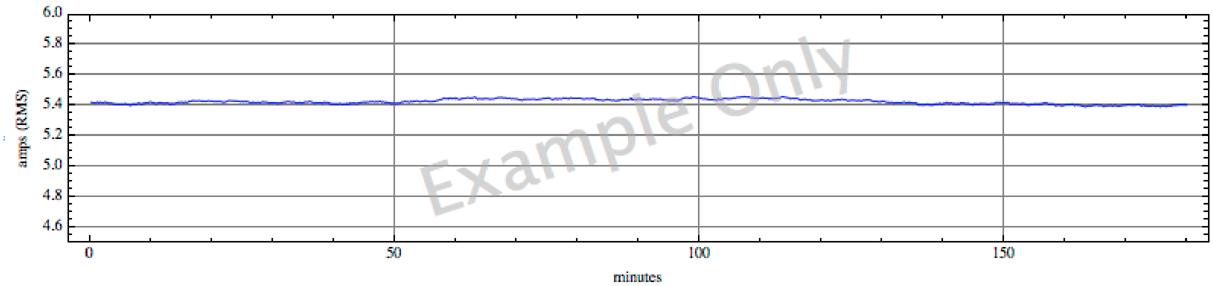
Testing Application: Extended Testing Data

Team Name: Template Team	**Registration Code:** ****-*********-******

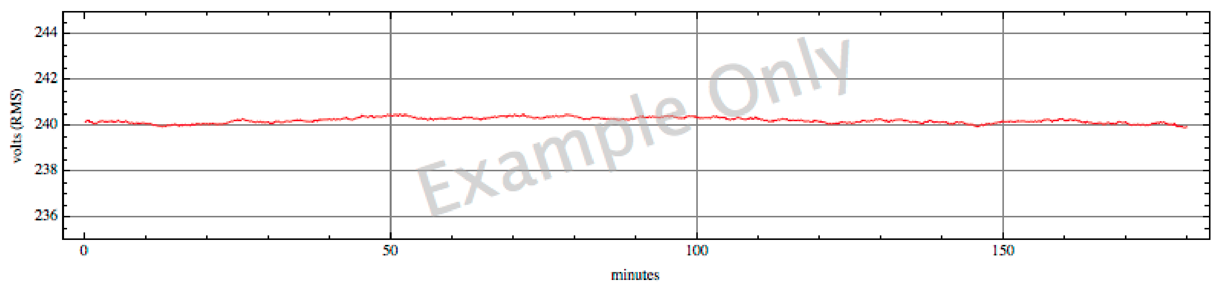
2 kVA Load DC Voltage Input



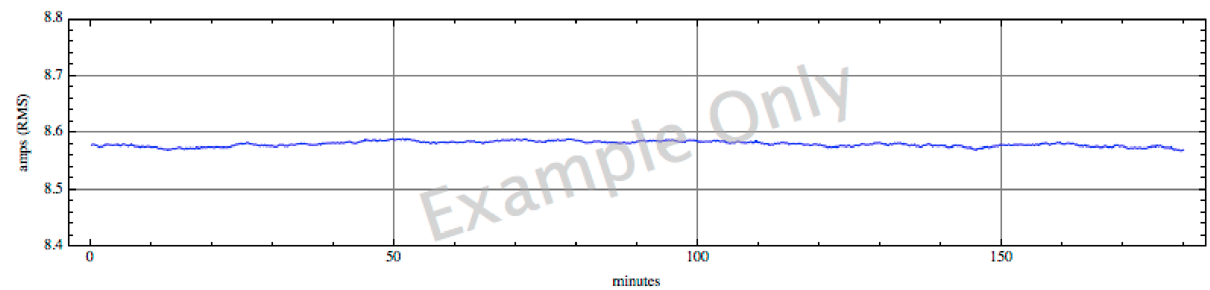
2 kVA Load DC Current Input



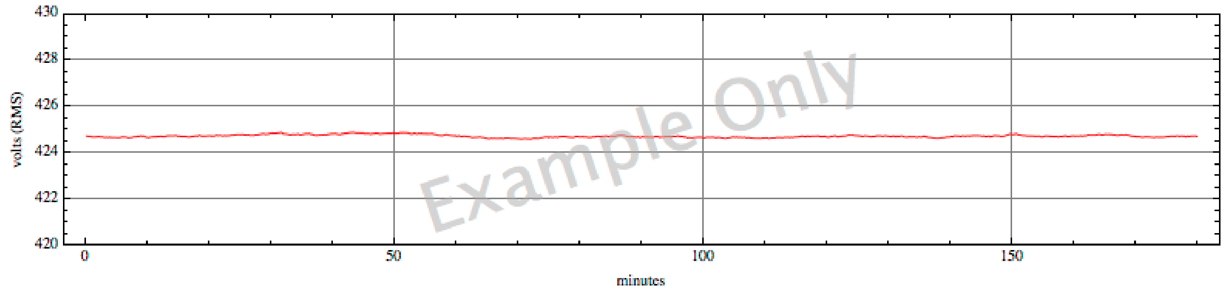
2 kVA Load AC Voltage Output



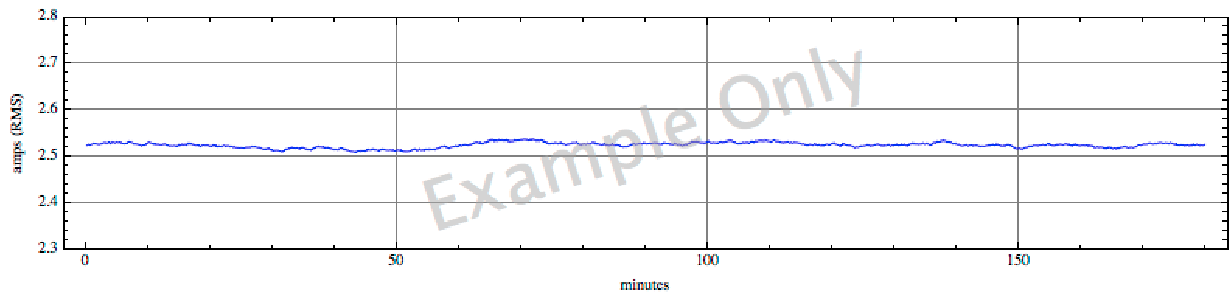
2 kVA Load AC Current Output



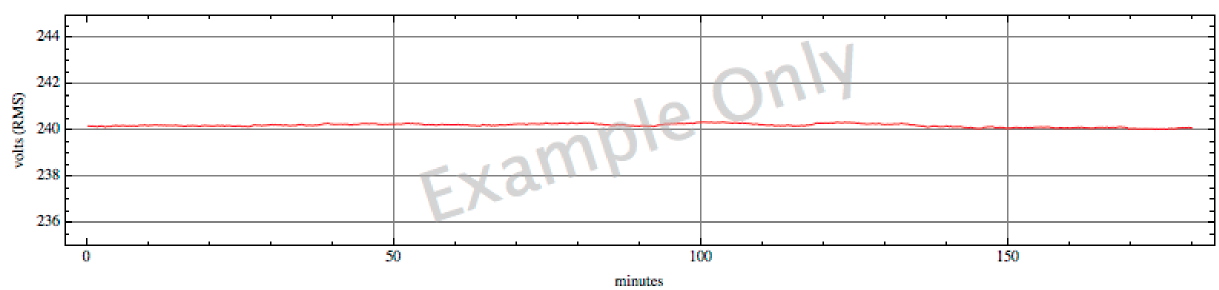
1 kVA Load DC Voltage Input



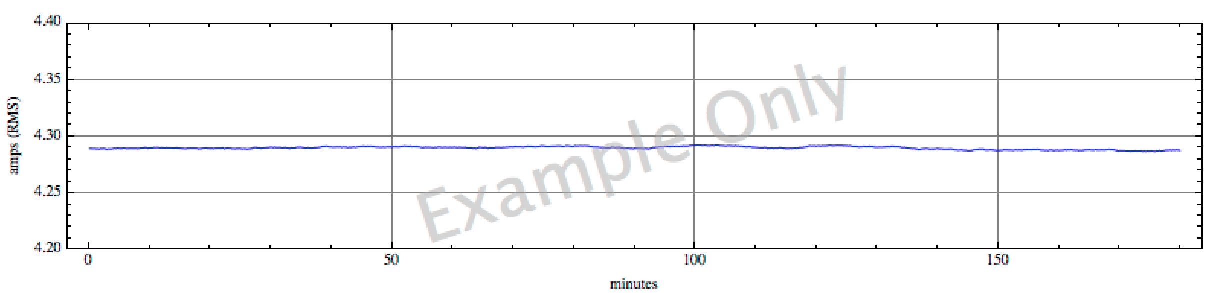
1 kVA Load DC Current Input



1 kVA Load AC Voltage Output



1 kVA Load AC Current Output



Testing Application: Device Pictures

Team Name: Template Team	**Registration Code:** ****-*********-******

Top View Enclosure Off:

Photograph of inverter, top view, with enclosure removed

Ruler shown for scale

Top View Enclosure On:

Photograph of inverter, top view, with enclosure in place

On/Off Switch, LED, NEMA 6-15 AC connector and DC Anderson Power Products PP75 connectors clearly visible

Ruler shown for scale

Side View Enclosure On:

Photograph of inverter, side view, with enclosure in place

Ruler shown for scale

Testing Application: Safety Questionnaire

Team Name: Template Team	**Registration Code: ****-*********-******

[To be included in updated version of this document]