SURFACE VEHICLE RECOMMENDED PRACTICE

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Inverter Requirements for Class Eight Trucks - Truck and Bus

RATIONALE

SAE J2697 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This SAE Recommended Practice is intended to describe the application of single-phase DC to AC inverters, and bidirectional inverter/chargers, which supply power to ac loads in Class heavy duty on-highway trucks (10K GVW). The document identifies appropriate operating performance requirements and adds some insight into inverter selection.

- This document applies to factory and after-market installed DC-to-AC inverter systems (Including inverter chargers) providing up 3000 W of 120 VAC line-voltage power as a convenience for operator and passenger use. Such inverters are intended to power user loads not essential to vehicle Operation or safety (e.g., HVAC, TV, microwave ovens, battery chargers for mobile phones or laptop computers, audio equipment, etc.).

- Systems incorporate the inverter itself as well as the input, output, control, and signal wiring associated with the inverter. Requirements are given for the performance, safety, reliability, and environmental compatibility of the system.

- These are recommended requirements to be used by vehicle manufacturers in the development of their own specifications, which may incorporate more or less stringent requirements.

- This document scope excludes military vehicles, bus and 28 V systems.

1.1 Purpose

The purpose of this document is to define requirements for inverters and inverter chargers used on class eight on highway heavy duty trucks.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J184 Qualifying a Sound Data Acquisition System

SAE J1113 Series of Standards for Electromagnetic Compatibility

SAE J1127 Low Voltage Battery Cable

SAE J1128 Low Voltage Primary Cable

SAE J1455 Recommended Environmental Practices for Electronic Equipment Design in Heavy-Duty Vehicle Applications

SAE J1939/15 Reduced Physical Layer, 250K bits/sec, UN-Shielded Twisted Pair (UTP)

SAE J2549 Single Conductor Cable for Heavy-Duty Applications - Truck and Bus

SAE J2698 Primary Single Phase Nominal 120 VAC Wiring Distribution Assembly Design - Truck and Bus

2.1.2 Underwriters Laboratories Publications

Available from Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 458 Standard for Power Converters/Inverters and Power Converter/Inverter Systems for Land Vehicles and Marine Crafts, Standard No. 458

UL 1699 Arc-Fault Circuit Interrupters

2.1.3 Canadian Standards Association Publication

Available from CSA International, 178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3, Tel: 416-747-4000, www.csa-international.org.

CSA 22.2 No. 107.1-01 General Use Power Supplies

2.1.4 Other EMC Standards

CISPR 25 Level 3 CISPR 25 Edition 3.0 2008-03

FCC Part 15, Class B Code Of Federal Regulation, Title 47, Federal Communications Commission.

2.1.5 Other Standards

ANSI/RVIA 12V Standard for Low Voltage Systems on Conversions and Recreational Vehicles

NFPA 70 National Electrical Code, 2008 Edition

ABYC Recommended Practice E-11 and A31 A-31 – Battery Chargers and Inverters; E-11 – AC & DC Electrical Systems on Boats

TMC RP160 Wiring and Circuit Protection Guidelines for 12 Volt DC to 120V AC in cab Inverter Systems.

3. ABBREVIATIONS AND DEFINITIONS

3.1 MSW

Modified sine wave, is defined as any wave form not sinusoidal. This may be square wave, step wave, or trapezoidal.

3.2 NEC

National Electric Code, 2008 edition.

3.3 TSW

True sine wave, is a true sinusoidal wave form with a frequency of 60 Hz.

3.4 TYPE 1

Installations inside the truck cab.

3.5 TYPE 2

Installations outside the truck cab usually on the frame rail.

3.6 AMPACITY

Current carry capacity of a conductor.

3.7 THD

Total Harmonic Distortion.

3.8 AFCI

Arc Fault Circuit Interrupter.

3.9 GFCI

Ground Fault Circuit Interrupter.

3.10 NOMINAL 120 VAC

Standard electrical voltage as supplied by electric utilities may vary in tolerance from 100 to 125 VAC is referenced in this document as nominal 120 VAC.

3.11 SHORE POWER

A fixed pedestal or other fixture that provides the interface to the truck for electricity from the land based power grid. An extension cord links the shore power with the truck's fixed shore power connectors.

3.12 SHORE POWER CONNECTOR

The standard connector used to connect on-board wiring to the external power supply from the land base power grid.

3.13 SURGE CURRENT

The surge current is the initial electrical current drawn by a load during its startup. This surge is typically less than 1 s in duration.

4. GENERAL APPLICATION CONSIDERATIONS

4.1 Location of Device

Is the area or location where the device will be mounted in the vehicle. The inverter system should be mounted as close as possible to the battery bank or energy source to minimize voltage drop on the DC cables. Excessive lengths will require the use of larger cables to limit the voltage drop due to the cables.

4.2 Maximum Surge Requirements

The system designer needs to ensure that the selected inverter can satisfy any startup surge requirement imposed by the anticipated loads. This surge current can easily be five times the steady state current and is typically less than a second in duration. Large inductive loads such as electric motors draw large instantaneous currents when starting – even more if they are driving a refrigeration or air conditioning compressor. Televisions and microwaves also have also have startup surge requirements.

4.3 Steady State Power Requirements

The system designer must size the system based on the steady state power requirements of the connected loads. The designer must add the power requirements of all loads which will be connected and operated simultaneously. For a typical cab this would be a TV, VCR/DVD player, and light. The design would add up all of the steady state power requirements and then size the inverter accordingly. Table 1 provides a sample of the typical steady state load of common appliances used in the trucking industry. These are not exact and the designer should check the rating on the appliances going to be used.

TABLE 1 - TYPICAL POWER RATING OF LOADS

Load	Typical Power Rating
13” Color TV	70 W
19” Color TV	300 W
Lap Top Computer	70 - 90 W
Electric Blanket	150 W
Coffee Maker	1250 W during brewing 200 W during warm cycle
Hair Dryer	800 - 1875 W
Satellite Receiver	20 W
DVD/VCR	50 - 100 W
Iron	1200 W
¼” Drill	300 W
Electric Frying Pan	1500 W
Microwave Oven	1000 W

4.4 Loads Attached to Power Source

The system designer needs to have an understanding of the type of loads which will be attached to the system. Some loads such as electric clocks do not keep time properly with MSW inverters. Some transformer less products also may have problems operating off of MSW inverters.

4.5 Battery Capacity Requirements for Run Time

The battery capacity of the system must be sized for the typical loads which will discharge the batteries to no more than 50% of charge by the end of the desired run time. In order to do this, one must calculate the number of amp-hours that will be used between charging cycles. When the required amp-hours are known, the size of the battery bank will be twice this amount. Typically the wattage of the load is marked on the nameplate. This wattage multiplied by number of hours of use give you the watt/hours. Amp-hours used equals roughly the AC watt-hours divided by 10 for a 12 VDC system. This will give you the required amp-hours. The designer must consider the effects of temperature and battery energy storage. As the temperature deceases towards freezing, the energy storage capacity of the battery diminishes.

4.6 Cable Harness Requirements (Over Current protection, DC disconnect)

The system designer must design the system to ensure the cable harness is protected for short circuit, over temperature, maximum current and high voltage. Typical system installation requires an over current protection device (fuse or circuit breaker) in the primary DC circuit path to protect the DC wire harness from excessive currents caused by short circuits. A DC disconnect may be used to disconnect the battery when the voltage is low or to remove all DC loads from the battery.

4.7 Low Battery Cut Off (Voltage) to Ensure Truck Starting

Most inverter systems are designed with a low battery cut off function internal to the unit. This low voltage cut off is designed to shut off the inverter when the battery voltage falls below a given set point to ensure the batteries have enough energy to start the truck. Typically, an “off the shelf inverter”, the low voltage trip point is set to 10.5 VDC. For a class eight truck battery system, a recommended cut off voltage is 11.8 VDC. If the set point is too high, the inverter may shut off prematurely during surge loads due to the voltage drop across the DC cable triggering the low battery cut off.

4.8 State of Charge

State of charge is the ability of the system to monitor the amount of energy stored in the batteries. This is usually measured in amp-hours. Utilizing state of charge is a more accurate way of ensuring the truck’s start batteries are not discharged beyond the capability to start the truck. This device measures all of the energy entering and exiting the batteries.

Voltage may not be an accurate method of determining the ability of a set of batteries to start a class 8 truck. As the battery is used it cycles through many charge/discharge cycles and its ability to hold charge will be diminished. In some cases the low voltage cutoff will not leave enough energy in the batteries to start the truck.

4.9 Technology Choices

Inverters (and inverter/chargers) are available in a large array of technology choices. Typically inverters are classified by waveform type, operating frequency, and number of conversion stages – each with its own set of compromises in the areas of functionality, cost, size and weight. Ideally they would all allow 120 VAC appliances to operate from battery power but even that may not be assured unless properly specified.

4.9.1 Waveform: True Sine Wave vs. Modified Sine Wave

There are two classes of output voltage offered by inverters: true sine wave (TSW) and modified sine wave (MSW). A TSW inverter will typically perform to a specification for waveform distortion (usually called THD) of less than 5% - that is, the output waveform is less than 5% different from a mathematically pure sine wave. An MSW waveform may have 40% distortion or more. There are also distinctly different subclasses of MSW in terms of what the distortion looks like, each with its own unique way of affecting the appliances. The product’s literature will indicate whether it is TSW or MSW but, if MSW, will not indicate which type of MSW. Thus experience gained with a known MSW inverter can not be assumed to apply to an unknown MSW inverter.

All devices designed for 120 VAC operation are designed to operate on a TSW voltage since that is the waveform provided by the utility. Many devices are not compatible with, or will operate differently on, MSW voltage.

Examples include the following:

- microwave ovens that may cook slower (or faster, or worse, with varying speed depending on battery voltage), or maybe refuse to work at all
- some TVs will not function on some MSW inverters
- digital clocks which derive their timebase from the incoming power (i.e., Non crystal-controlled clocks) may not keep time properly
- cordless tool or shaver battery chargers may not charge properly, or fail prematurely, or become unsafe
- speed controlled tools or light dimmers may not work properly
- potential for video or audio interference on A/V equipment
- some GFCI breakers do not operate correctly and become unsafe

4.9.2 High Frequency or Low Frequency Topologies

The designer of an inverter will choose a high frequency (HF) design approach to reduce the size and weight of the magnetic components within the inverter – this is the primary advantage to high frequency. The disadvantage is that the power devices in the HF design operate at frequencies up to 100 kHz and these designs may be less efficient and generate more heat. A low frequency design (LF) has the power devices operating at 60 Hz and is usually simpler to design. It might also be deemed more reliable due to there being fewer parts – but will generally be larger and heavier than an HF design.

4.9.3 Single Stage vs. Multi-Stage

In a single stage (SS) design the battery power is converted directly into 120 VAC. In a multi-stage (MS) design the battery power is converted to an intermediate voltage within the inverter by one stage of power conversion and then into the 120 VAC output by a second stage of power conversion. There might even be three stages of power conversion in which there are two intermediate voltages within the unit. An SS design will put a large amount of ripple current onto the DC system that powers the inverter; this may cause problems related to battery heating or interference with A/V equipment – it can also be more sensitive to input wiring inductance. An MS inverter can decouple the output from the input and may control the battery ripple. It is also commonly assumed that SS inverters must be more efficient than MS inverters but this statement can not be made as a general claim and the specifications of competing units must be compared.

4.9.4 Communications Interfaces, Canbus Interface, RS 485 Interface, LIN, etc. (Optional)

Many of the newer systems have the ability to communicate via a communications prototcol like SAE J1939 or RS232. This allows the system designer to integrate this device into the trucks onboard systems for configuration and diagnostics.

4.10 Inverter/Charger Combination Units

Inverter/charger combination units are bidirectional systems which convert DC to AC when connected to a battery and convert AC to DC (to recharge the batteries) when connected to shore power. The device can only operate in one direction, charging or inverting, not both simultaneously.

5. INSTALLATION

5.1 Location and Mounting

5.1.1 In-cab (Type 1)

In cab mounting is when the inverter is installed in the sleeper cab or storage compartment. Typically the DC power is routed through the cab floor. Care must be taken to ensure the entry point of the wiring has a grommet to minimize water intrusion and wire chafing.

5.1.2 External Mounted Products (Type 2)

External cab mounting is when the inverter is installed external to the sleeper cab. A typical installation may be the frame rail below the cab. Typically the AC wiring is routed through the cab floor. Care must be taken to ensure the entry point of the wiring has a grommet to minimize water intrusion and wire chafing.

5.2 Audible Noise

Typically, the specification for audible noise is 60 dB from 6 ft away. Measure the audible noise using SAE J184 procedures when the inverter is producing the maximum noise level (e.g., when fans are running).

5.3 Wiring

5.3.1 AC Wiring

Wire selection, routing and installation shall follow SAE J2698, Primary Single Phase Nominal 120 VAC Wiring Distribution Assembly Design.

5.3.2 GFCI/AFCI Compatibility

Where GFCI and/or AFCI protection is required for inverter output circuits the designer must be aware that some GFCI and AFCI devices may not function correctly with some inverters – particularly those inverters with an MSW output waveform. The designer must ensure that the selected GFCI or AFCI device models are compatible with the selected inverter model by either testing the selected devices on the selected inverter according to the appropriate UL standards (UL 458 for GFCI and UL 1699 for AFCI). This tested need not be done if the inverter manufacturer has performed the test and can provide the information.

5.3.3 DC Wiring

Care must be taken to ensure that the DC wiring system has an ampacity rating appropriate for the installation, particularly with respect to steady-state and surge current demanded by the inverter and the voltage drop between the battery and the inverter. If the voltage drop becomes excessive the inverter will not operate correctly. The inverter may also be rated to supply power in excess of its steady-state rating for up to 30 min or more. The recommended design sequence follows:

- Select over current protection device so as not to open on the anticipated surge demand of the inverter. The inverter manufacturer will need to provide a surge current vs. time curve to aid in this process.
- Select a wire type based on SAE J1128, SAE J1127, or SAE J2549.
- Select a wire size based on SAE J1128 and based on the rating selected for the over current protection device.

- Check voltage drop from battery to inverter and verify that it is acceptable for the intended application.
- The inverter should be wired electrically close to the battery to limit voltage drop. The inverter should have a direct connection to the battery negative terminal; not through the chassis.

6. ELECTRICAL PERFORMANCE

6.1 AC Output

6.1.1 Waveform

Sine wave, 5% THD
MSW, 40% THD

6.1.2 Voltage

120 VAC (±10%)

6.1.3 AC Current Rating

The AC current rating of some inverter or inverter/charger is determined by the output power and transfer current of the shore power. When installing an inverter or inverter/charger it is imperative that the steady state and surge currents is known so AC wiring is sized appropriately for ampacity and thermal rating.

6.1.4 Frequency

60 Hz (±5%)

6.1.5 Isolation

The isolation requirements should follow the requirements outlined in UL 458, Section 39.

6.2 DC Input

6.2.1 DC Input Voltage

12 V nominal, 9 V to 16 V range, as specified by SAE J1455, Section 4.11.

6.2.2 DC Input Current

The DC input current is determined by the output power of the inverter or inverter charger. When installing the device one shall verify the steady state and surge current the device uses to ensure the DC wire is sized correctly for ampacity and thermal rating. The surge and steady-state current demand will dictate the rating of the over current protection device and the DC wire size must be coordinated with the circuit protection. Refer to the 2008 edition of the National Electrical Code for wire sizing based on ampacity required. The cable should meet the requirements of SAE J1128, Low tension Primary Cable.

The designer must verify that the installed vehicle alternator is of large enough capacity to operate the vehicle's power demand (see SAE J1343) and fulfill the capacity of the inverter load.

6.2.3 Isolation Voltage to Chassis

The isolation requirements should follow the requirements outlined in UL 458, Section 39.

6.3 Inverter Charger AC Input

6.3.1 AC Input

120 VAC ± 10%, 60 Hz ± 5%.

6.4 Inverter Charger DC Output

6.4.1 DC Output Voltage

The DC voltage is based on charging Algorithm (typically between 12 V to 15 VDC).

6.4.2 DC Output Current

The DC output current is dependent on the power rating of the charger and typically which stage of the charge algorithm the device is in (refer to Figure 1).

6.4.3 Algorithm

The charger may use a single or multi stage charging algorithm as dictated by how the charger is intended to be used. An example 3-stage charging algorithm is shown in Figure 1.

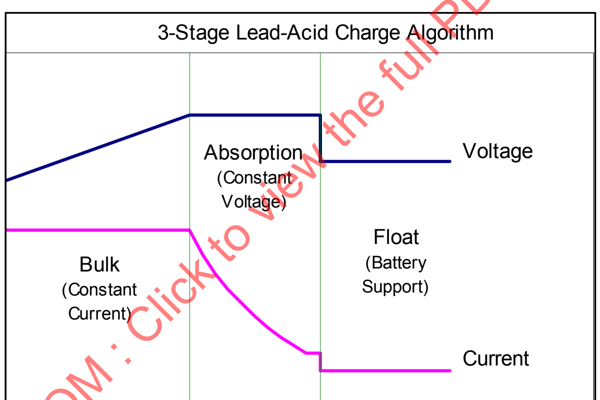

FIGURE 1 - THREE STAGE CHARGING PROFILE

6.4.4 Inverter/Shore Power Transfer System

This can be an external transfer switch meeting NEC/UL requirements or internal to the device. The transfer system must afford back feed protection, i.e., it must prevent the appearance of the inverter output voltage on the shore power line even in the case of a single fault (e.g., the transfer relay becoming welded).

6.4.5 Neutral to Ground Bonding

Based on requirements for commercial buildings and homes as specified in NEC, it is suggested that the truck's AC voltage system neutral must be locally bonded to ground when the inverter is running and must not be bonded locally to ground when the system is powered by shore power. There are many ways to perform the bonding based on installation. Figures 2 through 4 illustrate examples of bonding for different installations. Considerations for bonding should follow SAE J2698 recommendations.

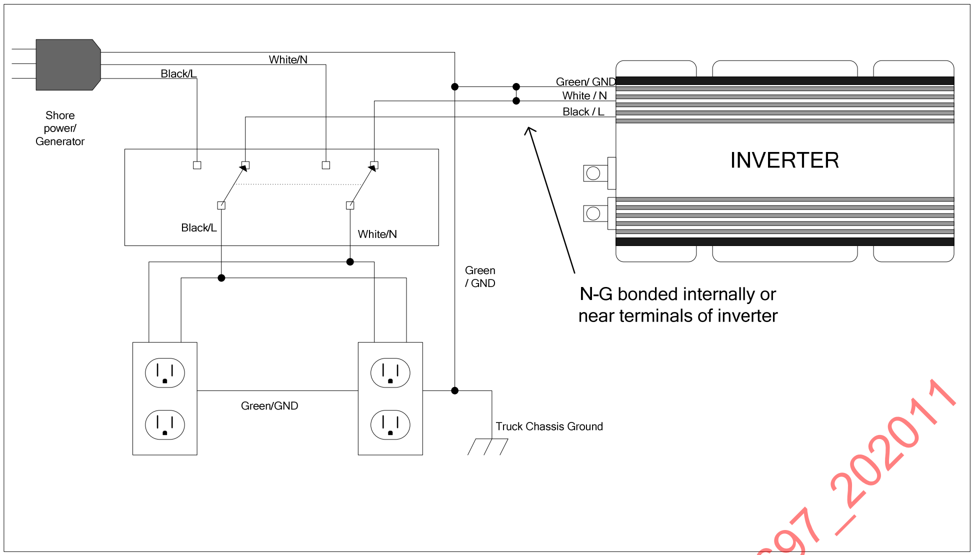

FIGURE 2 - NEUTRAL BONDING WITH EXTERNAL TRANSFER SWITCH

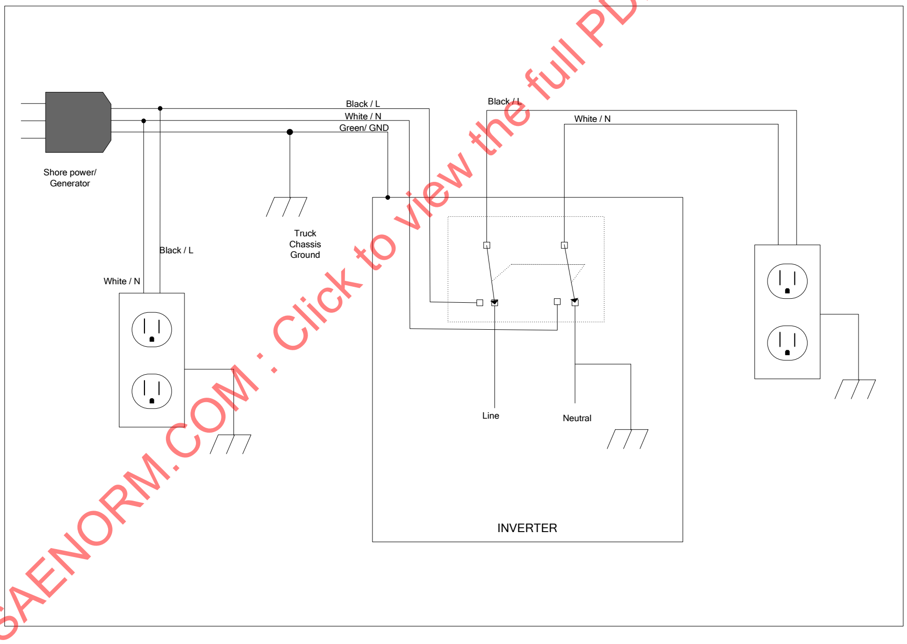

FIGURE 3 - NEUTRAL BONDING WITH INTERNAL TRANSFER SWITCH