Engineering Bulletin 1002-2010 – Ungrounded DC Systems

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Purpose:

The purpose of this bulletin is to discuss the application of ungrounded DC photovoltaic systems in the US and to give guidance on their use within the National Electric Code (NEC).

Traditionally, the US has used only grounded DC systems whereas Europe and Japan have used ungrounded systems. The Europeans have demonstrated that ungrounded systems result in higher system efficiencies. Now there is a trend in the US to begin to use ungrounded systems to take advantage of the higher efficiencies. This bulletin will discuss where the improvement of efficiency comes from, the need for going to ungrounded systems, and how the National Electric Code (NEC) is addressing ungrounded systems.

The Isolation Transformer:

Inverter topology determines the application of a grounded versus an ungrounded system. In the US, with grounded systems, inverters incorporate an isolation transformer in their topology. Figure 1 shows a typical single-phase grid-tie inverter used in the US (PV Powered). The isolation transformer represents a significant part of the overall volume and cost of the inverter.

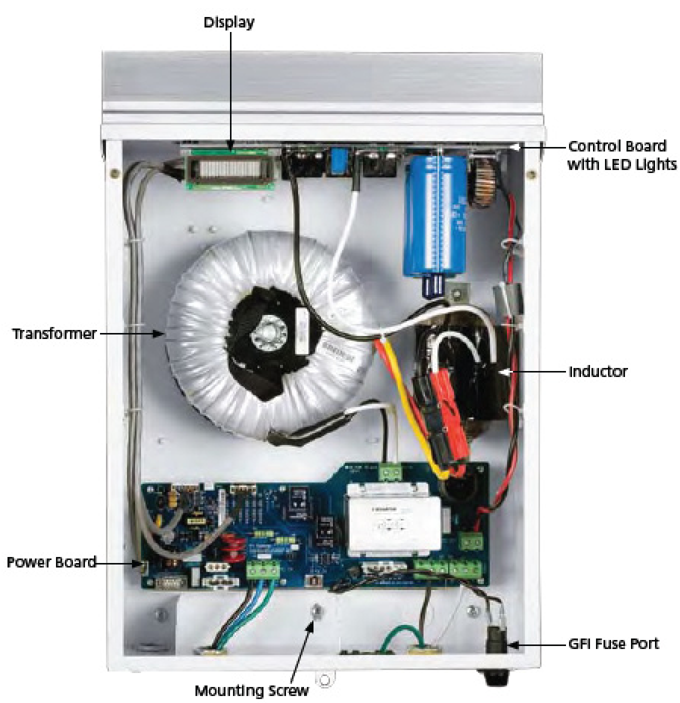


Figure 1 – Typical Grid-tie Inverter Used in the US

The isolation transformer provides three features to the inverter:

1. *Output Filter:* The transformer, being a reactive component, helps in filtering the inverter's pulse-width modulation signal. The transformer is generally not the only reactive component in the filter design.

An inductor (identified in Figure 1) and a capacitor (large sky-blue component in the top-right corner near control board of the inverter) provide additional filtering so that a pure sine wave is generated at the inverter's AC output.

2. *Voltage Step-up:* The maximum voltage that an inverter can output is slightly (about 10%) less than the maximum voltage that can be produced on the DC side of the system. In the US the typical maximum DC voltage is 600VDC with the actual operating voltage as low as 330VDC.

   The output voltage of the inverter, on the other hand, must match the grid's maximum voltage. For a 240V AC installation the peak grid voltage can be as high as 373V. For a 480V three-phase AC system maximum peak grid voltage can be as much as 747V. An isolation transformer permits stepping-up of voltage to match the grid voltage for a given input DC voltage.

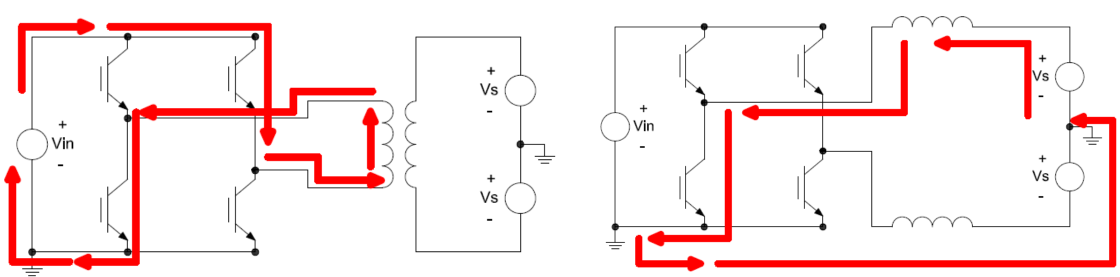
3. *Decoupling between the AC and DC:* With grounded systems the DC system needs to isolate from the AC system so that each system's grounds are not coupled through the source circuits.

An isolation transformer generates system losses (1 to 2%) and lowers the overall system efficiency. To improve the efficiency of inverter the isolation transformer should be eliminated. Elimination of the isolation transformer will require the features listed above each be addressed.

The first item, output filter, can easily be solved with the addition of properly designed filter elements, the addition of an inductor and/or capacitor.

The second item, voltage step-up, can only be addressed by using higher DC voltage. For smaller single-phase inverters 330V to 600V DC is generally adequate. For 480V AC three-phase systems this will require 1000V DC input voltages.

The third item drives the grounded/ungrounded issue. Figure 2 shows an inverter schematic with and without an isolation transformer. In both diagrams the DC system is grounded. With the isolation transformer (Figure 2a) there is no direct path between the DC and AC grounds but once the transformer is replace with line inductors (Figure 2b) there is a direct short through the coupled grounds.



a) With Isolation Transformer *b) Without Isolation Transformer*

Figure 2 – Inverter With and Without an Isolation Transformer.

To avoid the coupled ground problem either the AC or the DC ground must be removed. The removal of the AC ground is not possible because the NEC does not permit it. The removal of the DC ground (ungrounded system) has now been addressed by NEC.

To summarize: one easy way to improve the efficiency of the inverter is to eliminate the isolation transformer. The elimination of the isolation transformer may require the DC voltage to be higher and will require the DC system to become ungrounded.

NEC Requirements of Ungrounded DC System:

The NEC, in its effort to harmonize with the European standards (IEC), has worked toward permitting ungrounded DC systems. The first guidance was given in the 2005 Code. At that time (2002 to 2004) there was no UL standard for double-insulated wire, a requirement for ungrounded systems. As a result there was no listed wire available for installation. With the advent of a new UL standard for “PV Wire”, around 2006, the next NEC code release (2008) was able to specifically require “PV Wire” for ungrounded installations. The US “PV Wire” rating is basically the same wire used in Europe with certification by UL under its new “PV Wire” standard.

The current requirement for installing an ungrounded PV system in the US is covered in NEC 2008 under section NEC 690.35. These requirements are as follows:

- Disconnects – All photovoltaic source and output circuit conductors shall have disconnects complying with 690, Part III
- Overcurrent Protection – All photovoltaic source and output circuit conductors shall have overcurrent protection complying with 690.9.
- Ground-Fault Protection – All photovoltaic source and output circuits shall be provided with a ground protection device or system that complies with: detects a ground fault; indicates that a ground fault has occurred; automatically disconnects all conductors of causes the inverter or charge controller connected to the fault circuit to automatically cease supplying power to output circuits
- Source Circuit Conductors – The photovoltaic source circuit conductors shall consist of the following: nonmetallic jacketed multi-conductor cable; conductors installed in a raceway; or conductors listed and identified as Photovoltaic (PV) Wire installed as exposed single conductors.

Conclusions:

1. The drive toward ungrounded systems comes from trying to get more efficiency out of the inverters, specifically through the elimination of the isolation transformer. Without an isolation transformer the DC system must be ungrounded.
2. NEC permits the use of ungrounded systems providing equipment is adequately protected and that double-jacketed listed “PV Wire” is used.