IEEE 1547 and Small Photovoltaic-Based Generation Case Studies

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IEEE 1547

- IEEE Standard for Interconnecting Distributed Resources with Electric Systems
- Applicable to any and all distributed resources with aggregate capacity of 10 MVA and less.
- Primarily targets radial primary and secondary distribution systems.
- "It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection."[1]

1. IEEE Std. 1547-2003

IEEE 1547 and UL 1741 Testing and Compliance

- **To comply with IEEE 1547 the interconnection system must:**
  - Exhibit a fixed 5-minute time delay or adjustable delay of 5 minutes or less on startup/restart
  - Respond to abnormal system conditions (voltage/frequency excursions) per IEEE 1547.
  - Not exceed steady-state harmonic and DC current content limits.
  - Not produce objectionable flicker.
  - Detect and cease energization of the grid during unintentional islanding within 2 seconds.
  - Pass synchronization and interconnect integrity testing (EMI and surge withstand).
- **UL 1741 listing indicates compliance with IEEE 1547 as far as manufacturer's design and production testing is concerned.**
- **UL 1741 listing has no bearing on the installed interconnection evaluation, commissioning test and periodic interconnection tests required by IEEE 1547.**

Basis for Commissioning Test from IEEE 1547

- IEEE 1547 requires a visual inspection to verify grounding coordination compliance and presence of isolation device (when required by utility).
- Commissioning tests to include:
  - Isolation device operability.
  - Cease to energize functionality test on each phase individually (refrain from unintentional islanding). Verification of maximum response time and specified time delay before reconnect.
  - Any of the design and/or production tests not already performed on the subject interconnection equipment (e.g. synchronization, response to abnormal voltage/frequency conditions, etc. when discrete relaying is used).

Case 1: Excessive Steady-State Voltage Due to Customer Generation

- 37.44 kW in Rated Photovoltaic System Capacity
- 37.5 kVA, 7.2 kV to 120/240 1-phase transformer at 2.5% Z
- Multiple DC to 240 VAC Inverters
- Little to no load in office/shop building from which PV system fed.
- System complied with IEEE 1547. Inverters are UL 1741 listed.

Example Utility-Interactive Inverter

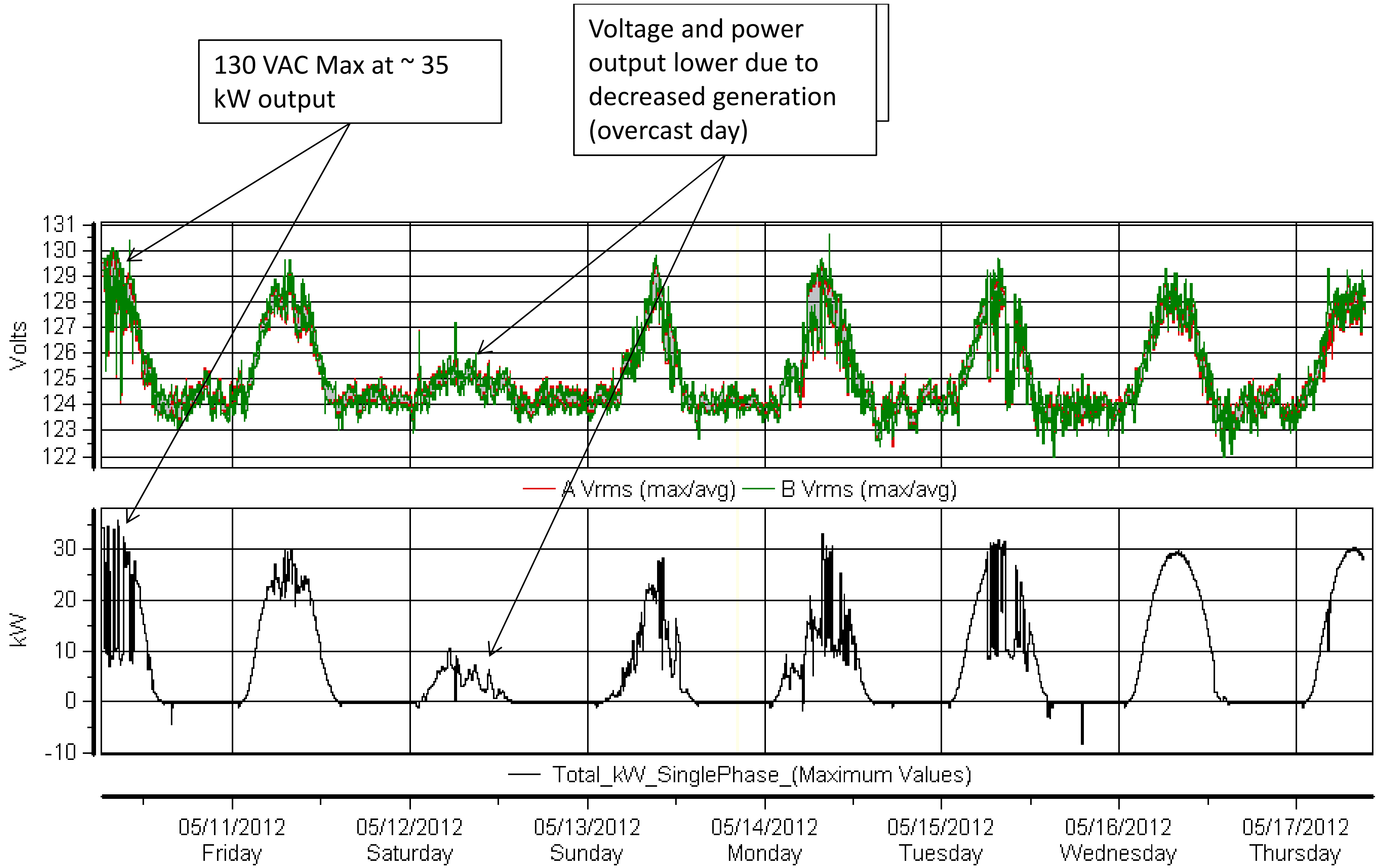


Fig. 1. Average/Maximum RMS Voltage and Average Total Power Output during each 5-minute Interval

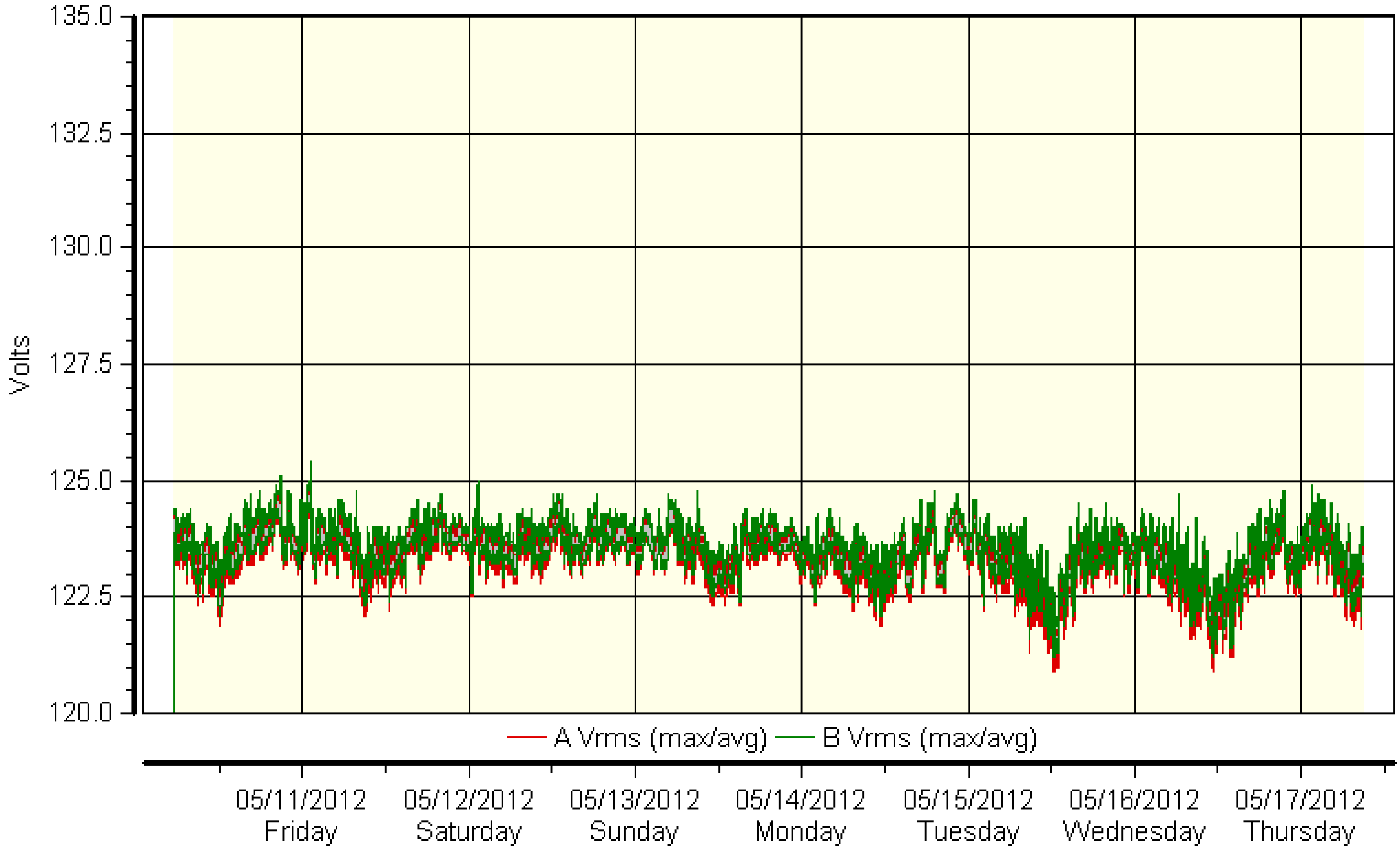


Fig. 2. Maximum/Average RMS Voltage during each 5-minute Interval at Other Customer Site Just Upstream on Distribution Circuit

Power Flow Equations

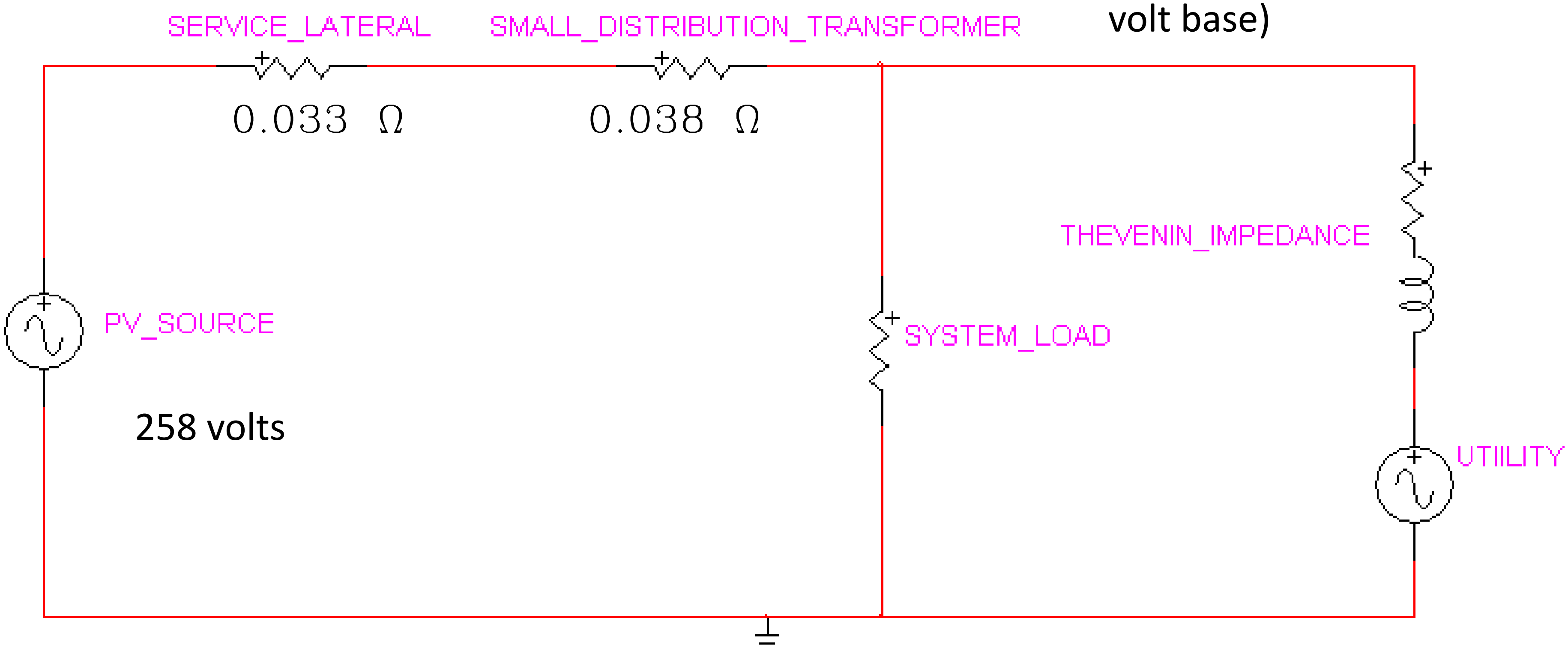
$$S_{12} = \frac{|V_1|^2}{Z^*} - \frac{V_1 V_2^*}{Z^*}$$

V_1 = Grid Voltage
V_2 = Voltage at Inverter or Generator Terminals

Mostly Resistive System (low-voltage systems)	Mostly Reactive System (high-voltage systems)
$P = \frac{V_1}{R}(V_2 \cos\delta - V_1)$	$P = \frac{V_1 V_2}{X}\sin\delta$
$Q = -j\frac{V_1 V_2}{R}\sin\delta$	$Q = \frac{V_1}{X}(V_2 \cos\delta - V_1)$

In Resistive Systems, Voltage at Inverter or Generator Terminals Must be Greater than the Grid Voltage for Power Transfer TO the Grid!!

248 volts (Utility primary voltage on 240 volt base)



258 volts

$$\frac{248 \times (258 - 248)}{0.071} \approx 35\,\mathrm{kW}$$

Recipe for Problems

- **Virtually no load on the transformer secondary** otherwise, most of the generated power would flow to the local load.
- **Mild temperatures** meaning reduced load on the utility system resulting in slightly elevated baseline voltage and slightly higher solar panel output.
- **PV system output near the kVA rating of the transformer.** Voltage drop or voltage rise across the transformer higher as load/generation increases.
- **Both the 260 volt RMS limit of the inverter and the 126/252 volt RMS ANSI limit for the customer's power system being exceeded.** This is a problem for both the inverters and, potentially, the customer's loads.

Note that elevated voltage exceeded ANSI C84.1 limits but did not constitute an abnormal voltage condition as defined in IEEE 1547.

Case 1 - The Fix

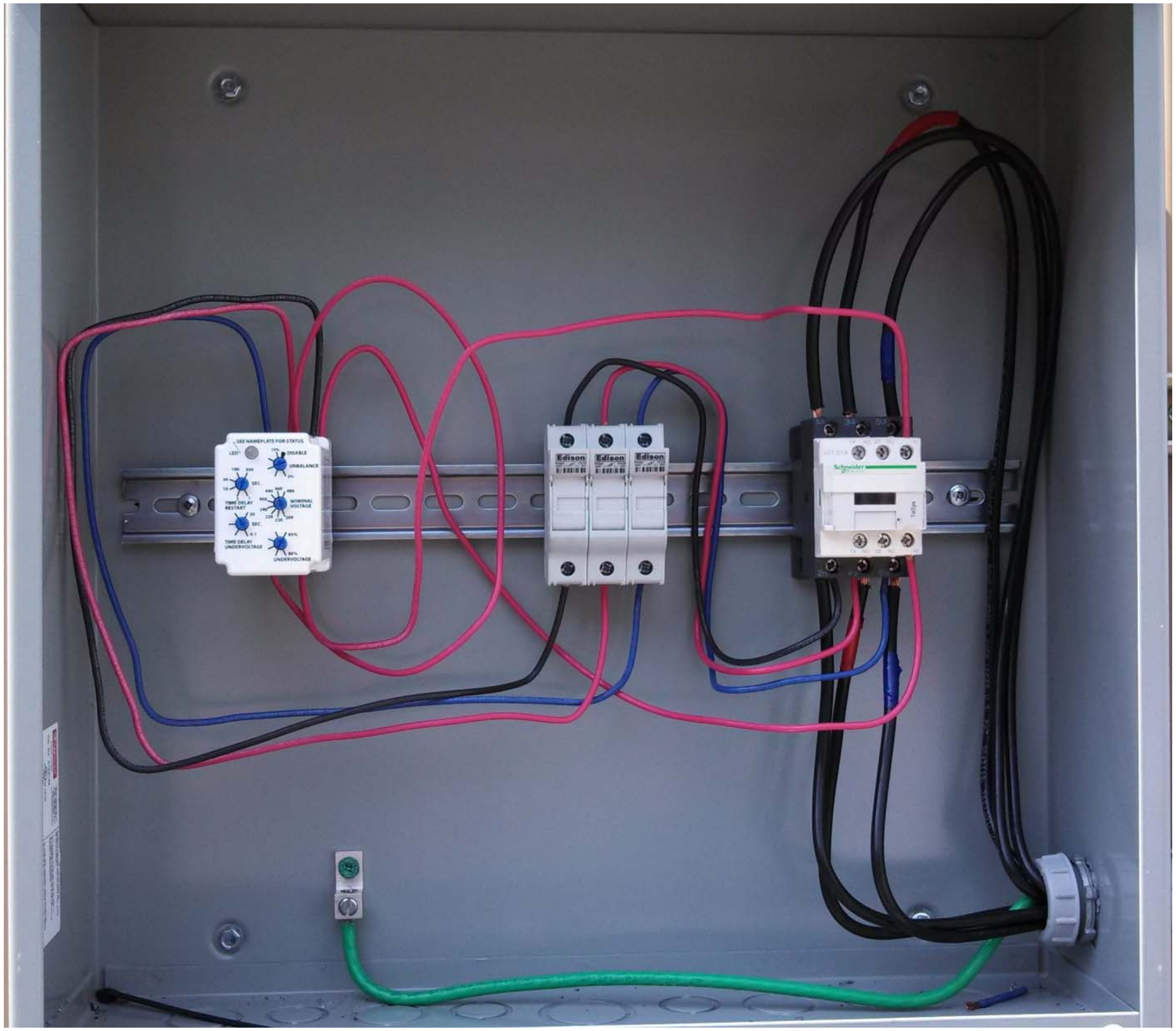
- Replaced transformer that had no taps with transformer with taps.
- Adjusted tap to lower secondary voltage.
- Everybody happy (except for whoever had to pay for the replacement transformer).

Case 2: Use of Single-Phase Inverters on a 3-phase System

- 208 volt three-phase installation
- 9.9 kW system
- Used 1-phase microinverters
- Performance of the “3-phase” interconnection system questionable considering no communication between the 1-phase units.

Examples of Microinverters

Common Workaround – Phase Monitor Relay



Concerns with Using Phase Monitor Relay as a Solution

- Only open phase and simultaneous disconnect of all three phases can be tested in typical commissioning test.
- Interconnection system includes components that have not been tested per IEEE 1547/UL 1741 in the factory, so commissioning test is to include testing response of the system to abnormal voltage/frequency conditions as well as other design/production tests.
- Design and production tests per IEEE 1547 require equipment under test to be connected to a simulated utility or signal injection test.
- Phase monitor relay performance may not satisfy IEEE 1547 requirements.

Other Solutions

- When inverters are installed using all three phases, a 3-phase inverter is the best solution.
- Some manufacturers make accessories to link individual 1-phase inverters together when installed separately on 3-phase systems. These accessories should have been factory tested per IEEE 1547 and UL 1741 listed.