Technical Brief

Verifying Five-Minute Timer Protective Requirements for Utility-Interactive Inverters

Introduction

The utility protective requirements for Utility-Interactive inverters are very thorough. This paper summarizes these requirements, focusing on the five-minute reconnection timer requirement and describing several methods of timer verification.

Utility Protective Functions

The "Utility-Interactive" marking comes with PV inverters that have passed rigorous safety testing. Utility protective functions are described, and specific requirements detailed, in the IEEE1547 standard. The protective functions prevent damage to utility distribution systems, utility protective equipment, consumer electronics, and electrical equipment, and they minimize the risk of injury to service personnel and PV system owners. Proper operation of the protective functions is essential in limiting utility company and equipment manufacturer liability.

Utility-Interactive inverters are designed to shut down automatically when the electrical grid they are connected to goes outside of predetermined operational limits. Inverters with the "Utility-Interactive" designation protect against voltage, frequency, and electrical service faults. In North America, the following default limits for voltage and frequency apply:

- Voltage — must remain within 88% and 110% of nominal voltage as measured from line-to-neutral, if a neutral is supplied. Otherwise the measurement is line-to-line.
- Frequency — must remain between 59.3Hz and 60.5Hz.

In addition to voltage and frequency limits, a Utility-Interactive inverter must detect the presence of an island condition. An island can exist if the real load (Watts) and the inductive and capacitive load (VAR) are precisely matched to the inverter output and the utility is disconnected. This condition is theoretically possible, though extremely unlikely.

Under any of these "out-of-limit" conditions, a Utility-Interactive inverter is required to automatically "cease exportation of power" and then monitor the health of the utility connection.

Adjustability of Limits

Voltage thresholds, frequency thresholds, response times, and timer duration can all be changed with the permission of the utility. The set points must be adjustable with individual inverters or aggregated installations with more than 30kW of peak generation capacity. Inverters without adjustable set points must be marked as such. Adjustability is not required for smaller installations, although it is allowed.

Essential Timer Requirements

After detecting an "out-of-bounds" condition, a Utility-Interactive inverter must remain offline until the utility has been within acceptable limits continuously for five minutes. If, during that five minutes, the utility again exceeds or falls short of acceptable limits, the timer must restart and the inverter must not reconnect (begin exportation of power) for an additional five minutes following the last out-of-bounds condition. This condition is tested as part of the UL1741 regulatory compliance test suite.

Field Verification

The protective functions in Utility-Interactive inverters are tested as a routine part of factory production. Many utilities perform field verification of each Utility-Interactive inverter's five-minute timer before allowing the PV system to export power to the electrical grid. As an additional benefit, the test can verify the "Loss of Mains" protective function of the inverter. Loss of Mains is also an IEEE1547 requirement.

Verification Techniques

1. Clamp on ammeter
2. Watch the meter
3. Power measurement

A Couple of Details

The following examples assume a typical (in the U.S.) 240v split-phase utility service. It is important that the type of service be determined accurately. The techniques for three-phase measurements are identical. These examples are specifically for the Enphase Microinverter system. Details vary, but the same principles apply to any inverter system.

Some inverters draw reactive power when idle. The reactive current may be either leading (capacitive) or lagging (inductive). From the utility's standpoint, a capacitive idle load is almost always preferable. Most loads are inductive or resistive. Enphase Microinverters provide 0.058 amps of capacitive var per inverter for M190 and .083 amps of capacitive var per inverter for M215 when connected to a 240vac utility.

What does this mean?

A PV inverter converts DC power generated by the PV modules into AC power for export to the electrical grid. PV modules must have direct sunlight to produce power; hence, PV inverters cannot export power at night. However, a small current (0.058A per microinverter for M190 and 0.083A per microinverter for the M215) can be measured on the branch circuit, even at night. This is the capacitive var current due to EMI filtering components in the inverter.

Procedures

1. Clamp on Ammeter

Clamp-on current meters come in several varieties. Some measure both AC and DC current, while others measure AC current only. In the discussion below we will use the term "current probe" to include both measurement types. All but the least expensive models provide true RMS measurements.

Clamp-on meters include an LCD, and most will also measure voltage. Clamp-on probes can provide the same functionality and are used in conjunction with a standard DMM. Both types of equipment are manufactured by Fluke, B+K Precision, Ideal, AEMC, Amprobe, and Extech, among others.

Procedure

Note: The PV array must be illuminated with direct sunlight; hence, this procedure will not work at night, early in the morning, or late in the afternoon.

1. Open the PV system switch or circuit breaker.
2. Clamp the current probe to one of the phase conductors.
3. Note the reading (should be zero).

4. While closing the circuit breaker or switch, note the time or start a stopwatch.
5. Wait a few seconds and then record the current reading. There will be approximately 0.058 amps of capacitive reactive current per inverter for M190 and approximately 0.083 amps of capacitive reactive current per inverter for M215.
6. Watch the current reading as the five minutes elapses (as noted in step 4). At some point between five minutes and five-and-one-half minutes after closing the circuit breaker or switch, the current value should change substantially.

There are a couple of shortcomings with this procedure—a) the measurement does not take power factor into account, and b) the measurement depends on irradiance—resulting in some ambiguity and the opportunity for error or misinterpretation of results. Specifically, if the irradiance and array size are such that the current during power export approximates the reactive current during non-export, it will be difficult to determine when the system begins exporting power.

There are three possible remedies:

1. After the five-minutes has elapsed, note the current reading, then cover some portion of the array and verify that the change in current is proportional to the obscured portion of the array.
2. Repeat the test when the irradiance is substantially different (either higher or lower).
3. Use one of the other methods described here.

2. Look at the Meter

This method is extremely simple, requires no test equipment, and is easy to perform. The one drawback is that absolute accuracy requires all other loads on the premises to be disconnected. The procedure also relies on the fact that the socketed meter only measures real power. In cases where a dedicated meter is associated with the PV system, this procedure is extremely reliable.

Procedure

Note: The PV array must be illuminated with direct sunlight; hence, this procedure will not work at night, early in the morning, or late in the afternoon.

1. Turn off the switch or circuit breaker to the PV system.
2. Turn off all circuit breakers associated with this meter.
3. Note the meter reading and caterpillar movement (the caterpillar should not be moving).
4. While turning on the breaker or switch, note the time or start a stopwatch.
5. Wait a few seconds and again note the lack of movement of the caterpillar.
6. Watch the caterpillar as the five minutes elapses (as noted in step 4). At some point between five and five-and-one-half minutes from turning on the breaker or switch, the caterpillar should start showing export of power.

3. Power Measurement Equipment

This is the most deterministic method, requiring the largest investment in capital equipment. It is extremely accurate and also provides basic verification of system performance.

Procedures will vary depending on the specific piece of test equipment used. Examples of equipment that can perform this test include:

- Fluke 1735
- Fluke 434
- Fluke 41B
- Fluke 43B
- Hioki USA 3169-20 (low cost)

This procedure is substantially simpler than the preceding methods.

Procedure

1. Open the PV system circuit breaker or disconnect switch.
2. Connect the power measurement equipment per the manufacturer's instructions, following all safety precautions.
3. Note the readings for Watts and var.
4. While closing the circuit breaker or switch, note the time or start a stopwatch.
5. Note the readings for Watts and var. The Watts will show extremely low consumption (milliwatts per inverter) and approximately 14var (capacitive, i.e., leading) per inverter.
6. After the five-minutes has elapsed, the system will show real power exportation (proportional to system size and irradiance) and near unity power factor.

Conclusion

Verifying the five-minute utility protective timer is an important step in gaining confidence in the protective functions of a Utility-Interactive inverter system. Several methods can be used to verify proper operation. The method chosen depends on the tester's initial confidence in the system equipment, availability of test equipment, and availability of natural sunlight.

Loss of Mains functionality can be verified following any of the test methods by opening the circuit breaker or disconnect switch after the system has begun exporting power. It is then a simple matter of confirming that the system returns to the conditions (watts and var or current) that existed prior to closing the circuit breaker or disconnect switch.