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IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

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IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

1. Overview

This standard provides interconnection technical specifications and requirements, and test specifications and requirements. Additionally, there is a bibliography included as Annex A that lists citations referred to in this standard for informative purposes, but that are not required to be used in conjunction with this standard.

1.1 Scope

This standard establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems (EPS).

1.2 Purpose

This standard provides a uniform standard for interconnection of distributed resources with electric power systems. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.

The requirements shall be met at the point of common coupling (PCC), although the devices used to meet these requirements can be located elsewhere. This standard applies to interconnection based on the aggregate rating of all the DR units that are within the Local EPS. The functions of the interconnection system hardware and software that affect the Area EPS are required to meet this standard regardless of their location on the EPS.

The stated specifications and requirements, both technical and testing, are universally needed for interconnection of DR, including synchronous machines, induction machines, or power inverters/converters, and will be sufficient for most installations.[1]

[1] Additional technical requirements and/or tests may be necessary for some limited situations.

Table 3—Maximum harmonic current distortion in percent of current (I)[a]

Individual harmonic order h (odd harmonics)[b]	h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35 ≤ h	Total demand distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).
[b]Even harmonics are limited to 25% of the odd harmonic limits above.

4.4 Islanding

4.4.1 Unintentional islanding

For an unintentional island in which the DR energizes a portion of the Area EPS through the PCC, the DR interconnection system shall detect the island and cease to energize the Area EPS within two seconds of the formation of an island.[12]

4.4.2 Intentional islanding

This topic is under consideration for future revisions of this standard.

5. Interconnection test specifications and requirements

This clause provides the test requirements to demonstrate that the interconnection system meets the requirements of Clause 4. The applicable tests from this clause are required for all interconnection systems. The results of these tests shall be formally documented.

The stated test specifications and requirements are universally needed for interconnection of DR including synchronous machines, induction machines, or static power inverters/converters, and will be sufficient for most installations.[13]

5.1 Design test

This design test shall be performed as applicable to the specific interconnection system technology. The test shall be performed on a representative sample, either in the factory, at a testing laboratory, or on equipment in the field.[14]

[12]Some examples by which this requirement may be met are:
1. The DR aggregate capacity is less than one-third of the minimum load of the Local EPS.
2. The DR is certified to pass an applicable non-islanding test.
3. The DR installation contains reverse or minimum power flow protection, sensed between the Point of DR Connection and the PCC, which will disconnect or isolate the DR if power flow from the Area EPS to the Local EPS reverses or falls below a set threshold.
4. The DR contains other non-islanding means, such as a) forced frequency or voltage shifting, b) transfer trip, or c) governor and excitation controls that maintain constant power and constant power factor.

[13]Additional tests may be necessary for some limited situations.
[14]The design test of 5.1 may be adopted as the testing basis for certification of interconnection systems.

This test applies to a packaged interconnection system using embedded components or to an interconnection system that uses an assembly of discrete components.

The design test shall be conducted on the same sample in the sequence of Table 4.

Table 4—Sequence for conducting design test

Required order	Design test clause and title
1	5.1.1 Response to abnormal voltage and frequency
2	5.1.2 Synchronization
3	5.1.3 Interconnect integrity test
Suggested order	
4	5.1.1 Response to abnormal voltage and frequency
5	5.1.2 Synchronization
6	5.1.4 Unintentional islanding
7	5.1.5 Limitation of dc injection
8	5.1.6 Harmonics

5.1.1 Response to abnormal voltage and frequency

This test shall demonstrate that the DR ceases to energize the Area EPS when the voltage or frequency exceeds the limits as specified in 4.2.3 and 4.2.4. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

5.1.2 Synchronization

Test results conforming to requirements of A, B, or C below are accepted as indicating compliance with the requirements of 4.1.3. The appropriate conditions to be met for specific interconnection system technology follow.

A. Synchronous interconnection to an EPS, or an energized local EPS to an energized Area EPS

This test shall demonstrate that at the moment of the paralleling-device closure, all three parameters in Table 5 are within the stated ranges. This test shall also demonstrate that if any of the parameters are outside of the ranges stated in the table, the paralleling-device shall not close.

B. Induction interconnection

Self-excited induction generators shall be tested as per A in 5.1.2.

This test shall determine the maximum start-up (in-rush) current drawn by the unit.[15] The results shall be used, along with Area EPS impedance information for the proposed location, to estimate the starting voltage

[15]NEMA MG 1-1998 contains an acceptable method for determining inrush current.

Table 5—Synchronization parameter limits for synchronous interconnection to an EPS, or an energized local EPS to an energized Area EPS

Aggregate rating of DR units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference (ΔΦ, °)
0 – 500	0.3	10	20
> 500 – 1 500	0.2	5	15
> 1 500 – 10 000	0.1	3	10

drop and verify that the unit shall not exceed the synchronization requirements in 4.1.3 and the flicker requirements in 4.3.2.

C. Inverter interconnection[16]

An inverter-based interconnection system that produces fundamental voltage before the paralleling device is closed shall be tested according to the procedure for synchronous interconnection as stated in A of 5.1.2.

All other inverter-based interconnection systems shall be tested to determine the maximum start-up current. The results shall be used, along with Area EPS impedance for the proposed location, to estimate the starting voltage magnitude change and verify that the unit shall meet the synchronization requirements in 4.1.3 and the flicker requirements in 4.3.2.

5.1.3 Interconnect integrity test

5.1.3.1 Protection from EMI

The interconnection system shall be tested in accordance with IEEE Std C37.90.2-1995 to confirm that the results are in compliance with 4.1.8.1. The influence of EMI shall not result in a change in state or mis-operation of the interconnection system.

5.1.3.2 Surge withstand performance

The interconnection system shall be tested for the requirement in 4.1.8.2 in all normal operating modes in accordance with IEEE Std C62.45-2002 for equipment rated less than 1000 V to confirm that the surge withstand capability is met by using the selected test level(s) from IEEE Std C62.41.2-2002. Interconnection system equipment rated greater than 1000 V shall be tested in accordance with manufacturer or system integrator designated applicable standards. For interconnection system equipment signal and control circuits, use IEEE Std C37.90.1-2002. The results of these tests shall indicate the unit did not fail, did not misoperate, and did not provide misinformation.

5.1.3.3 Paralleling device

A dielectric test across the open-circuited paralleling device shall be conducted to confirm compliance with the requirements of 4.1.8.3.

5.1.4 Unintentional Islanding

A test or field verification shall be conducted to confirm that 4.4.1 is met regardless of the selected method of detecting isolation.[17]

[16]Some inverter-based interconnection systems may need to be tested to both requirements of C in 5.1.2.

5.1.5 Limitation of dc injection

Inverter based DR shall be tested to confirm that the DR does not inject dc current greater than prescribed limits that are listed in 4.3.1.

5.1.6 Harmonics

The intent of the harmonics interconnection test is to assess that under a controlled set of conditions the DR unit meets the harmonic limits specified in 4.3.3.

The DR shall be operated in parallel with a predominantly inductive voltage source with a short circuit current capacity I_{SC} of not less than 20 times the DR rated output current at fundamental frequency. The voltage and frequency output of the voltage source shall correspond to the rated voltage and frequency of the DR. The unloaded voltage waveform produced by the Area EPS or simulated utility voltage source shall have a total harmonic distortion (THD) less than 2.5%.

The DR shall be operated at an output test load current, I_L, of 33%, 66%, and at a level as close to 100% of rated output current as practical. Use total rated-current distortion (TRD) in place of TDD. TRD is the total rms value of the sum of the current harmonics created by the DR unit operating into a linear balanced load divided by the greater of the test load current (I_L) demand or the rated current capacity of the DR unit (Irated). The individual harmonic distortion and TRD of the DR output current shall be measured for the first 40 harmonics. The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DR connected. The test results shall not exceed the values in 4.3.3, Table 3.[18]

As an alternative, a synchronous generator DR shall be tested to meet the requirements of 4.3.3; either after installation or while powering a balanced resistive load and isolated from any other sources. The voltage harmonics while powering a resistive load at 100% of the machine kVA rating shall not exceed the levels in Table 6. Voltage harmonics shall be measured line to line for 3-phase/3 wire systems, and line to neutral for 3-phase/4-wire systems.

Table 6—Maximum harmonic voltage distortion in percent of rated voltage for synchronous machines

Individual harmonic order	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	Total harmonic distortion
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

5.2 Production tests

Each interconnection system shall be subjected to requirements of 5.1.1 and 5.1.2. Interconnection systems with adjustable set points shall be tested at a single set of set points as specified by the manufacturer. This test may be conducted as a factory test or may be performed as part of a commissioning test (see 5.4).

[17]An example test is in UL 1741 [B14].

[18]These values or lower values may be required to meet the TDD of 5% at the PCC.

5.3 Interconnection installation evaluation

5.3.1 Grounding integration with Area EPS

A system design verification shall be made to ensure that the requirements of 4.1.2 have been met.

5.3.2 Isolation device

A system design verification shall be made to ensure that the requirements of 4.1.7 have been met.

5.3.3 Monitoring provisions

A system design verification shall be made to ensure that the provisions for monitoring are in accordance with 4.1.6.

5.3.4 Area EPS faults

A system design verification shall be made to ensure that the requirements of 4.2.1 have been met.

5.3.5 Area EPS reclosing coordination

A system design verification shall be made to verify the interconnection system is coordinated with the Area EPS reclosing practices in accordance with 4.2.2.

5.4 Commissioning tests

All commissioning tests shall be performed based on written test procedures.[19] The following visual inspections shall be performed.

— A visual inspection shall be made to ensure that the grounding coordination requirement of 4.1.2 has been implemented.
— A visual inspection shall be made to confirm the presence of the isolation device if required by 4.1.7.

Initial commissioning tests shall be performed on the installed DR and interconnection system equipment prior to the initial parallel operation of the DR. The following tests are required:

— Operability test on the isolation device
— Unintentional-islanding functionality as specified in 5.4.1
— Cease to energize functionality as specified in 5.4.2
— Any tests of 5.1 that have not been previously performed on a representative sample and formally documented
— Any tests of 5.2 that have not been previously performed

The applicable tests of 5.1 shall be repeated when:

— Functional software or firmware changes have been made on the interconnection system
— Any hardware component of the interconnection system has been modified in the field, or, replaced or repaired with parts different from the tested configuration.

Sublauses 5.4.1 and 5.4.2, and the applicable tests of 5.2 shall be repeated if:

[19]Test procedures are commonly provided by equipment manufacturer(s) or system integrator(s) and approved by the equipment owner and Area EPS operator.

— Protection settings have been changed after factory testing.
— Protection functions have been adjusted after the initial commissioning process.

5.4.1 Unintentional islanding functionality test

5.4.1.1 Reverse-power or minimum power test

A reverse-power or minimum power function, if used to meet the requirements of 4.4.1, shall be tested using injection techniques or by adjusting the DR output and local loads to verify that the reverse power or minimum power function is met.

5.4.1.2 Non-islanding functionality test

For non-islanding interconnection systems, 5.4.2 satisfies this requirement.

5.4.1.3 Other unintentional islanding functionality tests

If tests in 5.4.1.1 and 5.4.1.2 are not applicable to the interconnection system, the interconnection system shall be tested in accordance with procedures provided by the manufacturer or system integrator.

5.4.2 Cease to energize functionality test

Check the cease to energize functionality by operating a load interrupting device and verify the equipment ceases to energize its output terminals and does not restart/reconnect for the required time delay. The test shall be performed on each phase individually. This test verifies conformance to the cease to energize requirement of 4.1.4, 4.2.1, 4.2.2, 4.2.3, 4.2.4, and 4.4.1.

5.5 Periodic interconnection tests

All interconnection-related protective functions and associated batteries shall be periodically tested at intervals specified by the manufacturer, system integrator, or the authority who has jurisdiction over the DR interconnection. Periodic test reports or a log for inspection shall be maintained.

Small Wind Turbine Application of the SEL-547

Bob Hughes

Introduction

The idea of small, widely distributed power generation has been talked about and implemented on a limited scale since the 1970s energy crisis. Since then, advances in technology and reliability have contributed to the large number of wind turbines installed in the last few years. Looking into the future, carbon limits, government incentives, and the decreasing cost of wind turbine technology will all contribute to the increased installation of distributed wind energy systems.

The SEL-547 Distributed Generator Interconnection Relay is a key system component that allows wind turbines to be connected to the electric utility grid. Since its introduction in 2002, the SEL-547 has been installed in hundreds of wind energy installations all over North America.

Why Use a Generator Interconnection Relay?

Connecting a basic load to the grid is a very simple process. All that is required is a service conductor from the electric utility transformer, a service entrance, an electric meter, and a circuit breaker. This simplicity is possible because the load will never produce its own voltage or current. If anything goes wrong with the load, the circuit breaker will separate the load from the utility grid before it can damage the grid equipment or interfere with its proper operation.

Now let us introduce an electrical generation source onto the electric utility power grid. Unlike the case of the simple load, it is no longer safe to close the breaker at will. To do so could cause catastrophic damage to the generator if it was not electrically synchronized to the grid. To prevent this from happening, a protective relay is used that only allows the breaker to close if the generator is synchronized to the grid and is producing the proper voltage.

Once the generator is connected to the grid, there are other conditions that could require the breaker to be opened. One example is "anti-islanding" protection. If there is a power outage on the grid, it is important that the generator be disconnected from the grid by opening the breaker. This is a safety precaution to protect the electric utility line crews from encountering an unexpected voltage on a disconnected line, among other issues.

A simple circuit breaker, like that used with a common service entrance, cannot provide these necessary protection features. The SEL-547 provides all of these protection functions and more.

Grid Interconnection Standards

The electric utility and/or state public utilities commission usually has published interconnection standards for distributed generation. These standards specify protective relay requirements. A distributed generation installation must meet these requirements if it will ever be connected to the grid.

Often, these local interconnection standards require that the system comply with the recommendations of IEEE 1547-2003, *Standard for Interconnecting Distributed Resources with Electric Power Systems*. The SEL-547 provides IEEE 1547-compliant protection.

AN EXAMPLE APPLICATION OF THE SEL-547

The SEL-547 has been successfully applied to small-scale wind generation installations all over the United States and Canada. Figure 1 shows one such installation at Hyannis Country Garden on Cape Cod. This net-metered installation allows power to flow in either direction. During windy conditions, the grid-connected turbine provides more power than needed by the garden store. In such circumstances, electric power is exported from the wind turbine to the power grid. In light wind conditions, the garden store supplements the wind turbine power with electric utility power.

In this application, the SEL-547 protects both the generator and the electric grid by opening the breaker if an adverse condition occurs. Examples include over-/undervoltage or over-/underfrequency conditions due to local system islanding or a system-wide voltage/frequency disturbance.

The SEL-547 accomplishes this by monitoring the system voltages and one of the phase currents, as shown in Figure 2. If the SEL-547 detects an abnormal voltage or frequency condition, it sends a trip signal to the breaker, thereby isolating the generator from the electric grid.

Once the generator has disconnected from the grid, the SEL-547 will not allow the generator to reconnect unless it detects that the utility supply and generator are within normal bounds (voltage, frequency, phase angle). This protects both the generator and the grid from damage caused by a nonsynchronized close.

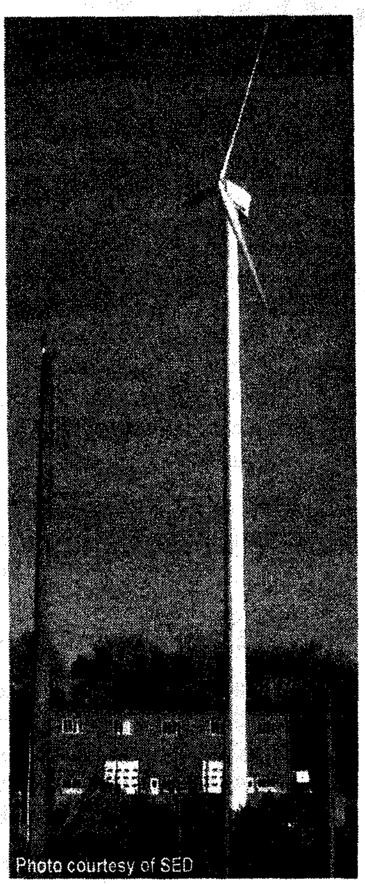

Figure 1 Hyannis Country Garden Wind Turbine

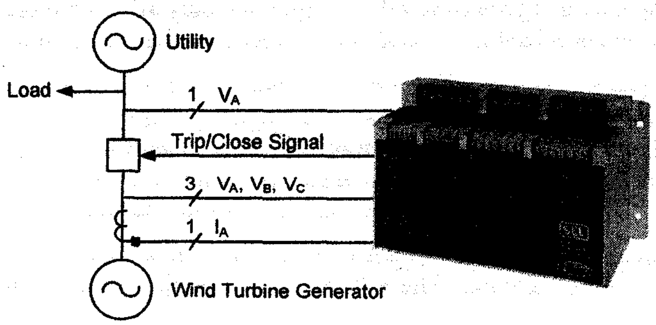

Figure 2 Typical SEL-547 Connections for a Net-Metered Distributed Generation Application

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