Technical Report

Validation of IEEE P1547.1 Interconnection Test Procedures: ASCO 7000 Soft Load Transfer System

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September 2003   •   NREL/TP-560-34870

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Nomenclature

A	scaling factor (PU is at least 110% of P_T) for step functions in time tests
a	manufacturer's stated accuracy for the PUT
DG	distributed generation
DR	distributed resources
EPS	electric power system
NREL	National Renewable Energy Laboratory
IEEE	Institute of Electrical and Electronics Engineers
P	parameter under test
P_b	ramp function starting value (within 10% of P_T)
P_N	nominal condition
P_T	test set point
P_U	final step function value
PUT	parameter under test
SLTS	Soft Load Transfer Switch
S/s	samples per second
t_h	hold time (greater than PUT time-delay setting)
t_i	ramp/step function start time
t_o	ramp/step function end time
t_r	ramp/step function rise time (less than 1% of PUT time-delay setting)
U	PUT time delay setting(s)
z	PUT time delay setting(s)

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1   Background

The Distributed Power Systems Integration Team at the National Renewable Energy Laboratory (NREL) has been instrumental in the effort to develop standard interconnection requirements for distributed resources (DR). DR are generation and storage located at or near the point of use. Examples include photovoltaics, wind turbines, microturbines, fuel cells, and internal combustion engines. When interconnected with the electric power system (EPS) at or near load centers, these technologies can provide increased efficiency, availability, reliability, and power quality as well as a variety of economic and power system benefits.

However, many obstacles have been encountered in the pursuit of these benefits. Confusion and division arise from differences of experience and expertise as well as from the wide variety of existing interconnection standards and requirements of utility, state, and regional organizations.

The Institute of Electrical and Electronics Engineers (IEEE) has created the IEEE 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems and is developing the accompanying P1547.1 Draft Conformance Test Procedures, P1547.2 Draft Application Guide, and P1547.3 Draft Guide for Monitoring, Information Exchange, and Control to help overcome the challenges facing DR. These standards are created through collaboration and agreement among experts from all related fields, including utilities, equipment manufacturers, and government laboratories. The IEEE 1547 consensus standard contains specific requirements related to the performance, operation, testing, safety, and maintenance of interconnections between DR and EPSs. Uniform interconnection requirements should help all parties realize the benefits of DR while saving time, money, and headache.

Figure 1. NREL DER Test Facility

Validation of the conformance test procedures from IEEE P1547.1 is being conducted at the NREL Distributed Energy Resources Test Facility near Boulder, Colorado (Figure 1). Although still under development, draft standard P1547.1 lists specific test procedures to demonstrate that DR interconnected with EPSs meet the requirements stated in IEEE 1547.

This report details the procedures of and results from testing the ASCO 7000 Soft Load Transfer Switch (SLTS) according to P1547.1 Draft 2. The ASCO device is designed to integrate synchronous generators with the utility grid. These generators can be integrated as emergency backup for power outages or parallel to the grid to reduce local load and corresponding energy costs.

2 Introduction

This report presents the preliminary results of testing the ASCO 7000 SLTS according to IEEE P1547.1 procedures. The ASCO SLTS interconnects synchronous generators with the EPS and provides monitoring and control for the generator and grid connection through extensive protective functions. This work continues efforts started in 2001 at the Nevada Test Site to demonstrate the validity of the 1547 interconnection tests and requirements. The purpose of this testing is to evaluate and give feedback on the contents of IEEE Draft Standard P1547.1 Conformance Tests Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems.

IEEE P1547.1 is one of three standards in progress to accompany IEEE 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems. P1547.1 is intended to provide test procedures for verifying distributed generation (DG) equipment conformance to 1547. As part of an effort to validate and refine the procedures being developed for P1547.1, more detailed testing was conducted on an ASCO 7000 SLTS based on P1547.1 Draft 2. The following is a summary of the testing and results, focusing on the ASCO response to over and underfrequency, over and undervoltage, and unintentional islanding.

3   Test Objectives

The objective of these tests is to validate some of the interconnection test procedures under development for IEEE P1547.1 Draft 2. The tests include response to abnormal voltage and frequency conditions as well as to unintentional islanding. These results will be shared with the P1547.1 working group to help in the development of the final test procedures for compliance to IEEE 1547.

4 System Configuration and Electrical Equipment

4.1 Electrical System Configuration

NREL's Distributed Energy Resources Test Facility provided the platform used in these tests. It includes a DG interconnection monitoring system and test switchboard that facilitates connecting a utility source, a DG source, and an emergency load bus. The ASCO SLTS, a 200-kW grid simulator, a 125-kW diesel generator, a 100-kW real load bank, and a 200-kW real and reactive (inductive and capacitive) load bank were incorporated into the switchboard as shown in Figure 2.
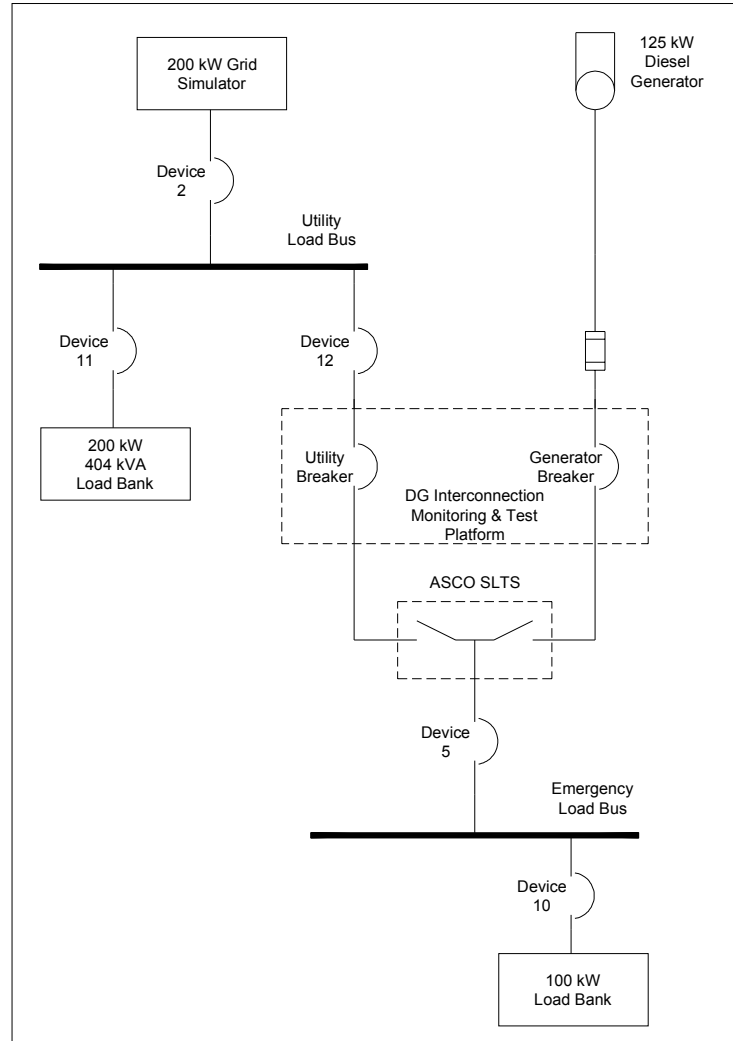
Figure 2. DG interconnection monitoring and test platform setup for ASCO SLTS testing

As stated earlier, the ASCO SLTS controls the interconnection between the DG, a 125-kW diesel generator in this case, and the "utility" or "EPS," a utility grid simulator here. The ASCO unit assumes voltage and frequency control of the diesel generator, allowing it to parallel and share load with the utility. Also, by controlling the shunt trip signal to the utility breaker, the ASCO unit manages the connection at the point of common coupling, where the local EPS connects to the entire grid.

4.2 The ASCO 7000 Series Soft Load Power Transfer Switch

Figure 3. ASCO SLTS front panel display

Figure 4. ASCO SLTS interior

The ASCO 7000 SLTS is designed to provide a safe and controllable interconnection of the EPS, a synchronous generator, and load. This interconnection switch has traditionally been used for emergency power applications but is increasingly being used for grid-parallel operation. Avoiding significant voltage or frequency transients, the ASCO SLTS can seamlessly transfer or share load between the generator and utility bus. This allows multiple operational modes, including:

- Utility load curtailment
- Generator base loading
- Utility import level based loading.

The setup employed for the ASCO SLTS is typical of devices used to interconnect DG equipment with utility busses and therefore provides a suitably general platform for the development and verification of standard test procedures. A typical installation of an ASCO SLTS is shown schematically in Figure 5. Both the utility and generator breakers shown have shunt trips. The output of the auxiliary contact of the utility shunt trip breaker is used as a trigger for capturing testing data.
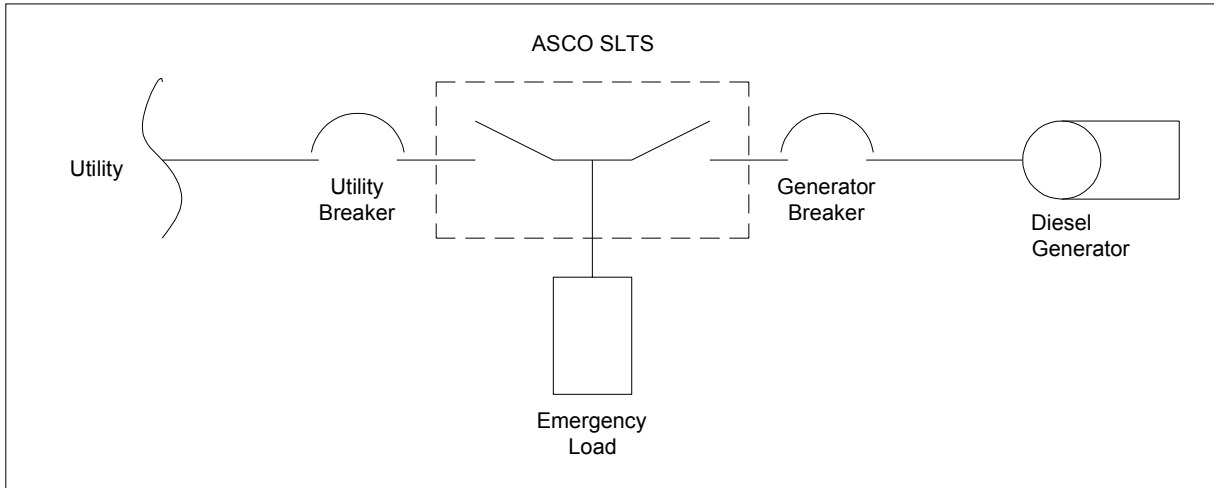
Figure 5. Typical ASCO SLTS installation

Additional features of the ASCO 7000 SLTS include:

- No voltage or frequency disruption in load transfers between the DG and EPS/utility
- Automatic transfer to onsite generation should utility power fail
- User-friendly graphical user interface to facilitate monitoring and control
- Extensive, programmable protection functions
- Ability to synchronize the DG with the EPS and control generator output and power factor.

The ASCO SLTS has a variety of protective relay functions, and many have adjustable tolerance ranges through the ASCO controls. These include:

- Overvoltage and undervoltage
- Overfrequency and underfrequency
- Reverse power and underpower
- Negative sequence voltage and current
- Directional overcurrent
- Loss of excitation.

The adjustable ranges for some of these functions are given in Table 1. Also, ASCO has developed a proprietary algorithm for detecting and disconnecting a generator during an island condition within the 2-second interval required by IEEE 1547.

Table 1. ASCO Adjustable Protective Function Settings

Adjustable Protection Settings: Percent Nominal Magnitudes		
Function	Dropout/Trip	Pickup/Restore
Undervoltage	70%–98%	85%–100%
Overvoltage	102%–115%	2% below trip
Underfrequency	85%–98%	90%–100%
Overfrequency	102%–110%	2% below trip
Voltage unbalance	5%–20%	1% below dropout

4.3 Data Acquisition System

Because many of the parameters tested involve subcycle transient times, a relatively high-speed data acquisition system was necessary to perform testing. A Yokogawa PZ4000 power analyzer was used to collect data. The PZ4000 is capable of sampling rates up to 5 million samples per second (S/s). For this testing, however, sampling rates range from 10,000 to 250,000 S/s. The PZ4000 voltage and current measurements are accurate to ±0.2% of the reading values with a time scale accuracy of ±0.05%. The Yokogawa PZ4000 was extremely useful in this application for saving the data as both data files and bitmap images of the scope display.

4.4 Utility Grid Simulator

An array of four Pacific Power Source grid simulators (see Figure 6) was used to perform controlled simulations of various grid failure conditions. Four units (model number 3060-MS) were paralleled to provide a combined capacity of 250 kVA (200 kW) at 120/208 V. The Pacific Power Source 3060-MS is a double-conversion power source. Commercial input power is rectified and then converted to precision AC power through high-frequency, pulse-width modulation. This design allows fully programmable control of individual phase voltage, current, and frequency. Output regulation and total harmonic distortion are less than 1% for normal 60-Hz operations. The 3060-MS is capable of fast response times, reacting to a 100% step load change in less than 300 μs. All four units are controlled via a master-slave arrangement that allows all units to operate simultaneously. Each unit is rated at 62.5 kVA and is capable of delivering power at frequencies from 50 Hz to 400 Hz. The output of the four-unit array is connected to a 125:277-V wye autotransformer to provide a three-phase, 480-V_{L-L} output.

Figure 6. 200-kW grid simulator array

4.5 Load Banks

The load bank used for these tests is a customized version of the Simplex Titan model, shown in Figure 7. This unit was modified to provide 165 kW real and 404 kVAR inductive and capacitive loads in step sizes as small as 125 W and 312.5 VAR. A LabView graphical user interface controls the unit through serial ports.

Figure 7. 165-kW Titan load bank (on left)

5   General Testing Information

IEEE 1547 designates a variety of system conditions under which a distributed resource should disconnect from the utility grid. For these tests, the utility breaker from Figure 5 functions as the point of common coupling and primary disconnect. The ASCO unit meets IEEE 1547 interconnection requirements by monitoring power conditions and sending a trip signal to the utility breaker after detecting any value outside of preset ranges.

The grid simulators were used to establish the test conditions. Only the parameter under test (PUT) was allowed to vary for each test. After establishing a certain test condition (undervoltage, overfrequency, unintentional island, etc.), the ASCO must trip the utility breaker to disconnect the DG from the utility system in less than the time required by IEEE 1547. This report details the procedures and results of testing the DG for response to abnormal voltage, abnormal frequency, and unintentional islanding conditions. The ASCO successfully disconnected the diesel generator well within the required times for all the abnormal voltage and frequency tests.

Adhering to IEEE P1547.1 Draft 2 sections 4.7.1 and 4.7.2, both a magnitude and a time test were performed for the voltage and frequency response. The function of the magnitude test was to determine the actual trip point. This was accomplished by varying the PUT in tiny increments gradually approaching the trip set point. The slow approach accounts for any time delays and ensures that the bus conditions at the time of the trip are virtually identical to the actual trip magnitudes. Ramp functions from IEEE P1547.1 and consistent with Figure 8 were programmed into and executed by the grid simulator. A description of the variables used in Figure 8 is given following the equations used to calculate the ramp functions.

$$P(t) = m \cdot (t - t_0) + P_b \tag{1}$$

$$m = \frac{(0.1 \cdot a)}{(4 \cdot z)} \tag{2}$$

Where:
P   = PUT
P_N = Nominal condition
P_b = Ramp function starting value (within 10% of P_T)
P_T = Test set point
t_h = Hold time (greater than PUT time-delay setting)
t_o = Ramp function start time
a   = Manufacturer's stated accuracy for PUT
z   = Trip operating time(s)
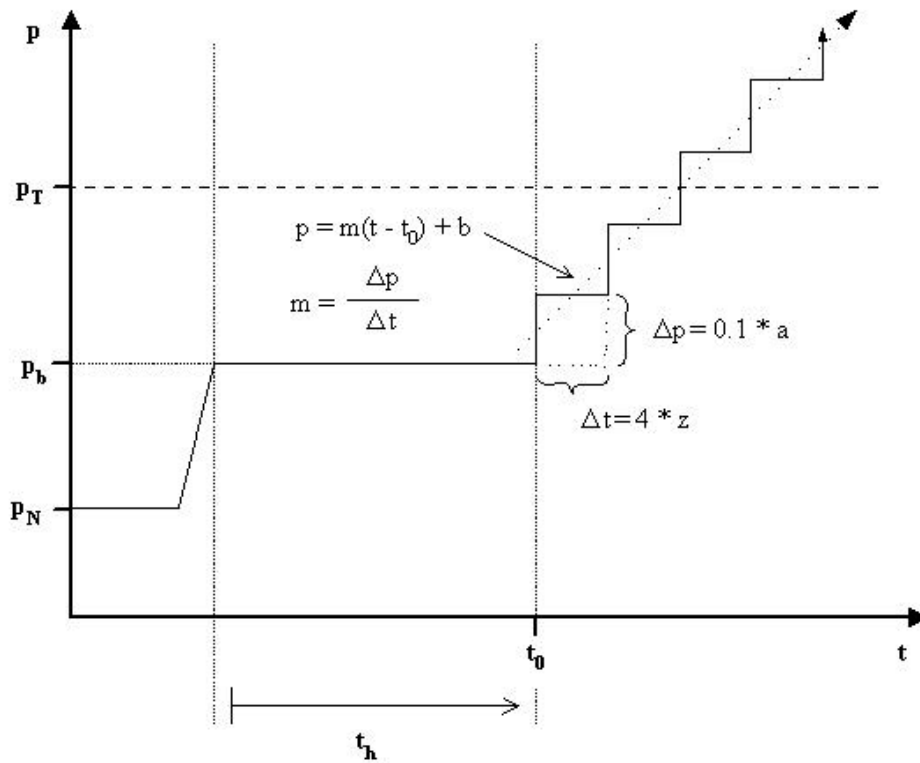
Figure 8. Typical magnitude test ramp function

Confusion arose during testing as to the proper value of "z" for the ramp functions. For these tests, z—the "manufacturer's stated operating time," which is defined as "the length of time for the equipment under test's output to change state (trigger a fault condition) based on an out-of-tolerance condition for the PUT"—was mistakenly assumed to be the time delay setting for each parameter. The time delay settings are variable from "instantaneous" to above 2 s. The operating time "z" is a fixed value of the fastest possible time for the ASCO unit to detect and trip on an out-of-tolerance condition without any added time delay. Even with the ASCO time delay set to "instantaneous," there is some delay for the breaker to trip. For this setup, that minimum operating time, the "z" value, is about 0.05 s, and this number should have been used in the slope calculation for all of the magnitude test ramp functions.

After finding the trip magnitude, the time tests were used to determine the time until the device tripped once the trip conditions, as determined in the magnitude test, were established. Figure 9 shows a typical time test step function. The idea is to quickly step from below to above (ordinarily at least 10% above) the trip magnitude fast enough to know when the parameter jumps out of bounds and to avoid introducing significant delays into the trip time. The equations and a description of the variables used to calculate the ramp functions follow.

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$$P(t) = A \cdot u(t - t_i) + P_b$$

Where:

P   = PUT
P_N = Nominal condition
P_b = Ramp function starting value (within 10% of P_T)
P_T = Test set point
P_U = Final step function value
t_h = Hold time (greater than PUT time-delay setting)
t_i = Ramp function start time
t_o = Ramp function end time
t_r = Ramp function rise time (less than 1% of PUT time-delay setting)
A   = Scaling factor (P_U is at least 110% of P_T)
U   = Operating time (s)
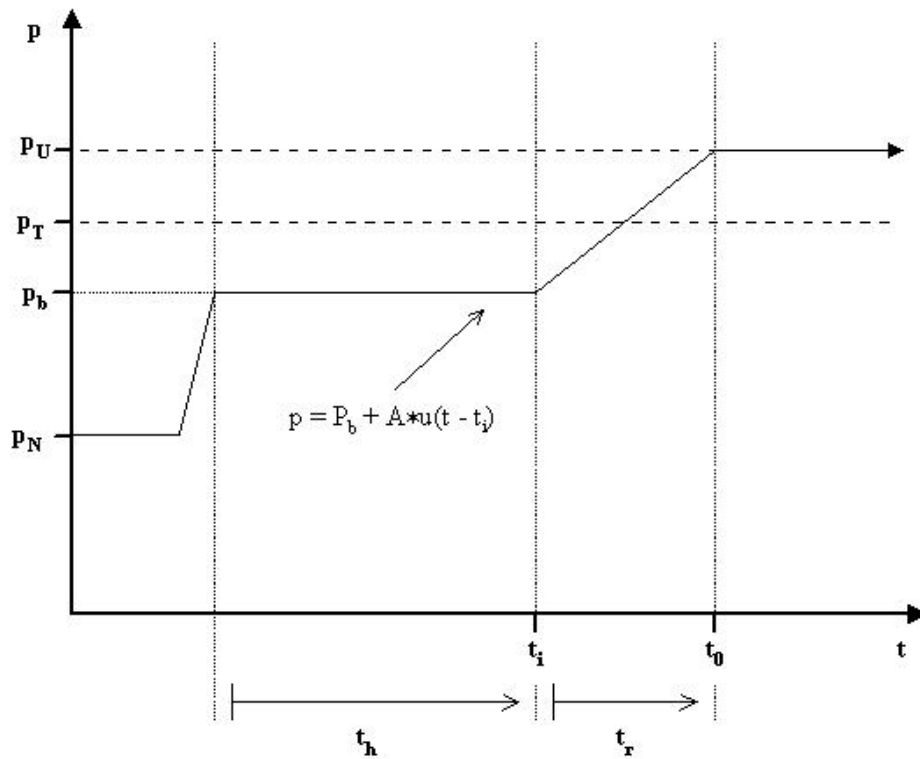
Figure 9. Typical time test step function

5.1 Frequency Test Results

5.1.1 General Testing Information
The following is a description of the under and overfrequency tests on the ASCO SLTS, including method, results, and explanation of any issues encountered.

The general conditions established for these tests were:

- The ASCO unit paralleled the 125-kW diesel generator to the simulated utility grid and closed all breakers.

- Load was added first to the utility bus (P_{util}) and then to the common bus. Both the utility and the DG are connected to the common load, shown as "emergency load" in Figure 5, through the ASCO breakers. Initially, the grid simulators fully supplied both loads.

- The ASCO SLTS then controlled the diesel generator power export (P_{export}) to assume the entire local load and to export some power back to the utility load.

Under these conditions, the ASCO unit controlled the diesel frequency to maintain P_{export}. So by maintaining the grid simulator rate of frequency change below the time response of the diesel governor, P_{export} could be held constant while bus frequency was decreased or increased.

5.1.2 Overfrequency Magnitude

For the overfrequency tests, the utility supplied 25 kW of a 30-kW utility-side load, and the diesel powered a separate 30-kW local load and exported 5 kW back to the utility load. The grid simulator varied the frequency according to the ramp function shown in Table 2.

Table 2. Overfrequency Magnitude

Trial Number	Trip Frequency
1	60.458
2	60.604
3	60.461
4	60.534
5	60.531
Average	**60.518**
Setting	**60.5**
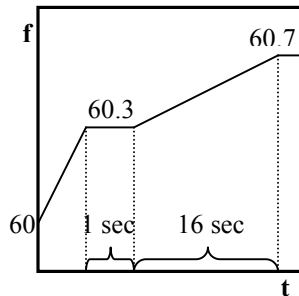
Figure 10. Overfrequency ramp function

The output of the auxiliary contact of the shunt trip utility breaker was used as the trigger for testing. By measuring the period of the last cycle before tripping, the Yokogawa scope found the trip frequency. Figure 11 shows the Yokogawa display following this test. Table 2 shows how the results compare with the 60.5-Hz overfrequency setting on the ASCO SLTS.
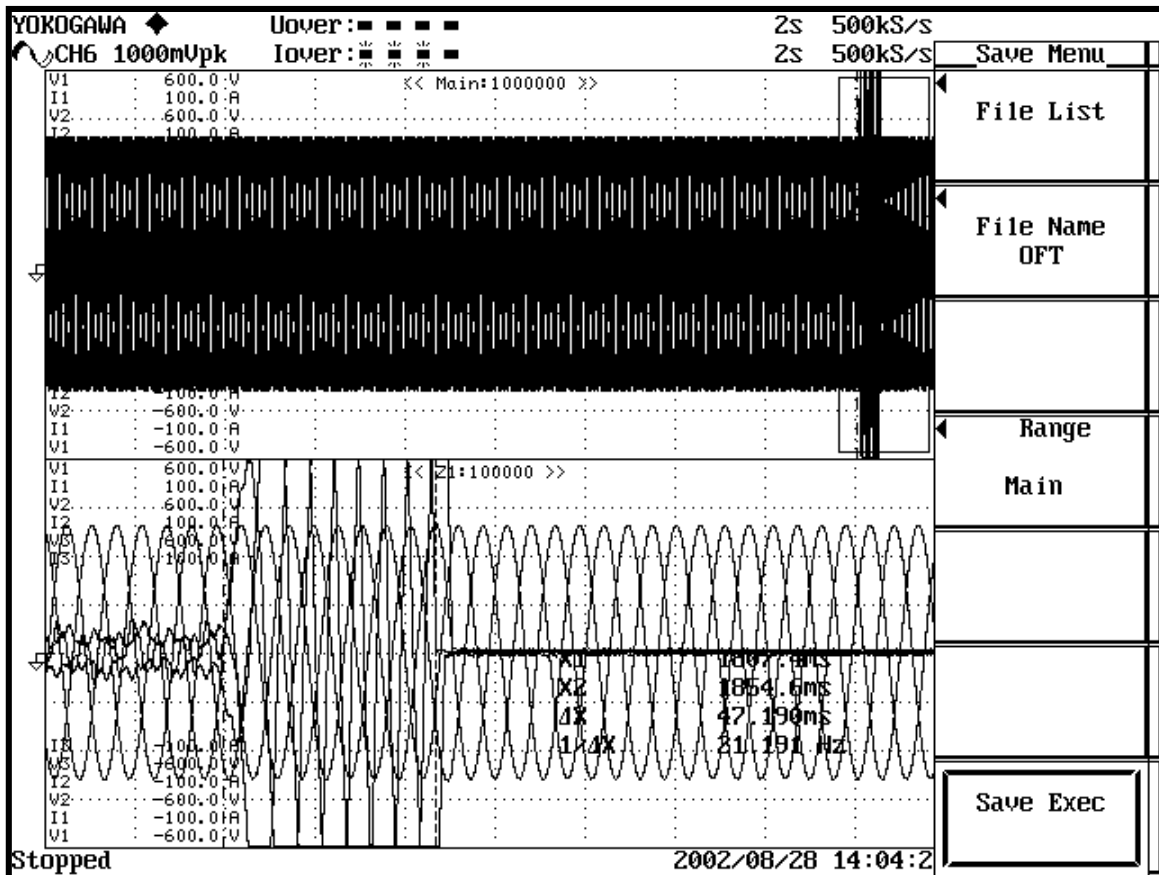
Figure 11. Overfrequency magnitude test

5.1.3 Overfrequency Time

Having determined the trip magnitude, the next task was to measure the time for the ASCO unit to disconnect the DG after the overfrequency magnitude was reached. The step function shown in Figure 12 was programmed into and executed by the grid simulator to almost instantly jump from below to above the overfrequency threshold. Using 110% of P_T (the trip magnitude, 60.5 Hz here) for P_U (the final limit for the step in the time test) caused the ASCO utility breaker to trip on a variety of protective functions. To trip only on underfrequency, a P_U of about 100.5% of P_T was used for the time test. The ASCO disconnected the DG in 45 ms, well under the 160 ms required by IEEE 1547. The results from Trial 2 are shown in Figure 13. The two dotted lines measure the time between the frequency step and the disconnect.
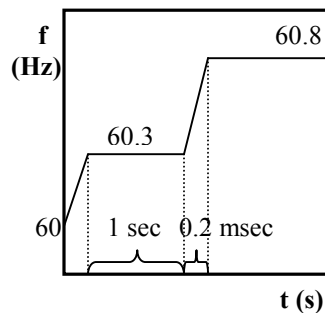
Figure 12. Overfrequency step function

Table 3. Overfrequency Time

Overfrequency Time	
Trial Number	Trip Time (ms)
1	47
2	58
3	40
4	40
5	39
Average	45
Required	160
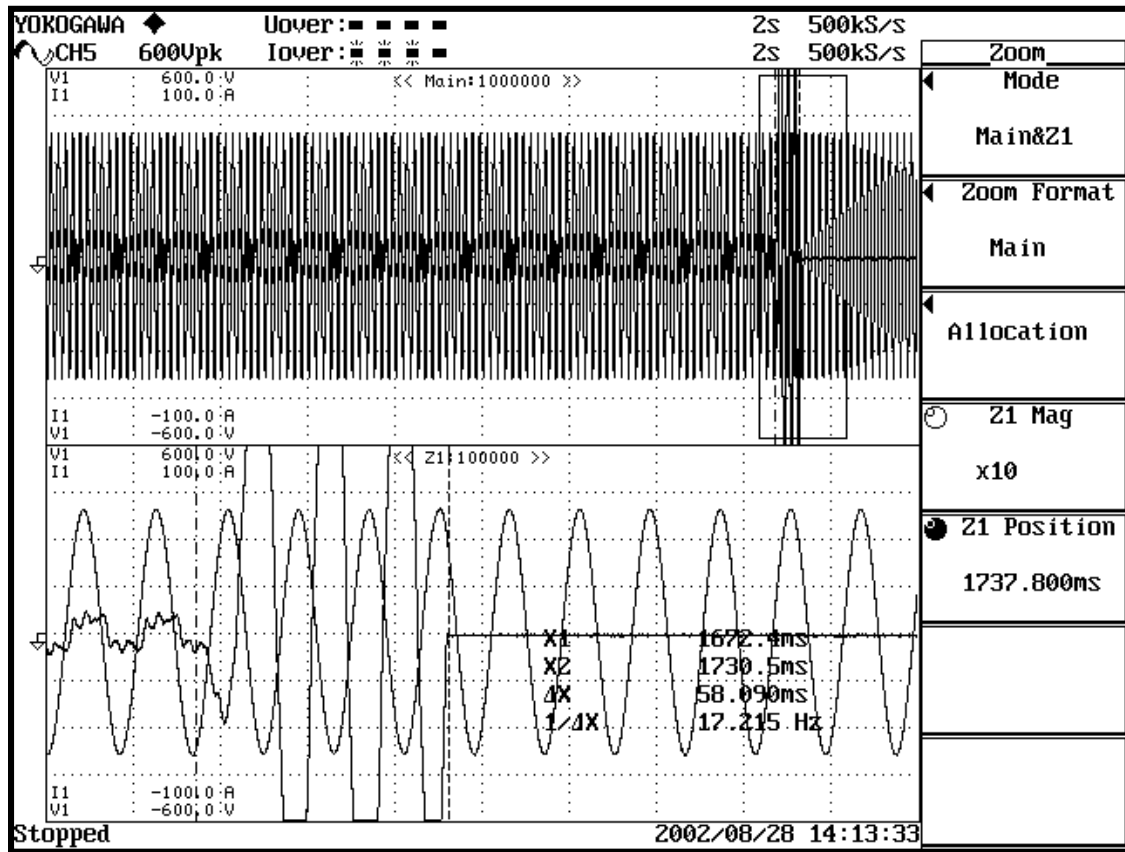
Figure 13. Overfrequency time test results

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5.1.4 Underfrequency Magnitude

For the underfrequency tests, the grid simulators supplied 50 kW of a 60-kW utility load, and the diesel powered a 20-kW local load and exported 10 kW back to the utility. Both a slow and a fast underfrequency requirement are specified in IEEE 1547 Section 4.2.4 Table 2 (Appendix A) for DG greater than 30 kW. Under 57 Hz, the DG must disconnect in less than 0.16 s, but between 57 and 59.8 Hz, the clearing time is adjustable up to 300 s. For the slow underfrequency test, 59.3 Hz was used for the ASCO trip setting at a clearing time delay of 1.7 s. The slow step function around 59.3 Hz is shown in Figure 14. The results using the Yokogawa power analyzer for Trial 4 are displayed in Figure 15. The dashed vertical lines measure the period of the red phase just before the trip signal.

Table 4. Underfrequency Magnitude

Underfrequency Magnitude	
Trial Number	Trip Frequency
1	59.301
2	59.311
3	59.298
4	59.312
5	59.284
Average	**59.301**
Setting	**59.3**
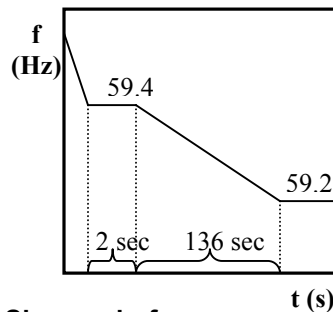
Figure 14. Slow underfrequency ramp function
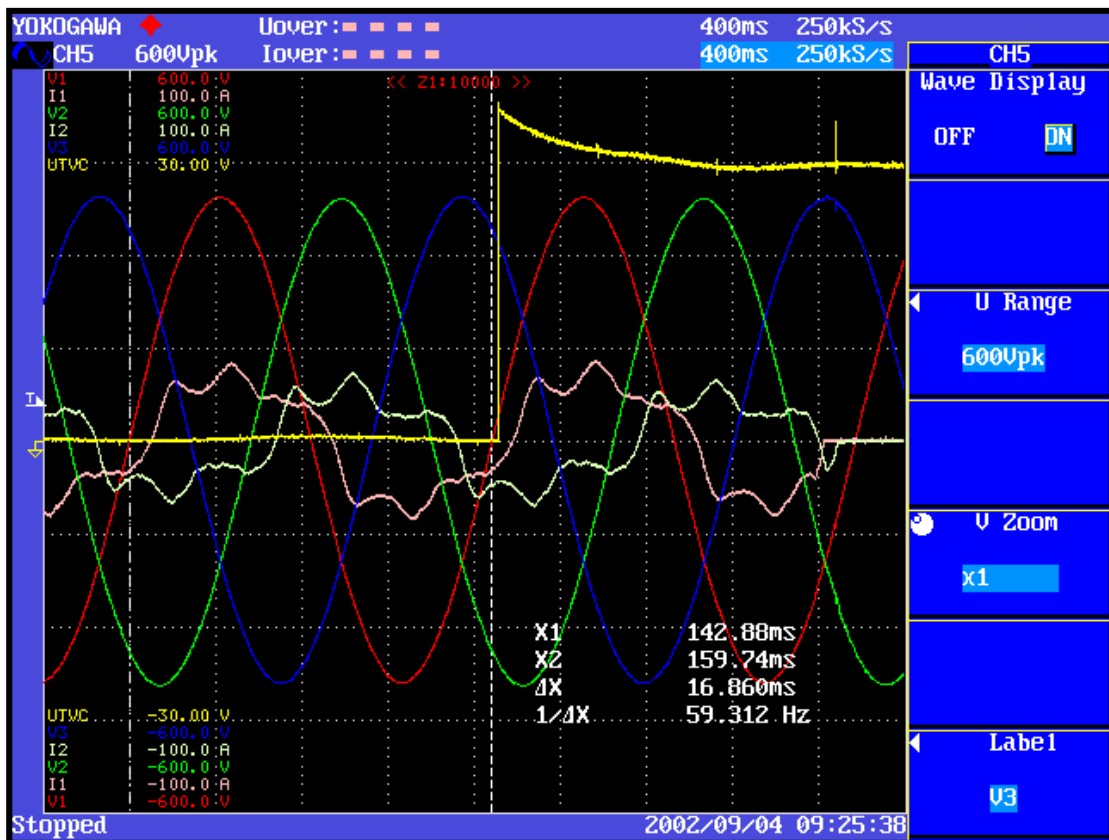
Figure 15. Underfrequency magnitude test results

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5.1.5 Underfrequency Time

Again, 99.5% of P_T was used for P_U instead of the 90% called for in the P1547.1 procedures to avoid tripping on other protective functions. The grid simulator frequency step function is shown in Figure 16, and Figure 17 illustrates the trip time from Trial 3.

Table 5. Underfrequency Time

Underfrequency Time	
Trial Number	Trip Time (s)
1	1.58
2	1.48
3	1.58
4	1.57
5	1.54
Average	**1.55**
Required	**1.70**
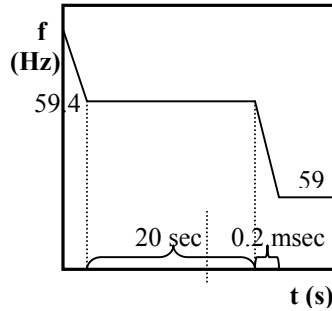
Figure 16. Underfrequency step function
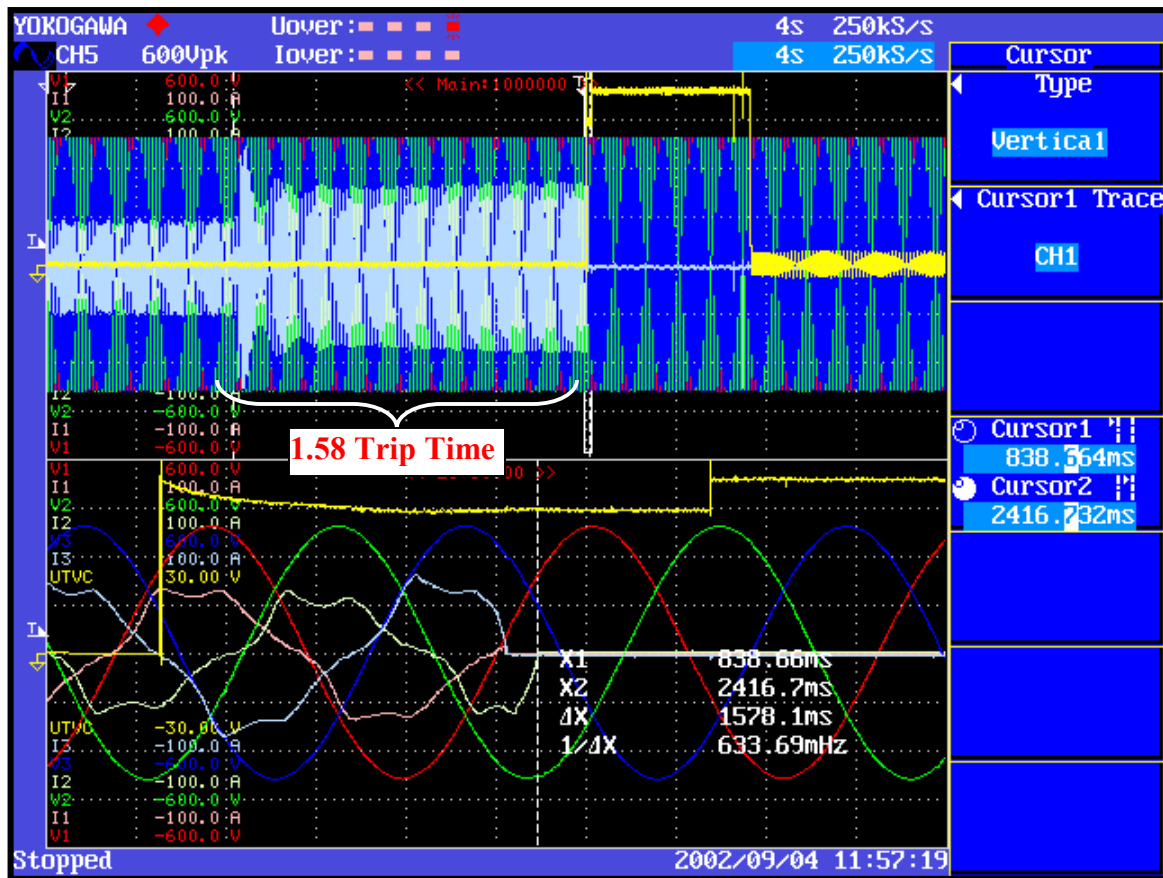
Figure 17. Underfrequency time test results

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5.1.6 Fast Underfrequency Magnitude

Even though the ASCO internal time delay setting for this parameter is instantaneous, using the 0.5 s inherent system delay for the value of z in Equation 2 to calculate the slope, m, gives a reasonable value of 0.1 Hz/20 s. Again, Figure 18 is the frequency ramp function used, and Figure 19 shows the frequency just before the breaker was tripped.
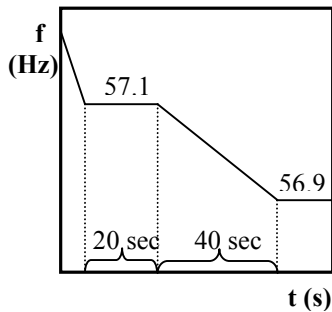
Figure 18. Fast underfrequency ramp

Table 6. Fast Underfrequency Magnitude

Fast Underfrequency Magnitude	
Trial Number	Trip Frequency
1	57.000
2	56.987
3	57.000
4	57.000
5	56.987
Average	**56.995**
Setting	**57.0**
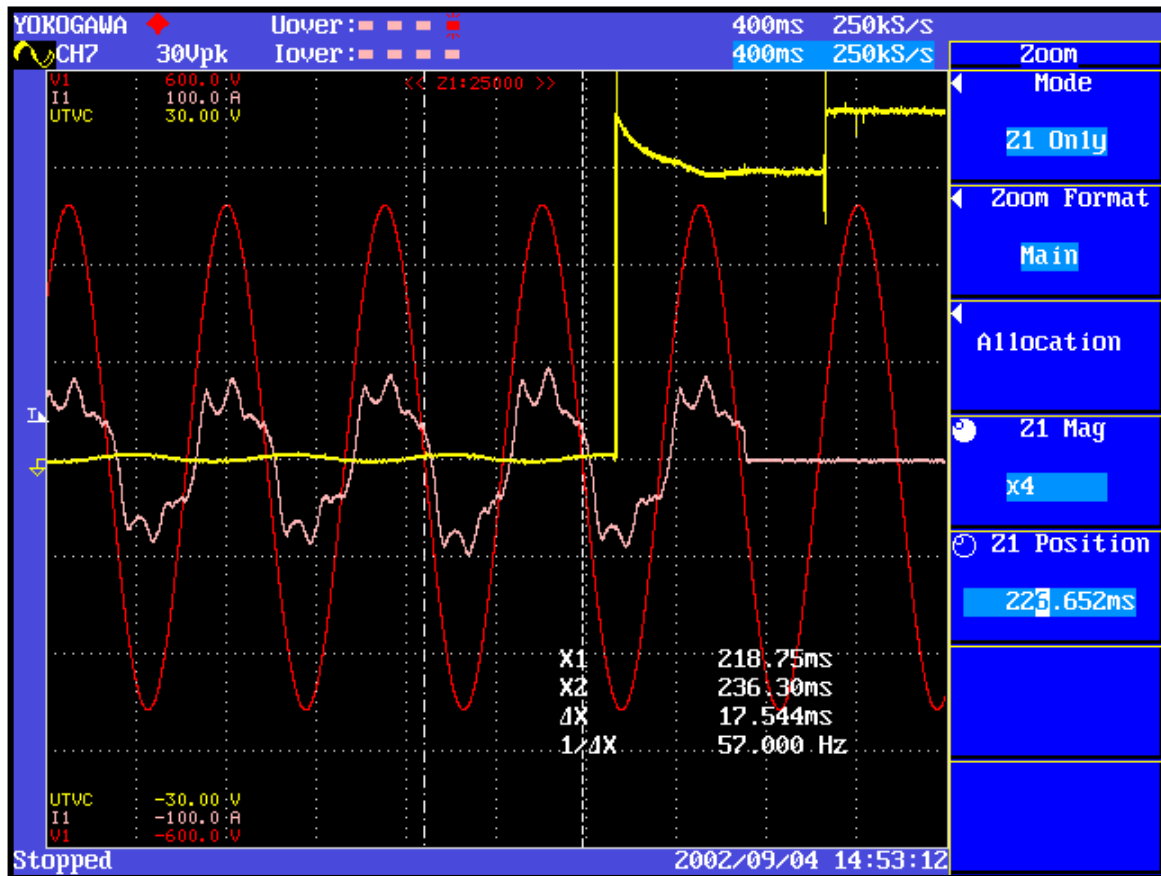
Figure 19. Fast underfrequency magnitude results

5.1.7 Fast Underfrequency Time

The final part of the abnormal frequency testing was nearly identical to the slow underfrequency time test but at a lower frequency, as shown in Figure 20, and with a faster disconnect time, as shown in Figure 21. Again, the ASCO disconnected the generator well before the required 160 ms.
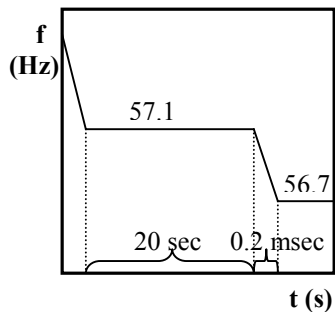
Figure 20. Fast underfrequency step

Table 7. Fast Underfrequency Time

Fast Underfrequency Time	
Trial Number	Trip Time (ms)
1	40.82
2	41.02
3	50.42
4	50.80
5	51.14
Average	**46.84**
Required	**160.0**
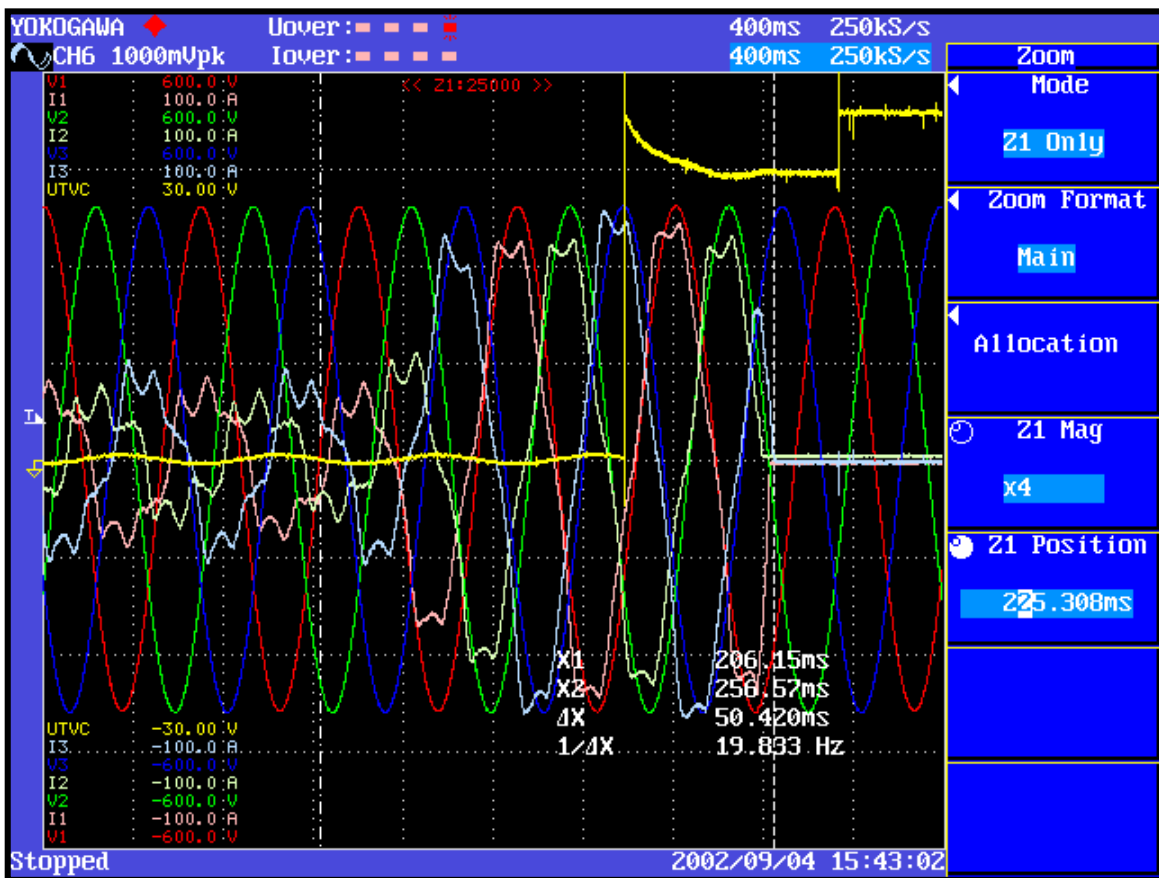
Figure 21. Fast underfrequency time test results

5.2 Voltage Test Results

5.2.1 General Information
The general conditions established for these tests were identical to those for frequency testing:

- The ASCO unit paralleled the 125-kW diesel to the simulated utility grid and closed all breakers.

- First, a 30-kW load was added to the utility bus (P_{util}), and then another 30 kW was placed on the common bus, interconnected with both the utility and the DG through the ASCO breakers (shown as "emergency load" in Figure 5). The grid simulators initially supplied all of both loads.

- The ASCO then controlled the diesel generator power export (P_{export}) to assume the entire 30-kW local load and to load share with the utility, exporting an additional 10 kW.

Under these conditions, the ASCO controlled the genset excitation to maintain power factor. By maintaining the grid simulator rate of voltage change below the time response of the diesel exciter, power factor could be held constant while bus voltage was decreased or increased.

For the voltage testing, the most consistent results were observed with a non-unity power factor setting for the diesel generator. A power factor of 0.9 was used for these tests. This also provided a reactive load sink to limit generator reverse VARs.

Also, the narrow range of the diesel voltage regulator would not allow testing at the voltage levels required by the IEEE 1547 and Draft P1547.1 standards. 1547 has no disconnect or testing requirements for voltages ranging between 89% and 109% of normal. The voltage levels closest to nominal values that IEEE 1547 requires to be tested are 88% of the nominal 480 V (422.4 V) for undervoltage and 110% (528 V) for overvoltage (see Appendix A, Table 1). These levels are for the slow response testing; the fast response goes all the way to less than 50% or greater than 120%, but even the slow response minimum values were unattainable. Voltage regulator settings prohibited the diesel generator from operating outside a range of only about ±6% of nominal voltage (450 V and 505 V). To work around this restriction, set points within the range of the diesel were tested. This was done by manually relaxing the voltage set points programmed into the ASCO controller to only ±25–30 V around the nominal 480 V. Testing over the full voltage range might have been possible after adjusting the diesel voltage regulator settings but could risk damaging the generator.

For all of the voltage tests, the utility supplied a 30-kW utility load, and the diesel fed a 30-kW local load and exported 10 kW back to the utility load. Peak voltage values at the trip were determined using the "measure" command on the Yokagawa scope. This command gave peak line-to-neutral voltage, which was converted to RMS phase-to-phase voltage by multiplying by $\sqrt{\frac{3}{2}}$.

5.2.2 Overvoltage Magnitude

With the ASCO overvoltage limit set to 504 V (only 105% nominal voltage because the 110%–120% specified in IEEE 1547 was unreachable without tripping other protective functions), the ramp function shown in Figure 20 gave the expected average trip magnitude of 504 V. Figure 23 shows the line-to-neutral voltage for Trial 5 as the Y1 value of the dotted horizontal line.

Multiplying by $\sqrt{\frac{3}{2}}$ converts back to the 504 V, RMS phase-to-phase voltage given in Table 8.

Table 8. Overvoltage Magnitude

Trial Number	Trip Voltage
1	504.300
2	502.500
3	504.700
4	504.600
5	504.150
Average	**504.050**
Setting	**504.0**
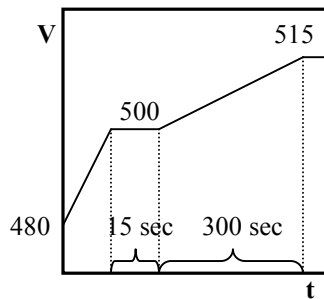
Figure 22. Overvoltage ramp function
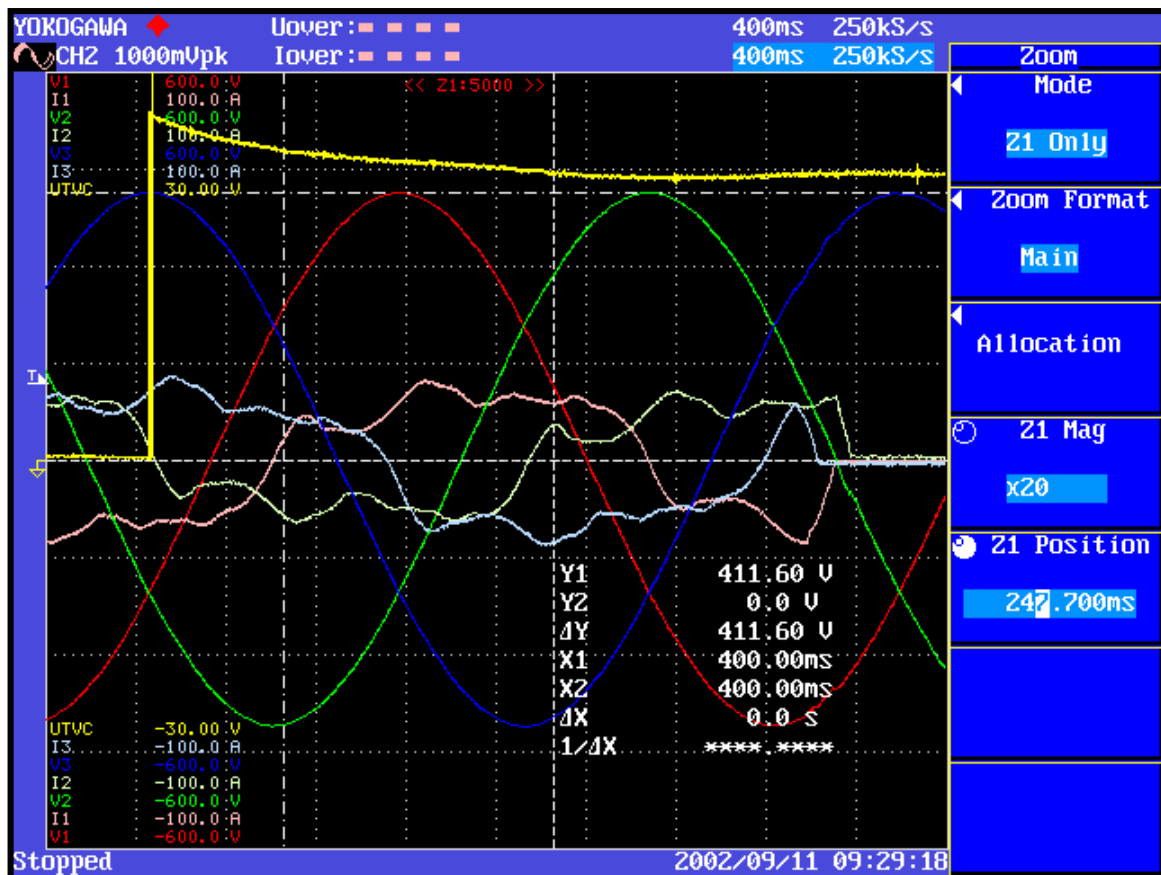
Figure 23. Overvoltage magnitude test results

5.2.3 Overvoltage Time

After determining the 504-V overvoltage trip point, the time test found the delay between exceeding that trip point and disconnecting the DG. Figure 24 shows the voltage function executed by the grid simulator. Figure 25 displays the results from Trial 5, with the lower half of the figure zoomed in at the voltage jump from 500 V to 510 V. Even though the voltage setting was abnormally low, the ASCO unit isolated the diesel in less than half of the 1-s disconnect time required by IEEE 1547 for 110%–120% of nominal voltage (Appendix A).
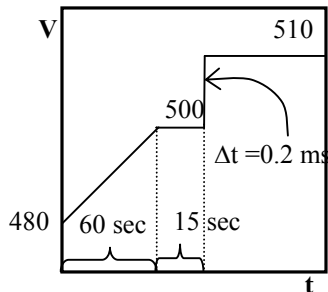
Figure 24. Overvoltage step function

Table 9. Overvoltage Time

Overvoltage Time	
Trial Number	Trip Time (s)
1	0.436
2	0.428
3	0.378
4	0.396
5	0.468
Average	**0.421**
Required	**1.00**
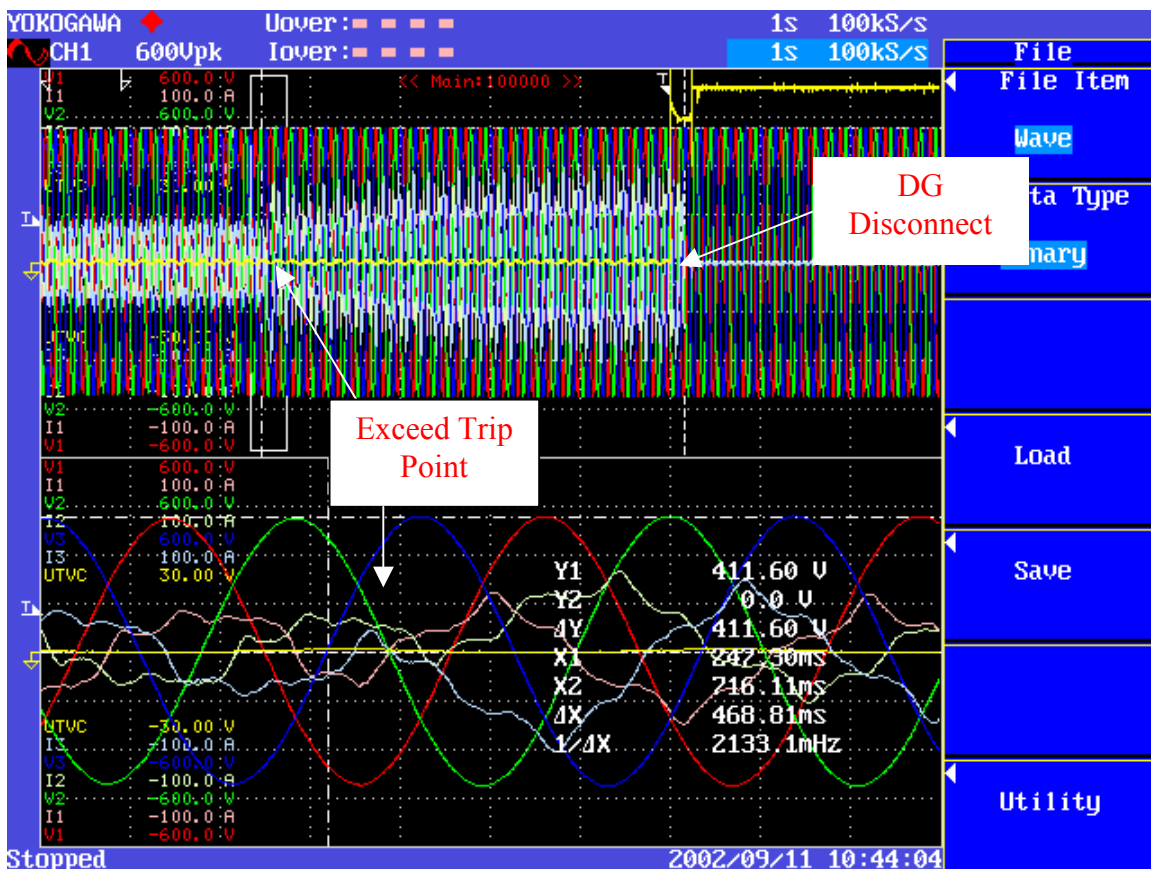
Figure 25. Overvoltage time test results

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5.2.4 Fast Overvoltage Magnitude

The horizontal dotted line Y1 in Figure 27 measures the peak voltage of the blue phase on the cycle just before the generator tripped. The average trip magnitude was found to be about 501.4 V for the fast overfrequency test. As with slow overfrequency, the overvoltage set point was still set at 504 V, but the time delay was now only 0.16 s.
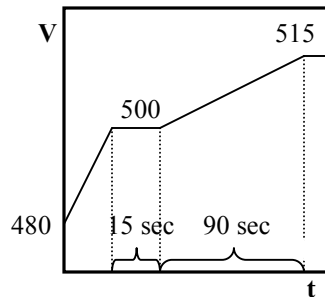
Figure 26. Fast overvoltage ramp function

Table 10. Fast Overvoltage Magnitude

Fast Overvoltage Magnitude	
Trial Number	Trip Voltage
1.0	501.7
2.0	499.8
3.0	501.7
4.0	501.7
5.0	502.2
Average	**501.4**
Setting	**504.0**
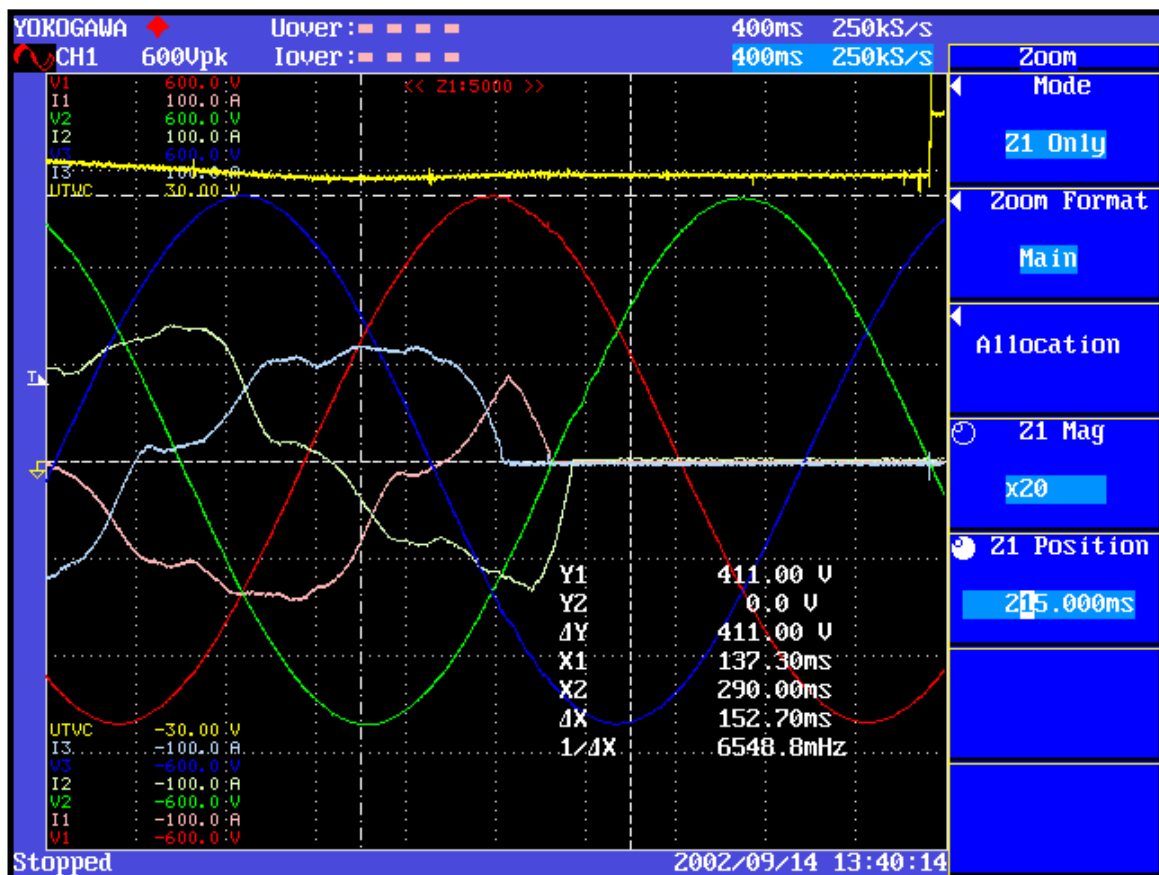
Figure 27. Fast overvoltage magnitude test results

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5.2.5 Fast Overvoltage Time

The ASCO unit had no trouble disconnecting within the 160 ms required for the faster response, even with the artificially low overvoltage. Every trial disconnected in fewer than 50 ms. Again, Figure 28 shows the voltage step function, and Figure 29 measures the trip time.
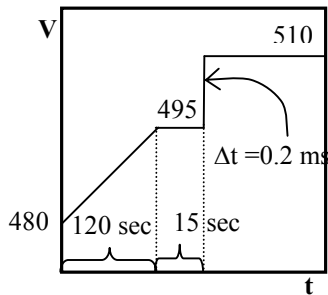
Figure 28. Fast overvoltage step function

Table 11. Fast Overvoltage Time

Fast Overvoltage Time	
Trial Number	Trip Time (ms)
1.0	40.2
2.0	41.4
3.0	36.5
4.0	46.9
5.0	48.1
Average	**42.6**
Required	**160.0**
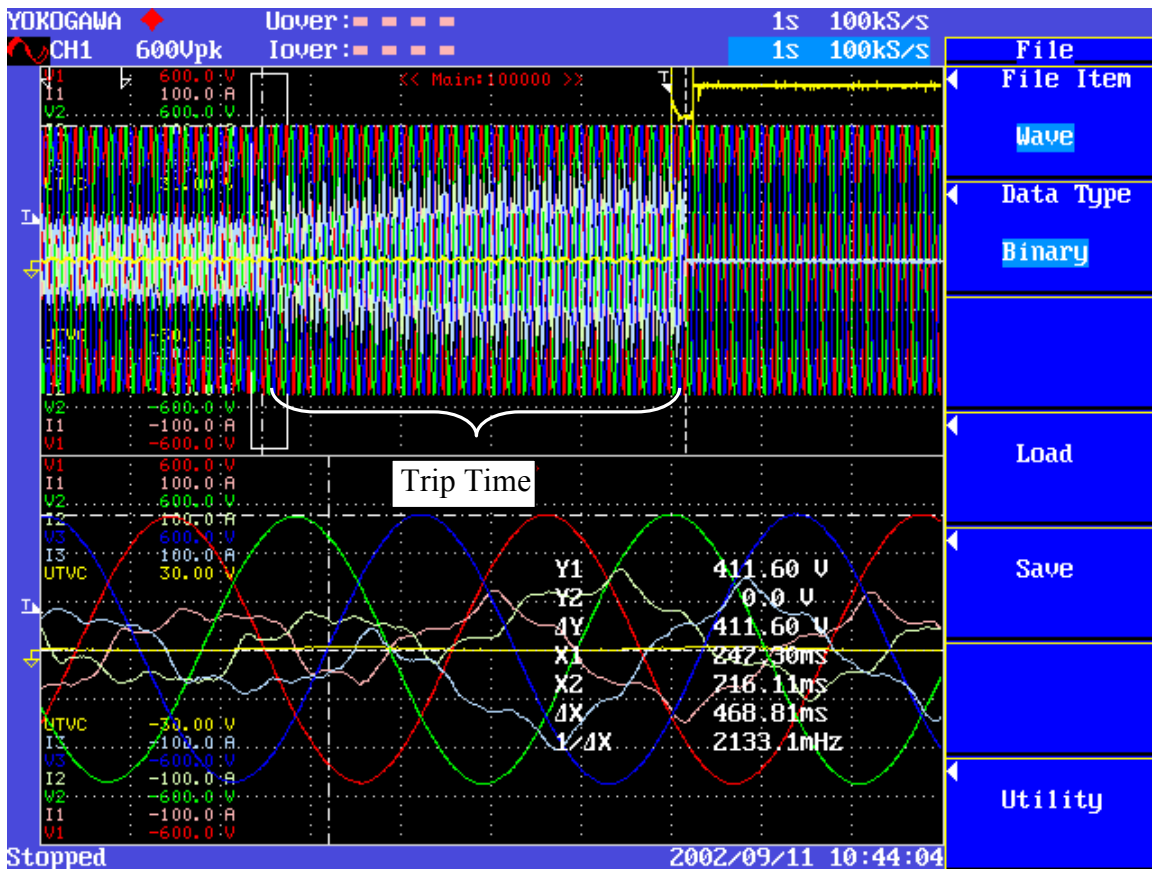
Figure 29. Fast overvoltage time test results

5.2.6 Undervoltage Magnitude

Again, for undervoltage as for overvoltage, settings had to be relaxed to allow for testing. In place of the 50%–88% of nominal voltage (240–422.4 V), only about 93% (446 V) could be reached before tripping on "reverse excess VARs." The undervoltage trip has a 1.7-s time delay setting, within the 2-s IEEE requirement. The ASCO unit tripped undervoltage at 458.1 V when set to trip at 456 V.
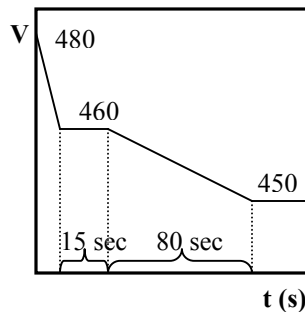
Figure 30. Undervoltage ramp function

Table 12. Undervoltage Magnitude

Undervoltage Magnitude	
Trial Number	Trip Voltage
1.0	459.8
2.0	453.4
3.0	458.7
4.0	458.7
5.0	459.8
Average	**458.1**
Setting	**456.0**
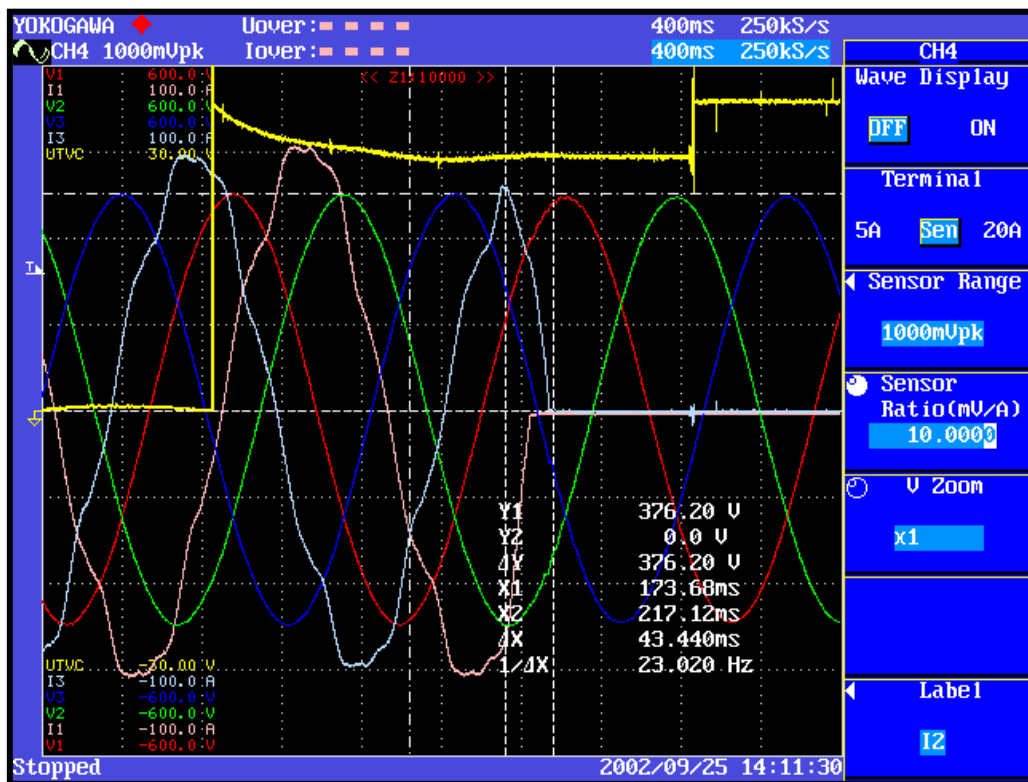
Figure 31. Undervoltage magnitude test results

5.2.7 Undervoltage Time

Quickly stepping below the 458.1-V trip magnitude as shown in Figure 33, the average trip time was found to be 1.91 s with the ASCO undervoltage time delay set to 2 s. Figure 33 shows the current steadily rising from the sudden voltage increase until the ASCO unit trips. The lower portion of the graph is an enlarged view of current dropping to zero when the ASCO unit disconnects the diesel.
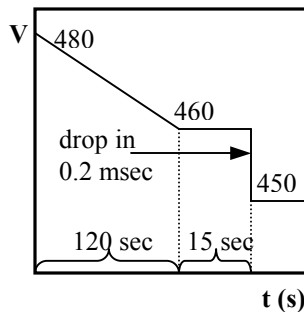
Figure 32. Undervoltage step function

Table 13. Undervoltage Time

Undervoltage Time	
Trial Number	Trip Time (s)
1.0	1.92
2.0	1.92
3.0	1.88
4.0	1.93
5.0	1.88
Average	**1.91**
Required	**2.00**
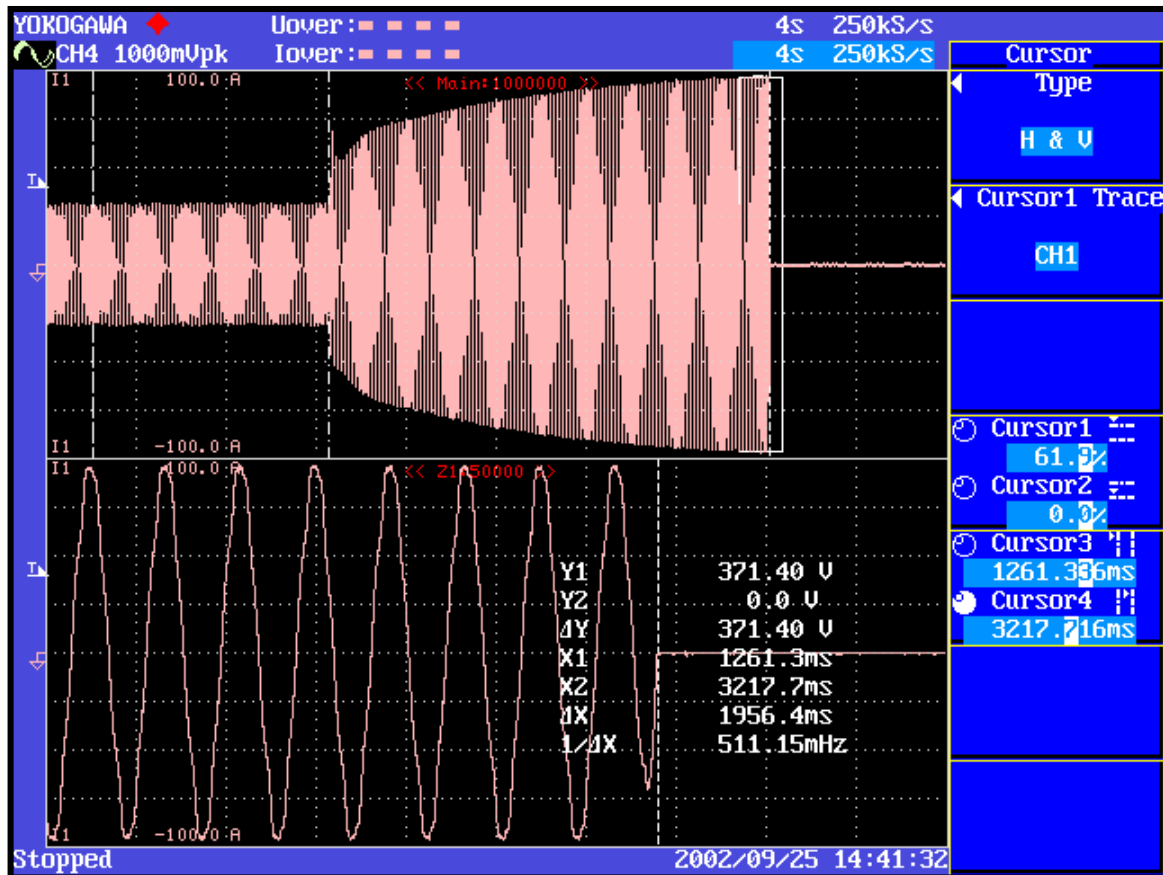
Figure 33. Undervoltage time test results

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5.2.8 Fast Undervoltage Magnitude

The final abnormal voltage or frequency test was fast undervoltage. For this test, 446 V was used as the trip voltage. However, the time setting was again 0.16 s, as with the fast overvoltage tests. During the gradual 460 V to 445 V grid simulator ramp given in Figure 34, the trip magnitude was found to be 453.1 V. Figure 35 shows the peak line voltage of 372 V for Trial 2.
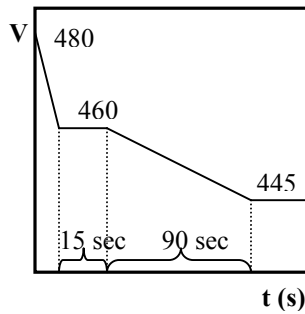
Figure 34. Fast undervoltage ramp function

Table 14. Fast Undervoltage Magnitude

Fast Undervoltage Magnitude	
Trial Number	Trip Voltage
1.0	451.9
2.0	455.6
3.0	454.9
4.0	454.1
5.0	449.0
Average	**453.1**
Setting	**446.0**
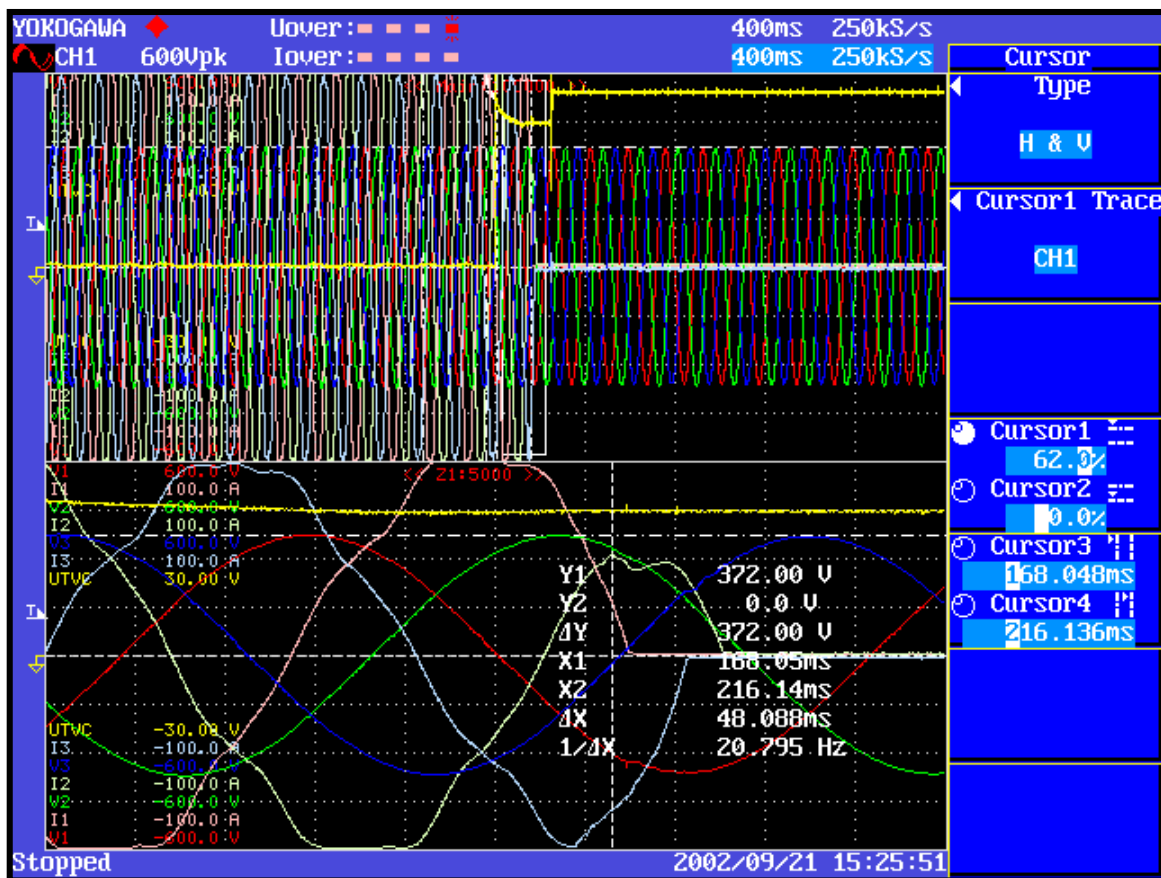
Figure 35. Fast undervoltage magnitude test results

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5.2.9 Fast Undervoltage Time

Finally, testing showed that the ASCO unit took about 57 ms to trip after the grid stepped below 453.1 V. This value was well under the 160-ms IEEE 1547 requirement. The time between the sharp current increase from the sudden drop in voltage to when the current drops to zeros with the ASCO trip is displayed in Figure 37 for Trial 4.

Table 15. Fast Undervoltage Time
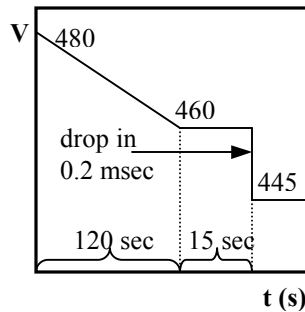
Figure 36. Fast undervoltage step function

Fast Undervoltage Time	
Trial Number	Trip Time (ms)
1.0	54.5
2.0	55.0
3.0	57.2
4.0	74.9
5.0	43.4
Average	**57.0**
Required	**160.0**
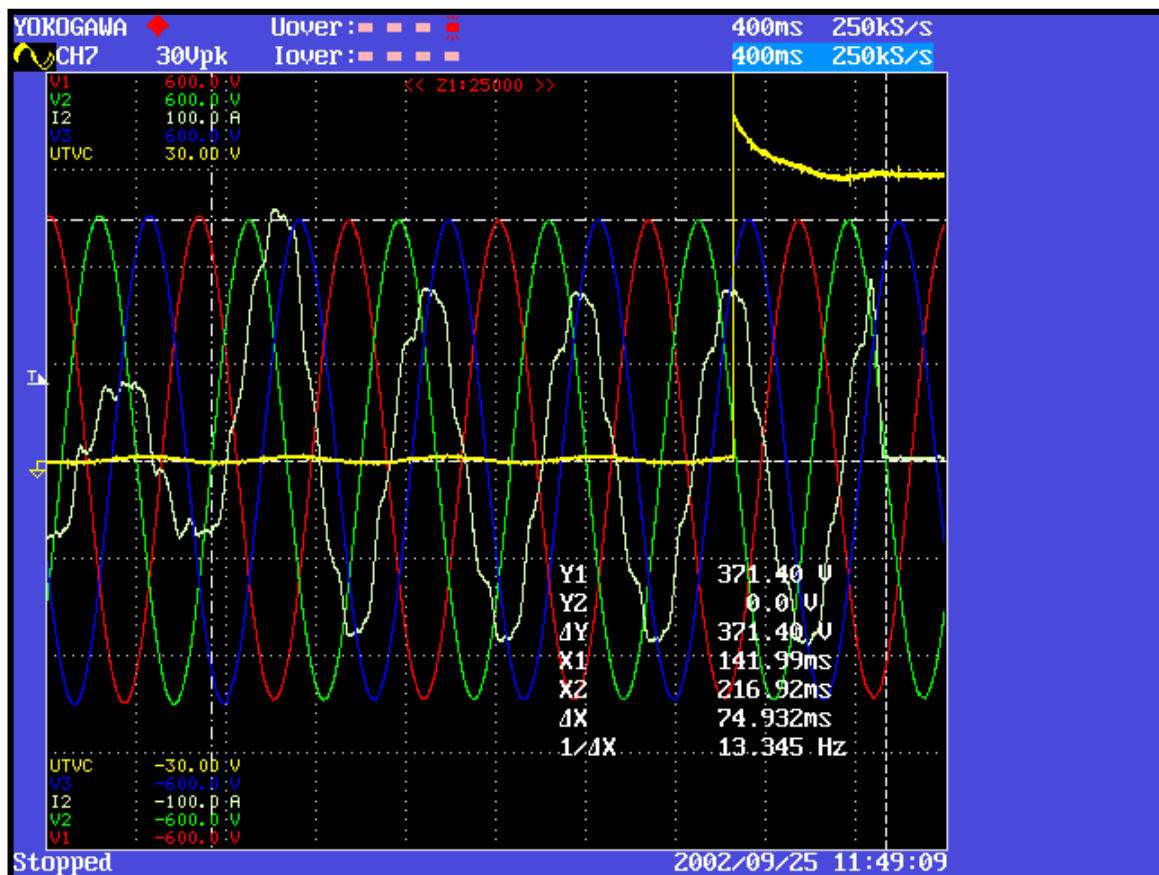
Figure 37. Fast undervoltage time test results

6　Anti-Islanding Testing

6.1　General Information

Islanding is when a distributed generator continues to supply power to a portion of the EPS when that portion of the grid is de-energized. Both power utilities and regulatory requirements demand the prevention of unintentional islands to ensure the safety of utility personnel and the integrity of the power system. Ideally, whatever event caused the local section of the grid to shut down should also trip the distributed generator protective function, or the sudden increase in load from the loss of local grid power should disrupt system conditions enough to trip the distributed generator.

Still, a laboratory environment can simulate the worst-case scenario of matching the generator output to the load, adding capacitive and inductive load for a quality factor (Q) of 1.8, and quietly dropping out the utility power without disturbing system parameters. Previous islanding testing used Q = 2.5; updated UL and IEEE standards now use Q = 1.8. Q = 2.5 corresponds to a load power factor of 0.37. Q = 1.8 corresponds to a load power factor of 0.55. Q = 2.5 originated with most difficult condition for inverter anti-islanding algorithm to work. Utility circuits typically operate above 0.75 pf in steady-state conditions; therefore, Q = 1.8 (pf = 0.55) is below the load power factor that the DR is expected to be islanded with. Although unlikely in the field, successful worst-case testing demonstrates that the device can identify islands and quickly disconnect in most any situation.

Passive anti-islanding schemes measure system voltage and frequency to detect and disconnect should an island occur. These strategies can work well as long as there is a variation in voltage or frequency great enough to detect the island when it is initiated. With the generator and load matched, the loss of the grid may not instantly produce significant changes, especially if there is reactive load to help maintain the system voltage and frequency. Active anti-islanding schemes periodically try to push the grid voltage or frequency out of bounds. If the grid is down, then the generator can dictate the values and, after exceeding a threshold, disconnect the generator. With the utility power system operational, the relatively small distributed generator cannot significantly influence the system voltage or frequency.

6.2 Anti-Islanding Test Setup

The anti-islanding tests were performed within the same system as abnormal voltage and frequency, shown in Figure 38.
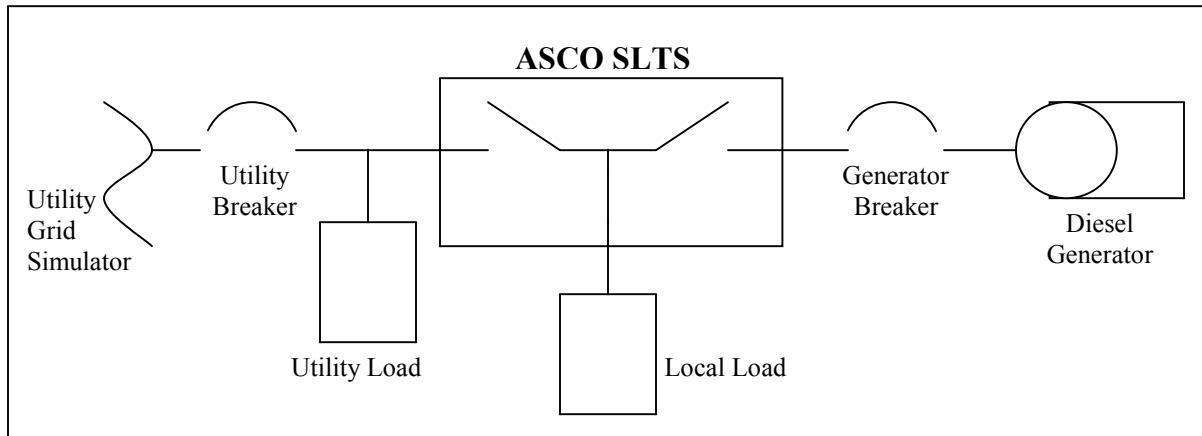
Figure 38. Anti-islanding test setup

Placement of the load, whether entirely at the utility load or the local load, did not significantly influence the ASCO detection times, which averaged 17.12 or 17.14 s without the anti-islanding function. Therefore, all the later tests used only the local load to better simulate a generator interconnected with the grid but completely supplying only a local load. When the grid becomes de-energized, the local system conditions do not immediately change, but the ASCO must still recognize the island formation and disconnect the generator within 2 s. To further challenge the ASCO unit, inductive and capacitive elements were added to the local load to create a 1.8 load quality factor to help maintain the local power characteristics after the loss of the utility.

Tests were conducted to investigate the effects of the diesel power factor setting, the generator load level, and the anti-islanding deadband setting on the ASCO trip time. Loads at 25% (30 kW), 50% (63 kW), and near 100% (100 kW) were all tested at unity load power factor with matching inductive and capacitive loads to create a 1.8 quality factor. Testing was conducted with the diesel power factor setting at unity, 0.9 lagging, and, in some cases, 0.95 lagging. The deadband setting of the anti-islanding function is an adjustable sensitivity range. The anti-islanding software attempts to disrupt the grid, and with no energized grid to maintain voltage and frequency, the ASCO can force values beyond the set deadband cushion before disconnecting the generator. Deadband settings of 0.1, 0.05, and 0.03 were used in tests.

The testing procedure for anti-islanding was similar to abnormal voltage and frequency. Initially, with the distributed generator disconnected, the grid simulator would supply a local load 10 kW or 20 kW greater than the desired diesel output to avoid backfeeding the grid simulators when ramping up the diesel. The diesel would then be paralleled and would supply most of the local load; the simulated utility still contributed 10–20 kW. Next, matched inductive and capacitive loads were added to achieve a quality factor of about 1.8. The capacitive load was then slightly increased to reach the desired power factor (accounting for transformer and other stray system inductances), and the resistive load setting was slowly reduced to match the diesel output with the load and eliminate current from the utility. Finally, the utility breaker external to the ASCO unit

was tripped to island the distributed generator and record the disconnect time. Test results are discussed in the following section.

6.3 Anti-Islanding Test Results

Under the matched, undisturbed conditions of the laboratory setup, the ASCO unit did not identify the island and disconnect in less than 2 s with the anti-islanding function disabled. In some cases, the island lasted longer than the 3-min maximum observation time.

Regardless of diesel power factor setting or generator loading, it appears that with the correct deadband setting, the anti-islanding software can always recognize an island and clear the generator in less than 2 s. At the 0.1 deadband setting, islanding detection was sporadic. However, the ASCO unit consistently detected and discontinued islands with the deadband at 0.05. Reducing the deadband to 0.03 seemed generally to be unnecessary. It was unclear whether a 0.03 deadband setting offered any advantage over the 0.05 setting, and the greater sensitivity of 0.03 would increase the risk of nuisance tripping.

Figure 39 shows clearing times for loads and deadband settings. The diesel is set to generate at a 0.9 power factor while carrying equal inductive and capacitive loads for a unity load power factor at a 1.8 quality factor.
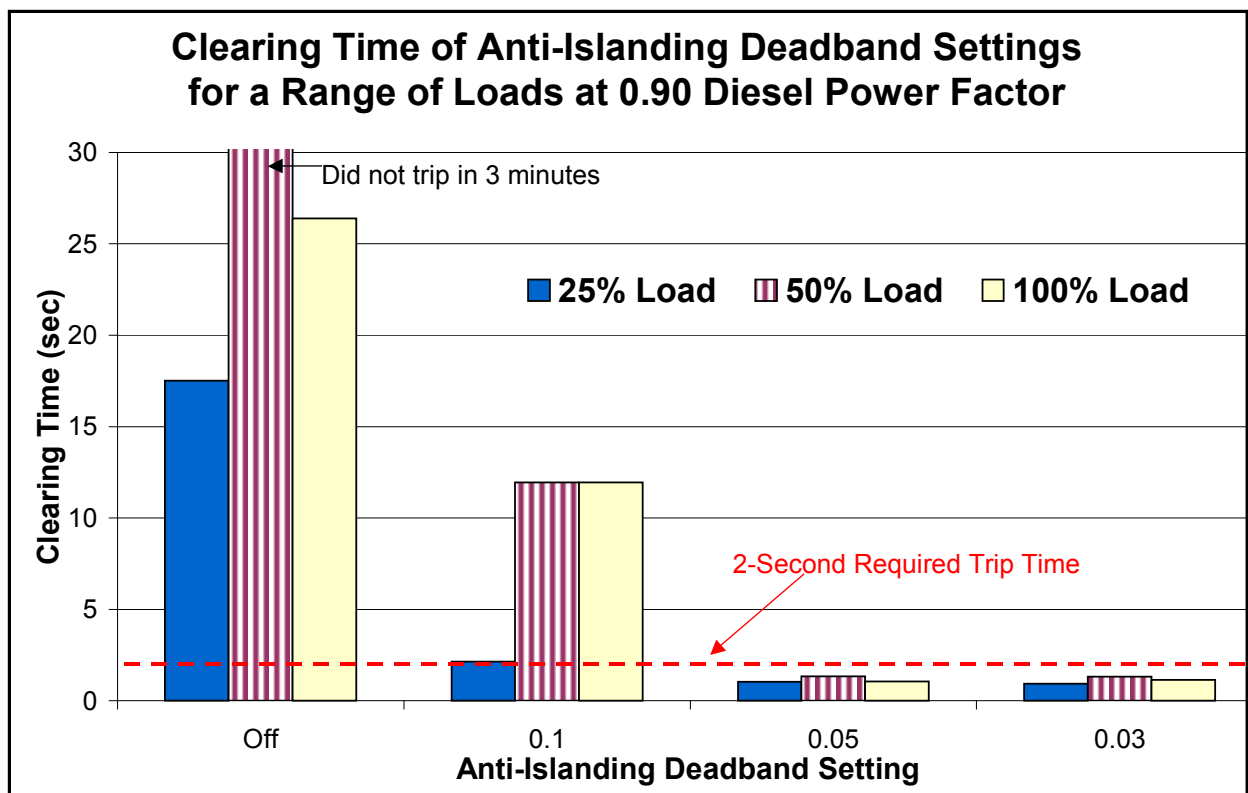
Figure 39. Anti-islanding clearing times comparison

Because the clearing time both increased and decreased based on changing power factor, the effect of the diesel power factor setting on anti-islanding clearing time was not as clear. Again, the load power factor was always unity for these tests. A comparison of 100 kW load data at 1, 0.95, and 0.9 diesel generator power factor settings, as shown in Figure 40, showed that somewhere in the middle—around 0.95—yielded the fastest trip times. More testing is necessary to verify these results.
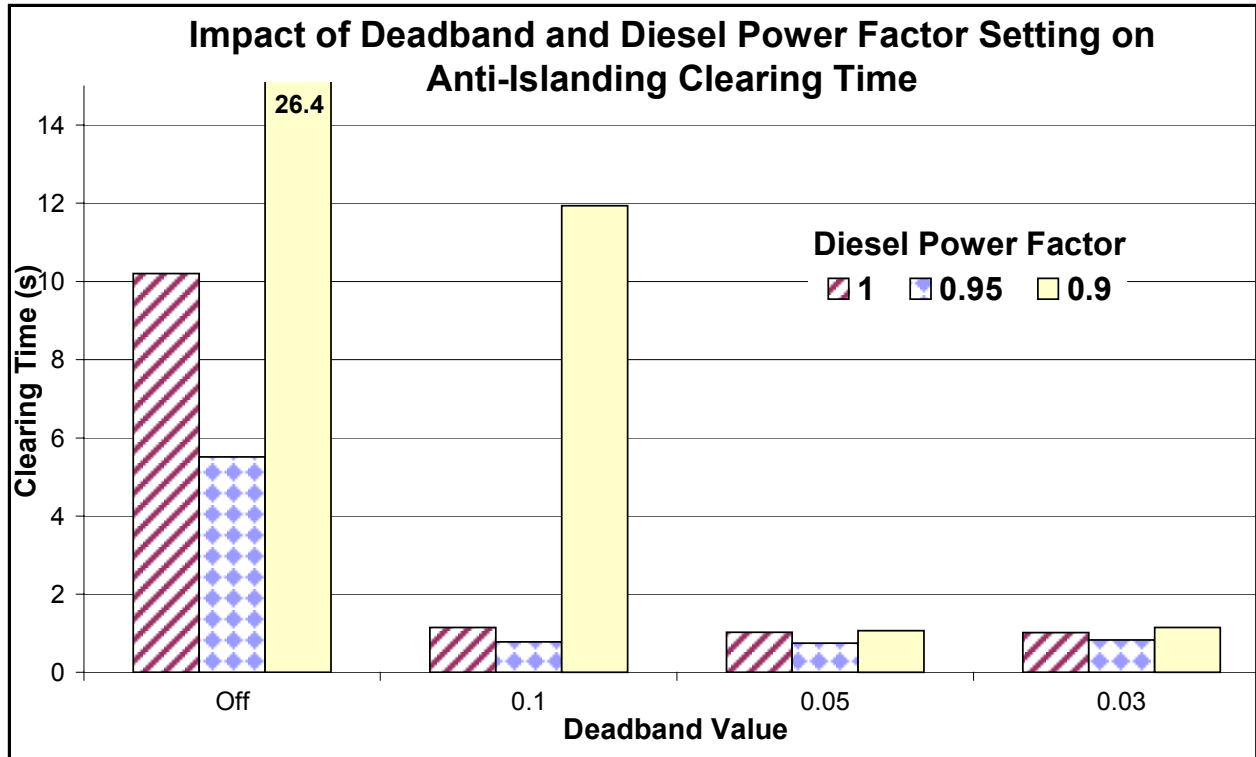
Figure 40. Power factor effect on anti-islanding loss of phase

Last, tests for loss of phase on the grid side were conducted to examine single-phase islanding. Using the same setup and procedure with the diesel running at 50% capacity (63 kW) at unity power factor, the ASCO unit single-phase cease-to-energize response was tested by stepping the voltage on each phase of the grid simulator to zero. Even without the active anti-islanding protection enabled, the ASCO SLTS was able to immediately identify the loss of any single phase. The ASCO SLTS quickly tripped on a wide variety of protective functions. The longest trip time was still less than a quarter of a second.

A summary of the single-phase results is shown in Table 16. The varying trip times for phases may be caused by slight imbalances in the system. The ASCO tripping was significantly different from three-phase islanding because here the utility breaker and output autotransformer were still connected while the grid simulator de-energized a single phase.

Table 16. Summary of Loss of Phase Results

Phase	Average Trip Time	Trip Function
	Phase Step to Zero	
A	0.0288 s	Rev current, overfreq
B	0.184 s	Overfreq, over/undervolt
C	0.0402 s	Undervolt, rev current
All three	0.0195 s	Rev current, underfreq

7 Summary of Testing Issues/ Recommendations to Writing Group

- Some discussion of generic monitoring, measurement, and testing strategies and requirements could be useful in P1547.1. The file size, sampling rate, and correct sampling window were significant factors of testing that could be mentioned in P1547.1 not to dictate values or procedures but as advice and warnings of issues to be aware of to aid smooth and accurate testing.

- Some values from the P1547.1 draft standard were incompatible with the testing setup. The minimum required value for the end point, P_U, of the step function in the time tests was not practical for frequency testing. At 110% or 90% of the trip magnitude for the over and underfrequency time tests, the ASCO tripped on other protective functions. P_U had to be reduced to isolate the frequency protection.

- Similarly, the voltage levels specified in the IEEE 1547 table (and the corresponding starting voltage level P_b for the ramp and step functions of P1547.1) could not be achieved by the diesel generator without adjusting voltage regulator settings. Varying the diesel voltage by more than about 30 V (6.25% versus the IEEE worst-case settings at − 50%/+20%) caused the diesel to trip on "excess reverse VARs." This issue may prove problematic if tested in the field with actual generators.

- Care must be taken to test each parameter individually without other protective functions operating.

- The abnormal voltage and frequency testing was conducted only on all three phases simultaneously. IEEE P1547.1 Section 5.0 Design Tests describes how each phase should be individually tested.

8   References

Bower, W.; Ropp, M. "Evaluation of Islanding Detection Methods for Utility-Interactive Inverters in Photovoltaic Systems." SAND2002-3591. Albuquerque, NM: Sandia National Laboratories. November 2002.

Daley, J.M.; Siciliano, R.L. "Application of Emergency and Standby Generation for Distributed Generation: Part 1." Industrial and Commercial Power Systems Technical Conference 2002. May 5–8, 2002; pp. 138–150.

Daley, J.M.; Siciliano, R.L. "Application of Emergency and Standby Generation for Distributed Generation: Part 2." Industrial and Commercial Power Systems Technical Conference 2002. May 5–8, 2002; pp. 151–157.

IEEE 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems. New York, NY: Institute of Electrical and Electronics Engineers, 2003.

IEEE P1547.1 Draft 2 Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems. New York, NY: Institute of Electrical and Electronics Engineers, 2003.

Kroposki, B.; DeBlasio, R.; Galdo, J. "Distributed Power Program DER Pilot Test at the Nevada Test Site." NREL/TP-560-32063. Golden, CO: National Renewable Energy Laboratory. May 2002.

Appendix A. IEEE P1547D10 Reference Information

Table A-1. Interconnection System Response to Abnormal Voltages

Voltage Range (% of Base Voltage[a])	Clearing Time[b] (s)
V < 50	0.16
50 ≤ V < 88	2
110 < V < 120	1
V ≥ 120	0.16

Notes (a) Base voltages are the nominal system voltages stated in ANSI C84.1 Table 1.
    (b) DR ≤ 30 kW, maximum clearing times; DR > 30 kW, default clearing times.

Table A-2. Interconnection System Response to Abnormal Frequencies

DR Size	Frequency Range (Hz)	Clearing Time[a] (s)
≤ 30 kW	> 60.5	0.16
	< 59.3	0.16
> 30 kW	> 60.5	0.16
	< {59.8–57.0} (adjustable set point)	Adjustable 0.16–300
	< 57.0	0.16

Note (a) DR ≤ 30 kW, maximum clearing times; DR > 30 kW, default clearing times.

Appendix B. Abnormal Frequency and Voltage Test Results

Table B-1. Abnormal Frequency and Voltage Test Results

Overfrequency Magnitude		Overfrequency Time	
Trial Number	Trip Frequency (Hz)	Trial Number	Trip Time (ms)
1	60.458	1	47
2	60.604	2	58
3	60.461	3	40
4	60.534	4	40
5	60.531	5	39
Average	**60.518**	**Average**	**45**
Setting	**60.500**	**Required**	**160**

Underfrequency Magnitude		Underfrequency Time	
Trial Number	Trip Frequency (Hz)	Trial Number	Trip Time (s)
1	59.301	1	1.58
2	59.311	2	1.48
3	59.298	3	1.58
4	59.312	4	1.57
5	59.284	5	1.54
Average	**59.301**	**Average**	**1.55**
Setting	**59.300**	**Required***	**1.70**

* Adjustable setting (0.16–300 s) for DG >30 kW was set to 1.70 s.

Fast Underfrequency Magnitude		Fast Underfrequency Time	
Trial Number	Trip Frequency (Hz)	Trial Number	Trip Time (ms)
1	57.000	1	40.82
2	56.987	2	41.02
3	57.000	3	50.42
4	57.000	4	50.80
5	56.987	5	51.14
Average	**56.995**	**Average**	**46.84**
Setting	**57.000**	**Required**	**160.00**

Overvoltage Magnitude		Overvoltage Time	
Trial Number	Trip Voltage (V)	Trial Number	Trip Time (s)
1	504.300	1	0.436
2	502.500	2	0.428
3	504.700	3	0.378
4	504.600	4	0.396
5	504.150	5	0.468
Average	**504.050**	**Average**	**0.421**
Setting	**504.000**	**Required**	**1.000**

Fast Overvoltage Magnitude		Fast Overvoltage Time	
Trial Number	Trip Voltage (V)	Trial Number	Trip Time (ms)
1.0	501.7	1.0	40.2
2.0	499.8	2.0	41.4
3.0	501.7	3.0	36.5
4.0	501.7	4.0	46.9
5.0	502.2	5.0	48.1
Average	**501.4**	**Average**	**42.6**
Setting	**504.0**	**Required**	**160.0**

Undervoltage Magnitude		Undervoltage Time	
Trial Number	Trip Voltage (V)	Trial Number	Trip Time (s)
1.0	459.8	1.0	1.92
2.0	453.4	2.0	1.92
3.0	458.7	3.0	1.88
4.0	458.7	4.0	1.93
5.0	459.8	5.0	1.88
Average	**458.1**	**Average**	**1.91**
Setting	**456.0**	**Required**	**2.00**

Fast Undervoltage Magnitude		Fast Undervoltage Time	
Trial Number	Trip Voltage (V)	Trial Number	Trip Time (ms)
1.0	451.9	1.0	54.5
2.0	455.6	2.0	55.0
3.0	454.9	3.0	57.2
4.0	454.1	4.0	74.9
5.0	449.0	5.0	43.4
Average	**453.1**	**Average**	**57.0**
Setting	**446.0**	**Required**	**160.0**

Appendix C. ASCO Anti-Islanding Test Results

Table C-1. ASCO Anti-Islanding Test Results

NREL Test Data

11/12/2002
Anti-Islanding Test

Test #	Lu (kW)	Lts (kW)	Lt (kW)	pf	Base Load	Active Anti-Island	Clear Time (s)	Detect Time (s)	Avg Clear Time (s)	Std. Dev. Clear Time (s)	Avg Detect Time (s)	Std. Dev. Detect Time (s)	
1	16.8	14.4	31.2	0.99	31kW @ .99pf	NO	15.6	15.1	16	0.44	15.5	0.44	
"	"	"	"	"	"	"	15.5	15					
"	"	"	"	"	"	"	16.1	15.6					
"	"	"	"	"	"	"	16.3	15.8					
"	"	"	"	"	"	"	16.5	16					
2	16.8	14.4	31.2	0.99	31kW @ .99pf	YES	0.875	0.375	0.859	0.07	0.3586	0.07	db=0.10Hz
"	"	"	"	"	"	"	0.912	0.412					"
"	"	"	"	"	"	"	0.812	0.312					"
"	"	"	"	"	"	"	0.932	0.432					"
"	"	"	"	"	"	"	0.762	0.262					"
3	31.7	0	31.7	0.99	31kW @ .99pf	NO	17.5	17	17.12	0.54	16.62	0.54	
"	"	"	"	"	"	"	17.1	16.6					
"	"	"	"	"	"	"	17.8	17.3					
"	"	"	"	"	"	"	16.6	16.1					
"	"	"	"	"	"	"	16.6	16.1					
4	31.7	0	31.7	0.99	31kW @ .99pf	YES	0.852	0.352	0.890	0.06	0.39	0.06	db=0.10Hz
"	"	"	"	"	"	"	0.942	0.442					"
"	"	"	"	"	"	"	0.812	0.312					"
"	"	"	"	"	"	"	0.922	0.422					"
"	"	"	"	"	"	"	0.922	0.422					"
5	1.8	28.5	30.3	0.99	31kW @ .99pf	NO	17.1	16.6	17.14	0.80	16.64	0.80	
"	"	"	"	"	"	"	16.4	15.9					
"	"	"	"	"	"	"	17.5	17					
"	"	"	"	"	"	"	16.4	15.9					

"	"	"	"	"	"	"	18.3	17.8					
6	1.8	28.5	30.3	0.99	31kW @ .99pf	YES	1.35	0.85	1.147	0.17	0.6474	0.17	db=0.10Hz
"	"	"	"	"	"	"	1.02	0.52					"
"	"	"	"	"	"	"	1.32	0.82					"
"	"	"	"	"	"	"	0.987	0.487					"
"	"	"	"	"	"	"	1.06	0.56					"
7	2.01	30.7	32.7	0.99	32kW @ .99pf	NO	61	60.5	61.44	0.88	60.94	0.88	
"	"	"	"	"	"	"	61	60.5					
"	"	"	"	"	"	"	63	62.5					
"	"	"	"	"	"	"	61.3	60.8					
"	"	"	"	"	"	"	60.9	60.4					
8	2.01	30.7	32.7	0.99	32kW @ .99pf	YES	52	51.5	51.060	1.30	50.56	1.30	db=0.10Hz
"	"	"	"	"	"	"	51.9	51.4					"
"	"	"	"	"	"	"	49.4	48.9					"
"	"	"	"	"	"	"	52.1	51.6					"
"	"	"	"	"	"	"	49.9	49.4					"
9	2.01	30.7	32.7	0.99	32kW @ .99pf	YES	1.48	0.98	1.98	0.74	1.48	0.74	db=0.03Hz
"	"	"	"	"	"	"	1.62	1.12					"
"	"	"	"	"	"	"	2.83	2.33					"
10	2.01	30.7	32.7	0.99	32kW @ .99pf	YES	1.17	0.67	1.066	0.08	0.5664	0.08	"
"	"	"	"	"	"	"	1.12	0.62					"
"	"	"	"	"	"	"	0.992	0.492					"
"	"	"	"	"	"	"	1.05	0.55					"
"	"	"	"	"	"	"	1	0.5					"
11	2.01	30.7	32.7	0.99	32kW @ .99pf	YES	0.94	0.44	1.404	0.81	0.904	0.81	db=0.05Hz
"	"	"	"	"	"	"	2.82	2.32					"
"	"	"	"	"	"	"	0.93	0.43					"
"	"	"	"	"	"	"	0.98	0.48					"
"	"	"	"	"	"	"	1.35	0.85					"
12	0	63.6	63.6	1.00	63kW @ 1.00pf	NO	>180	######	#DIV/0!	#####	######	######	
"	"	"	"	"	"	"	>540	######					
13	0	63.6	63.6	1.00	63kW @ 1.00pf	YES	0.992	0.492	0.9732	0.06	0.4732	0.06	db=0.03Hz
"	"	"	"	"	"	"	1.03	0.53					"
"	"	"	"	"	"	"	1.02	0.52					"
"	"	"	"	"	"	"	0.922	0.422					"

"	"	"	"	"	"	"	0.902	0.402					"
14	0	63.6	63.6	1.00	63kW @ 1.00pf	YES	1.16	0.66	1.498	0.79	0.998	0.79	db=0.05Hz
"	"	"	"	"	"	"	1.18	0.68					"
"	"	"	"	"	"	"	1.24	0.74					"
"	"	"	"	"	"	"	1.01	0.51					"
"	"	"	"	"	"	"	2.9	2.4					"
15	0	63.6	63.6	1.00	63kW @ 1.00pf	YES	>180	######	#DIV/0!	#####	######	######	db=0.10Hz
"	"	"	"	"	"	"	>180	######					"
16	0	108.5	109	1.00	108kW @ 1.00pf	NO	10.52	10.02	10.198	0.55	9.698	0.55	
"	"	"	"	"	"	"	9.82	9.32					"
"	"	"	"	"	"	"	9.42	8.92					"
"	"	"	"	"	"	"	10.59	10.09					"
"	"	"	"	"	"	"	10.64	10.14					"
17	0	108.5	109	1.00	108kW @ 1.00pf	YES	1.04	0.54	1.147	0.21	0.6474	0.21	db=0.10Hz
"	"	"	"	"	"	"	1.47	0.97					"
"	"	"	"	"	"	"	0.927	0.427					"
"	"	"	"	"	"	"	1.1	0.6					"
"	"	"	"	"	"	"	1.2	0.7					"
18	0	108.5	109	1.00	108kW @ 1.00pf	YES	0.992	0.492	1.021	0.04	0.5212	0.04	db=0.05Hz
"	"	"	"	"	"	"	1.08	0.58					"
"	"	"	"	"	"	"	0.994	0.494					"
"	"	"	"	"	"	"	1.02	0.52					"
"	"	"	"	"	"	"	1.02	0.52					"
19	0	108.5	109	1.00	108kW @ 1.00pf	YES	1.16	0.66	1.020	0.11	0.5204	0.11	db=0.03Hz
"	"	"	"	"	"	"	0.924	0.424					"
"	"	"	"	"	"	"	0.984	0.484					"
"	"	"	"	"	"	"	0.924	0.424					"
"	"	"	"	"	"	"	1.11	0.61					"
20	0	29.5	29.5	0.90	30kW @ 0.90pf	NO	17.24	16.74	17.510	1.62	17.01	1.62	
"	"	"	"	"	"	"	16.44	15.94					"
"	"	"	"	"	"	"	15.84	15.34					"
"	"	"	"	"	"	"	20	19.5					"
"	"	"	"	"	"	"	18.03	17.53					"

21	0	29.5	29.5	0.90	30kW @ 0.90pf	YES	5.16	4.66	2.148	1.73	1.648	1.73	db=0.10Hz
"	"	"	"	"	"	"	2.05	1.55					"
"	"	"	"	"	"	"	1.25	0.75					"
"	"	"	"	"	"	"	1.05	0.55					"
"	"	"	"	"	"	"	1.23	0.73					"
22	0	29.5	29.5	0.90	30kW @ 0.90pf	YES	1.13	0.63	1.037	0.09	0.5368	0.09	db=0.05Hz
"	"	"	"	"	"	"	0.894	0.394					"
"	"	"	"	"	"	"	1.02	0.52					"
"	"	"	"	"	"	"	1.08	0.58					"
"	"	"	"	"	"	"	1.06	0.56					"
23	0	29.5	29.5	0.90	30kW @ 0.90pf	YES	0.953	0.453	0.932	0.04	0.4324	0.04	db=0.03Hz
"	"	"	"	"	"	"	0.983	0.483					"
"	"	"	"	"	"	"	0.954	0.454					"
"	"	"	"	"	"	"	0.891	0.391					"
"	"	"	"	"	"	"	0.881	0.381					"
24	0	61.1	61.1	0.90	62kW @ 0.90pf	NO	>180	######	#DIV/0!	#####	######	######	
25	0	61.1	61.1	0.90	62kW @ 0.90pf	YES	>180	######	#DIV/0!	#####	######	######	db=0.10Hz
26	0	61.1	61.1	0.90	62kW @ 0.90pf	YES	0.867	0.367	1.335	0.46	0.8354	0.46	db=0.05Hz
"	"	"	"	"	"	"	1.96	1.46					"
"	"	"	"	"	"	"	1.17	0.67					"
"	"	"	"	"	"	"	1.67	1.17					"
"	"	"	"	"	"	"	1.01	0.51					"
27	0	61.1	61.1	0.90	62kW @ 0.90pf	YES	1.38	0.88	1.328	0.18	0.828	0.18	db=0.03Hz
"	"	"	"	"	"	"	1.31	0.81					"
"	"	"	"	"	"	"	1.56	1.06					"
"	"	"	"	"	"	"	1.07	0.57					"
"	"	"	"	"	"	"	1.32	0.82					"
28	0	100.2	100	0.90	101kW @ 0.90pf	NO	26.4	25.9	26.380	0.28	25.88	0.28	
"	"	"	"	"	"	"	26.5	26					
"	"	"	"	"	"	"	26.5	26					
"	"	"	"	"	"	"	26.6	26.1					
"	"	"	"	"	"	"	25.9	25.4					

29	0	100.2	100	0.90	101kW @ 0.90pf	YES	0.987	0.487	11.937	8.06	11.437	8.06	db=0.10Hz
"	"	"	"	"	"	"	17	16.5					"
"	"	"	"	"	"	"	6	5.5					"
"	"	"	"	"	"	"	20	19.5					"
"	"	"	"	"	"	"	15.7	15.2					"
30	0	100.2	100	0.90	101kW @ 0.90pf	YES	1.04	0.54	1.06	0.10	0.56	0.10	db=0.05Hz
"	"	"	"	"	"	"	1.23	0.73					"
"	"	"	"	"	"	"	0.976	0.476					"
"	"	"	"	"	"	"	1.01	0.51					"
"	"	"	"	"	"	"	1.02	0.52					"
31	0	100.2	100	0.90	101kW @ 0.90pf	YES	1.04	0.54	1.146	0.12	0.646	0.12	db=0.03Hz
"	"	"	"	"	"	"	1.08	0.58					"
"	"	"	"	"	"	"	1.06	0.56					"
"	"	"	"	"	"	"	1.29	0.79					"
"	"	"	"	"	"	"	1.26	0.76					"
32	0	99.7	99.7	0.88	101kW @ 0.95pf	NO	5.97	5.47	5.51	0.57	5.01	0.57	
"	"	"	"	"	"	"	5.37	4.87					
"	"	"	"	"	"	"	5.03	4.53					
"	"	"	"	"	"	"	4.95	4.45					
"	"	"	"	"	"	"	6.23	5.73					
33	0	99.7	99.7	0.88	101kW @ 0.95pf	YES	0.797	0.297	0.78	0.06	0.28	0.06	db=0.10Hz
"	"	"	"	"	"	"	0.69	0.19					"
"	"	"	"	"	"	"	0.81	0.31					"
"	"	"	"	"	"	"	0.83	0.33					"
"	"	"	"	"	"	"	0.75	0.25					"
34	0	99.7	99.7	0.88	101kW @ 0.95pf	YES	0.76	0.26	0.75	0.05	0.25	0.05	db=0.05Hz
"	"	"	"	"	"	"	0.74	0.24					"
"	"	"	"	"	"	"	0.67	0.17					"
"	"	"	"	"	"	"	0.8	0.3					"
"	"	"	"	"	"	"	0.79	0.29					"
35	0	99.7	99.7	0.88	101kW @ 0.95pf	YES	0.683	0.183	0.83	0.26	0.33	0.26	db=0.03Hz
"	"	"	"	"	"	"	0.693	0.193					"
"	"	"	"	"	"	"	1.27	0.77					"
"	"	"	"	"	"	"	0.857	0.357					"
"	"	"	"	"	"	"	0.667	0.167					"

36	0	63.9	63.9	1.00	62kW @ 1.00pf	NO	9.1	8.6	9.76	2.00	9.26	2.00	
"	"	"	"	"	"	"	9	8.5					
"	"	"	"	"	"	"	9.06	8.56					
"	"	"	"	"	"	"	8.36	7.86					
"	"	"	"	"	"	"	13.3	12.8					
37	0	63.9	63.9	1.00	62kW @ 1.00pf	YES	0.76	0.26	1.03	0.40	0.53	0.40	db=0Hz
"	"	"	"	"	"	"	1.4	0.9					Vpk=0.34
"	"	"	"	"	"	"	1.31	0.81					50ms updt
"	"	"	"	"	"	"	1.22	0.72					
"	"	"	"	"	"	"	0.457	-0.043					
38	0	63.5	63.5	1.00	63kW @ 1.00pf	NO	>180	######	#DIV/0!	#####	######	######	
39	0	63.5	63.5	1.00	63kW @ 1.00pf	YES	3.55	3.05	4.35	1.78	3.85	1.78	db=0Hz
"	"	"	"	"	"	"	7	6.5					Vpk=0.34
"	"	"	"	"	"	"	2.14	1.64					100ms updt
"	"	"	"	"	"	"	4.47	3.97					
"	"	"	"	"	"	"	4.6	4.1					
40	0	63.9	63.9	1.00	63kW @ 1.00pf	YES	3.92	3.42	3.14	1.46	2.64	1.46	db=0Hz
"	"	"	"	"	"	"	1.88	1.38					Vpk=0.38
"	"	"	"	"	"	"	1.28	0.78					100ms updt
"	"	"	"	"	"	"	4.08	3.58					
"	"	"	"	"	"	"	4.56	4.06					
46	0	63.9	63.9	1.00	63kW @ 1.00pf	NO	>180						
47	0	63.9	63.9	1.00	63kW @ 1.00pf	YES	1.007	0.507	1.11	0.13	0.61	0.13	db = 0.03Hz
"	"	"	"	"	"	"	0.983	0.4832					Vpk=0.42
"	"	"	"	"	"	"	1.288	0.788					
"	"	"	"	"	"	"	1.215	0.715					
"	"	"	"	"	"	"	1.064	0.564					

Note: Test Data showing ##### – Unit did not trip, and test was terminated after 180 s.

Appendix D. ASCO Single-Phase Anti-Islanding Test Result

Table D-1. ASCO Single-Phase Anti-Islanding Test Results

NREL Test Data
Single-Phase Test   11/14/2002

Test #	Lts (kW)	pf	Base Load	Active Anti-Islanding	Clear Time (s)	Average Clear Time (s)	Std. Dev. Clear Time (s)	Trip Function	Fault Description
41	63.9	1.00	63kW @ 1.00pf	NO	0.0175	0.0288	0.009	Rev current, overfreq.	Phase A step to zero
"	"	"	"	"	0.0375			Rev current, overfreq.	"
"	"	"	"	"	0.0224			Rev current, underfreq.	"
"	"	"	"	"	0.0285			Rev current, rev kW, overfreq	"
"	"	"	"	"	0.0379			Rev current, overfreq., undervolt	"
42	63.9	1.00	63kW @ 1.00pf	NO	0.183	0.184	0.053	Overvolt, overfreq.	Phase B step to zero
"	"	"	"	"	0.1024			Overfreq.	"
"	"	"	"	"	0.177			Overfreq., undervolt	"
"	"	"	"	"	0.2452			Overfreq., undervolt, underfreq.	"
"	"	"	"	"	0.214			Overvolt, overfreq., underfreq.	"
43	63.9	1.00	63kW @ 1.00pf	NO	0.042	0.0402	0.012	Undervolt	Phase C step to zero
"	"	"	"	"	0.052			Undervolt, rev current	"
"	"	"	"	"	0.0372			Undervolt, rev current, underfreq.	"
"	"	"	"	"	0.0219			Undervolt, rev current	"
"	"	"	"	"	0.0478			Undervolt	"
44	63.9	1.00	63kW @ 1.00pf	NO				Neg seq. current (13.3%)	Phase A 20-s ramp to 80%
45	63.9	1.00	63kW @ 1.00pf	NO	0.0203	0.0195	0.005	Undervolt, underfreq.	Three phases step to zero
"	"	"	"	"	0.016			Rev current, underfreq.	"
"	"	"	"	"	0.0151			Rev current, underfreq., overfreq.	"
"	"	"	"	"	0.0275			Rev current, rev kW, UF, OF, UV	"
"	"	"	"	"	0.0185			Rev current, UF, OF, UV	"

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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE September 2003	3. REPORT TYPE AND DATES COVERED Subcontract report	
4. TITLE AND SUBTITLE Validation of IEEE P1547.1 Interconnection Test Procedures: ASCO 7000 Soft Load Transfer System			5. FUNDING NUMBERS DP03.1001
6. AUTHOR(S) B. Kroposki, S. Englebretson, C. Pink, J. Daley, R. Siciliano, and D. Hinton			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			8. PERFORMING ORGANIZATION REPORT NUMBER NREL/TP-560-34870
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents the preliminary results of testing the ASCO 7000 Soft Load Transfer System according to IEEE P1547.1 procedures. The ASCO system interconnects synchronous generators with the electric power system and provides monitoring and control for the generator and grid connection through extensive protective functions. The purpose of this testing is to evaluate and give feedback on the contents of IEEE Draft Standard P1547.1 Conformance Tests Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems.

14. SUBJECT TERMS standards; testing; IEEE P1547.1; IEEE 1547; islanding; anti-islanding; Distributed Energy Resources Test Facility; distributed power; distributed generation; distributed energy resources; DP; DG; DER; International Electrical and Electronics Engineers; Distribution and Interconnection R&D; National Renewable Energy Laboratory; NREL		15. NUMBER OF PAGES
		16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified
20. LIMITATION OF ABSTRACT UL		