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Residential Air Conditioner with VFD Test Procedures

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1.0 OBJECTIVE

The objective of this testing is to investigate one phase (1-Φ) ductless air conditioner (A/C) with variable frequency drive (VFD) units performance during voltage/frequency fluctuations and oscillations that typically occur on the grid, in particular its stalling conditions. Additionally, it will provide an understanding of the characteristics of these A/C's in steady-state; such as the harmonic distortion levels and electrical protection and controls. The test data is needed to build, test, and/or validate VFD A/C model for dynamic, steady-state, and harmonic performance. A supplemental intent of this testing is to find out if these A/C's are "grid friendly" devices and/or what is needed to remedy any potential impacts to the electric power system.

A/C performance data is needed for validation of power system simulation models used for power system planning studies. The inadequacy of residential load models became evident when Southern California Edison (SCE) and other utilities in the US, and other countries, experienced several delayed voltage recovery events after transmission or sub transmission fault clearing. The most significant occurrence of this event in the SCE system took place on August 5, 1997. During the fault, the system voltage dropped below 60% causing many residential air conditioner compressor motors in the system to stall, increasing the VAR demand, and delaying the voltage recovery. The model used for the simulation of the August 5 event was more optimistic than the measured event data (i.e. the simulation showed a slightly faster recovery than the measured event data).

2.0 INSTALLATION AND SETUP

The grid simulator and the EUT (VFD A/C unit) will be connected as shown in Figure 2.1.1 below. The thermostat remote control will be placed in an adjacent area. The power analyzer will record the voltage and current at a sampling rate specified in each test. The grid simulator will generate the specified voltage or frequency transients needed for each of the tests.

2.1 A/C Test bed

The test set up will have the protection devices such as circuit breakers (CB) and/or fuses for the safety of personnel and equipment. The test equipment used in the test set up are:

- Grid simulator (GS): supplies typical actual voltage and frequency deviations
- Equipment under test (EUT): variable frequency drive air conditioner units
- Power analyzer (PA): records voltage and current at high sampling rates
- Computer (CPU): control the grid simulator and power analyzer

Additionally, the test bed have test panel that are used to control and protect the testing devices.

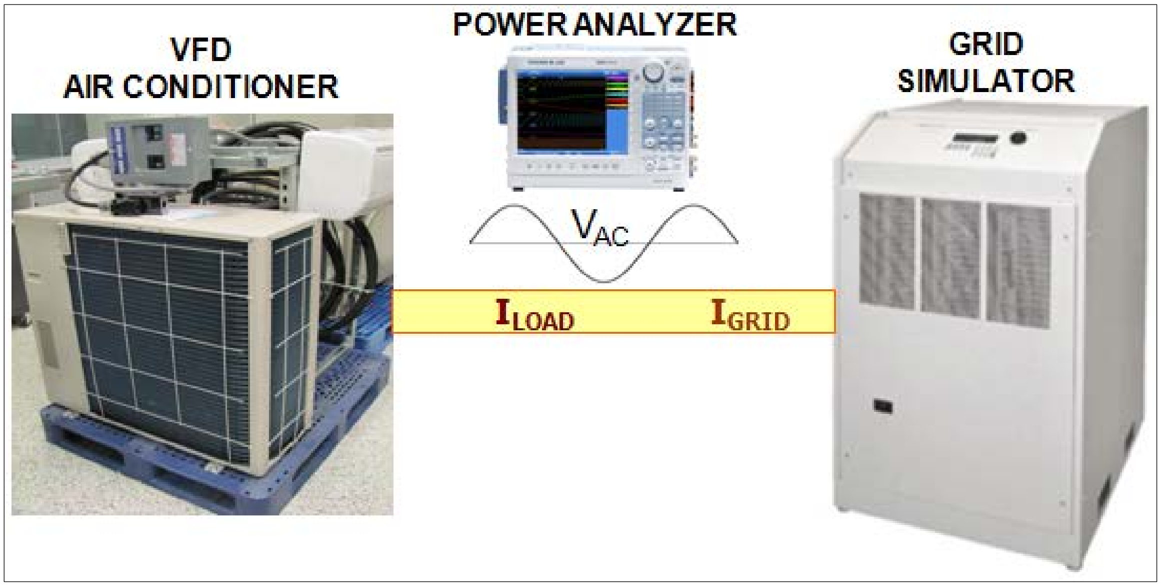

Figure 2.1.1 Test Setup Block Diagram

Sinusoidal Voltages and currents will be measured at the input of the EUT. Additionally, temperatures at the input and output sides of the air conditioner will be measured and recorded. It is desired to measure the currents for the compressor separate from the rest of currents in order to see the actual compressor performance. The RMS performance will be processed after the testing where it will include real power, reactive power, power factor, frequency, voltage RMS, and current RMS. All the tests must be logged into a laboratory log notebook and maintain it as test records. An example of a log notebook has been provided in the appendix of this document.

3.0 DYNAMIC PERFORMANCE TESTS

In these tests, the equipment will be set as shown in figure 2.1.1 above. The system voltage or frequency is changed to assess the EUT dynamic performance. Each of the tests will have to be subjected to the described tests at least three times for consistency. The grid simulator (GS) switching shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

3.1 **Test#1 –** Compressor Power OFF Test

The purpose of this test is to assess the power consumption of other devices when the compressor is OFF and how long will it take to shutdown. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant, at 240 V and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed.

This test should be performed in accordance with the following steps and figures (Figure 3.1.1and Figure 3.1.2):

STEP 1: EUT should be running at steady state

STEP 2: Shut down the EUT by raising the thermostat temperature

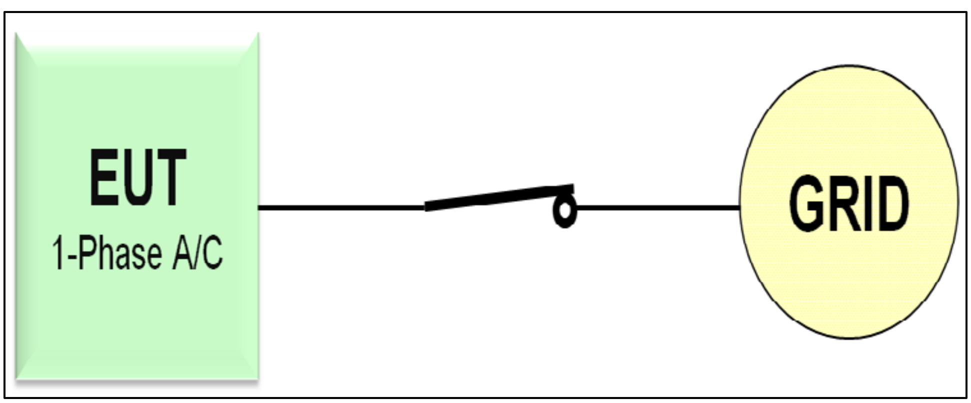

Figure 3.1.1 Compressor Power OFF Test

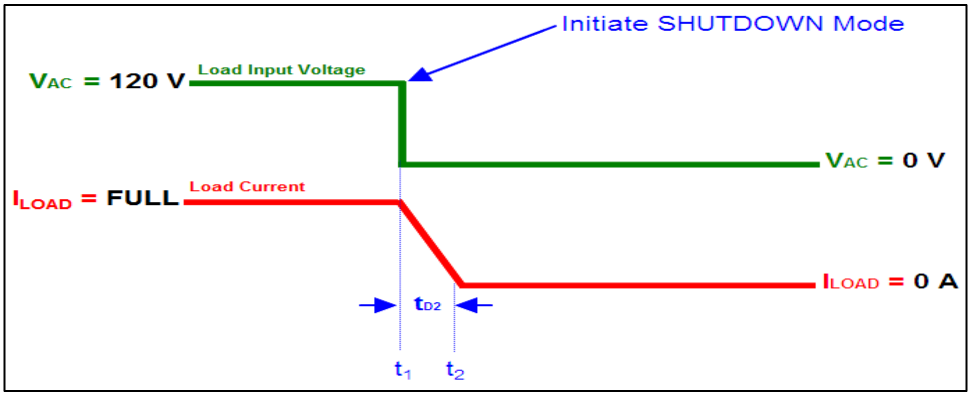

Figure 3.1.2 Shut-Down Time Delay Test

3.2 **Test#2 –** Inrush Current Test

This test is performed to record the EUT behavior during start up, especially the inrush current. The grid simulator shall be prepared to provide power to the test bed. The EUT shall be connected to the power supply but in the OFF state, triggered by the thermostat. The grid simulator voltage and frequency shall remain constant, at 240 V and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed.

This test should be performed in the following steps and figures (Figure 3.2.1and Figure 3.2.2):

STEP 1: Grid simulator shall be ON and ready to provide power to the system

STEP 2: EUT should be at the OFF state

STEP 3: Turn on the EUT by closing the CB or raise the temperature in the thermostat

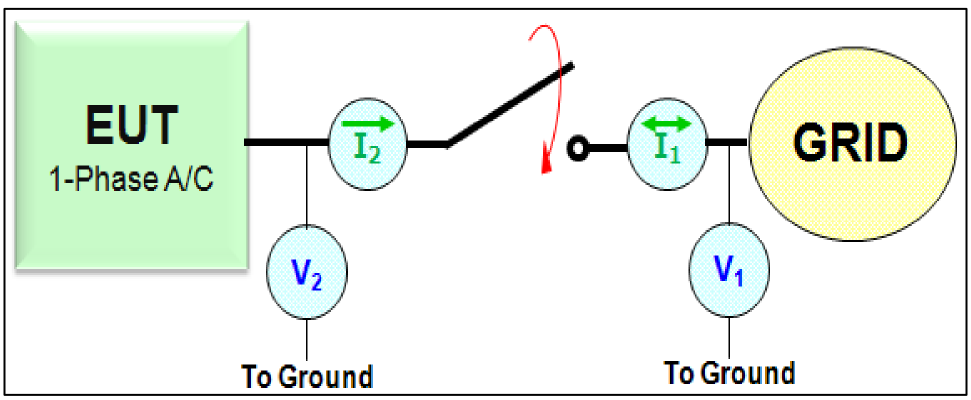

Figure 3.2.1 A/C Inrush current test

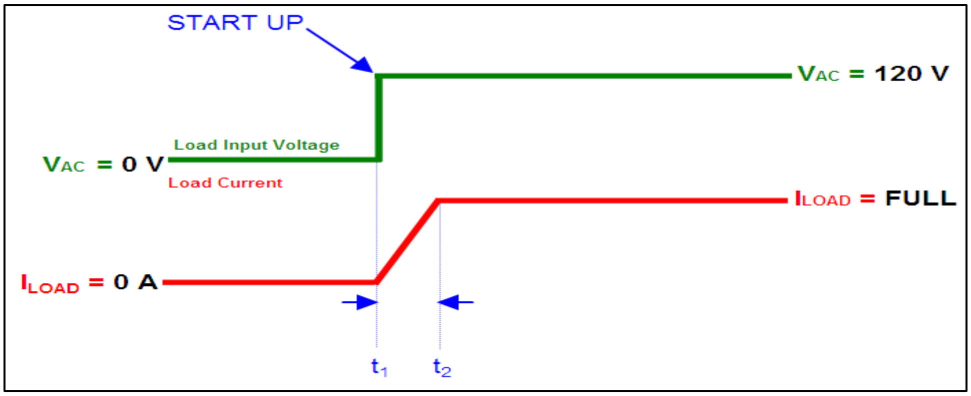

Figure 3.2.2 Residential Load Inrush Test

3.3 **Test#3 –** Balanced Under-voltage Test

The purpose of this test is to assess the EUT performance during under-voltage transients and/or sags typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. Grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage transients shown in Figure 3.3.1 below. These voltage sags shall have t cycles of duration time and 1 sec (or the time needed for the compressor to reach to steady state condition) of interval time between voltage changes. Each of the different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, 130, and 10800 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

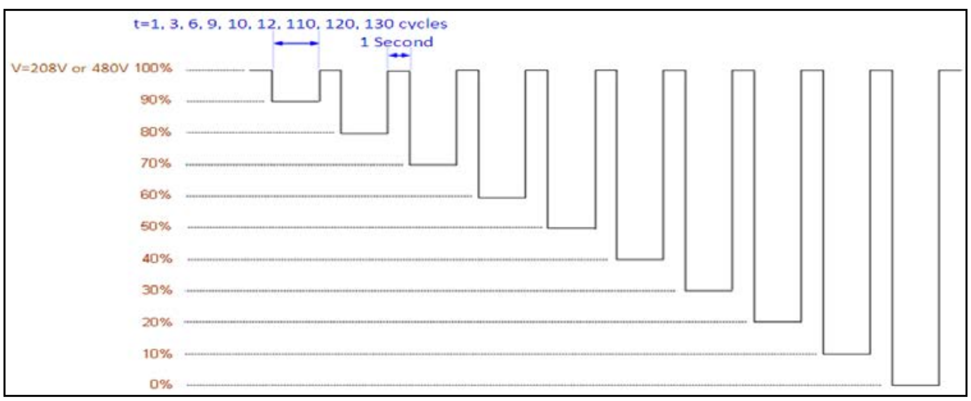

Figure 3.3.1 Balanced Under-voltage Test

If this test is unsuccessful, the under-voltage transients will have to be performed individually as shown in Figure 3.3.2. This can provide additional information such as power contractor drop out and pickup.

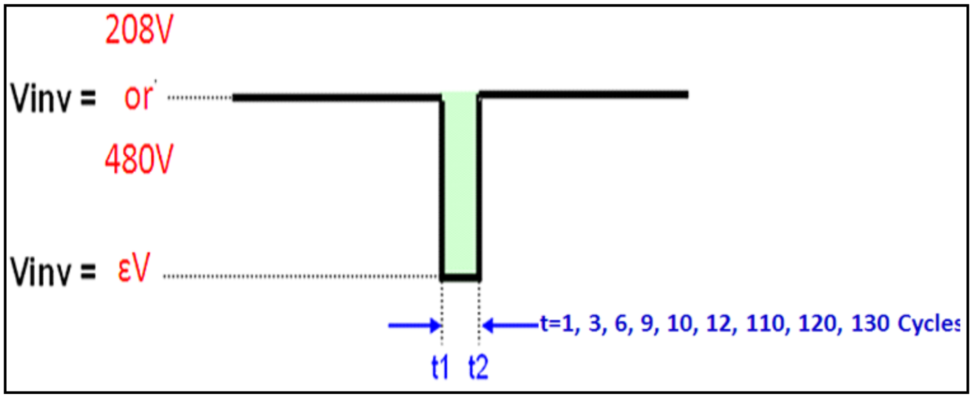

Figure 3.3.2 Balanced Under-voltage Single Test

3.4 **Test#4 –** Balance Over-voltage Test

The purpose of this test is to assess the EUT performance during over-voltage transients and/or swells typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. Grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage transients shown in Figure 3.4.1 below. These voltage sags shall have t cycles of duration time and 1 sec (or the time needed for the compressor to reach to steady state condition) of interval time between voltage changes. These different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, and 130 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

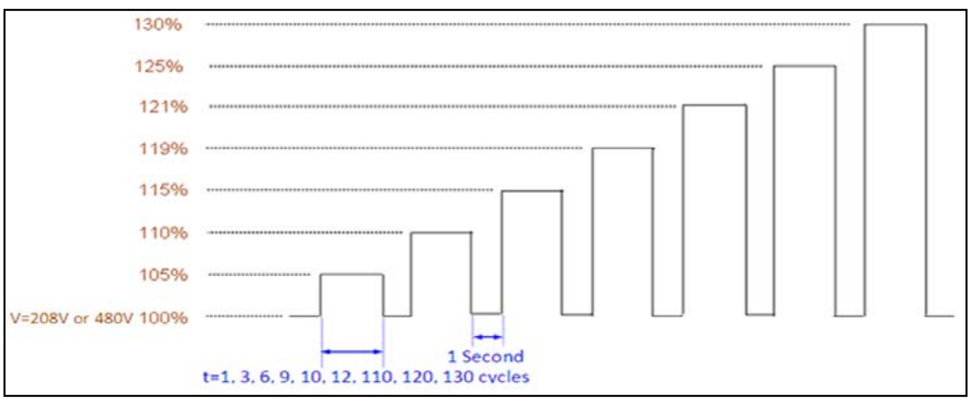

Figure 3.4.1 Balanced Over-voltage Test

If this test is unsuccessful, the over-voltage transients will have to be performed individually as shown in Figure 3.4.2.

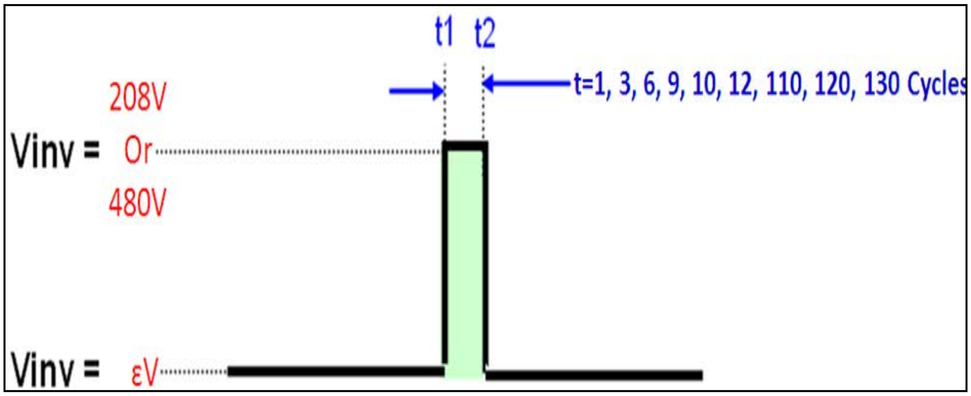

Figure 3.4.2 Balanced Over-voltage Single Test

3.5 **Test#5 –** Unbalanced Under-voltage Test

The purpose of this test is to assess the EUT performance during under-voltage transients and/or sags typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. The grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage transients shown in Figure 3.5.1 below. These voltage sags shall have t cycles of duration time and 1 sec (or the time needed for the compressor to reach to steady state condition) of interval time between voltage changes. Each of the different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, and 130 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

Each of the grid simulator output line-to-neutral voltages shall be dropped to the sag voltage (ε V) at t1 and rise back to nominal voltage at t2 in the combinations needed. The sag voltage (ε V) level is performed by the grid simulator starting at 90% and reduced in decrements of 10% until the unit shuts down.

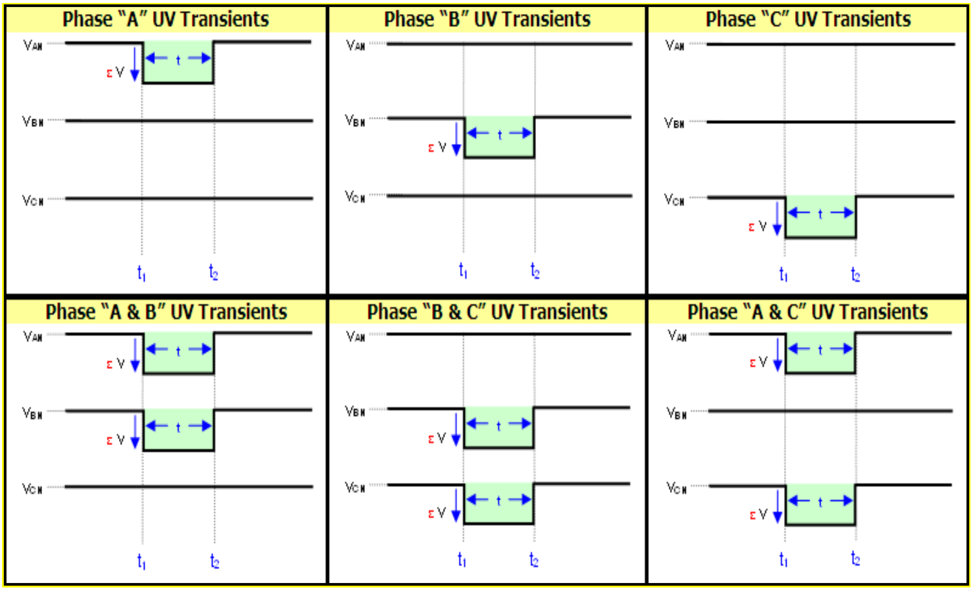

Figure 3.5.1 Unbalanced Under-voltage Test

3.6 **Test#6 –** Unbalanced Over-voltage Test

The purpose of this test is to assess the EUT performance during under-voltage transients and/or sags typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. The grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage transients shown in Figure 3.6.1 below. These voltage sags shall have t cycles of duration time and 1 sec of interval time between voltage changes. These different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, and 130 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

Each of the grid simulator output line-to-neutral voltages shall be increased to the rise voltage (ε V) at t1 and fall back to nominal voltage at t2 in combinations needed. The rise voltage (ε V) level is performed by the grid simulator starting at 100% and increased in increments of 5% until the unit reaches 135%.

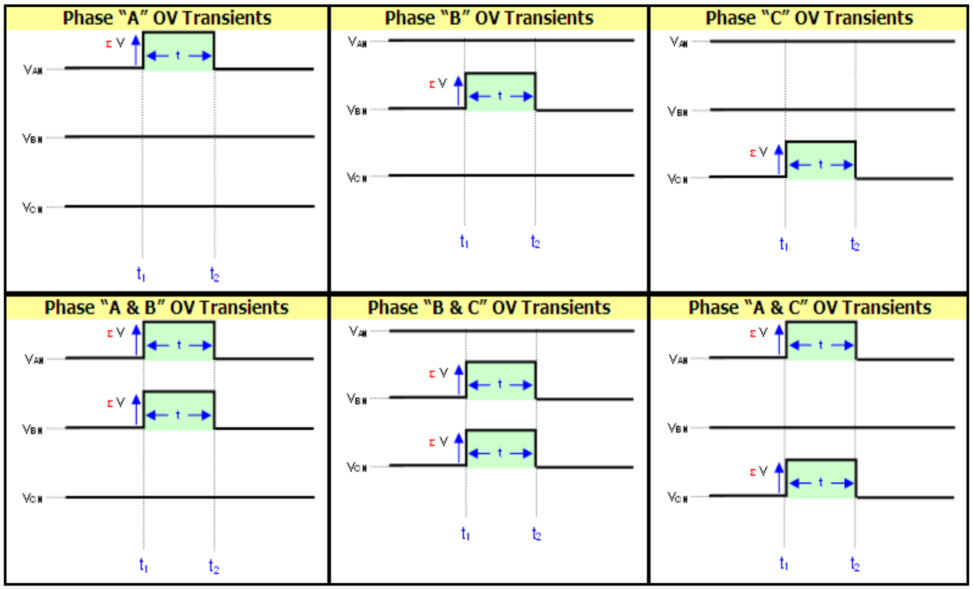

Figure 3.6.1 Unbalanced Over-voltage Test

3.7 **Test#7 –** Voltage Oscillation Test

This test will help understand the behavior of the A/C during voltage oscillations typical in the grid during disturbances. The grid simulator voltage shall be at its nominal voltage (240 V) before starting this test.

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage oscillation shown in Figure 3.7.1 and Table 3.7.1 below. The grid simulator voltage amplitude will be modulated between 100% and 90%, in 1% intervals, at different modulation frequencies (f (swing) = 0.1, 0.25, 0.7, 1, 2 Hz) (Figure 3.7.1 and Table 3.7.1). These different envelope frequencies (f (swing) = 0.1, 0.25, 0.7, 1, 2 Hz) represent the oscillation of the grid. The grid simulator frequency shall remain constant at 60 Hz. Voltage and current data will be collected at a sampling rate of Ψ thousand samples per second for Δ seconds.

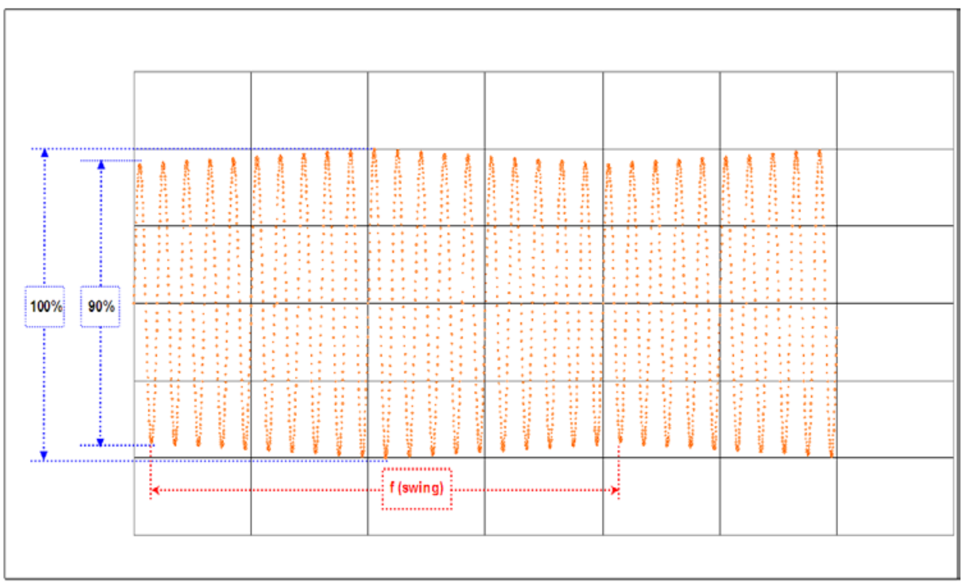

Figure 3.7.1 Voltage Oscillations Test

f (swing)		0.10
t (swing)		10.0
V		**t(V)**
99%	237.6	0.50
98%	235.2	0.50
97%	232.8	0.50
96%	230.4	0.50
95%	228.0	0.50
94%	225.6	0.50
93%	223.2	0.50
92%	220.8	0.50
91%	218.4	0.50
90%	216.0	0.50
91%	218.4	0.50
92%	220.8	0.50
93%	223.2	0.50
94%	225.6	0.50
95%	228.0	0.50
96%	230.4	0.50
97%	232.8	0.50
98%	235.2	0.50
99%	237.6	0.50
100%	240.0	0.50
Total Time		10.00
	Δ =	40
	Ψ =	2.5

f (swing)		0.25
t (swing)		4.0
V		**t(V)**
99%	237.6	0.20
98%	235.2	0.20
97%	232.8	0.20
96%	230.4	0.20
95%	228.0	0.20
94%	225.6	0.20
93%	223.2	0.20
92%	220.8	0.20
91%	218.4	0.20
90%	216.0	0.20
91%	218.4	0.20
92%	220.8	0.20
93%	223.2	0.20
94%	225.6	0.20
95%	228.0	0.20
96%	230.4	0.20
97%	232.8	0.20
98%	235.2	0.20
99%	237.6	0.20
100%	240.0	0.20
Total Time		4.00
	Δ =	20
	Ψ =	5

f (swing)		0.70
t (swing)		1.4
V		**t(V)**
99%	237.6	0.071
98%	235.2	0.071
97%	232.8	0.071
96%	230.4	0.071
95%	228.0	0.071
94%	225.6	0.071
93%	223.2	0.071
92%	220.8	0.071
91%	218.4	0.071
90%	216.0	0.071
91%	218.4	0.071
92%	220.8	0.071
93%	223.2	0.071
94%	225.6	0.071
95%	228.0	0.071
96%	230.4	0.071
97%	232.8	0.071
98%	235.2	0.071
99%	237.6	0.071
100%	240.0	0.071
Total Time		1.43
	Δ =	10
	Ψ =	10

f (swing)		1.00
t (swing)		1.0
V		**t(V)**
99%	237.6	0.050
98%	235.2	0.050
97%	232.8	0.050
96%	230.4	0.050
95%	228.0	0.050
94%	225.6	0.050
93%	223.2	0.050
92%	220.8	0.050
91%	218.4	0.050
90%	216.0	0.050
91%	218.4	0.050
92%	220.8	0.050
93%	223.2	0.050
94%	225.6	0.050
95%	228.0	0.050
96%	230.4	0.050
97%	232.8	0.050
98%	235.2	0.050
99%	237.6	0.050
100%	240.0	0.050
Total Time		1.00
	Δ =	4
	Ψ =	25

f (swing)		2.00
t (swing)		0.5
V		**t(V)**
99%	237.6	0.025
98%	235.2	0.025
97%	232.8	0.025
96%	230.4	0.025
95%	228.0	0.025
94%	225.6	0.025
93%	223.2	0.025
92%	220.8	0.025
91%	218.4	0.025
90%	216.0	0.025
91%	218.4	0.025
92%	220.8	0.025
93%	223.2	0.025
94%	225.6	0.025
95%	228.0	0.025
96%	230.4	0.025
97%	232.8	0.025
98%	235.2	0.025
99%	237.6	0.025
100%	240.0	0.025
Total Time		0.50
	Δ =	4
	Ψ =	25

Table 3.7.1 Voltage Oscillations Test Table

3.8 **Test#8 –** Under-frequency Test

The purpose of this test is to assess the EUT performance during under-frequency transients typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. The grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the frequency transients shown in Figure 3.8.1 below. These voltage sags shall have t cycles of duration time and 1 sec of interval time between voltage changes. These different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, and 130 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

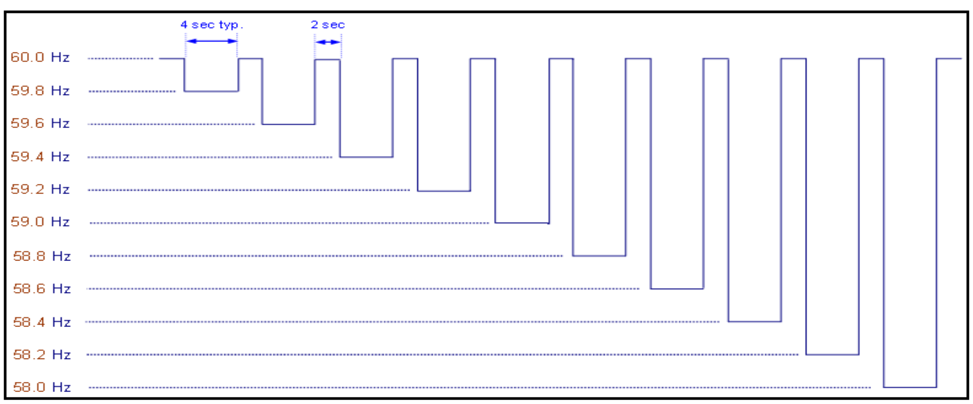

Figure 3.8.1 Under-frequency Transient Test

If this test is unsuccessful, the under-frequency transients will have to be performed individually as shown in Figure 3.8.2.

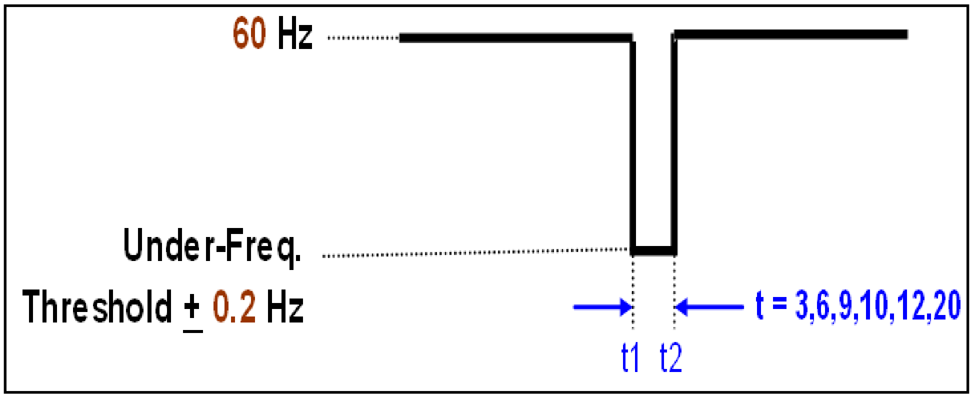

Figure 3.8.2 Under-frequency Transient Test

3.9 **Test#9 –** Over-frequency Test

The purpose of this test is to assess the EUT performance during over-frequency transients typically found in the grid. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. The grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the frequency transients shown in Figure 3.9.1 below. These frequency transients shall have t cycles of duration time and 2sec of interval time between voltage changes. These different sag voltage duration times (t = 1, 3, 6, 9, and 12 cycles) represent switching times for some common circuit breakers. Some additional tests are also performed on the A/C units (t = 10, 110, 120, and 130 cycles). Finally, the test (t=1 cycle) represents a fast transient generated by switching equipment.

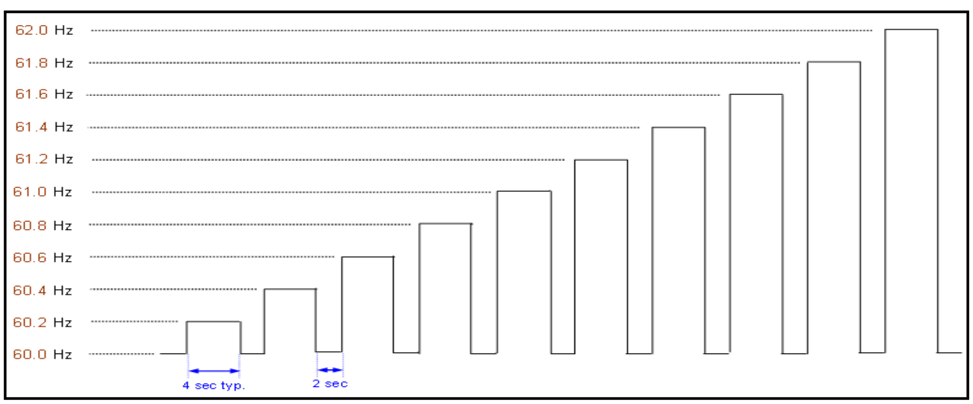

Figure 3.9.1 Over-frequency Transient Test

If this test is unsuccessful, the over-frequency transients will have to be performed individually as shown in Figure 3.9.2.

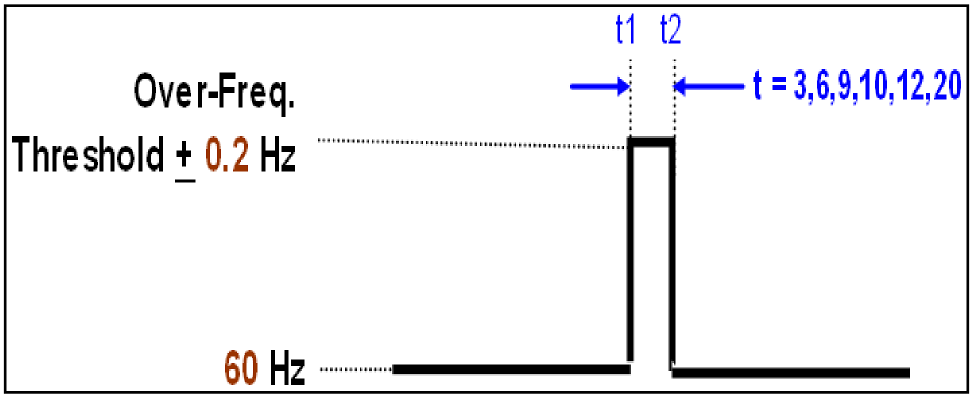

Figure 3.9.2 Over-frequency Transient Test

3.10 **Test#10 –** Frequency Oscillation Test

This test will provide understanding of the A/C's behavior during grid frequency oscillations. The grid simulator voltage shall be at its nominal voltage (240 V) before starting this test. Voltage and current data will be collected at a sampling rate of Ψ thousand samples per second for Δ seconds. These tests shall have a resolution of 100 k samples per test.

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the frequency transients shown in Figure 3.10.1 below. The grid simulator voltage's frequency shall be modulated between 61 Hz and 59 Hz at different envelope frequencies (f (swing) = 0.1, 0.25, 0.7, 1, 2 Hz) (See Figure 3.10.1 and Table 3.10.1). These different envelope frequencies represent the oscillation of the system.

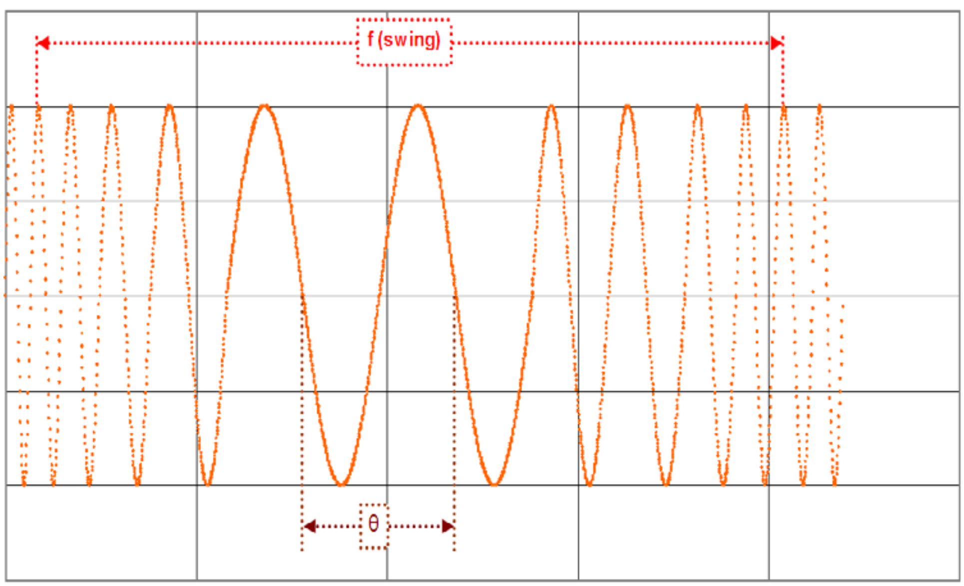

Figure 3.10.1 Frequency Oscillation Test

f (swing)	0.10	f (swing)	0.25	f (swing)	0.70	f (swing)	1.00	f (swing)	2.00
t (swing)	10.0	t (swing)	4.0	t (swing)	1.4	t (swing)	1.0	t (swing)	0.5
θ	t(θ)	θ	t(θ)	θ	t(θ)	θ	t(θ)	θ	t(θ)
61.0 Hz	0.475	61.0 Hz	0.190	61.0 Hz	0.066	61.0 Hz	0.047	61.0 Hz	0.024
60.8 Hz	0.475	60.8 Hz	0.190	60.8 Hz	0.066	60.8 Hz	0.047	60.8 Hz	0.024
60.6 Hz	0.475	60.6 Hz	0.190	60.6 Hz	0.066	60.6 Hz	0.047	60.6 Hz	0.024
60.4 Hz	0.475	60.4 Hz	0.190	60.4 Hz	0.066	60.4 Hz	0.047	60.4 Hz	0.024
60.2 Hz	0.475	60.2 Hz	0.190	60.2 Hz	0.066	60.2 Hz	0.047	60.2 Hz	0.024
60.0 Hz	0.475	60.0 Hz	0.190	60.0 Hz	0.066	60.0 Hz	0.047	60.0 Hz	0.024
59.8 Hz	0.475	59.8 Hz	0.190	59.8 Hz	0.066	59.8 Hz	0.047	59.8 Hz	0.024
59.6 Hz	0.475	59.6 Hz	0.190	59.6 Hz	0.066	59.6 Hz	0.047	59.6 Hz	0.024
59.4 Hz	0.475	59.4 Hz	0.190	59.4 Hz	0.066	59.4 Hz	0.047	59.4 Hz	0.024
59.2 Hz	0.475	59.2 Hz	0.190	59.2 Hz	0.066	59.2 Hz	0.047	59.2 Hz	0.024
59.0 Hz	0.475	59.0 Hz	0.190	59.0 Hz	0.066	59.0 Hz	0.047	59.0 Hz	0.024
59.2 Hz	0.475	59.2 Hz	0.190	59.2 Hz	0.066	59.2 Hz	0.047	59.2 Hz	0.024
59.4 Hz	0.475	59.4 Hz	0.190	59.4 Hz	0.066	59.4 Hz	0.047	59.4 Hz	0.024
59.6 Hz	0.475	59.6 Hz	0.190	59.6 Hz	0.066	59.6 Hz	0.047	59.6 Hz	0.024
59.8 Hz	0.475	59.8 Hz	0.190	59.8 Hz	0.066	59.8 Hz	0.047	59.8 Hz	0.024
60.0 Hz	0.475	60.0 Hz	0.190	60.0 Hz	0.066	60.0 Hz	0.047	60.0 Hz	0.024
60.2 Hz	0.475	60.2 Hz	0.190	60.2 Hz	0.066	60.2 Hz	0.047	60.2 Hz	0.024
60.4 Hz	0.475	60.4 Hz	0.190	60.4 Hz	0.066	60.4 Hz	0.047	60.4 Hz	0.024
60.6 Hz	0.475	60.6 Hz	0.190	60.6 Hz	0.066	60.6 Hz	0.047	60.6 Hz	0.024
60.8 Hz	0.475	60.8 Hz	0.190	60.8 Hz	0.066	60.8 Hz	0.047	60.8 Hz	0.024
61.0 Hz	0.475	61.0 Hz	0.190	61.0 Hz	0.066	61.0 Hz	0.047	61.0 Hz	0.024
Total Time	9.975 sec.	**Total Time**	3.99 sec.	**Total Time**	1.386 sec.	**Total Time**	0.987 sec.	**Total Time**	0.504 sec.
Δ =	40	Δ =	20	Δ =	10	Δ =	4	Δ =	4
Ψ =	2.5	Ψ =	5	Ψ =	10	Ψ =	25	Ψ =	25

Table 3.10.1 Frequency Oscillation Test

3.11 **Test#11 –** Voltage Ramp Test

The purpose of this test is to assess the EUT performance during a dynamic under-voltage condition (voltage ramp down and up).Contactor drop out and pick up points will be determined. This test will help us capture I, P, Q at different voltages. This data will be later used for model development and validation. The EUT and the grid simulator shall be at steady state before starting the test. The grid simulator voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. Grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the voltage ramp shown in Figure 3.11.1 below. This test is to ramp-down and ramp-up the grid simulator output voltage (test bus voltage), in 1, 2, 4, and 8 seconds from 100 percent to 90, 80, 70, 60, and 50 percent voltage. If the EUT stalls during the test, hold the voltage level at the stall level (e.g. 70, 60 or 50) for 1, 2, 4, and 8 seconds before the ramp up begins. This will provide information on how long the thermal overload relay takes to operate, and if the overload has not actuated, this will provide information on reaccelerating a hot motor.

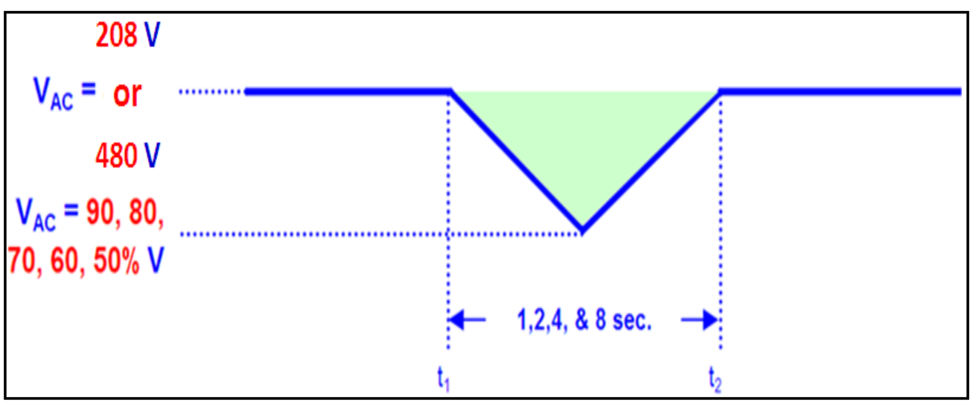

Figure 3.11.1 Voltage Ramp Test

3.12 **Test#12 –** Frequency Ramp Test

The purpose of this test is to assess the EUT performance during a dynamic under-frequency condition (frequency ramp down and up). This test will help us capture I, P, Q at different frequencies. This data will be later used for model development and validation. The EUT and the grid simulator shall be at steady state before starting the test, voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. The voltage and current sinusoidal waveform should be collected at a rate of 10 thousand samples per second for 10 seconds, longer or shorter when needed. Grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be running at steady state

STEP 2: Trigger the grid simulator to playback the frequency ramp shown in Figure 3.12.1 below. This test is to ramp-down and ramp-up the grid simulator output frequency (test bus voltage), in 1, 2, 4, and 8 seconds from 60 Hz to 50 Hz.

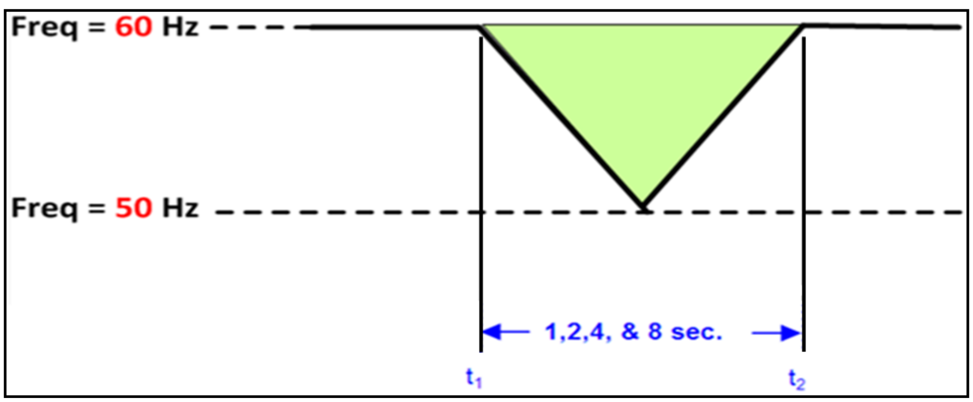

Figure 3.12.1 Frequency Ramp Test

4.0 POWER QUALITY TESTS

These tests will provide the EUT power quality details. In these tests the grid simulator and the residential loads will be connected as shown in Figure 2.1.1. Voltage and current data will be collected at a sampling rate of 100,000 samples per second within the test period or faster when needed.

4.1 **Test#13 –** Harmonics

The purpose of this test is to assess the EUT harmonics generation. This data will be later used for model development and validation. The EUT and the grid simulator shall be at steady state when performing this harmonics recording. The voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. The voltage and current sinusoidal waveform should be collected at a rate of 100 thousand samples per second for 10 seconds.

4.2 **Test#14 –** Conservation Voltage Reduction (CVR)

The objective of this test is to assess the A/C performance during conservation voltage reduction. CVR is typically used by utilities to reduce power consumption by its customers. This test will help us capture I, P, Q at different voltages. The EUT and the grid simulator shall be at steady state before starting the test, voltage and frequency shall remain constant at rated voltage (240 V) and 60 Hz respectively. Data should be collected at a voltage and current sampling rate of 1 thousand samples per second for the time needed. Grid simulator switching states shall be done as quickly as possible (0.2 ms grid simulator switching time is used in these tests).

This test should be performed in the following manner:

STEP 1: EUT should be warmed up and running at steady state

STEP 2: Trigger the grid simulator to playback the voltage steps of 5 seconds as shown in Figure 4.2.1 below. Perform an additional test of 5 minutes at each level to assess the A/C performance in particular, its cooling performance during longer type of events. This test is to step-down (from 100% to 90%) and step-up (90% to 105%) the system voltage (test bus voltage).

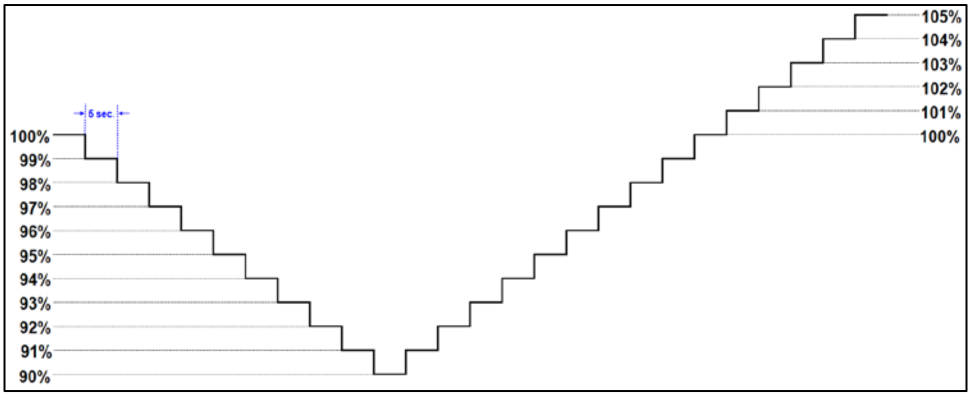

Figure 4.2.1 CVR Test

APPENDIX

Logging Sample Laboratory Notebook Sheet

Inverter #201 SMA – SMC 7000HV

Date	Time	Test #	Proc. #	Record Duration	# of Samples	File name	Comments
3/8/13	2:00	1	DC2	5 sec	100K	1P_I201_T1_DC off	DC OVP triggered
3/8/13	2:23	2	DC1	300 sec	600K	1P_I201_T2_DC on	
3/8/13	2:31	3	DC3	600 sec	600K	1P_I201_T3_Irradiance Profile	Cloudy day at 100x speed
3/8/13	2:45	4	AC1	300 sec	600K	1P_I201_T4_Output Delay	
3/8/13	3:01	5	AC2	5 sec	100K	1P_I201_T5_Island_0%_Load	Inv Load = 0KW (1.41 pu TOV
3/8/13	3:12	6	AC2	5 sec	100K	1P_I201_T6_Island_0%_Load	Inv Load = 0KW (1.43 pu TOV)
3/8/13	3:18	7	AC2	5 sec	100K	1P_I201_T7_Island_0%_Load	Inv Load = 0KW (1.45 pu TOV)
3/8/13	3:27	8	AC2	5 sec	100K	1P_I201_T8_Island_0%_Load	Inv Load = 0KW (1.44 pu TOV)
3/11/13	10:55	9	AC2	5 sec	100K	1P_I201_T9_Island_20%_Load	Inv Load = 1.4 KW (1.32 pu TO
3/11/13	11:07	10	AC2	5 sec	100K	1P_I201_T10_Island_20%_Load	Inv Load = 1.4 kW (1.33 pu TO
3/11/13	11:12	11	AC2	5 sec	100K	1P_I201_T11_Island_20%_Load	Inv Load = 1.4 kW (1.31 pu TO
3/11/13	11:17	12	AC2	5 sec	100K	1P_I201_T12_Island_50%_Load	Inv Load = 3.47 kW (1.22 pu TO
3/11/13	11:21	13	AC2	5 sec	100K	1P_I201_T13_Island_50%_Load	Inv Load = 3.47 kW (1.22 pu T
3/11/13	11:24	14	AC2	5 sec	100K	1P_I201_T14_Island_50%_Load	Inv Load = 3.47 kW (1.21 pu T
3/11/13	11:29	15	AC2	5 sec	100K	1P_I201_T15_Island_79%_Load	Inv Load = 5.55 kW (1.16 pu T
3/11/13	11:32	16	AC2	5 sec	100K	1P_I201_T16_Island_79%_Load	Inv Load = 5.55 kW (1.15 pu
3/11/13	11:36	17	AC2	5 sec	100K	1P_I201_T17_Island_79%_Load	Inv Load = 5.55 kW (1.14 pu
3/11/13	11:40	18	AC2	5 sec	100K	1P_I201_T18_Island_98%_Load	Inv Load = 6.89 kW (1.03 pu
3/11/13	11:44	19	AC2	5 sec	100K	1P_I201_T19_Island_98%_Load	Inv Load = 6.89 kW (1.02 pu
3/11/13	11:48	20	AC2	5 sec	100K	1P_I201_T20_Island_98%_Load	Inv Load = 6.89 kW (1.02 pu
3/11/13	11:52	21	AC3	50 sec	1M	1P_I201_T21_Under Voltage_130 cyc	Inv trips @ 80% in 9cyc
3/11/13	11:59	22	AC3	50 sec	1M	1P_I201_T22_Under Voltage_9cyc	Inv trips @ 80% in 9cyc
3/11/13	12:03	23	AC3	50 sec	1M	1P_I201_T23_Under Voltage_8cyc	Inv trips @ 60% in 1cyc
3/11/13	12:09	24	AC3	50 sec	1M	1P_I201_T24_Under Voltage_7cyc	Inv trips @ 50% in 1cyc
			AC3	50	1M	1P_I201_T25_Under Voltage_6cyc	Inv trips @ 40% in 1cyc