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Test Protocols for Advanced Inverter Interoperability Functions – Appendices

Jay Johnson, Sigifredo Gonzalez, Mark E. Ralph, Abraham Ellis, and Robert Broderick

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Test Protocols for Advanced Inverter Interoperability Functions - Appendices

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Distributed energy resources (DER) such as photovoltaic (PV) systems, when deployed in a large scale, are capable of influencing significantly the operation of power systems. Looking to the future, stakeholders are working on standards to make it possible to manage the potentially complex interactions between DER and the power system.

In 2009, the Electric Power Research Institute (EPRI), Sandia National Laboratories (SNL) with the U.S. Department of Energy (DOE), and the Solar Electric Power Association (SEPA) initiated a large industry collaborative to identify and standardize definitions for a set of DER grid support functions. While the initial effort concentrated on grid-tied PV inverters and energy storage systems, the concepts have applicability to all DER. A partial product of this on-going effort is a reference definitions document (IEC TR 61850-90-7, Object models for power converters in distributed energy resources (DER) systems) that has become a basis for expansion of related International Electrotechnical Commission (IEC) standards, and is supported by US National Institute of Standards and Technology (NIST) Smart Grid Interoperability Panel (SGIP). Some industry-led organizations advancing communications protocols have also embraced this work.

As standards continue to evolve, it is necessary to develop test protocols to independently verify that the inverters are properly executing the advanced functions. Interoperability is assured by establishing common definitions for the functions and a method to test compliance with operational requirements. This document describes test protocols developed by SNL to evaluate the electrical performance and operational capabilities of PV inverters and energy storage, as described in IEC TR 61850-90-7. While many of these functions are not now required by existing grid codes or may not be widely available commercially, the industry is rapidly moving in that direction. Interoperability issues are already apparent as some of these inverter capabilities are being incorporated in large demonstration and commercial projects. The test protocols are intended to be used to verify acceptable performance of inverters within the standard framework described in IEC TR 61850-90-7. These test protocols, as they are refined and validated over time, can become precursors for future certification test procedures for DER advanced grid support functions.

ACKNOWLEDGEMENTS

Sandia National Laboratories acknowledges the support of the U.S. Department of Energy Solar Energy Program that sponsored the development of this protocol and of the Electric Power Research Institute, who is leading the related effort to develop definitions for utility-based functions for advanced inverters and Distributed Energy Resource controls. SNL also acknowledges SRA International for their valuable technical review and content contributions.

CONTENTS

ACRONYMS

AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
DER	Distributed Energy Resources
DMS	Distribution Management System
DOE	Department of Energy
ECP	Electrical Coupling Point
EMS	Emergency Management System
EPRI	Electric Power Research Institute
EPS	Electric Power System (electric utilities or their surrogates)
EUT	Equipment Under Test
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
NEC	National Electrical Code
NFPA	National Fire Protection Association
NIST	National Institute for Standards and Technology
NTP	Network Time Protocol
PV	Photovoltaic
RLC	Resistive/Inductive/Capacitive
SEP	Smart Energy Profile
SEPA	Solar Electric Power Association
SGIP	Smart Grid Interoperability Panel
SOC	State Of Charge
SNL	Sandia National Laboratories
SNTP	Simple Network Time Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
UL	Underwriters Laboratories

Appendix 1 – INV1 Connect/Disconnect

Version 1.0 19 OCT 2012 – Original Version
Version 2.0 8 MAY 2013 – Revisions
Version 3.0 1 AUG 2013 – Minor Revisions
Version 3.1 12 NOV 2013 – Revised Test Matrix

Function INV1 – Connect/Disconnect

This function causes the EUT to electrically connect or disconnect from the grid in response to a command from the utility controller or a combination of local conditions, modes, schedules, etc. Inverters may connect or disconnect using mechanical contactors for electrical isolation from the grid or by using electronic relays or switches. Therefore, it is possible for a DER inverter output current to be zero, but the DER inverter could still be "synchronized" to the grid. For anti-islanding or protection, physical disconnection from the grid could be required, but for the functions covered in this test protocol, it is sufficient if the inverter is not supplying power to the grid. Therefore, for the functions of this test protocol document, the inverter current can be monitored to determine the connection status.

A1.1 Parameters and Function Capability Table (FCT)

Connect/Disconnect is a required parameter.

Time window is an optional parameter in which the command is executed after a delay. The delay will be a random time uniformly distributed between zero and the time window.

If the time window is zero, the command should execute immediately.

If not included, then the default time window for this function will be used. The default time window is chosen by the EUT manufacturer.

Timeout period is an optional parameter that defines the time after which the EUT will revert to its default status (reconnect or stay connected).

If not included, then the default timeout period for this function will be used.

The INV1 function will be tested according to the protocol in this Appendix. The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

Optional Capability	Yes/No?	Action
Time window	No	-
	Yes	Additional tests using procedures in Appendix 17
Timeout period	No	-
	Yes	Additional tests using procedures in Appendix 19

Table A1- 1. INV1 Function Capability Table

A1.2 Test Precursors

The default value of the EUT is to connect when powered up.

To test *disconnect*, the EUT is connected to the Utility or Utility Simulator with operation within normal voltage range for a minimum of 5 minutes.

To test *connect*, the EUT is first given the *disconnect* command and executes it. The EUT remains physically but not electrically connected to the Utility or Utility Simulator for a minimum of 3 minutes (but not longer than the *timeout period*).

The EUT is connected to PV or PV simulator, with sufficient power available to operate the EUT above 50% of rated power.

Communication is established between the Utility Management System (UMS) Simulator and the EUT.
Default parameters have been set in the EUT.
The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A1.3 INV1 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	1	Request Status to EUT.	**DS93** (Status Reporting) & Direct Measurement (**DM**) of inverter output	Log time sent.
	2	UMS receives response to the DS93.command.		Log time received.
	3	Inverter output is measured and logged		Direct Measurement sensors record inverter output
	4	UMS issues a Disconnect /Connect Command to EUT.	**INV1** – Connect/ Disconnect	Log time sent. Command may include the following parameters: time window (optional) timeout period (optional) ramp rate (optional)
	4	EUT responds to the command.	**DS92 –** change in status is noted	Expected response message from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Electrical Behavior	5	Verify command was successfully executed (DS92 and DM).	**DM –** EUT output is recorded & logged	Monitor electrical output of EUT to determine if EUT connects/ disconnects and at what time. Measure voltage, current, power factor Record time
	6	Repeat test with varying parameters (see Table A1-3). Each test should be repeated at least once as needed.	–	
Analysis	7	Characterize EUT's response.	**DS92; DM**	Determine how command was executed.

Table A1- 2. INV1 Test Protocol Sequence.

Steps 1 – 6 of Table A1-2 show the sequence for testing the INV1 command. Table A1-3 displays an example set of parameters which could be used for testing. If an inverter does not have a particular capability (e.g., cannot change timeout period), then the tests for that column will not be required. During the tests, the following are performed:

- Validate that the EUT will not change state when disconnected and sent a disconnect command, and when connected and sent a connect command.
- Validate that the EUT will not respond to commands that are not addressed to the EUT specifically by repeating the steps with an address different from the EUT's.

- Validate that the EUT will respond to the Broadcast Address (UMS should not receive responses to the command).

Test Number	EUT Initial Operating State	Connect/Disconnect Command	Time Window (seconds)	Timeout Period (seconds)
Test 1	>50% rated power, unity power factor	Disconnect 1	Default (e.g., 0)	Default (e.g., 0)
Test 2	Inverter off	Connect 1	Default (e.g., 0)	Default (e.g., 0)
Test 3	>50% rated power, unity power factor	Disconnect 2	0	Default (e.g., 0)
Test 4	Inverter off	Connect 2	0	Default (e.g., 0)
Test 5	>50% rated power, unity power factor	Disconnect 3	90 seconds	30
Test 6	>50% rated power, unity power factor	Disconnect 4	60 seconds	0 (No Timeout)
Test 7	Inverter off	Connect 4	60 seconds	0 (No Timeout)

Table A1- 3. Possible Test Matrix for INV1.

A1.4 Expected Results

Disconnect Command – after the specified or default time window, direct measured (DM) EUT output current is zero.

Reconnect Command – after the specified or default timeout period, the EUT will reconnect (there may be a delay as EUT determines PV input is above minimum).

Determine if the EUT complies with all options, with immediate disconnect, reconnect delay, or if it reconnects after timeout period. It is assumed that the default timeout period is on the order of 5 minutes.

Determine if the EUT accepts/acts on optional parameters (ramp rate and time delay).

Appendix 2 – INV2 Adjust Maximum Generation Level Up/Down

Version 1.0 19 OCT 2012 – Original Version
Version 2.0 8 MAY 2013 – Revisions
Version 2.1 7 June 2013 – Correct PV output
Version 2.2 17 JUL 2013 – Minor Edits
Version 3.0 1 AUG 2013 – Minor Revisions
Version 3.1 28 OCT 2013 – Minor Revisions
Version 3.2 12 NOV 2013 – Updated Test Matrix

Function INV2 – Adjust Maximum Generation Level Up/Down

This function sets the maximum generation level as a percentage of nameplate capacity in response to a command from the utility controller or a combination of local conditions, modes, schedules, etc. A ramp rate and a time window within which to randomly start will also be included. A timeout period is included for reverting to the default state of the EUT.

A2.1 Parameters and FCT

Maximum Active Power (Wmax) is a required parameter in percent of active power capacity rating. The power that could be generated in excess of the maximum requested power level may be limited by the EUT, or it may be used to charge an energy storage device[1].

Requested ramp time is an optional parameter defining the time the EUT must move from the current set point to the new set point.

If not included, then the default ramp time for this function will be used.

Time window is an optional parameter in which the command is executed after a delay. The delay will be a random time uniformly distributed between zero and the time window.

If the time window is zero, the command should execute immediately.

If not included, then the default time window for this function will be used. The default time window is chosen by the EUT manufacturer.

Timeout period is an optional parameter that defines the time after which the EUT will reset the maximum power set point to the default value.

If not included, then the default time window for this function will be used.

The INV2 function will be tested according to the protocol in this Appendix. The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

Optional Capability	Yes/No?	Action
Time window	No	-
	Yes	Additional tests using procedures in Appendix 17
Ramp Rate	No	-
	Yes	Additional tests using procedures in Appendix 18
Timeout period	No	
	Yes	Additional tests using procedures in Appendix 19

Table A2- 1. INV2 Function Capability Table

A2.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within normal voltage range for a minimum of 5 minutes.

[1] IEC TR 61850-90-7.

The EUT is connected to PV or PV simulator, with power available to (20%) EUT rated power output.
Communication is established between the Utility Management System (UMS) Simulator and the EUT.
Default timing and ramping parameters have been set/noted in the EUT.
Maximum watts, maximum vars, reference voltage, and other ratings have been set/noted.
The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A2.3 INV2 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	**1**	Request status.	**DS93** (Status Reporting) & Direct Measurement (**DM**) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received. If EUT is online, continue with command.
	3	Inverter output is measured and logged		
	4	Issue Adjust Max Generation Level.	**INV2** – Adjust Max Generation Level Up/Down	Log time sent. Command to include at least three power levels: 100% rated 50% rated 25% rated Command may include: ramp rate (optional) time window (optional) timeout period (optional)
	5	EUT responds to the command.	**DS92** – change in status is noted	Log time received. Expected response from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Electrical Behavior	**6**	Verify command was successfully executed. (DS92 and DM). Conduct the test while varying input PV power according to Table A2-3 and Figure A2- 1.	**DM** – EUT output is recorded & logged	Monitor output power level to determine if output is adjusted correctly. Measure power and power factor Determine ramp rate of response Record time For three-phase EUTs observe all three phases.
	7	Repeat test while varying optional parameters, varying input PV power according to Table A2-3 and Figure A2-1. Each test should be repeated until behavior of the inverter is reasonably understood.	–	

Analysis	8	Characterize EUT's response.	**DS92; DM**	Determine how command was executed. Verify compliance with time window, ramp rate, time delay, as appropriate

Table A2- 2. INV2 Test Protocol Sequence.

In order to fully evaluate the INV2 function at various EUT output states, it is recommended that the input power level be varied. For a PV inverter, for example, a PV simulator could be used to vary the available PV power input to the EUT according to Table A2-3 and Figure A2- 1, or similar. After 6 minutes (360 seconds) the output power level will repeat the cycle.

Time (seconds)	Power Level (% rating)
0	20
15	20
95	100
130	100
134	20
154	20
156	60
191	60
193	20
213	20
217.5	110
253	110
353	20
360	20

Table A2-3. PV Power Available

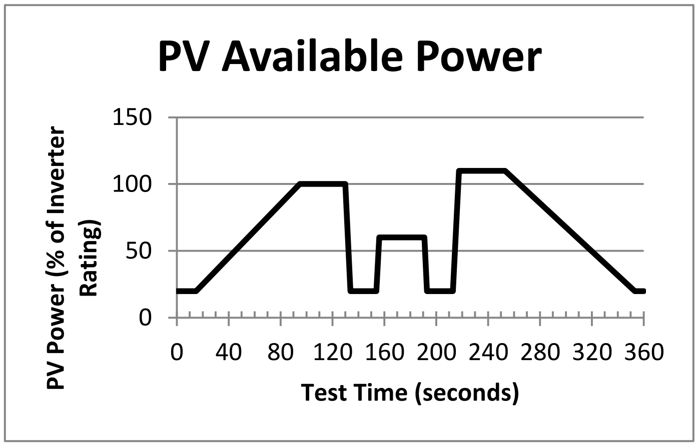


Figure A2- 1. Input PV Power Curve.

Table A2-4 suggests possible combinations of parameters to be tested. Performing all possible combinations may not be feasible. If an inverter does not have a particular capability (e.g., cannot change ramp rate), then the values for that column will be eliminated. The option of using available inverter output greater than zero to charge storage is provided for in IEC TR 61850-90-7 Section 3.1.3.

Test Number	*WMax* (% nameplate)	Ramp Rate (% nameplate watts/sec)	Time Delay (sec)	Timeout Period (sec)	Input PV Power Curve
Test 1	25	Default	0 (immediate)	Default (e.g., 0)	Figure A2- 1
Test 2	90	Default	300	Default (e.g., 0)	Figure A2- 1
Test 3	50	20	60	30	Figure A2- 1
Test 4	100 (default)	Default	0	Default (e.g., 0)	Figure A2- 1
Test 5	0	2	0	0 (No Timeout)	Constant at 100%
Test 6	100	2	0	0 (No Timeout)	Constant at 100%

Table A2-4. Test Matrix for INV2.

A2.4 Expected Results

The maximum output power is limited according to the WMax set point or less if the input power available to the EUT is less than the set point sent by the command. It is expected that as the input power is varied according to Figure A2-1, the maximum real output power of the EUT will be curtailed to WMax or less (if the PV input results in EUT output power < WMax).

When the time window is not specified, the default time window is used. When it is specified to be greater than zero, the EUT should react randomly within the time window. This variance in start time is desired to stagger the operation of multiple inverters. Observe and document the variations in response time according to the procedure in Appendix 17.

The INV2 command may be received when the PV input is not at steady state (Figure A2- 1). This is a normal condition, as in the field the PV output is not expected to be constant for long periods. For the test of the INV2 function, the output of the EUT should be examined to ensure it is appropriate for the changing levels of PV input to the EUT.

Tests 5 and 6 are methods of shutting down and restarting (or turning on) the EUT using a ramp rate. This functionality is not included in the INV1 function. For these tests, the power is maintained at a constant 100% to verify the ramp rate is accurately followed.

The analysis of the EUT should include a determination of whether the EUT complies with immediate reduced power operation, return to max power operation after time period, and if the EUT accepts/acts on optional parameters.

Appendix 3 – INV3 Adjust Power Factor

Version 1.0 19 OCT 2012 – Original Version
Version 2.0 8 MAY 2013 – Revisions
Version 2.1 7 June 2013 – Correct PV output & test matrix
Version 2.2 17 July 2013 – Revised PF parameter and test matrix
Version 3.0 28 OCT 2013 – Minor Revisions

Function INV3– Adjust Power Factor

This function sets the power factor (i.e., Displacement Factor) angle in response to a command from the utility controller or a combination of local conditions, modes, schedules, etc. A ramp rate and a delay time before starting may also be included. A timeout period may be included for reverting to the default state of the EUT. Possible values for acceptable power factor ranges may be -0.5 to 0.5 or -0.8 to 0.8. It should be kept in mind that at low power levels, power factor is undefined. The manufacturer should be consulted about the expected response to a power factor command under low power output conditions.

A3.1 Parameters and FCT

Requested power factor is a required parameter defining the desired operating power factor set point. The power factor set point includes three elements:

1. signed power factor value
2. PFExt identification of "overexcited" or "underexcited"
3. PFsign convention indicator (EEI or IEC), which may be set to default or nameplate for the tests.

Requested ramp time is an optional parameter defining the time the EUT must move from the current set point to the new set point.

If not included, then the default ramp time for this function will be used.

Time window is an optional parameter in which the command can be randomly executed.

If the time window is zero, the command will execute immediately.
If not included, then the default time window for this function will be used.

Timeout period is an optional parameter that defines the time after which the EUT will reset the power factor set point to the default value.

If not included, then the default timeout period for this function will be used. The default timeout period is expected to be around 5 minutes.

The INV3 function will be tested according to the protocol in this Appendix. The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

Optional Capability	Yes/No?	Action
Time window	No	-
	Yes	Additional tests using procedures in Appendix 17
Ramp Rate	No	-
	Yes	Additional tests using procedures in Appendix 18
Timeout period	No	
	Yes	Additional tests using procedures in Appendix 19

Table A3-1. INV3 Function Capability Table

A3.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage range for a minimum of 1 minute. The Utility or Simulator shall be capable of operating with the EUT sourcing and consuming vars.

The EUT is connected to a PV simulator, with sufficient power available to deliver full EUT rated power output.

Communication is established between the Utility Management System (UMS) simulator and the EUT.

Default timing and ramping parameters have been set in the EUT

Maximum watts, maximum vars, reference voltage, PF sign convention, and other ratings have been set

The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A3.3 INV3 Test Protocol Sequence

	Step	Task	Function	Notes
	1	UMS requests status.	**DS93** (Status Reporting) & **DM** (direct Measurement) of EUT output	Log time sent.
	2	UMS receives response to DS93 command		Log time received
	3	Inverter EUT output is measured and logged		
Communication	**4**	Issue Adjust Power Factor Command.	**INV3** – Adjust Power Factor	Log time sent. Commands include the power factor along with: requested ramp rate (optional) time window (optional) timeout period (optional)
Communication	**5**	EUT responds to command.	**DS92** – change in status noted	Log time received. Expected response from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Behavior	**6**	Verify command was successfully executed. (DS92 and DM). Conduct the test while varying input PV power according to Table A3-3, Figure A3-1.	–	Monitor output power factor level to determine if output is adjusted correctly. Measure power and power factor Determine ramp rate of response Record time For three-phase EUTs observe all three phases.
Behavior	**7**	Repeat test with optional parameters (Table A3-4). Each test should be repeated until behavior of the inverter is reasonably understood.	–	

Analysis	8	Characterize EUT's response.	**DS92; DM**	Determine how command was executed. Verify compliance with time window, ramp rate, time delay, as appropriate

Table A3- 2. INV3 Test Protocol Sequence.

In order to fully evaluate the INV3 function at various DER output states, it is recommended that the input power level be varied. For a PV inverter, for example, a PV simulator could be used to vary the available PV power according to Table A2-3 and Figure A2- 1, or similar. After 6 minutes (360 seconds) the output power level can be repeated.

Time (seconds)	Power Level (% rating)
0	20
15	20
95	100
130	100
134	20
154	20
156	60
191	60
193	20
213	20
217.5	110
253	110
353	20
360	20

Table A3- 3. PV Power Available

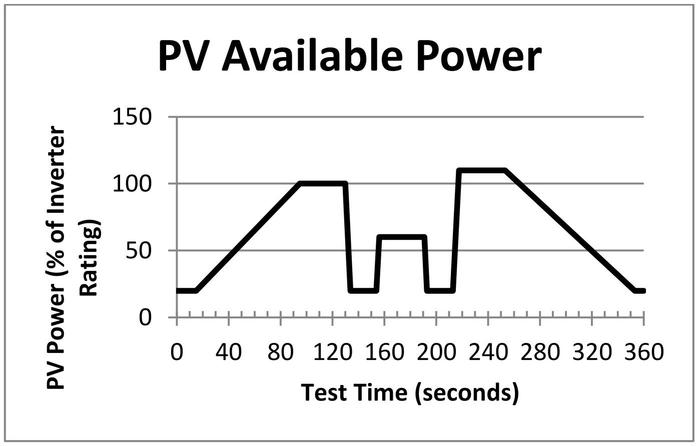


Figure A3- 2. Input PV Power Curve.

Table A3- 4 suggests possible combinations of optional parameters to be tested. Performing all possible combinations may not be feasible. If an inverter does not have a particular capability (e.g., cannot change ramp rate), then the tests for that column will be eliminated.

Power Factor (INV3)	**Ramp Rate** (% nameplate watts/sec)	**Time Window** (seconds)	**Timeout Period** (seconds)
1.00 (default)	Default	0 sec	Default
MinPFOverAval (e.g., 0.80 Overexcited)	Default	60	600
MinPFUnderAvail (e.g., 0.80 Underexcited)	Default	300	Default
0.5 + MinPFOverAval/2 (e.g., 0.90 Overexcited)	10	Default	Default
0.5 + MinPFUnderAvail/2 (e.g., 0.90 Underexcited)	Default	Default	1800

Table A3- 4. Test Matrix for INV3.

A3.4 Expected Results

The fixed power factor is adjusted proportionally to the power factor angle issued if there is adequate inverter capacity to supply both PV watts available and vars.

If the EUT is operating at rated power, the EUT may not have the capacity to generate or absorb vars while prioritizing active power production. Observe and record the behavior of the EUT under these conditions.

When the time window is not specified, the default time window is used. When it is specified to be greater than zero, the EUT should react randomly within the time window. This deviation is desirable to stagger the operation of multiple inverters. Observe and document the variations in response time. See Test protocol for Time Window in Appendix 17.

The INV3 command may be received when the PV input is not at steady state (Figure A3-1). This is a normal condition, as in the field the PV output is not expected to be constant for long periods. For the test of the INV3 function, the output power factor of the inverter should be examined to ensure it is appropriate for the changing levels of PV input.

Appendix 4 – INV4 Request Active Power from Storage

Version 1.0 19 OCT 2012 – Original Version
Version 2.0 8 MAY 2013 – Revisions
Version 2.1 1 AUG 2013 – Minor Revisions

Function INV4 – Request Active Power from Storage

This function, in combination with the battery charge level, can be used to achieve desired daily charge/discharge behaviors. The command requests the energy storage system to either charge or discharge a percentage of the storage system. The ramp rates will be the minimum of the INV4 *ramp rate* and the ramp rates limits of the inverter and storage system. An energy storage simulator may be used in the test to reduce the time needed for the test by reducing charge and/or discharge times. It should be noted that charge/discharge requests are always subject to the state of charge, temperature, ramp rate limits, and other conditions of the battery. Therefore, the INV4 function should be executed only to the extent that the request is feasible, as determined by the local energy storage control system.

A4.1 Parameters and FCT

Requested ramp time is an optional parameter defining the time the EUT must move from the current set point to the new set point.

If not included, then the default ramp time for this function will be used.

Time window is an optional parameter in which the command can be randomly executed.

If the time window is zero, the command will execute immediately.
If not included, then the default time window for this function will be used.

Timeout period is an optional parameter that defines the time after which the EUT will revert to the default value.

If not included, then the default timeout period for this function will be used.

Storage charge from grid setting defines whether the storage system can be charged from the grid.

The INV4 function will be tested according to the protocol in this Appendix. The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

Optional Capability	Yes/No?	Action
Time window	No	-
	Yes	Additional tests using procedures in Appendix 17
Timeout period	No	-
	Yes	Additional tests using procedures in Appendix 19

Table A4-1. INV4 Function Capability Table

A4.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage range for a minimum of 5 minutes.
The EUT is powered on to a level required to receive the command.
EUT is connected to an energy storage device or an energy storage simulator.
Energy storage state of charge (SOC) should be at a known state, and the test sequence should be modified accordingly.

- Communication is established between the Utility Management System (UMS) and the EUT.
- Default timing and ramping parameters have been set in the EUT and the energy storage device.
- Set maximum power and other ratings.
- The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A4.3 INV4 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	**1**	UMS requests status.	**DS93 –** Status Reporting	Log time sent. Expected response message: Successful Rejected (include reason)
	2	UMS receives response to the command.		Log time received. If EUT is online, continue with command.
	3	Issue Request Active Power (Charge or Discharge Storage) Command as a % of maximum charging or discharging rates.	**INV4** – Request Active Power	Log time sent. Command may include: ramp rate (optional) time window (optional) timeout period (optional) storage charge from grid setting (yes/no)
	4	Receive response to the command.	–	Log time received. Expected response message: Successful Rejected (include reason)
Electrical Behavior	**5**	Verify command was successfully executed.	–	Monitoring output power level and battery power to determine if output is adjusted correctly.
	6	Repeat test with optional parameters (Table A4-2). Each test should be repeated until behavior of the EUT is reasonably understood.	–	
Analysis	**7**	Characterize EUT's response.	**DS92; DM**	Determine how command was executed.

Table A4-2. INV4 Test Protocol Sequence.

Table A4-3 suggests possible combinations of parameters to be tested. Performing all possible combinations may not be feasible. If an inverter does not have a particular capability, then the tests for that column will be eliminated.

INV4	Ramp Rate (% nameplate watts / sec)	Time Delay (seconds)	Timeout period (seconds)	Storage Management		
				Storage Charge From Grid Setting?	Device is: Fully charged?	Device is: At its minimum charge level?
Charge at MaxWatts	Default	0	Default	NO	NO	NO
Charge at MaxWatts/2	0.75	0	none	YES	NO	NO
Discharge at MaxWatts	0.75	60	Default	YES	NO	NO
Discharge at MaxWatts/2	Default	60	900	YES	NO	YES
Discharge at MaxWatts/4	Default	300	Default	NO	YES	NO

Table A4-3. Test Matrix for INV4.

A4.4 Expected Results

The output power reflects the setting sent to the PV/storage system.

The EUT protects the storage system (does not allow over charging/discharging of battery).

Random start time within the boundaries of the time window shall be tested and verified as described in Appendix 17. If advanced DER commands are used for electric vehicle (EV) charging, a much larger time window, of 3 to 5 hours, might be needed to spread charging over the off-peak period, but such long test times are not practical. For this protocol, the tests described above are sufficient to determine that the time window and timeout functions work properly.

Appendix 5 – INV5 Signal for Charge/Discharge Action

Version 1.0 19 OCT 2012 – Original Version
Version 2.0 8 MAY 2013 – Revisions
Version 3.0 1 AUG 2013 – Revisions including example pricing vs power profile

Function INV5 –Signal for Charge/Discharge Action

This command can be used by the utility/EPS or the customer EMS to issue a pricing or other signal to the EUT system. The energy storage system uses this information to decide on whether to charge or discharge, and at what level to do so, based on algorithms determined by the manufacturer. There are multiple ways this command may be implemented, so testing the behavior may require long timeframes. Because of these factors, the test protocol may only be able to address the communication portions of this command. An energy storage simulator may be used in the test to reduce the time needed by being able to "charge" or "discharge" faster than an actual storage device would be able to. It should be noted that charge/discharge requests are always subject to the state of charge, temperature, ramp rate limits, and other conditions of the battery. Therefore, the INV5 function should be executed only to the extent that the request is feasible, as determined by the local energy storage control system.

A5.1 Parameters and FCT

Storage charge from grid setting defines whether the storage system can be charged/discharged from/to the grid.

To avoid transients caused by simultaneous initiation of charge or discharge actions by many storage devices, a *time window* (Appendix 17) with random time delays before initiating the requested action, will be required, as was done for INV1, INV2, INV3, and INV4. It is also possible that additional optional parameters for adjusting maximum charge/discharge *ramp rate* or *timeout period* of the INV5 command (unless refreshed) may be used. Table A5-1 presents these possible optional Function Capabilities. The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

This appendix presents the protocol both for testing INV5 communications with control initiation (Table A5-2) and for full testing that includes the electrical behavior of the storage device (Table A5-3).

Optional Capability	Yes/No?	Action
Time window	No	-
	Yes	Additional tests using procedures in Appendix 17
Ramp Rate	No	-
	Yes	Additional tests using procedures in Appendix 18
Timeout period	No	
	Yes	Additional tests using procedures in Appendix 19

Table A5- 1. INV2 Function Capability Table

A5.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage and frequency range for a minimum of 5 minutes.

EUT is connected to an energy storage device or an energy storage simulator.

The EUT is powered with sufficient power available to deliver the command.

Energy storage state of charge (SOC) of the energy storage device should be known, and the test sequence should be adjusted accordingly.

Communication is established between the Utility DMS simulator and the EUT.

Default timing and ramping parameters have been set in the EUT

Set maximum watts and other ratings.

The output of the EUT (voltage, current, power factor), the input to the storage device, and the state of charge of the storage device are measured and logged.

If testing only the communications and control logic (Table A5-2), then a contactor or relay (to indicate actions in response to charge/discharge commands) and an energy storage simulator (to provide state of charge) are required.

Pre-set range of pricing signals.

Various charging/discharging responses and rates across the range of pricing signals.

A5.3 INV5 Test Protocol Sequence

Table A5-2 outlines the INV5 test protocol sequence for communications and control testing only, to verify the inverter receives the command and initiates action correctly. Table A5- 3 provides a test protocol sequence for the full INV5 command, including the response of the storage device. This approach allows for the possibility of testing interoperability of the energy storage controller without actually transferring energy to or from the energy storage device.

	Step	Task	Function	Notes
Communication	1	UMS requests status.	**DS93 –** Status Reporting	Log time sent. Expected response message: Successful Rejected (include reason)
	2	UMS receives response to the command.		Log time received.
	3	Issue signal or price signal within pre-set range.	**INV5 –** Provide Signal	Log time sent. Command includes: Signal ramp time (optional) time window (optional) timeout period (optional)
	4	Receive response to the command.	**DS92**	Log time received. Expected response message Successful Rejected (include reason)
	5	Request status for each INV5 parameter.	**DS93 –** Status Reporting	Log time sent. Expected response message: Successful Rejected (include reason)
	6	UMS receives response to the command.		Log time received. Verify each parameter was updated.
Analysis	7	Characterize storage system response.		Determine if command was executed according to pre-set signal responses.

Table A5-2. INV5 Test Protocol Sequence - Communications and Command Initiation Only

	Step	Task	Function	Notes
Communication	**1**	UMS requests status.	**DS93 (**Status Reporting) and **DM** (Direct Measurement) of EUT output	Log time sent. Expected response message: Successful Rejected (include reason)
	2	UMS receives response to the DS93 command.		Log time received.
	3	Issue signal or price signal within pre-set range.	**INV5 –** Provide Signal	Log time sent. Command includes: Signal ramp time (optional) time window (optional) timeout period (optional)
	4	EUT responds to the command.	**DS92** – change in status noted	Log time received. Expected response message Successful Rejected (include reason)
Electrical Behavior	**5**	Verify command was successfully executed.	**DM** – EUT (inverter & storage device) output and storage device input and state of charge are recorded & logged	Monitoring output power level and battery power input, output, state of charge) to determine if output is adjusted correctly.
	6	Repeat test with optional parameters (Table A5-3). Each test should be repeated until behavior of the EUT is reasonably understood.		Test the limits of price (or other) signals which cause the battery to charge and discharge.
Analysis	**7**	Characterize storage system response.	**DS92; DM**	Determine if command was executed according to pre-set signal responses.

Table A5- 3. INV5 Test Protocol Sequence – Full Command Execution Test

The goal of the tests is to determine if the storage system operates according to a programed behavior dependent on a signal, e.g., price signal. One such behavior is shown in Figure A5-1. Here the charge and discharge rates depend on the price of electricity.

Depending on the profile, the test to verify the pricing profile was successfully sent to the DER will change. In the case of a pricing profile shown in Figure A5-1, selecting numerous price signals 0 to greater than $\$_{max\ discharge}$ would be necessary to characterize correct operation of INV5.

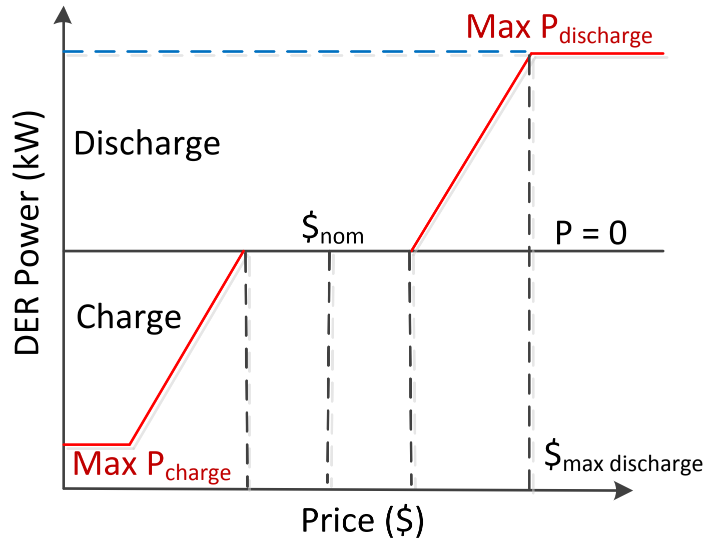


Figure A5-1. Example signal vs battery operation curve.

Table A5- 4 suggests possible combinations of parameters to be tested. Performing all possible combinations may not be feasible. If an inverter does not have a particular capability, then the tests for that column will be eliminated.

INV5	Ramp Rate (% nameplate watts/sec)	Time Delay (seconds)	Timeout period (seconds)
Charge/discharge vs signal profile #1 (e.g., Figure A5-1)	Default	0 (immediate action)	none
Charge/discharge vs signal profile #2 (e.g., Figure A5-1)	0.75	60	900
Charge/discharge vs signal profile #3 (e.g., Figure A5-1)	Default	Default	Default

Table A5- 4. Test Matrix for INV5.

A5.4 Expected Results

If a signal message is defined by the manufacturer, the signal is changed in the energy storage system.

The storage system reacts (charge/discharge) as appropriate to the signal.

The EUT protects the storage system (does not allow over charging/discharging of battery).

Random start time within the boundaries of the time window shall be tested and verified as described in Appendix 17. If advanced DER commands are used for electric vehicle (EV) charging, a much larger time window, of 3 to 5 hours, might be needed to spread charging over the off-peak period, but such long test times are not practical. For this protocol, the tests described above are sufficient to determine that the time window and timeout functions work properly.

Appendix 6 – VV Volt/Var Mode

Version 1.0 3 MAR 2013 – Original Sandia Version
Version 2.0 10 MAY 2013 – Revisions
Version 2.1 5 June 2013 – Revisions to test case parameters
Version 2.2 22 June 2013 – allow VV12 in response to any external parameters
Version 2.3 1 AUG 2013 – Minor Revisions

Function VV – Volt/Var Mode

This function defines how an inverter will provide reactive power (var) support to the grid. There are four possible modes for the EUT:

- Provide a certain percentage of available vars, based on the system voltage (VV11)
- Provide the maximum vars possible during certain conditions, as when system voltage is within specified ranges (VV12). This command could be used during transmission emergencies
- Fixed settings to provide vars as a function of EUT output level; these settings do not vary with system voltage (VV13)
- Provide maximum active power (unity power factor, with no vars). This is the default setting. (VV14)

A6.1 Parameters and FCT

The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. There are 4 possible VV modes (VV11, VV12, VV13, VV14) and 3 optional parameters (random time window to initiate, ramp rate to change output, timeout period for the command). The FCT indicates which tests are specified for each VV mode. If the EUT has the capabilities of acting on any of the optional parameters, then additional tests of those capabilities shall be performed, as indicated in the FCT.

Mode and Optional Parameters	Yes/ No?	Action
VV11 – available var support with no impact on watts (watt priority)		Parameters as specified in A6.1.1; Tests specified in Table A6-4
VV12 – maximum var support without exceeding maximum watts (var priority)		Parameters as specified in A6.1.2; Tests specified in Table A6-5
VV13 – static settings		Parameters as specified in A6.1.3; Tests specified in Table A6-6
VV14 – No vars		Default setting; output returns to unity power factor
Time window (optional parameter)	No	-
	Yes	Additional tests using procedures in Appendix 17; Typical value 60 seconds
Ramp Rate (optional parameter)	No	-
	Yes	Additional tests using procedures in Appendix 18
Timeout period (optional parameter)	No	
	Yes	Additional tests using procedures in Appendix 19

Table A6-1. VV Function Capability Table

A6.1.1 VV11 – vars based on local voltage

VV11 is used to specify how to sink or source reactive power as a function of terminal voltage, in order to support the grid voltage. In this mode, EUT will be provided with a sequence of (voltage, reactive power) pairs that describe the volt/var setpoints. This sequence of points defines a set of voltage levels and their corresponding reactive power levels as a percentage of available reactive power range.

VV11 command has the following parameters:

VV11 initiation command. This is a required parameter.

Array consisting of a series of (V, Q) pairs, e.g., V_1, Q_1, V_2, Q_2,…,V_x, Q_x, that define the volt/var curve. Figure A6-1 shows an example volt/var curve generated from a set of four (V, Q) set points. Optionally, the (V, Q) pairs can also be used to specify hysteresis.

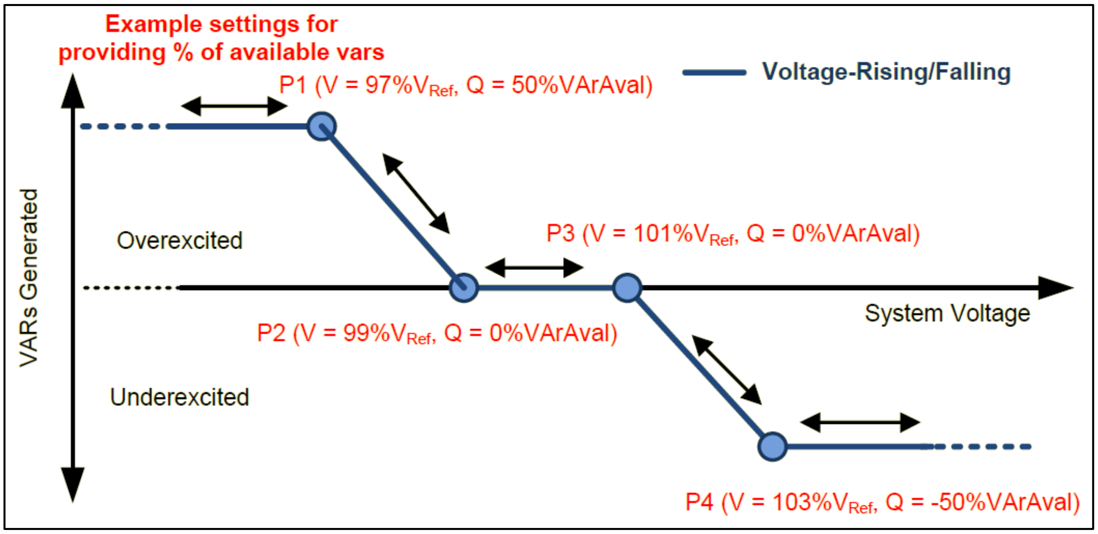


Figure A6-1: Example Volt/Var Array for VV11.

Requested ramp time is an optional parameter, expressed as a percentage of available vars per second, defining the time the EUT is expected to respond.

- If not included, then the default ramp rate for this function coded in the EUT will be used.
- A typical value for this function would be to limit var increase or decrease per second to 10-20% of the total vars available (%VArAval/s).

Time window is an optional parameter specifying the time within which the command is executed. The actual time in which the EUT begins to execute the command will be a random time uniformly distributed between zero and the *Time Window*.

- The VV command changes the parameters under which the EUT responds to local conditions; a VV command does not necessarily result in an immediate change in EUT output. Therefore, a large time window for initiation is usually not needed to prevent simultaneous operation of numerous inverters. A typical value for this function is 60 seconds.
- If the time window is zero, the command will execute immediately.
- If not included, then the default time window for this function coded in the EUT will be used.

Timeout period is an optional parameter that defines the time after which the EUT will revert to its default volt/var operating mode.

- If not included, then the default timeout period for this function coded in the EUT will be used.

A6.1.2 VV12 – maximum var support based on maximum power available from inverter

VV12 is used to command the inverter-based DER systems to provide the maximum vars possible without exceeding the maximum amount of apparent power the inverter can produce at any time. (This is typically used to provide var support to the grid during transmission emergencies.) In this mode, EUT will be provided with a sequence of (voltage, reactive power) pairs that describe the volt/var setpoints. This sequence of points defines a set of voltage levels and their corresponding reactive power levels, generating maximum capacitive vars for low voltages (to the VMin cut-off point). As voltage increases, var generation is decreased.

VV12 command has the following parameters:

VV12 initiation command. This is a required parameter.

In the example below, var support is triggered by low system voltage, where the system voltage still remains above the cut-out voltage (the voltage below which the inverter disconnects). VV12 can initiate maximum var support in response to other external variables, such as during periods of high ambient temperature (with a concomitant high inductive – i.e., reactive power – load) or when the price of kVAr is high.

For VV12 triggered by low system voltage, an array consisting of a series of (V, Q) pairs, e.g., V_1, Q_1, V_2, Q_2,…,V_x, Q_x, that define the volt/var curve. Figure A6-2 shows an example volt/var curve generated from a set of four (V, Q) set points. Optionally, the (V, Q) pairs can also be used to specify hysteresis.

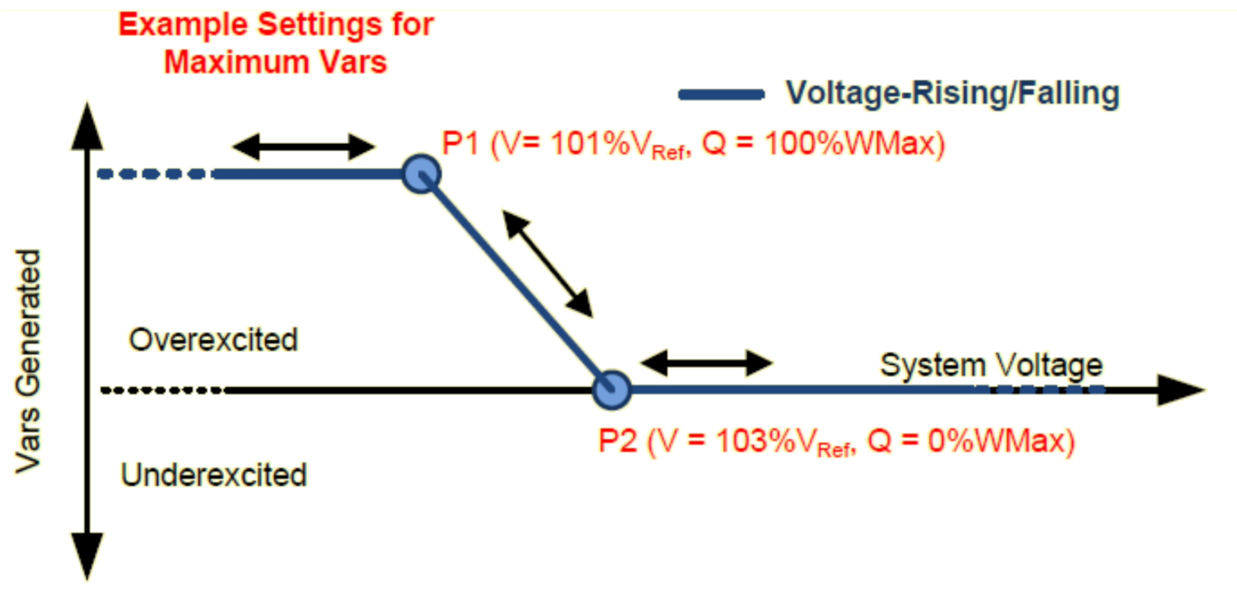


Figure A6-2. Example Volt/Var Array for VV12

Requested ramp time is an optional parameter, expressed as a percentage of available vars per second, defining the time the EUT is expected to respond.

- If not included, then the default ramp rate for this function coded in the EUT will be used.

- A typical value for this function would be to limit var increase or decrease per second to 10-20% of the total vars available (%VArAval/s).

Time window is an optional parameter specifying the time within which the command is executed. The actual time in which the EUT begins to execute the command will be a random time uniformly distributed between zero and the *Time Window*.
- The VV command changes the parameters under which the EUT responds to local conditions; a VV command does not necessarily result in an immediate change in EUT output. Therefore, a large time window for initiation is usually not needed to prevent simultaneous operation of numerous inverters. A typical value for this function is 60 seconds.
- If the time window is zero, the command will execute immediately.
- If not included, then the default time window for this function coded in the EUT will be used.

Timeout period is an optional parameter that defines the time after which the EUT will revert to its default volt/var operating mode.
- If not included, then the default timeout period for this function coded in the EUT will be used.

A6.1.3 VV13 – static inverter settings
VV13 establishes fixed settings for var output of an inverter. Such settings can be based on the maximum available watt or var output of the inverter. It is anticipated that VV13 would be used by a local facility or microgrid DER controller to manage power and var output of several individual inverters under its control, on a minute by minute basis, in order dispatch numerous DER to meet overall grid support objectives of the facility or microgrid. One of the motivations for the VV controls in general is to enable inverters to provide var support to the grid based on local conditions, without the utility/grid management system's having to individually manage thousands of inverters' outputs. However, for a local microgrid controller, managing approximately 10 DER individually is quite feasible.

VV13 command has the following parameters:

VV12 initiation command. This is a required parameter.

The required parameter for VV13 is:
- inverter output as a percentage of available vars (VArAval) (no impact on watt output);
- inverter var output as a percentage of maximum watts (VArWMax) (may affect total watt output);
- or inverter var output as a percentage of maximum vars available (VArMax).

Figure A6-3 shows an example, with the desired var output represented by a straight horizontal line at Q percentage (between + or – 100%) until the regulatory voltage minimum/maximum or the inverter protective limits are reached.

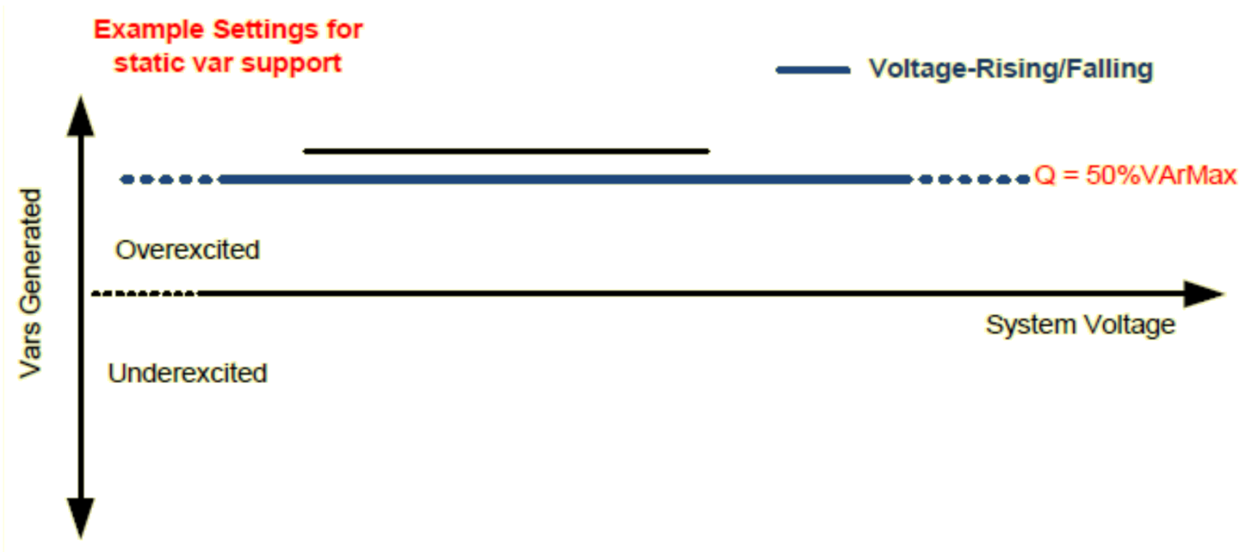


Figure A6-3. Example Volt/Var curve for VV13

A6.1.4 VV14 – Default setting; unity power factor output

VV14 is the default setting of an inverter, where it is in passive mode, providing no vars. An inverter-based DER will revert to this setting upon power up, if there are no schedules or curves that trigger another VV mode (VV11, VV12, or VV13), or when another VV command expires.

A6.2 Test Precursors

The EUT is connected to the Utility Simulator operating within nominal voltage range and under the EUT's default volt/var mode.

The EUT is connected to a PV simulator, with sufficient power available to deliver full EUT rated power output so that volt/var behavior at full or partial power can be observed.

Communications is established between the Utility Management System simulator and the EUT.

Default timing and ramping parameters have been set/noted in the EUT.

Maximum watts, maximum vars, reference voltage, and other ratings have been set/noted.

The EUT is allowed to stabilize (e.g., find the maximum power point).

The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A6.3 VV Test Protocol Sequence

Table A6-2 outlines the VV test protocol sequence to verify the inverter receives the command and initiates action correctly.

	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93 (**Status Reporting) & **DM** (Direct Measurement) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	Inverter output is measured and logged	**DM**	

	Step	Task	Function	Notes
	4	UMS issues a Volt/Var (VV) Command to EUT.	**VV** – Volt/Var command issued	Log time sent. Command may include the following optional parameters: Requested ramp rate time window timeout period
	5	EUT responds to the command.	**DS92** – change in status is noted	Expected response message: Successful (DS92 status change) Rejected (includes reason)
Electrical Behavior	6	Verify command was successfully executed by varying the voltage profile using the grid simulator and output values of the PV simulator specified in: • Figure A6-4 for VV11 • Table A6-5 for VV12 • Table A6-6 for VV13 • Unity power factor output for VV14		Monitor and record electrical output of EUT. • Voltage • Active power • Reactive power
	7	Repeat test with varying parameters as described in: • Table A6-4 for VV11 • Table A6-5 for VV12 • Table A6-6 for VV13 Each test should be repeated until behavior of the EUT is reasonably understood. Test the time out period by rerunning the test profile in Table A6-3.	–	
Analysis	8	Characterize EUT response.		Determine if command was executed correctly.

Table A6-2. VV Test Protocol Sequence.

The VV test procedure in Table A6-2 uses the voltage settings of Figure A9-4 and one of the sets of parameters in Table A6-4, A6-5, or A6-6, as appropriate for the VV mode being tested.

In order to test the VV functions Steps 1 – 6 are repeated for each set of parameters on Table A6-4, A6-5, or A6-6.

Step 1: Request status from EUT (DS93)
Steps 2 - 3: Receive confirmation of status and log results
Step 4: Send VV Command.
Step 5: Wait for confirmation response. (DS92)
Step 6: Verify the EUT has successfully *updated the volt/var parameters* by transitioning the local voltage (using the grid simulator) from 1.0 p.u. to a new voltage value, as shown in Table A6-3 and graphically represented in Figure A6-4.
Step 7: Repeat Steps 1 – 6 for the conditions of each row of a Table A6-4 (for VV11); Table A6-5 (for VV12); Table A6-6 (for VV13). These conditions specify:

- EUT initial operating state (i.e., output of the PV simulator)
- Volt/var curves
- Time window
- Ramp rate
- Command timeout period

For VV14, send the VV14 command after completing testing of VV11, VV12, or VV13, and observe whether the EUT output reverts to the default of unity power factor.

Note that Tables A6-4, A6-5 and A6-6 provide *suggested* parameter combinations and operating conditions to test the VV functions. These tables can be adapted to observe EUT operation with other levels of EUT operating state (PV production), different volt/var curves, and additional values of the optional (time window, ramp rate, timeout period) parameters.

Time (sec)	Voltage (% nominal)
0	100
30	100
30	106
60	106
60	94
90	94
90	100
120	100
135	106
150	106
180	94
195	94
210	100
240	100
245	106
250	106
260	94
265	94
270	100
300	100

Table A6-3: Volt/Var test profile

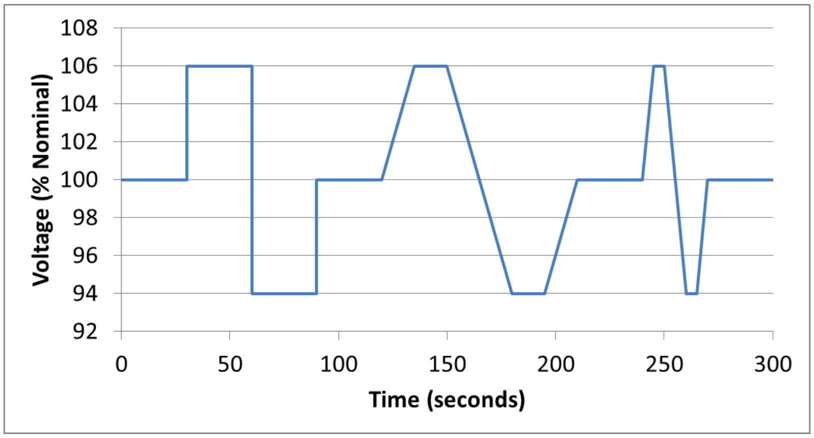


Figure A6-4: Volt/Var test profile

Table A6-4 suggests possible combinations of parameters to be tested for VV11. If the default *Time Window* and *Timeout Period* coded into the EUT are too long, alternative values can be specified.

Test	EUT Initial Operating State	Volt/Var Initiation	Volt/Var [V,Q] Array				Requested Ramp Time (% VArAval/s)	Time Window (seconds)	Timeout Period (seconds)
1	100% rated power, unity power factor	Binary, 1	V1	97	Q1	50	-	-	-
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
2	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	-	-	-
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
3	90% rated power, unity power factor	Binary, 1	V1	97	Q1	50	10	-	-
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
4	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	-	60	-
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
5	30% rated power, unity power factor	Binary, 1	V1	97	Q1	50	-	-	300
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
6	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	10	60	500
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
7	50% rated power, unity power factor	Binary, 1	V1	97	Q1	100	10	60	500
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-100			
8	50% rated power, unity power factor	Binary, 1	V1	95	Q1	50	10	60	500
			V2	98	Q2	0			
			V3	102	Q3	0			
			V4	105	Q4	-50			
9	50% rated power, unity power factor	Binary, 1	V1	80	Q1	100	10	60	500
			V2	95	Q2	0			
			V3	105	Q3	0			
			V4	120	Q4	-100			

Table A6-4. Test Matrix for VV11.

Table A6-5 suggests possible combinations of parameters to be tested for VV12.

EUT Initial Operating State	Volt/Var Initiation	Volt/Var [V,Q] Array				Requested Ramp Time (% VArAval/s)	Time Window (seconds)	Timeout Period (seconds)
50% rated power, unity power factor	Binary, 1	V1	101	Q1	100	-	-	-
		V2	103	Q2	0			
90% rated power, unity power factor	Binary, 1	V1	101	Q1	100	10	-	-
		V2	103	Q2	0			
50% rated power, unity power factor	Binary, 1	V1	101	Q1	100	-	60	-
		V2	103	Q2	0			
100% rated power, unity power factor	Binary, 1	V1	101	Q1	100	-	-	300
		V2	103	Q2	0			
50% rated power, unity power factor	Binary, 1	V1	101	Q1	100	10	60	500
		V2	103	Q2	0			
50% rated power, unity power factor	Binary, 1	V1	101	Q1	100	10	60	500
		V2	103	Q2	0			
50% rated power, unity power factor	Binary, 1	V1	101	Q1	100	10	60	500
		V2	103	Q2	0			
50% rated power, unity power factor		V1	102	Q1	100	-	-	-
		V2	120	Q2	0			

Table A6-5. Test Matrix for VV12.

Table A6-6 suggests possible combinations of parameters to be tested for VV13

EUT Initial Operating State	Volt/Var Initiation	Inverter output (% of Max)*		Requested Ramp Time (% VArAval/s)	Time Window (seconds)	Timeout Period (seconds)
50% rated power, unity power factor	Binary, 1	Test #1	100	-	-	-
		Test #2	50			
90% rated power, unity power factor	Binary, 1	Test #1	100	10	-	-
		Test #2	50			
50% rated power, unity power factor	Binary, 1	Test #1	75	-	60	-
		Test #2	30			
100% rated power, unity power factor	Binary, 1	Test #1	100	-	-	300
		Test #2	50			
50% rated power, unity power factor	Binary, 1	Test #1	100	10	60	500
		Test #2	50			

* **Inverter output setting is % of of VArAval; VArWMax; and/or VArMax, depending on EUT capabilities**

Table A6-6. Test Matrix for VV13.

After testing VV11, VV12, and/or V13, the VV14 command is sent and the EUT output is observed to verify it returns to unity power factor (i.e., zero vars).

A6.4 Expected Results

After the VV command is received by the EUT, the volt/var test profile will demonstrate a change in the output vars as the voltage changes.

Random start time within the boundaries of the time window shall be tested and verified as described in Appendix 17. For this protocol, the tests described above are sufficient to determine that the time window and timeout functions work properly.

Appendix 7 – FW Frequency/Watt Mode

Version 1.0 3 MAR 2013 – Original Version
Version 2.0 10 MAY 2013 – Revisions
Version 3.0 7 JUN 2013 – Revisions to simplify test matrices & procedures
Version 4.0 1 AUG 2013 – Additional revisions to clarify, Raises questions of interpretation
Version 5.0 30 OCT 2013 – Major revisions to make FW21 use parameters and FW22 use curves.

Function FW – Frequency/Watt Mode

Frequency-triggered management of DER is used to mitigate grid frequency deviations by increasing or decreasing power supplied by the DER. Such actions may be taken during emergency conditions, or this capability may be used during normal operations to "smooth" minor frequency variations, such as in a microgrid.

There are two FW modes. Both modes adjust DER active power output in response to frequency excursions. FW21 has a single curve, with or without hysteresis, built with values WGra, HzStr, HzStop, HysEna, and HzStopWGra. FW22 enables the inverter to have multiple curves (up to two for generating and up to two for charging) which describe limits placed on power production/absorption based on frequency changes.

In FW21, the frequency-watt curve is relatively simple. It is defined by the parameters:

- WGra - The slope of the reduction in the maximum allowed watts output as a function of frequency (units of % max power/ Hz).
- HzStr - The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken to act as the "capped" power level (P_M) and above which reduction in power output occurs.
- HzStop - The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the cap on the power level value is removed.
- HysEna - A boolean indicating whether or not hysteresis is enabled.
- HzStopWGra - The maximum time-based rate of change at which power output returns to normal after having been capped by an over frequency event.

Using these parameters, a simple curve can be established which allows for a DER active power reduction as frequency rises. Then, as frequency returns to normal, active power output is allowed to increase to original levels.

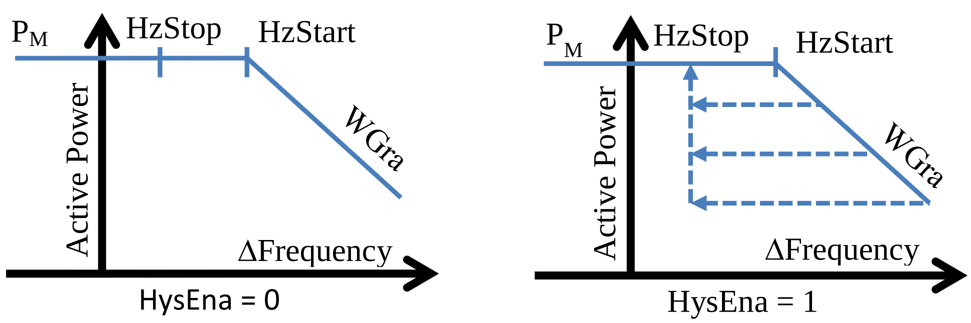


Figure A7-1: Example Freq/Watt Array for FW21 with and without Hysteresis.

FW22 is similar to FW21, except one or more frequency-watt curves are used to *limit* active power generation and charging (in the case of a storage system). If frequency increases, power generation is limited to maintain nominal grid frequency. If frequency falls, storage charging rates are limited (referenced to the maximum charging power, $P_{M\_charging}$) to maintain nominal grid frequency. These curves bound an operating region, as shown in Figure A7-2.

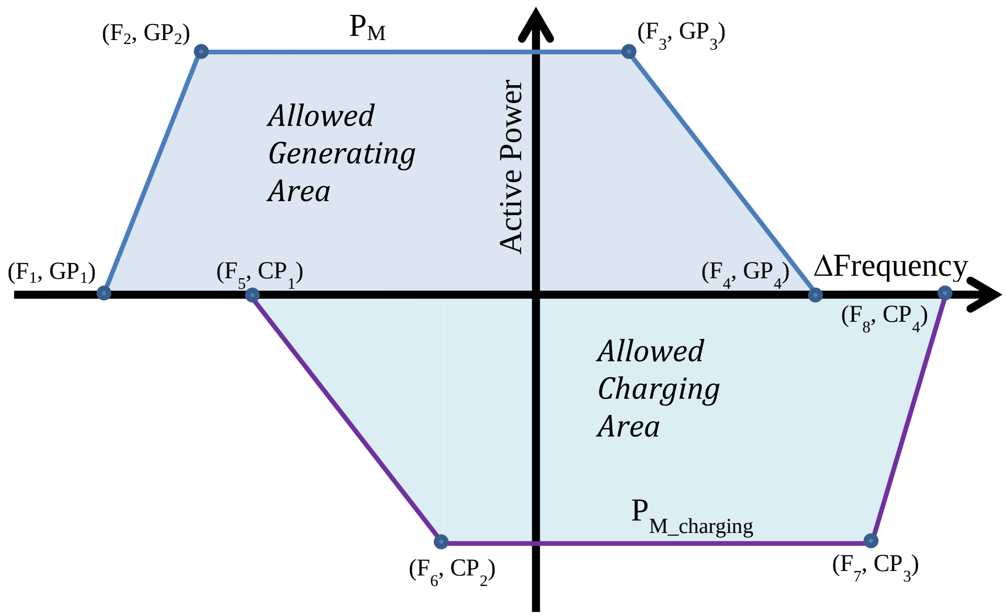


Figure A7-2: Example Freq/Watt Array for FW22 without Hysteresis.

FW22 can also include hysteresis by establishing a 2nd curve for the generating and/or charging curves. These 2nd curves are limits for frequency-falling or frequency-rising situations only, as shown in Figure A7-3.

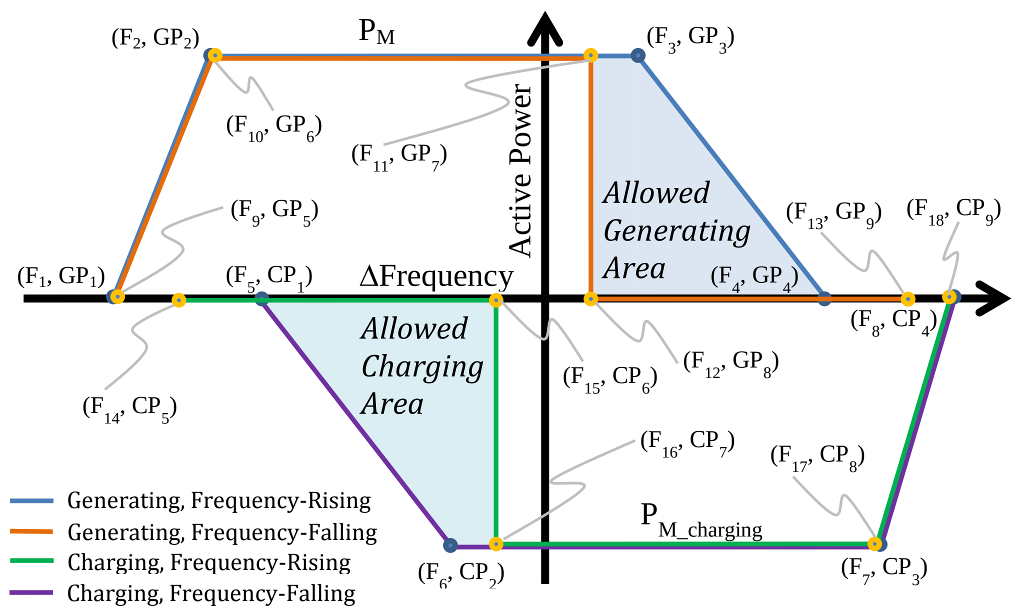


Figure A7-3: Example FW22 with Frequency-Rising and Frequency-Falling Curves.

A7.1 Parameters and FCT

The Function Capability Table (FCT) should be filled out based on the capabilities of the EUT. There are 4 possible FW modes: with and without use of hysteresis curves; and with and without energy storage. There is also an optional *Recovery Ramp Rate* parameter that defines the maximum power ramp rate that the DER power can return to nominal after being curtailed.

The FCT indicates which tests are specified for FW21 mode. If the EUT has the capability of acting on the *Recovery Ramp Rate* optional parameter, then additional tests of that capability shall be performed, as indicated in the FCT.

To test FW22, download at least 2 different FW21 parameter sets and change the external conditions to observe that this triggers the EUT to switch the FW parameter set it executes.

Mode and Optional Parameters	Energy Storage?	Use of Hysteresis curve?	Tests
FW21 – High frequency deviation reduces EUT active power output	N/A	No	Table A7-4 tests 1,2,5
		Yes	Table A7-4 tests 1-6
FW22 –multiple frequency-watt curves are programmed in the EUT	No	No	Table A7-5 tests 1,2,3,5,6
		Yes	Table A7-5 tests 1-8
	Yes	No	Table A7-6 tests 1,2,3,5,6
		Yes	Table A7-6 tests 1-8
Recovery Ramp Rate (optional parameter)	Perform Tests 2 and 6 in Table A7-4 (no storage) or Table A7-5 (with storage)		

Table A7-1. FW Function Capability Table

A7.1.1 FW21 – frequency-watt mode where high frequency deviations reduce active power output

FW21 Frequency/Watt command has the following parameters:

FW21 initiation command. This is required.

WGra - The slope of the reduction in the maximum allowed watts output as a function of frequency (units of % max power/ Hz).

HzStr - The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken to act as the “capped” power level (P_M) and above which reduction in power output occurs.

HzStop - The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the cap on the power level value is removed.

HysEna - A boolean indicating whether or not hysteresis is enabled.

HzStopWGra - The maximum time-based rate of change at which power output returns to normal after having been capped by an over frequency event.

A7.1.2 FW22 – multiple frequency-watt modes define how frequency deviations change active power output

FW22 allows more than one frequency-watt curve to be specified. Further, frequency-watt settings may be different when the frequency is increasing or decreasing.

FW22 Frequency/Watt command has the following parameters:

FW22 initiation command. This is required.

One or more arrays of (F, GP) pairs (e.g., F_1, GP_1, F_2, GP_2,…, F_x, GP_x) which define a piecewise linear frequency/watt curve, plus a specification of the conditions under which each array is to be applied (generating/charging, frequency-rising/frequency-falling/both). An example frequency/watt FW22 curve for a system without hysteresis or energy storage is given in Figure A7-4.

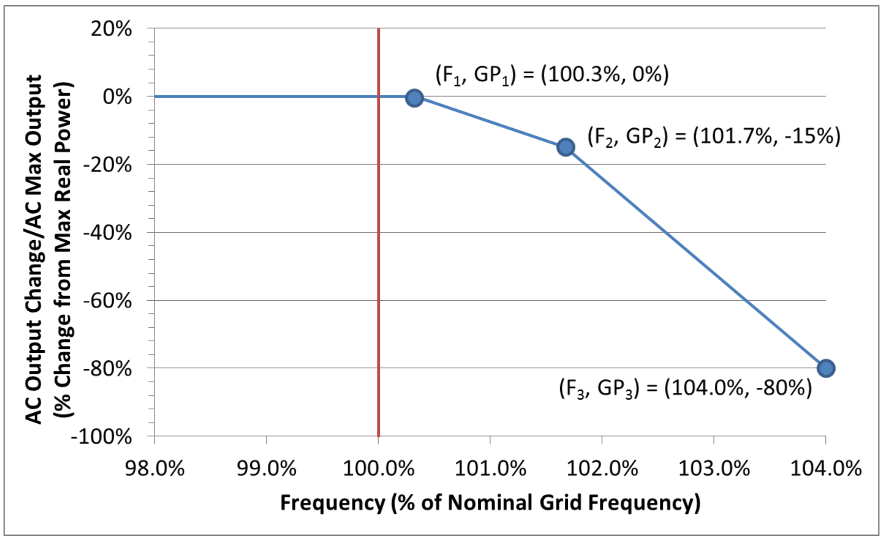


Figure A7-4: Example Freq/Watt Array for FW22 without Hysteresis.

Without energy storage, the FW21 function is only used to reduce DER output when system frequency is rising. If energy storage is available, then FW22 can reduce charging rates when the frequency is below the nominal grid frequency. Figures A7-2 and A7-3 demonstrate the expanded functionality for FW22 if energy storage is available.

Recovery Ramp Rate is an optional parameter defining how quickly the DER output returns to normal (default) values after frequency returns to nominal.

Requested ramp time is an optional parameter defining the time the EUT must move from the current set point to the new set point.

If not included, then the default ramp time for this function will be used.

Time window is an optional parameter in which the command can be randomly executed.

If the time window is zero, the command will execute immediately.

If not included, then the default time window for this function will be used.

Timeout period is an optional parameter that defines the time after which the EUT will reset the power factor set point to the default value.

If not included, then the default timeout period for this function will be used. The default timeout period is expected to be around 5 minutes.

A7.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage range for a minimum of 5 minutes.

The EUT is connected to PV simulator, with sufficient power available to deliver full EUT rated power output or at least the power level required by the command to be given.

If the capability to manage an energy storage device is to compensate for frequency deviations is to be tested, then an energy storage simulator shall be connected to the EUT.

Communications is established between the Utility Management System (UMS) simulator and the EUT.

Default timing and ramping parameters have been set in the EUT.

The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A7.3 FW Test Protocol Sequence

Table A7-2 outlines the FW test protocol sequence to verify the inverter receives the FW21 command and initiates action correctly.

	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93 (**Status Reporting) & **DM** (Direct Monitoring) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	EUT output is measured and logged	**DM**	
	4	UMS issues a FW Command to EUT.	**FW21 or FW22** – Freq/Watt	Log time sent. Command may include Recovery Ramp Rate (optional)
	5	EUT responds to the command.	**DS92** – status change is noted	Expected response message: Successful (DS92 status change) Rejected (includes reason)
Electrical Behavior	6	Verify command was successfully executed by varying the frequency of the grid simulator (Table A7-3 & Figure A7-5). If the test causes the inverter to trip off, communications need to be re-established with the DS93 command.		Monitor electrical output of EUT. Voltage Active power Reactive power
	7	Repeat test with varying parameters, as specified in Table A7-4, or similar values. Each test should be repeated until behavior of the EUT is reasonably understood.		–

	Step	Task	Function	Notes
	8	For EUTs with energy storage being tested for FW22, repeat test (steps 1 – 7) with the parameters shown in Table A7-6.		
Analysis	9	Characterize EUT's response.	**DS92; DM**	Determine if command was executed correctly.

Table A7-2: Freq/Watt Test Protocol Sequence.

The FW21 function is first tested in Table A7-2 (Steps 1 – 7); this utilizes a single frequency-watt mode, with and without hysteresis. Step 8 is added to test FW when energy storage is available. To test the FW22 function, Step 9 repeats the previous tests in a manner to verify that the FW curves changed when the conditions changed.

A summary of the Test steps in Table A7-2 is:

Step 1: Request status from EUT (DS93)
Steps 2-3: Receive confirmation of status and log results
Step 4: Send *FW* Command.
Step 5: Wait for confirmation response (DS92)
Step 6: Verify EUT has successfully updated the frequency-watt parameters by transitioning the frequency (using the grid simulator) from nominal voltage according to Table A7-3 and Figure A7-5.
Step 7: Repeat Steps 1 – 6 for each value of Table A7-4, including varying the hysteresis curve and recovery ramp rate as specified.
Step 8: To exercise FW with energy storage, repeat Steps 1 – 7 with the values of Table A7-5.
Step 9: To test FW22 (an array of FW curves), upload two FW curves and the conditions under which they apply, as shown in Table A7-6.
Step 10: Analyze performance data collected to characterize the EUT's responses and determine whether the EUT has successfully *updated the Frequency/Watt curve parameters*.

Time (sec)	Frequency (% nominal)
0	100.0
30	100.0
30	103.0
60	103.0
60	97.0
90	97.0
90	103.0
95	103.0
95	100.0
125	100.0
155	102.0
185	102.0
215	98.0
245	98.0

260	102.0
275	102.0
280	100.0
295	100.0
310	100.3
325	100.3
340	100.0
360	100.0

Table A7-3: Freq/Watt test profile.

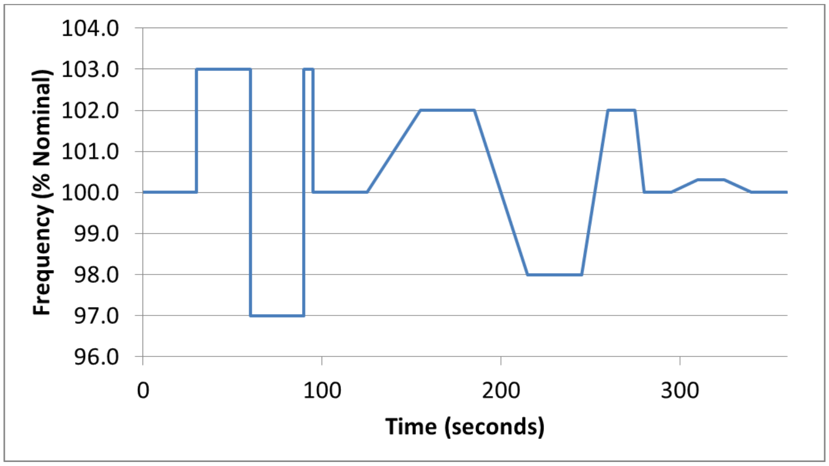


Figure A7-5: Freq/Watt test profile.

Table A7-4 suggests parameter sets to be tested for the FW21 function, with and without hysteresis.

WGra - The slope of the reduction in the maximum allowed watts output as a function of frequency (units of % max power/ Hz).

HzStr - The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken to act as the "capped" power level (P_M) and above which reduction in power output occurs.

HzStop - The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the cap on the power level value is removed.

HysEna - A boolean indicating whether or not hysteresis is enabled.

HzStopWGra - The maximum time-based rate of change at which power output returns to normal after having been capped by an over frequency event.

Test Number	EUT Initial Operating State	WGra (%Max Power/Hz)	HzStr (%F_{nom})	HzStop (%F_{nom})	Hysteresis Activation (HysEna)	HzStopWGra (%Max Power/min)
Test 1	100% rated power, unity power factor	10	100.33	-	0	-
Test 2	100% rated power,	20	100.66	-	0	100

	unity power factor					
Test 3	50% rated power, unity power factor	50	100.33	100.33	1	-
Test 4	100% rated power, unity power factor	20	101	100.33	1	-
Test 5	50% rated power, unity power factor	150	100.33	-	0	-
Test 6	100% rated power, unity power factor	150	101	100.66	1	10

Table A7-4: Test Matrix for FW21.

Test	EUT Initial Operating State	Freq/Watt [F,GP] Array For Generation				Freq-Rising	Freq/Watt [F,PG] Array For Generation with Frequency-Falling				Freq-Falling	Time Window	Ramp Rate	Time out
Test 1	100% rated power, unity power factor	F1	100.3%	PG1	0%	N	-				N	Default	0 %/s	Default
		F2	101.7%	PG2	-15%									
		F3	104.0%	PG3	-80%									
Test 2	50% rated power, unity power factor	F1	100.3%	PG1	0%	N	-				N	Default	0 %/s	Default
		F2	101.7%	PG2	-15%									
		F3	104.0%	PG3	-80%									
Test 3	100% rated power, unity power factor	F1	100.3%	PG1	0%	N	-				N	10	50 %/s	Default
		F2	101.7%	PG2	-15%									
		F3	104.0%	PG3	-80%									
Test 4	100% rated power, unity power factor	F1	100.3%	PG1	0%	Y	F1	100.3%	PG1	0%	Y	Default	Default	Default
		F2	101.7%	PG2	-15%		F2	100.3%	PG2	-80%				
		F3	104.0%	PG3	-80%		F3	104.0%	PG3	-80%				
Test 5	100% rated power, unity power factor	F1	100.5%	PG1	0%	N	-				N	Default	Default	600 s
		F2	104.0%	PG2	-50%									
Test 6	100% rated power, unity power factor	F1	100.5%	PG1	0%	N	-				N	Default	20 %/s	Default
		F2	104.0%	PG2	-50%									
Test 7	100% rated power, unity power factor	F1	100.5%	PG1	0%	Y	F1	100.5%	PG1	0%	Y	50	Default	Default
		F2	104.0%	PG2	-50%		F2	100.5%	PG2	-50%				
Test 8	100% rated power, unity power factor	F1	101.0%	PG1	0%	Y	F1	100.5%	PG1	0%	Y	Default	Default	1800 s
		F2	103.0%	PG2	-80%		F2	100.5%	PG2	-80%				

Table A7-5: Test Matrix for FW22.

Test	EUT Initial Operating State	Freq/Watt [F,GP] Array For Charging Storage				Freq-Rising	Freq/Watt [F,PG] Array For Charging Storage with Frequency-Falling				Freq-Falling
Test 1	Test 1, with the following energy storage settings	F1	99.7%	PG1	0%	N	-				N
		F2	98.3%	PG2	15%						
		F3	96.0%	PG3	80%						
Test 2	Test 2, with the following energy storage settings	F1	99.7%	PG1	0%	N	-				N
		F2	98.3%	PG2	15%						
		F3	96.0%	PG3	80%						
Test 3	Test 3, with the following energy storage settings	F1	99.7%	PG1	0%	N	-				N
		F2	98.3%	PG2	15%						
		F3	96.0%	PG3	80%						
Test 4	Test 4, with the following energy storage settings	F1	99.7%	PG1	0%	Y	F1	99.7%	PG1	0%	Y
		F2	98.3%	PG2	15%		F2	98.3%	PG2	80%	
		F3	96.0%	PG3	80%		F3	96.0%	PG3	80%	
Test 5	Test 5, with the following energy storage settings	F1	99.5%	PG1	0%	N	-				N
		F2	96.0%	PG2	50%						
Test 6	Test 6, with the following energy storage settings	F1	99.5%	PG1	0%	N	-				N
		F2	96.0%	PG2	50%						
Test 7	Test 7, with the following energy storage settings	F1	99.5%	PG1	0%	Y	F1	99.5%	PG1	0%	Y
		F2	96.0%	PG2	50%		F2	99.5%	PG2	50%	
Test 8	Test 8, with the following energy storage settings	F1	99.0%	PG1	0%	Y	F1	99.5%	PG1	0%	Y
		F2	97.0%	PG2	80%		F2	99.5%	PG2	80%	

Table A7-6: Test Matrix for FW22 - Additional tests for systems with energy storage.

A7.4 Expected Results

After the FW command is received by the EUT, the Freq/Watt test profile will demonstrate a change in the output power as the frequency changes. For FW22, the EUT output will follow one Frequency-Watt curve or be bounded by two to four different FW curves. The curve limits will be reached depending on the rising or falling characteristics of the grid frequency.

Appendix 8 – TV Dynamic Reactive Current Support (TV31)

Version 1.0 10 JUL 2013 – First Draft and Preliminary notes on approach

Version 2.0 18 JUL 2013 – Created test matrices and voltage test profile

Version 2.1 1 AUG 2013 – Minor Corrections

Function TV – Dynamic Reactive Current Support

This function causes the EUT to supply reactive current to the grid during short voltage sags or swells. However, if the system voltage becomes too far out of range, the EUT will disconnect, in accordance with IEEE 1547 or other applicable safety standards.

A8.1 Parameters and FCT

The function is activated for certain values of rate of change of voltage and duration of those abnormal voltage sags/swells. The "triggering" condition is the change in voltage:

delta voltage (DelV) = present measured voltage – moving average voltage (V_{avg})

where, VAv is the moving average value of measured voltage over a period of filter time, FilTms, defined by

$$V_{avg}(t) = \frac{1}{FilTms}\int_{t_{present}-FilTms}^{t_{present}} V(t)dt$$

for continuous time measurements, or, more practically,

$$\mathrm{V_{avg}} = \frac{1}{k_{samples}}\sum_{k=t_{present}-FilTms}^{t_{present}} V_k$$

for discrete voltage measurements of V_k, where $k_{samples}$ is the number of samples between the present time, $t_{present}$, and the time, FilTms seconds ago.

The continuous case is illustrated in Figure A8-1.

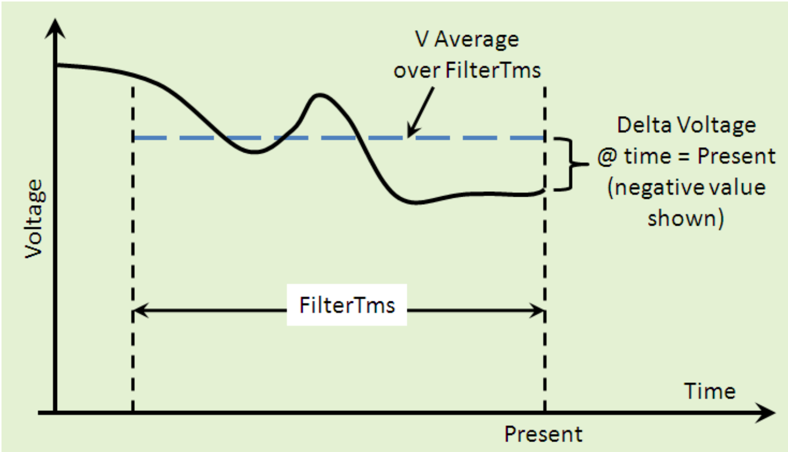


Figure A8-1. Calculation of delta voltage over a filter time window

The EUT injects reactive current to the grid until the rate of change of voltage returns to within normal bounds (i.e., DelV decreases) or the system voltage reaches the disconnect time allowed for the EUT. There is also the option of continuing the reactive power support for a specified time after DelV (delta voltage) returns within normal range. The amount of reactive current to be provided by the EUT is dependent upon the delta voltage.

All DER have some self-imposed limit of the depth and duration of voltage sags which they can support; the TV function allows more constrained limits to be set, as may be required by country codes. This also provides a hysteresis zone, where the reactive current provided by the EUT is different if the delta voltage is decreasing (within normal limits).

The parameters of the TV31 function are:

- *TV31 initiation* command. This is a required parameter.
- *DbVmin* and *DbVmax*, a deadband around nominal delta voltage (DelV) within which the EUT does not supply reactive current under TV31. Figure A8-2 illustrates the deadband.
- *HoldTmms* is the time after DelV returns to values within the deadband before reactive current support is ended. Figure A8-3 illustrates this.
- *ArGraSag* and *ArGraSwell*, the change in reactive current (as a percentage of rated current) injected by the EUT based on level of DelV during low voltage (sag) or high voltage (swell) events. Figure A8-2 illustrates this concept, where the reactive current provided by the EUT tends toward zero if DelV is near the limits of the deadband.
- *ArGraMod* is an optional variable that allows a step change in the EUT reactive current when the triggering event begins. *ArGraMod* = 0 or is not specified if the relationship in Figure A8-2 is used. If *ArGraMod* = 1, then Figure A8-4 depicts the dependence of the EUT's reactive current output on the value of DelV.
- *BlkZnTmms*, *BlkZnV*, *HysBlkZnV* are optional; parameters used to define a range of voltages where the EUT will not provide additional reactive current support (i.e., a blocking zone). A hysteresis capability (defined by *HysBlkZnV*) differentiates behavior between when system voltage is deviating from nominal or returning to nominal. Figure A8-5 defines these variables.

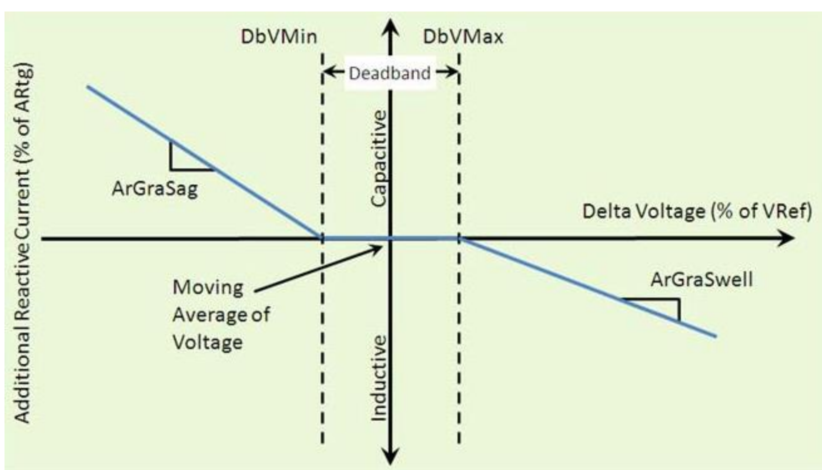


Figure A8-2. Basic concepts of the TV function

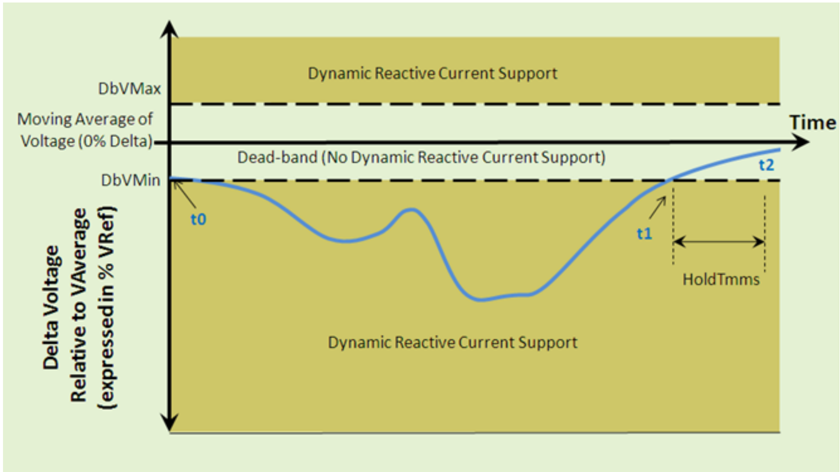


Figure A8-3. Activation zones for dynamic reactive current support

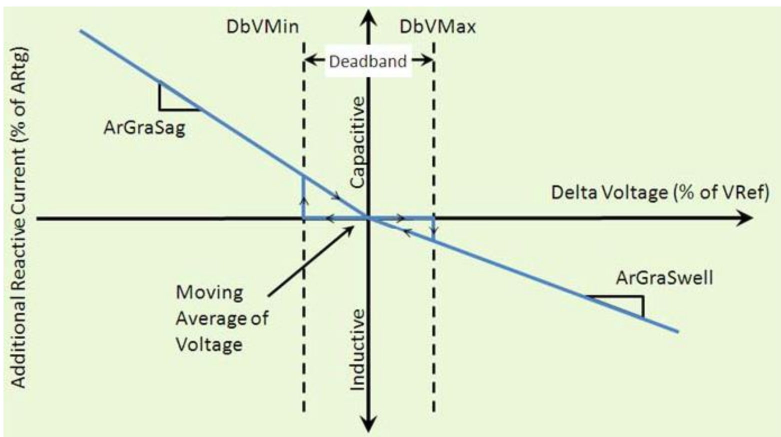


Figure A8-4. Alternative reactive current support behavior

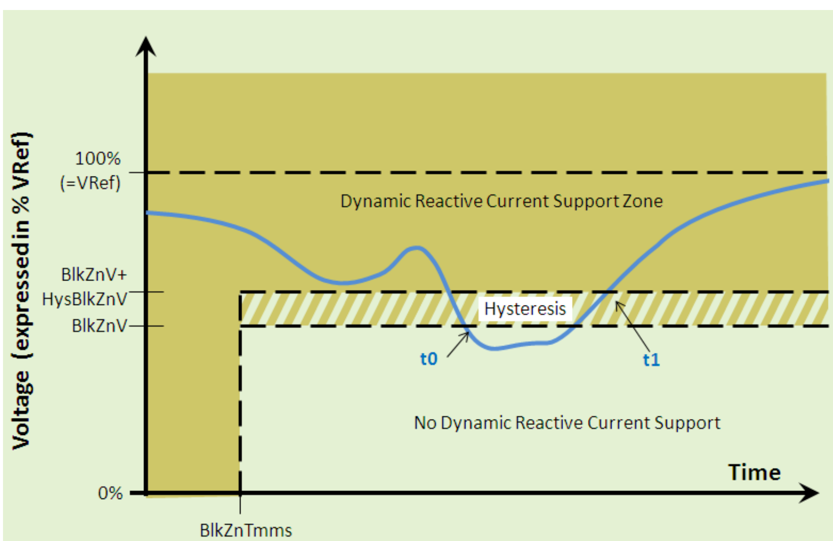


Figure A8-5. Settings to define a "blocking zone"

The Function Capability Table (FCT) should be filled out based on which of these options the EUT is capable of.

TV31 Mode and Optional Parameters	Test Parameter Sets
ArGraMod = 0 or unspecified	Table A8-3
ArGraMod = 1	Table A8-4
Capability to specify a Blocking Zone	Table A8-5

Table A8-1. TV31 Function Capability Table

A8.2 Test Precursors

- The EUT is connected to the Utility Simulator operating within nominal voltage range for a minimum of 5 minutes.
- The EUT is connected to a PV simulator, with sufficient power available to deliver full EUT rated power output.
- Communications is established between the Utility Management System simulator and the EUT.

A8.3 TV Test Protocol Sequence

	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93 (**Status Reporting) & **DM** (Direct Measurement) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	Inverter output is measured and logged	**DM**	
	4	UMS issues a dynamic reactive current support TV (TV) Command to EUT.	**TV** – dynamic support command issued	Log time sent.
	5	EUT responds to the command.	**DS92** – change in status is noted	Expected response message: Successful (DS92 status change) Rejected (includes reason)
Electrical Behavior	6	Verify command was successfully executed by rapidly changing the system voltage in the Us according to the values specified in: • Table A8-3 if for no support at limits of deadband • Table A8-4 for step function of dynamic support at limits of deadband Each test should be repeated until behavior of the EUT is reasonably understood At low system voltage (last parameter set in Table A8-3 or A8-4), EUT should disconnect.	**DM**	Monitor and record electrical output of EUT. • Current • Power factor
	7	Repeat test with varying parameters as described in Table A8-5 if EUT is capable of specifying a Blocking Zone.	–	Monitor and record electrical output of EUT. • Current • Power factor

	Step	Task	Function	Notes
Analysis	8	Characterize EUT's response.		Determine if command was executed correctly.

Table A8-2. TV31 Test Protocol Sequence.

To test the sag and swell compensation of the DER, the trip points for IEEE 1547/1547a must not be reached. Therefore, relatively small values for the deadband and the voltage profiles are used. The suggested test profile is shown in Tables A8-3, A8-5, and A8-6.

Time (sec)	Frequency (% nominal)
0	100
9.99	100
10	108
19.99	108
20	90
29.99	90
30	100
40	100
45	106
50	106
60	94
65	94
70	100
80	100
82	106
84	106
87	94
89	94
91	100
100	100

Table A8-3: TV31 test profile.

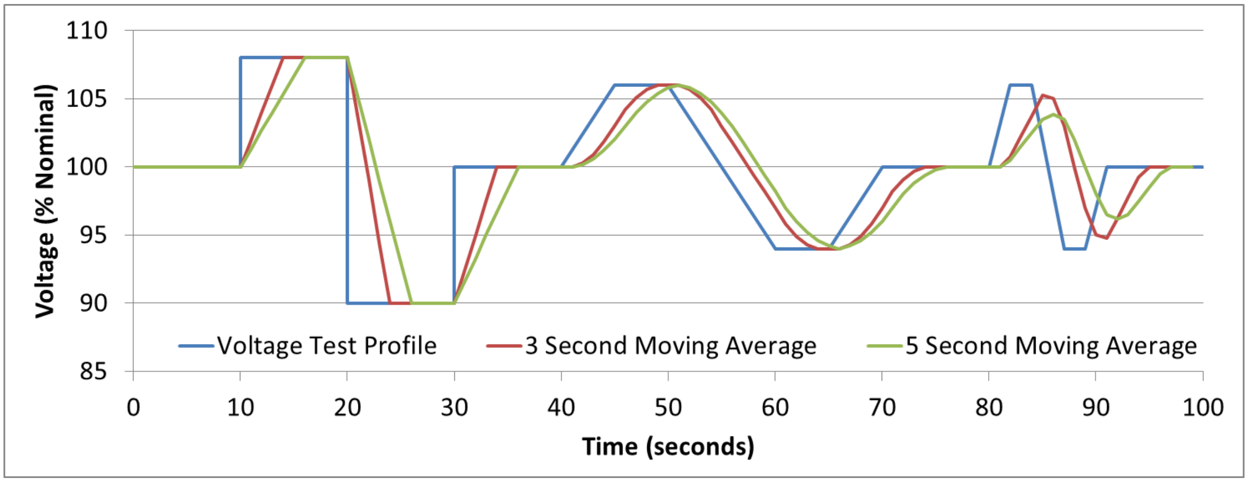


Figure A8-5: TV31 test profile with FilTms = 3 sec and 5 sec for 1 second sampling rate.

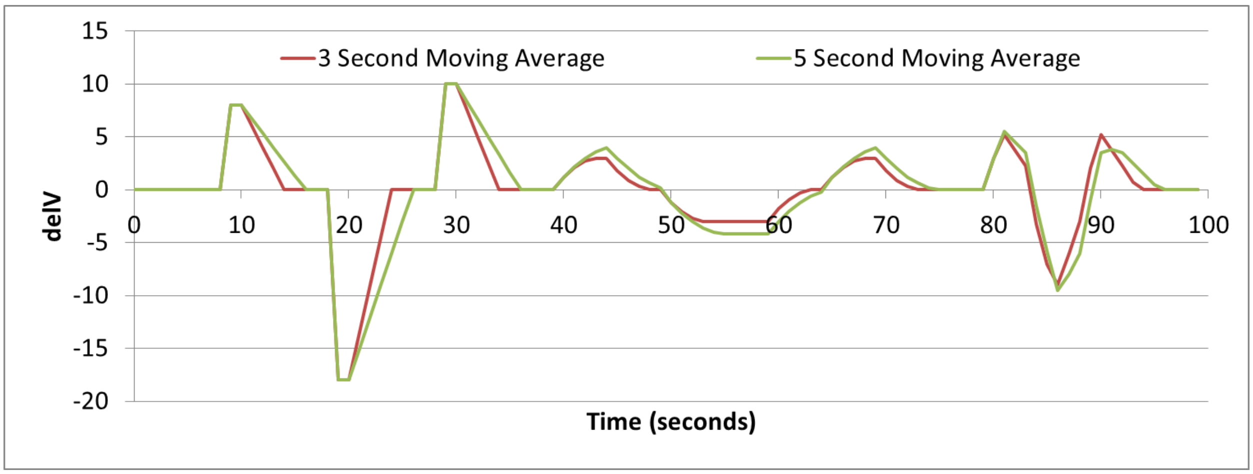


Figure A8-6: TV31 delV values for FilTms = 3 sec and 5 sec for 1 second sampling rate.

Table A8.3 and A8.4 have parameters to test a short-term voltage sag (EUT produces capacitive current), a short-term voltage swell (EUT produces inductive current), and a low voltage at which the EUT will disconnect.

TV31	DbVmin	DbVmax	HoldTmms	ArGraSag (% rated/V)	ArGraSwell	BlkZn Tmms	BlkZnV	HysBl kZnV
On	0	0	0	10	10	Default	Default	Default
On	-2	2	1	10	10	Default	Default	Default
On	-2	2	2	5	5	Default	Default	Default

Table A8-3. TV31 Test Matrix for ArGraMod = 0 or not defined.

TV31	DbVmin	DbVmax	HoldTmms	ArGraSag (% rated/V)	ArGraSwell	BlkZn Tmms	BlkZnV	HysBl kZnV
On	0	0	0	10	10	Default	Default	Default
On	-2	2	1	10	10	Default	Default	Default
On	-2	2	2	5	5	Default	Default	Default

Table A8-4. TV31 Test Matrix for ArGraMod = 1.

A8.4 Expected Results

After the TV31 command is received by the EUT, and the system voltage is rapidly varied (delta voltage), the EUT will provide capacitive or inductive current as specified. As delta voltage decreases within the specified deadband, the EUT will cease to provide reactive current support.

When the voltage drops below a minimum level, the EUT will disconnect, as required by IEEE 1547.

Appendix 9 – L/HVRT Low and High Voltage Ride Through

Version 1.0 3 MAR 2013 – Original Sandia Version
Version 2.0 10 MAY 2013 – Revisions

Function L/HVRT – Low and High Voltage Ride Through

For safety reasons (both personnel and equipment), inverters are required to disconnect (i.e., "trip") from the grid during certain conditions. While some standards specify those conditions, it is becoming infeasible to permanently set trip points in an inverter, as the standards vary by region and jurisdictions, the standards' requirements are changing, and also utilities are finding that certain other conditions or circumstances influence the voltage or frequency levels at which an inverter must disconnect (or must remain connected). Therefore, this function is designed for those inverters with capability to update their connect/disconnect (or "ride-through") parameters. In the future, and for some jurisdictions, this capability may be required.

A9.1 Parameters

The *L/HVRT* command has the following parameters:

L/HVRT initiation command. This is required. The command consists of four set of point pairs in the form (t_1, V_1, t_2, V_2,…, t_x, V_x) that define the *L/HVRT* zones shown in Figure A9-1.

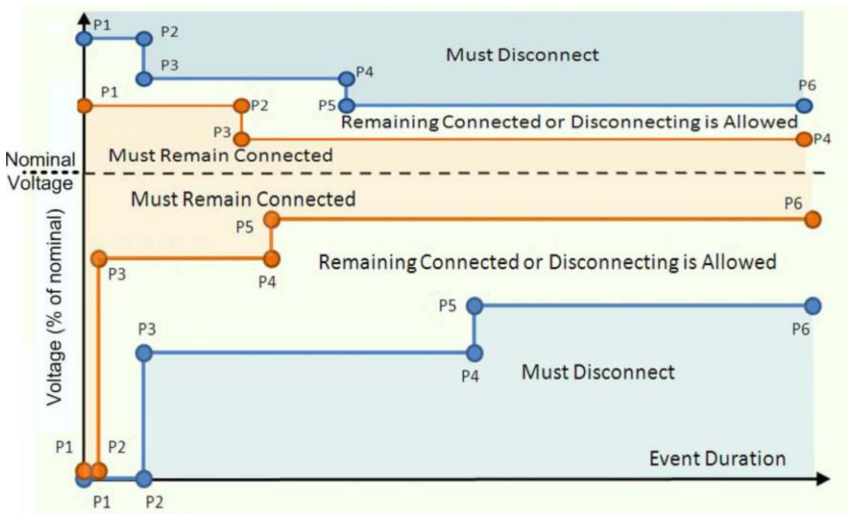


Figure A9-1: L/HVRT points with zones for "must remain connected," "may remain connected," and "must disconnect."

L/HVRT sets the ranges of voltage for which the inverter must disconnect or remain connected. Time window, ramp rate, and command timeout settings are not included so no Function Capability Table needs to be generated for L/HVRT.

A9.2 Test Precursors

The EUT is connected to the Utility Simulator with operation within nominal voltage range for a minimum of 5 minutes. The Utility simulator has the capability to vary the voltage seen by the EUT.

The EUT is connected to PV simulator, with sufficient power available to deliver full EUT rated power output.

Communications is established between the UMS simulator and the EUT.

The output of the EUT (voltage, current, power factor) is measured, and the data are logged.

A9.3 L/HVRT Test Protocol Sequence

Table A9-1 outlines the L/HVRT test protocol sequence to verify the inverter receives the command and initiates action correctly.

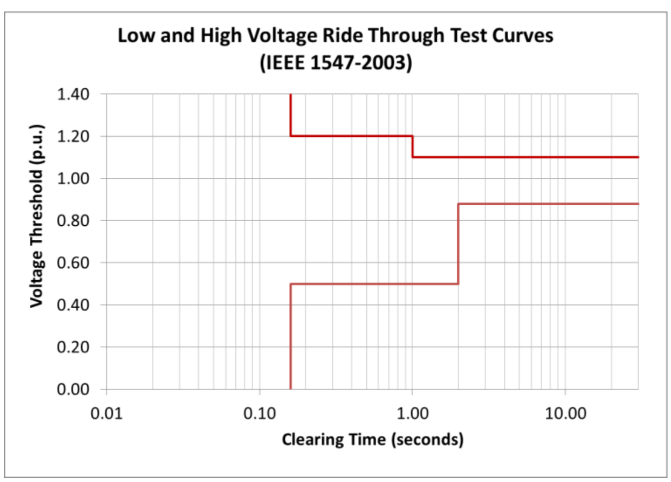
	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93(**Status Reporting) and **DM** (Direct Measurement) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	UMS issues a L/HVRT Command to EUT, using one of the sets of parameters in Table A9-2 and Figure A9-2.	**L/HVRT**	Log time sent. *Command will include 4 sets of point pairs, as indicated in Figure A9-1, with values as specified in one of the groupings of Table A9-2.*
	4	EUT responds to the command.	**DS92** – Change in status noted	Expected response message: Successful Rejected (includes reason)
Electrical Behavior	5	If Success response received, verify command was successfully executed by running voltage tests as suggested in Table A9-3 with the grid simulator. If the test causes the inverter to trip off, communications need to be re-established with the DS93 command.	**DM** – EUT output is recorded and logged	Monitor electrical output of EUT.
	6	Repeat test with varying parameters (Table A9-3). Each test should be repeated until behavior of the EUT is reasonably understood.		
Analysis	7	Characterize EUT's response.	**DS92; DM**	Determine if command was executed correctly.

Table A9-1: L/HVRT Test Protocol Sequence.

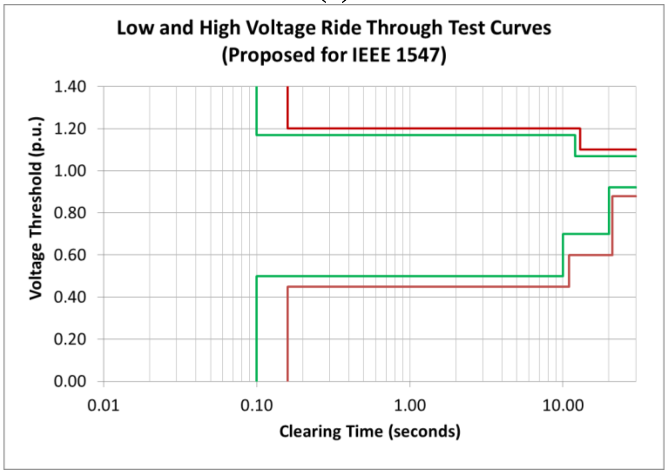
L/HVRT trip curves vary from region to region but they insure the safety of grid operators. Table A9-2 suggests three parameter sets to be tested. The curves are taken from IEEE 1547, IEEE 1547a, IEEE 1547a with ride-through curves, and NERC Standard PRC-024-1.

Update L/HVRT Command	Must Trip Upper Limit				May Trip Upper Limit				Must Trip Lower Limit				May Trip Lower Limit			
IEEE 1547	t_1	0.16	V_1	2.00					t_1	0.16	V_1	0.00				
	t_2	0.16	V_2	1.20					t_2	0.16	V_2	0.50				
	t_3	1.00	V_3	1.20					t_3	2.00	V_3	0.50				
	t_4	1.00	V_4	1.10					t_4	2.00	V_4	0.88				
	t_5	30.00	V_5	1.10					t_5	30.00	V_5	0.88				
IEEE 1547a	t_1	0.16	V_1	2.00					t_1	0.16	V_1	0.00				
	t_2	0.16	V_2	1.20					t_2	0.16	V_2	0.45				
	t_3	1.00	V_3	1.20					t_3	11.00	V_3	0.45				
	t_4	1.00	V_4	1.10					t_4	11.00	V_4	0.60				
	t_5	30.00	V_5	1.10					t_5	21.00	V_5	0.60				
									t_6	21.00	V_6	0.88				
									t_7	30.00	V_7	0.88				
IEEE 1547a with Ride-Through Curves	t_1	0.16	V_1	2.00	t_1	0.10	V_1	2.00	t_1	0.16	V_1	0.00	t_1	0.10	V_1	0.00
	t_2	0.16	V_2	1.20	t_2	0.10	V_2	1.17	t_2	0.16	V_2	0.45	t_2	0.10	V_2	0.50
	t_3	1.00	V_3	1.20	t_3	12.00	V_3	1.17	t_3	11.00	V_3	0.45	t_3	10.00	V_3	0.50
	t_4	1.00	V_4	1.10	t_4	12.00	V_4	1.07	t_4	11.00	V_4	0.60	t_4	10.00	V_4	0.70
	t_5	30.00	V_5	1.10	t_5	30.00	V_5	1.07	t_5	21.00	V_5	0.60	t_5	20.00	V_5	0.70
									t_6	21.00	V_6	0.88	t_6	20.00	V_6	0.92
									t_7	30.00	V_7	0.88	t_7	30.00	V_7	0.92
Standard PRC-024-1	t_1	0.00	V_1	1.20					t_1	0.15	V_1	0.00				
	t_2	0.20	V_2	1.20					t_2	0.15	V_2	0.45				
	t_3	0.20	V_3	1.18					t_3	0.30	V_3	0.45				
	t_4	0.50	V_4	1.18					t_4	0.30	V_4	0.65				
	t_5	0.50	V_5	1.15					t_5	2.00	V_5	0.65				
	t_6	1.00	V_6	1.15					t_6	2.00	V_6	0.75				
	t_7	1.00	V_7	1.10					t_7	3.00	V_7	0.75				
	t_8	30.00	V_8	1.10					t_8	3.00	V_8	0.90				
									t_9	30.00	V_9	0.90				

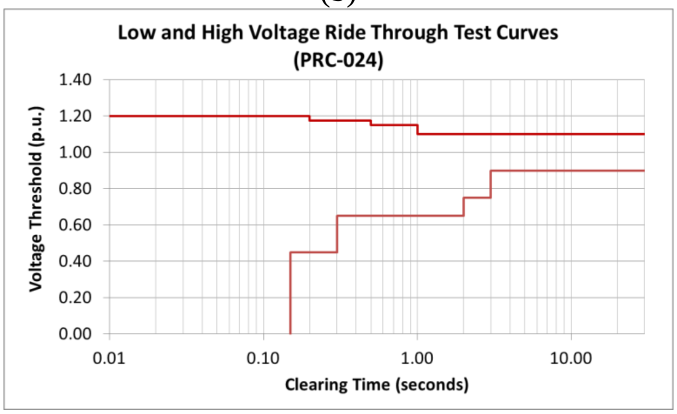
Table A9-2: Test Matrix for L/HVRT.



(a)



(b)



(c)

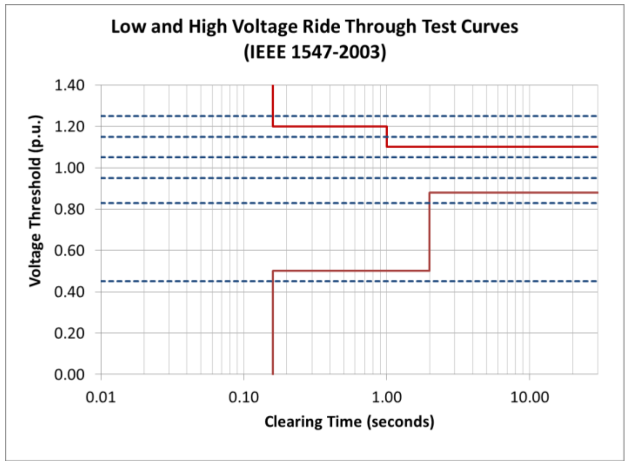
Figure A9-2: Different H/LVRT Test Curves.

The test procedure in Table A9-1 uses one of the sets of parameters in Table A9-2 and Figure A9-2. 2 In order to test the L/HVRT function Steps 1 – 5 are repeated for each voltage test in Table A9-3.

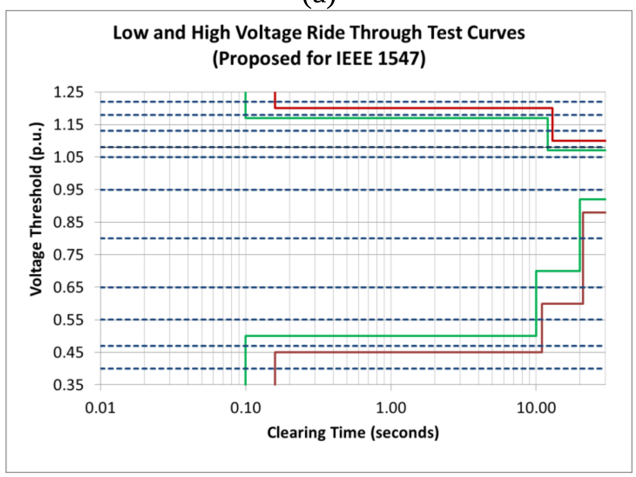
Step 1: Request status from EUT (DS93)
Step 2: Receive confirmation of status
Step 3: Send *L/HVRT* Command.
Step 4: Wait for confirmation response. (DS92)
Step 5: Verify the EUT has successfully *updated the L/HVRT curve parameters* by transitioning from 1.0 p.u. to a new voltage value, as shown in in Table A9-3Table, and graphically represented in Figure A9-3.
Step 6: Repeat Steps 1 – 5 for each value of a group (1547, proposed 1547, or PRC-024-1) of Table A9-3.

L/HVRT Curve	Test Number	Voltage Test Points
IEEE 1547	Test 1	0.45
	Test 2	0.83
	Test 3	0.95
	Test 4	1.05
	Test 5	1.15
	Test 6	1.25
IEEE 1547a	Test 1	0.4
	Test 2	0.47
	Test 3	0.55
	Test 4	0.65
	Test 5	0.8
	Test 6	0.95
	Test 7	1.05
	Test 8	1.08
	Test 9	1.13
	Test 10	1.18
	Test 11	1.22
IEEE 1547a with Ride-Through Curves	Test 1	0.4
	Test 2	0.47
	Test 3	0.55
	Test 4	0.65
	Test 5	0.8
	Test 6	0.95
	Test 7	1.05
	Test 8	1.08
	Test 9	1.13
	Test 10	1.18
	Test 11	1.22
Standard PRC-024-1	Test 1	0.40
	Test 2	0.60
	Test 3	0.70
	Test 4	0.80
	Test 5	0.95
	Test 6	1.05
	Test 7	1.13
	Test 8	1.16
	Test 9	1.19

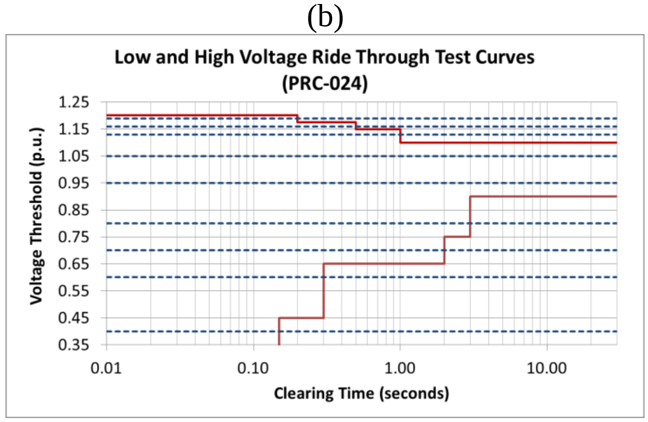
Table A9-3: Test Matrix for L/HVRT.



(a)



(b)



(c)

Figure A9-3: Different H/LVRT Test Curves with Voltage Test Points.

A9.4 Expected Results

If L/HVRT command is received by the EUT, for each of the voltage test points, the EUT will connect, disconnect, or remain connected/disconnected, as appropriate, for the L/HVRT zones defined by the 4 point pairs in the command. This will be verified by direct measurement of EUT output (DM) and by logging of EUT status and data (DS92).

Appendix 10 – Watt-Power Factor Settings (WP41, WP42)

Version 1.0   10 JUL 2013 – Original Draft

Version 1.1   18 JUL 2013 – Revisions

Version 2.0   1 AUG 2013 – Raises questions of interpretation of the commands

Version 3.0 30 OCT 2013 – Major revisions to parameters in WP41 and curves in WP42.

Function WP – Feed-in Power Controls Power Factor

This function allows the power factor of the EUT output to be varied according to the value of the feed-in power from a PV array or other energy source. Once specified, such settings (WP41 or WP42) are not expected to be changed often, if at all, over the life of the EUT. However, a schedule for different watt-power factor curves from WP41 or WP42 could also be employed. The only difference in the two WP modes is the method of defining the curves: parameters (WStr, WStop, etc.) are set in WP41, whereas Watt-PF pair arrays are set in WP42.

A10.1 Parameters and FCT

If the watt-power factor specified with WP41, then no Function Capability Table (FCT) is required. If WP42 is used, then the optional parameters of ramp time, time window with random time delay, and timeout period are specified. Table A10.1 provides the FCT for the WP42 function.

Optional Capability for WP42	Yes/No	Action
Time window	No	Run all tests in Table A10-6 without inclusion of the time window
	Yes	Run tests with time window in Table A10-6 using procedures in Appendix 17
Ramp Time	No	Run all tests in Table A10-6 without inclusion of the ramp time
	Yes	Run tests with ramp time in Table A10-6 using procedures in Appendix 18
Timeout period	No	Run all tests in Table A10-6 without inclusion of the timeout period
	Yes	Run tests with timeout period in Table A10-6 using procedures in Appendix 19

Table A10-1. WP42 Function Capability Table

A10.1.1 WP41 – feed-in power controls output power factor

WP41 is used to specify the power factor of the EUT output based on the amount of feed-in power into the EUT. WP41 has the following parameters, as depicted in figure A10-1. All are required parameters.

WP41 initiation - This is a required parameter.

PFStr - This is the (typically, overexcited) power factor of the EUT output at the minimum power output.

PFStop - This is the (typically, underexcited) power factor of the EUT output at the maximum power output.

WStr - This is the maximum level of active power feed-in at which the power factor of EUT output is *PFStr*.

WStop - This is the minimum level of active power feed-in at which the power factor of EUT output is *PFStop*.

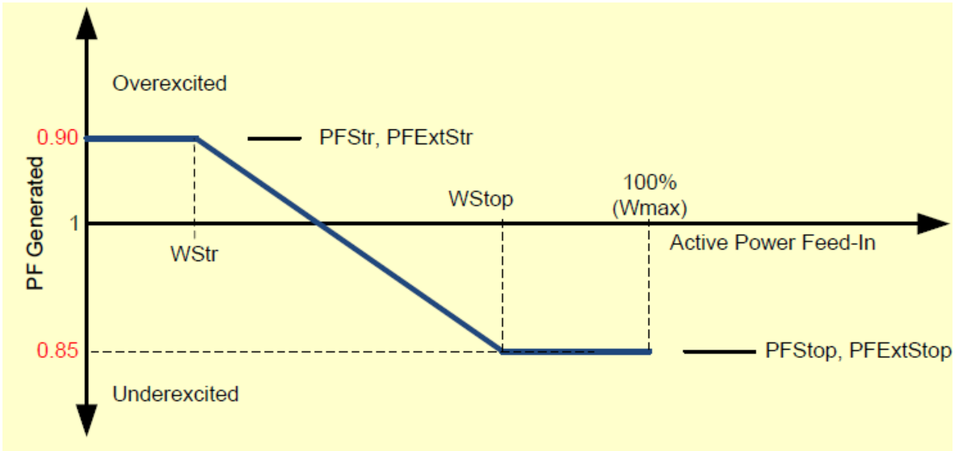


Figure A10-1. Parameters of WP41 Function.

A10.1.2 WP42 – feed-in power controls output power factor with a curve

For WP42, the feed-in power-power factor curve is specified using an array. In addition, there are optional parameters to set the time window, ramp rate, timeout period.

The WP42 array curve will be created using a series of active power-power factor (W, PF) pairs, e.g., W_1, PF_1, W_2, PF_2,…,W_x, PF_x, that define the watt-PF curve. For output power less than W_1, active feed-in power values below W_1 will assume PF_1 target values. Active feed-in power above W_x will target a power factor of PF_x.

Time window is an optional parameter in which the command can be randomly executed.

- If the time window is zero, the command will execute immediately.
- If a time window is specified, then the command will execute at a random time, t, between t = 0 (i.e., immediately) and t = the time window.
- If not included, than the default command time window (if an) or zero (immediate execution) will be used.

Requested ramp time is an optional parameter defining the requested ramp time for the EUT to move from the current setpoint to the new setpoint if it is now either being constrained or released from a constraint.

- If not included, then the default ramp time, if any, for this function will be used.

Timeout period is an optional parameter that defines the time after which the EUT will revert to the default WP curve.

- If not included, then the default timeout period for this function will be used. The default timeout period is expected to be around 15 minutes.

A10.2 Test Precursors

- The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage range for a minimum of 5 minutes. The Utility or Simulator shall be capable of operating with the EUT sourcing and consuming vars.
- The EUT is connected to PV or a PV simulator, with sufficient power available to deliver full EUT rated power output.
- Communication is established between the Utility Management System (UMS) simulator and the EUT.
- Default timing and ramping parameters have been set in the EUT.
- Default power factor of EUT output and PF sign convention have been set.
- The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A10.3 WP41 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	**1**	UMS requests status.	**DS93 (**Status Reporting) & **DM** (direct Measurement) of EUT output	Log time sent.
	2	UMS receives response to DS93 command		Log time received
	3	Inverter EUT output is measured and logged		
	4	Issue command to set Output Power Factor according to feed-in power.	**WP41**– Set Power Factor by feed-in power amount	Log time sent. Command parameters specified in Table A10-4.
	5	EUT responds to command.	**DS92** – change in status noted	Log time received. Expected response from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Electrical Behavior Characterization	**6**	Verify command was successfully executed. (DS92 and DM). Conduct the test while varying input PV power according to Table A10-3 and Figure A10-2.	–	Monitor output power factor level to determine if output is adjusted correctly. Measure and record time, power, and power factor. For three-phase EUTs observe all three phases.
Analysis	**7**	Characterize EUT's response.	**DS92; DM**	Determine how command was executed.

Table A10- 2. WP41 Test Protocol Sequence.

In order to fully evaluate the WP41 function at various DER output states, the input power level must be varied. For a PV inverter, for example, a PV simulator could be used to vary the available PV power according to Table A2-3 and Figure A2- 1, or similar. After 6 minutes (360 seconds) the output power level will remain at 20% WMax.

Time (seconds)	Power Level (% rating)
0	20
15	20
95	100
130	100
134	20
154	20
156	60
191	60
193	20
213	20
217.5	110
253	110
353	20
360	20

Table A10- 3. PV Power Available

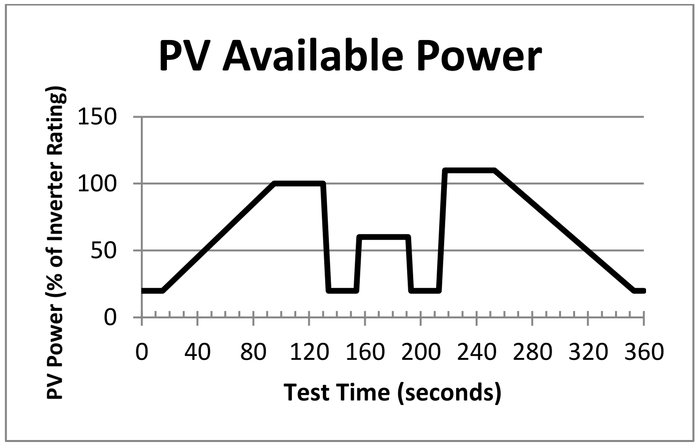


Figure A10-2. Input PV Power Curve.

Table A10-4 suggests parameters to test WP41 as the PV output is being varied as specified in Table A10-3 and Figure A10-2.

Test Number	Powers (% WMax)		Power Factors					
Test 1	WStr	20	PFStr	0.9	PFExtStr	Overexcited	PFSignStr	IEC
	WStop	40	PFStop	0.85	PFExtStop	Underexcited	PFSignStop	IEC
Test 2	WStr	30	PFStr	0.95	PFExtStr	Overexcited	PFSignStr	IEC
	WStop	80	PFStop	0.95	PFExtStop	Underexcited	PFSignStop	IEC
Test 3	WStr	25	PFStr	0.9	PFExtStr	Overexcited	PFSignStr	IEC
	WStop	75	PFStop	0.95	PFExtStop	Underexcited	PFSignStop	IEC
Test 4	WStr	40	PFStr	0.85	PFExtStr	Overexcited	PFSignStr	IEC
	WStop	60	PFStop	0.85	PFExtStop	Underexcited	PFSignStop	IEC

Table A10-4. Suggested Command Parameters for WP41 Test

To test WP42, a WP curve will be set to the inverter. Table A10-5 provides the test sequence. During the test, the PV output (from the PV simulator) will be varied as shown in Table A10-3 and figure A10-2.

	Step	Task	Function	Notes
Communication	1	UMS requests status.	**DS93 (**Status Reporting) & **DM** (direct measurement) of EUT output	Log time sent.
	2	UMS receives response to DS93 command		Log time received
	3	Inverter EUT output is measured and logged		
	4	Issue command to set Output Power Factor according to feed-in power.	**WP42**– Set Power Factor as function of output power.	Log time sent. Command parameters specified in Table A10-6.
	5	EUT responds to command.	**DS92** – change in status noted	Log time received. Expected response from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Electrical Behavior Characterization	6	Verify command was successfully executed. (DS92 and DM). Conduct the test while varying input PV power according to Table A10-3, Figure A10-2.	–	Monitor output power factor level to determine if output is adjusted correctly. Measure and record time, power, and power factor. For three-phase EUTs observe all three phases.
Analysis	9	Characterize EUT's response.	**DS92; DM**	Determine how command was executed.

Table A10- 5. WP42 Test Protocol Sequence.

Table A3- 4 suggests possible parameters to be used for the test of WP42. The PV output is varied as specified in Table A10-3 and Figure A10-2 during each test.

Test Number	Power (% WMax)		Power Factor (IEC notation)		Time Window (sec)	Ramp Time (sec)	Timeout Period (sec)
1	W1 W2	20 40	PF1 PF2	0.85 overexcited 0.85 underexcited	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)
2	W1 W2	25 75	PF1 PF2	0.95 overexcited 0.85 underexcited	Default (e.g., 0)	Default (e.g., 0)	174
3	W1 W2	20 40	PF1 PF2	0.85 overexcited 0.85 overexcited	Default (e.g., 0)	30	174
4	W1 W2	20 40	PF1 PF2	0.85 overexcited 1	30	0	0
5	W1 W2 W3	20 40 80	PF1 PF2 PF3	0.85 overexcited 1 0.90 underexcited	0	0	0
6	W1 W2 W3	20 75 95	PF1 PF2 PF3	0.85 overexcited 1 0.85 underexcited	0	0	0

Table A10-6. Suggested Command Parameters for WP42 Test.

A10.4 Expected Results

After the WP41 command is received by the EUT, and the PV output is varied, the power factor of the EUT varies appropriately.

For WP42, the effect will be the same except the curve is defined with an array as opposed to parameters.

To test the Timeout Period the WP42 command will be released partway through the PV simulator curve so that the EUT returns to unity power factor. This same method is used to test the ramp rate, because as the WP42 command is cancelled with the Timeout Period, the EUT must ramp its unity power factor power over the period defined by the ramp time.

Appendix 11 – VW Set Output to Smooth Voltage Variations (VW51, VW52)

Version 1.0 11 JUL 2013 – Original Draft
Version 2.0 18 JUL 2013 – New test matrix and test profile.
Version 3.0 12 NOV 2013 – Major revision of the VW protocol language and test matrix.

Function VW – Set Output to Smooth Voltage Variations

Voltage-triggered management of DER is used to smooth voltage deviations by increasing or decreasing power supplied by the DER. Multiple voltage-watt modes may be used, such as during peak versus off-peak times, or when the DER is islanded versus grid-connected.

There are two VW modes:
VW51 reduces the DER active power output in response to high grid voltage.

- As voltage rises above nominal, active power output of the DER is reduced. As voltage returns to nominal range, active power output is allowed to increase to original levels.

VW52 limits energy storage charging rates in response to low grid voltage.

- If voltage drops below nominal and energy storage is available, then maximum storage charging rates are reduced.

A11.1 Parameters and FCT

Theoretically it is possible to incorporate hysteresis into a VW mode (different voltage-watt paths when system voltage is deviating from normal versus returning to normal). It is also possible that a random time delay when changing VW modes, a command timeout feature (to revert to default VW mode), and/or ramp rate/time requests (rate of change in EUT output – inverter or storage device – beyond EUT manufacturer-set constraints) may be desired. However, these are not discussed in IEC TR 61850-90-7. Therefore, no Function Capability Table (FCT) is needed for the VW function. If any of these features are indeed included in a DER's VW functionality, they can be tested using the same protocols to test for these features as are used for INV2 and INV4

Optional Capability for VW51 and VW52	Yes/No	Action
Time window	No	Run all tests in Table A10-6 without inclusion of the time window
	Yes	Run tests with time window in Table A10-6 using procedures in Appendix 17
Recovery Ramp Rate	No	Run all tests in Table A10-6 without inclusion of the ramp rate
	Yes	Run tests with recovery ramp rate in Table A10-6
Ramp Rate	No	Run all tests in Table A10-6 without inclusion of the ramp rate
	Yes	Run tests with ramp time in Table A10-6 using procedures in Appendix 18
Timeout period	No	Run all tests in Table A10-6 without inclusion of the timeout period
	Yes	Run tests with timeout period in Table A10-6 using procedures in Appendix 19

VW Voltage/Watt command has the following parameters:

- *VW initiation* command. (VW51 or VW52.) This is required.

- Array of (P, V) pairs (P_1, V_1,…, P_x, Vx) which define a piecewise linear voltage/watt curve.

- *Recovery Ramp Rate* is an optional parameter defining how quickly the DER output returns to normal (default) values after voltage returns to nominal.
- *Requested ramp time* is an optional parameter defining the time the EUT must move from the current set point to the new set point.

  If not included, then the default ramp time for this function will be used.

- *Time window* is an optional parameter in which the command can be randomly executed.

  If the time window is zero, the command will execute immediately. If not included, then the default time window for this function will be used.

- *Timeout period* is an optional parameter that defines the time after which the EUT will reset the power factor set point to the default value.

  If not included, then the default timeout period for this function will be used. The default timeout period is expected to be around 5 minutes.

An example voltage/watt curve for a system is given in Figure A11-1. Figure A11-2 provides an example VW52 voltage/watt curve for an EUT with energy storage.

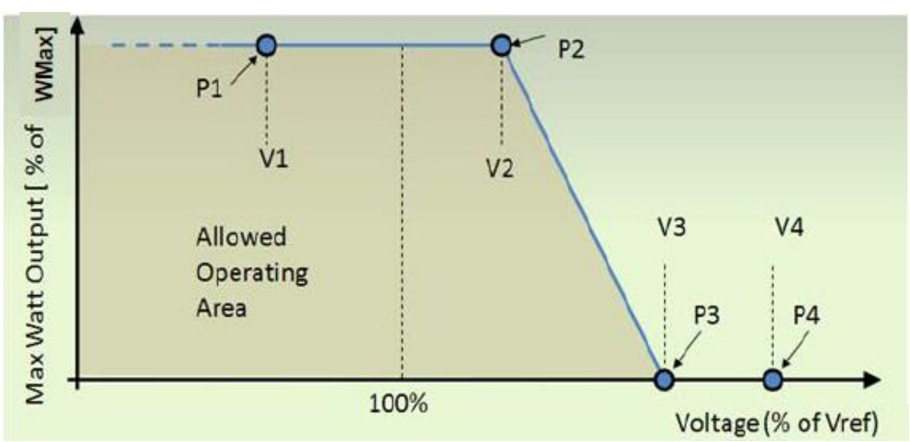


Figure A11-1. Example curve for maximum watts vs. voltage (VW51)

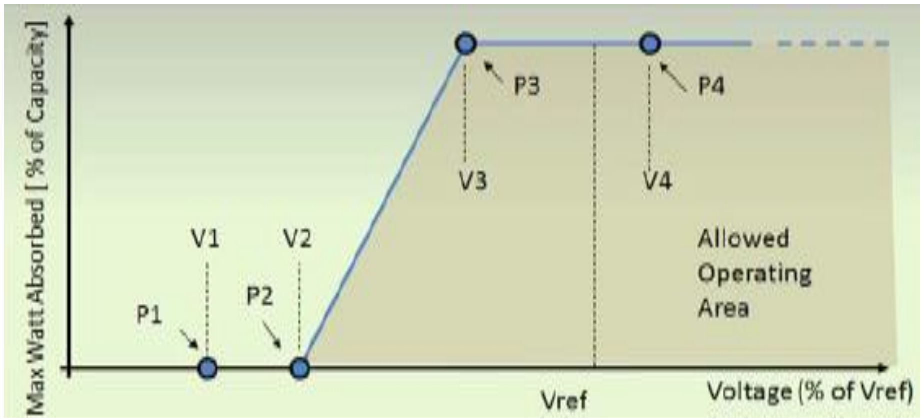


Figure A11-2. Example curve for maximum watts absorbed by energy storage vs. voltage (VW52)

A11.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator with operation within nominal voltage range for a minimum of 5 minutes.

Communications is established between the Utility Management System (UMS) simulator and the EUT.

The EUT is connected to a PV simulator, with sufficient power available to deliver full EUT-rated power output (for VW51).

For VW52, an energy storage simulator with less than full charge (e.g., 30% charge level) shall be connected to the EUT. The EUT is then requested to charge at the maximum rate.

The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A11.3 VW Test Protocol Sequence

Table A11-1 outlines the VW test protocol sequence to verify the inverter receives the VW command and initiates action correctly.

	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93 (**Status Reporting) & **DM** (Direct Monitoring) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	EUT output is measured and logged	**DM**	
	4	UMS issues a VW Command to EUT. (Table A11-2)	**VW51 or VW52** – Voltage/Watt	Log time sent. Command may include Recovery Ramp Rate (optional)
	5	EUT responds to the command.	**DS92** – status change is noted	Expected response message: Successful (DS92 status change) Rejected (includes reason)
Electrical Behavior	6	Verify command was successfully executed by varying the voltage of the grid simulator (Table A11-3) and observing the output of the EUT (VW51) or the charge rate of the EUT (VW52) . Note: The PCS needs to be running in the charge mode to verify the reduction in charging for VW52. The test should be repeated until behavior of the EUT is reasonably understood.		Monitor electrical output/input of EUT. Voltage Active power Reactive power
Analysis	7	Characterize EUT's response.	**DS92; DM**	Determine if command was executed correctly.

Table A11-1: Voltage/Watt Test Protocol Sequence.

Table 11-2 suggests parameters to test VW51. The VW51 curve is defined by (V, P) point pairs, where V is a percentage of nominal system voltage and P is a percentage of rated EUT output power capacity. The grid simulator voltage profile shown in Table A11-3 and Figure A11-4 is executed for each of the tests in Table A11-2.

Test Number	VW51				Time window (sec)	Recovery Ramp Rate (sec)	Ramp Rate (%WMax/sec)	Timeout period (sec)
1	V_1	94	P_1	100	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)
	V_2	101	P_2	100				
	V_3	105	P_3	0				
	V_4	108	P_4	0				
2	V_1	102	P_1	100	20	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)
	V_2	104	P_2	0				
3	V_1	94	P_1	100	0	20	0	20
	V_2	101	P_2	100				
	V_3	105	P_3	0				
4	V_1	94	P_1	100	0	0	5	0
	V_2	101	P_2	100				
	V_3	105	P_3	0				
	V_4	108	P_4	0				
5	V_1	94	P_1	100	0	0	0	0
	V_2	101	P_2	100				
	V_3	105	P_3	50				
	V_4	108	P_4	50				
6	V_1	94	P_1	100	0	0	0	0
	V_2	101	P_2	80				
	V_3	104	P_3	40				
	V_4	108	P_4	0				

Table A11-2. Test matrix for VW51.

Table 11-3 suggests parameters to test VW52. The VW52 curve is defined by (V, P) point pairs, where V is a percentage of nominal system voltage and P is a percentage of maximum EUT charging power, W_{charge}. The grid simulator voltage profile shown in Table A11-3 and Figure A11-4 is executed for each of the tests in Table A11-2.

Test Number	VW51				Time window (sec)	Recovery Ramp Rate (sec)	Ramp Rate ($\%W_{charge}$/sec)	Timeout period (sec)
1	V_1	92	P_1	0	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)
	V_2	95	P_2	0				
	V_3	99	P_3	100				
	V_4	106	P_4	100				
2	V_1	95	P_1	0	20	Default (e.g., 0)	Default (e.g., 0)	Default (e.g., 0)
	V_2	99	P_2	100				
3	V_1	95	P_1	0	0	20	0	20
	V_2	99	P_2	0				
	V_3	106	P_3	100				
4	V_1	92	P_1	0	0	0	5	0
	V_2	95	P_2	0				
	V_3	99	P_3	100				
	V_4	106	P_4	100				
5	V_1	92	P_1	50	0	0	0	0
	V_2	95	P_2	50				
	V_3	99	P_3	100				
	V_4	106	P_4	100				
6	V_1	92	P_1	0	0	0	0	0
	V_2	95	P_2	40				
	V_3	99	P_3	80				
	V_4	106	P_4	100				

Table A11-3. Test matrix for VW52.

Time (sec)	Voltage (% nominal)
0	100
30	100
30	106
60	106
60	94
90	94
90	100
120	100
135	106
150	106
180	94
195	94
210	100
240	100
245	106
250	106
260	94
265	94
270	100
300	100

Table A11-3: Volt/Watt test profile.

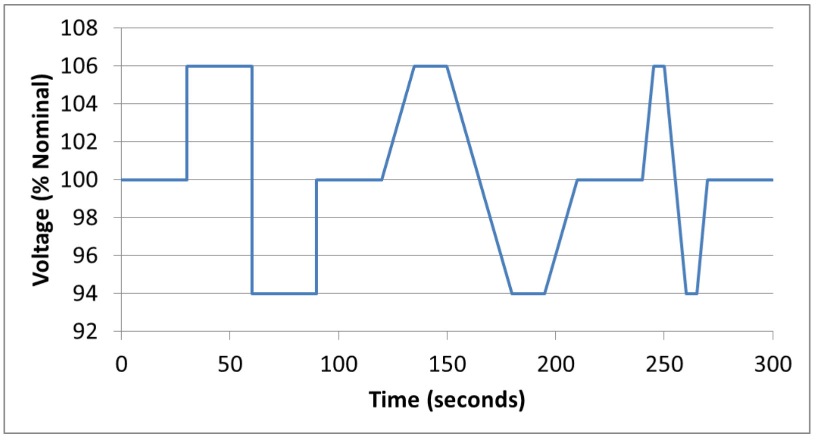


Figure A11-4: Volt/Watt test profile.

A11.4 Expected Results

After the VW command is received by the EUT, the grid voltage will run through the test profile. For VW51, the EUT power output will decrease when the system voltage increases sufficiently. As system voltage is decreased, the EUT output will return to the maximum output.

For VW52, the rate of charging will begin to decrease as system voltage decreases sufficiently. The charging rate will return to the commanded (maximum) values when the voltage increases again.

Appendix 12 – TMP Temperature Mode Behavior

Version 1.0 22 JUN 2013 – Original DRAFT
Version 2.0 18 JUL 2013 – Revised
Version 3.0 1 AUG 2013 - Revised

Function TMP – Temperature Mode Behavior

The temperature mode invokes a temperature curve that triggers an action based on ambient temperature as an external variable. In the temperature curve, the temperature is the primary value of the curve, while the secondary value identifies the action to take, classified as an advanced inverter function (as specified in Table 1 and Appendices 1 -11 or 20). Actions to be taken when the temperature is within one of the specified temperature ranges can include basic functions, such as adjust power factor (INV3), or other modes, such as maximum var support mode (VV12).

The logic that would formulate a command based on temperature and action to be taken would likely reside in a higher level controller: managing a building, a campus, a power park, a microgrid, a load aggregation, etc. In these instances, the higher level controller would function like a Utility Management System Simulator (UMSS) functions. Testing a controller (or UMSS) as EUT is outside the scope of this protocol.

Therefore, to test an inverter's ability to respond to ambient temperature according to a specified Temperature Mode Curve, different inverter functions will be enabled when the temperature changes. Two examples are provided below for temperature-enabled INV commands. Those commands from the controller could be any of the commands defined in Appendices 1 – 11, and they will be tested according to the protocols in Appendices 1 – 11. A basic command, such as INV4 (request power from storage) would be given when the controller calculates that high temperatures will cause peak loads and warrants discharging the storage medium.

A more involved function could be the decision to support the grid with maximum var output (from storage and inverters) when the temperature is high enough (this is the TMP example given in IEC TR 61850-90-7). This would be a VV12 function triggered by high ambient temperatures.

An example test matrix for verifying temperature as a variable is shown in Table A12-1. In order to test the TMP function, temperatures within each of the temperature ranges are selected and the behavior of the inverter mode is characterized. For example, test one could be completed by selecting temperatures of 5, 20, and 35°C and then running the test profile from INV3 in Figure A3-1. In order to avoid having to actually vary the ambient temperature during the test, a simulated temperature measurement can be used as input, with the capability of varying the reported temperature, just as the utility simulator can vary to "observed" voltage.

Test	Temperature Range	Inverter Mode	Inverter Mode Parameters			
1	T ≥ 30°C	INV3	PF = 0.90 underexcited	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
	10°C < T < 30°C	INV3	PF = 0.95 underexcited	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
	T ≤ 10°C	INV3	PF = 1	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
2	T > 25°C	INV1	Disconnect			
	T ≤ 25°C	INV2	Connect			

Table A12-1: Example TMP test matrix.

To test the EUT's response to a TMP command, the TMP command will be formulated to change the parameters of another advanced DER inverter command and the test protocol for that command (Appendices 1 – 11 or 20) will be followed, to verify that the proposed temperature-related parameters were set correctly and the command executed properly.

To summarize, TMP commands will be treated as modifying the parameters of another command or defining the logic of a controller that will function as a UMSS. The test protocols in Appendices 1 – 11 or Appendix 20 will not be affected, since in populating the Function Capability Tables (FCT) for each command, the possibility of using temperature as an external variable that triggers an inverter (or storage) action has already been provided.

Appendix 13 – PS Utility Signal Mode

Version 1.0 22 June 2013 – Original DRAFT
Version 2.0 18 JUL 2013 – Revised
Version 3.0 1 AUG 2013 - Revised

Function PS – Utility Signal mode

This function simply provides values for a utility price signal as an independent variable.

IEC TR 61850-90-7 specifies that price may vary by time of day. This could be by period (e.g., 6 am to 2 pm, or 0600 – 1400), hourly, or at any other interval, such as by half hour or by 15-minute period.

The price could be for energy ($/kWh), reserves ($/kW), reactive power support ($/kVAr), frequency support, or other ancillary services.

The PS command, as defined in IEC TR 61850-90-7, consists of a "pricing signal curve" and a dependent variable defining the action to be taken.

The points of the price signal curve can be specified by:

- Time
- Unit of price to be defined (e.g., kW, kWh, kVAr)
- Numerical value of the price

There could be multiple price curves, such as one for kW or kWh and one for kVAr, as long as they are not contradictory (e.g., two curves for watts).

In fact, internal logic at the DER or higher-level aggregator (for a building, campus, power park, microgrid, or load aggregation) will likely be required to determine the action to take in terms of prioritization/optimization when there are multiple price curves, even if the curves are "non-contradictory," as defined in 61850-90-7. As an example, the higher-level controller could be required at times of high kWh and high kVAr prices, both calling for maximizing output of storage. In this case, is the storage output (discharge) provided at unity (kWh) or other (kVAr for maximum var support) power factor?

This logic would likely reside in a higher level controller: managing a building, a campus, a power park, a microgrid, a load aggregation, etc. In these instances, the higher level controller would function identically to how the Utility Management System Simulator (UMSS) functions. Testing such a controller (or UMSS) as EUT is outside the scope of this protocol (as is testing the response of multiple interconnected inverters to an advanced function).

To test an individual DER's ability to respond to a utility signal, a range of methods could be used, but knowledge of the inverters controls is necessary to verify it has the ability to change modes of operation.

For example, a basic command, such as INV4 (request power from storage) would be activated when the EUT receives a signal indicating that the current electricity price ($/kW or $/kWh) warrants discharging the storage medium.

A more involved function could be the decision to support the grid with maximum var output (from storage and inverters) when the price of a kVAr is high enough. This would be a VV12 function triggered by high kVAr prices.

To test the EUT's response to a PS command, the PS command will be formulated to change the parameters of a table or another advanced DER inverter command and the test protocol for that command (specified in Appendices 1 – 11 or 20) will be followed to verify that the proposed response to a utility signal or curve/mode to be activated by a utility signal were set correctly and the command executed properly.

For instance, Test 1 in the Table A13-1 could be completed by selecting energy prices of \$0.05/kWh, \$0.15/kWh, and \$0.25/kWh. Specifics of the test must be determined depending on the pricing-action logic, the inverter mode, and the type of EUT.

Test	Price Range	Inverter Mode	Inverter Mode Parameters			
1	P ≥ \$0.20/kWh	INV4	Discharge@ MaxWatts	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
	\$0.06/kWh < P, P < \$0.20/kWh	INV4	Charge@ MaxWatts/2	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
	T ≤ \$0.06/kWh	INV4	Charge@ MaxWatts	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
2	T > \$0.15/kWh	INV4	Disharge@ MaxWatts/2	Ramp Rate = 10	Time Window = 60	Timeout Period = 600
	T ≤ \$0.15/kWh	INV4	Charge@ MaxWatts/2	Ramp Rate = 10	Time Window = 60	Timeout Period = 600

Table A13-1: Example PS test matrix.

To summarize, PS commands will be treated as modifying the parameters of another command (Table 1 in the Main Document) or defining the logic of a controller that will function as a UMSS. The test protocols in Appendices 1 – 11 or Appendix 20 will not be affected, since in populating the Function Capability Tables (FCT) for each command, the possibility of using price or other utility signal as an external variable that triggers an inverter (or storage) action has already provided.

Appendix 14– DS92 Event History/Logging

Version 1.0 19 October 2012 – Original Version

DS92 – Event/History Logging

Event/history logs are maintained by the inverter-based DER systems to record key time-stamped events. This function reads the event log by selecting the time ranges in response to a command from the utility controller or "event codes." This function enables the different users of the DER to retrieve event logs with relevant information for their purposes.

A14.1 Parameters

1. Start time: Initial timestamp from which event history will be retrieved. If start time = 0, then the start time will be the beginning of the log
2. Stop time: End timestamp for event history query. If stop time = 0, then the stop time will be the end of the log
3. Event Code: Field to query a specific event type.

A14.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator for a minimum of 5 minutes.
Communication is established between the Utility DMS simulator and the EUT.
This test will be conducted with the other test commands. After each test sequence for the previous commands, verify the information stored in the log file by performing this test sequence.
The fields in the event log have been pre-set, including as a minimum date and timestamp, reference to the data element triggering the log entry, and the value of that data element
The triggers for inclusion in the event log have been established, including:

- All errors or failures (service tracking and logging)
- All startup and shutdown actions (logging)
- All control actions (service tracking and logging)
- All responses to control actions (service tracking and logging)
- All limit violations, including returns within limits (logging)

Inverter log must have events stored in Log file in order to complete test. A test log file can be loaded with sample events to demonstrate ability to retrieve and display events.

A14.3 Event to be Tested

Table A14- 1 presents a list of specific events to be tested. Not all events will be available on each inverter. If an event is not available on the specific inverter under test, the event will be identified as unavailable in the test report. If there are additional events available within the inverter, these shall be added to the list and test results documented.

Domain	Part	Type	Attribute	Description
Communication	Messaging	Status	Success	Request received successfully. Value field identifies the request as a "demand response"
	Messaging	Status	Success	Command received successfully. Value field identifies the command as a "Direct command"
	Messaging	Status	Acknowledged	Response – acknowledgment sent
	Messaging	Alarm	Message Failed	Response – alarm invalid message. Value field contains type of error
	Network Interface	Alarm	Comm. Failed	Alarm communications error. Value field contains

				type of error
PV System	Inverter	Command	Success	Action taken successfully (details are provided in Mode and Command events)
	Inverter	Command	Failed	Requested action failed. Value field contains type of error.
	Inverter	Command	Deviation	Action taken is a deviation from the requested action. Data Reference and Value fields contain indication of this deviation
	Inverter	Command	INV Command	Inverter responded to one of the INV commands, as indicated in the Value field
	Inverter	Status	Limit Exceeded	Inverter status changed due to internal control threshold exceeded. Data Reference and Value fields provide details
	Mode	Status	Inverter Mode	Inverter is in one of the inverter modes, as indicated in the Value field
	Schedule	Schedule Change	Success	Action was successfully taken in response to the scheduled requirement
	Schedule	Schedule Change	Failed	Action failed in response to the scheduled requirement. Value field indicates the type of error
	Power	Status	Power Out	Inverter power turned off
	Power	Status	Power On	Inverter power turned on
	Power	Alarm	Power Out	Power tripped off due to internal situation
	Power	Alarm	DC Voltage	Inadequate DC bus voltage, Value field provide measured value
	Power	End Alarm	DC Voltage	DC bus voltage within limits. Value field provide measured value
	Temperature	Alarm	Limit Exceeded	Temperature limit exceeded. Value field contains type of error.
	Temperature	End Alarm	Limit Exceeded	Returned within temperature limit. Value field contains type of error
Grid Power	ECP Switch	Status	Connected	Switch at the ECP between inverter and the grid is connected
	ECP Switch	Status	Disconnected	Switch at the ECP between inverter and the grid is disconnected
	Voltage	Alarm	Limit exceeded	Voltage limit exceeded. Value field contains voltage measurement
	Voltage	Alarm End	Limit exceeded	Returned within voltage limit. Value field contains voltage measurement
	Voltage	Alarm	Limit exceeded	Voltage distortion limit exceeded. Value field contains voltage distortion
	Voltage	Alarm End	Limit exceeded	Returned within voltage distortion limit. Value field contains voltage distortion
	Current	Alarm	Limit exceeded	Current limit exceeded. Value field contains current measurement
	Current	Alarm End	Limit exceeded	Returned within current limit. Value field contains current measurement
	Power Quality	Alarm	Limit exceeded	Harmonic limit exceeded. Value field contains harmonic measurement
	Power Quality	Alarm End	Limit exceeded	Returned within harmonic limit. Value field contains harmonic measurement
	Other 1547 Parameters	Alarm	Limit exceeded	High/low limit exceeded
	Other 1547 Parameters	Alarm End	Limit exceeded	Returned within high/low limit
Device Asset	Logs	Status	Almost Full	Log is almost full. Value contains percentage full
	Logs	Alarm	Full	Log full: new events to overwrite unread events
	Time	Alarm	Clock Failed	Clock failure. Value contains error information
	Time	Alarm	Synch Failed	Synchronization failed. Value contains error information
	Time	Setting	Synchronized	Synchronized. Value contains delta between new time and old time
	Time	Setting	Daylight Adjust	Daylight time or Standard time adjustment. Value indicates Daylight of Standard
	Firmware	Alarm	Data Error	Data error detected in firmware. Value indicates type of error

Table A14- 1. Event List.

A14.4 Test Protocol Guidelines

Table A14- 2 outlines the DS92 test protocol sequence. This sequence will be used for each of the events defined in Table 1. In addition to the events defined in Table 1, the following datasets / event log categories shall be conducted.

- Log Dump: Start Time = 0, End Time = 0
- All errors or failures
- All startup and shutdown actions
- All control actions
- All response to control actions
- All limit violations including return to within limits.

Each individual event log review and each of the above listed reviews shall be conducted four times.

1. Start Time = 0, End Time = 0
2. Start Time = A, Stop Time = B
3. Start Time = C, Stop Time = D
4. Start Time = E, Stop Time = F

Where A, B, C, D, E, and F represent different times.

Step	Task	Function	Notes
1	Issue read Event/History Log.	**DS92** – Event/History Logging	Log time sent. Command includes: event codes to retrieve start/stop time for which to retrieve events
2	Receive response to the command.	–	Log time received. Expected response message: Successful Rejected (include reason)
3	Verify command was successfully executed by reviewing log entries.	–	Requested log entries should be transmitted. Verify appropriate log messages corresponding to the previous commands and responses received from other testing

Table A14- 2. DS92 Test Protocol Sequence.

All tests results (Pass / Fail) shall be documented in a table similar to Table A14- 3.

A14.5 Expected Results and Test Log

Table A14-3 presents the expected results for each test and a place to log the results for each test. For conditions that are not supported by the inverter, document this exception within the results table. For capabilities beyond those presented, these capabilities shall be documented in the test results table along with the results of the test.

Domain	Part	Type	Expected Result	Test 1 (Pass/Fail)	Test 2 (Pass/Fail)	Test 3 (Pass/Fail)	Test 4 (Pass/Fail)
Communication	Messaging	Status	Expected Log Entries				
	Messaging	Status	Expected Log Entries				
	Messaging	Status	Expected Log Entries				
	Messaging	Alarm	Expected Log Entries				
	Network Interface	Alarm	Expected Log Entries				
PV System	Inverter	Command	Expected Log Entries				
	Inverter	Command	Expected Log Entries				
	Inverter	Command	Expected Log Entries				
	Inverter	Command	Expected Log Entries				
	Inverter	Status	Expected Log Entries				
	Mode	Status	Expected Log Entries				
	Schedule	Schedule Change	Expected Log Entries				
	Schedule	Schedule Change	Expected Log Entries				
	Power	Status	Expected Log Entries				
	Power	Status	Expected Log Entries				
	Power	Alarm	Expected Log Entries				
	Power	Alarm	Expected Log Entries				
	Power	End Alarm	Expected Log Entries				
	Temperature	Alarm	Expected Log Entries				
	Temperature	End Alarm	Expected Log Entries				
Grid Power	ECP Switch	Status	Expected Log Entries				
	ECP Switch	Status	Expected Log Entries				
	Voltage	Alarm	Expected Log Entries				
	Voltage	Alarm End	Expected Log Entries				
	Voltage	Alarm	Expected Log Entries				
	Voltage	Alarm End	Expected Log Entries				
	Current	Alarm	Expected Log Entries				
	Current	Alarm End	Expected Log Entries				
	Power Quality	Alarm	Expected Log Entries				
	Power Quality	Alarm End	Expected Log Entries				
	Other 1547 Parameters	Alarm	Expected Log Entries				
	Other 1547 Parameters	Alarm End	Expected Log Entries				

Domain	Part	Type	Expected Result	Test 1 (Pass/Fail)	Test 2 (Pass/Fail)	Test 3 (Pass/Fail)	Test 4 (Pass/Fail)
Device Asset	Logs	Status	Expected Log Entries				
	Logs	Alarm	Expected Log Entries				
	Time	Alarm	Expected Log Entries				
	Time	Alarm	Expected Log Entries				
	Time	Setting	Expected Log Entries				
	Time	Setting	Expected Log Entries				
	Firmware	Alarm	Expected Log Entries				
Log Dump			Expected Log Entries				
All Failures			Expected Log Entries				
All Startup/Shutdown			Expected Log Entries				
All Control Actions			Expected Log Entries				
Control Action Responses			Expected Log Entries				
Limit Violations			Expected Log Entries				

Table A14- 3. Expected Results and Test Record.

Appendix 15 – DS93 Status Reporting

Version 1.0   19 October 2012 – Original Version

DS93 – Status Reporting

Many functions require the status of the inverter-based DER system either periodically, on significant change of a value, or upon request. This function requests the current operational state of the PV/storage system in response to a command from the utility controller. Manufacturers are required to provide reporting status of one or more data elements on receiving a request. The manufacturer may also provide for status updates periodically or upon significant status change. The details of implementing the status reporting are left up to the manufacturers.

A15.1 Parameters

Status value or status data sets are left up to the manufacturer but it is recommended that they contain parameters shown in Table A15-1.

Status Point	Description	Verification
Primary information		
Connect Status	Whether or not the EUT is currently connected to the EPS	Verify EPS is present and within standard voltage range.
PV output available	Yes/No – (PV available above min for time window)	Verify PV array is present and within EUT specified range.
Storage output available	Yes/No – (Storage connected and SOC above minimum)	Verify storage is connected and within EUT specified range.
Status of var capability	Yes/No – (EUT capable of adjusting var output)	If yes, verify operation according to EUT specification.
EUT active power output	Current power output in watts – (Instantaneous or minimum average reading)	Verify measured output is the same as status message.
EUT reactive power output	Current reactive power output in vars – (Instantaneous or minimum average reading)	Verify measured output is the same as status message.
Current mode	Current operating mode – (enumeration of possible operating modes including “owner mode”)	
Detailed information		
Inverter status	On/off/standby (on- operating, off – not able to operate, standby – capable of operating but not on)	Verify status with operating modes.
DC current level available for operation	Yes/No (Is there sufficient DC current available to operate)	Compare status reported when Irradiance (available PV) is very low and at high level.
EUT Inverter’s active power output	Current power output of inverter in watts – (Instantaneous or minimum average reading)	Verify measured output is the same as status message.
DC inverter input power	Current power input to inverter in watts – (Instantaneous or minimum average reading)	Verify measured DC input is the same as status message.
Local/Remote control mode	EUT is under local or remote control	Verify operating state.
Real power set point	Value of real power set point	Verify power output matches set point with adequate available input power.
Reactive power set point	Value of reactive power set point	Verify reactive power output matches set point with adequate available input power (real and reactive).
Power factor set point	Value of power factor set point	Verify output power factor matches set point with adequate available input power (real and reactive).
Power measurements		
Real power	Current real output power plus high and low limits.	Verify EUT output matches status message.
Reactive power	Current reactive output power plus high and low limits.	Verify EUT output matches status message.
Voltage phase to neutral or ground	Current phase voltages to neutral or ground plus high and low limits	Verify voltages match status message.
Power Factor	Current output power factor plus high and low limits	Verify EUT output matches status message.
Storage status (if included in EUT)		
Capacity rating	Usable capacity of the storage (Wh)	
State of charge	Current available energy as percent of capacity (%)	

Status Point	Description	Verification
Available energy	Current number of Wh available for use	
Maximum charge rate	Maximum allowable rate of energy transfer into storage (W)	
Maximum discharge rate	Maximum allowable rate of energy transfer out of storage (W)	
Battery voltage	Current battery terminal voltage	Verify measured DC voltage is the same as status message.
DC inverter power input from storage	Current power input to inverter from storage in watts – (Instantaneous or minimum average reading)	Verify measured DC input is the same as status message.
Nameplate and Setting information		
Manufacturers name	Text string	Record value.
Model	Text string	Record value.
Serial number	Text string	Record value, verify number matches unit if available.
EUT power rating	Continuous output power rating (W)	Verify EUT can output rated power.
EUT apparent power rating	Continuous output apparent power rating (VA)	Verify EUT can output rated apparent power in VA.
EUT reactive power rating	Continuous output reactive power rating (var)	Verify EUT can output rated reactive power.
Maximum charge rate	Maximum allowable rate of energy transfer into storage (W)	
Maximum discharge rate	Maximum allowable rate of energy transfer out of storage (W)	
Storage present	Yes/No – does system contain storage	Record value.
PV present indicator	Yes/No – does system contain PV	Record value.
Time resolution	EUT clock resolution and precision	Record value.
Source of time synchronization	Text string	Record value.

Table A15-1. Standardized Status Messages.

A15.2 Test Precursor

The EUT is connected to the Utility or Utility Simulator for a minimum of 15 minutes.

Communication is established between the Utility DMS simulator and the EUT.

Any sets of data to be reported together are established.

A15.3 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	**1**	Identify available status points and method for obtaining them.		
Communication	**2**	Issue Request Status Command.	**DS93** – Status Reporting	Log time sent. Command includes: identity of which status value or which data set to return
Communication	**3**	Receive response to the command.	–	Log time received. The following is returned: requested status values timestamp quality of status values or Failed (include reason)
Communication	**4**	Repeat as needed	–	
Analysis	**5**	Characterize EUT's response.		Determine if the function was executed as expected. Determine if status is valid.

Table A15- 2. DS93 Protocol Test Guidelines.

Steps 2 through 5 will be repeated a minimum of three (3) times (Scheduled, On-Demand, and upon status value change) for each of the values presented in Table 4. Status messages not available in the inverter will not be tested but will be documented in the test results as not available. Any status messages available in the inverter and not listed in Table 1 will be added to the test and have the test results documented.

All tests shall be conducted to be able to retrieve status messages locally through a communication port on the inverter as well as over the network connection. The above stated tests shall be conducted under both of these conditions.

A15.4 Expected Results and Test Result Log

Table A15- 3 presents the expected results for each test and a place to log the results for each test. For conditions that are not supported by the inverter, document this exception within the results table. For capabilities beyond those presented, these capabilities shall be documented in the test results table along with the results of the test.

Status Point	Expected Value	Test 1 (Scheduled) Pass/Fail	Test 2: (On-Demand Pass/Fail	Test 3: (Status Change)
Primary information				
Connect Status	Whether or not the EUT is currently connected to the EPS			
PV output available	Yes/No – (PV available above min for time window)			
Storage output available	Yes/No – (Storage connected and SOC above minimum)			
Status of var capability	Yes/No – (EUT capable of adjusting var output)			
EUT active power output	Current power output in watts – (Instantaneous or minimum average reading)			
EUT reactive power output	Current reactive power output in vars – (Instantaneous or minimum average reading)			
Current mode	Current operating mode – (enumeration of possible operating modes including “owner mode”)			
Detailed information				
Inverter status	On/off/standby (on- operating, off – not able to operate, standby – capable of operating but not on)			
DC current level available for operation	Yes/No (Is there sufficient DC current available to operate)			
EUT Inverter’s active power output	Current power output of inverter in watts – (Instantaneous or minimum average reading)			
DC inverter input power	Current power input to inverter in watts – (Instantaneous or minimum average reading)			
Local/Remote control mode	EUT is under local or remote control			
Real power set point	Value of real power set point			
Reactive power set point	Value of reactive power set point			
Power factor set point	Value of power factor set point			
Power measurements				
Real power	Current real output power plus high and low limits.			
Reactive power	Current reactive output power plus high			

Status Point	Expected Value	Test 1 (Scheduled) Pass/Fail	Test 2: (On-Demand Pass/Fail	Test 3: (Status Change)
	and low limits.			
Voltage phase to neutral or ground	Current phase voltages to neutral or ground plus high and low limits			
Power Factor	Current output power factor plus high and low limits			
Storage status (if included in EUT)	Storage status (if included in EUT)			
Capacity rating	Usable capacity of the storage (Wh)			
State of charge	Current available energy as percent of capacity (%)			
Available energy	Current number of Wh available for use			
Maximum charge rate	Maximum allowable rate of energy transfer into storage (W)			
Maximum discharge rate	Maximum allowable rate of energy transfer out of storage (W)			
Battery voltage	Current battery terminal voltage			
DC inverter power input from storage	Current power input to inverter from storage in watts – (Instantaneous or minimum average reading)			
Nameplate and Setting information				
Manufacturers name	Text string			
Model	Text string			
Serial number	Text string			
EUT power rating	Continuous output power rating (W)			
EUT apparent power rating	Continuous output apparent power rating (VA)			
EUT reactive power rating	Continuous output reactive power rating (var)			
Maximum charge rate	Maximum allowable rate of energy transfer into storage (W)			
Maximum discharge rate	Maximum allowable rate of energy transfer out of storage (W)			
Storage present	Yes/No – does system contain storage			
PV present indicator	Yes/No – does system contain PV			
Time resolution	EUT clock resolution and precision			
Source of time synchronization	Text string			

Table A15- 3. DS93 Expected Results and Test Log.

A15.5 Special Remarks

Any settable data should be readable upon request. The list of that data will be implementation – and/or vendor – specific, but it should utilize existing standards where possible.

Appendix 16 – DS94 Time Synchronization

Version 1.0 19 October 2012 – Original Version

DS94 – Time Synchronization

The inverter-based DER system will use the time synchronization services specified in IEC 61850-8-1. This function synchronizes the EUT time to its controlling entity in response to a command from the utility management system. This function uses the Network Time Protocol (NTP) (RFC-1305) or Simple Network Time Protocol (SNTP) (RFC-1305) between the controlling entity and the EUT to set time.

A16.1 Parameters

None

A16.2 Test Precursors

The EUT is connected to the Utility or Utility Simulator for a minimum of 15 minutes.
Communication is established between the Utility DMS simulator and the EUT.
An NTP and/or SNTP server is available on the network.

A16.3 Test Protocol Sequence

	Step	Task	Function	Notes
Communication	**1**	Issue time synchronization command.	**DS94** – Time Synch	Log time sent. Supply NTP and SNTP time servers on the network.
	2	Verify the time setting using the status function.	–	
	3	Validate that the EUT will respond to the Broadcast Address (responses to the commands should not be received).		
Analysis	**4**	Characterize EUT's response.		Determine if the function was executed as expected. Determine if status is valid.

Table A16- 1. DS94 Test Protocol Sequence.

NTP is capable of operating in three configurations and shall be tested under each configuration. These are:

- **Client/Server:** a host that requires timing information (the client) sends a request to a designated unicast server and expects a reply from that server. In some contexts this would be described as a "pull" operation, in that the client pulls the time from the server.
- **Symmetric:** or peer modes are intended for configurations were a clique of low-stratum peers operate as mutual backups for each other. Each peer operates with one or more

primary reference sources, such as a radio clock, or a subset of secondary servers known to be reliable. Should one of the peers lose all reference sources or simply cease operation, the other peers will automatically reconfigure so that time can flow from the surviving peers to all the others in the clique.

- **Broadcast:** Broadcast modes are intended for configurations involving one or a few servers and a possibly very large client population on the same subnet. In broadcast modes, the broadcast server should generate broadcast messages continuously at some pre-specified interval. A broadcast client should respond to the first message received, after waiting for a random interval, by polling the server in burst mode in order to quickly set the host clock and validate the source. Once the clock has been set, the broadcast client should not send any further messages to the server and should simply listen for broadcast messages on the designated interface.

A16.4 Expected Results

Table A16- 2 presents the expected results for each test and a place to log the results for each test. For conditions that are not supported by the inverter, document this exception within the results table.

Metric	Expected Value	Client/Server (Pass/Fail)	Symmetric (Pass/ Fail)	Broadcast (pass/Fail)
Time	EUT time matches Reference Time			

Table A16- 2. DS94 Expected Results and Test Log.

Appendix 17 – Time Window & Random Time Delay

Version 1.0 19 October 2012 – Original Version
Version 2.0 10 May 2013 – Revisions

Time Window and Random Time Delay

With tens of thousands of inverter-based DER in an electric power system, an immediate and simultaneous action by each inverter could affect system stability, cause transients in transmission and distribution lines, and/or activate protective devices or initiate system stabilization measures. While some actions must happen as soon as possible, such as disconnecting the inverter in compliance with anti-islanding safety standards, others are aimed at improving system efficiency and can take several minutes, or longer, to initiate and to complete. An example of the latter is the command to charge or discharge energy storage, in response to a broadcast utility price signal or a change in tier of a time of use rate.

A17.1 Parameters

Time window is an optional parameter in which the command is executed after a delay. The delay will be a random time uniformly distributed between zero and the time window.

If the time window is zero, the command should execute immediately.
If not included, then the default time window for this function will be used. The default time window is chosen by the EUT manufacturer.

A17.2 Test Precursors

- To implement the random time delay, each inverter shall be assigned a number between 0 and 1. The value of that number shall be random, uniformly distributed between 0 and 1. Manufacturers may choose to have the inverter select the random number in different ways:
- Every time the inverter receives an INV command, it generates a random number.
- The manufacturer may randomly assign a constant time delay number to each inverter.
- The manufacturer must specify how the random number is selected, assigned, or generated.

A17.3 Test Protocol Guidelines

- The time delay test does not have to be repeated for each combination of the other optional parameters (ramp rate and timeout period) for a function. The test of the time period delay can be conducted for one set of other optional parameters.
- For DER that include electric vehicle chargers, the INV4 (storage charge/discharge) and INV5 (storage respond to signal) commands might be used to level the charging schedule EV over the utility's off-peak period. In this case, time windows of 3 to 5 hours might be used, and if so, could be tested. However, for this protocol, only shorter time windows are included in order to keep the duration of the test manageable. The protocol verifies the operation of the time delay function, and changing the time delay parameter.
- The test protocols for each function (previous appendices) specify suggested values of *Time Window* to be tested. The objectives of the tests of this Appendix are:
    - To verify that the time delay is varies randomly by inverter and/or for each command execution. (i.e., to verify that the same fixed time delay is not used every time for every inverter)

- To test a wider range of *Time Window* parameters than is specified for each individual function.

Random number generated with each command:

- To test this, the INV command shall be communicated 3 times, and the time of operation of the EUT in response shall be recorded. The test will verify that the action was initiated after 3 different delays, each delay being between 0 and Time Period seconds after the INV command was received.

Random number assigned to each inverter:

- To test random time delay in this case, the function shall be broadcast 3 times, with 3 different time delays as specified in Table A17- 1, or similar values. For example, if the time delay windows are 60 and 300 seconds, the test shall verify that the time of operation was d and 5d minutes (with $0<d<1$) for the 3 operations. This verifies that there is a built-in time delay. To verify that the delay is random (i.e., not uniform for all the manufacturer's inverters), 3 separate inverters shall be examined and tested.

Function	Time Delays to be Tested (seconds)
INV1	0, 60, 300
INV2	0, 60, 300
INV3	0, 60, 300
INV4	0, 60, 300; possibly 3 – 5 hours for EV charge testing
INV5	0, 60, 300; possibly 3 – 5 hours for EV charge testing

Table A17- 1. Time Delay Windows to be Tested or Each INV Function.

A17.4 Expected Results

The EUT begins to execute the command after a random length delay within the specified time window.

Appendix 18 – Ramp Rate

Version 1.0   19 October 2012 – Original Version
Version 2.0   10 May 2013 – Revisions
Version 3.0   22 Nov 2013 – Redefined parameter

Ramp Rate

Devices cannot change their output instantaneously; all have an inherent rate of change capability. The time it takes to go from one setting to another is the ramp rate. Some equipment may be damaged by too fast a transition (e.g., rapid charge or discharge of a battery), and the manufacturer will build in constraints to the rate of change to prevent this.

In addition to the manufacturer-implemented ramp rate constraints, there may be a further constraint, in watts/second, on how quickly output of a DER (or, in the case of battery charging, input to the DER) can change.

A18.1 Parameters

Ramp rate is expressed as a percentage of the specific capability. For instance, if the ramp rate controls DER power, the ramp rate will be in units of percentage max output power per unit time, i.e., % Wmax/sec. *Ramp rate* is an optional parameter. If not included, then the default ramp rate will be used. The default ramp rate is chosen by the EUT manufacturer.

A18.2 Test Precursors

A ramp rate constraint (in terms of % of allowable ramp rate) is selected.

A18.3 Test Protocol guidelines

- The test protocols for each function (previous appendices) specify suggested values of *Ramp Rate* to be tested. The objective of this Appendix is to describe the generic procedure for testing *Ramp Rate*, if it is desired to test more *Ramp Rate* parameter values than are specified in the individual function test protocols.
- The ramp rate test does not have to be repeated for each combination of the other optional parameters (time delay and timeout period) for a command. The test of the ramp rate can be conducted for one set of other optional parameters.
- The *Ramp Rate* test procedure is:
  - A function (i.e., INV command) is tested with the manufacturer's default ramp rate.
  - A new ramp rate is sent to the EUT.
  - The INV command is sent to the EUT.
  - The EUT's response is noted and compared to the response with no ramp rate specified (i.e., the default ramp rate is used).
  - Set a new ramp rate of 0.75 of the default in order to test the ability to change maximum ramp rate of the EUT.

A18.4 Expected Results

The magnitude of output of the EUT conforms to the ramp rate constraint.

Appendix 19 – Command Timeout

Version 1.0   19 October 2012 – Original Version
Version 2.0   10 May 2013 – Revisions

Command Timeout

When powering up, DER revert to their default states. For example, when an inverter is energized, it automatically will connect to the PV panel and the power system. Control commands from a power system (utility management system), local controller (building energy management system), or internal (to the DER) modes or schedule may change the DER performance to other than default. The command timeout capability guards against missed (not received) commands or failures communications from the utility management system (or other local control system) to the DER by ensuring that the DER will revert to its default state after a certain time if there is no command to the contrary.

As an example, an INV3 command could change the inverter output power factor from default (1.0) to 0.8 overexcited. If the inverter fails to receive the subsequent command to return to default (1.0) power factor, then it will do so anyway after the timeout period. With a timeout period of 15 minutes, the INV3 command to set output power factor to 0.8 should be "refreshed" or rebroadcast every 10 minutes.

A19.1 Parameters

Timeout Period for commands affecting specific parameters of the DER/EUT.

A19.2 Test Precursors

EUT is operating in default state for a minimum of 5 minutes.

A command timeout period is selected.

A19.3 Test Protocol Guidelines

The test protocols for each function (previous appendices) specify suggested values of *Command Timeout* to be tested. The objective of this Appendix is to describe the generic procedure for testing *Command Timeout*, if it is desired to test more *Command Timeout* parameter values than are specified in the individual function test protocols.

The timeout test does not have to be repeated for each combination of the other optional parameters (time delay and ramp rate) for INV1 – INV5. The test of the timeout period can be conducted for one set of other optional parameters.

The *Command Timeout* test procedure is:

- A function command is sent to the EUT, with a timeout rate specified.
- The function command is repeated, within the timeout period.
- The function command is not repeated within the timeout period (i.e., the function command is allowed to "expire")
- The EUT's response is noted to determine:
    - That the EUT accepted and responded correctly to the function command and its re-broadcast
    - That the EUT reverted to default conditions after the function command had not been re-broadcast a second time within the timeout period

- Note that for some functions (e.g., energy storage charge scheduling for electric vehicles, using INV4 or INV5), the time response window and period of execution could be quite long. For the test, an artificially shorter time window and timeout period may be used in order to conduct the tests within a reasonable length of time. However, for functions and applications that require large timeout periods (e.g., setting a power factor for a 6 to 8 hour period; charging an electric vehicle over the course of a 10 hour nighttime period), at least one actual test sequence with a multi-hour timeout period should be included.

A19.4 Expected Results

The EUT retains the changed settings when a function command is re-broadcast within the timeout period.

The EUT reverts to default settings when no new command is received before the timeout period elapses.

Appendix 20 – L/HFRT Low and High Frequency Ride Through

Version 1.0 3 July 2013 – Original DRAFT
Version 2.0 1 AUG 2013 – Revisions
Version 3.0 12 NOV 2013 – Major revisions to text and test matrix.

Function L/HFRT – Low and High Frequency Ride Through

For safety reasons (both personnel and equipment), inverters are required to disconnect (i.e., "trip") from the grid during certain conditions. While some standards, such as IEEE 1547, specify those conditions, the standards' requirements are changing. For example, IEEE 1547a is an update to the base IEEE 1547 introduced in 2003. Its main purpose is to permit the DER system to actively regulate frequency at the point of common coupling (PCC), so long as the Area EPS operator approves and this active frequency regulation does not compromise the unintentional islanding detection and disconnect function. It will also permit the high and low limits of both voltage and frequency to be extended for specific time periods so that voltage and frequency ride-through by DER systems can occur.

The L/HFRT function is designed for those inverters with the capability to update their trip curves and their ride-through (or "must-stay-connected") curves.

A20.1 Parameters and Function Capability Table (FCT)

L/H FRT is not a function in IEC TR 61850-90-7, but it has been proposed as a mandatory inverter capability for California under CEC/CPUC Rule 21[2]. The reason is that the higher penetrations of renewable energy on the grid are providing a wider range of normal operating frequencies, and as a result the utility does not wish to lose the power generation of DERs if a frequency drop is caused by changing production or load, not a fault.

Since L/HFRT is not included in IEC TR 61850-90-7 and does not have optional parameters there is no Function Capability Table (FCT). However, the *L/HFRT* command has the following parameters:

L/HFRT initiation command. This is required. The command consists of:

- Four sets of point pairs in the form (t_1, F_1, t_2, F_2,…, t_x, F_x) that define the *L/HFRT* curves. An example, *disconnect/must-trip* or *may-trip* (also known as *must-stay-connected*) pair of curves is shown in Figure A20-1. The requirements in IEEE Standard 1547 and 1547a are located in Tables A20-1 and A20-2.

[2] CEC/CPUC, Candidate DER Capabilities: Recommendations for Updating Technical Requirements in Rule 21, Version 16, June, 2013

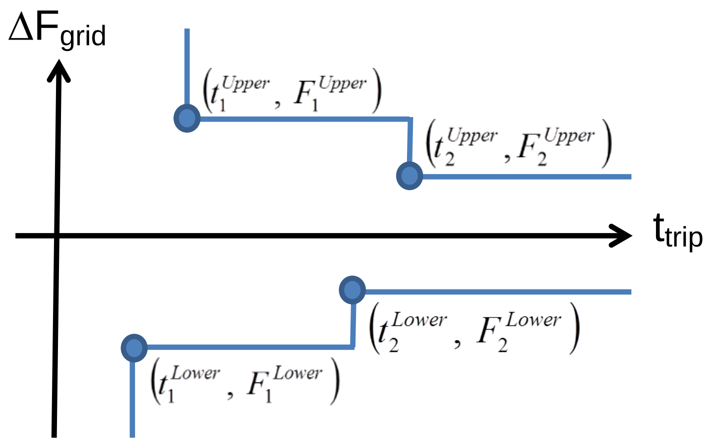


Figure A20-1: Example L/HFRT curves using (t, F) point pairs.

DR size	**Frequency range (Hz)**	**Clearing time(s)[a]**
≤ 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 to 300
	< 57.0	0.16
[a]DR ≤ 30 kW, maximum clearing times; DR > 30 kW, default clearing times.		

Table A20-1: IEEE Standard 1547 L/HFRT curves.

Function	Default settings		Ranges of adjustability[(a)]	
	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s)
UF1	57	0.16	56 – 60	0 – 10
UF2	59.5	20	56 – 60	0 – 300
OF1	60.5	20	60 – 64	0 – 300
OF2	62	0.16	60 - 64	0 - 10
(a) Unless otherwise specified, default ranges of adjustability shall be as stated.				

Table A20-2: IEEE Standard 1547a L/HFRT curves.

A20.2 Test Precursors

- The EUT is connected to the Utility Simulator with operation within nominal voltage and frequency range for a minimum of 5 minutes. The Utility simulator has the capability to vary the frequency seen by the EUT.
- The EUT is connected to PV simulator, with sufficient power available to deliver full EUT rated power output or at least the power level required by the command to be given.
- Communication is established between the UMS simulator and the EUT.
- The output of the EUT (voltage, current, power factor) is measured directly, and the data are logged.

A20.3 L/HFRT Test Protocol Sequence

Table A20-3 outlines the L/HFRT test protocol sequence to verify the inverter receives the command and initiates action correctly. In general, the initiation of advanced DER functions is not time-critical.

	Step	Task	Function	Notes
Communication	1	UMS requests status from EUT.	**DS93** (Status Reporting) and **DM** (Direct Measurement) of inverter output	Log time sent.
	2	UMS receives response to the DS93 command.		Log time received.
	3	UMS issues a L/HFRT Command to EUT, using one of the sets of parameters in Table A20-5.	**L/HFRT**	Log time sent. *Command will include sets of point pairs, as indicated in Figure A20-1, with values specified in one of the groupings of Table A20-4.*
	4	EUT responds to the command.	**DS92** – Change in status noted	Expected response message: - Successful - Rejected (includes reason)
Electrical Behavior	5	Set the power level to 33% or 100% using the PV simulation. Verify L/HFRT command was successfully executed by setting grid frequencies according to the Table A20-5 with the grid simulator. If the test causes the inverter to trip off, communications need to be re-established with the DS93 command.	**DM** – EUT output is recorded and logged	Monitor electrical output of EUT.
	6	Repeat test with varying parameters (Table A20-4). Each test should be repeated until behavior of the EUT is reasonably understood.		

	Step	Task	Function	Notes
Analysis	7	Characterize EUT's response.	**DS92; DM**	Determine if command was executed correctly.

Table A20-3: L/HFRT Test Protocol Sequence.

Table A20-5 gives suggested test parameters. For each tests, the (t, F) parameters in Table A20-4, are sent to the EUT and the grid frequency is set to F_{nom}. The frequency will be set to values of 0.2 % greater and less than each of the F_i points. For instance, in Test 1, all the F values are 98.83 and 100.83 % of F_{nom}. Therefore the test frequencies will be 98.83±0.2% and 100.83±0.2% or 98.63, 99.03, 100.63 and 101.03 percent of nominal grid frequency. These frequency values will be run until the EUT trips off or after 305 seconds (slightly longer than the greatest t_i value). In some cases the number of test frequencies can be reduced.

Test # and L/HFRT Curves	Must Trip Upper Limit				May Trip Upper Limit				Must Trip Lower Limit				May Trip Lower Limit			
1. IEEE 1547 ≤ 30 kW	t_1	0.16	F_1	100.83					t_1	0.16	F_1	98.83				
2. IEEE 1547 > 30 kW (max t_2, min F_2)	t_1	0.16	F_1	100.83					t_1	0.16	F_1	95.00				
									t_2	300	F_2	99.67				
3. IEEE 1547 > 30 kW (max t_2, max F_2)	t_1	0.16	F_1	100.83					t_1	300	F_1	95.00				
4. IEEE 1547 > 30 kW (max t_2, min F_2)	t_1	0.16	F_1	100.83					t_1	0.16	F_1	95.00				
									t_2	300	F_2	99.67				
5. IEEE 1547a 30 kW (Default)	t_1	0.16	F_1	103.33					t_1	0.16	F_1	95.00				
	t_2	20.00	F_2	100.83					t_2	20.00	F_2	99.16				
6. IEEE 1547a ("Wide Open")	t_1	300	F_1	106.67					t_1	300	F_1	93.33				
7. IEEE 1547a 30 kW (Default with RT)	t_1	0.16	F_1	103.33	t_1	0.08	F_1	102.00	t_1	0.16	F_1	95.00	t_1	0.08	F_1	97.00
	t_2	20.00	F_2	100.83	t_2	10.00	F_2	100.50	t_2	20.00	F_2	99.16	t_2	10.00	F_2	99.50
8. IEEE 1547a ("Wide Open" with RT)	t_1	300	F_1	106.67	t_1	1.00	F_1	103.00	t_1	300	F_1	93.33	t_1	1.00	F_1	97.00
					t_2	10.00	F_2	101.00					t_2	10.00	F_2	99.00

Table A20-4: Test matrix for L/HFRT tests. Each test is conducted at 33% and 100% of rated power by adjusting the PV simulator.

Test # and L/HFRT Curves	Test Frequencies (% F_{nom})	Frequencies for 60 Hz Grid (Hz)	Frequencies for 50 Hz Grid (Hz)	Expected Result
1. IEEE 1547, ≤ 30 kW	98.63	59.178	49.315	Trip by 0.16 s
	99.03	59.418	49.515	No trip
	100.63	60.378	50.315	No trip
	101.03	60.618	50.515	Trip by 0.16 s
2. IEEE 1547, > 30 kW (max t_2, min F_2)	94.80	56.880	47.400	Trip by 0.16 s
	95.20	57.120	47.600	Trip by 300 s
	98.63	59.178	49.315	Trip by 300 s
	99.03	59.418	49.515	No trip
	100.63	60.378	50.315	No trip
	101.03	60.618	50.515	Trip by 0.16 s
3. IEEE 1547, > 30 kW (max t_2, max F_2)	94.80	56.880	47.400	Trip by 300 s
	95.20	57.120	47.600	No trip
	100.63	60.378	50.315	No trip
	101.03	60.618	50.515	Trip by 0.16 s
4. IEEE 1547, > 30 kW (max t_2, min F_2)	98.63	59.178	49.315	Trip by 0.16 s
	99.03	59.418	49.515	Trip by 300 s
	94.80	56.880	47.400	Trip by 300 s
	95.20	57.120	47.600	No trip
	101.63	60.978	50.815	No trip
	100.83	60.498	50.415	Trip by 0.16 s
5. IEEE 1547a (Default)	94.80	56.880	47.400	Trip by 0.16 s
	95.20	57.120	47.600	Trip by 20 s
	98.96	59.376	49.480	Trip by 20 s
	99.36	59.616	49.680	No trip
	100.63	60.378	50.315	No trip
	101.03	60.618	50.515	Trip by 20 s
	103.13	61.878	51.565	Trip by 20 s
	103.53	62.118	51.765	Trip by 0.16 s
6. IEEE 1547a ("Wide Open")	93.13	55.878	46.565	Trip by 300 s
	93.53	56.118	46.765	No trip
	106.47	63.882	53.235	No trip
	106.87	64.122	53.435	Trip by 300 s
7. IEEE 1547a (Default with RT)	94.80	56.880	47.400	On 0.08 s, Trip by 0.16 s
	95.20	57.120	47.600	On 0.08 s, Trip by 20 s
	96.80	58.080	48.400	On 0.08 s, Trip by 20 s
	97.20	58.320	48.600	On 10 s, Trip by 20 s
	98.96	59.376	49.480	On 10 s, Trip by 20 s
	99.30	59.580	49.650	On 10 s, No Trip
	99.36	59.616	49.680	On 10 s, No Trip
	99.70	59.820	49.850	No Trip
	100.30	60.180	50.150	No trip
	100.63	60.378	50.315	On 10 s, No Trip
	100.70	60.420	50.350	On 10 s, No Trip
	101.03	60.618	50.515	On 10 s, Trip by 20 s
	101.80	61.080	50.900	On 10 s, Trip by 20 s
	102.20	61.320	51.100	On 0.08 s, Trip by 20 s
	103.13	61.878	51.565	On 0.08 s, Trip by 20 s
	103.53	62.118	51.765	On 0.08 s, Trip by 0.16 s

8. IEEE 1547a (“Wide Open” with RT)	93.13	55.878	46.565	Trip by 300 s
	93.53	56.118	46.765	On 1.00 s
	96.80	58.080	48.400	On 1.00 s
	97.20	58.320	48.600	On 10.00 s
	98.80	59.280	49.400	On 10.00 s
	99.20	59.520	49.600	No trip
	100.80	60.480	50.400	No trip
	101.20	60.720	50.600	On 10.00 s
	102.80	61.680	51.400	On 10.00 s
	103.20	61.920	51.600	On 1.00 s
	106.47	63.882	53.235	On 1.00 s
	106.87	64.122	53.435	Trip by 300 s

Table A20-5: Test matrix for L/HFRT tests. Each test (the L/HFRT Curves) is conducted at 33% and 100% of rated power by adjusting the PV simulator.

A20.4 Expected Results

If L/H FRT command is received by the EUT, for each of the frequency test points, the EUT will connect, disconnect, or remain connected/disconnected, as appropriate, for the L/H FRT zones defined by the (t, F) point pairs in the command. This will be verified by direct measurement of EUT output (DM) and by logging of EUT status and data (DS92). The tests will be conducted at 33 and 100% of rated power of the EUT.

APPENDIX A – Event Log Fields

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All event logs will contain the following five fields:

Date and time stamp: The accuracy of this timestamp will be determined by the frequency of time synchronization and the innate precision in keeping time of the PV system, and is therefore outside the scope of this specification. Zeros can be used to pad any timestamp if the accuracy does not match the format.

Data reference: The reference to the data item that triggered the event log entry. For instance, if it is a voltage-related event, the Data Reference will be to that data object. If it is a PV Mode event, the Data Reference will be to the PV Mode data object.

Value: Value field of the Data reference field that is triggering the event, including commands, state changes of monitored values, quality code changes, mode setting, etc. For instance, the request to go into a specific PV mode will be logged with the Value containing the PV mode identity.

Event code: Four-part code to uniquely identify the type of event – see Table A1- 2.

Optional text field: Text of supporting information. This text will not be standardized, but can be used to provide additional details about the event.

To enable the filtering of events so that different users can select different types of events to retrieve, event codes are established. These event codes are based on the IEC 61968-9 (CIM for distribution) event codes, with additions as necessary to address inverter events. The Event Code standard contains many codes, with only a small fraction relevant to PV/Storage systems. The more important ones (including additional ones) are described in Table A1- 2, but different implementations may choose different sets of event types, including vendor-specific and/or implementation-specific event types.

The codes are built from four levels: Domain, Part, Type, and Attribute. In this Specification, four existing Domains are used:

Communications (for communication-related events)
Grid power (for power system events)
Device asset (for time and asset-related events)
Security (for security-related events)

Two new domains are defined:

PV system (for PV inverter events, as well as other PV events)
Storage system (for storage inverter events, as well as other storage events)

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