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Technical Reference

Protective Relay Functions for Capstone Microturbines

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1. Introduction

The Capstone MicroTurbine® generator may be connected in parallel to a utility grid to power local grid connected loads. When installed in this fashion, power generated by the microturbine is supplied to these loads only when the utility grid voltage is present. Utilities commonly require that protective relay devices be installed with generators connected to their grid. The primary purpose of these devices is to ensure that the local generator will not energize utility wires de-energized by the utility. Typically, these protective relay devices are dedicated relays or solid state power analyzers that provide control signals to disconnecting devices. This document presents information for the protective relay functions incorporated into Capstone Microturbines.

Capstone Microturbines include intelligent power controllers, which operate as self-commutated, current controlled inverters when connected to a utility grid.

The power controller in the various models is referred to as:

- Digital Power Controller (DPC) in the Model C30.
- Engine Control Module (ECM) and Load Control Module (LCM) in the Model C65 microturbine.
- Generator Control Module (GCM) and Load Control Module (LCM) in the Model C200 and C1000 series microturbine.

To maintain consistency and ease of reference, all models will be referred to as the "power controller" throughout this document.

The microturbine has protective relay functions built into the power controller unit. Programmable settings for the protective relay functions are stored in nonvolatile memory within the power controller. As a result, any changes remain set even after an interruption in utility power. Detailed information on the Capstone Microturbine may be found in the microturbine User's Manual.

During utility grid voltage interruptions, the microturbine senses the loss of utility voltage and disconnects from the grid and the local loads. When the grid voltage returns to within its specified limits, the microturbine may be programmed to restart and supply power to the connected loads. Figure 1 shows the relationship between the microturbine, local loads and the utility grid.

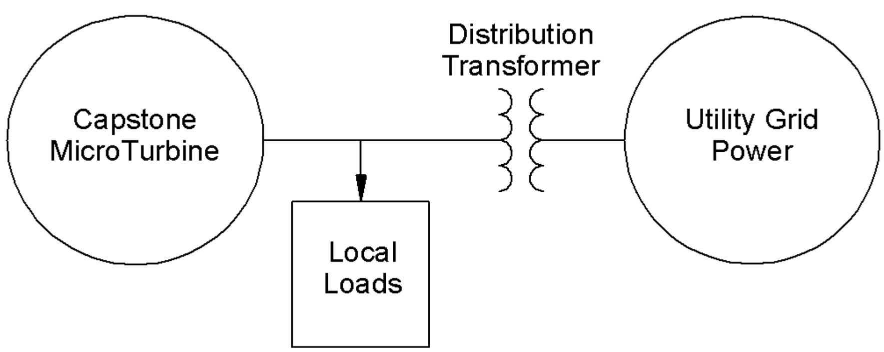


Figure 1. Capstone Microturbine Grid Connect System Configuration

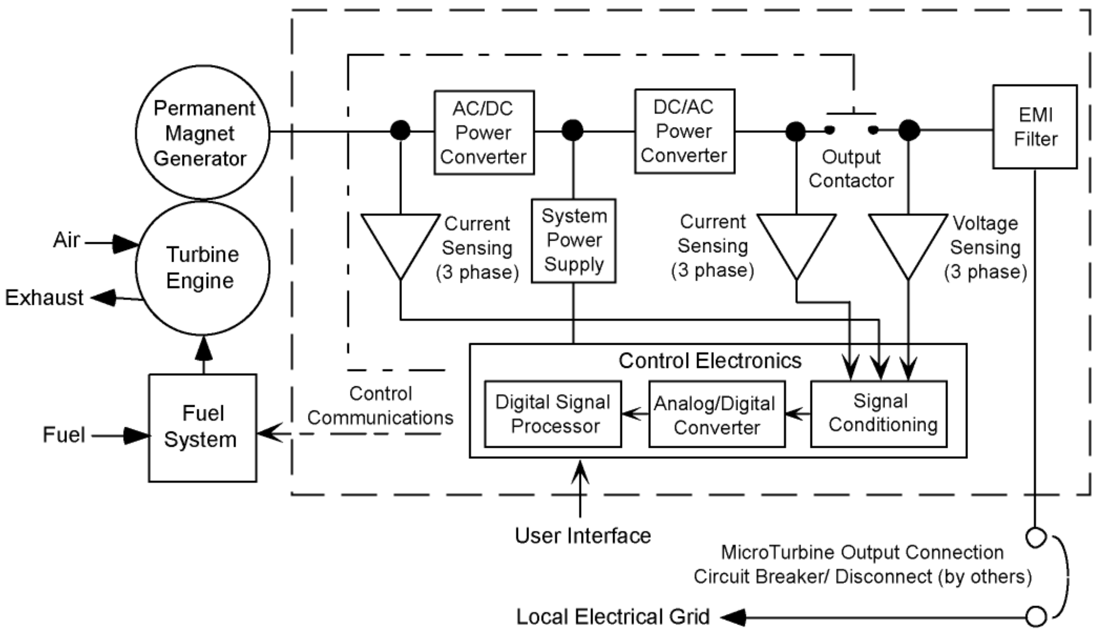
2. Power Controller Operation Overview

Figure 2 shows a block diagram of the microturbine installed in Grid Connect mode.

A gas turbine engine integral with a high-speed permanent magnet generator is called the turbogenerator.

The power controller converts high frequency power from the turbogenerator into 50/60 cycle AC power.

During the startup sequence, power flow through the power controller is reversed. Grid power is used to motor the turbogenerator. When power is available from the turbogenerator, the power controller converts generator output to a 3-phase 50/60 Hz power synchronized with the utility grid.



NOTE: It is essential for safe operation and service that a current limiting disconnect device be installed between the power controller and the utility grid. Local electric codes will almost always require such a disconnect. The added protection of this disconnect device is not considered here.

Figure 2. Capstone Microturbine – Functional Block Diagram for C30, C65 and C200 Models

2.1. Power Controller Components and Function

The operation and power conversion functions of the microturbine are controlled by the power controller. Major components of the power controller are two 3-phase inverters, power-conditioning equipment, a microprocessor-based system controller, and an auxiliary power supply for the controls.

The output power requirements for voltage and current including fault limits can be found in the Model C30 Electrical (410000), Model C65 Electrical (410001), Model C200 (410066) and C1000 Series (410072) Technical Reference documents. Voltage and current harmonics of the power controller conform to IEEE 519-1992[1] at rated power.

Other power controller functions include:

- Supervisory control of the microturbine operation (including protective relay functions)
- Microturbine safety supervision
- Internal communications with auxiliaries
- External communications with the user and with other equipment

3. Grid Connect Features

When connected to an energized grid, the power controller inverter supplies current into the grid. Under these conditions, the power controller follows the prevailing grid voltage and frequency.

	NOTE: Due to line and/or transformer impedance, the current produced by the Capstone Microturbine may change the voltage at the point of connection.

Power delivered by the power controller is proportional to the product of current flow and the line voltage. The power controller will deliver constant power, subject to power controller hardware current limits, until the user initiates a control change or one of the protective relay functions described below becomes active.

The algorithms used to operate the power controller provide excellent protection against islanding[2] in the absence of utility-supplied grid voltage. Near short or near open islands are detected within a few cycles through loss of current control. Islands whose loads are more closely matched to the power controller output will be detected by the Rate of Change of Frequency and built-in Active Anti-Islanding protection.

[1] IEEE 519-1992. IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. Institute of Electrical and Electronics Engineers, New York.

[2] Islanding: "A condition in which a portion of the utility system that contains both load and operating generation, which is not under utility control, remains energized while isolated from the remainder of the utility system.

4. Protective Functions

The protective functions included in the power controller are described in this section. Voltage sensing and signal processing are illustrated in Figure 2. The Protective Function designator numbers correspond to those published by IEEE[3].

▶	NOTE: All protective function measurements and calculations are based on the Line-to-Neutral voltage values. However, for convenience, all protective function settings are entered as equivalent Line-to-Line voltage values.

4.1. Under Voltage (Protective Function 27)

4.1.1. Primary Under Voltage Trip

Refer to Table 1 for the adjustable ranges and microturbine defaults for the primary under voltage settings. These settings include the under voltage trip point and the allowable time period before the voltage trip occurs. The primary voltage trip point may be adjusted upwards within the range indicated in Table 1 and still comply with UL1741. The primary duration to trip may also be adjusted downwards as indicated in Table 1 and still comply with UL1741.

The UL1741 requirement for this function is:

- The device should cease to energize the output within 2 seconds when any of the phase voltages is lower than 244 V_{L-N} while the other phase voltages remain at 277 V_{L-N}.

The California Rule 21 requirement for this function is:

- The device should cease to energize the output within 2 seconds when the distribution system voltage drops below 88% of generating system voltage.

4.1.2. Fast Under Voltage Trip

Refer to Table 1 for the adjustable ranges and microturbine defaults for the fast under voltage settings. These settings include the fast under voltage trip point and the allowable time period before the voltage trip occurs. The fast under voltage trip point may be adjusted upwards as indicated in Table 1 and still complies with UL1741. The duration to the voltage trip may also be adjusted downwards as indicated in Table 1 and still comply with UL1741.

The UL1741 requirement for this function is:

- The device should cease to energize the output within 6 cycles when any of the phase voltages is lower than 139 V_{L-N} while the other phase voltages remain at 277 V_{L-N}.

The California Rule 21 requirement for this function is:

- The device should cease to energize the output within 0.16 seconds when the distribution system voltage drops below 50% of generating system voltage.

[3] IEEE C37.90-1989. IEEE Standard relays and Relay Systems Associated with Electric Power Apparatus. Institute of Electrical and Electronics Engineers, New York.

4.1.3. Microturbine Under Voltage Implementation

As shipped, each power controller is tested to verify that it meets both UL1741 and California Rule 21 requirements to do the following:

- Initiate a Grid Fault Shutdown if any phase-to-neutral voltage sags to less than 264 V_{L-N} for duration greater than 2.0 seconds.
- Cease power export to the grid within 100 ms if the voltage drops to 139 V_{L-N}. If the grid voltage re-stabilizes to a level between the primary under voltage trip and the primary over voltage trip levels within 1.0 second of the initial fast under voltage event, then the power controller will resume power export to the grid, otherwise a grid fault shutdown is initiated.

The Under Voltage protective functions are illustrated in Figure 3 and Figure 4. The under voltage trips are programmed into the power controller as phase-to-phase voltages. Voltages indicated in Figure 3 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 1. Under Voltage Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Range	Default	RS-232 Command
Under Voltage	If the voltage on any phase falls below this setting for greater than Under Voltage Time, the system will shut down.	352 to Over Voltage (L-L) in 1 Volt increments	C30: 428 C65/C200: 422	UNDVLT
Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Under Voltage limit.	C30: 0.3 to 10 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 1.90 C65/C200: 2.00	UVLTTM
Fast Under Voltage	The system will cease to export power to the grid if any phase voltage drops below this voltage for greater than Fast Under Voltage Time.	0 to Under Voltage (L-L) in 1 Volt increments	C30: 264 C65/C200: 240	FSTUVL
Fast Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Fast Under Voltage limit.	C30: 0.03 to 1.00 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 0.095 C65/C200: 0.100	UVFSTM

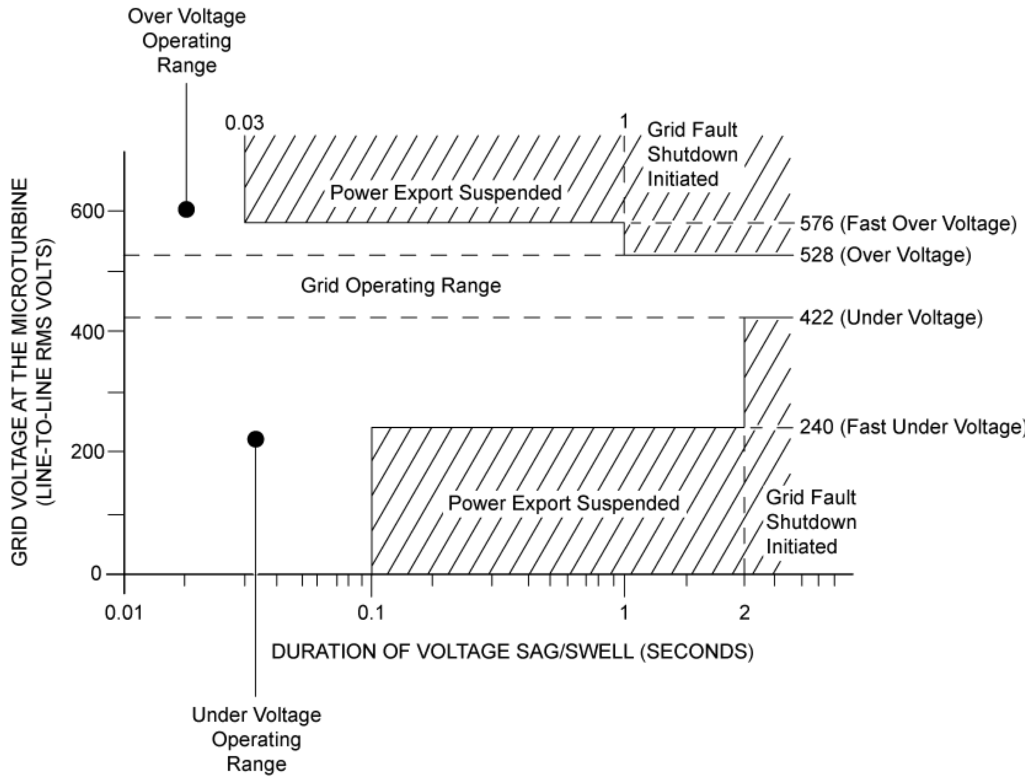


Figure 3. Grid Fault Shutdown Trip Limits for Over/Under Voltage Events (C65/C200)

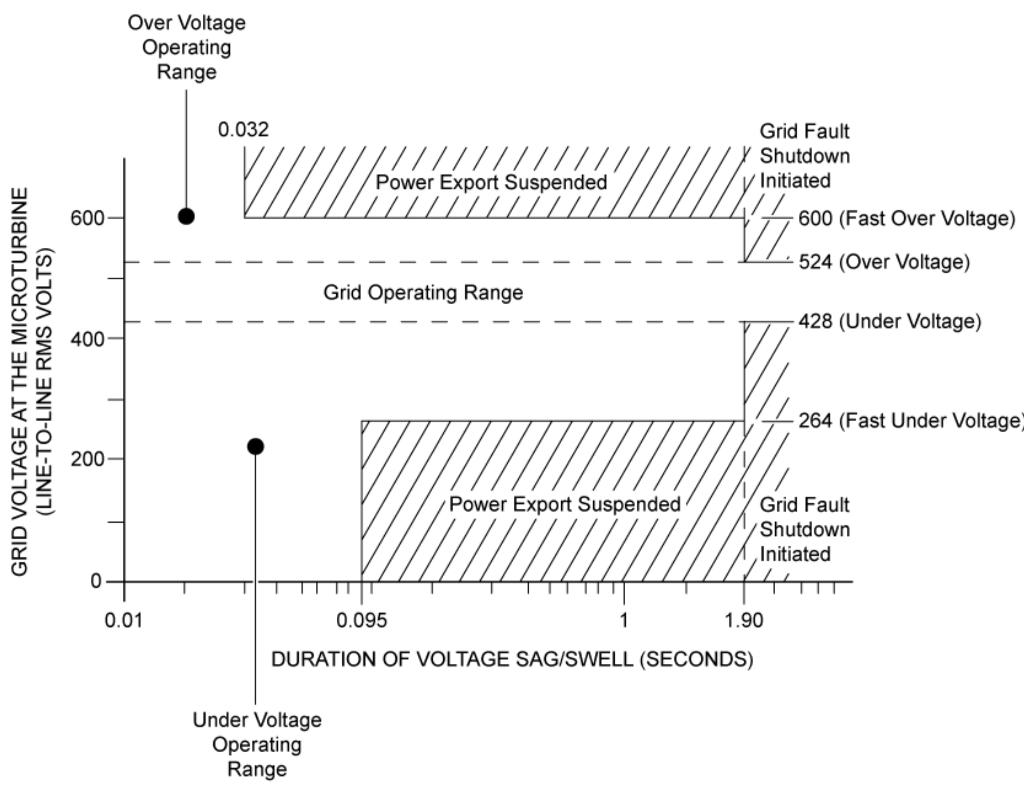


Figure 4. Grid Fault Shutdown Trip Limits for Over/Under Voltage Events (C30)

4.2. Over Voltage (Protective Function 59)

4.2.1. Primary Over Voltage Trip

Refer to Table 2 for the adjustable ranges and microturbine defaults for the primary over voltage settings. These settings include the over voltage trip point and the allowable time period before the voltage trip occurs. The primary voltage trip point may be adjusted downwards within the range indicated in Table 2 and still comply with UL1741. The primary duration to trip may also be adjusted downwards as indicated in Table 2 and still comply with UL1741.

The UL1741 requirement for this function is:

- The device should cease to energize the output within 2 seconds when any of the phase voltages is higher than 305 V_{L-N} while the other phase voltages remain at 277 V_{L-N}.

The California Rule 21 requirement for this function is:

- The device should cease to energize the output within 1 second when the distribution system voltage exceeds 110% of generating system voltage.

4.2.2. Fast Over Voltage Trip

Refer to Table 2 for the adjustable ranges and microturbine defaults for the fast over voltage settings. These settings include the fast over voltage trip point and the allowable time period before the voltage trip occurs. The fast over voltage trip point may be adjusted downwards as indicated in Table 2 and still comply with UL1741. The duration to Fast Over Voltage Trip may also be adjusted downwards as indicated in Table 2 and still comply with UL1741.

The UL1741 requirement for this function is:

- The device should cease to energize the output within 2 cycles when any of the phase voltages is higher than 379 V_{L-N} while the other phase voltages remain at 277 V_{L-N}.

The California Rule 21 requirement for this function is:

- The device should cease to energize the output within 0.16 second when the distribution system voltage exceeds 120% of generating system voltage.

4.2.3. Microturbine Over Voltage Implementation

As shipped, each power controller is tested to verify that it meets both UL1741 and California Rule 21 requirements to do the following:

- Initiate a grid fault shutdown if any phase voltage swells to greater than 305 V_{L-N} for duration greater than 2.0 seconds.
- Cease power export to the grid within 32 ms if any phase voltage swells to 312 V_{L-N}. If the grid voltage re-stabilizes to a level between the primary under voltage trip and the primary over voltage trip levels within 1.0 second of the initial fast over voltage event, then the power controller will resume power export to the grid, otherwise a grid fault shutdown is initiated.

The over voltage protective functions are illustrated in Figure 3 and Figure 4. The over voltage trips are programmed into the power controller as phase-to-phase voltages. Voltages indicated in Figure 3 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 2. Over Voltage Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Default	RS-232 Command
Over Voltage	If the voltage on any phase rises above this setting for greater than Over Voltage time, the system will shut down.	Under Voltage to 528 V (L-L) in 1 Volt increments	C30: 524 C65/C200: 528	OVRVLT
Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Over Voltage limit.	C30: 0.3 to 10 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 1.90 C65/C200: 1.00	OVLTTM
Fast Over Voltage	The system will cease to export power to the if any phase voltage rises above this voltage for greater than Fast Over Voltage time.	Over Voltage to 635 V (L-L) in 1 Volt increments	C30: 600 C65/C200: 576	FSTOVL
Fast Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Fast Over Voltage limit.	C30: 0.03 to 1.00 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 0.032 C65/C200: 0.03	OVFSTM

4.3. Over/Under Frequency (Protective Function 81 O/U)

Refer to Table 3 for the adjustable ranges and microturbine defaults for the over/under frequency settings. These settings include the frequency trip points and the allowable time period before the frequency trip occurs. The over frequency trip limit may be adjusted downwards as indicated in Table 3 and still comply with UL1741. The under frequency trip limit may be adjusted upwards as indicated in Table 3 and still comply with UL1741. The duration to trip may also be adjusted downwards as indicated in Table 3 and still comply with UL1741.

The UL1741 [Rule 21] requirement for over frequency function is:

- The device should cease to energize the output within 6 [10] cycles when the grid frequency is higher than 60.5 Hz.

The UL1741 [Rule 21] requirement for under frequency function is:

- The device should cease to energize the output within 6 [10] cycles when the grid frequency is lower than 59.3 Hz.

As shipped, each power controller is tested to verify that it meets both UL1741 and California Rule 21 requirements to initiate a grid fault shutdown, if the line frequency is greater than 60.5 Hz or is less than 59.3 Hz for a duration of 100 ms.

▶	NOTE: Ensure that the over frequency and under frequency limits are set prior to setting the Power Foldback on Over Frequency parameters (paragraph 4.7). The over frequency limit must be set in order for the power foldback to work, and if the installation requires VDE-AR-N 4105 compliance, the under frequency limit must be set as specified in Table 3.

Table 3. Over/Under Frequency Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Default	RS-232 Command
Under Frequency	If the grid frequency falls below this value for greater than Under Frequency Time, the system will shut down.	45 Hz to Over Frequency in 0.1 Hz increments For VDE compliance this setting must be 47.5 Hz	59.3	UNDFRQ
Under Frequency Time	Establishes the time period allowed for the Frequency to fall below the Under Frequency limit.	C30: 0.06 to 10 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 0.09 C65/C200: 0.10	UFRQTM
Over Frequency	If the grid frequency rises above this value for greater than Over Frequency Time, the system will shut down.	Under Frequency to 65 Hz in 0.1 Hz increments For VDE compliance this setting must be 51.5 Hz.	60.5	OVRFRQ
Over Frequency Time	Establishes the time period allowed for the Frequency to rise above the Over Frequency limit.	C30: 0.06 to 10 sec C65/C200: 0.01 to 300 sec Adjustable in 0.01 second increments	C30: 0.09 C65/C200: 0.10	OFRQTM
Fast Under Frequency (C65/C200 only)	If grid frequency drops below this value for greater than the fast under frequency time, the system will shut down.	0 to Under Frequency in 0.1 Hz increments	57.0	N/A
Fast Under Frequency Time (C65/C200 only)	Establishes the time period allowed for the frequency to drop below the Fast Under Frequency limit.	0.01 to 300 sec in 0.01 second increments	0.10	N/A

4.4. Stand Alone to Grid Reconnect Condition

The C65, C200, and C1000 series microturbine models provide protective relay functions during the transition from Stand Alone to Grid Connect mode. These protective relay functions establish parameters to specify the conditions at which the microturbine can reconnect to the grid. Refer to Table 4 for the adjustable ranges and microturbine defaults for grid reconnect condition settings.

Table 4. Stand Alone to Grid Reconnect Condition Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Default	RS-232 Command
Minimum Grid Voltage	Minimum grid voltage at which the microturbine will connect to the grid.	480 V to Under Voltage in 1 Volt increments	424	N/A
Maximum Grid Voltage	Maximum grid voltage at which the microturbine will connect to the grid.	480 V to Over Voltage in 1 Volt increments	508	N/A
Minimum Grid Frequency	Minimum grid frequency at which the microturbine will connect to the grid.	60 Hz to Under Frequency in 0.1 Hz increments	59.30	N/A
Maximum Grid Frequency	Maximum grid frequency at which the microturbine will connect to the grid.	60 Hz to Over Frequency in 0.1 Hz Hz increments	60.50	N/A

4.5. Rate of Change of Frequency (Anti-Islanding Protective Function)

The power controller contains integrated active anti-islanding protective functions. These include an excessive Rate of Change of Frequency protective function, which will cause a Grid Fault Shutdown. The anti-islanding protection is tested and verified as part of the UL1741 listing.

4.5.1. Over Current and Fault Current

In the Grid Connect mode, the total fault current capacity at the installation site is the sum of the fault current from the electric utility grid and that produced by all the on-site generators, including microturbines. The rating of fault current interrupting devices at the site should be checked to ensure that they are capable of interrupting the total fault current available.

The electric utility grid operator will usually wish to be informed of the microturbine fault current contribution in order to assess the impact of the additional fault current on the electric utility grid and customers connected to it. At most installation sites the addition of a Capstone Microturbine may not result in a significant increase in the total fault current. However, the potential impact of the increase in fault current should be assessed.

When operating in Grid Connect mode, the power controller operation is controlled to deliver current corresponding to the power delivery set point. It will be less than the steady state current limit as defined in the electrical specifications of each product.

The power controller does not include overcurrent protection, but it does serve as an extremely fast current limiting device. The power controller output acts as a current source, using the grid voltage as a reference for both magnitude and phase angle. Active current control ensures that the steady-state current of each model will not be exceeded, regardless of the utility voltage.

Under transient or fault conditions, active current control and sub-cycle current interruption capability ensure that the RMS current in any half cycle does not exceed limits as defined in the electrical specifications of each product.

For some severe transients, the inverter may shut down within 1 or 2 cycles due to excessive or unstable current. Even under these conditions, the RMS current in any half cycle will not exceed the above values.

For less severe transients, the active current control will maintain the current at a value not more than the steady state current. The power controller will continue to operate in this mode until some other protective function stops power flow. For example, the Fast Under Voltage protective function can be set to detect a reduced utility voltage and initiate a Grid-Fault Shutdown within 2 cycles.

It is essential for safe operation and service that a current limiting disconnect device (breaker or fused disconnect) be installed between the power controller and the utility grid. The disconnect device must be rated for the total fault current. Local electric codes will almost always require such a disconnect. The added protection of this disconnect device is not considered here.

4.6. Reverse Power Flow (Protective Function 32)

The power controller may be programmed to initiate a Normal Shutdown upon detection of reverse power flow at a remote location by installing a pulse-issuing power meter at a remote location between the utility service entrance and the point where the microturbine is connected.

As shipped, the Reverse Power Protective function in the power controller is not enabled. It may be enabled at installation. When enabled, the Reverse Power Flow Protective function will initiate a Normal Shutdown when reverse power flow is measured for a duration of 120 seconds. This duration may be adjusted downwards to 0 second.

Note that a duration of zero (0) seconds cannot be realistically achieved. The minimum duration depends on the kWh per pulse calibration factor of the power meter and the magnitude of the reverse power flow. In practice, if the duration is set as 0 second, the shutdown will be initiated when the first reverse power flow pulse is received.

Alternatively, a reverse power flow relay may be interfaced with the external fault inputs to initiate a Grid Fault Shutdown when reverse power flow is detected.

If the microturbine output is greater than the local load demand, the excess power generated by the microturbine will flow back to the grid. Return flow to the grid may be undesirable for two reasons:

1. The connected electric utility may not allow power to be exported to its grid, and therefore may require that generating equipment cease operation if this condition exists, or
2. The electric utility may not offer "net metering", and therefore reverse power flow represents an economic loss to the microturbine user.

The microturbine can be configured to provide reverse power flow protection in two different ways. Either method requires an external device be installed at the appropriate point in the distribution circuit to measure power flow. Utilities are normally most concerned about power flow back into their utility grid, and measure this flow at a Point of Common Coupling (or PCC) with onsite generating equipment. The three basic methods are:

- Power meter with pulse outputs to the microturbine
- Power meter with Modbus output to C1000 Series control system
- Reverse power relay with trip signal to the microturbine.

4.6.1. Power Meter with Pulse Outputs

The C30, C65 and C200 microturbine models can be programmed to initiate a Normal Shutdown by installing a power meter with pulse outputs at the utility point of common coupling. Two pulses are required. Once pulse to detect power being imported, and the other to detect power being exported.

The reverse power protective function uses the exporting pulse, and can be configured to initiate a Normal Shutdown when reverse power flow is measured for a duration of 0 to 120 seconds. Note that an overall response time of zero (0) seconds cannot be realistically achieved. The minimum duration depends on the kWh-per-pulse calibration factor of the power meter and the magnitude of the reverse power flow. In practice, if the duration is set as 0 second, the shutdown will be initiated when the first reverse power flow pulse is received. Normal Shutdown allows cooldown of the microturbine to occur as opposed to a Grid Fault warmdown (shutdown) caused by the microturbine's integrated voltage, frequency, and anti-islanding protection.

4.6.2. Power Meter with Modbus Output

The C1000 Series microturbine models can be programmed to initiate a Normal Shutdown by installing a power meter with Modbus protocol at the utility point of common coupling. Custom programming is required to integrate the Modbus power meter, determine the required export kW limit and duration. This will be defined by the local Utilities interconnection agreement.

Normal Shutdown allows cooldown of the microturbine to occur as opposed to a Grid Fault warmdown (shutdown) caused by the microturbine's integrated voltage, frequency, and anti-islanding protection.

4.6.3. Reverse Power Relay with Trip Signal

The C30, C65, C200 and C1000 Series microturbine models can be programmed to accept a fault input from a reverse power flow relay, to initiate a Grid Fault Shutdown when reverse power flow is detected. The shutdown can be configured to be a Normal Shutdown (cooldown) or a warmdown. Refer to Shutdown section for further information.

	NOTE: Some regulatory agencies and utilities have rigid requirements regarding proper reverse power flow to the utility during grid disturbances. In this case, the best approach is to use a utility-approved reverse power flow relay to provide a trip signal to the microturbine. The relay trip signal output should interface with one of the microturbine digital fault inputs and be software configured to fault severity level 4 (warmdown). When properly setup, the main output contactor on the microturbine will open to stop exporting power as soon as a trip signal from the reverse power protective relay is detected.

4.7. Power Foldback on Over Frequency

▷	NOTE: The Power Foldback on Over Frequency settings are available for CE systems only, and they can only be applied if the turbine software is compatible. The software versions that accept power factor settings are as follows: 1. Software version 5.40 (gaseous) or 2.20 (liquid fuel) and higher for C65 microturbines. 2. Software version 1.80 (gaseous) and higher for C200 microturbines and C600/C800/C1000 turbine assemblies.

The Power Foldback on Over Frequency function provides power reduction at a selected ramp rate between a minimum frequency setpoint and the Over Frequency setting. This function complies with Verband der Elektrotechnik (VDE-AR-N 4105) specifications for low voltage grid connections, and it must be activated for use in microturbines that have the appropriate software.

The "minimum frequency setpoint," i.e. crossover frequency setting, establishes the frequency, when exceeded, at which the microturbine will begin reducing power before grid frequency reaches the Over Frequency limit. The "minimum frequency setpoint" should not be confused with the Under Frequency setting described in paragraph 4.3. Both the Under Frequency and Over Frequency settings must be set to specific values in order to be VDE-AR-N 4105 compliant, as shown in Table 3. Power Foldback on Over Frequency settings are provided in Table 5.

▷	NOTE: Ensure that the over frequency and under frequency limits (paragraph 4.3) are set prior to setting the Power Foldback on Over Frequency parameters. The over frequency limit must be set in order for this function to work, and if the installation requires VDE-AR-N 4105 compliance, the under frequency limit must be set as specified in Table 3.

Table 5. Power Foldback on Over Frequency Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Default	RS-232 Command
Enable/Disable	Enables and Disables Power Foldback on Over Frequency function.	0: Disabled 1: Enabled	0	APSCOF
Minimum Frequency	Minimum Frequency setpoint in Hz. When grid frequency crosses over this setpoint, microturbine begins power reduction sequence.	0 to 100.0 in 0.1 Hz increments For VDE compliance, this setting must be 50.2 Hz.	50.2	APCMNF
Power Reduction Gradient	Power reduction gradient expressed as percentage of power reduction per Hz.	0 to 100 in 1% increments For VDE compliance, this setting must be 40%.	40	APSCGR

4.8. Shutdown

When one or more of the protective relay functions initiates a Grid Fault Shutdown, the microturbine enters the warmdown state and the following events occur:

- The power controller contactor (Figure 2) is opened within 100 ms; output power flow ceases
- Fuel flow to the turbogenerator stops

A warm shutdown ensues during which control power is supplied from the microturbine generator as it slows down. The warmdown lasts 1-2 minutes before the rotor is stopped. The control software provides for an optional automatic restart when grid voltage and frequency are within permitted limits for a programmable period of time (from 5 to 60 minutes).

When a Normal Shutdown is initiated by the Reverse Power Flow function, the microturbine enters the cooldown state and the following sequential events occur:

- Fuel flow to the turbogenerator stops
- A cooldown of the engine takes place lasting up to 10 minutes. (During cooldown, the grid power is used to motor the engine.)
- The power controller contactor (Figure 2) is opened upon completion of cooldown.