Operation

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Qualified Persons

⚠ WARNING

Only qualified persons who are knowledgeable in the installation, operation, and maintenance of overhead and underground electric distribution equipment, along with all associated hazards, may install, operate, and maintain the equipment covered by this publication. A qualified person is someone who is trained and competent in:

- The skills and techniques necessary to distinguish exposed live parts from nonlive parts of electrical equipment
- The skills and techniques necessary to determine the proper approach distances corresponding to the voltages to which the qualified person will be exposed
- The proper use of special precautionary techniques, personal protective equipment, insulated and shielding materials, and insulated tools for working on or near exposed energized parts of electrical equipment

These instructions are intended ONLY for such qualified persons. They are not intended to be a substitute for adequate training and experience in safety procedures for this type of equipment.

Read this Instruction Sheet

NOTICE

Thoroughly and carefully read this instruction sheet and all materials included in the product's instruction handbook before installing or operating the GridMaster Microgrid Control System. Familiarize yourself with the Safety Information and Safety Precautions on pages 4 through 5. The latest version of this publication is available online in PDF format at **sandc.com/en/support/product-literature/**.

Retain this Instruction Sheet

This instruction sheet is a permanent part of your GridMaster Microgrid Control System. Designate a location where you can easily retrieve and refer to this publication.

Proper Application

⚠ WARNING

The equipment in this publication must be selected for a specific application. The application must be within the ratings furnished for the selected equipment.

Warranty

The warranty and/or obligations described in S&C's Price Sheet 150, "Standard Conditions of Sale–Immediate Purchasers in the United States," (or Price Sheet 153, "Standard Conditions of Sale–Immediate Purchasers Outside the United States,") plus any special warranty provisions, as set forth in the applicable product-line specification bulletin, are exclusive. The remedies provided in the former for breach of these warranties shall constitute the immediate purchaser's or end user's exclusive remedy and a fulfillment of the seller's entire liability. In no event shall the seller's liability to the immediate purchaser or end user exceed the price of the specific product that gives rise to the immediate purchaser's or end user's claim. All other warranties, whether express or implied or arising by operation of law, course of dealing, usage of trade or otherwise, are excluded. The only warranties are those stated in Price Sheet 150 (or Price Sheet 153), and THERE ARE NO EXPRESS OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. ANY EXPRESS WARRANTY OR OTHER OBLIGATION PROVIDED IN PRICE SHEET 150 (OR PRICE SHEET 153) IS GRANTED ONLY TO THE IMMEDIATE PURCHASER AND END USER, AS DEFINED THEREIN. OTHER THAN AN END USER, NO REMOTE PURCHASER MAY RELY ON ANY AFFIRMATION OF FACT OR PROMISE THAT RELATES TO THE GOODS DESCRIBED HEREIN, ANY DESCRIPTION THAT RELATES TO THE GOODS, OR ANY REMEDIAL PROMISE INCLUDED IN PRICE SHEET 150 (or PRICE SHEET 153).

Warranty Qualifications

Warranty of GridMaster Microgrid Controllers is contingent upon the installation, configuration, and use of the control and software in accordance with S&C's applicable instruction sheets. This warranty does not apply to major components not manufactured by S&C, such as batteries, communication devices, and the IED associated with the microgrid controller. However, S&C will assign to the immediate purchaser or end user all manufacturers' warranties that apply to such major components.

Warranty of equipment/services packages is contingent upon receipt of adequate information on the user's distribution system, sufficiently detailed to prepare a technical analysis. The seller is not liable if an act of nature or parties beyond S&C's control negatively impact performance of equipment/services packages; for example, new construction that impedes radio communication, or changes to the distribution system that impact protection systems, available fault currents, or system-loading characteristics.

Understanding Safety-Alert Messages

Several types of safety-alert messages may appear throughout this instruction sheet and on labels and tags attached to the GridMaster Microgrid Control System. Familiarize yourself with these types of messages and the importance of these various signal words:

⚠ DANGER

"DANGER" identifies the most serious and immediate hazards that will likely result in serious personal injury or death if instructions, including recommended precautions, are not followed.

⚠ WARNING

"WARNING" identifies hazards or unsafe practices that can result in serious personal injury or death if instructions, including recommended precautions, are not followed.

⚠ CAUTION

"CAUTION" identifies hazards or unsafe practices that can result in minor personal injury if instructions, including recommended precautions, are not followed.

NOTICE

"NOTICE" identifies important procedures or requirements that can result in product or property damage if instructions are not followed.

Following Safety Instructions

If you do not understand any portion of this instruction sheet and need assistance, contact your nearest S&C Sales Office or S&C Authorized Distributor. Their telephone numbers are listed on S&C's website **sandc.com**, or call the S&C Global Support and Monitoring Center at 1-888-762-1100.

NOTICE

Read this instruction sheet thoroughly and carefully before operating your GridMaster Microgrid Control System.

Replacement Instructions and Labels

If additional copies of this instruction sheet are needed, contact your nearest S&C Sales Office, S&C Authorized Distributor, S&C Headquarters, or S&C Electric Canada Ltd.

It is important that any missing, damaged, or faded labels on the equipment be replaced immediately. Replacement labels are available by contacting your nearest S&C Sales Office, S&C Authorized Distributor, S&C Headquarters, or S&C Electric Canada Ltd.

⚠ DANGER

The GridMaster Microgrid Control System operates high-voltage systems. Failure to observe the precautions below will result in serious personal injury or death.

Some of these precautions may differ from your company's operating procedures and rules. Where a discrepancy exists, follow your company's operating procedures and rules.

1. **QUALIFIED PERSONS.** Access to a GridMaster Microgrid Control System must be restricted only to qualified persons. See the "Qualified Persons" section on page 2.
2. **SAFETY PROCEDURES.** Always follow safe operating procedures and rules.
3. **PERSONAL PROTECTIVE EQUIPMENT.** Always use suitable protective equipment, such as rubber gloves, rubber mats, hard hats, safety glasses, and flash clothing, in accordance with safe operating procedures and rules.
4. **SAFETY LABELS.** Do not remove or obscure any of the "DANGER," "WARNING," "CAUTION," or "NOTICE" labels. Remove tags only if instructed to do so.
5. **MAINTAINING PROPER CLEARANCE.** Always maintain proper clearance from energized components.

When a GridMaster Microgrid Control System is installed, S&C engineers provide operating instructions and software created specifically for that system layout and equipment. The provided instructions will be similar in layout to this document, but the system description and operating details will be different.

This instruction sheet is a general guide for system and human machine interface (HMI) operation. All system examples are hypothetical and the microgrid system shown in Figure 1 on page 7 is the example system for this document.

A microgrid is a group of interconnected loads and distributed energy resources with clearly defined electrical boundaries. It acts as a single controllable entity that can be connected to the grid in **Grid-Tied** mode or be completely disconnected to operate in **Island** mode.

The GridMaster Microgrid Control System operates generation, storage, and electrical distribution equipment. GridMaster Intelligent Power Controllers (IPCs) can be located on-site in the equipment enclosures and are built to operate in extreme environmental conditions. Unlike centralized control (a single-point for failure), the IPCs use distributed intelligence and peer-to-peer communication. Multiple on-site IPCs have inherent operation resilience and data-access security. GridMaster IPCs are easy to configure, and more controllers can be added to expand a microgrid.

GridMaster controllers report system conditions and receive operation requests from all common communication protocols and media:

- DNP3 over Ethernet (or other utility proprietary systems)
- Modbus over serial
- Modbus over TCP

The graphical user interface (GUI) is browser-based, so the operating computer only needs a network connection and an installed Web browser. Operators observe and control microgrid operation through the Human Machine Interface (HMI) computer located in the control room. The *Main Schematic* screen displays equipment status and enables manual control of generation and distribution. Microgrid performance information is displayed graphically on other screens.

Acronyms

Microgrid control systems commonly use these acronyms:

ADMS Advanced Distribution Management System

AI Analog Input

ATS Automatic Transfer Switch

BESS Battery Energy Storage System

BIOS Basic Input-Output System

CB Circuit Breaker

DER Distributed Energy Resource

DI Digital Input

DMS Distribution Management System

DO Digital Output

EV Electric vehicle

GEN Generator

GMT Greenwich Mean Time

GUI Graphical User Interface

HMI Human Machine Interface
IA Information Assurance
IAVM Information Assurance Vulnerability Management
NTP Network Time Protocol
PV Photovoltaic
SBC Single Board Computer
STIG Security Technical Implementation Guides
USB Universal Serial Bus

Concept of Operation

Generation, storage, switching equipment, and loads are displayed on the *Schematic* screen. See Figure 1. This sample microgrid has three GridMaster IPCs networked with the entire microgrid, providing redundant control of all equipment and operations. Each IPC communicates with a specific set of equipment. The microgrid has multiple modes of operation: **Grid-Tied**, **Storm**, and **Island** mode. Depending on the specific microgrid design and underlying capabilities, multiple methods for transitioning between the different modes include: closed transition, open transition, black start, and seamless unplanned transfer trip.

Note: The microgrid and corresponding graphical user interface depicted in this document is a generic system meant to serve as an illustrative example for system users. Each GridMaster Microgrid Control System GUI created for a specific customer or utility is unique, so it will not appear exactly like the examples shown in this document. The working principles for the operation of the GUI are similar, but not exact.

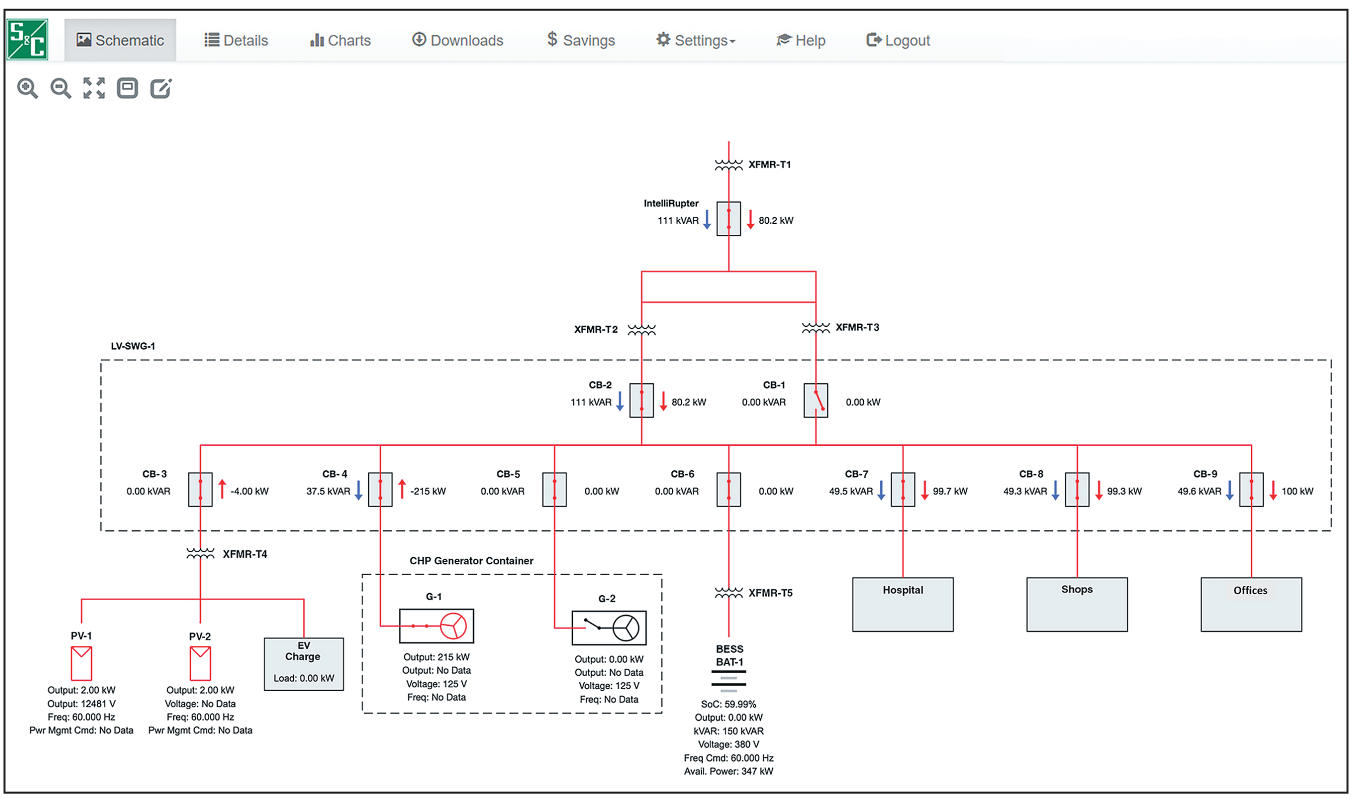

Figure 1. Microgrid equipment displayed on the *Schematic* screen.

This example microgrid consists of five generation assets:

- Two 265-kW combined heat and power natural gas generators
- One 250-kW BESS
- Two small 5-kW solar PV arrays

The GridMaster controllers do not require installation in specific equipment at the site, and they communicate on an Ethernet-based network. They oversee microgrid operation and maintain safe operating parameters. Every controller serves as a failover unit in the event another controller has operating problems. When running in **Island** mode, the GridMaster system oversees microgrid operation by dispatching and curtailing generation sources and loads as appropriate. In **Grid-Tied** mode, it maintains loads and storage to minimize new power import. In **Storm** mode, battery charging is the priority.

The main goals of GridMaster control software are to:

- Identify the state of the utility, generators, and battery system
- Allow a user to enter and exit **Island** mode
- Identify basic warnings and faults in the system and notify the user
- Dispatch and curtail sources as necessary to maintain load while minimizing net power import in **Grid-Tied** mode

Graphical User Interface

The GUI allows an operator to view and interact with the microgrid and microgrid control system. S&C will supply the specific URL address to be used in a browser on any on any HMI computer connected to the network. Then, operators must enter their pre-assigned username and password to access the GUI. The GUI screens include:

- **Login—**Limits system access to authorized personnel
- **Schematic—**Shows system information, controls, and a visual schematic
- **Details—**Provides information about the state of the microgrid; all data and command values are displayed
- **Charts—**Presents graphs of live and historical data
- **Downloads—**Enables data-stream downloads
- **Settings/User Administration—**Adjusts user roles and adds/edits/removes user accounts
- **Settings/My Account—**Adjusts user data: first name, last name, and password

Equipment-specific information collected from the physical devices is viewable in the GUI. The actions taken by the GridMaster system software are based on the monitored equipment state and the measured power consumption on the microgrid. Based on this information, the GridMaster controller performs supervisory control of the microgrid.

GridMaster System Controls

GridMaster controllers are pre-programmed with information about every piece of microgrid equipment. They provide operating data and information about equipment capabilities and limitations. Figure 2 on page 9 shows the rack-mounted controller, and Figure 3 on page 9 shows the wall-mounted controller. Additional connections for GPS antennas and other hardware are available.

Figure 2. The rack-mounted GridMaster controller.

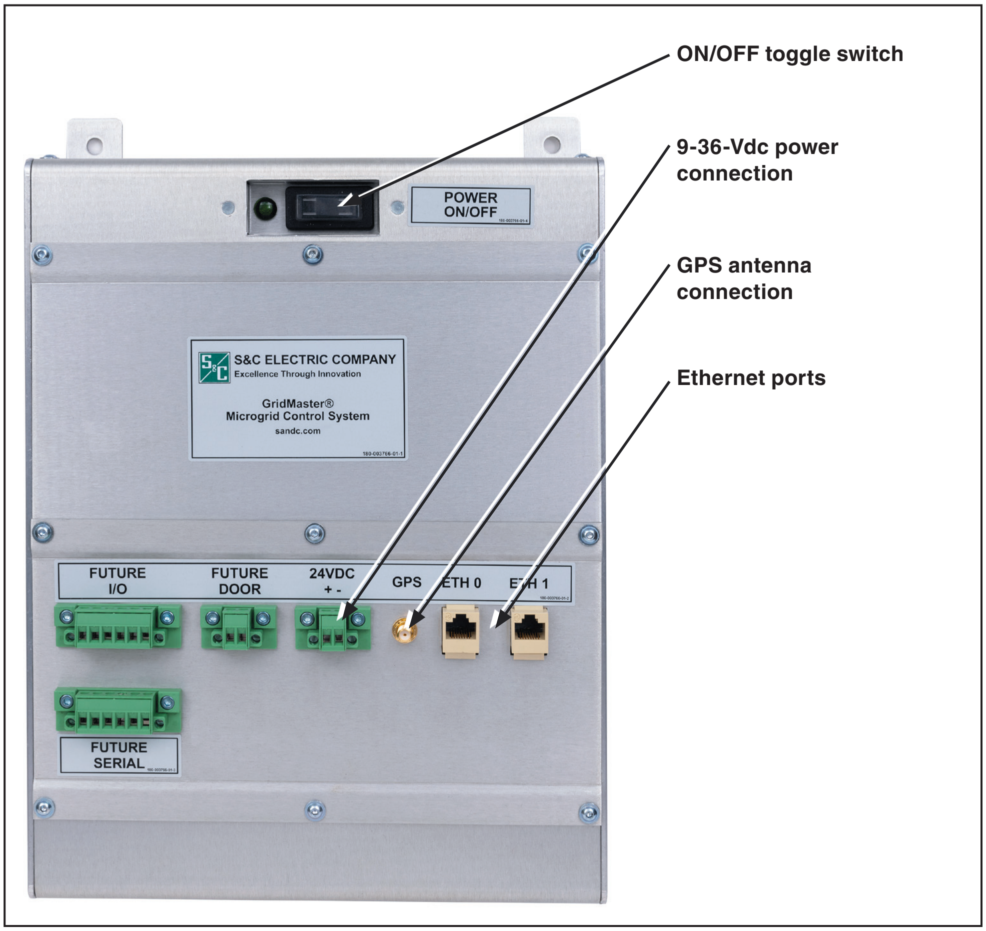

Figure 3. The wall-mounted GridMaster controller.

NOTICE

The GridMaster system can automatically open or close breakers and switch power sources. If these actions could cause damage to the system, the control system should not be enabled when **Auto Entry** mode is selected. Always set the system to **Disabled** mode before performing microgrid maintenance.

When utility power is available, **Island** mode can be entered with **Closed Transition**, **Open Transition**, or **Black Start** mode and the control system will automatically open or close breakers, switch generators on or off, etc. If these actions could cause damage to the system, the control system should not be set to **Island** mode.

The control system will not enter **Island** mode when any switch is not in its configured **Normal** position.

Island mode should be used when a persistent utility outage is expected. It can also be used preemptively for an expected outage, impending storm, or other natural event affecting the local power grid.

Login Accounts

The system administrator can manage user accounts and the level of access with the **User Administration** tab. User types and login credentials include:

- **Administrator—**Adds/deletes/edits user names and passwords
- **View user—**Views values but cannot set the controls
- **Control user—**Views values and sets the controls
- **Data user—**Downloads archived data values

Follow these steps to change a user password:

STEP 1. In the top menu, click on the **Settings | My Account** options. The screen shown in Figure 4 on page 11 will open to allow the password change.

STEP 2. The dialog box prompts for entry of the first and last name.

STEP 3. Select the Change Password checkbox and follow the prompts.

For a very secure microgrid, the password must meet the following requirements:

- The password must have at lease one uppercase letter, one lowercase letter, one number, and one special character. At least four characters in the original password must be changed.
- A password must have a minimum of 15 characters.
- The password must be case-sensitive.

The system administrator may change a password for any user with the **User Administration** menu. Password changes made on any HMI apply for all other HMIs. When logging in after the password expiration date, a prompt to change the password opens.

Note: The user must log in to the Windows HMI computer before logging in to the GridMaster control system.

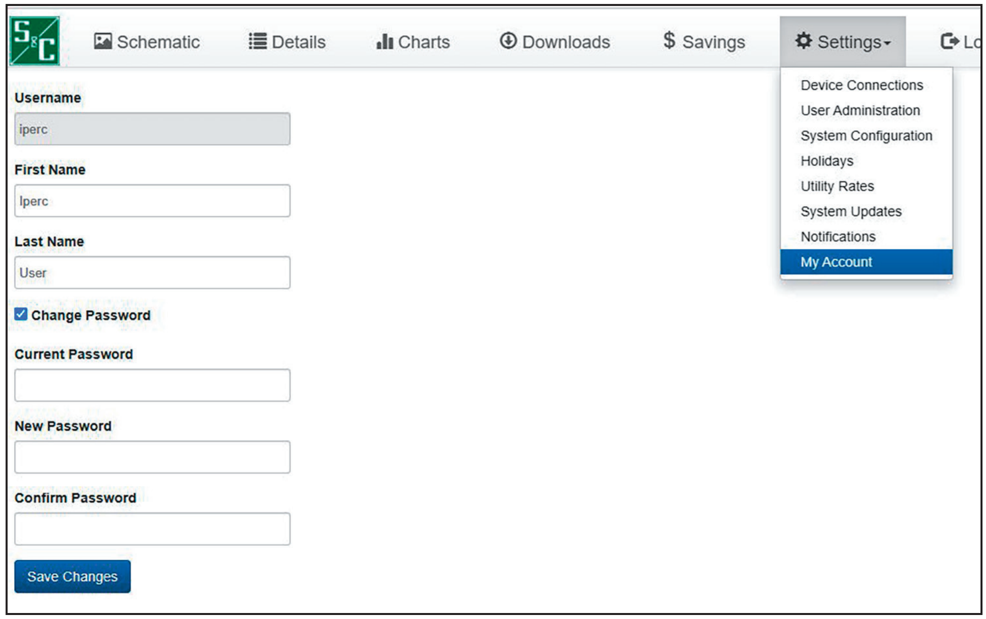

Figure 4. The *Change Password* screen.

Schematic Screen

After logging in, the *Schematic* screen opens. See Figure 5. This screen has four sections: the **Screen Navigation** field, the **Main** field, the **Alerts** field, and the **Status and Controls** field.

The **Main** field is the default view and displays the microgrid schematic. The **System Status** and **System Controls** fields on the right side shows the summary of system operation. Alerts, messages, and warnings are shown in the **Alerts** field at the bottom of the screen. The screen design allows an operator to see pertinent information immediately. A close-up view of **Status** fields is shown in Figure 6 on page 13.

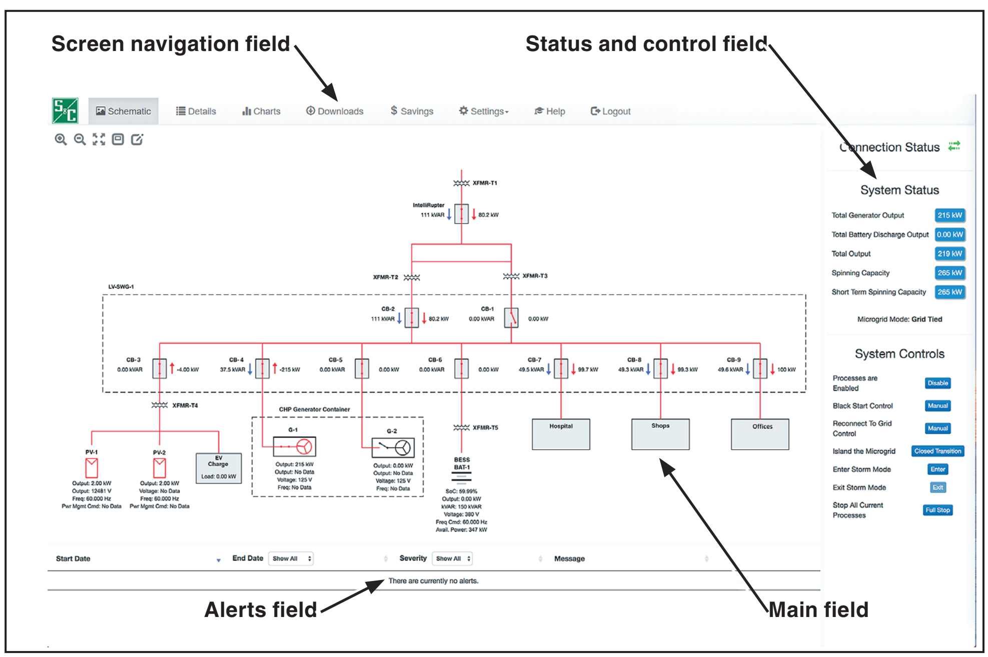

Figure 5. The *Schematic* screen sections.

System Status

- **Connection Status—**Green arrows are displayed when the HMI and control system are communicating. If there is a problem with the link between the HMI computer and the control system, the arrows turn red and a timer appears indicating the duration of the communication loss. The control system continues to operate even with no communication between the HMI and GridMaster controllers.
- **System Status—**This section shows total power flow and available power from the various microgrid assets. The **Total Battery Output** value is positive when supplying power to the grid and negative when the battery is charging.

System Controls

The **System Controls** field is not shown for a user with view-only privilege.

- **Processes are Enabled—**This command disables the control system so it cannot make decisions or issue commands to the microgrid equipment. The control system should be disabled for safety when personnel are working on equipment or the system.
- **Black Start Control—**This command selects a manual or automatic transition from **Grid-Tied** to **Island** mode if the utility voltage is lost for a specified amount of time.
- **Reconnect to Grid Control—**In **Automatic** mode, the system will transition from **Island** to **Grid-Tied** mode without user input when the utility voltage is stable for a specified amount of time. In **Manual** mode, the user will have to initiate the transition back to **Grid-Tied** mode.
- **Island the Microgrid—**Clicking on the **Closed Transition** button to island the microgrid causes the system to produce enough generation and disconnect from the utility without dropping power to any loads.
- **Enter Storm Mode—**This command causes the battery system to charge at a higher rate than normal operation and maintain the higher charge rate in anticipation of a storm or other utility power loss.
- **Exit Storm Mode—**This command returns the battery system to the normal upper and lower limits for state of charge.
- **Stop All Current Processes—**Clicking on the **Full Stop** button stops any processes in progress and prevents any additional processes from initiating. For example, using this button stops a **Closed Transition** operation before it has completed.

Note: Issuing a **Disable** command to prepare for upcoming maintenance, instead of a **Full Stop** command, allows presently running processes to finish correctly and prevents new processes from starting.

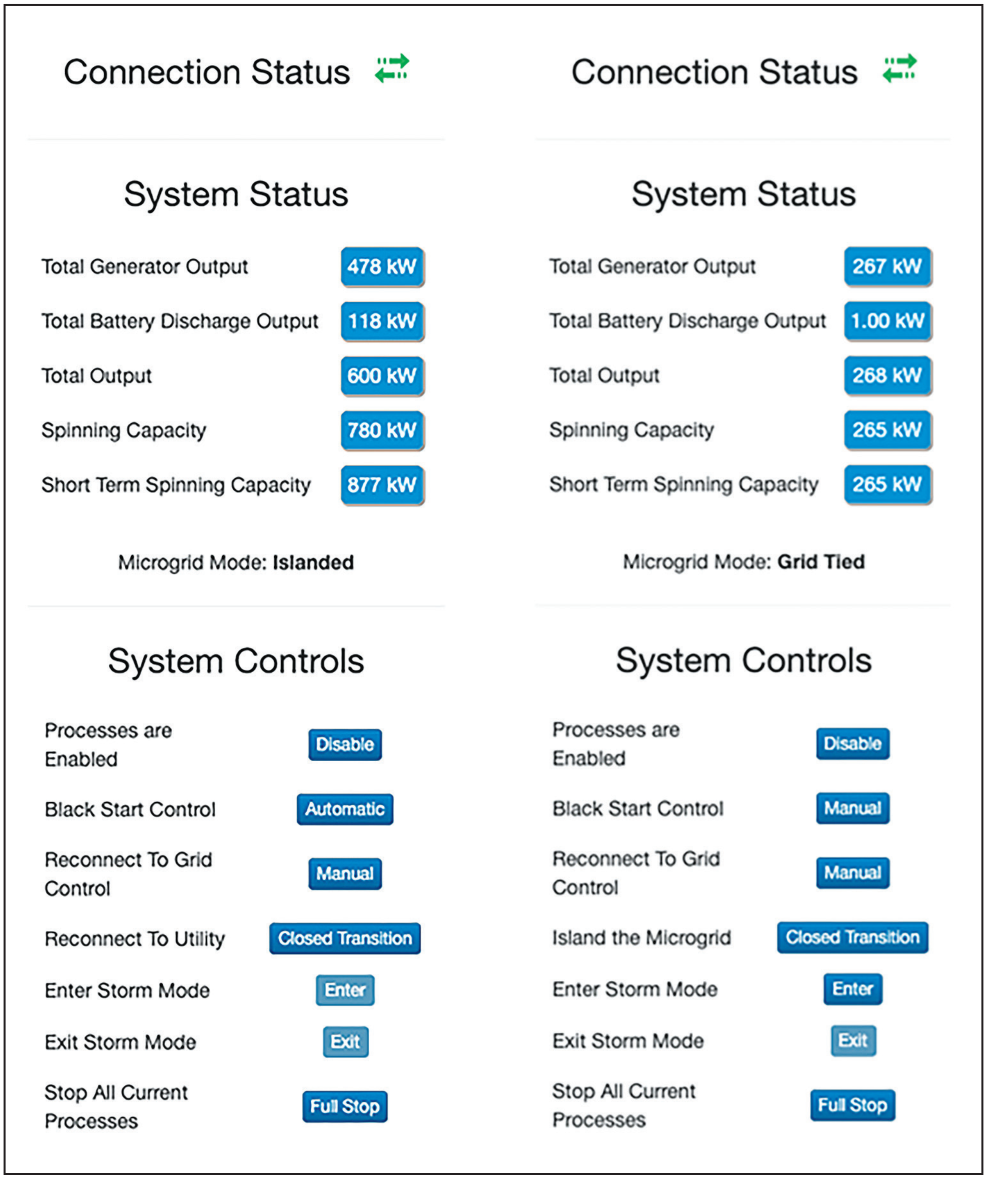

Figure 6. A close-up view of the Islanded (left) and Grid-Tied (right) status fields on the *Schematic* screen.

Schematic Functions

The *Schematic* screen is not a standard electrical one-line diagram—When a system icon is shown to be de-energized, that is not a confirmation (the schematic is more representative than literal), and normal safety precautions should be taken as if working around energized equipment. If a system icon is shown as unavailable, this is not a replacement for a normal Lock-Out/Tag-Out procedure.

When equipment status is measured, it is displayed as energized in red and de-energized in black. Switches are shown in the **Open** or **Closed** position. When the status is unknown, the switch position is shown with a bar perpendicular to power flow between the open contacts, and other equipment is displayed in purple color or dashed purple lines. Figure 7 shows schematic figures.

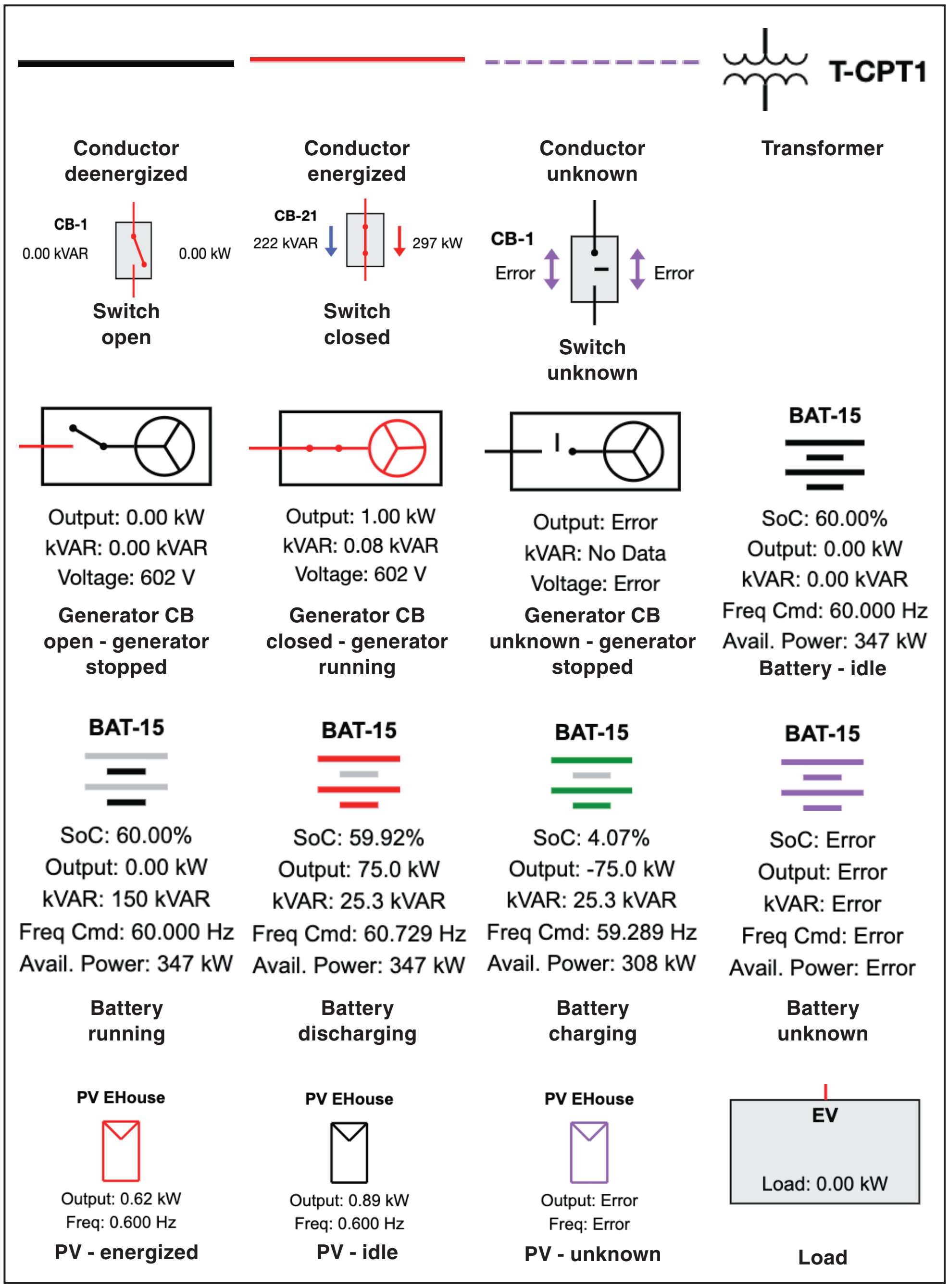

Figure 7. Sample icons shown on the *Schematic* screen.

Details Screen

Information about equipment behavior is accessed and adjusted by clicking on an equipment icon on the *Schematic* screen or by clicking on the **Details** tab. The default values are listed and may be changed depending on the season (winter/summer) and operator knowledge of microgrid behavior. The values list can be narrowed with the drop-down list in the upper left corner. Filters for devices, units and commands are located above their respective columns, which can be sorted alphabetically by clicking on the column header. See Figure 8. See Table 1 for sample settings.

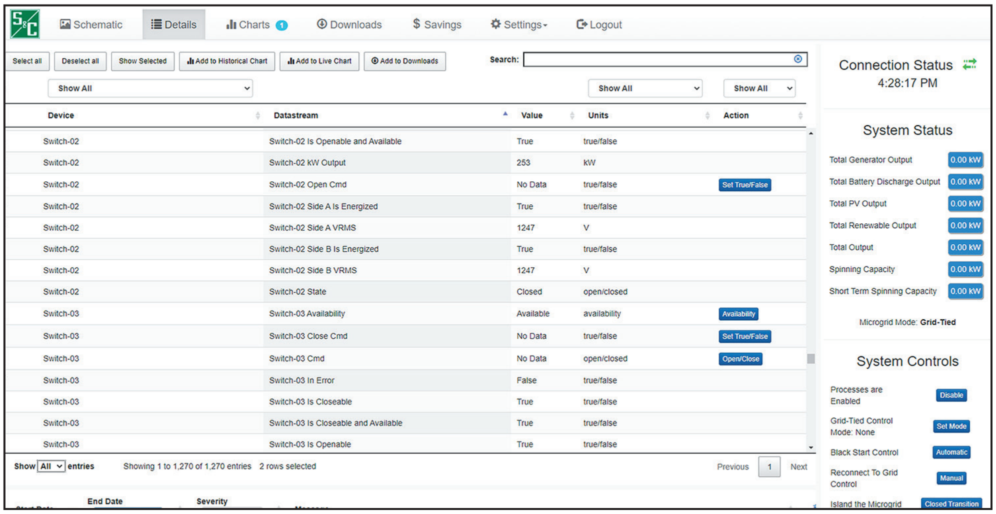

Figure 8. The *Details* screen.

Table 1. Sample Configurable System Settings

Detail Setting Name	Default Value	Comment
Automatic Enter Island Delay	60 seconds	The delay after power loss is detected prior to entering **Island** mode when **Entry** mode is set to the **Automatic** state
Automatic Exit Island Delay	300 seconds	The delay after utility power is detected prior to reconnecting to **Grid-Tied** mode when **Reconnection** mode is set to the **Automatic** state
BAT-1 Default Charge Rate While Grid Tied	-50 kW	The default charge rate for BAT-1 while in **Grid-Tied** mode
Island Enter Mode	Automatic	Sets manual or automatic entry into **Island** mode
Island Exit Mode	Manual	Sets manual or automatic exit from **Island** mode (Manual entry is recommended so an operator can check whether the utility is supplying power.)
Run Processes Automatically	On	Setting this to the **Off** setting limits the processes run to those initiated by the user through the HMI

Charts Screen

On the *Details* screen, any of the data values in the table can be selected to create real-time or historic graphs of the data. Click on either the **Add to Live Chart** button or the **Add to Historical Chart** button in the upper-left corner of the screen. See Figure 9. The charts will open on the *Charts* screen. See Figure 10. Multiple charts can be created and displayed simultaneously. Multiple data streams can be added to each chart. The size of a chart is adjustable by dragging or pulling on the bottom right-hand corner.

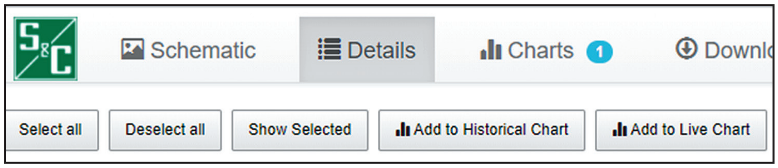

Figure 9. The buttons used for creating charts.

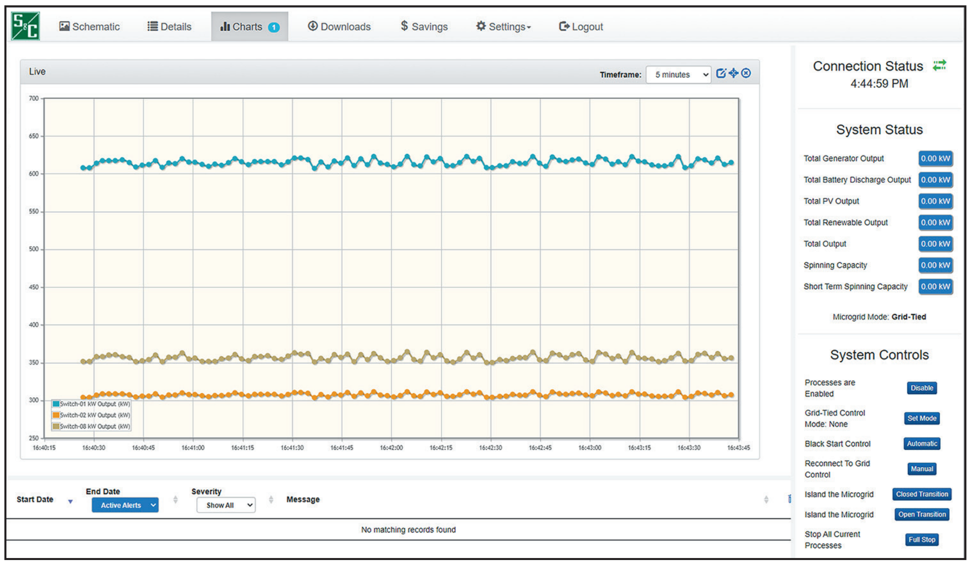

Figure 10. The *Charts* screen.

Downloads Screen

Operators with Data User access can download system data with the **Downloads** tab on the *Schematic* screen. Information from the GridMaster controllers and all controls is stored in the system logs. The system logs can be used to debug problems or cybersecurity concerns. Each GridMaster controller has sufficient memory to store several months of data before information is overwritten.

The *Downloads* screen is shown in Figure 11. For each download request, the start and stop date is required, as is noting whether the measured values (Data) or system log values (Audit Log) should be downloaded. See Figure 12. Depending on the date range selected, each download may take several minutes to complete.

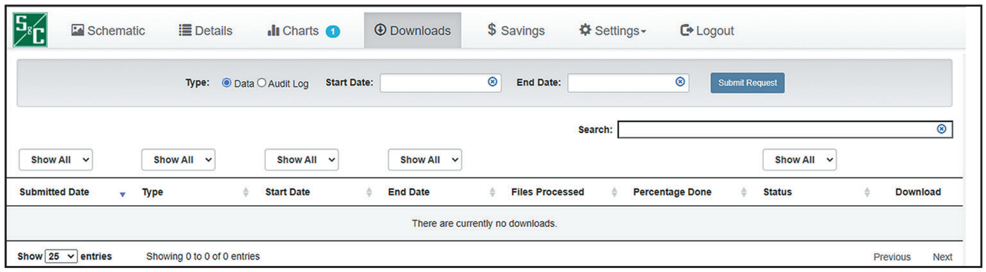

Figure 11. The *Downloads* screen.

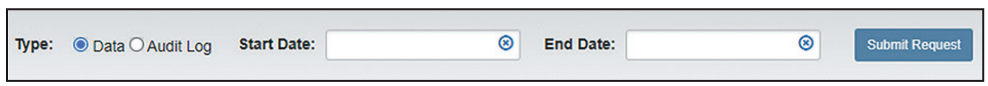

Figure 12. The Download Request fields.

System alarms and notifications are described in this section as well as the system contingency strategies, self-diagnostics, and fail-safes built into the microgrid control system.

The **Alert** field on the *Schematic* screen shows messages generated by the system software. There are three categories:

- **Informational—**Useful information not requiring immediate action
- **Warning—**More critical than informational and indicates impending problems may become critical
- **Alert—**Critical problems requiring immediate operator response

All messages are deleted from the **Alert** field within 24 hours after the issue has been remedied. However, all alerts are saved in memory and are downloadable in the Audit logs. Sample message types are shown in Tables 2 through 4 and include the associated troubleshooting description:

Table 2. Sample Informational Alerts

Message	Description
ADMS Cmd to Enable IPC Automatic mode	ADMS **Enable System** command received—enabling system
Is in Island mode	System is in **Island** mode

Table 3. Sample Warning Alerts

Message	Description
CB1 Availability	Breaker has been marked unavailable (Set CB1 Availability to once issue is resolved.)
CB1 Close Inhibit	CB1 Close is inhibited
CB1 Is Comm Good	Cannot communicate with CB1
BAT-1 Is Comm Good	Cannot communicate with BAT-1
G-1 Alarm Over Frequency	G-1 **Over Frequency** alarm

Table 4. Sample Critical Alerts

Message	Description
CB-5 SCADA Close Command Received	CB-5 SCADA **Close** command received—disabling system
Generator G-1 Alarm Engine EStop	Generator G-1 engine **EStop** alarm
Meter Is Comm Good	Cannot communicate with PV-2 meter
IntelliRupter SCADA Open Command Received	IntelliRupter® fault interrupter SCADA **Open** command received—disabling system

The GridMaster IPCs perform self-diagnostics to prevent problems caused by communication or hardware errors. These diagnostics include:

- A periodic check that the main application set is running
- A periodic check on the Web server computer that the Web service is running
- All controls mutually determining one system model and checking that the programs are running
- Each control checking disk space and memory availability
- Each control performing quality checks on the measured data, including whether information is out of range or stale (These parameter thresholds are set in the GridMaster controller configuration files.

The GridMaster IPC can be programmed to protect the system should contingencies occur, including:

- Loss of communication between controllers for an extended period
- A self-diagnosed controller performance problem that cannot be fixed
- An electrical network problem such as a non-functioning breaker

To illustrate operating considerations, the following scenarios specifically reference the sample microgrid shown in Figure 1 on page 7. A different microgrid will be provided documentation for its specific requirements and limitations.

Island Mode

When operating in **Island** mode, the operator works closely with the facilities managers to maintain loads well below 530 kW.

The generators operate in **Isochronous** mode and the BESS operates in **Voltage-Source** mode, changing power output based on the **Frequency** setpoint. Generation is automatically regulated to match the load on the power system through primary device controls located in the generators and BESS. These controls are integral to the units and are provided by the generator and BESS manufacturers.

The generators are the primary voltage reference on the system in **Island** mode. Both generators operate all the time, even in low-load scenarios. The BESS is used as an artificial load to keep the generators running at their designed minimum output. The control system will curtail the PV and dispatch the BESS resource depending on the system load conditions.

If the microgrid load exceeds the total microgrid source capacity in **Island** mode, the microgrid sources will trip and a complete outage will occur. For example, an outage will occur when the BESS battery runs out of charge if the load exceeds the available capacity of the generators and PV sources. An outage could also occur during load pickup, e.g., when starting a large motor, if the sources are operating near their maximum capacity.

Load shedding based on the user-defined load priority is used to maintain the grid during peak-load periods. To allow the system to pick up additional load, the generators are maintained at 75% or less of their rated capacity, when possible. To achieve this, the microgrid control system commands the BESS to supply power when the generators are loaded at 90% or more of their capacity. When system load exceeds a preset level, the full capacity of the generators will be used.

When system load is low enough to allow charging the BESS batteries, the battery state of charge (SoC) will be maintained at 85%. The PV source is curtailed if system load is less than 50% of the combined capacity of the generators. This maintains a minimum load on the generators, as recommended by the manufacturer.

Grid-Tied Mode

In **Grid-Tied** mode, the microgrid is primarily operated so the generation sources minimize the amount of net power provided by the utility to the microgrid loads. This amount of net power is expected to be approximately 50 kW to 150 kW and will be based on utility protection requirements and the power system constraints to maintain voltage and system stability, as determined by the power system studies.

Export Power Allowance and Mitigation

The microgrid isolation device (either CB-1 or CB-2) has reverse-power protection, and the GridMaster control system maintains a minimum power import with enough headroom to prevent nuisance tripping of this device. If the utility allows power to be exported from the microgrid for brief periods to accommodate transient and dynamic system events, then the power-import setpoint targeted by the microgrid controller can be reduced, allowing the microgrid sources to supply a greater portion of the microgrid load during normal operation. Brief periods of power export must be allowed to support closed transition between the **Grid-Tied** and **Island** mode of operation. The utility has agreed to allow the microgrid to export up to 175 kW for up to 30 seconds.

The GridMaster control system uses a specific strategy to prevent a sustained export of power, so it prevents tripping on reverse power when possible. The control system uses the BESS system to compensate for the slow power ramp-rate of the generators in **Grid-Tied** mode.

Each of the two generators has a power ramp-rate limit of 1 kW per second in **Grid-Tied** mode. The largest microgrid system loads are two (2) 100-HP motors, about 100 kW input power each. Suppose the power imported from the utility is being maintained at 50 kW. Now suppose both 100-kW motors trip or turn off simultaneously. This would result in initially exporting 150 kW to the utility. Because of the ramp-rate limit of the generators, it takes 75 seconds for the generators to ramp down and reduce the exported power to zero. To make it possible to eliminate the reverse-power condition in 30 seconds, the microgrid control system limits the charge rate of the BESS in **Grid-Tied** mode to 100 kW under normal conditions. In the event of a sudden reverse-power condition, the control system calculates the load requirement and commands the BESS to charge up to its full rated power, resulting in an additional import power of at least 150 kW. The process of detecting the reverse-power condition and changing the BESS power setpoint is completed in less than 30 seconds.

The protective relays for the microgrid isolation breakers support four levels of directional power protection. They are programmed to trip in the event of an extreme or sustained reverse-power condition that cannot be appropriately mitigated with the GridMaster control system.

In the example described above, if a reverse-power condition persists after 28 seconds, the tying protective relays trip one or both generators. If a reverse-power condition persists after 30 seconds, as the final protective measure the intertie protective relays trip the microgrid intertie breaker. A 600-V load feeder trip may result in a power export of greater than 175 kW. In this extreme case, the protective relays will trip one or both generators after a very brief time delay. If the condition persists, the relays trip the microgrid intertie breaker.

Grid-Tied Transition

There are two options to transition from **Island** to **Grid-Tied** mode. In an open transition, the microgrid loads experience a momentary outage, while in a closed transition the loads do not experience any outage. In source-transfer terminology, an open transition is "break before make," and a closed transition is "make before break."

The transition from **Island** to **Grid-Tied** mode can be made in **Automatic** mode (e.g., after utility voltage is healthy for some predetermined period) or **Manual** mode with a SCADA or HMI command. The return transition will be made in **Manual** mode when a manual transition from **Grid-Tied** to **Island** mode is initiated while the utility source is healthy. For example, during a demonstration of the microgrid islanding capability, setting the return transition to **Manual** mode prevents the system from immediately automatically returning to **Grid-Tied** mode.

Open Transition to Grid-Tied Mode

The sample microgrid can return to **Grid-Tied** mode from **Island** mode with an open transition, dropping the microgrid loads. This transition occurs with a combination of system primary and secondary control system sensing, logic, and commands. To accomplish this, the control system has voltage/frequency sensing on the utility side of the microgrid isolation device. For open transition, the isolation breakers are programmed to verify the microgrid side of the circuit breaker is de-energized prior to closing the circuit breaker. Actual component synchronization is handled by the devices' primary controllers when the microgrid isolation device has been closed by the secondary control system.

Returning to **Grid-Tied** mode with an open transition will proceed at "control" speed (the span of time from initializing the transition to closing of the microgrid isolation device could take several seconds to minutes, depending on utility preference.

These steps occur for an open transition to **Grid-Tied** mode from **Island** mode:

STEP 1. The operator uses a GUI command to the control system to reconnect through open transition.

STEP 2. The control system determines whether CB-1 or CB-2 is acting as islanding breaker by polling the breakers to determine the configuration of the circuit breaker key interlocks.

STEP 3. The system verifies it is operating in **Island** mode.

STEP 4. The system verifies the utility source is healthy, the transfer trip signal from the utility is "off," and the transfer trip communication channel is OK.

STEP 5. All generation sources are commanded to disconnect simultaneously by tripping their respective disconnect device (circuit breaker or contactor) via an SEL-351S relay.

Note: The generator manufacturer recommends not shutting down the generators in this manner (i.e. shutdown while loaded), but it is expected that open transition will rarely be performed because the closed transition is supported.

STEP 6. Load feeder breakers CB-7, CB-8, and CB-9 are commanded to open.

STEP 7. The system verifies no voltage on microgrid side of the IntelliRupter fault interrupter.

STEP 8. Islanding breaker (CB-1 or CB-2) is commanded to close.

STEP 9. Load feeder breakers (e.g. CB-7, CB-8, CB-9) are commanded to close.

STEP 10. The PV inverter is commanded to resume.

STEP 11. Generators are commanded to turn on.

STEP 12. The BESS is commanded to resume.

Closed Transition to Grid-Tied Mode

These steps occur for a closed transition to **Grid-Tied** mode from **Island** mode:

STEP 1. The operator uses a GUI command to the control system to perform a closed transition to **Grid-Tied** mode (if the system is in **Manual Return** mode) or the presence of utility voltage for a predetermined period occurs (if the system is in **Automatic Return** mode). The **Automatic** or **Manual Return** mode may be controlled by a SCADA control point.

STEP 2. The control system determines whether CB-1 or CB-2 is acting as an islanding breaker by polling the breakers to determine the configuration of the circuit breaker key interlocks.

STEP 3. The system verifies it is operating in **Island** mode.

STEP 4. The system verifies the utility source is healthy, the transfer trip signal from the utility is "off," and the transfer trip communication channel is OK.

STEP 5. The PV inverter is commanded to idle.

STEP 6. The **Manual** setpoint of generators set to its minimum value, reducing the possibility of exporting power back to the utility when reconnected.

STEP 7. A small, brief export of power may occur immediately after reconnection.

STEP 8. The islanding breaker is commanded to close when synchronized.

STEP 9. It may take 30 to 90 seconds for the microgrid to come into synchronism with the utility because of the steady-state frequency variation of the generators.

STEP 10. The islanding breaker closes and immediately notifies the microgrid generators the system is tied to the grid and the sources should operate in **Grid-Following** mode.

STEP 11. Any open load switches (e.g. CB-7, CB-8, CB-9) are commanded to close.

STEP 12. The BESS remains in service through the transition.

STEP 13. The PV inverter is commanded to resume power output.

Islanded Transition

There are two methods for entering **Island** mode from **Grid-Tied** mode: open and closed transition. In the open transition, the microgrid loads take a brief outage while the island is formed. In a closed transition, the local sources are synchronized with the utility prior to opening the islanding breaker. In source-transfer terminology, an open transition is “break before make,” and closed transition is “make before break.”

There are control connections between the islanding breakers (CB-1 and CB-2) and the generators to communicate the **Grid-Tied** status. The generators are programmed to automatically be in **Isochronous** or **Grid-Following** mode when they are islanded or grid-tied, respectively.

Transitioning from **Grid-Tied** to **Island** mode can happen either manually with a SCADA/HMI command or automatically (on a programmed loss-of-utility circumstance). When a manual transition is successfully initiated, the GridMaster controller disables **Automatic Return to Grid-Tied** mode. In this case, the system runs in **Island** mode until a manual return transfer is requested, as described in the previous section.

Planned Open Transition From Grid-Tied to Island Mode

In this scenario, the microgrid disconnects from the utility followed by a black start. These steps occur for an open transition from **Grid-Tied** mode to **Island** mode:

STEP 1. The operator uses a GUI command to the control system to reconnect through open transition.

STEP 2. The system confirms there is sufficient local generation capacity (and SoC of the battery) to support islanding.

STEP 3. If there is insufficient generation capacity to supply the load, the system informs the user **Island** mode cannot be started because of the generation/loading mismatch.

STEP 4. System operators can manually reduce load and attempt to island again.

STEP 5. Any manually shed loads must remain disconnected while the system is islanded.

STEP 6. The system reduces generator output.

STEP 7. The system commands the BESS to be in idle.

STEP 8. The PV inverter is commanded to idle.

STEP 9. The system commands the BESS units to unload and turn off.

STEP 10. The system verifies local sources have been turned off and commands the islanding breakers CB-1 and/or CB-2 to open.

STEP 11. Load breakers CB-7, CB-8, and CB-9 are commanded to open.

STEP 12. Generators are commanded to turn on.

STEP 13. The BESS is commanded to resume.

Dispatch of Loads

When the system has performed an open transition from **Grid-Tied** to **Island** mode, it is necessary to restore the loads in a safe fashion and account for the inability of the generators to take a block load greater than about 70 kW per generator. To restore the loads, the BESS will be used to preload the generators, and the BESS **Autonomous Frequency Response** feature will be enabled. The BESS will be put into **Charging** mode prior to the restoration of the large feeder loads. When the feeder load is connected, the BESS will see a frequency drop and switch to **Discharge** mode, based on the BESS **Autonomous Frequency Response** mode. The net effect will be comparable to the generators accepting a block load within their rated capabilities.

These steps show the overall sequence:

STEP 1. When generators are verified to be "on," the BESS is configured to charge/discharge at predetermined amounts for both before and after the load has been restored.

STEP 2. The initial charging load on the BESS will be done in incremental steps (e.g., 25 kW) to avoid large block loads on the generators.

Example: The BESS is set to charge at 150 kW, so the generators are producing 150 kW at this point and the BESS is consuming 150 kW. The BESS automatically adjusts its output based on the frequency of the grid.

STEP 3. Breaker CB-7 is commanded to close, at which point the load will come on line. The sudden load change causes a decrease in system frequency and the BESS responds with the autonomous frequency response.

Example: Suppose the load is 400 kW and, after closing CB-7, the BESS is now discharging at 250 kW. After the system stabilizes, the load on the generators is the same as it was prior to closing CB-7 (150 kW). In practice, the BESS will be discharging at some predetermined value.

STEP 4. When the system reaches a steady state, the BESS is set to charge at a new value and subsequent post-load discharge at another value. The BESS power setpoint is changed in incremental steps (e.g., 25 kW) to avoid large block loads on the generators.

STEP 5. Breaker CB-8 is closed to bring the load on line. The resulting frequency drop causes the BESS to respond with the autonomous frequency response.

STEP 6. When the system reaches a steady state, breaker CB-9 is closed. The load is expected to be in the range of 10 to 20 kW, so it does not need the pre-charge strategy on the BESS.

STEP 7. The BESS is commanded to disable the **Autonomous Frequency Response** feature.

STEP 8. The PV inverter is commanded to resume.

Open Transition to Island Mode Because of Grid Power Loss

For faults on the utility system, it is expected the utility feeder recloser will begin its reclosing cycle and the utility will immediately send a transfer trip signal to the microgrid generators. When the transfer trip signal is received, the microgrid generation sources are disconnected from the system by tripping their respective circuit breakers. The loads will remain connected to the utility. The system does not automatically transition to **Island** mode in this case. If the utility reclosing operation successfully clears the fault and restores the system, the microgrid loads will have only a momentary outage during the reclosing process.

In a sustained loss of utility power, where the utility reclosing does not successfully clear the utility fault, the microgrid, after a pre-determined amount of time, opens the microgrid isolation device and initiates a black start operation. The LV switchgear and the connected loads only are energized; the 12.47-kV distribution system, including the 12.47-kV/600-V pad-mounted service transformers, are not energized. This transition into **Island** mode is not seamless, and the microgrid loads experience an outage for the length of time it takes for the **Loss of Utility Voltage** timer to time out, plus time for the microgrid generation sources (i.e., the generators, under most scenarios) to black start the system loads. Typically, this outage is tens of seconds to a few minutes, depending on utility preferences and device capabilities.

Closed Transition to Island Mode

When transitioning manually, the generators are commanded to minimize the net power imported from the utility source through the microgrid isolation device. When the net power flow is sufficiently low, the secondary control system initializes a transition to **Island** mode. The microgrid isolation device is opened with a SCADA trip command and the generators switch to isochronous operation when the isolation device is detected to be open. The microgrid loads experience a seamless transition with no outage.

The system is programmed to allow the user to island the microgrid through a closed transition. These steps show the process:

STEP 1. The operator uses a GUI command to the control system to reconnect through closed transition.

STEP 2. The PV inverter is commanded to idle.

STEP 3. The generators are commanded to turn on (if not running).

STEP 4. The system commands the generators to meet the measured system load minus 50 kW or 100 kW.

STEP 5. The BESS may be commanded to discharge power if the generator capacity is insufficient.

STEP 6. The control system commands CB-1 or CB-2 to open.

Seamless Unplanned Transfer Trip

In certain situations, the system can seamlessly transition from **Grid-Tied** to **Island** mode operation in the event of an unexpected utility outage. A number of criteria must be met for the seamless unplanned transfer trip signal to be activated. When active, the system will quickly trip open CB-1 or CB-2 and rely on the generators to pick up any additional load change. These system conditions are required:

- Both generators are online and running.
- Maximum total power is below the user-defined threshold (475-kW default value).
- Total power flow across CB-1 or CB-2 is less than 100 kW.
- **Island** mode is authorized by the grid remote terminal unit.

When any of these conditions are not met, the system will instead trip off all sources and the grid will go dark. The **Island** mode would then be formed from a **Black Start** state.

DER Power Flow

The microgrid controller manages the power output of the sources when in both **Grid-Tied** and **Island** mode.

Power Flow Operations When Grid Tied

In **Grid-Tied** mode, the GridMaster control system monitors the net power flow across the microgrid isolation breaker (CB-1 or CB-2) and adjusts the microgrid generation as appropriate to keep a net minimum power flow from the utility source. This adjustment happens at control speeds, for several seconds, and not at protection speeds, for a few power system cycles. The microgrid protection system is designed to include reverse-power protection at the microgrid isolation device to prevent any sustained backfeed from microgrid generation to the utility system. The **Net Minimum Power Flow** setpoint is selected to avoid tripping the microgrid isolation breaker for reverse-power protection. The **Net Minimum Power Flow** setpoint can be manually changed at any time through the GUI. Follow these basic process steps:

STEP 1. Calculate the total load of the system as the sum of power measured at the 600-V microgrid isolation breakers plus the output of all sources within the microgrid.

STEP 2. Manually set the generator output at the total load minus the **Net Minimum Import Power Flow** setpoint.

Typically in **Grid-Tied** mode, both generators will be constantly running. However, when operating the generators in **Base Load** mode (grid-tied), their power output cannot be set to less than 50% of the generator output rating. Therefore, during light loading conditions, the microgrid controller needs to shut down one of the generators to avoid exporting power to the utility.

To avoid depleting the batteries in **Grid-Tied** mode, the BESS resource is not used to help minimize power import from the utility. In **Grid-Tied** mode the BESS is operated in one of three control modes depending on user selection, described in the next sections.

Power Flow Operations When Islanded

In **Island** mode, DER power flow is a function of the microgrid load and the available generation sources, as described in the “Island Mode” section on page 20.

Power Quality

In **Island** mode, the generators supply reactive power (vars). Nominally, they can supply their rated power output (265 kW) at a rated power factor of 0.8 lagging. The BESS will be commanded to supply only active power (kW) in **Island** mode.

In **Grid-Tied** mode, the generators operate at a constant power factor, settable between 0.8 lagging and 0.95 leading. The **Power Factor** setpoint can be programmed locally at the generators' HMI but cannot be adjusted through SCADA. The generator power factor is set to match that of the microgrid loads. The BESS can be commanded by the microgrid control system to supply reactive power. The microgrid controller has a mode in which it attempts to control the reactive power imported from the utility to a particular small value, for example, 50 kvar. This setpoint can be changed manually through the GUI. If the imported reactive power deviates from 50 kvar by some deadband, the GridMaster controller will command the BESS to supply or absorb enough reactive power to adjust imported vars to 50 kvar. The BESS has the capability to supply up to 250 kVA at any power factor. Changing the **Reactive Power** setpoint happens at control speeds, with several seconds of latency between the measurement and the control signal.

No device on the microgrid system is equipped to filter harmonics from the power system.

PV Smoothing

When the PV smoothing functionality of the microgrid is enabled, the GridMaster control system monitors changes in the PV system output and revises the BESS **Power Output** setpoint to attempt to maintain a constant output of the PV at 50 percent of its expected output given the time of day and day of year. This occurs at control speeds (every few seconds) and will not entirely eliminate the irregular PV output. The 50 percent value can be adjusted by the user.

This functionality is only enabled in **Grid-Tied** mode. The process steps are:

STEP 1. The GridMaster control system measures the output of the PV inverter.

STEP 2. The BESS is commanded to charge or discharge based on the difference between the average desired smoothed power level and the actual PV output.

The battery state of charge will be affected by the target percent value and the insolation conditions. When the battery state of charge falls below a certain level, the **PV Smoothing** feature is disabled.

Storm Preparedness

In **Storm Preparedness** mode, the GridMaster control system attempts to charge the BESS to an optimum state of charge (85%). Other features, such as **PV smoothing**, may be disabled. The charging rate of the BESS in this application is user-definable up to 100 kW (which is less than the maximum rate of 250 kW) to maintain the ability to eliminate sudden power-export conditions, as described in the "Export Power Allowance and Mitigation" section on page 20.

Demand Response

Demand Response mode is limited to control of the microgrid generator setpoints, the BESS energy storage system, the electric vehicle charging station, and PV during **Grid-Tied** mode to maintain a net zero or net minimum power import. See the "Grid-Tied Mode" section on page 20 for more information.

This section describes the protection schemes and short-circuit fault scenarios for **Grid-Tied** and **Island** modes.

Each DER protective device uses the same protection settings in **Grid-Tied** and **Island** mode. The integral protection of the BESS is programmed for voltage and frequency-based protection, set with enough delay to ride through system disturbances caused by external faults or by the load steps during **Island** mode. The BESS also has backup overcurrent and overload protection.

The PV inverters have voltage and frequency protection set in accordance with the IEEE 1547 standard. The PV inverters may trip during external faults and system transients.

Microprocessor-based protective relays in the 600-V switchgear may be programmed with two different settings groups, and the active group is selected based on whether the system is in **Grid-Tied** or **Island** mode.

Protection for Grid-Tied Mode

In **Grid-Tied** mode, the general protection principles typical for a small generator interconnect apply. The utility can provide enough available fault current that primary system protection, including DERs, is based on overcurrent elements. Protective relays respond to fault conditions to protect the associated devices.

Fault on the Utility System

For a utility system fault, the utility connection trips for the fault and the utility sends a transfer-trip signal to the microgrid generation sources. When the transfer-trip signal is received, the microgrid generation sources trip their circuit breakers but the loads remain connected. If the utility-protection operation successfully clears the fault and restores power, the microgrid loads incur only a momentary outage.

If the transfer trip communication channel is lost, the microgrid generation sources disconnect from the system within five seconds of loosing the channel.

In the event of a failure to disconnect any of the microgrid sources when the transfer-trip signal is received, the DER equipment will detect breaker failure and trip the 600-V microgrid isolation breakers CB-1 and/or CB-2 to disconnect the microgrid sources and loads from the utility.

For a fault on the utility system that does not result in a transfer-trip signal from the utility, up to two times rated current is expected to be contributed by the inverter-based DERs and up to six times rated current is expected to be contributed by the generators. Online generators are expected to supply enough fault current that the fault can be detected by relays at the 600-V switchgear by using directional overcurrent, voltage, or frequency protection, resulting in the 600-V main breaker tripping. The inverter-based DERs will trip on their voltage or frequency protective elements.

Fault on the Microgrid System

For a fault on the 600-V microgrid system in **Grid-Tied** mode, proper coordination and fault isolation is achieved with overcurrent-based protection. For faults downstream of load breakers, the generators and BESS are expected to ride through the fault and remain online. Faults may cause the inverter-based DERs to trip for the same reasons described in the utility-fault scenarios.

Protection for Island Mode

When the microgrid system is in **Island** mode, system protection, including DERs, is based around a combination of overcurrent elements in the 600-V switchgear and overcurrent, voltage, and frequency elements in the DER controls.

Fault on the Microgrid System

Fault-current levels In **Island** mode are substantially lower than the fault-current levels possible in **Grid-Tied** mode. Overcurrent elements intended to identify and isolate Island mode faults must be set more sensitively than for **Grid-Tied** mode. In **Island** mode, the GridMaster controller instructs the microprocessor-based relays in the 600-V switchgear to operate their more sensitive Group 2 protection settings. The PV inverters are expected to trip offline based on the IEEE 1547 protection settings used in **Island** mode.

For a branch-circuit fault, fault current supplied by microgrid sources is expected to be high enough to selectively coordinate and clear, without collapse of the entire microgrid power system.

For faults on main feeders close to the 600-V switchgear, or near a building service entrance, the protection system may not coordinate and clear a fault fast enough to prevent a DER control from operating. Therefore, feeder-level faults may result in an outage on the entire microgrid system, with inverter-based DERs tripping on voltage/frequency settings and generators tripping on overcurrent settings. Fault location, isolation, and system restoration after such an event is expected to be performed manually by utility personnel.