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DEVCOM Army Research Laboratory Mobile Unattended Ground Sensor (MUGS) Installation Guide

by Brandon Parks, Abigail Snellman, and David Hull

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DEVCOM Army Research Laboratory

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14. ABSTRACT

Electric power (EP) is a fundamental resource to nearly all modern activities. The ability to measure and understand EP is of vital importance to all military and commercial organizations. The US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) has developed EP sensing and analysis hardware and software solutions capable of high-resolution data processing and storage. The ARL Mobile Unattended Ground Sensor (MUGS) hardware contains a phasor processing architecture that can provide information beyond standard power quality measurements typically provided by commercial-grade power-quality analysis equipment. This report provides general information on the sensing technology in addition to guidance on installation and configuration. Checklists and examples are provided as appendixes.

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1. Introduction

This report contains background information, use cases, and instructions for the installation and basic use of the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) electric power (EP) sensing hardware. The base sections contain information on the type of electrical systems and circuits that can be monitored, which hardware options exist, and step-by-step guides for the installation process and basic system configuration checks. In addition, appendixes are included that can be used during installation and for ongoing status checks with installed sensor systems. Specifically, Appendix A contains the most important installation information on a single page; it can be printed out for quick reference. Appendix B is an example of a completed sensor installation worksheet; the blank template is provided in Appendix C. Appendix D contains a checklist and notes for approvals that are often required for the installation of power sensing equipment in electrical distribution equipment. Finally, Appendixes E and F contain status-check worksheets that can be used with single or multiple sensor hardware installs.

2. ARL-MUGS Use Case and Specifications

The ARL-Mobile Unattended Ground Sensor (MUGS) is an 8- or 16-channel data collection system that can be configured to process a variety of sensor assets, including EP current clamps and voltage probes. The system is housed in a small, aluminum case with 8 or 16 Bayonet Neill–Concelman (BNC) connectors for traditional commercial off-the-shelf low-frequency sensors. In addition, LEMO[*] connectors are available for multichannel, custom Government off-the-shelf "smart" sensors, and USB inputs can be used for auxiliary sensors or external storage. In many cases, sensors such as current clamps and differential voltage probes are used to measure individual conductors and differential signals to monitor current and voltage in a single- or multi-phase circuit. For three-phase power systems, it is recommended that at least one voltage and all current in a circuit be measured to provide accurate EP data. There are several MUGS variants that have been designed by ARL. A description of the basic specifications for each unit are listed in Table 1. The software stack, field-programmable gate array (FPGA) processing, and general capabilities are all similar; however, the user should be aware of the differences.

[*] LEMO is a registered trademark of the LEMO Group. All rights reserved.

Table 1 General specifications of MUGS hardware

Description	MUGS-8 (v2)	MUGS-8 (2000)	MUGS-16 (3000)	MUGS-16 (3100)
Length	8 inches	10 inches	10 inches	10 inches
Height	2 inches	2 inches	2 inches	2 inches
Weight	3 lb	4 lb	4 lb	4lb
Channels	8	8	16	16
ARTEMIS	v2	v4	v4	v5
Low-power mode	No	No	No	Yes
Comms	Wi-Fi, Ethernet	Wi-Fi, Ethernet	Wi-Fi, Ethernet	Wi-Fi, Ethernet
Primary battery	38 W-h	66 W-h	66 W-h	73 W-h
Software	ViPERS, dLAMP	ViPERS, dLAMP	ViPERS, dLAMP	ViPERS, dLAMP
Ubuntu OS	18.04 or 20.04	18.04 or 20.04	18.04 or 20.04	20.04
Processor	Zynq-7010	Zynq-7010	Zynq-7020	Zynq-7020
OS/Data storage	64 or 128 GB	128 GB	128 GB	256 GB
Raw storage	128 GB SD × 2	128 GB SD × 2	128 GB SD × 2	256 GB SD × 2
USB charging	Quick Charge (QC) 3.0 (micro)	QC 3.0 (micro)	QC 3.0 (micro)	QC 3.0 (micro)
USB ports	1	3	3	3

In addition to the specifications outlined in Table 1, there are additional differences and technical details to be aware of when setting up and using a specific ARL-MUGS variant. Users should consult the *ARL Visualization and Processing for Embedded Systems (ARL-ViPERS) User Manual* for more information.[1]

ARL-MUGS systems are often provided in “kits” (Fig. 1) that may include 1) a variety of sensors that can be used for monitoring an EP circuit, 2) a USB cable and charger, 3) a multi-TB hard drive for long-term data recording, and 4) a MUGS unit. Any low-frequency (DC-6.4 kHz) sensor with a low-voltage BNC output can be used with MUGS units.

Fig. 1 MUGS kit containing Probemaster 4232 voltage probes and 200-A split-core current clamps

2.1 Standard MUGS-kit Sensors

2.1.1 200-A Split-Core[2] Current Clamp (Variable Quantity)

Current clamps are placed around a **single conductor** in closed loop and provide a safe (low voltage or current) signal output that can be connected to measurement devices. MUGS units provided in a kit nominally come with several 200-A split-core current clamps that provide an AC low-voltage output signal proportional to the current in the conductor it has been placed around. There is a snap-in-place piece that is removed to allow installation around a conductor. Ensure that this piece fully snaps back on to close the loop around the conductor; if not, the measurement signal will be negatively impacted. In addition, this (and most) current clamps are marked to designate which side should face in the direction of the load and/or which side should face the source (e.g., generator, transformer, input to panel). If the clamp is installed with the incorrect orientation, it will introduce a 180° phase shift in the output signal.

2.1.2 Probemaster-4232[3] (Variable Quantity)

This differential measurement sensor provides an isolated, 100:1 attenuation of voltages up to 1400 V (peak-to-peak). The differential voltage probes **DO** require power from a 120-V outlet (batteries can be used as well but will need to be replaced frequently). The red probe should be placed in contact with the phase (e.g., A) conductor (e.g., on copper, screwed into conductor block), while the black probe should either be connected to the neutral/ground (typical for Wye-configured circuits) or another phase (e.g., B) conductor (typical for delta-configured circuits).

It may be necessary to insert more than one probe into a block or breaker if multiple differential probes are being used in a single circuit.

Note: Sensor installation in EP distribution equipment, especially voltage probes, requires one or more certified electricians. Users should not attempt to install these sensors unless certified and authorized.

2.2 Alternative Compatible Sensors

2.2.1 800-A Split-Core Current Clamp

Current clamps (Fig. 2) are placed around a **single conductor** in closed loop and provide a safe (low voltage or current) signal output that can be connected to measurement devices. For high-amperage circuits, there are 1500-A split-core current clamps available that provide an AC low-voltage output signal proportional to the current in the conductor it has been placed around. The split-core clamps have limited frequency-response range—typically, 30–1000 Hz.

2.2.2 Fluke i5s[4] Current Clamp

Fluke i5s sensors are typically used to monitor individual current-carrying conductors in selected 480-V, three-phase circuits. The probes have 40- and 400-A settings and provide a line-level voltage output proportional to the current through the monitored circuits. These clamp-on sensors do not require any external power. The Fluke i5s current clamps have a wide frequency response (40 Hz–5 kHz).

2.2.3 Fluke i400s[5] Current Clamp

Fluke i400s sensors are typically used to monitor individual current-carrying conductors in selected 120- or 480-V circuits. The probes have 40- and 400-A settings and provide a line-level voltage output proportional to the current through the monitored circuits. These clamp-on sensors do not require any external power. Fluke i400s current clamps have a wide frequency response (5 Hz–10 kHz).

Photographs of the specified sensors are shown in Fig. 2 and details on these sensors relevant to use with the MUGS hardware appear in Table 2.

Fig. 2 Left to right: Fluke i5s, i400s, split-core current clamps, and Probemaster-4232 differential voltage probe

Table 2 Specifications and recommended setting for standard sensors (10:1 Probemaster setting will exceed MUGS input threshold in most standard EP circuits)

Sensor name	Type	Sensor options	ViPERS setting	Recommended hardware setting
Probemaster 4232	Voltage	100:1 or 10:1 V/V	100 or 10 mV/V	10:1
Fluke i400s	Current	400 A or 40 A	1 or 10 mV/A	1:1
Split Core AC 200 A	Current	0.333 V at 200 A	1.665 mV/A	1:1
Split Core AC 1500 A	Current	0.333 V at 1500 A	0.222 mV/A	1:1
Fluke i5s	Current	0.4 V at 5 A	400 mV/A	1:1

2.3 MUGS-Kit Peripherals

2.3.1 Quick Charge USB Block and Cable

A QC USB power supply and micro-USB cable (high-quality cable is recommended) are included with MUGS kits. A *QC charger **MUST** be used*; if not, the MUGS unit will not receive enough power to sustain operation. Both QC 2.0 and 3.0 standards provide enough power for sustained operation of the hardware. Standard USB power sources do not negotiate charging voltage; therefore, they will provide less than the 4 W of power (nominal MUGS power use) needed to run the unit long term.

2.3.2 GPS Antenna

A GPS antenna is provided for use with ARL-MUGS. This antenna is connected to the labeled SubMiniature version A (SMA) connector on the “back side” of the ARL-MUGS unit. If indoors, a GPS cable extension may be required to place the antenna outdoors or near a location where a signal can be received. GPS can be disabled in the ARTEMIS firmware, and a terminator can also be used if GPS is not authorized at the installation site.

2.3.3 Wi-Fi Whip Antenna

A Wi-Fi antenna is provided for use with ARL-MUGS. This antenna is connected to the labeled reverse-gender SMA connector on the “back side” of the ARL-MUGS unit. Wi-Fi can be disabled using the Visualizing and Processing on Embedded Research Systems (ViPERS) configuration software, and a terminator can also be used if Wi-Fi is not authorized at the installation site.

2.3.4 Rugged External Hard Drive

There are several options for external hard drives, but rugged hard drives are preferred to provide improved environmental resilience. LaCie 2/5 TB rugged hard disk drives (HDDs) shown in Fig. 3 may be provided with MUGS kits. All hard drives must be formatted as extensible file allocation table (exFAT) for use with MUGS. Hard drives can be connected to MUGS using one of the three USB peripheral ports near the Wi-Fi and GPS connectors.

Fig. 3 Provided USB QC charging block (top left), GPS antenna (top right), view of MUGS connectors (bottom left), and rugged LaCie HDD (bottom right)

3. Detailed Installation Guide

The installation of power sensors for data acquisition, processing, and analysis is highly site-specific and will almost always require thorough communication with multiple individuals associated with the monitoring location. Depending on the goals of the installation, the importance of the location, and the power distribution level, it may take months to fully plan and definitively schedule sensor/sensor system installations. Due to the complex and highly variable nature of EP installations, this installation guide cannot provide a simple step-by-step process. We do, however, provide a list of recommendations, suggestions, and technical solutions that cover most use cases.

3.1 Approval Authorities and General Recommendations Prior to Installation

Approval authorities may be required to install ARL-ARTEMIS-MUGS software and associated sensors. We recommend identifying the relevant points of contact for the following authorities so that written approvals can be obtained before scheduling installation.

1) *Authority Having Jurisdiction (AHJ)*. The facility power engineer (or equivalent position) who approves work on the electrical system.

2) *Certified Electrician with Lock-Out-Tag-Out authority*. This person is authorized to work on electrical equipment (opening a power panel, installing voltage and current probes, etc.).

3) *Equipment Owner*. The shop foreman, line engineer, or equivalent position who authorizes equipment to be temporarily taken out of service. Any live electrical work usually requires additional risk analyses, approvals, coordination with the electrician and AHJ, and additional personal protective equipment and/or safety procedures. Additionally, the equipment owner may want to place restrictions on the distribution and/or use of any operational power data collected.

4) *Equipment Manufacturer*. This person may be needed to preserve the equipment warranty or service contract. In general, installing a MUGS system is equivalent to installing a three-phase power-quality analyzer.

5) *Lithium-Ion Battery Restrictions*. Battery specifications and safety considerations should be discussed prior to installation. In some cases, additional paperwork may be required.

6) *Information Systems Security Officer*. The sensor systems run a Linux OS and can send and receive raw and processed data in real time. Ethernet and Wi-Fi can be disabled, if needed, or restricted to point-to-point communications with a single PC or other device. The sensors can also be networked on a local-area network (LAN) that is air-gapped. If needed, the sensor can be completely configured before installation, and operated as a stand-alone data acquisition system.

7) *IT Specialist*. The IT specialist configures, monitors, and/or tests the network; adds IT equipment to a LAN/wide-area network (WAN); and/or verifies the configuration of the sensor such that it cannot connect to internal networks.

3.2 Preparing for ARL-MUGS Installation

Once all approvals have been obtained to install sensors and sensor hardware, the appropriate sensors for the electrical system to be monitored will need to be identified. These specifics can only be determined after reviewing electrical distribution documents (e.g., line diagrams/electrical drawings) and/or consulting with electrical experts at the install site. MUGS can be used with single-, split-, or three-phase circuits. A brief summary of these concepts is included here. More comprehensive information can be found in literature reviews.[6,7]

Electrical power is most often broadly distributed using three-phase AC configurations. It is a voltage-regulated system, meaning the voltage is meant to be stable in frequency (60 Hz in the United States), phase, and amplitude. The relative phase between any two phases of power should reliably be 120°. The voltage amplitude depends on the power distribution level. Transformers are used to step voltage levels up or down. The total EP must remain the same; therefore, the current (amperage) change will be inversely proportional to the change in voltage. Higher voltages are used to provide EP over large distances because current is what drives the size of conductors (larger conductors needed to avoid overheating and degradation with larger current). Therefore, higher points in electrical distribution not only carry more power; they also carry higher voltage to deliver the current safely and with minimally sized conductors.

These basics are important to understand when planning an installation so that the appropriate sensors can be selected based on what type of electrical equipment is being monitored. Voltage levels above 480 V are often capable of being monitored in substations, which may contain potential transformer (PT) and current transformer (CT) outputs that can be safely accessed by a certified electrician.

The differential voltage is determined by the potential difference between conductors or ground in a 120-/208-V three-phase system.[6*] If the circuit is Wye-configured, it is advisable to place a differential probe between the phase and neutral conductor. For delta-configurations, monitoring between phase conductors is advised. In many cases, only monitoring the ground and neutral at the input is needed, but specific power quality studies focused on grounding may require clamps to be placed on grounds at multiple locations. The goal of the electrical monitoring should drive which voltage, current, and ground are instrumented.

In the case of a standard three-phase EP analysis (the primary use case described in this guide), we recommend monitoring all three voltage differentials, plus a neutral-ground differential when possible. However, if more current channels are needed,

[*] Refer to www.electricaltechnology.org for additional information and graphical representations.

a **minimum of one voltage differential probe** can be installed and connected to MUGS. It is important to monitor each three-phase conductor using current clamps. We recommend monitoring the neutral and ground conductors as well when available. The major classes of installations are listed here in increasing order of complexity:

1) *Individual equipment*. This is likely to be the simplest type of installation, but there will still often be coordination requirements prior to installing sensors. Manufacturer warranty concerns can become a concern "day/week of install;" therefore, it is highly advisable to communicate these considerations well before the install date and receive written approval prior to scheduling the install. Most often, the equipment will only require one set of voltage and current measurements, but in some cases there may be sub-circuitry that can be monitored as well.

2) *Distribution boxes*. This type of electrical equipment often exists in large generator power distribution setups. These boxes will contain breakers that are rated appropriately for the output cables. For example, they may possess a 200-A input cable and multiple 100- or 60-A output cable assemblies. When using a 16-channel MUGS unit, it is possible to monitor three to four circuits simultaneously if only one set of voltage measurements are made. The goals of the monitoring should be considered for this decision. For example, in a power quality analysis, it is important to measure the voltage in each circuit. Alternatively, if the goal is to understand load use, only a single set of voltage measurements may be necessary. This will free up more channels to monitor the current on additional circuits.

3) *Generators*. The power provided by generators is often carried through individual insulated conductors prior to being run through an insulated cable assembly containing all phase, neutral, and ground conductors. In this case, the overall power consumed by all electrical loads can be monitored at the source. There may also be a distribution box (Fig. 4) near the generator, in which case a MUGS unit can be set up at this distribution point to monitor both the overall generator power and sub-circuits on the output of the distribution box.

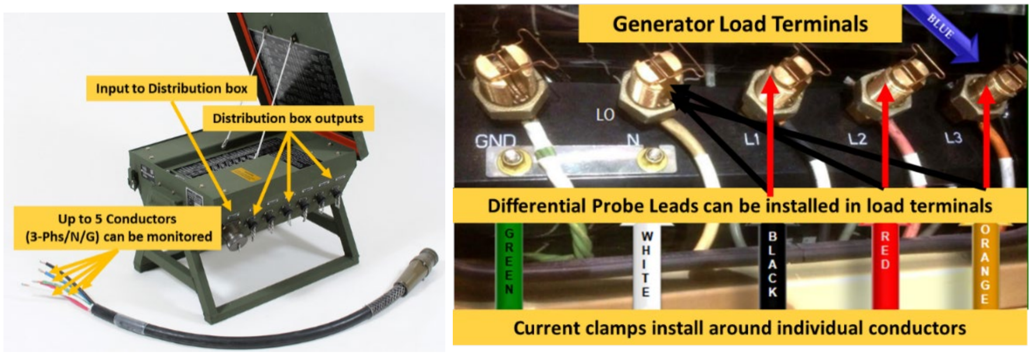

Fig. 4 Distribution boxes support input and multiple output cables (left); the BLACK/RED pair of differential probe leads can be screwed into terminals (right)

4) *Power Panels and Load Centers*. This category of monitoring locations is common in facilities and will typically be comparable to distribution boxes in terms of number of measurement options/opportunities. In some cases, spare breakers will be available that can be used to monitor voltage with differential probes. This is not required but may be easier than installing leads in the same block with conductors. Some considerations when installing in power panels follow:

    a. Provide clear, written instructions to the electrician(s) installing the sensors to ensure that all sensors are installed in the desired locations.

    b. Current clamps that do not lock in place (e.g., Fluke i400s) must be installed with care to avoid becoming loose when/if conductors are moved during the installation and when the panel is resealed.

    c. Ensure that clamps are oriented properly regarding load/source direction.

    d. Ensure that differential probe leads are correct (**RED** vs. **BLACK**).

    e. Differential probe settings (recommend 100:1) should be taped or otherwise secured in place.

    f. Panel knockouts may be necessary to run BNC cables out and provide 120-V power to the differential probes.

    g. Label each BNC connector by the measurement being made. If an extension is required, also label each end of the extension.

    h. Use zip-ties to neatly bundle all sensor cables as they exit the panel; continue regularly as cables are routed to the ARL-MUGS unit for measurement.

i. If allowed, take photographs of each installed sensor. Panels will likely be inaccessible after the install date.

5) *Substations*. Monitoring EP in substations is likely to require the most extensive and comprehensive coordination prior to sensor installation. Substations provide power to many consumers; therefore, outages may be prohibitively difficult to coordinate. However, there are prescheduled outages in some cases that can be used opportunistically to install sensors. This assumes that an outage is necessary. Most substations monitor EP using the output of PTs and CTs. These bring high voltages down to safe (usually 120 V) levels, and high current down to safe (usually 5 A max) levels.

Certified and authorized electricians may be able to access panels containing PTs/CTs without an outage, but this depends on the site and decisions of the approving authorities. In either case, electricians are required to install the probes and clamps. The previously described Fluke i5s clamps are specifically designed to measure the output of CTs. These measurement clamps are recommended for CT monitoring in substations. Table 3 lists specification details and sensor-use scenarios. Photographs of installed sensors are shown in Fig. 5.

Table 3 List of recommended sensors in lower-voltage three-phase circuits. Only one voltage channel is required per circuit, but all three can be included. Optionally, a ground-neutral differential measurement can be included in Wye circuits (four channels total). All current phases should be included (three channels), with an optional ground/neutral channel (four channels total).

Equipment voltage (most common) (V)	Recommended sensor	Recommended setting	Differential measurement	Sensor-channels per circuit
120	Probemaster-4232	100:1	Phase-Neutral	1–4
208	Probemaster-4232	100:1	Phase-Phase	1–3
277	Probemaster-4232	100:1	Phase-Neutral	1–4
480	Probemaster-4232	100:1	Phase-Phase	1–3
Conductor rating (most common) (A)	**Recommended current clamp**	**Recommended setting**	**Amperage measurement**	**Sensor-channel /circuit**
40 or less	Fluke i400s	40 A	Phase × 3 (Neutral)	3 (4)
40–200	Split-core 200 A	NA	Phase × 3 (Neutral)	3 (4)
200–400	Fluke i400s	400 A	Phase × 3 (Neutral)	3 (4)
400–1500	Split-core 1500 A	NA	Phase × 3 (Neutral)	3 (4)

Fig. 5 Examples of current clamps and voltage probes installed in CTs and PTs outputs at a substation

3.3 ARL-MUGS Initial Setup

The ARL-MUGS is a sensor system that can be used in a variety of ways with a various low-frequency sensors. The MUGS provides LEMO connections for smart sensors, which are powered by the ARTEMIS unit. If LEMO sensors are being used, you must set the ARTEMIS sensor to LEMO through the ViPERS interface. However, the default setting assumes BNC inputs. Most power sensing applications make use of unpowered or self/externally powered sensors. These include the differential probes and clamps described in Section 2. Installed sensors provide a safe output voltage that connects to BNC connectors on the front of the ARL-MUGS hardware (Fig. 6).

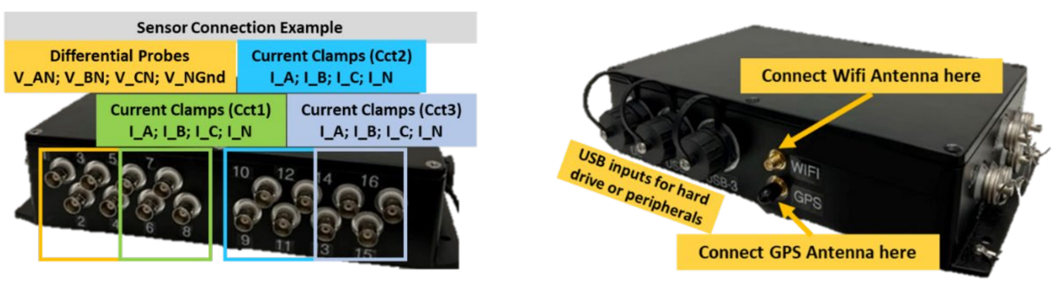

Fig. 6 Example of installed sensor connections to ARL-MUGS (left); and peripheral connections (right)

Once sensors and circuits have been selected and the installation is complete, the ARL-MUGS unit can be configured to store and process data. The hardware will digitize, process, analyze, store, and/or distribute sensor output signals. An individual unit can analyze multiple electrical circuits simultaneously. After all connections have been made to the ARL-MUGS unit, data collection and analysis of the sensor readings can begin.

Use the following steps to initialize ARL-MUGS:

1) Connect the USB charging cable to the provided USB QC power source (provided in ARL-MUGS kit).

2) Connect the USB QC block to a power outlet, surge protector, uninterruptable power supply (UPS), or other 120-V power source. Note: Standard USB chargers or laptop power are insufficient.

3) Connect the micro-USB end of the cable to the ARL-MUGS micro-USB connector.

4) If an external hard drive is being used, connect the hard drive to a USB peripheral port prior to powering **ON**.

5) Ensure that the "Battery" LED (Fig. 7) turns on and is **Red** (charging) or **Green** (charged).

6) Press and hold the round power button on the right side of the face containing status LEDs (Fig. 7) for at least 8 s.

7) If the ARL-MUGS unit has sufficient power and the power button has held for at least 8 s, the "Power" status LED will turn **Blue**.

8) If the status LED does not turn **Blue**, check the Battery LED and ensure that it is **Red** or **Green**. If confirmed, hold down the power button again to ensure that it was held down long enough. Note: In 3100-series units, there will be a faint audible click that can be heard when the unit turns on.

9) After 15–45 s, the ARL-MUGS status LED should begin blinking **Red** or **Green**.

10) If the ARL-MUGS unit status LED remains **Blue**, hold down the power button until the status LED turns **OFF**. Release the button, wait a few seconds, and repeat the process starting at **Step 6**.

11) If the unit does not begin blinking and remains **Blue** after multiple start-up attempts, contact the authors of this document at ARL with the serial number, location, hardware delivery date, and notes regarding the installation and power source used with the USB power block.

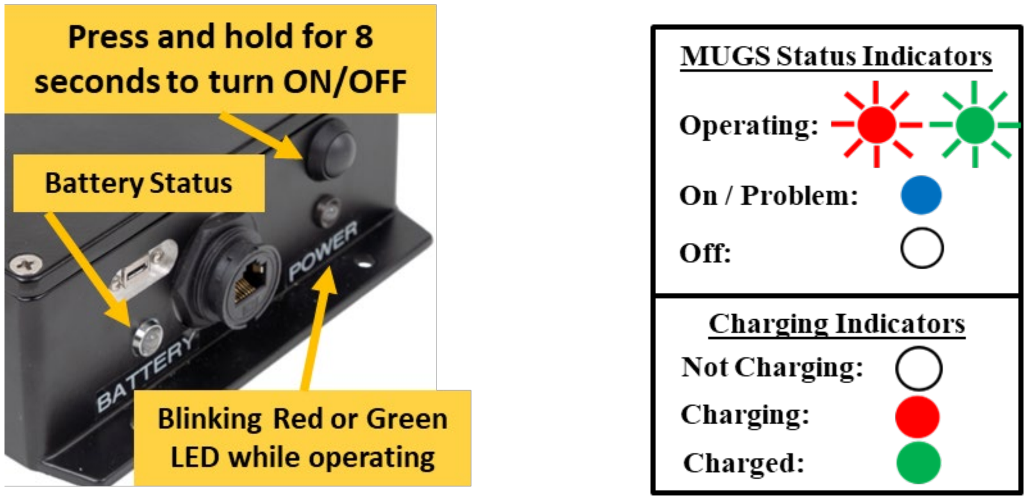

Fig. 7 Status LEDs, power, and ethernet for ARL-MUGS (left). Status LEDs provide information regarding the charging and operation of the unit (right).

Once powered **ON**, data processing and storage will begin if the unit is configured to do so. If the user is solely responsible for installing and confirming base operation of the ARL-MUGS unit, this process will be complete after confirming that the unit is charging, and the status LEDs are blinking. This may be the case if the unit is preconfigured. To configure the unit and/or status checks beyond LED, continue to Section 3.4.

3.4 Basic Configuration and System Checks

The ViPERS web-based user interface embedded in the device provides several capabilities related to EP sensing. Sensor sensitivities, circuit configurations, and EP displays are available through these interfaces. Detailed explanations of this software are available in the ViPERS User Manual.[1] The ViPERS web server operates with the device in the embedded processor, which can be accessed at IP address ***10.10.0.1***. In the standard configuration, ViPERS cannot connect via Ethernet cable connected to an ARTEMIS unit and typing ***10.10.0.1*** into a browser's address bar. The laptop, tablet, or other device must be configured for dynamic host configuration protocol (DHCP[7] to interact with the device from the user's machine. Once the user interface (UI) appears in the user's browser (Firefox and Chrome supported), they will be prompted for a username and password on a login screen (Fig. 8).

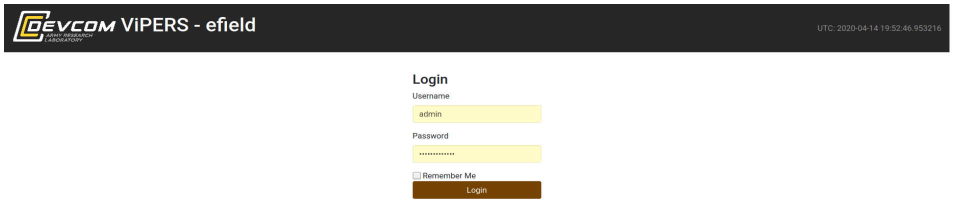

Fig. 8 ViPERS login screen

Once logged in, different pages can be viewed from the home page by clicking their icons (Fig. 9) or typing their URL into the address bar. For instance, ***10.10.0.1/index*** will return the user to the main index page. ViPERS can also be accessed through other IP addresses (e.g., ***192.168.1.15***) if connected to a local network and the Mobile Power Meter (MPM)/MUGS is not setup as an access point.

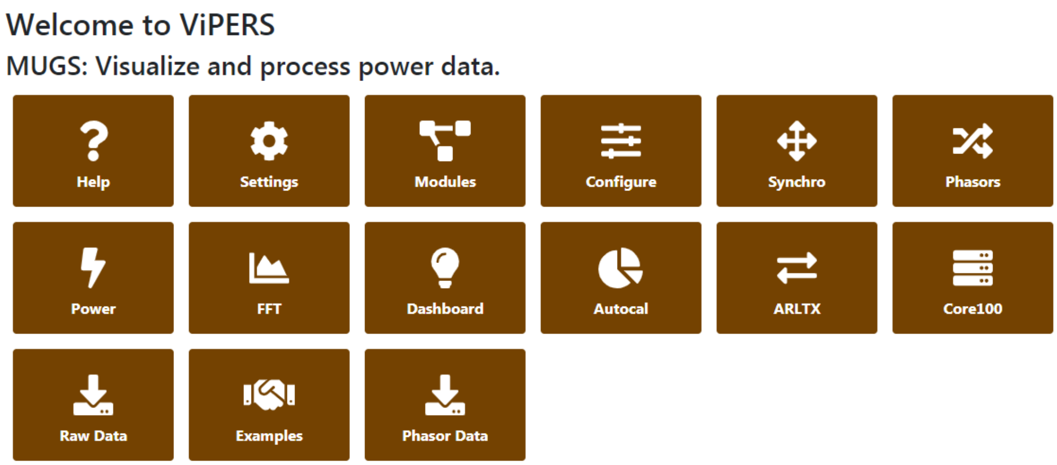

Fig. 9 ViPERS home page with links to all primary pages

The ViPERS application home screen contains several icons. These represent individual pages used to interact with the device. Some of these pages are designed to display system information and system configuration, while others are focused on data display, interaction, and download. Note: The specific apps and layout included may be different, but the primary setup pages identified by yellow numbers are included in all units (Fig. 10).

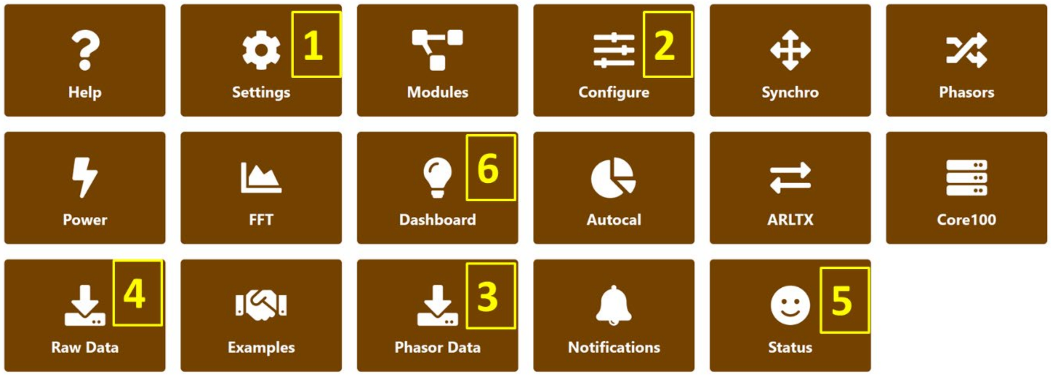

Fig. 10 Use the application's home page to select different UIs during the setup process

3.4.1 Step 1: Settings

In some install locations, you may not have a GPS signal (front LED blinking red). When powered down, the unit does not track time; therefore, the time will need to be manually set in the absence of a network connection or GPS. To set the date and time, select the **Settings** (**1**) page and the **Date and Time** tab. Use the drop-down boxes to manually set the current date and time (Fig. 11). The time must be set to the current coordinated universal time (UTC). Once the time is set, confirm that the date and time are correct in the top right of the web page banner.

Fig. 11 If not connected to a network and GPS is not present, the UTC date/time must be manually set

3.4.2 Step 2: Configure

Once the proper date and time are set, left click the "ARL DEVCOM" logo at the top left to return to the home page; select the **Configure** (**2**) page. On the **Hardware** tab, there are a list of options for how to configure the unit (Fig. 12). Most of these settings are considered advanced settings. However, ensure that the "Broadcast" option is selected. The "Source" should be set to either **tcp** or **dbus**, either option is acceptable for collecting and processing sensor data.

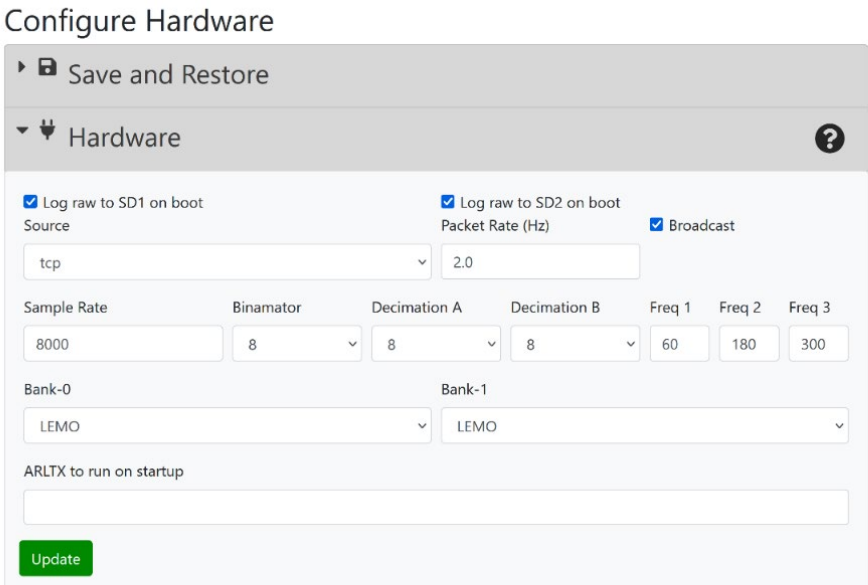

Fig. 12 The saved hardware settings will be applied immediately and at each start-up

To collect raw data, select the "Log raw to SD on boot" option. When the user clicks "Update" the raw SD cards will be set to store raw samples of data directly from the analog-to-digital converters (ADCs). This data is higher bandwidth and requires a bit over 22 GB/day of storage. The standard SD cards used for raw storage are 256 GB; therefore, raw data can be logged for just over 3 weeks before running out of space. There are options to stop recording or overwrite the oldest data, which can be accessed on the **Raw** page. If the unit loses power, these settings will be remembered, and data collection will continue when power is restored.

Raw sampled data in ADC counts can be written to dedicated SD cards in the ARTEMIS hardware. Nominally, ARTEMIS hardware is delivered with two 256 GB cards. Standard operation is to overwrite the oldest files once the data cards are full. These and other settings can be modified using the ViPERS UI. The SD raw data specifications for ARTEMIS are listed in Table 4, assuming a standard sampling rate of 8 ksps.

Table 4 Data storage information for the internal raw SD cards (8-ksps rate)

Hardware	SD card storage	Data rate	Duration (2 × 256 GB)
MPM	2 × 256 GB	256 kB/s (22.1 GB/day)	23 days
MUGS-8	2 × 256 GB	256 kB/s (22.1 GB/day)	23 days
MUGS-16	2 × 256 GB	512 kB/s (44.2 GB/day)	11.5 days

ViPERS-ARTEMIS may arrive preconfigured for three-phase delta or three-phase Wye power monitoring without any additional configuration. Simply connect 10-mV/V voltage probes to channels 1–4 (for phases A, B, C, and N, respectively), and 100-mA/V current clamps to channels 5–8 (for phases A, B, C, and N, respectively). If using sensors with different sensitivity or another phasing scheme (e.g., monitoring two delta circuits), settings will need to be updated.

The BNC inputs accept signals in the –1 to +1 V range, or the –10 to +10 V range (with the BNC 10:1 attenuator selected). ARL-MUGS units have two primary settings for input signals: 1:1 and 10:1. The default setting is 10:1, with which ARL-MUGS units can process up to a 10-V AC input signal (peak to peak). The 1:1 setting can be configured through the ViPERS web interface, which is covered in more detail in the following sections. The 1:1 setting can be used to process up to 1-V AC input signals, and is best-suited for processing (lower noise and improved dynamic range over 10:1) if the sensors being used will not exceed 1 V. Remember that the standard voltage probes provided with MUGS kits **WILL** exceed 1 V with 120/208 V and 277/480 V circuits; thus, the **10:1 setting in MUGS units should be used on these channels**.

The input signal level can be selected from the ***/configure/hardware*** page. These are set up as four-channel "banks"—meaning, as an example, only channels 1–4 can be set as BNC 1:1 and channels 5 and 6 can be set as BNC 10:1, but an arbitrary selection of BNC channels cannot be selected.

Once signals are connected and the ARTEMIS is receiving data, the signals need to be transformed to physically useful units. As seen in Fig. 13, on this page the channels can be named; we recommend using names such as "*I_A*" or "*V_A*". **The characters "." and ":" are not allowed.**

We recommend using unique names within a circuit. Channels with the same name, reference, and circuit may lead to overwritten and, therefore, lost data. However, channel names can be repeated for different circuits. For instance, the user may have both an ***I_A*** and ***V_A*** in circuit ***Main Breaker*** and circuit ***Garage Breaker***. Circuits are discussed further in the ViPERS manual.[1]

The following channel types provide additional sorting in the database:

- Voltage (can be used as reference phasor)
- Current
- EField (can be used as reference phasor)
- HField
- Unknown (can be used as reference phasor)

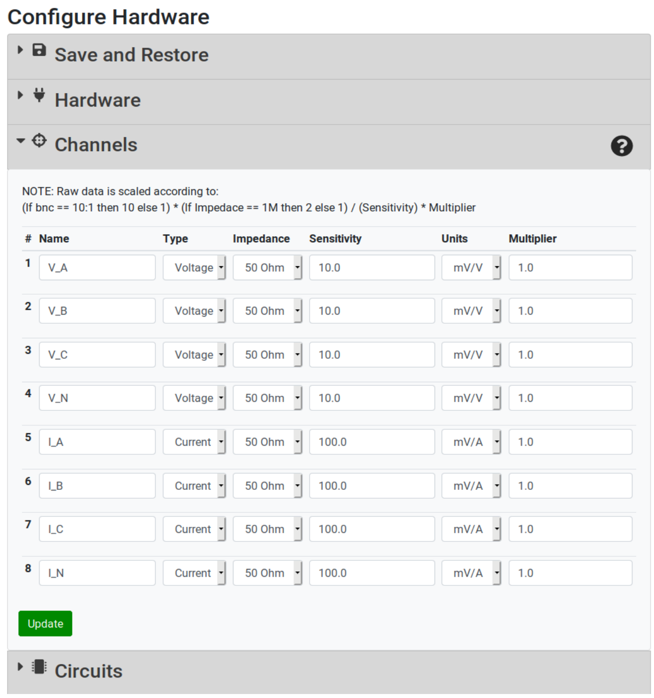

Fig. 13 The Channels page specifies channel scaling factors. This allows physical units to be applied during data processing.

The "Phase" of the channel refers to how the measurement is performed. For instance, voltage can be measured either between the phase and neutral (AN) or between two phases (AB). If measuring between phase BA, use phase AB with a –1 multiplier. By selecting the phase correctly here, the correct phase factors are applied at the circuit level to turn current and voltages into real and reactive power.

Impedance allows the user to compensate for high-impedance (1M Ω) sensors. Most sensors are 50-Ω impedance.

Sensitivities are usually listed in the sensor data sheet and are typically in the form, mV/A or mV/V. The phasor values are *divided* by the sensitivities. See the following examples.

- Example 1: A voltage probe is showing 1.2 V on the synchrophasor page and has a sensitivity of 10 mV/V. After this stage, the phasor will have a value of

$$1.2V/(10mV/V) = 1200mV/(10mV/V) = 120V\ . \tag{1}$$

- Example 2: A current clamp is showing 200 mV on the synchrophasor page and has a sensitivity of 100 mV/A. After this stage, the phasor will have a value of

$$200mV/(100mV/A) = 2A \ . \quad (2)$$

Finally, there is an arbitrary multiplier, which allows the user to incorporate additional factors. For example, for a sensor installed backward, a multiplier of –1 can be used. For a 5:1 step-down coil, a multiplier of 5 will bring the values back to what is being measured.

ViPERS uses **Circuits** to compare current and voltage phasors. By referencing a current to a voltage phasor and using “phasing” real and apparent power can be extracted. Figure 14 shows the ViPERS interface for constructing circuits.

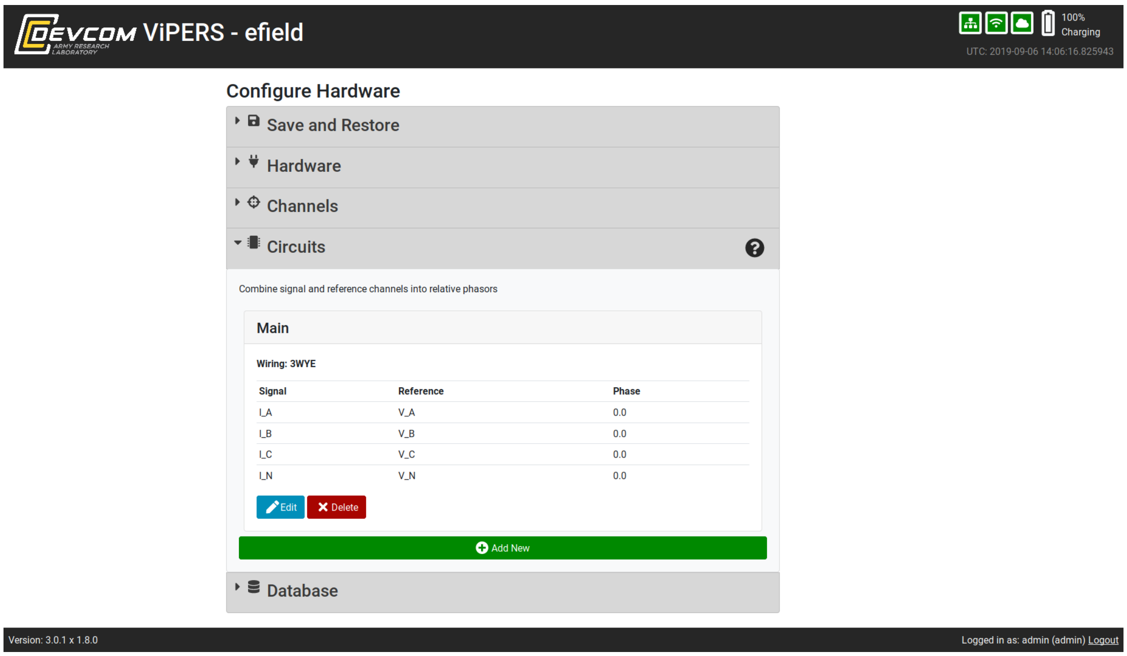

Fig. 14 Channels are referenced and combined into circuits

Each current should have a voltage reference. The easiest configuration is to reference each current to the corresponding voltage.

Example 1: (phasing = “NONE”, “3DELTA”, “3WYE”):

- **I_A : V_A**
- **I_B : V_B**
- **I_C : V_C**

However, if only one voltage is included because of the goals of the experiment, the user may want to configure the circuit differently. For example, monitoring two three-phase circuits with a single MUGS-8. In this case, current can be referenced to a single voltage and a “phasing” scheme applied.

Example 2: (phasing = “3DELTA”, “3WYE”):

- **I_A : V_A**
- **I_B : V_A**
- **I_C : V_A**

Once the circuits have been set, power information will be provided to applications running in the unit. More extensive details on these features are provided in the ViPERS User Manual.[1]

3.4.3 Step 3: Phasor Data

The next step in the setup process involves writing phasor data to file. Select the **Phasor Data** (**3**) button from the home page. This takes the user to a page for phasor data management, where they should select the “Phasor Data Storage” tab. This tab contains a section to display existing files and a menu for configuring the data logging. Here, the user can set the length of individual files (the default is 720 min), which produces two files/day. If the “Enable raw logging” option is selected (Fig. 15), there will be files (shown as yellow blocks) in the display. If the box is not selected, the user should select the box and click “Update” to ensure that phasor data is being logged to the device. Hovering over individual file blocks will display start and end times for the files.

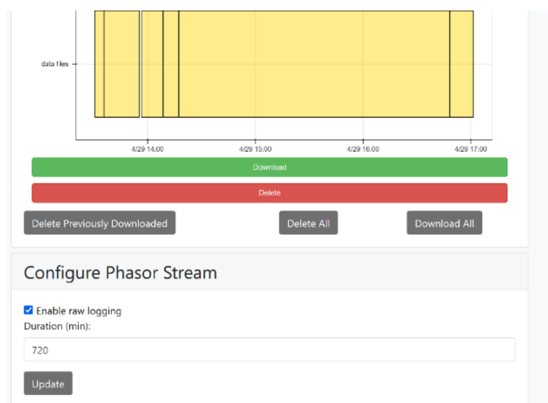

Fig. 15 The “Phasor Data” page allows phasor data to be logged, viewed, and downloaded

Phasor data can be written to files located in the internal storage on ARTEMIS systems. Files will stop being written to the disk once 95% of the storage has been consumed. The length of the files can be modified using the ViPERS UI (Fig. 16). The phasor data specifications for ARTEMIS are listed in Table 5, assuming the nominal phasor rate of 15.625 phasors/s. Units are typically shipped with 256 GB of internal storage, which is shared by the OS, database, and any application-specific storage.

Table 5 **Data storage information for phasor data using internal SD card storage**

Hardware	Internal SD card storage (GB)	Data rate	Duration 230 GB (days)
MPM	256	3.9 kB/s (335 MB/day)	~690
MUGS-8	256	3.9 kB/s (335 MB/day)	~690
MUGS-16	256	7.8 kB/s (670 MB/day)	~345

3.4.4 Step 4: Raw Data

Once the user has verified that the phasor data is being written to file and optionally, configured the unit for live autocalibration, they should proceed to the **Raw** (**4**) page. If the configuration steps were followed in this setup for the **Settings/Hardware** page, the user should already be setup and collecting data on the raw SD cards. To verify this, go to the **Raw** SD card tab, and view the "Toggle SD Card" section. If the current auto-write status is green: Card 1/2 Active, live data writing is active. If it is Red, it can be activated using the drop-down boxes (Fig. 16).

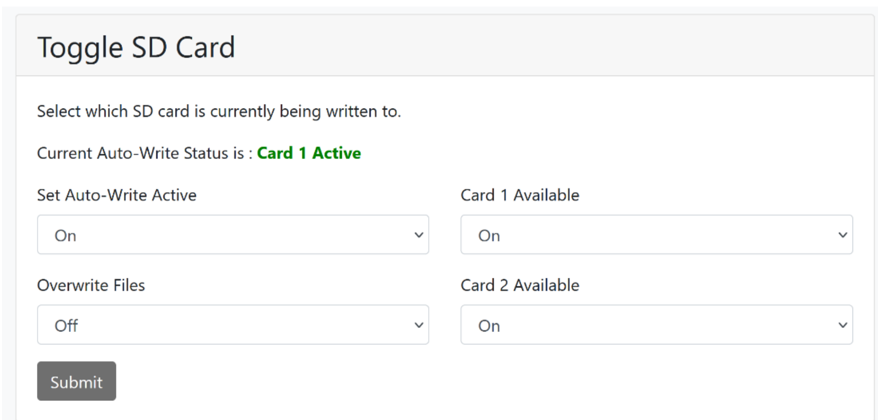

Fig. 16 The raw SD card status can be viewed and reconfigured using the drop-down boxes. The Hardware page is also used to set up writing to the SD card.

Raw SD files in MUGS are created every 3.5 min (MUGS-16) or 7 min (MUGS-8) (default 8 ksps settings) and will not be displayed (Fig. 17) until the file is complete and closed. The user can view completed files in the "Files Ready For Download" Section. These files can be downloaded by selecting "Box Select" from the options on the right side of the plot. However, **raw SD file downloads should not be initiated while actively writing to that SD card**. Reading and writing to the SD card simultaneously is extremely slow and will not complete. Each raw file is approximately 100 MB and download speeds (when SD card is inactive) are 10 MB/s maximum (possibly slower depending on the current processing on the MPM). One hour of raw data is slightly less than 1 GB of data.

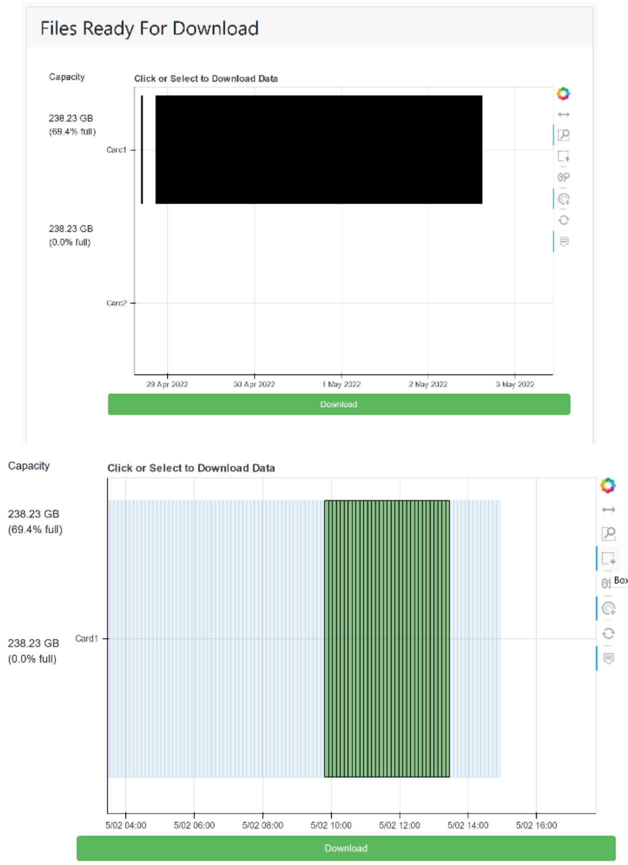

Fig. 17 Individual raw files can be viewed on the Raw SD page. Files can be downloaded using the "box select" option on the right side of the plot.

3.4.4.1 External Hard Drive Raw Data

Raw sampled data in ADC counts can be written to an external hard drive connected to the USB ports on MUGS systems. Completed data sets can be downloaded using the UI shown in Fig. 18. Files will stop being written to the external hard drive once all of the space has been used. The length of the files can be modified using the ViPERS UI. The HDD raw data specifications for ARTEMIS are listed in Table 6, assuming a standard sampling rate of 8 ksps.

Table 6 Data storage information for raw data written to an external hard drive

Hardware	HDD storage (TB)	Data rate	Duration 2 × 256 GB (days)
MPM	None	NA	NA
MUGS-8	5	257 kB/s (22.2 GB/day)	225
MUGS-16	5	514 kB/s (44.4 GB/day)	112

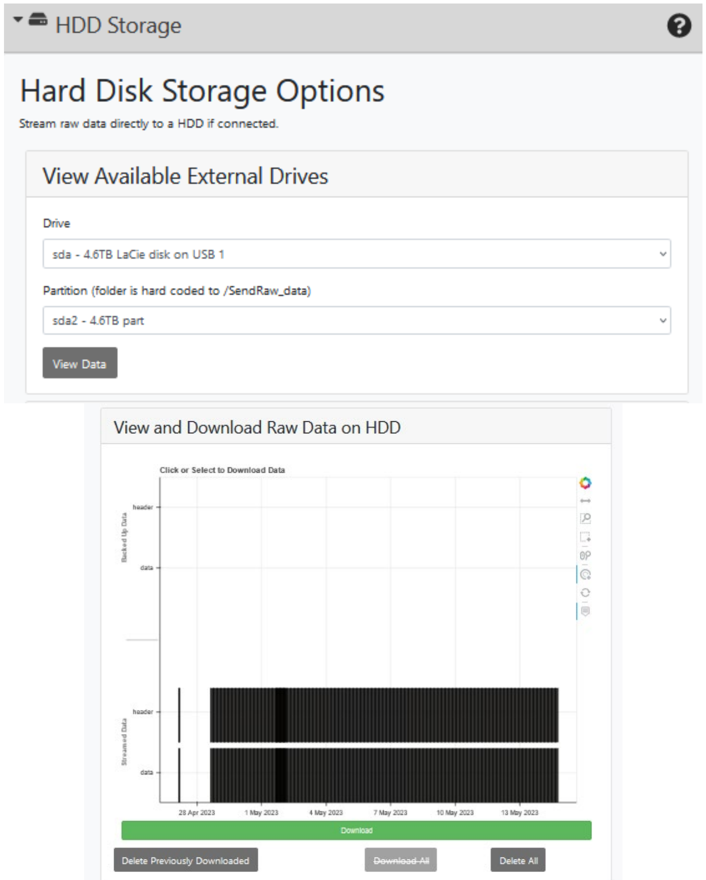

Fig. 18 The HDD Storage page displays raw data files written to external storage as well as headers containing metadata and sensor scale factors

3.4.5 Step 5: Status

Navigate to the Status page from the main menu. Here, the statuses of the charger, battery, data collection, and disk storage can be viewed.

- The HDD status may be Red or Yellow if 1) no hard drive is attached or 2) there is a problem with the attached hard drive. Consult the ViPERS User Manual[1] if hard drives require troubleshooting.
- If the charger is not connected, make sure the oulet is powered and check that the USB connections are secure.
- Core100 is the low-level firmware that interacts with the hardware. This status must be Green for nearly all system functions to work. A Red icon will also present as a solid Blue LED on the ARL-MUGS units.
- The status page displays the primary disk space used, and will be Red or Yellow if this space is near capacity. In this case, consult the ViPERS User

Manual[1] for preventative measures and information regarding freeing up space.

- Data Collector is an application used to provide information to the dashboards. This is not considered an essential application. However, if the status icon is Red, features such as the dashboard data display, alert notifications, and summary notifications will be unavailable.

For additional status information beyond basic checks, the user can navigate to the Modules page. Here, there are several modules that should have green or red circles with status information next to them. The left screen capture in Fig. 19 shows the likely configuration for the MPM if the setup instructions in this guide were followed. The following modules should be green for data collection and basic operation:

- data_collector.py
- phs_stream.py
- relative.py
- synchro.py

Finally, the following module should be enabled, but Red:

- hardware.py

If any of these modules are not enabled, the user must find them in the list of inactive modules and select the enable box next to them. There may be other active modules depending on how the unit is configured.

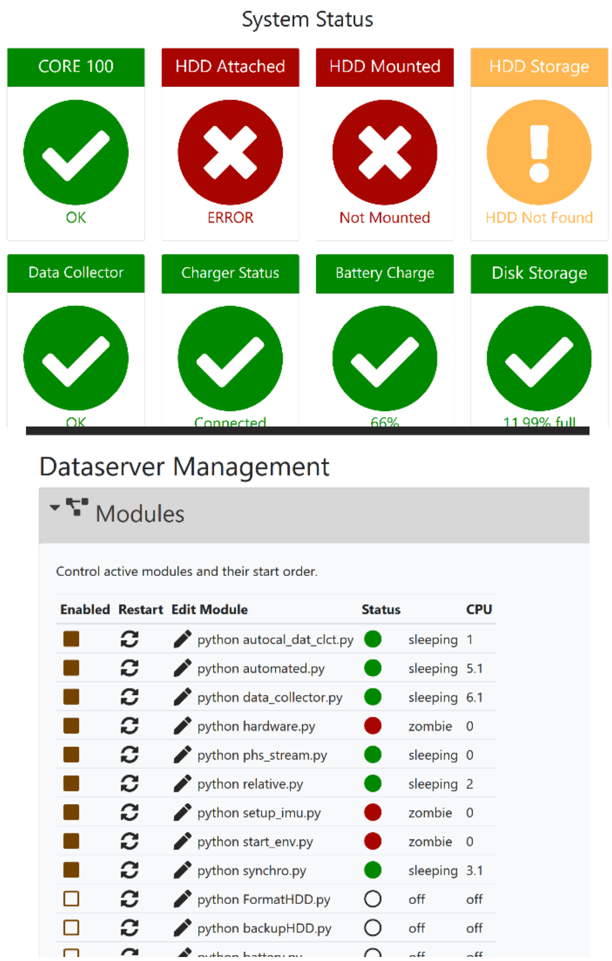

Fig. 19 The Status page (top) displays the current status of the primary components of the MPM. The modules page (bottom) shows the active modules running on the unit.

3.4.6 Step 6: Dashboard

The **Dashboard** page (selectable from the home page) can be selected to show live and historical data from specific date/time ranges. After entering the login information (default is username: admin, with the standard ViPERS password), the user will see the home dashboard, which is a live update of the last 15 min of power data. The live data on this page shows the active power consumption, voltage, current, and additional EP information (Fig. 20).

Fig. 20 Live view of data shown on the Dashboard page

If data is not displayed on the dashboard, troubleshooting the following may resolve the issue:

- Verify that the ARL-MUGS unit is set to the correct UTC time. If not, update the time according to Step 1 in this guide.
- Verify that the laptop's (or other device) date/time is set properly. The dashboard app will use the device's time zone when displaying data; therefore, it can be set to local time as long as the time zone is also properly set.
- Verify that **Data Collector** is green on the **Status** page.
- Verify that the Step 2 process is complete and at least one circuit has been set up. The first circuit should be titled "Main."

4. Status Checks

The networking of ARL-MUGS sensors yields additional capabilities beyond those described in this installation manual—in particular, regarding status and alert notifications. However, in the common case that network approvals have not been granted, we recommend that periodic status checks be performed to verify that the sensors are undisturbed and fully operational. Status check spreadsheets have been included in the appendixes for use with ARL-MUGS sensors. These include a detailed checklist for an individual sensor (Appendix E), and a quick checklist if multiple sensors are installed in a location (Appendix F). These checklists can be used together, depending on the frequency of sensor status checks.

Basic visual status check recommendations are as follows. (Reference the images shown in Fig. 7):

- *Battery LED Check*. Look at the LED labeled “Battery” near the USB power connector. The following are recommended codes for the battery:
  - **R**: Solid red LED (charging)
  - **G**: Solid green LED (charged)
  - **Off**: No color (not receiving power)
  - **Oth**: Any other color or unexpected indicators
- *Status LED Check*. Look at the LED labeled “Power” near the power button. The recommended codes for status are as follows:
  - **kR**: Blinking red LED (operating normally)
  - **kG**: Blinking green LED (operating normally with GPS signal)
  - **B**: Blue LED (problem with processing and/or system)
  - **Off**: No color (powered down)
  - **Oth**: Any other color or unexpected indicators

If a laptop, tablet, or other device can interact with MUGS sensors, additional status checks can be performed using the embedded web-based UIs. Logging into the MUGS sensor was described in Section 3.4. Once logged in using ViPERS, the user navigates to the **Status** (**5**) page (Fig. 21). The status page has several icons with descriptions of statuses for several key system functions:

- Core100: System firmware for hardware interaction and lowest-level data streams.
- HDD Attached: External hard drive is present when Green.
- HDD Mounted: External hard drive can be written to when Green.
- HDD Storage: Display percent space left on the device.
- Data Collector: Application that inserts EP data in database. Green is required for dashboard displays.
- Charger Status: Comparable status information for the “Battery” LED. Green means battery is charged/charging.
- Battery Charge: The estimated charge percentage of the battery. Note: Battery charge percentage is an estimate.

- Disk Storage: Percentage of the primary system storage used. If Yellow, steps should be taken to free up disk space. Consult the ViPERS User Manual[1] for instructions.

- Additional Alert Status: Applications and dashboard alerts can be setup to provide additional status information. These will be specific to the unit; therefore, the user should consult with whoever configured the unit regarding any additional status information.

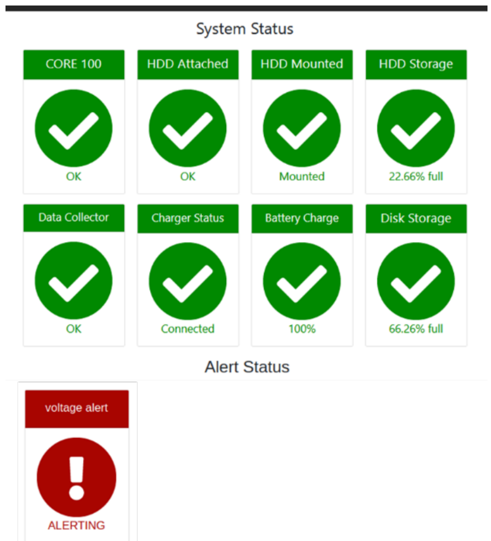

Fig. 21 Status icons on the Status page provide a high-level system status summary

5. Conclusion

This report describes the installation, setup, and use of ARL-MUGS hardware, with particular emphasis on power-sensing applications. Sensing technology contains several data processing, storage, visualization, and communications options to support a variety of applications. The associated ViPERS User Manual[1] should be used in coordination with this report for more detailed descriptions of the main configuration interface for ARTEMIS devices. More advanced analyses can be found in the ARL distributed Live Animated Multi-Phasor (dLAMP) user manual and programming guide. The web-based (ARL-dLAMP) HTML documentation is available to advanced users and developers (included in the development software package that can be requested from the authors of this report).

6. References

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4. Fluke. Fluke i5S AC Current Clamp. Flukc Coporation; c2023 [accessed 2023 Aug 8]. https://www.fluke.com/en-us/product/accessories/current-clamps/fluke-i5s

5. Fluke. Fluke i400s AC Current Clamp. Flukc Coporation; c2023 [accessed 2023 Aug 8]. https://www.fluke.com/en-us/product/accessories/current-clamps/fluke-i400s

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Appendix A. Single Page Quick Guide

ARL-MUGS

Electric-power data collection, processing, communications and display

Planning/Coordination Quick Guide

ARL-MUGS Overview and Lingo

- **Electric-power data collection and analysis**
  - Power Panels and Load Centers
  - Substation circuits
  - Generators and Distribution boxes
- **Long-term USB-Powered Operation**
  - Short-term Battery Operation (Specs in manual)
- **Government-owned Technology**
- **Sensor inputs. signal processing, UIs and comms**
  - Voltage and Current Probes
  - FPGA + Linux Operating System
  - Wifi (can be disabled), USB and Ethernet comms
  - GPS (can be disabled) and IMU

ARL-MUGS Site-specific Recommendations

- **Coordinate and communicate with Facility managers prior to planning installation**
  - Site-specific requirements (e.g. Li-Ion restrictions)
  - Security requirements for power measurement data
  - Access to installation sites
  - Gov/Ctr/Electrician support; warranty considerations
  - Are standard 120V outlets available?
  - Approvals and work orders for electrical system
  - Outage scheduling/coordination
- **Consult with local power distribution experts**
  - What measurement locations are desired?
  - Substation? Is CT/PT output available?
  - Electric Power Specifications
    - Voltage level (e.g. 120,480 or higher?)
    - Amperage ratings (e.g. 200, 400, other?)
    - Power circuit type (e.g. Delta, Wye, split-phase)
- **Electrician support required (provided by facility?)**
  - Lock-Out-Tag-Out authority
  - Specify sensors to be installed on conductors
    - Potential probes connect to bare copper (spare breakers can be used if available)
    - Current clamp rating higher than circuit breaker
- **Identify security POC and notify of monitoring intent**
  - Physical Security and/or Information Security
  - Provide specifications and ARL-provided Manuals
  - Obtain approvals in writing (e.g. signed email)

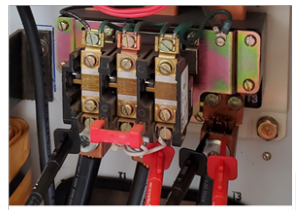
Networking Options

- Coordinate with Information Security POCs
- Identity IT specialist to add equipment to a LAN/WAN
  - Email/Text alerting and summary report options
  - VPN options for WAN (contact ARL)
- Standalone, local network or distributed options
- Consult ARL manuals for specifics

MUGS Installation Quick Guide

Voltage and current

Probemaster: Up to 1000V RMS
Use PT output at higher Voltage

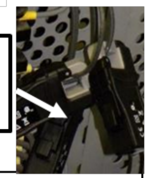


Differential Probes
Red Probe : Phase-1 Conductor
Black Probe: Phase-2 Conductor or Neutral/Ground

Split-core AC: 200 or 1500A

Fluke i400s: 40 or 400A

Fluke i5s: Substation 5A CT loops



Clamps must lock in place (around single conductor)

Sensor Connections

- Sensor Output Max ±10V
- Label BNC by sensor and channel number
- Connect BNC connector to proper channel number

Install Recommendations

- Set Probemaster to 100:1
- Label BNC cable ends
- Ziptie cable runs
- Route around walkways
- Bring BNC extensions
- Extra surge protectors
- Power extension cords
- Can use 1 set of voltages for multiple current sets

Power-on After Install to Operate

MUGS Status Indicators

Operating: (red / green)
On / Problem: (blue)
Off: (unlit)

Charging Indicators

Not Charging: (unlit)
Charging: (red)
Charged: (green)

- Connect configuration laptop with wired Ethernet
- Login to ViPERS with Firefox/Chrome at http://10.10.0.1
- See User Manual for configuration details

Appendix B. Example ARL Mobile Unattended Ground Sensor (MUGS)-16 Sensor Configurations and Scaling

Channel	sps	Range	Chan_name	Sensor location	CT/PT ratio	Sensor scaling	Rated I or V
1	8000	±10 V	V_AB_Brk3	DstBx-2 Brk5	1:1	10 mV/V	480 V
2	8000	±10 V	V_BC_Brk3	DstBx-2 Brk5	1:1	10 mV/V	480 V
3	8000	±10 V	V_CA_Brk3	DstBx-2 Brk5	1:1	10 mV/V	480 V
4	8000	±10 V	I_G	DstBx-2 Gnd	1:1	1 mV/A	100 A
5	8000	±1 V	I_A_Main	DstBx-2 Brk1	1:1	1 mV/A	400 A
6	8000	±1 V	I_B_Main	DstBx-2 Brk1	1:1	1 mV/A	400 A
7	8000	±1 V	I_C_Main	DstBx-2 Brk1	1:1	1 mV/A	400 A
8	8000	±1 V	I_A_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
9	8000	±1 V	I_B_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
10	8000	±1 V	I_C_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
11	8000	±1 V	I_A_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
12	8000	±1 V	I_B_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
13	8000	±1 V	I_C_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
14	8000	±1 V	I_A_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A
15	8000	±1 V	I_B_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A
16	8000	±1 V	I_C_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A

Channel	sps	Range	Chan_name	Sensor location	CT/PT ratio	Sensor scaling	Rated I or V
1	8000	±10 V	V_AN_x1	Scd_XFMR-1	1:1	10 mV/V	120 V
2	8000	±10 V	V_BN_ x1	Scd_XFMR-1	1:1	10 mV/V	120 V
3	8000	±10 V	V_CN_ x1	Scd_XFMR-1	1:1	10 mV/V	120 V
4	8000	±10 V	V_AN_ x2	Scd_XFMR-2	1:1	10 mV/V	120 V
5	8000	±10 V	V_BN_ x2	Scd_XFMR-2	1:1	10 mV/V	400 A
6	8000	±10 V	V_CN_ x2	Scd_XFMR-2	1:1	10 mV/V	400 A
7	8000	±10 V	I_C_Main	DstBx-2 Brk1	1:1	1 mV/A	400 A
8	8000	±10 V	I_A_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
9	8000	±1 V	I_B_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
10	8000	±1 V	I_C_Cct2	DstBx-2 Brk2	1:1	1.67 mV/A	30 A
11	8000	±1 V	I_A_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
12	8000	±1 V	I_B_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
13	8000	±1 V	I_C_Cct3	DstBx-2 Brk3	1:1	1.67 mV/A	50 A
14	8000	±1 V	I_A_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A
15	8000	±1 V	I_B_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A
16	8000	±1 V	I_C_Cct4	DstBx-2 Brk4	1:1	1 mV/A	200 A

Appendix C. Blank Configuration Template

MUGS Channel Settings and Scale Factors							
Channel	**sps**	**Range**	**Chan_name**	**Sensor Location**	**CT/PT Ratio**	**Sensor Scaling**	**Rated I or V**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							

Appendix D. Approval Checkoff/Signature Sheet

MUGS install coordination and approval tracking checklist			
Category	**Description**	**Primary POC**	**Status**
Authority Having Jurisdiction (AHJ) approval	Approval to install Electric Power sensing system in electrical infrastructure	Unknown	Identify POC
Electrician work orders	Work orders for electrician to install voltage/current sensors in specified locations	Unknown	Identify POC
Equipment owner approval	Notification and approval to install sensors in electrical equipment	Unknown	Identify POC
Equipment manufacturer approval	Equipment warranty considerations communicated	Unknown	Identify POC
Physical security approval	Approval to install Electric Power sensing system to monitor facility power	Unknown	Identify POC
Information systems approval	Information Systems Security Officer (ISSO) or equivalent. Stand-alone, point-to-point communications, LAN or WAN networked.	Unknown	Identify POC
IT specialist	Can add IT equipment to LAN/WAN or configure sensor to prevent connection. Coordinate networking as needed	Unknown	Identify POC
FOR NETWORKED SENSORS ONLY			
Network specialist	Can add IT equipment to LAN/WAN. Can monitor and/or test network	Unknown	Identify POC
ARL IT coordination	Coordinate with ARL (**if needed**) for WAN sensor connections	Dave Hull david.m.hull6.civ@army.mil	Notify of intent to network sensor
Networking hardware procurement	Procure networking hardware as needed	Unknown	Identify POC
Final network configuration approval	Validate, test, and confirm approval of networking	Unknown	Identify POC

Appendix E. Individual ARL Mobile Unattended Ground Sensor (MUGS) Status Checklist

(INSERT SN HERE) MUGS Status Checklist							
Date (MM/DD/YYYY)	Status LED	Battery LED	ViPERS Status Pg	Disk Stora ge	HDD Storage	Dashboard Check	Alert Status

Appendix F. Multiple ARL Mobile Unattended Ground Sensor (MUGS) Status Checklist

(INSERT Location HERE) MUGS Status Checklist						
Sensor	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY
MUGS-SN1						
MUGS-SN2						
MUGS-SN3						
MUGS-SN4						
MUGS-SN5						
MUGS-SN6						
MUGS-SN7						
MUGS-SN8						
MUGS-SN9						
MUGS-SN10						
MUGS-SN11						
MUGS-SN12						
MUGS-SN13						
MUGS-SN14						
MUGS-SN15						
MUGS-SN16						
MUGS-SN17						
MUGS-SN18						
MUGS-SN19						
MUGS-SN20						
MUGS-SN21						
MUGS-SN22						
MUGS-SN23						
MUGS-SN24						
MUGS-SN25						

List of Symbols, Abbreviations, and Acronyms

AC	alternating current
ADC	analog-to-digital converter
AHJ	Authority Having Jurisdiction
ARL	Army Research Laboratory
ARL-ARTEMIS	ARL Autonomous Real-Time Electric-power Measurement and Instrumentation System
ARL-dLAMP	ARL distributed Live Animated Multi-Phasor
ARL-MPM	ARL Mobile Power Meter
ARL-MUGS	ARL Mobile Unattended Ground Sensor
ARL-ViPERS	ARL Visualizing and Processing on Embedded Research Systems
BNC	Bayonet Neill–Concelman
CT	current transformer
DC	direct current
DEVCOM	US Army Combat Capabilities Development Command
DHCP	dynamic host configuration protocol
EP	electric power
exFAT	extensible file allocation table
FPGA	field-programmable gate array
GPS	global positioning system
HDD	hard-disk drive
IP	Internet protocol
LAN	local-area network
LED	light-emitting diode
OS	operating system
PC	personal computer
PT	potential transformer
QC	Quick Charge

SD	secure digital
SMA	SubMiniature version A (connector)
SN	serial number
TB	terabyte
UI	user interface
UPS	uninterruptible power supply
URL	universal resource locator
USB	universal serial bus
UTC	universal coordinated time
WAN	wide-area network

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