ARL-SR-0490 ● JAN 2024

DEVCOM Army Research Laboratory Mobile Power Meter (MPM) Installation Guide

by Brandon Parks, Abigail Snellman, Hugh Chung, and David Hull

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

ARL-SR-0490 ● JAN 2024

DEVCOM Army Research Laboratory Mobile Power Meter (MPM) Installation Guide

Brandon Parks, Abigail Snellman, and David Hull
DEVCOM Army Research Laboratory

Hugh Chung
General Technical Services

REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED	
		START DATE	END DATE
January 2024	Special Report	2/01/2022	9/30/2024

4. TITLE AND SUBTITLE
DEVCOM Army Research Laboratory Mobile Power Meter (MPM) Installation Guide

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
5d. PROJECT NUMBER 22AR-148	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

6. AUTHOR(S)
Brandon Parks, Abigail Snellman, Hugh Chung, and David Hull

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
DEVCOM Army Research Laboratory ATTN: FCDD-RLA-LD Adelphi, MD 20784-1197	ARL-SR-0490

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
ORCID ID(s): David Hull, 0000-0002-4200-7636

14. ABSTRACT
Electric power (EP) is a fundamental resource for modern activities. The ability to measure and understand EP is important 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 Mobile Power Meter (MPM) is a nonintrusive integrated EP technology solution containing sensing, processing, data storage, and communications. MPM units utilize ARL's ARTEMIS processing technology to implement a phasor processing architecture that provides information beyond the standard power quality measurements in 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.

15. SUBJECT TERMS
Electromagnetic Spectrum Sciences; Network, Cyber, and Computational Sciences; electric power; electric field; magnetic field; non-intrusive load monitoring; power sensing; embedded processing; Internet of Things

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
a. REPORT	b. ABSTRACT	C. THIS PAGE		
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UU	42

19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER *(Include area code)*
Brandon Parks	(301) 394-2347

STANDARD FORM 298 (REV. 5/2020)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction

This installation guide provides background information, use scenarios, and step-by-step instructions for using the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) Mobile Power Meter[1] (MPM). This technology operates differently than traditional electric power (EP) sensors. Therefore, understanding the installation process and appropriate locations is important to fully comprehending the EP data that can be collected and analyzed with the MPM. While the primary intent of this document is to provide basic information so that installers with limited background in this technology can install and operate the device, there is additional information contained throughout the document that provides details on the physics, sensors, and processing/analysis capabilities for reference. This information may be valuable to more advanced use of the MPM, but the basic step-by-step instructions are all that should be needed to install and collect data. Additional appendixes are included that provide a quick-start guide (Appendix A), installation checklist (Appendix B), and maintenance sheets (Appendix C and D) to record information during status checks.

2. The ARL Mobile Power Meter

The ARL MPM integrates several ARL technologies developed for a variety of electric and magnetic-field (E/H-field) sensing applications. The hardware package includes integrated processing capabilities necessary to process the field sensor data and compute the true three-phase power in a low size, weight, and power form factor. The MPM's design conforms to the outer insulation of three-phase multiconductor power cables and measures the E/H-field at several locations around the cable. The design includes two compatible "cable sensor" printed circuit boards (PCBs)[2] each with three commercial-off-the-shelf Hall-effect (magnetic-field) sensors and one ARL "D-dot" (electric-field) sensor on a PCB. These PCBs fit into two "wings" that are built into the MPM body. The orientation and spacing between the H-field sensors provide unique field information relative to the spacing of wires within the cable. With sufficiently unique (uncorrelated) field measurements from multiple independent sensors, the MPM can fully characterize and monitor EP. The two cable sensors used in the MPM (Fig. 1) provide two ARL D-dot sensors and six Hall-effect sensors that are geometrically configured to provide field diversity when measuring the E/H-field produced by each conductor. ARL's ARTEMIS[3] unit powers the cable sensor in the MPM, which receives and digitizes the signal outputs.

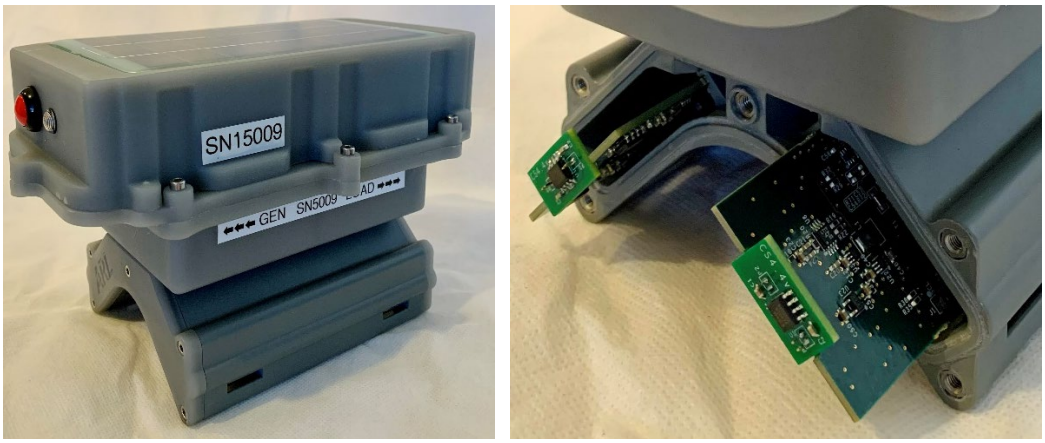


Fig. 1 Fully assembled MPM including large battery power module (left) and E/H-field cable sensors (right)

ARL has developed multiple methods for transforming field measurements associated with the MPM to estimates of EP. The two primary methods are load-based calibration (can be used with any cable) and model-based calibration[4] (requires an E/H-field model of the specific cable model). The first step in either process is to estimate a linear transformation matrix, also known as a phasor calibration matrix. The second step applies this calibration matrix (which does not change as long as the sensor gains and physical relationships do not change) to the set (or vector) of measured field phasors to transform them into load phasors (i.e., the instantaneous measured fields into instantaneous voltages and currents). The output load phasors are comparable to that of standard power meters. These phasors can be used to compute the true power according to the reconstructed voltages and currents within the cable on each individual phase, at which point the MPM can perform power quality and load analyses in the same manner as with standard equipment using voltage and current sensors. An example of this calibration process is shown in Figs. 2 and 3.

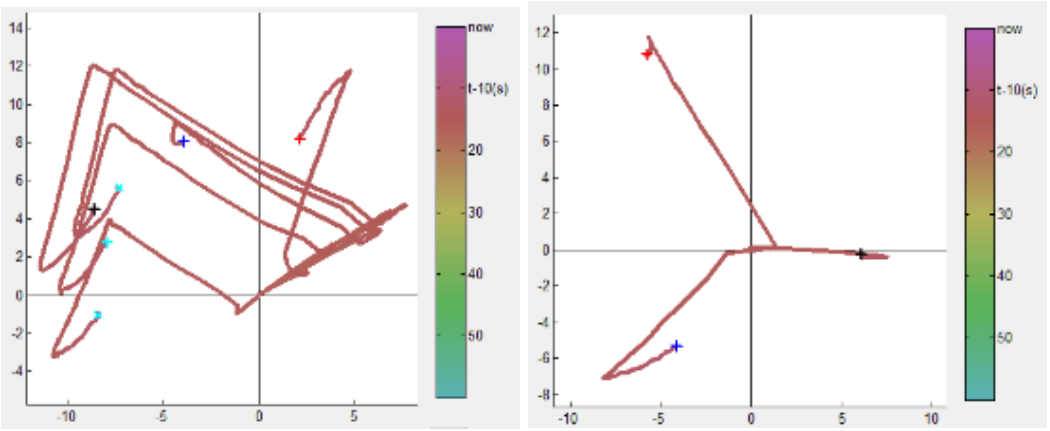


Fig. 2 Field measurements translated to load estimates using an MPM

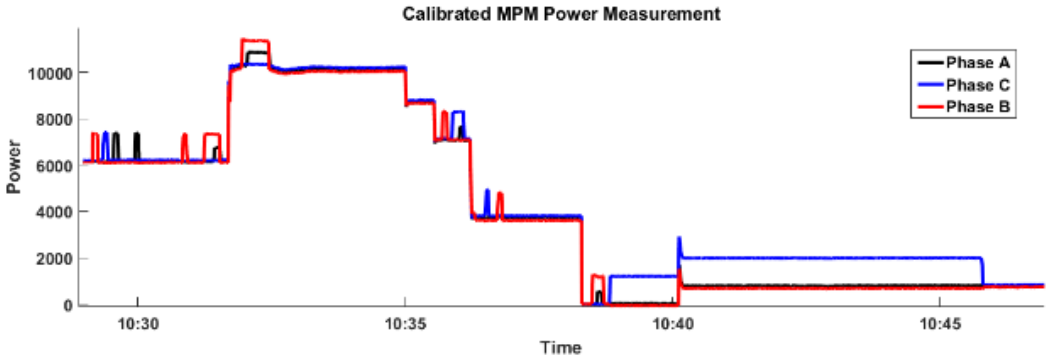


Fig. 3 Three-phase power estimates vs. time with MPM (Phase 2) after load-based calibration

The full MPM package consists of an enclosure that houses E/H-field sensors, ARTEMIS, battery and power conditioning, and wired/wireless communications. Multiple versions of the MPM hardware have been designed and built for various nonintrusive load monitoring applications, with improvements made in newer models. MPM units built in 2019 and later (4000-series and beyond) include a modular hardware design that enables hot-swappable batteries. These models also include cable sensor upgrades with better-optimized sensor spacing for NATO power cables, upgraded electric-field sensors, and an embedded microcontroller to support low-power operations. A full list of product specifications for each MPM version can be found in Table 1. MPMs are typically delivered in a Pelican case with the required charging block and USB-C charging cable as seen in Fig. 4.

Table 1 MPM models and specifications

Specification			
	MPM-v2	**MPM-v3 (4000 series)**	**MPM-v3 (5000 series)**
Length	6.25 inches	7.5 inches	7.5 inches
Height (without wings)	2 inches	3.25 inches	3.25 inches
Weight	1.6 lb	2.6 lb	1.6 or 2.6 lb
ARTEMIS-Mobile	v2; snickerdoodle	v5; snickerdoodle black	v5; snickerdoodle black
Low-power mode	No	Yes	Yes
Comms capabilities	Serial, Wi-Fi, Ethernet	Serial, Wi-Fi, Ethernet, 4G	Serial, Wi-Fi, Ethernet
Primary battery	22 W-h	88 W-h	5.5 or 88 W-h
Backup battery	None	10 W-h	5.5 W-h
Software	ViPERS, dLAMP	ViPERS, dLAMP	ViPERS, dLAMP
Ubuntu OS	18.04	18.04 or 20.04	18.04 or 20.04
Processor	Zynq-7010, Dual-ARM	Zynq-7020, Dual-ARM	Zynq-7020, Dual-ARM
DB+phasor storage	64 or 128 GB	128 GB	256 GB
Raw storage	128 GB SD × 2	128 GB SD × 2	128 GB SD × 2

Fig. 4 MPM hardware is typically delivered in a case with modified USB chargers and USB-C cables

3. Battery Life and USB Chargers

MPM hardware is designed to operate for short durations (~6–24 h) using only the battery, depending on the specific model and ARTEMIS-powered sensors being used. MPM units are shipped with specially modified chargers to eliminate clutter signals that can be introduced by off-the-shelf chargers. Chargers shipped with the unit are the only chargers that are guaranteed to work with the shipped MPM model. MPM units (depending on model) consume an average of 4 W and require the Quick Charge protocol to charge properly. Standard USB charging will only provide approximately 2.5 W, which will cause the battery to ultimately drain, leaving MPMs with insufficient power. Given these strict requirements, MPMs should always be used with the provided charger. Charger details are provided in Table 2.

Table 2 Battery and charger information for MPM models

ARTEMIS model	ARTEMIS version/ Zynq FPGA	Recommended charger	Fully charged battery uptime (expected) (h)
Original MPM	v2/7010	Anker Quick Charge 3.0 (micro-USB)	6
Modular MPM (Large battery)	v5/7020	ARL-provided charger (USB-C)	24
Modular MPM (Small battery)	v5/7020	ARL-provided charger (USB-C)	4

4. Approvals and Recommendations Prior to Installation

Although the MPM is designed for ease of use and installation, several factors should be considered prior to scheduling an MPM installation, ranging from physical and information security to electrical safety to installation requirements. Review the information in this section carefully prior to scheduling an MPM installation to improve the likelihood of a well-coordinated and smooth MPM installation.

The following is a list of approval authorities that may be required to install an MPM. It is recommended that these individuals be identified and written approvals be obtained prior to the day of the planned installation.

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

2. *Certified Electrician with Lock-Out-Tag-Out authority.* This person authorizes work on electrical equipment. Although this authorization may be unnecessary for MPM installations, you must confirm prior to installation.

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. The equipment owner may also 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.

5. *Information Systems Security Officer or equivalent.* The MPM sensor systems run a Linux operating system 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.

6. *IT Specialist.* The IT specialist configures, monitors, and 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.

When using the nonintrusive MPM, a specification of the three-phase power[5,6] cable (and conduit, if any) to be monitored should be provided by the facility the cable is located in. Most facilities will have electrical diagrams and information on the cables used to distribute power. Approvals 1–3 may not be required since no electrical panels need to be opened and no traditional voltage or current sensors need to be installed. However, written confirmation of the requirements should be obtained prior to scheduling the MPM installations.

Additional factors regarding batteries should also be considered. In some cases, lithium-ion battery restrictions may apply at the install site. The battery specifications and safety considerations should be discussed prior to installation. Additional paperwork may be required as well.

5. MPM Installation

The first step in the installation process is to identify the electrical circuit to be monitored. This is best determined by those with knowledge of the electrical infrastructure and loads. Consulting line diagrams and/or discussing the electrical infrastructure with knowledgeable on-site personnel is recommended to identify potential measurement points. MPM models can be zip-tied or otherwise strapped to power cables during operation. It is strongly recommended that MPM install locations on cables are as far away from other electrical cables as possible to avoid interference with adjacent cables.

5.1 Power Cable Locations, Specifications, and Configurations

While the MPM is nonintrusive and much easier to install than traditional sensors that require access to electrical conductors, there are limitations to consider when evaluating potential MPM install locations. The MPM design is such that it can be installed on several cable types using the zip-tie slots located on the bottom. Depending on the cable type, the MPM wings may conform well and provide a *snug fit*, whereas smaller cables may have some overhang as seen in Fig. 5. For example, a 60-A NATO cable has a much smaller circumference than 100+ amp cables, so extra care should be taken when securing the MPM to prevent slipping and movement.

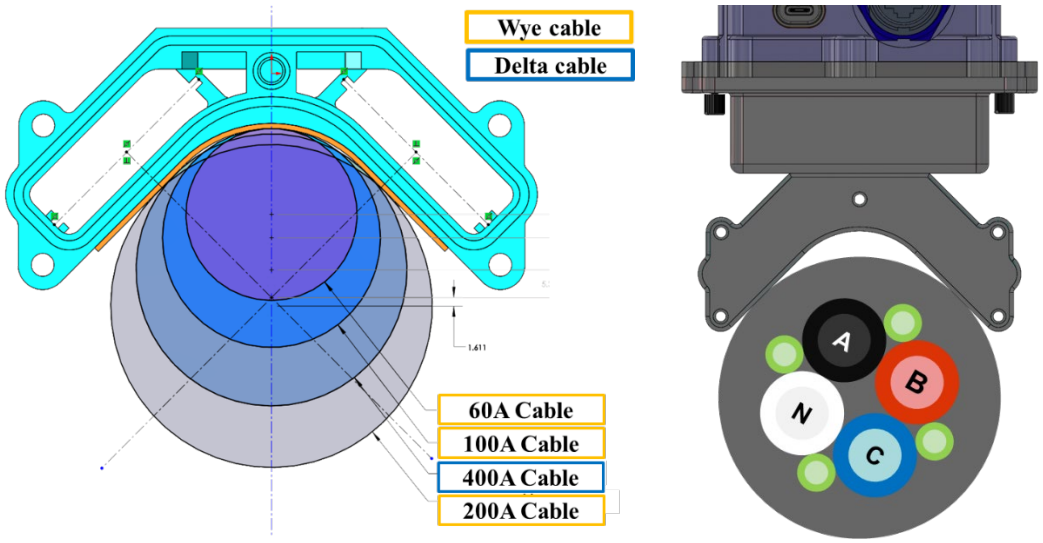


Fig. 5 The MPM can be installed on multiple cable types (left). The position of the conductors inside of the insulation is unknown, requiring MPM load-based or model-based calibration (right).

The cable types will depend on the voltage/amperage being provided with the cable as well as how the power is distributed. While it may be obvious to EP professionals that the cable circumference will grow with the amperage rating (due to the required increase in conductor size), the number of conductors may also be different depending on the distribution type, which will affect the cable assembly size. In addition, high-voltage cables will likely be shielded, which can be a complicating factor for MPM installations. In general, measurements of the magnetic field (produced by load currents) may still be possible, but electric-field measurements (produced by EP voltage) will likely be difficult. If the **cables are shielded** and/or have a diameter larger than **70 cm** or smaller than **20 cm**, we recommend consulting the authors of this report regarding MPM use on the cable.

ARL has evaluated the following cable types:

- Three-phase wye
- Three-phase delta
- Cable diameter less than 70 cm
- Cable diameter greater than 20 cm
- Unshielded cables

ARL has modeled 200-A, 100-A, and 60-A NATO cables (wye configuration) as well as a 400-A LSTGU cable (delta configuration) for use with MPM **model-based calibration**. If these cables are used with the MPM, the installation steps in

the next section are sufficient for both installation and calibration of the MPM. If the MPM is used on other cable types, a **load-based calibration** will likely be needed. This process is described in the ViPERS User Manual[7] and can be performed after the installation steps have been completed.

5.2 Step-by-Step MPM Setup and Install Guide

The MPM is designed to be easy to set up and install, even by users with limited knowledge of how EP is distributed and used by loads. This guide is intended to provide step-by-step instructions for setting up the MPM to measure EP and collect data. ARL has developed several software tools to use with the MPM. Some of these are embedded in the MPM itself, while others must be used with a laptop/desktop computer.

Once a circuit has been identified, you must find an appropriate place to install the MPM. Since the MPM is strapped to the exterior insulation of cable, there is typically a low risk of electrical hazard. However, it is imperative that you visually verify that there are **no exposed conductors (e.g., visible copper outside of insulation; open electrical panels) in the area that you are installing the MPMs** and consult with on-site personnel regarding any potential risks of electrical hazard or any other potential risks. This is especially true where the power is distributed by voltages that are 277/480 V and above.

Once the installation area has been visually inspected and no risks are present, several things must be considered before installing the MPM (Fig. 6):

- Attempt to install the MPM as far away from other cables as possible.
- Attempt to install the MPM as far away from metal structures as possible.
- Attempt to install the MPM on as straight of a section of the cable as possible (limited cable bend).
- Ensure there is a 120-V outlet in the vicinity of the install location for extended data collections. The MPM has limited battery life and will need to receive external power.
- Verify that there is enough space to fit the MPM wings around the cable so that the bottom of the MPM rests on the insulation and the zip ties can secure the device.
- Avoid MPM installs on a cable where the cable runs along the ground in favor of a section where there is some elevation when possible.

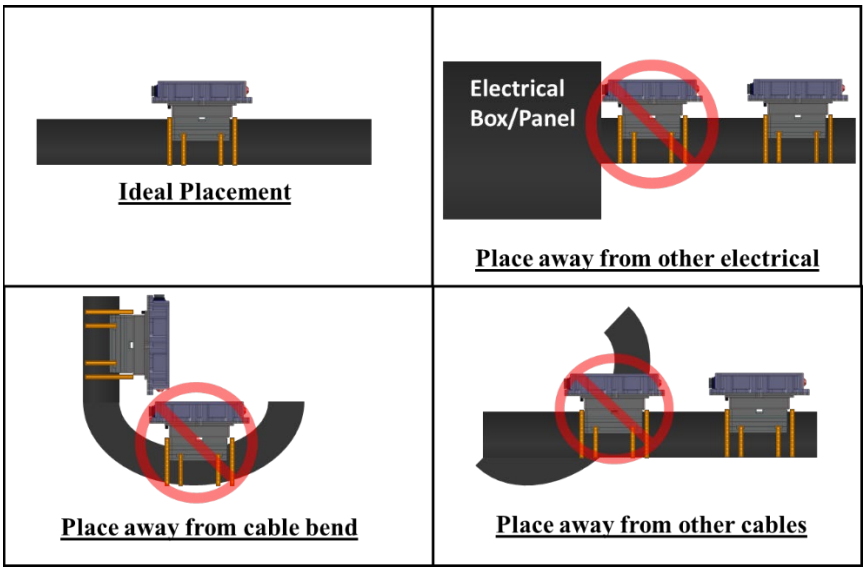


Fig. 6 A straight cable section far away from other cables and electrical equipment is ideal for MPM install

Once you have identified the best possible install point, you can proceed with securing the MPM. The bottom of the MPM has several slots (Fig. 7, left) that can be used to run zip ties. Ideally, two zip ties will be used to ensure that the MPM is secure and will not jostle or slip. Prior to securing the MPM with the zip ties, **double-check the orientation of the MPM**. The power button must face the source and the USB/Ethernet connectors must face the load as seen in Fig. 7 (right). If oriented properly, run the zip ties through the slots and around the cable being measured. Finally, secure the zip ties so that the MPM is snug against the outer insulation. The rubber pad on the bottom will help to avoid slipping if the zip ties are tight.

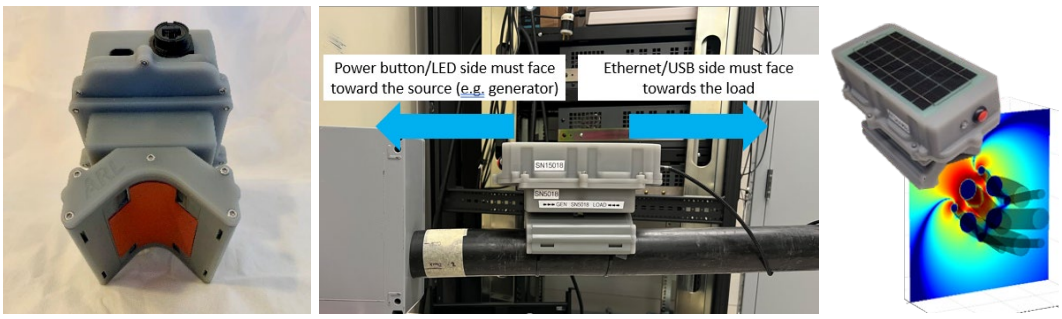


Fig. 7 There are slots on the bottom of the MPM (left) to run zip ties to secure the MPM to a cable. The MPM must be oriented properly (center). Once installed, the MPM will measure the fields produced by EP (right).

The **location of the MPM should be marked** (Gaffer tape is recommended) on install and checked alongside the previously described status checks. If tape is

placed around the cable where the MPM is installed, permanent ink (or other) can mark the position of the sensor wings around the cable. This will provide a starting position that can be verified to ensure that no movement has taken place during sensor data collection. This is especially important if a load-based calibration is needed.

5.2.1 MPM Start-up

Once the MPM has been installed, you can proceed to start up the unit (in some cases, the unit may already be on):

1. Plug in the USB-C connector if the provided USB power brick has been plugged into an outlet. If the MPM battery was drained while on, restoring external power to the device will turn it on.
2. If the MPM was manually shut down previously, hold down the power button (red or black circular protrusion next to the circular LED) for about 10 s. You should hear a click when you have held the power button long enough.
3. If the unit has sufficient power and the power button has been held for at least 8 s, the "Power" status LED will turn blue.
4. After 15–45 s, the MPM status LED should begin to blink red or green.
5. If the 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 2.
6. If the unit does not begin blinking and remains blue after multiple start-up attempts, contact the authors of this report with the serial number, location, hardware delivery date, and notes regarding the installation and power source used with the USB power block.

A purple/pink LED will be present if there is external power charging the battery but the unit is not on. A blue LED means the unit is starting up. If a blue LED appears for longer than 1 min, there was a problem with start-up and the unit should be manually restarted (hold down the button for 10 s to power down, then 10 s to power up). A blinking red (no GPS signal) or green (GPS signal) LED means all basic MPM operations are good. Figure 8 shows the location of the LED and status indicators.

Once the MPM is powered on, it will restore the previous configuration. This means the data logging will commence if it was previously configured this way. If you are

unsure how the MPM is configured or are using the device for the first time, use the configuration process described in the following section.

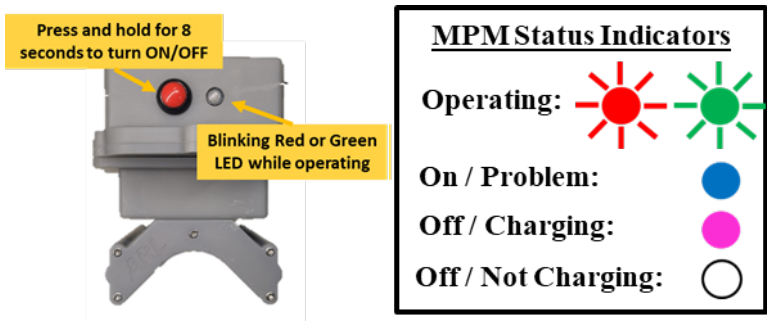


Fig. 8 The MPM (left) can be turned on and off by holding the power button for 8 s; the LED provides information on the active status (right)

5.2.2 MPM Configuration

As described in the full user manual,[7] the MPM comes equipped with a web-based user interface (ViPERS) that can be used to set up the sensor, configure data-logging settings, and view live or historical data. ViPERS is web-based, so it is accessible using a web browser on a connected computer. The default configuration runs a dynamic host configuration protocol (DHCP) server on the wired LAN, meaning connecting should be easy if your laptop is configured for DHCP.[6] The IP address (i.e., web address to type into the browser) is "10.10.0.1". This address should work with most up-to-date browsers; if not, try the full URL: http://10.10.0.1. If this does not work, the most likely problems are 1) the Ethernet cable is not connected from the MPM to the laptop, 2) the laptop is not configured to receive an IP address via DHCP, or 3) the laptop has a firewall configuration that prevents web traffic. Assuming the laptop is, or can be, configured properly, the ViPERS login page will appear (Fig. 9). The default username is "admin" and the default password is "snickerdoodle".

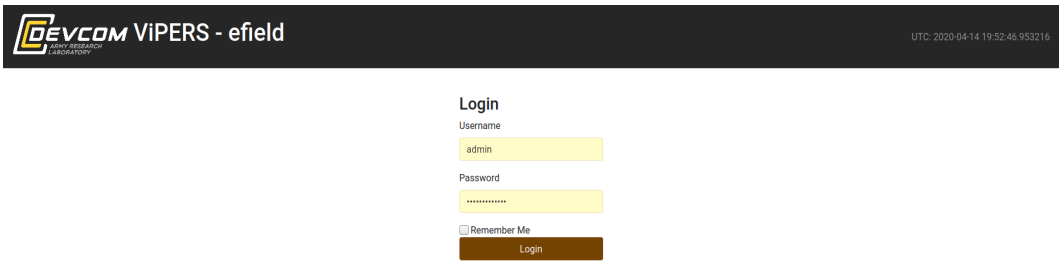


Fig. 9 The ViPERS login page

Once logged into the ViPERS app, you will be directed to the home screen, which consists of several icons. These icons (Fig. 10) 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.

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

5.2.2.1 Step 1: Settings

In some install locations, you may not have a GPS signal (front LED blinking red). When powered down, the MPM does not track time so 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" page and the "Date and Time" tab. Use the drop-down boxes to set the current date and time seen in Fig. 11. The time must be set to the current UTC time. Once you set the time, 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 data/time must be manually set

5.2.2.2 Step 2: Configure

Once the proper date and time are set, left-click the top-left ARL DEVCOM logo to return to the home page and select the "Configure" page. On the "Hardware" tab, you will see a list of options for how to configure the unit, shown in Fig. 12. Ensure

that the “Broadcast” option is selected, and the “Source” is set to either tcp or dbus—either option works for collecting and processing sensor data.

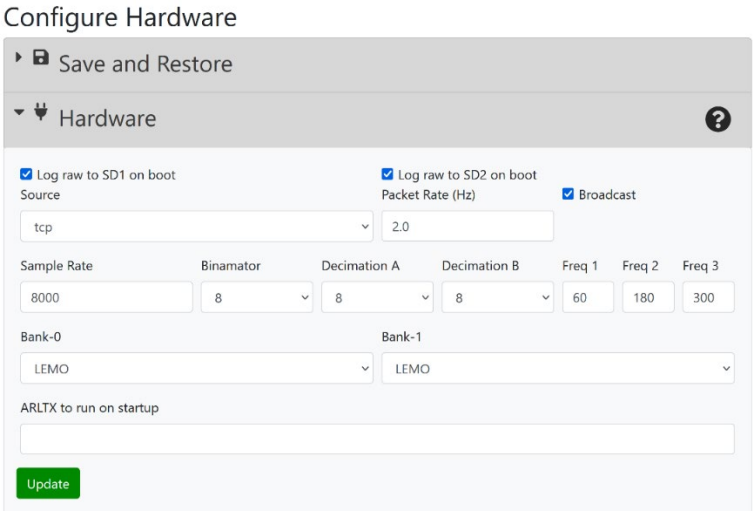


Fig. 12 The hardware settings are saved and will be applied immediately on each start-up

If you intend to collect raw data, select the “Log raw to SD on boot” option. When you click “Update”, this will set the raw secure digital (SD) cards to store raw sample data directly from the analog-to-digital converters. This higher-bandwidth data requires over 22 GB/day of storage. The standard SD cards used for raw storage are 256 GB, so raw data can be logged for slightly 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.

5.2.2.3 Step 3: Phasor Data

The next step in the setup process involves writing phasor data to the file. Select the “Phasor Data” button from the home page. This will take you to a page for phasor data management shown in Fig. 13. Then select the “Phasor Data Storage” tab. This tab contains a section that displays existing files and a menu for configuring the data logging. Here, you 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, there will be files (shown as yellow blocks) in the display. If the box is not selected, select the box and click “Update” to ensure that phasor data is being logged onto the device. Hovering over individual file blocks will display start and end times for the files.

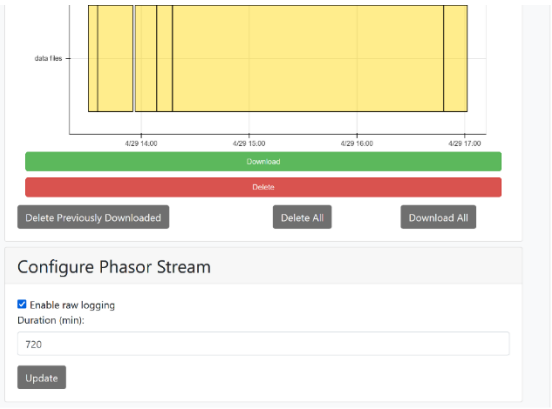


Fig. 13 The Phasor Data page allows phasor data to be logged, viewed, and downloaded

5.2.2.4 Step 4: Autocal

Once you have set the MPM to record phasor data, proceed to the "Autocal" page. This step is not required for data logging but is required if you want to apply phasor calibrations (estimate true voltage and current) to live data. For model-based calibration, only certain cables (namely, NATO 8 conductor 200, 100, and 60 A) have been embedded in the MPM at the time this version of the installation manual was released. A model also exists for the Navy LSTGU-400 cable for use in postprocessing. In the "Settings" tab, there are several options for setting up the Autocal phasor calibration. In most cases, the MPM will be "Production" (5000 series) and the cable twist will be –2.25. You can select 200 A, 100 A, or 60 A, depending on the NATO cable being used. The nominal voltage should be set to the voltage of the cable being measured. Further information on MPM calibration can be found in the reference material.[8,9]

There are several options for the Estimator block. These are algorithms used to estimate the voltages and currents on the conductors. Select "VoltageEstimator" if you are unsure which algorithm to apply. Once these settings are applied, you can view the "Streaming" tab to see live estimates out of the phasor calibration (Fig. 14, right). If the "data collection module" is running, the output of the autocalibration algorithm (EP estimates) will be inserted into the local database.

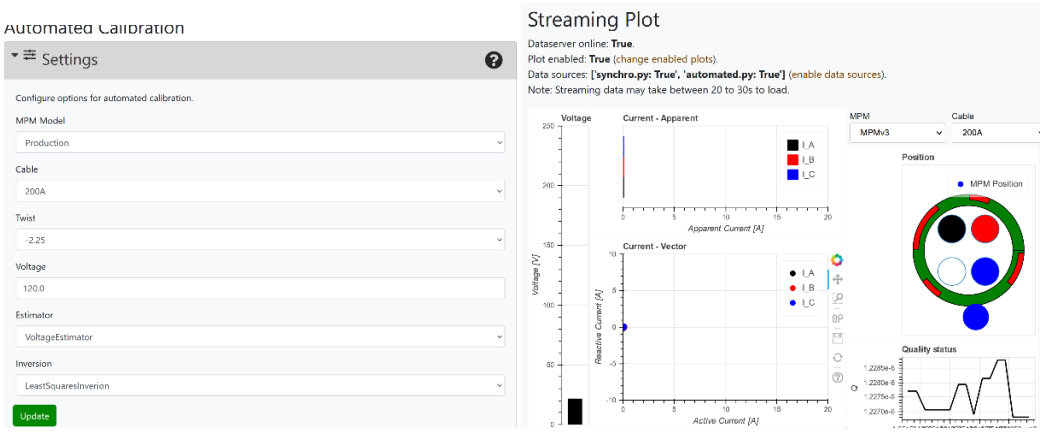


Fig. 14 The Autocal page has user interfaces (UIs) to configure the MPM for different cable types, nominal voltages, and algorithm parameters

5.2.2.5 Step 5: Raw Data

Once you have verified that the phasor data is being written to a file and, optionally, configured the unit for live autocalibration, proceed to the "Raw" page. There is no USB input for an external hard disk drive (HDD) in the MPM, so the internal raw SD cards are the only way to store raw data. If you followed the configuration steps in Section 5.2.2.2 for the "Settings/Hardware" page, you should already be set up and collecting data on the raw SD cards. To verify this, go to the "Raw SD" tab and view the "Toggle SD Card" section. If there is a green "Card 1/2 Active", live data writing is active. If it is red, activate it using the drop-down boxes shown in Fig. 15.

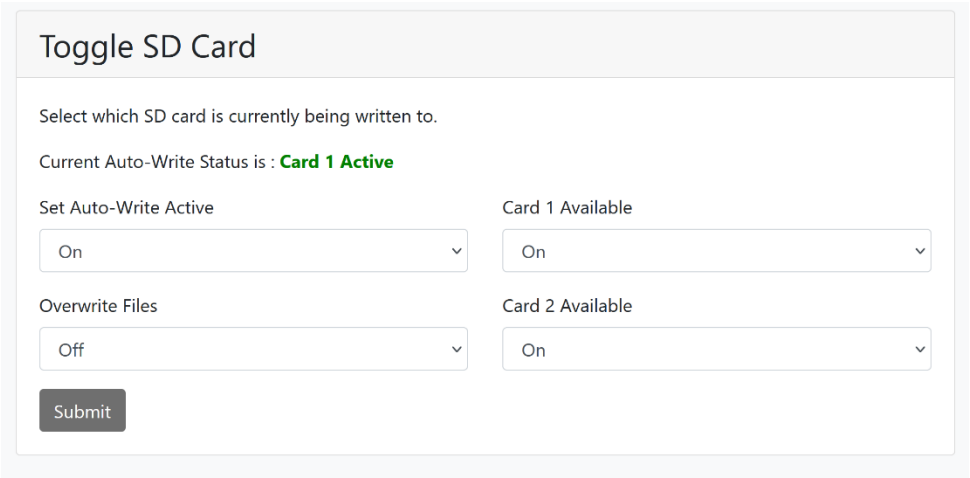


Fig. 15 Raw SD card status can be viewed and reconfigured using the drop-down boxes. The Hardware page is used to set up SD card writing as well.

Raw SD files in the MPM are created every 7 min (assuming default sampling setting) and will not be displayed (as in Fig. 16) until the file is complete and closed.

You 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 SD card writing is ongoing. 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 the SD card is inactive) are 10 MB/s maximum and possibly slower depending on the current processing on the MPM. One hour of raw data is slightly less than 1 GB of data.

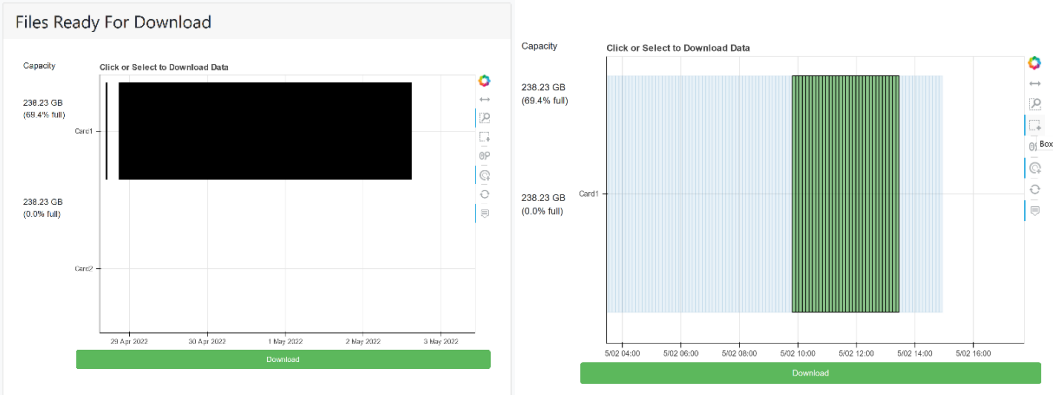


Fig. 16 Individual raw files can be viewed on the Raw SD page. Files can be downloaded using the “box select” option on the right side of the plot.

5.2.2.6 Step 6: Modules

For the final steps in the MPM setup process, navigate to the “Modules” page. Here, there are several modules that should have green or red circles and some status information next to them. The left screen capture in Fig. 17 shows the likely configuration for your MPM if you followed the setup instructions in this guide. The following modules should be green for data collection and basic operation:

- Data_collector.py
- Phs_stream.py
- Relative.py
- Synchro.py

The following modules should be green if using “Autocalibration”:

- Autocal_dat_clct.py
- Automated.py

The following modules should be enabled, but red:

- hardware.py
- start_env.py
- setup_imu.py

If any of these modules are not enabled, find them in the list of inactive modules and select the enable box next to them.

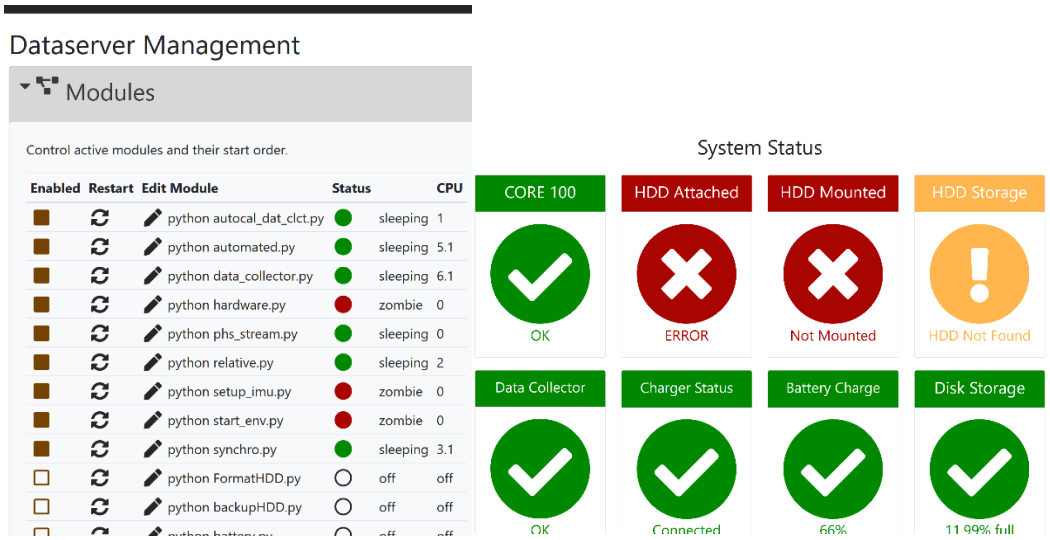


Fig. 17 The Modules page (left) shows active modules running on the unit. The Status page (right) displays the current status of the primary components of the MPM. The MPM HDD status will show an error.

5.2.2.7 Step 7: Status

Navigate to the "Status" page from the main menu. Here, you can view the status of the charger, battery, data collection, and disk storage. Since this is an MPM, the HDD status will be red or yellow. If the charger is not connected, make sure the oulet is powered and check that the USB connections are secure.

5.2.2.8 Step 8: MPM Dashboard

The "Dashboard" page (selectable from the home page) can be selected to show live and historical data from specific date/time ranges (Fig. 18). After entering the log-in information (default username is "admin" with the standard ViPERS password, "snickerdoodle"), you will see the home dashboard, which is a live update of the last 15 min of power data. The live data on this page provides feedback on what the sensors are measuring on the cable and whether any adjustments may be needed.

Fig. 18 Live view of data from the MPM E/H-field sensors

Near the top left is a selectable menu titled "General". Selecting that title will take you to a page where you can select other dashboards. If you have set up autocalibration, you can view the multiphase power estimates by selecting the "Calibrated MPM" dashboard (Fig. 19).

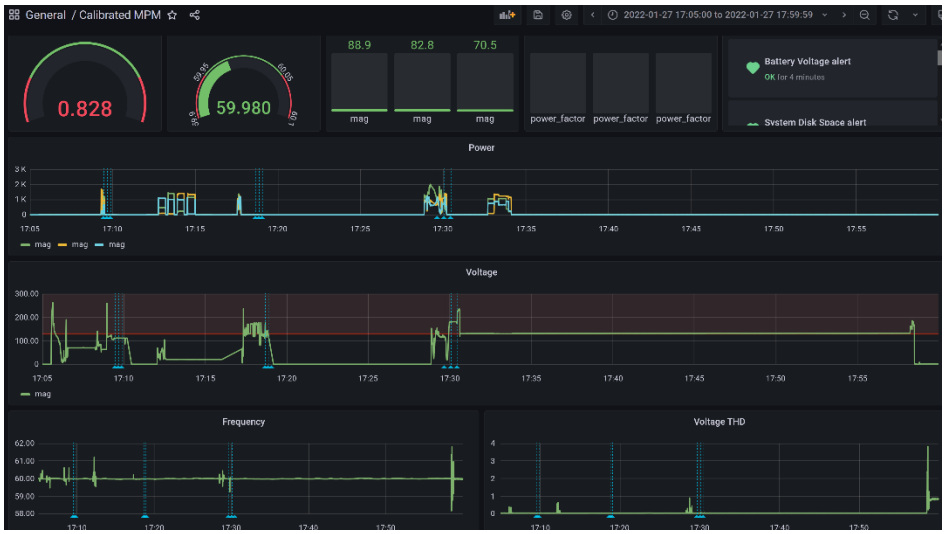


Fig. 19 Live view of calibrated MPM EP estimates

6. Status Checks

The networking of ARL's Mobile Unattended Ground Sensors (MUGSs) yields additional capabilities beyond those described in this installation manual (in particular, regarding status and alert notifications). However, in the case that network approvals have not been granted, it is recommended that periodic status

checks be performed to verify that the sensors are undisturbed and are fully operational. Status check spreadsheets have been included in this report for use with ARL's MPM sensors. There is a detailed checklist for an individual sensor (Appendix C) and a quick checklist in the case that multiple sensors are installed in a location (Appendix D). These checklists can be used together as well, depending on the frequency of sensor status checks.

Basic visual status check recommendations are as follows:

- Battery LED check: Look at the LED labeled "Battery" near the USB power connector. The following codes are recommended 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 following codes are recommended for status:
    - 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 you have a laptop, tablet, or other device capable of interacting with MUGS, additional status checks can be performed using the embedded web-based UIs. Logging into the MPM sensor is described in the Section 5.2.2 of this manual. Once logged in using ViPERS, navigate to the "Status" page as seen in Fig. 20.

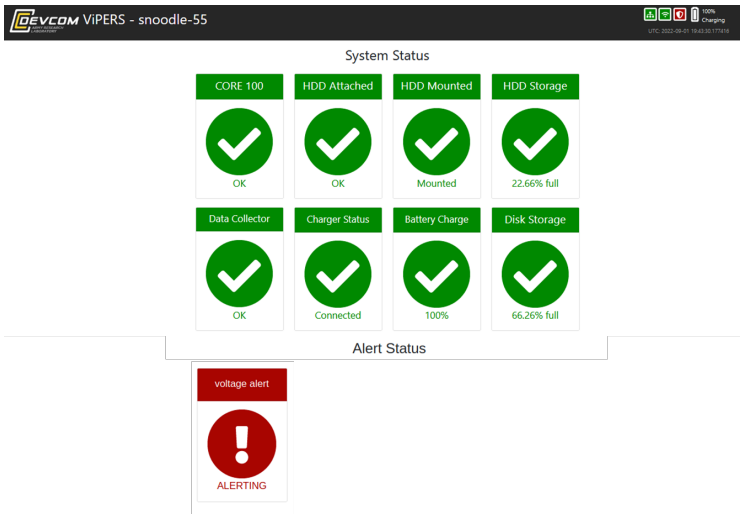


Fig. 20 Status icons on the Status page provide a high-level summary beyond basic LED checks

The Status page has several icons with descriptions of status regarding several key system functions:

- Core100: System firmware for hardware interaction and lowest-level data streams.
- HDD Attached: This will likely be red. No external USB ports.
- HDD Mounted: This will likely be red. No external USB ports.
- HDD Storage: Displays percent space left on external drive.
- Data Collector: Application that inserts MPM data in database. Green status is required for dashboard displays.
- Charger Status: Comparable status information to the battery LED. Green means battery is charged/charging.
- Battery Charge: The estimated percentage full of the battery. (Battery charge percentage is an estimate and should be treated as such.)
- Disk Storage: Percent use of the primary system storage. If yellow, steps should be taken to free up disk space. Consult the user manual[7] for instructions.
- Additional Alert Status: Applications and dashboard alerts can be set up to provide additional status information. These will be specific to the unit, so consult with the individual(s) who configured the unit regarding any additional status information.

Finally, the location of the MPM should be marked (Gaffer tape is recommended) on install and checked alongside the previously described status checks. If tape is placed around the cable where the MPM is installed, permanent ink (or other) can mark the position of the sensor wings around the cable. This will provide a starting position that can be verified to ensure that no movement has taken place during sensor data collection. This is especially important if a load-based calibration is needed.

7. Data Downloads

Data can be periodically retrieved from ARTEMIS units in either a networked or stand-alone setup. In the case of a multi-MPM setup, we recommend that the phasor files be pulled whenever possible. Unless a custom application has been built for data pulling, phasor data can be retrieved using the ViPERS UI described in Step 3 of the install process. To retrieve data from a given sensor or group if sensors, we recommend the following process.

7.1 Data Download Step 1: Storage Device and Directory

A storage device for data downloads should be selected that is sized appropriately for the number of units and data types being pulled. In the default MPM configuration, the data requirements in Table 3 can be assumed.

Table 3 Data requirements for MPM

Data type	Data/sensor/day	10 MPM/26-week storage needed
Phasor	335 MB	610 GB
Raw	22.1 GB	40.2 TB

Organizing data files from sensors in a consistent manner supports efforts to ease data management and analysis. Some of these processes will be automated with future sensor networking and software releases. The following directory structure should be used:

- Sensor Install Site (e.g., Scranton_PA_BLDG534)
    - Site Location (e.g., Room_203)
        - Sensor Name (e.g., MPM SN5003)
            - phasor_data (If a zipped dataset is downloaded, this will be created automatically when unzipping.)
            - raw_data (If a zipped dataset is downloaded, this will be created automatically when unzipping.)

- Sensor Name (e.g., MPM SN5004)
    - phasor_data
    - raw_data

7.2 Data Download Step 2: Pulling Data Using ViPERS

Once a storage device and directory structure have been prepared, data can be pulled from units at appropriate intervals. Unless other requirements exist, we recommend that the most recent data file **not** be pulled, as the data file is open and being actively written to. If data is being pulled multiple times, this will be the first file selected when a group of files are pulled for download. If the unit has not been powered down, the previously downloaded files will appear in green, while files not downloaded since the unit was powered on will be yellow. Examples of the page view with accessible data files and an unpackaged zip download are shown in Figs. 21 and 22, respectively.

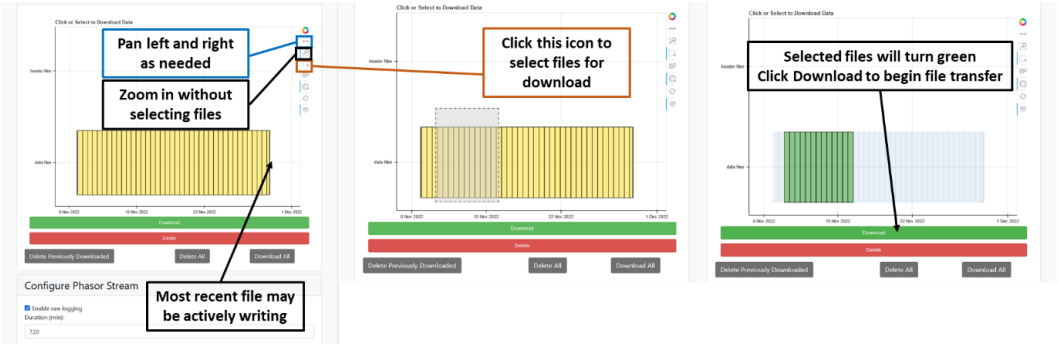


Fig. 21 Pan and zoom functions can be used to navigate files. Box select will enable file selection for download.

Name	Date modified	Type	Size
data_2022_04_06_142100.dat	4/19/2022 11:51 AM	DAT File	163,483 KB
data_2022_04_07_022101.dat	4/19/2022 11:51 AM	DAT File	163,483 KB
data_2022_04_07_142102.dat	4/19/2022 11:51 AM	DAT File	163,483 KB
data_2022_04_08_022103.dat	4/19/2022 11:51 AM	DAT File	163,483 KB
data_2022_04_08_142104.dat	4/19/2022 11:51 AM	DAT File	15,259 KB
phasors.conf	4/19/2022 11:51 AM	CONF File	2 KB

Fig. 22 Phasor file directory with configuration file will be unpacked when unzipped

8. Summary

This installation manual describes the setup and use of ARL's MPM hardware. This sensing technology contains several data processing, storage, visualization, and communications options to support a variety of applications. The associated user manual[7] should be used alongside this document for more detailed descriptions of the main configuration interface for ARTEMIS devices. ViPERS and dLAMP programming documentation is available as part of each software development package.

More advanced analyses than those included in this manual can be found in the dLAMP documentation provided with the software. The dLAMP document complements the ARTEMIS user guide and can be requested from the authors of this document. Additional dLAMP modules, available in the dLAMP-PC executable and the dLAMP development environment (MATLAB), can be integrated into the MPM/MUGS hardware. There are drivers for reading and analyzing MPM/MUGS data files and receiving live data streams when connected to the devices. dLAMP is the primary tool used for advanced power analyses and is capable processing all levels of data produced by ARTEMIS units.

9. References

1. Parks BS, Adelman R, Hull DM, Heintzelman SM. Non-intrusive power monitoring in multi-conductor cables. Military Sensing Symposium (MSS BAMS); 2016; Gaithersburg, MD.

2. Heintzelman S, Ghionea S, Hull D, inventors; US Department of Army, assignee. Non-contact multi-phase cable sensor. United States patent US 10775420B2. 2020 Sep 15.

3. Hull D, Waite J, Vinci S, Parks B. Low-SWaP, rugged sensing system for unattended applications. Military Sensing Symposium; 2017. Arlington, VA.

4. Chung H, Parks B, Heintzelman S, Adelman R, Hull D. Accuracy of model-based phasor calibration. Military Sensing Symposium; 2022. San Diego, CA.

5. Three-phase electric power. Wikipedia; last updated 2023 Aug 28 [accessed 2023 Aug 29]. https://en.wikipedia.org/wiki/Three-phase_electric_power

6. William D, Stevenson J. Elements of power system analysis. 3rd ed. McGraw-Hill; 1975.

7. Snellman A, Parks B, Hull D, Drummond Z. DEVCOM Army Research Laboratory Visualization and Processing for Embedded Research Systems (ARL-ViPERS) user manual. DEVCOM Army Research Laboratory (US); 2023 Aug. Report No.: ARL-SR-0477.

8. Chung H, Parks B, Heintzelman S, Adelman R, Hull D. Accuracy of model-based phasor calibration for non-contact power sensing. Military Sensing Symposium (MSS BAMS); 2022. San Diego, CA.

9. Claytor K, Adelman R, Parks B, Hull B. Model-based characterization of a non-contact power meter. Military Sensing Symposium; 2017. Arlington, VA.

Appendix A. Single-Page Quick Guide

Mobile Power Meter (MPM) Install Cheat Sheet

Safe, Easy and Fully Non-intrusive Electric-power Sensing

Planning/Coordination Quick Guide

ARL-MPM Overview and Lingo

- **Non-intrusive Power Sensor**
  - NO outage requirements
  - NO electrician required
  - NO additional equipment needed
- **Approved for Indoor Install and Operation**
  - Outdoor use model-specific (Specs in manual)
- **Long-term USB-Powered Operation**
  - Short-term Battery Operation (Specs in manual)
- **Government-owned Technology**
- **Integrated sensing, signal processing, UIs and comms**
  - Electric and Magnetic-field sensors
  - FPGA + Linux Operating System
  - Wifi (can be disabled), USB and Ethernet comms
  - GPS (can be disabled) and IMU
  - Embedded web-browser UIs

ARL-MPM Site-specific Recommendations

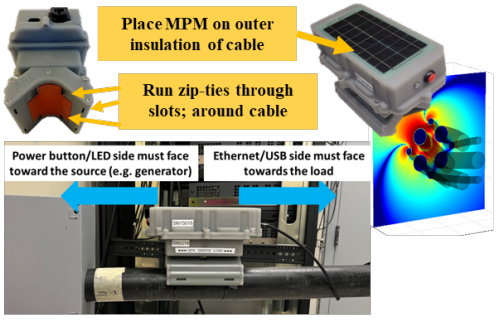
- **Coordinate and communicate with Facility managers prior to planning installation**
  - Site-specific requirements (e.g. Li-Ion restrictions)
  - Security requirements for power measurement data
  - Access to installation sites
  - Gov/Ctr support and warranty considerations
  - Are standard 120V outlets available?
- **Consult with local power distribution experts**
  - What measurement locations are desired?
  - What power cables are accessible? What model?
  - 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)
- **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

MPM Installation Quick Guide

Install on Outer Insulation of Multi-phase Cable



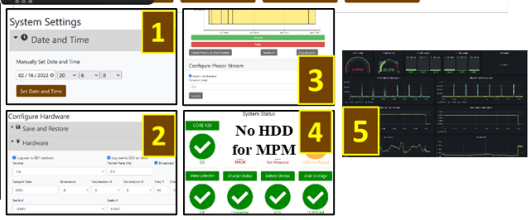
Power-on after Install to Operate

MPM Status Indicators

- Operating:
- On / Problem:
- Off / Charging:
- Off / Not Charging:

Additional Initial Configuration (Recommended)

- Connect configuration laptop to MPM with wired Ethernet
- Login to ViPERS with Firefox/Chrome at http://10.10.0.1



Appendix B. Approval Checkoff/Signature Sheet

MUGS Install Coordination and Approval Tracking Checklist			
Category	**Description**	**Primary POC**	**Status**
Authority Having Jurisdiction (AHJ) Approval	Approval to install MPM for EP monitoring	Unknown	Identify POC
Electrician Work Orders	May be unnecessary. Work orders for electrician to support install in specified locations	Unknown	Identify POC
Equipment Owner Approval	Notification and approval to install MPM on power cable	Unknown	Identify POC
Equipment Manufacturer Approval	Equipment warranty considerations communicated	Unknown	Identify POC
Lithium-ion Battery Approval	Restrictions on Lithium-ion batteries may require approval	Unknown	Identify POC
Physical Security Approval	Approval to install Electric Power sensing system to monitor electric power	Unknown	Identify POC
Information Systems Approval	Information Systems Security Officer 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 C. Individual Mobile Power Meter (MPM) Status Checklist

(INSERT SN HERE) MPM Status Checklist						
Date (MM/DD/YYYY)	**Status LED**	**ViPERS Status Pg**	**Disk Storage**	**Dashboard Check**	**Alert Status**	**Position/MPM Movement Check**

Appendix D. Multiple Mobile Power Meter (MPM) Status Checklist

(INSERT Location HERE) MPM Status Checklist						
Sensor	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY	MM/DD/YYYY
MPM-1						
MPM-2						
MPM-3						
MPM-4						
MPM-5						
MPM-6						
MPM-7						
MPM-8						
MPM-9						
MPM-10						
MPM-11						
MPM-12						
MPM-13						
MPM-14						
MPM-15						
MPM-16						
MPM-17						
MPM-18						
MPM-19						
MPM-20						
MPM-21						
MPM-22						
MPM-23						
MPM-24						
MPM-25						

List of Symbols, Abbreviations, and Acronyms

AHJ	Authority Having Jurisdiction
ARL	Army Research Laboratory
ARTEMIS	Autonomous Real-Time Electric-power Measurement and Instrumentation System
DEVCOM	US Army Combat Capabilities Development Command
DHCP	dynamic host configuration protocol
dLAMP	Distributed Live Animated Multi-Phasor
EP	electric power
E/H-field	electric and magnetic-field
GPS	global positioning system
HDD	hard disk drive
LAN	local-area network
LED	light-emitting diode
MPM	Mobile Power Meter
MUGS	Mobile Unattended Ground Sensor
NATO	North Atlantic Treaty Organization
OS	operating system
PCB	printed circuit board
SD	secure digital
SN	serial number
TCP	transport control protocol
UI	user interface
UTC	Universal Coordinated Time
USB	universal serial bus
ViPERS	Visualizing and Processing on Embedded Research Systems
WAN	wide-area network

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
1 (PDF)	DEVCOM ARL FCDD RLB CI TECH LIB
3 (PDF)	DEVCOM ARL FCDD RLA LB A SNELLMAN D HULL FCDD RLA LD B PARKS