



Smart Power™ M5

Power Conversion System

Installation & Operation

Manual



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INTRODUCTION

Thank you for choosing the Beacon Power *Smart Powerä M5*, Power Conversion System – a “one box” solution optimized for utility-connected renewable energy installations.

The M5 Power Conversion System (PCS) integrates a 5 kVA DC-to-AC inverter with a 100 Amp DC-to-DC battery charger for grid interconnection of a photovoltaic (PV) array and critical circuit backup power functionality. The outdoor-rated chassis contains all the necessary components except for the battery circuit breaker to support a typical residential or light-commercial renewable energy system.

Power from the sun is efficiently exported to the utility on the customer’s side of the electric meter, running the meter backwards (where net-metering is permitted – contact your local utility). The battery bank is constantly monitored by the M5 and charged as necessary in order to enable it to supply power within 30 milliseconds if the utility power (the “grid”) should fail. When the grid is restored, the batteries are recharged from the renewable energy source.

The Smart Power M5 is ready to operate in the utility-connected mode “out of the box” – as soon as it is installed, without further configuration, when standard PV and battery equipment is utilized. Three LED indicators provide a simple means of monitoring the M5’s operating status. For customized systems, setpoints and operational function may be changed and monitored through the Beacon Power *Smart Powerä Monitor* software. An external computer connects to the M5 via an isolated RS-485 interface.

This manual is oriented toward PV applications; hence, the DC input to the M5 will be referred to as the “PV input”.

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IMPORTANT SAFETY INSTRUCTIONS

SAVE THESE INSTRUCTIONS -- This manual contains important safety and operating instructions for the Beacon Power, Smart Power™ M5, Power Conversion System for use in residential and commercial applications.

If you do not fully understand any of the concepts, terminologies, or hazards outlined in this manual, refer installation to a qualified technician or electrician. This manual is not meant to be a complete explanation of the installation of a renewable energy system.

Beacon Power is not responsible for potential battery failures or reduction in battery life due to improper battery charging settings (i.e. internal setpoints). The installer is responsible for checking battery settings with manufacturer's recommendations.

GENERAL PRECAUTIONS

1. This inverter is not qualified for supplying emergency loads, life support systems, or for medical applications. Beacon Power's products are not authorized for use as critical components in life support devices or systems. As used herein: Life support devices or systems are devices or systems which support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

2. Before using the Smart Power™ M5 Power Conversion System, read all instructions and cautionary markings in/on the:

- M5
- Batteries
- Photovoltaic modules or other power sources
- All appropriate sections of this manual.

3. **CAUTION:** To reduce risk of injury, connect only VRLA deep-cycle lead-acid type rechargeable batteries. Other types of batteries may leak or burst, causing injury and damage. Nickel-Cadmium and Nickel-Iron batteries are not supported at this time.

4. Do not expose the M5 to excessively dusty or corrosive environments.

5. Do not disassemble the unit. Doing so voids the warranty. If service is required, please contact a qualified service center. Incorrect service may result in a risk of electric shock or fire.

6. To reduce risk of electric shock, disconnect all wiring before attempting any maintenance or cleaning. **Turning off the inverter will not significantly reduce this risk.** Solar modules continue to produce power when exposed to light. When it is not possible to disconnect the photovoltaic power by an external means such as a string combiner, cover the modules with an opaque material. Ensure that no DC voltage is present on the PV wiring before servicing any connected equipment.

7. **WARNING** -- WORKING WITH OR IN THE VICINITY OF A LEAD-ACID BATTERY REQUIRES SPECIAL PRECAUTION. BATTERIES CAN GENERATE HAZARDOUS GASES DURING NORMAL OPERATION. FOR THIS REASON, IT IS OF THE UTMOST IMPORTANCE THAT BEFORE SERVICING EQUIPMENT IN THE VICINITY OF THE BATTERIES, YOU REVIEW THIS MANUAL AND FOLLOW THE INSTRUCTIONS CAREFULLY.

To reduce risk of accident or injury, follow the instructions in this manual and those published by the battery manufacturer as well as by the manufacturer of any additional equipment used in the vicinity of the battery. Observe and follow all cautionary markings on these products.

PERSONAL PRECAUTIONS

1. Do not work alone. Someone should be within range of your voice or close enough to come to your aid when you work with or near electrical equipment or batteries.
2. The Smart Power™ M5 weighs 120 pounds. To avoid injury, enlist at least two people to lift the unit from its shipping carton and onto its mounting bracket.

BATTERY SAFETY

Beacon Power is not responsible for potential battery failures or reduction in battery life due to improper battery charging settings (i.e. internal setpoints). The installer is responsible for checking battery settings with manufacturer's recommendations.

1. Prior to connecting batteries, study all the battery manufacturer's specific precautions, such as recommended rates of charge, charge voltages, mounting, and maintenance.
2. Provide ventilation to outdoors from the battery compartment. The battery enclosure should be designed to prevent accumulation and concentration of hydrogen gas in "pockets" at the top of the compartment. Vent the battery compartment from the highest point. A sloped lid can also be used to direct the flow to the vent opening location.
3. Thoroughly clean all battery terminals prior to connecting. Very high currents are drawn from the batteries; even a very small electrical resistance in battery connections can pose a risk of fire.
4. Have plenty of fresh water and soap nearby in case battery acid contacts skin, clothing, or eyes.
5. Wear complete eye protection and clothing protection. Avoid touching eyes while working near batteries. Wash your hands when done.
6. If battery acid or battery terminal corrosion contacts skin or clothing, wash immediately with soap and water. If acid enters eye, immediately flood eye with cool running water for at least 15 minutes and get medical attention immediately. Baking soda neutralizes lead acid battery electrolyte. Keep a supply on hand in the area of the batteries.
7. NEVER smoke or allow a spark or flame in vicinity of a battery.
8. Be extra cautious when using metal tools. Dropping a metal tool onto batteries can short-circuit the batteries or other electrical parts. The resulting spark can lead to personal injury or equipment damage.
9. Remove rings, bracelets, necklaces, and watches when working with batteries, photovoltaic modules, or connected wiring. Power from a battery, an illuminated photovoltaic array, or current-carrying wires can produce a short-circuit current high enough to melt such metal and cause injuries.
10. Never attempt to use or charge a frozen battery.
11. When it is necessary to remove the battery, make sure that the battery bank disconnect is in the open (disconnected) position and that the PV breakers are in the OFF position. Then remove the negative terminal from the battery first.

SYSTEM OVERVIEW

The Smart Power M5 is a 5000 Watt Power Conversion System that manages a photovoltaic energy source, exports power to the grid and maintains batteries, for a backup power supply to critical loads. For planning purposes this section will outline the system layout as well as the associated components. This will provide the basis for applying the full potential of the Smart Power M5.

M5 SYSTEM LAYOUT

The Smart Power M5 is optimized for a utility-connected application where surplus power from a photovoltaic energy source can be exported to the utility. A battery bank provides energy storage to power the electrical loads if utility power is interrupted. Figure 1 shows a typical installation of an M5 in a PV energy system.

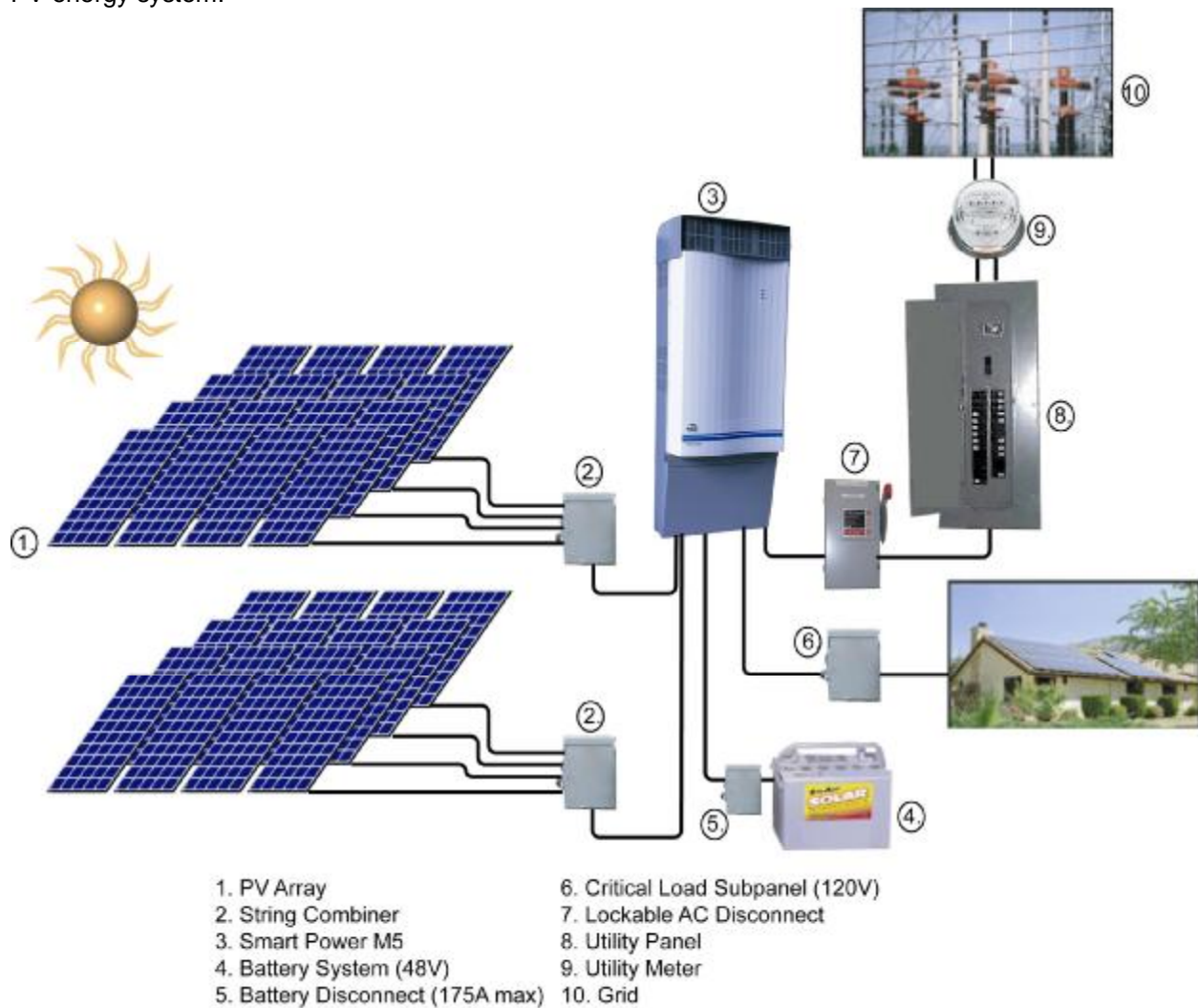


Figure 1: Typical M5 system layout

Internal M5 Layout

The Smart Power M5 has been designed to hold all components necessary in one box for a grid connected solar electric system with battery back-up. The following components are included inside the M5:

- 100A Battery Charger with Maximum Power Point Tracking (MPPT)
- 5kW DC to AC grid connect capable inverter (Stand Alone surge 7.5kW for 10 sec.)
- PV (DC) Disconnect with built in Ground Fault Interrupt (GFI)
- Backup Circuit Transfer Contactor
- AC Circuit Breakers for Inverter Output, Grid Connection, and Load Output
- RS485 Communications Interface

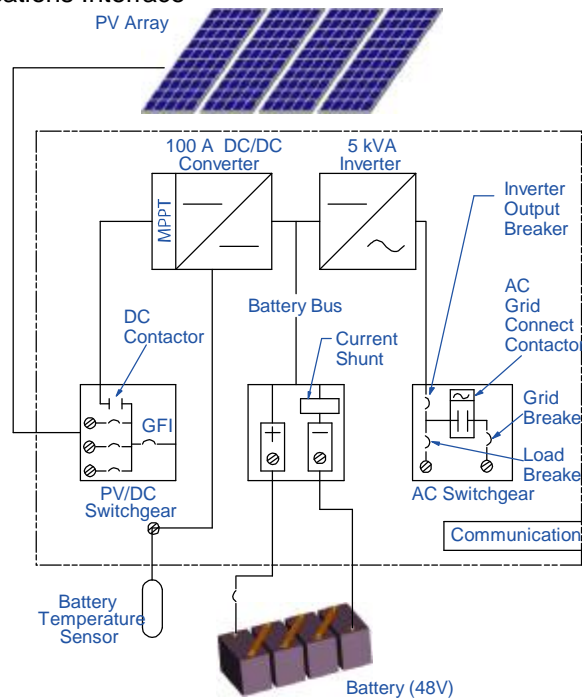


Figure 2: M5 internal component diagram

These components will be discussed in more detail in the later sections of this manual.

AC Circuit Diagram

The inverter output circuit was designed to make sure that the dedicated loads are always powered. To better understand how the inverter output is wired to provide backup power to the sub-panel, refer to Figure 3. There are three AC circuit breakers that serve as over-current protection as well as manual switching capability. The Inverter Output circuit breaker allows manual disconnection of the Inverter from the AC terminals. The Grid circuit breaker will disconnect the utility from the AC circuits. The Load circuit breaker allows disconnection of any power to the sub-panel. An additional AC contactor is located between the grid connection and the backup sub-panel. When a utility outage occurs, the AC contactor opens, allowing the inverter to continue to run and provide power to the critical loads. When the utility returns, the inverter has to wait 5 minutes before reconnecting to the grid. During these five minutes, the contactor will close and the inverter will stop exporting, allowing the loads to be run directly from the grid.

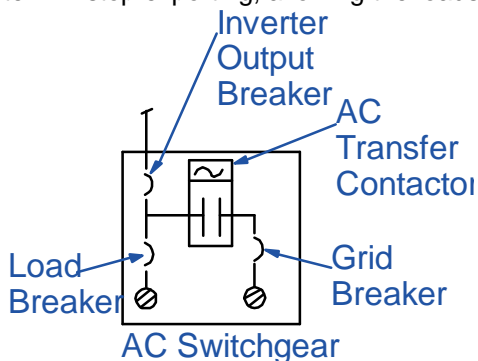


Figure 3: AC switchgear diagram

M5 FUNCTIONALITY

Before discussing individual components within the system, this section will cover the operational behavior of various aspects of the M5.

MPPT Characteristics

The DC-DC converter contains a unique Maximum Power Point Tracking (MPPT) algorithm that will maximize the power usage of the PV array. The DC input to the converter is designed for a 48Volt nominal PV string. The MPPT range comes preset to start at a nominal maximum power at 60.0Vdc, with limits of 50Vdc low and 85Vdc high.

MPP LOW	=	50.0 Vdc
MPP NOMINAL	=	60.0 Vdc
MPP HIGH	=	85.0 Vdc

Should the array in use fall outside this range the values can be changed by adjusting some setpoints. When the PV array starts providing power, the converter will start pulling power at the nominal maximum power voltage. It will then change the voltage and analyze the power change, followed by another voltage adjustment in the direction of increased power. It continues to do this a number of times each second, to make sure that it always pulls the maximum power from the PV array.

Charging Characteristics

The M5 is currently designed to manage 48 Volt VRLA deep cycle batteries so they are fully charged at all times to provide maximum back-up time during a utility outage. In addition, the "Stand-by" feature keeps the battery charge current to a minimum for the rest of the day, maximizing the PV power availability for export to the grid.

Consider batteries that were fully charged the previous day. When the PV array starts providing power in the morning, the battery charger (DC-DC converter) will start out in float charge mode. In this mode, the battery will be held at the float voltage, and be charged if necessary at the required current to achieve maximum State Of Charge (SOC). The M5 will use all available PV to charge the batteries as needed, and export the balance to the utility. After the batteries have reached full charge, the charger will go into Stand-by charging mode, where it will limit the current to and from the batteries to zero Amps, and export all PV power. A small amount of fluctuating current (0.2A – 0.8A) might be observed due to ripple currents from the inverter.

Battery float Voltage	=	54.5 Volts
Battery High Voltage	=	62.0 Volts
Battery Low Voltage	=	46.5 Volts
Max Charge Voltage	=	59.0 Volts
Default Ah Rating	=	100 Ah

In the case of a utility outage, the M5 will always utilize available PV power first to supply power to the loads, before tapping into the battery storage. This feature again minimizes the amount of current flowing through the batteries, which minimizes losses and maximizes battery life.

The charger also regulates the charge voltage dependent on battery temperature. The **temperature compensation** is defined by

Temp. Adjustment below 25°C: +0.25%of target bat V / degree C
Temp. Adjustment above 25°C: -0.15%of target bat V / degree C

Should the battery voltage rise to above the **High Voltage** setpoint of 62.0V, the M5 will proceed into hardware shutdown, switch the unit into Grid-to-Load mode, and disable the inverter and the charger. The Run LED will blink twice, and the auxiliary relay will audibly click on and off. The system and batteries will

have to be checked by qualified service personnel. When normal battery voltage returns, the unit will have to be manually reset by turning the grid breaker off and on. A grid outage and return could also reset this state.

Should the battery voltage drop below the **Low Voltage** setpoint of 46.5V for 60 seconds or longer, the M5 will proceed into hardware shutdown, switch the unit to Grid to Load mode, and disable the inverter. The charger will remain enabled and wait for available PV power. The Run LED will blink twice, and the auxiliary relay will audibly click on and off. Should this occur when no PV power is available, the M5 will stay in this configuration until the PV source returns, at which point the DC-DC converter will attempt to charge the batteries. Once the batteries have charged enough to obtain a voltage above 46.5Volts, the unit will return to normal operation.

Anti-Islanding

In order to be permitted to connect directly to the utility's grid, the M5 must meet certain code requirements. If the grid experiences an abnormal condition such as a brownout or blackout, the utility company requires that power generation sources be removed from the grid. If a distributed generation device, such as the M5, continues to produce power during a power outage, it is possible to develop an "island" of generation and loads connected to high voltage utility lines. All distributed generation devices must detect outages and cease to energize the utility lines. For rotating generators this is often accomplished by using a protective relay switch that opens if non-compliant voltage or frequency fluctuations are experienced. Inverters have the unique ability to stop producing power so quickly that a relay is often unnecessary.

Additional sophisticated circuitry is built into PV inverters that goes beyond basic sensing requirements and actively destabilizes the distributed generation device. This eliminates the possibility of a stable island forming that would be undetected by standard voltage and frequency sensing. This function – referred to as the "anti-islanding" feature – ensures that any utility line worker who may be working to restore normal operation to the grid will not be injured from such devices (such as the M5), which export electricity to the grid.

This unit continually monitors the grid voltage and frequency, and can disconnect from the grid in less than 2 seconds if the grid is interrupted while still providing power to the backup circuits. The normal operating voltage range of this product is from 106Vac to 132Vac. These values are in compliance with UL1741 (Table 46.1) limits, as are the required disconnect times for over and under voltage conditions. The normal operating frequency range of this product is from 59.3Hz to 60.5Hz. These values are in compliance with UL1741 (Table 46.1) limits. The field adjustable operating voltage range is from 103Vac to 135Vac. These values are only adjustable with the permission of the local utility service.

When the grid returns the M5 must wait 5 minutes before exporting power. During these 5 minutes the sub-panel loads will be powered directly from the grid. If, during these 5 minutes, another abnormal event occurs, the inverter will reset the 5 minute wait to export.

Operating Modes

The M5 has 4 operating modes (see Figure 4):

1. OFF

In this mode the M5 Inverter is off, and grid power may be available at the sub-panel.

2. GRID TO LOAD (Grd/Ld)

In this mode, the inverter is bypassed and the sub-panel is powered directly from the grid. This occurs at night, when no PV power is available. The M5 will also be in this mode after a grid outage, during the 5 - minute anti-islanding reconnect delay, or if a fault occurred with available grid.

3. EXPORT

In this mode, PV power is available for the inverter to export to the grid. Loads running in the sub-panel, will first use the power. If excess is available, it will then power the loads running in the main panel. Once all sub-panel and main panel loads are satisfied, power will be exported to the grid. Only in the last case will your electric meter spin backwards. This is most likely to occur at midday during sunny weather when house loads are low and the PV power is high.

4. STAND ALONE (Std/Aln)

In this mode, the grid has failed (or is turned off) and the inverter is running the loads in the sub-panel from either the PV power, the batteries, or a combination of PV and battery power.

The M5 automatically handles all of these modes to ensure properly charged batteries, and continuous power to the back-up circuits. The following flow diagram explains how the M5 automatically switches between these modes.

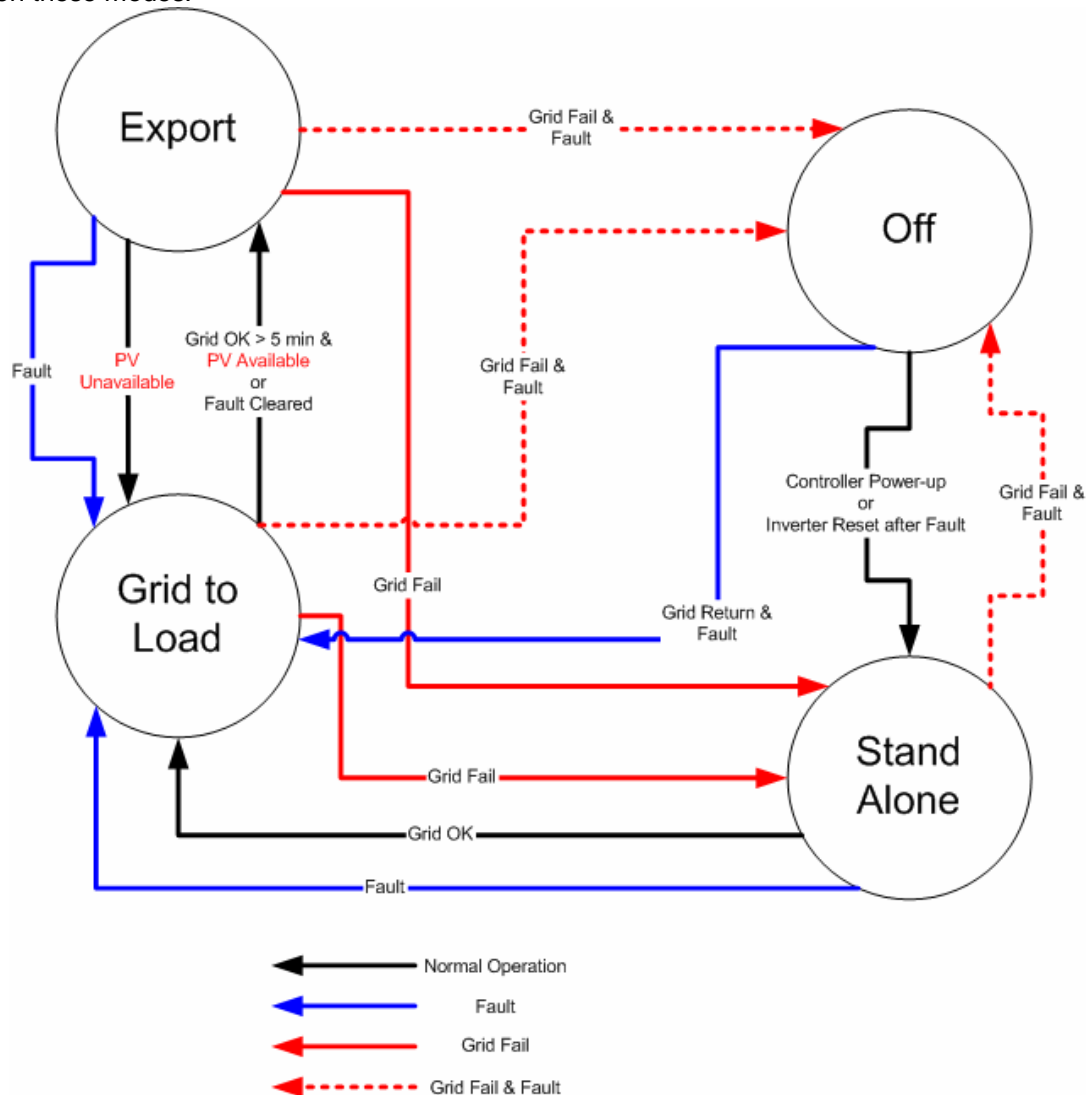


Figure 4: Flow diagram of operating modes in grid connect applications

Should a Hardware Fault occur, the M5 would analyze the fault and make sure that if at all possible, the backup sub-panel remains energized. A permanent fault will automatically switch the M5 into Grid to Load Mode, and cause auxiliary relay 3 to click on and off as well as the Run LED to blink red twice every 4 seconds.

SYSTEM PLANNING

Before going into detailed installation instructions, the System Planning section will cover the necessary theory and overview to fully understand the system capabilities of the Smart Power M5.

Location / Environment

The overall design intent of the M5 is to allow it to be installed indoors and outdoors. However some considerations should be made before installation may begin.

Smart Power M5

The M5 may be located indoors or outdoors; its chassis is rainproof, and “lawn-sprinkler proof”, however, locations exposed to frequent spraying water must be avoided. Hot locations, whether indoors or out, are undesirable as they could cause unnecessary over-temperature shutdowns and reduced reliability. Outdoors, avoid locations in direct sun; indoors, allow good ventilation and avoid closets or unventilated utility rooms, unventilated sheds, and the like. For ventilation purposes allow minimum clearance of 6 inches on each side of the unit.

Since the unit is fan cooled, ambient air is drawn into the chassis, and the possibility for dust and corrosion exists. In very dusty or salt air environments, indoor installation is desirable. Air is drawn into the M5 chassis through the lower set of perforations on the side panels of the chassis, and discharged through the upper openings. Care must be taken to allow at least six inches of free air space on both sides of the unit. The cooling fans may require servicing or replacement in the future (average life of fans under typical conditions is 10 years); thus, you should allow at least 17 inches of unobstructed space on the left or right side, and 12 inches on top of the M5 in order to easily remove the fans.

In the ideal installation, the M5 would be located immediately adjacent to the AC distribution panel(s), the (well-ventilated) battery bank, and the PV array string combiner(s).

The M5 weighs 120 pounds. The mounting bracket (see **Figure 5**) is designed to safely carry this weight. It should be attached to a concrete or masonry wall with suitable anchors and bolts, or with lag screws directly into the wall studs. In some installations, a section of ¾-inch plywood may be attached to the wall, and the chassis attached to the plywood by means of lag or wood screws. For more information see the section of this manual titled MOUNTING.

The lower compartment of the power unit contains circuit breakers and wiring points, and is legally an electrical distribution panel. The NEC requires that there be three feet of accessible space in front of any electrical distribution panel. The unit may be wired from the bottom of the chassis only. Wiring to the unit must pass through conduit; metal conduit (EMT, rigid, or liquid-tight with metal jacket) is recommended to improve Electro Magnetic Interference (EMI) shielding.

For outdoor / wet environments, make conduit connections to bottom plate using raintight or wet location hubs. These should comply with the requirements in the Standard for Fittings for Conduit and Outlet Boxes, UL 514B.

Batteries

The DC wiring – particularly that which is connected to the battery bank – should be as short as possible. It is recommended that battery wiring be kept to 5 feet to preserve the surge capabilities of the inverter and reduce voltage drops. Under all circumstances, battery wiring must be 20 feet or less (one way). The batteries must be housed in their own separately ventilated enclosure to protect the system from corrosive gases and the explosion hazard caused by the release of hydrogen by the batteries. If possible avoid installing the battery bank in outdoor locations where excessive heat or freezing may occur. This is necessary to ensure long battery life. See battery manufacturer recommendations.

String Combiner

One or more String Combiners (Beacon Power String Combiner is recommended) can be located either near the PV array or next to the M5. When choosing the installation location for the string combiners, one must consider that it should be accessible in case fuses or circuit breakers within the combiner need to be replaced or reset. The combiner also acts as a means of disconnecting the PV array from the wiring to the M5. If the combiner is located outdoors, it must have a properly rated outdoor enclosure.

Determining the proper location for the string combiner will be up to the installer. Locating the string combiner near the PV Array will minimize the amount of wires running from the roof, but might make checking the fuses or disconnecting the fuses difficult. Roof access may be required to troubleshoot the array and to deenergize the wiring to the inverter. Locating the string combiner near the M5 requires all PV Array strings to be wired to this location, while making PV module fuse or breaker disconnection and inspection easier.

PV Input

The photovoltaic or PV array is the primary energy source for the M5 inverter. A PV array has varying output that changes in two primary ways:

- 1) The current from the array increases with increasing intensity of the sunlight on the array; and,
- 2) The voltage from the array decreases as the temperature of the array increases. These two effects are central to understanding how the output of a PV array will vary throughout each day, and how the output will change on a seasonal basis.

The orientation of the PV array will determine when the array will receive the most intense sunlight. Generally, in the Northern Hemisphere, a PV array will be oriented to the south at a tilt angle of between latitude and latitude minus 15 degrees (e.g. Los Angeles is at 34° North Latitude—typical tilt angles would be between 34° to 19° from horizontal. Often orientations may not be facing exactly South due to a variety of site constraints (roof orientations, tree shading, obstructions, etc...). The installer must be aware of the impact that various orientations have on system performance. Array temperature is affected by intensity of sunlight, the location (warm or cold region), and how the array is mounted (e.g. on a roof or on an open rack)

Array Sizing

Properly sizing the PV array is critical for the proper operation of the M5. Below are the DC input characteristics of the M5 inverter.

Max. Power	6000 Watts (real power, not STC)
Vdc Max Open Circuit:	110 Vdc
Input Operating Range:	48 – 110 Vdc
Max. Operating Current:	100 Amps
Max. Array Short Circuit:	120 Amps
MPPT Low:	50 Vdc
MPPT Nominal:	60 Vdc
MPPT High:	85 Vdc

The M5 is designed for a 48 Vdc nominal array input voltage. There are many different PV modules on the market today, but the predominant PV modules are 12 Vdc and 24 Vdc modules. These voltages represent the “nominal” module voltage. A 24 Vdc module will produce maximum power between 25-42 Vdc depending on how hot the module is. This means that the inverter will accept multiple of four, 12 Vdc PV modules in series or two, 24 Vdc PV modules in series and have an operating voltage of between 50-85 Vdc.

The maximum voltage is set at 110 Vdc to accommodate the open circuit voltage of the array at very cold temperatures. On the coldest winter days in many areas of the United States, the maximum open circuit voltage of a “48-Vdc” array can exceed 100 Vdc. The intention of the 110 Vdc maximum is to

accommodate a 48-Vdc (four “12-Volt” modules in series, or two “24-Vdc” modules in series) array in cold climates. Do not install a 60-Vdc array (five “12-Vdc” modules in series), as in cold conditions the open circuit voltage will be higher than the allowable maximum of 110 Vdc. If this should occur, the charge controller will not enable until the voltage drops to below 110 Vdc. Should voltages higher than 120Vdc open circuit be attached to the PV input, the charge controller may be damaged. This will void warranty. Please refer to the Beacon Power online string sizing tool for detailed string sizing calculations.

PV Input Calculations

The M5 has three separate 50A input overcurrent protection circuit breakers. Each circuit breaker can accept up to 40 Amps of rated array short circuit current (Isc). Since the charge controller is internally current limited the overcurrent protection according to NEC 690.8(B)(2) is required to be 125% of Isc. Calculation: $50A / 125\% = 40A$ of Isc. If the rated Isc of a module were 5 Amps at Standard Test Conditions (STC), the M5 would allow $40A / 5A = 8$ strings or less to be combined in parallel before the combined output is connected to one terminal of the PV (DC) input.

Once you have determined how many strings you can connect into each input of the M5, it is important to understand the total maximum PV power input of the M5. We recommend limiting the input to a maximum of 6000 Watts of real input power. This is actual Volts times Amps = Watts of DC input. The M5 is rated at 6000W, since this is the maximum amount of input power that will allow full 5kVA of AC export.

Since PV modules are rated at Standard Test Condition (STC) output, the combined total STC power of your array may seem to be greater than the above 6000 Watts of actual input. A PV module generally has an output power of 70% of STC rated power. If the rated module power of a nominal “24-Vdc” module is 150 Watts at STC, you may generally see $150W \times 70\% = 105W$ of power from this module. Let’s assume that the total combined input power after calculating each input’s allowable number of strings is 7200Watts STC, then you might realistically see 5040Watts of real input power. This value of course depends on many variables, such as available light, cell temperature and cloud edge enhancement. Should the array occasionally produce power levels above the amount of current the charge controller can handle (100A), the M5 electronically limits the input power.

String Combiner

To connect multiple strings to each input terminal on the M5 DC input, you will need to use one or more string combiners. A string combiner, connects a number of strings in parallel, protects each string with an overcurrent fuse or circuit breaker and combines the strings into a single output. This output will then be connected to one of the DC inputs on the M5. The overcurrent fuse or circuit breaker needs to be sized according to the module being used. The Amp value of the overcurrent device needs to be higher than $125\% \times 125\% = 156\%$ times the short circuit current (Isc) rating of the solar module, and equal to or lower than the maximum series fuse rating of the module. For example, if the rated short circuit current (Isc) of a module is 5 Amps, and the modular fuse rating is 15 Amps, then the fuse should be between $5A \times 156\% = 7.8A$ and 15A.

Backup Circuits

The key advantage of a battery-based PV system is the ability to accommodate multiple uses for the inverter. Not only can the inverter convert clean, renewable photovoltaic energy into valuable electricity, but the inverter can also be used to maintain electrical power to key electrical loads in a home or small office when the grid fails. PV systems without batteries must shut down and disconnect from the utility during power outages to prevent the energizing of electric circuits connected to the electrical distribution system. Therefore a Smart Power M5 PV system presents an added feature of backup power and utilization of the sun's energy even when the grid has failed.

To provide power during a grid outage, the M5 has to first disconnect (anti-island) just like a PV system without batteries. It then isolates the critical loads from the grid by opening the grid contactor. Finally, the M5 reenergizes the system output to provide power to the critical loads. The M5 does this in just 32 milliseconds, providing seamless power operation for almost all types of loads, including most computer systems.

To ensure that the M5 system will yield an adequate amount of time to back-up the critical loads, it is important to keep these loads within the capabilities of the M5 output characteristics. The M5 is capable of producing 5kW (42 Amps @ 120V) of continuous and up to 7.5kW (62.5 Amps) of surge power.

The critical load portion of the system is considered by the National Electrical Code (NEC) to be an Optional Standby System covered by Article 702 in the NEC. This requires that all critical loads must be wired into a separate sub-panel for connection to the standby output of the inverter.

NEC Article 702—Optional Standby Systems allows sizing based on supply of all equipment intended to be operated at one time (NEC 702-5). This means that all the 120-Volt loads could be run off of a single-pole 50-amp breaker from an optional standby system as long as the actual continuous load is below the 80% limit for continuous operation of a standard breaker (40 Amps).

Types of Loads:

It is extremely important that the installer works closely with the customer to prioritize the electrical loads to run on the backup system. Most customers would prefer to operate all their electrical loads in the event of a utility outage, but this is prohibitively expensive for most homes and offices. Developing a priority list of electrical loads, along with detailed power consumption information for those loads, is of primary importance for the proper operation of a backup system.

Loads like central air conditioning systems or electric water heaters and electric stoves typically consume too much power to operate on a modest inverter system. Although these large electrical loads are not run off backup systems, they are also loads that are generally less critical to the customer. Loads such as lighting, entertainment, computers, and refrigerators consume much less power, but offer substantial benefit during a power outage. This is why the priority list must include the need for the appliance in the event of an outage as well as the power consumption of the appliance.

Detailed information may not be available on the power consumption of different electrical loads. When this information is lacking, an alternative is to make actual measurements at the customer's site. First, the circuits must be identified that serve the most important loads. This can be done with the help of a circuit breaker finder or by simply turning off individual breakers until the proper circuit is identified.

Design Considerations

The **first** design consideration is the total **continuous load** which could be applied to the critical load sub-panel if all connected circuits were run at once. Should a combined total of 6000 Watts of load be connected to the output of the system and all these loads run at the same time the system would be overloaded and shutdown. When connecting loads to the critical load sub-panel it is important to follow sound decision making to keep total power draw at levels supportable by the energy storage system. You

may allow for some large standby loads provided that their operation time is limited, such as user interactive devices like toaster ovens and microwaves.

Other types of loads in back-up circuits are essential and will start and run on demand without any human interaction, examples include: refrigerator compressors, heating/cooling fans, and water and sump pumps. Because it is possible for all these loads to be running at the same time the load calculation should consider this situation, and total load power should be equal or less than the M5 output capability. Your list should include basic lighting, communications, appliances pumps and motors which would likely to be running at the same time. This calculation determines the continuous output requirements of your inverter. **The combined critical load continuous power draw should not exceed 5,000 Watts (42 Amps).**

Full Load Design

Maximum Output Current:	42 Amps
Maximum Output Power:	5000 W

The **second** design consideration is the **surge** or **inrush current** demands of some loads. Many electrical loads, and most especially motors, draw more current upon startup than when running. Many motors will draw up to three times their rated operating current during startup. Determine which appliances and other loads which might start up at once (refrigerator, water pump, etc.) and add their rated inrush current(s) together. **The combined critical load inrush power draw should be added to the continuous power draw and not exceed 7500 Watts (62.5 Amps).**

Surge Load Design

Maximum Output Current:	62.5 Amps <10 seconds
Maximum Output Power:	7500 W for <10 seconds

The **third** design consideration is the **estimated operating time** of each of the continuous loads. This estimation is largely objective, and requires some input from the customer. Fill in the amount of time each load runs in the "Hours" column. This value is the amount of run hours per 24 hour period.

How large of a load an inverter can support and how long it can run the load is determined by a different set of variables and design considerations. How large is dependent on inverter size, how long is dependent upon the amount of energy stored or available. The M5 always uses power from the PV array to run loads during power outages, with any excess power routed to the batteries to recharge them for evening use. When the sun is not shining or during the night, the power for the loads comes from the batteries. Simply put, the larger the battery bank the greater amount of available energy storage to the customer during power outages.

Load Calculations

To make the load calculation and battery bank sizing simpler, please use the worksheet provided in the Appendix. The spreadsheet in Excel format may be obtained by contacting Beacon Customer Service: service@beaconpower.com. This section will use examples to explain the worksheet.

Battery Sizing Worksheet							
Load (Circuit)	Continuous Amps	Continuous Run Watts	Surge Amps	Surge Watts	Estimated Run Hours	Wh's	kWh's
Circuit 5: TV, Lights, Living Room Outlets	6.00	720		0	4	2880	2.88
Circuit 9: Refrigerator	4.00	480	12	1440	4	1920	1.92
Circuit 14: Home Office, 2 Bedroom Outlets	6.00	720		0	2	1440	1.44
Circuit 18: Furnace Fan	5.00	600		0	4	2400	2.40
		0		0		0	0.00
1.5 HP Well Pump	9.32	1118.4	28	3360	0.5	559	0.56
		0		0		0	0.00
Misc system losses	0.63	75		0	0.5	38	0.04
Inverter Tare Loss	0.15	18		0	6	108	0.11
Total:	31.10	3731		6933			
						Backup Loads in kW/h	9.34
						Power Electronic Efficiency Factor	0.90
						Backup Loads in kW/h	10.38
						Desired days of autonomy	0.5
						Load battery must support in kW/h	5.19
						System Voltage	48.00
						Load battery must support in Amp/h	108.16
						Allowable battery DOD(depth of discharge)	60%
						Battery charge/discharge efficiency	80%
						Battery size to support load in Amp/h	225.33

Table 1: Calculation worksheet for backup load capacity 120/240 Volt appliances

When making load calculations for a new construction simply use the value of each device that is to be run through the critical load panel. Slightly different would be the design approach for a retrofit installation, where the M5 is installed in an existing home. The upcoming example will be based on a retrofit installation and therefore refer to loads as circuits. In either case loads or circuits may be substituted for one another.

Start by determining the **continuous load** on each circuit. The continuous load can be found by operating the electrical loads in the house or office in the same way as is typical of the heaviest usage. For a typical home, this is the evening when lights are on, televisions are being watched, computers are being used, and kitchen circuits are most heavily loaded. Turning ON all the loads that would be operating during such a situation can simulate this. With the help of a clamp-on ammeter, the most important circuits can be tested for their actual current flow. This is often the simplest and most reliable method of determining the electrical needs of the proposed backup circuits.

Step 1: Make a list of the circuit or load currents and enter them in the column labeled "Load (Circuit)" and "Continuous Amps."

Step 2: Multiply the "Continuous Amps" by 120 Volts to obtain the "Continuous Run Watts" Value and enter this in the appropriate column. The total "Run Watts" should not exceed 5kW.

- Step 3:** If any loads have starting surge currents multiply these by 120 Volts and enter them in the column labeled “Surge Watts.” Add the surge watts minus the continuous watts for that load to the continuous load total, and make sure that it does not exceed 7.5kW.
- Step 4:** Determine the estimated amount of hours per 24 hour period that each load will be running, and enter it in the column labeled “Estimated Run Hours.”
- Step 5:** Enter the “Desired days of autonomy” in the appropriate field.
- Step 6:** Enter the “allowable battery DOD (depth of discharge)” in the appropriate field. By default this value is set to 60%.

240 Volt Applications

The output of the M5 is 120 Volts AC and can power most household 120 Volt appliances. Occasionally a homeowner has a critical load that is 240 Volts AC such as a water pump. 240 Volt water pumps range in sizes from $\frac{3}{4}$ to 5 horsepower (hp). The starting current of water pumps varies so it is important that the actual starting current requirements be obtained from the pump manufacturer. Pumps that incorporate starting capacitors often have much lower starting currents than those without capacitors. Without detailed starting current information, it is wise not to attempt to power pumps larger than 1.5 hp due to the high starting currents generally required by larger pumps.

Should it be necessary to run a 240 Volt application on the back-up circuits of the M5, a step-up transformer, also called auto-transformer will be necessary. Remember to double the 240 Volt current requirement when calculating the 120 Volt load capacity. For example an appliance that operates 10 Amps at 240 Volts will pull 20 Amps at 120 Volts.

Multi-Wire Branch Circuits

It is common for dwellings to have pairs of 120 Volt circuits fed by single 240 Volt, 3-wire circuits. This configuration is referred to as a **multi-wire branch circuit** by the National Electrical Code (NEC) and is installed to reduce the cost and labor of wiring the many circuits required by the NEC. However, this presents a problem for backup inverters operating at 120 Volts. Multi-wire circuits supply a single neutral wire for two 120 Volt circuits. This is allowed due to the fact that the neutral currents cancel one another on two 120 Volt circuit derived from opposite sides of a 120/240 Volt service panel. For instance, if one of the two circuits is drawing 12 Amps while the other circuit is drawing 8 Amps, the neutral current will be 4 Amps (12 Amps – 8 Amps = 4 Amps). However, if the circuits are derived from the same 120 Volt bus, as in the case with the output of the M5, the neutral currents add rather than subtract causing a 20 Amp load to flow in the neutral. This can cause dangerous overloading and eventual failure of the neutral conductor.

Many of the high priority circuits of a customer are found to be on multi-wire circuits. There are only two options available if those circuits are to be powered with the M5. The first option is to run new circuit wiring to the point where the multi-wire circuit is split. This can be difficult and time-consuming depending on the access available to these circuits. The second option is to install a 120/240 Volt step-up split-phase transformer. The transformer supplies the needed opposite phase 120 Volts to the 3-wire circuit allowing the 120 Volt inverter to power these circuits safely. Do not use an autotransformer for this purpose.

Battery System (48Vdc)

Battery Basics

Battery systems complement the performance of a PV system in several ways. Two key ways they provide benefit is

- (1) by supplying a reserve of electrical energy in the event of a utility outage during cloudy periods or night, and
- (2) by supplying surge currents for the appliances at stable voltages. Without batteries it would be impossible to operate critical loads when refrigerators or pumps require starting current in excess of the array output.

There are many types of batteries on the market. The type of battery to select depends on the application. A PV standby system operates in a similar way to an uninterruptible power supply (UPS) for computer systems. Just as with a UPS, the PV standby system should maintain the battery at a full state of charge to keep the largest possible energy available in the case of an outage. Battery capacity tends to be much smaller than for stand-alone PV applications because the amount of battery autonomy needed is generally less than for a stand-alone system. As with a UPS system, power is needed virtually instantaneously to ensure that no loss in power is experienced by electronic equipment. A standard UPS designed for computer use will have a transfer time of about 1 cycle or 1/60th of a second. Although the M5 transfer rate is not quite this fast, it is fast enough to keep nearly all available computer equipment fully operational in the event of a utility outage.

The type of battery most commonly used in a UPS is the absorbed glass mat or AGM battery configuration. This special type of lead acid battery is classified as a valve-regulated lead-acid (VRLA) battery. Some refer to these batteries as “sealed” batteries, but they are sealed with a pressure vent that opens when they are improperly overcharged, preventing rupture. The two main types of VRLA batteries are AGM and Gel.

Flooded lead-acid batteries are also used in standby systems, but they are **NOT** to be used with the M5. A drawback to using flooded lead acid batteries is the design of the battery. Most PV system suppliers use lead-antimony batteries that are designed for motive or traction applications (golf carts, floor sweepers, and fork lifts). Although these motive batteries have excellent deep discharge capabilities, they are not well suited for standby applications because their self-discharge rate increases at full charge. This means that a typical flooded battery will consume more energy to maintain full charge than an AGM VRLA.

It is generally recommended that the storage battery system consist of maintenance-free valve-regulated lead-acid VRLA batteries with AGM or Gel construction since these require no maintenance by the homeowner. Other types of batteries may become available in the future that are equally suited to this application, but do not attempt to use any battery that has not been thoroughly tested in Uninterruptible Power System (UPS) applications. Always refer to the battery manufacturer for additional uses / applications of their batteries.

Sizing the Battery System

The M5 is designed to operate with a 48 Vdc nominal battery bank. Only valve regulated lead acid (VRLA) absorbed glass mat (AGM) or Gel batteries are to be used in the system. The batteries will need to have a minimum total voltage of 47.0 Volts for first power up, or 11.75 Volts minimum per battery. The batteries should be installed in a dry, well-ventilated location, and away from excessive hot and cold temperatures.

The amount of time critical loads can operate depends on the amount of power they consume and the size of the battery system. The amount of energy stored in the batteries will, to a large degree, determine the length of time critical loads will run.

To size the battery the amount of back-up power required should be calculated by using the Load Calculation spread sheet in the Appendix (explained in the Backup Circuits section and Table 1). Put

simply, loads are multiplied by time and added up. A typical backup battery system will be sized to operate at around 1 kW continuous load which is the average usage for a home that is not running an air conditioner or other large electrical appliances. It is important to note that sizing the inverter is different from sizing the battery system.

Most power outages last for six hours or less. Using the 'typical' system above which would call for 6 kWh (nominal) of energy storage the following formula can be used to determine the size of battery required:

$6\text{kWh} \times 1000 = 6000 \text{ Watt-hours} / 0.90 \text{ (inverter efficiency)} = 6742 \text{ Watt-hours} / 48 \text{ Volts} = 140 \text{ amp hours energy required} / .6 \text{ (Allowable Depth of Discharge of battery)} = 233 \text{ Amp-hour battery required.}$

For 48 Volt systems, a simple rule of thumb is that each 100 Amp-hours of battery rating will provide approximately 3.5 kW-hours of energy storage. We recommend that the smallest battery storage system consist of at least 7 kW-hours of energy storage. The absolute minimum battery size requirement is 100 Ah in order for the system to function properly.

Battery Temperature and Location

Regardless of battery type, the battery storage cabinet must be kept out of the sun and in as cool a place as practical to extend battery life. Every battery storage system also requires ventilation. The Battery storage cabinet must be ventilated to the outdoors; vents need to be at the high and low points in the cabinet. Although placing batteries within a dwelling is rare, if this is the best battery location due to severe outside or garage temperatures, consider applying ventilation requirements that are used for combustion water heaters. These requirements are readily understood by local inspectors, or Authorities Having Jurisdiction (AHJ's), and provide several times the necessary ventilation for most residential-scale battery systems. Refer to the battery manufacturer for more detail.

Battery Capacity Test

A battery capacity test is an important way to determine the health of the battery system. A simple test can be performed using a constant load. The first step is to shut down the PV array and bypass the inverter to maintain the standby loads in the house. With the battery at full charge, connect an electrical load that is equivalent to the average load on the standby sub-panel. For instance, if the average load is 1 kW, find a heater, or other resistive load that draws 1 kW and operate it from one of the critical load circuits, while timing the length of operation. Operate the load until the inverter shuts down on low battery voltage. Record the elapsed time that the system operated the 1 kW load. The battery should be replaced when it reaches half its original capacity. For example, if the battery originally had an 6 kWh energy storage capability when it was new, the battery should be replaced when the capacity reduces to 3 kWh.

Battery Protection / Disconnect

The M5 does not include a battery disconnect or over current protection device. A maximum 175 Amp protection device is required, located closest to the batteries. This may be in the form of a circuit breaker or a replaceable fuse and disconnect switch. The Beacon Power battery and disconnect enclosures include the required 175 Amp disconnect.

Battery Maintenance

The type of battery and its application determine the maintenance that a battery requires. Most grid-connected PV systems use "maintenance-free" valve-regulated lead acid (VRLA) batteries, which are kept at full charge except for an occasional utility outage.

- Maintenance-Free VRLA

VRLA batteries do not allow for addition of water or electrolyte and therefore earn the name "maintenance-free." On a bi-yearly basis, inspect the battery terminals for any visible corrosion. If corrosion develops quickly from one month to the next, it may mean that the battery is running at too high of a voltage, which in turn results in electrolyte loss. Also check the battery casings for leaks. If there are

any signs that electrolyte is seeping out of the battery at any location, immediately notify the battery supplier.

Be aware that while VRLA batteries may have access holes with covers that can be removed, be sure to avoid doing so because the life of the battery can be significantly shortened if the covers for these holes are unsealed.

- Annual Battery Maintenance

With the system shut down and the battery breaker open, check for loose battery terminal connections by gently but firmly moving the cables back and forth perpendicular to the fastening bolt or stud. If the connection moves with minimal effort, then the connection should be unbolted, cleaned, and refastened to the proper tension. The terminals should be coated with petroleum grease or another compound recommended by the battery manufacturer and a torque wrench should be used to ensure that they are tightened according to specifications.

Battery Charging

The M5 maintains the battery at full charge in preparation for a utility outage. In a typical grid-connect situation the batteries are at float charge voltage only for about 30 minutes each morning. After ~30 minutes the charger will lower the voltage to standby-voltage, saving energy for the rest of the day. This ensures that the battery is fully charged each day but also allows the battery to rest the remainder of the day. This also substantially increases the battery life. If the M5 experiences a utility outage at night, the battery charging cycle is prolonged during sunlight to return the battery to full charge as quickly as possible. The battery is only charged by the PV array, a more efficient energy source than the utility grid. The M5 never uses the grid power to charge the batteries, since it would be less efficient to do so.

Grid Connection

Theory of Grid Connection

When NOT connected to the grid, the M5 is in Stand-Alone mode. This mode regulates the output voltage by limiting power from the PV array, and using excess PV power to charge the battery. If the battery is fully charged, the PV array will only be used to supply power to the backup loads since the excess power from the array cannot be sent to the utility.

In utility-interactive operation, called Export mode, the M5 is **connected to the grid**. In this operating mode the M5 is using the first available PV power to charge the batteries, and then sending the excess power to the grid, where it may either be used by

- a) your critical loads
- b) other loads in your house
- c) exported to the utility (spinning the utility meter backwards)
- d) a combination of a), b) and c) .

This concept where the utility meter is allowed to turn in either direction is called net metering. To allow connection to the grid the M5 has to adhere to utility interconnection standards discussed earlier in this manual. To perform as designed the M5 has to be connected to the utility taking into account local electrical and utility codes. The options available for utility connection are discussed below.

Connection to Utility

The connection to the utility panel, or point of connection as it is referred to in the NEC, is governed by section 690.64. This section covers connection on:

- A. the **Load Side** of the service entrance (after the first over-current device, generally in the utility panel), and
- B. the **Supply Side** of the service entrance (between the utility meter and first over-current device).

Option A is preferred and the easiest form of connection is through a dedicated circuit breaker in the main service panel. This connection however might not always be code compliant; therefore Option B may be required.

A. Load Side

Although a circuit breaker is often the preferred method of interconnection, the requirements of NEC 690.64 are often difficult to manage. For dwelling units (the NEC's term for a residence) an allowance is made for supply breakers to be connected to the bus bar of a service panel. NEC 690.64 (B) (2) exception states:

“For a dwelling unit, the sum of the ampere ratings of the over-current devices shall not exceed 120 percent of the rating of the bus bar or conductor.”

This means that a 100-Amp bus bar with a 100-Amp main breaker can receive an additional 20-Amp supply circuit breaker making the sum of the ampere ratings of the supply breakers 120% of the bus bar ($1.2 \times 100 \text{ Amps} = 120 \text{ Amps}$; subtract the 100-Amp main breaker leaves an allowable 20 Amps for the PV supply breaker. Likewise a 200-Amp bus bar allows 40 Amps for the PV supply breaker).

Since the M5 requires a 50-Amp, 120V breaker for the point of connection, one must consider the options.

100-Amp Service

At first this may seem very difficult for customers with 100-Amp services. However, the NEC requirement refers to the bus bar rating not the service rating. Most main service panels built in the past 10-20 years have bus bars rated greater than the main breaker rating. For instance, a typical 100-Amp load center available currently will have a 125-Amp bus bar rating. Therefore the maximum additional supply breaker is 50 Amps rather than the 20 Amps computed above ($1.2 \times 125 \text{ Amps} = 150 \text{ Amps}$; subtract the 100-Amp main breaker leaves an allowable 50 Amps for the PV supply breaker).

If the customer has an older 100-Amp service where the bus bar rating is unknown or equivalent 100-Amps, the panel must be replaced. Use a higher rated service panel. At this point it might be time to upgrade the service to 200-Amps.

50 or 60-Amp Service

Should you encounter a 50 or 60-Amp Service, it is wise to upgrade to a higher rated panel that can accommodate the 50-Amp breaker for the M5 connection.

200-Amp Service

As with the 100-Amp service, a 200-Amp service generally has a higher bus bar rating, which allows for the connection of the 50-Amp breaker for the M5 connection. Should the bus bar be rated at 200-Amps, you may have to upgrade the panel, or replacing the main 200-Amp breaker with a 180-Amps or less (if such a breaker is available for the particular service panel). $1.2 \times 200 \text{ Amps} = 240 \text{ Amps}$. If main breaker capacity is decreased to 180-Amps, the 50-Amp breaker for the M5 adds to 230-Amps. It is important to check whether downsizing the main input breaker to 180Amps creates problems with the amount of loads on the panel. Take into account the loads on the sub panel, since these are powered by the grid, when PV is not available.

Always check the rating of the bus bar and main breaker when quoting a PV system. Often older service panels do need to be replaced to comply with the requirements of 690.64. Make sure that you have evaluated this and included it in your system estimate to avoid surprise price increases for your customer.

B. Supply Side

Other options exist for making the utility connection. Although the supply side is not often used as the point of connection, in some cases it is the most cost-effective. Any connection made on the supply side must comply with the requirements of Article 230 of the NEC.

Caution: Remember any connections made to the supply side of the utility panel will be hot unless the utility meter has been removed.

Check if the main input breaker to the service panel has double lugs on the supply side. If it does not, check if a double lug circuit breaker is available for that specific service panel. You may use the second unused lugs as the connection point of the M5. If you cannot find a double lug breaker, consider an insulated distribution terminal block that is wired prior to the input of the main breaker.

If space permits, use a wiretap to connect directly to bare supply side wires.

Check if the utility meter has double lug inputs, if not, see if one is available. Generally the utility meter is replaced by the utility shortly after a grid connected PV system has been installed. If this is the case, you may upgrade the utility meter system with a double meter, where the second meter is used to connect the M5. This will also allow keeping track of the excess power production of the M5.

AC Disconnect

Many utilities across the U.S. require a utility accessible AC disconnect between the M5 and the final utility connection. Accessibility often means that it must be in close proximity to the utility meter at a residence. Occasionally utility meters are read remotely so the disconnect may need to be located in a more accessible location than the meter location. This AC disconnect can be the NEC required maintenance disconnect as long as the inverter is also in close proximity to the switch. Utilities throughout the U.S. are fairly similar in their specifications that this switch have:

1. visible blades that are clear when the switch is open (circuit breakers do not have visible blades).
2. the ability to be locked in the open position (the specification may include a "3/8" shank lock").

In residential systems the switch may be used by maintenance personnel other than the utility, and therefore must be load-break rated (must be switch able under power). Make sure that it is properly listed for the maximum voltage and current of the application.

Monitoring (optional)

The Smart Power M5 can be monitored using the optional Smart Power Monitor a Windows® based software. During installation, should it be necessary to change any of the default setpoints, such as battery charging characteristics or the MPPT range, you will need to interface with the M5 using a computer and this software. It is recommended to have this available during installation, since it will aid in observing system functionality.

INSTALLATION

Before beginning the installation of the Smart Power M5 please make sure that you have read the System Planning Section and properly defined your system design. This section will cover specifics about the installation of the M5 in a photovoltaic application.

REQUIRED EQUIPMENT

Sheet metal punch for conduit connections (drill type only if bottom plate is removed)

Digital multi meter

AC and DC Current Clamp Meter

Tools required for AC and DC wiring connections:

- a. cable cutters and strippers for #2/0, #8, #6 or #4, and #20 wires
- b. ¼" hex key (Allen wrench)
- c. #2 phillips screwdriver
- d. 3/16" flat blade screwdriver
- e. 1/8" flat blade screwdriver

INSTALLATION KIT CONTENTS

- a. (9) nine 6-32 phillips flat head screws
- b. (7) ¼" diameter galvanized lag bolts
- c. Wall hanger
- d. Rear panel hanger
- e. 1.75" finishing plug
- f. Battery temperature sensor cable
- g. (6) six spare 6-32 philips flat head screws

GENERAL INSTRUCTIONS

Use caution when unpacking the Smart Power M5 from its shipping container to avoid damage to the unit and shipping container itself. In the event that repair becomes necessary, the unit must be returned in its original carton to avoid damage during shipping. Please save all packing material. We strongly recommend two people transport and remove the unit from the shipping carton due to its weight (120 lbs). This will avoid possible damage to the M5 and strain on the installer(s).

The preferred and recommended method for mounting the Smart Power M5 Inverter to dry wall, masonry, or concrete walls, is to attach it to a section of ¾" plywood that has been previously secured with suitably sized anchors and bolts, or lag bolts directly into wall studs to safely carry the weight. The section of plywood should be larger than the overall outside dimensions of the unit. When attaching the Smart Power M5 to the side of a house with vinyl, aluminum, or wood siding, the plywood sheet is not necessary as long as the wall hanger and bottom flange of the Smart Power M5 are lagged directly into the sheathing or preferably, the wall studs. In all installations, the M5 must be level and plum.

NOTE: Be aware that the unit's weight is centered towards the top.

The M5 is shipped on a sheet of plywood or wood frame for added protection. This wood is not intended for installation and must be removed before mounting. Store the wood with the carton after unpacking.

UNPACKING

With the assistance of at least one other helper, carefully remove the M5 from the shipping container according to the following instructions.

1. Lay the shipping box on the floor with the backside facing upward.
2. Determine heavy end of shipping container. Stand the shipping container up vertically with the heavy end down.
3. Open shipping container to gain access to inside box. Remove several foam blocks from corners and flatten.



4. Place foam blocks on the ground in front of shipping container as shown.
5. Open inside box making sure to hold onto the M5 unit (top of unit should be to the bottom, since this is where most of the weight is located.)
6. Slowly bring the unit down onto the foam pieces.



7. Place additional foam blocks on suitable tabletop or equivalent surface capable of supporting at least three times M5 weight (360 lb) to remove shipping bolts, PVC support tube, and plywood sheet or wood frame. Use two people (minimum) to carry the unit to a tabletop. Remove small cardboard box.
8. Place inverter on the foam, on its side as shown.

7

Transport To Tabletop



9. Remove shipping bolt.
10. Remove (3) three shipping bolts on lower flange.



11. Remove wood frame and PVC tube from rear of unit. Return all mounting hardware, PVC tube, and wood frame to shipping container.
12. Place Finishing Plug into open hole on the rear of the unit.



13. Attach the Rear Panel Hanger to the back of the M5 as shown below. Secure in place with (9) nine 6-32 flat head screws provided. Torque each screw to 9-10 in-lbs.



MOUNTING

Using the mounting bracket (Figure 5) as a template, mark the location of the holes on the plywood sheet or side of house. Keep in mind the cooling fans may require servicing or replacement in the future (average life of fans under typical conditions is 10 years); thus, you must allow at least seventeen inches of unobstructed space on the left or right side of the M5 and 12 inches on top in order to easily access the fans.

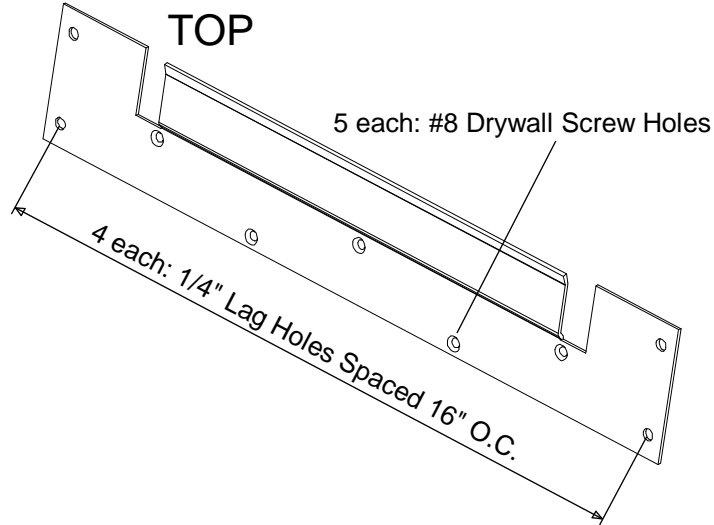


Figure 5: Wall Mounting Bracket

The most secure mounting scheme involves installing four 1/4-inch lag screws in each of the bracket's corner holes through the plywood sheet into wall frame and four drywall screws in the center to keep the bracket from flexing. An alternate approach is to substitute 1/4" x 3/4" long lag bolts for the 1/4" x 2" long bolts lagged into the plywood sheet only. Be sure the bracket is level after screws and bolts are installed.

Once the mounting bracket is secured, lift up the unit with two or more people and hook it onto the bracket. Center the M5 relative to bracket for maximum engagement. Make sure that the M5 is hanging on the bracket, and not on the top cover of the enclosure. The mounting brackets are properly engaged when the cover screw on either side of the unit lines up with the bottom of the wall mounting bracket (Figure 6).

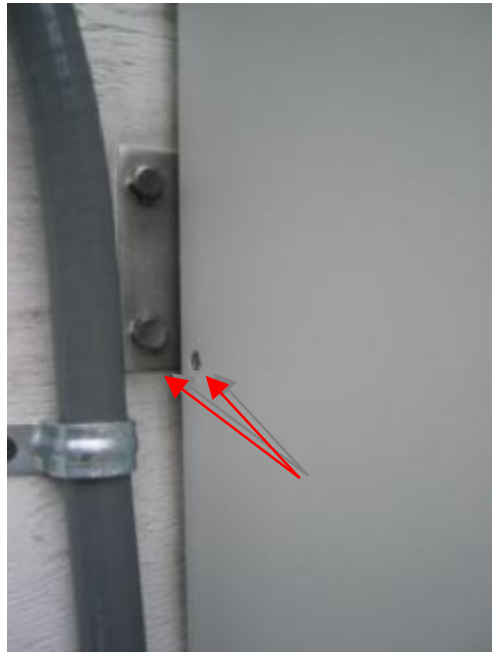


Figure 6: Mounting bracket alignment

The mounting holes on the lower flange of the power unit do not carry significant weight, but they prevent the unit from pulling away from the wall or lifting upward off the mounting bracket. Install three 1/4" lag bolts in the middle and end hole locations on the lower flange (Figure 7). Mounting the Smart Power M5 is complete.

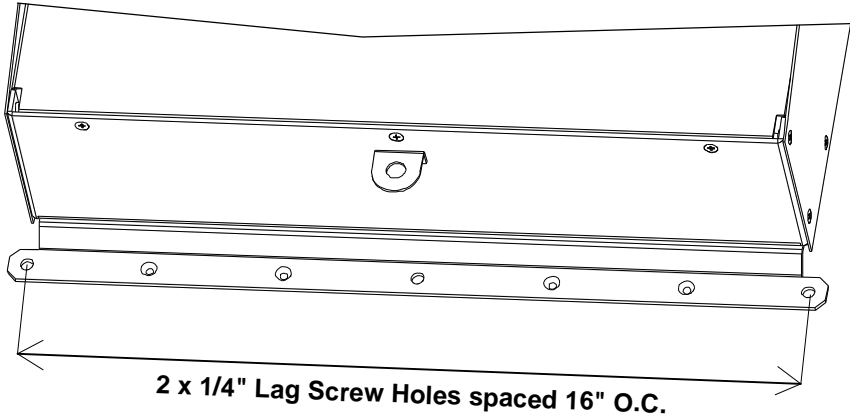


Figure 7: Lower Flange Mounting Holes

ELECTRICAL CONNECTIONS

The electrical connections to the M5 are made in the bottom compartment of the unit after removing the false front cover. Figure 8 shows an overview of the bottom compartment, including the disconnect switches, LED indicators and Communications port.

CAUTION – RISK OF SHOCK. When removing and reinstalling the false front after wire connections have been made, all power sources to the M5 **MUST** be turned off externally, including the battery and PV sources.

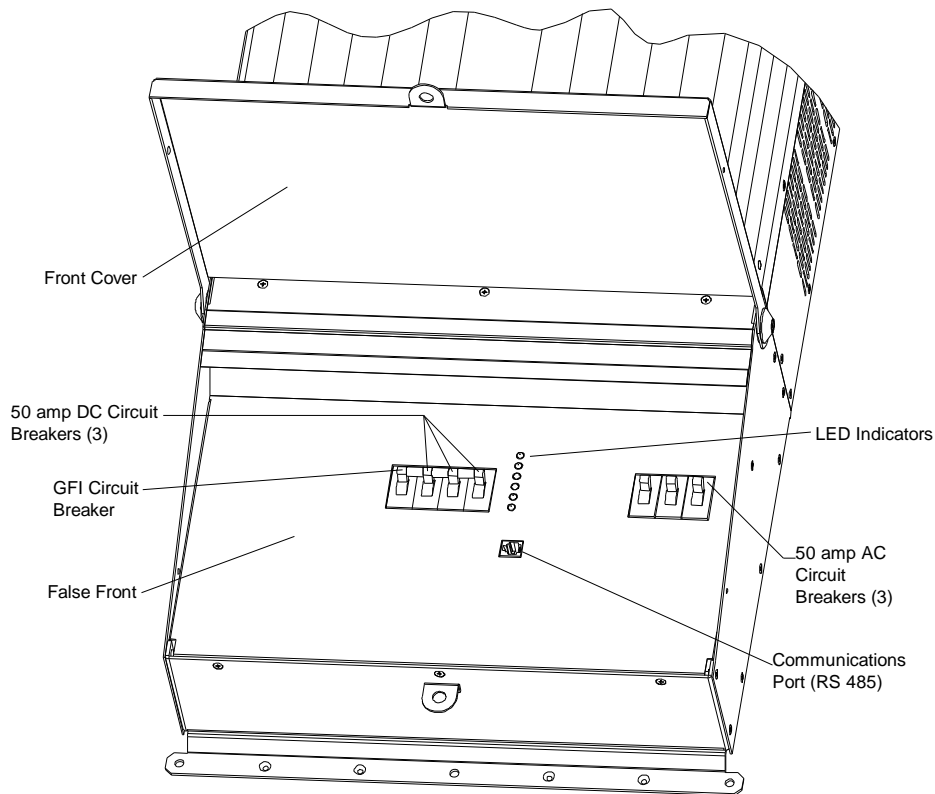


Figure 8: User circuit breaker compartment and false front

To get to the terminal compartment where all connections are made, the false front cover has to be removed.

False Front Cover Removal Instructions

1. Remove the 8 screws marked with the symbol ① as shown in Figure 9.
2. Pull the two bottom corners outward, making sure to clear the LED's and circuit breakers.
3. Slowly pull the false front downward and remove.

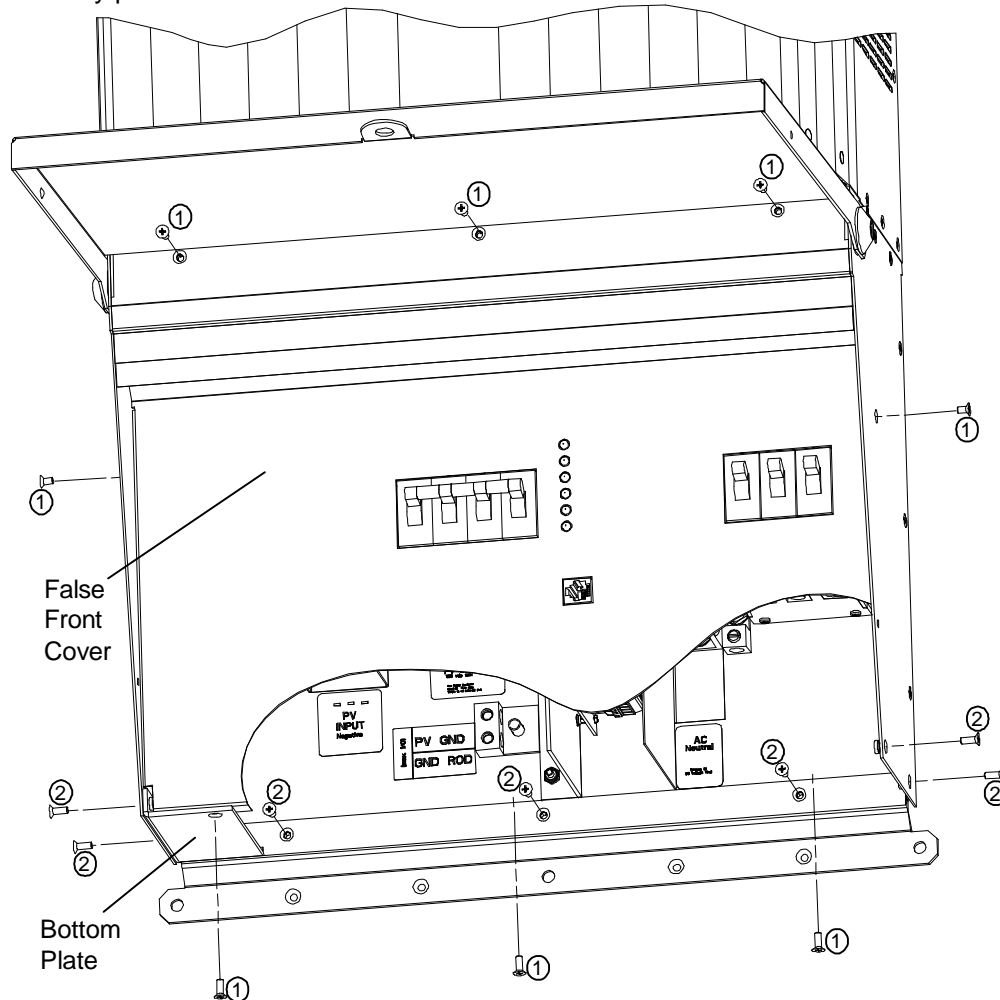


Figure 9: False front screws: ①
Bottom plate screws: ②

Conduit Connections

All wiring and cables connected to the M5 must run through conduit, except for the communications wire. It is recommended that metal conduit (EMT, rigid, or liquid-tight with metal jacket) be used. Refer to NEC code for proper wire / conduit size.

Holes for conduit may only be punched. The drilling of holes into the switchgear compartment may cause metal chips to affect electronic components, and will void warranty. Drilling may only be done to the bottom plate after it has been removed from the M5. Side and rear panel entry will void warranty since it affects the outdoor rating of the M5.

See Figure 9 for removal instructions of the 7 screws to remove the bottom plate. The screws are marked with the symbol ②. Once the plate is removed, punch the necessary holes for the conduit connections

Switchgear and Terminal Compartment

After the false front has been removed, the connection terminals and internal switch gear becomes visible. See Figure 10 for detail.

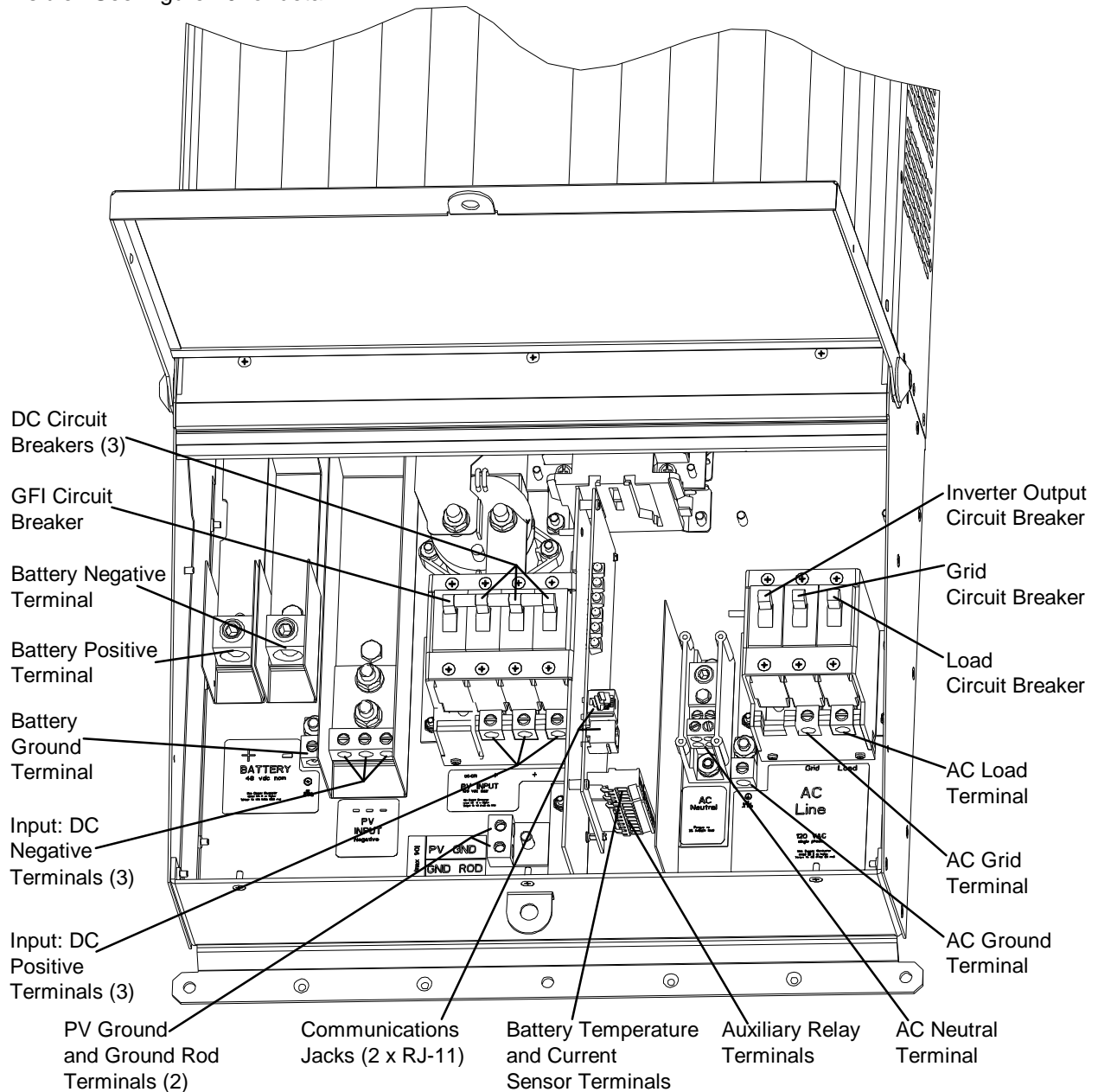


Figure 10: Switchgear compartment overview

AC Connections

The terminals provided for making the AC connections contain the following size and torque specifications:

Terminal	Wire Size	Torque
Grid – Hot	6 or 4 AWG	45 in-lbs (5.1 Nm)
Grid - Neutral	6 or 4 AWG	35 in-lbs (4.0 Nm)
Load – Hot	6 or 4 AWG	45 in-lbs (5.1 Nm)
Load - Neutral	6 or 4 AWG	35 in-lbs (4.0 Nm)
Ground	6 AWG	45 in-lbs (5.1 Nm)

Table 2: AC terminal information

AC wiring must be copper. Use #6 or #4 AWG cable rated for 75° C such as THWN. The largest wire size accommodated by the AC terminals is #4. Increase wire diameter for long distances and use a reducing lug to meet the #4 AWG terminal.

The AC output *neutral* conductors are not connected (bonded) to the chassis (ground). System grounding, as required by articles 690-40 through 690-43 of the National Electric Code, and ANSI/NFPA 70-1996, is the responsibility of the system installer. All installations must comply with local and national electrical codes and standards. Refer to the *SYSTEM GROUNDING* section for more information.

Load Connection

Connection of the sub-panel circuit on the M5 is shown in Figure 11. The hot is connected to the load terminal, the neutral to the common AC neutral terminal, and the ground wire to the shared ground lug.

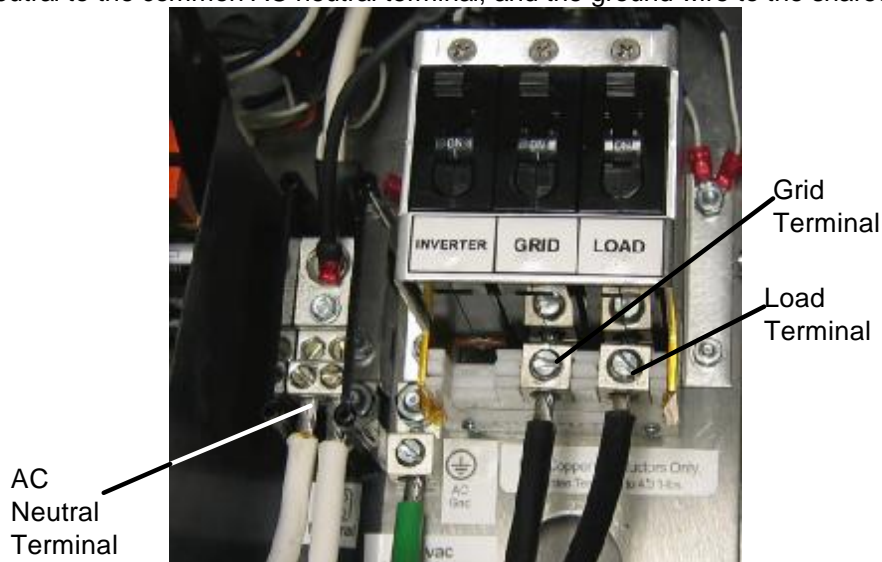


Figure 11: Grid and sub-panel load connection

The sub-panel does not need to have a separate main over-current disconnect, since this is provided by the 50A circuit breaker inside the M5. All dedicated circuits for the backup loads should all be wired to code, and need adequate over-current protection dependent on the current carrying conductor. Should it be necessary to power a 240 Vac load, wire the transformer to one of the outputs of the sub-panel.

NOTE: Multi Wire Branch Circuit

Some existing circuits may be wired with a multi wire branch circuit. As discussed in the System Planning section, multi wire branch circuit needs special attention when used to connect to the critical load sub-panel. If you should need to wire multi wire branch circuits, you will need to install a 120/240 Volt step-up split-phase transformer.

Grid Connection

M5 Connection

Connection of the grid connect circuit is shown in Figure 11. The hot grid wire is connected to the GRID terminal of the AC output terminals, the neutral to the common AC neutral terminal, and the ground wire to the shared ground lug.

Lockable AC Disconnect

Most utilities across the United States require a lockable disconnect, accessible by utility personnel. This disconnect will generally be located near the utility meter, and needs to be wired between the M5 and the utility connection point. It shall be wired according to NEC code.

Grid Connection

Connecting to the M5 requires special considerations. Please refer to the previous System Planning 'Grid Connection' section. UL requires the following statement: To reduce the risk of fire, connect only to a circuit provided with 50 amperes maximum branch circuit over-current protection in accordance with the National Electric Code, ANSI/NFPA 70. Should you be connecting to the load side of the utility, it is important that you utilize a single-phase 120Vac, maximum 50A circuit breaker to connect into the utility panel.

Communication Cable Connection

For connection of a monitoring device, such as a computer with Smart Power Monitor software installed and an RS-485 to RS-232 adapter, there are two RJ11 communication jacks. These are found on the Relay Card in the switchgear section of the M5 (refer to Figure 10). Both outlets are identical but only one may be used at a time, as connecting two communication devices will disrupt the signal.

The cable may be a standard four wire phone cable terminated RJ-11 with "twist". If both ends of the cable are held together side-by-side (with the RJ-11 clip tabs both facing down), a "twisted" cable will have the individual wire strands ordered opposite one another. For example, if the strand order is black, red, green, yellow (when read from the left to the right side) for one end of the cable, the other end of the cable should be ordered yellow, green red, black (when read from the left to the right side). If the colored wires are in the same order, then the cable is a "straight" cable. A straight cable will not allow the SP Monitor software to communicate with the M5.

When making a permanent communication connection, use the interior RJ11 communication jack. A punched hole through the bottom plate and a conduit connection are required to pass the cable to the outside of the unit. If the cable is run with current carrying conductors, make sure that the communications cable has the appropriate voltage rating. For outdoor installations without a conduit, use a liquid-tight cord grip and outdoor rated communications cable.

Temporary communications may use the RJ11 jack that protrudes through the false front.

CEC kWh Meter Requirement

NOTE: This section applies ONLY to installations to qualify under the California Energy Commission (CEC) rebate program.

The CEC requires a **System Performance Meter** that measures "the total energy produced by the system. The meter must retain the kilowatt-hour production data in the event of a power outage and must provide a display of system output that the customer can easily understand."

To meet this requirement, an external kWh meter utilizing a split-core current transducer must be installed. The meter must be a 2-wire meter capable of measuring up to 5000 Watts at 120 Volts and 50 Amps. Therefore, the current transducer should be rated 50A or greater.

Connections

CAUTION – RISK OF SHOCK. These instructions require working inside the M5. Turn OFF all external power to the unit, including Battery, PV Disconnect, and Grid. After turning off all external power, wait 5 minutes for capacitors to discharge, before connecting any measuring devices.

The split core current transducer needs to be connected around the inverter output wire, inside the lower switchgear compartment (Figure 12). This is the wire that is connected to the top connection of the Inverter circuit breaker. Most CT's need to be connected, such that the "H1 Side" is facing the power source. In this case the power source is the inverter, which is coming from above. Make sure not to damage any of the existing wiring assemblies in the vicinity of this connection. Follow manufacturer's installation instructions to minimize measurement errors.

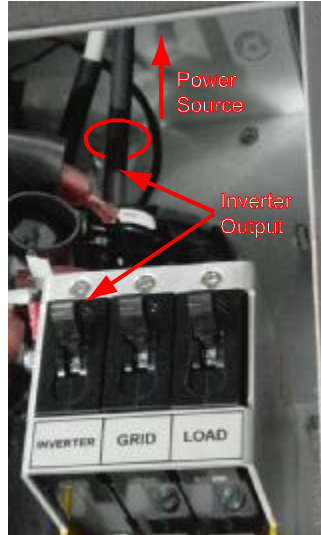


Figure 12: Inverter output wire, connected to top of inverter CB

The voltage needs to be measured at the Load terminal. DO NOT use the Grid terminal. Use the Load terminal and the Neutral terminal, to connect the voltage sensing wires (Figure 13). After connecting the monitoring wire, pull on it to make sure it is properly connected to the terminal. Again, follow manufacturer's installation instructions.

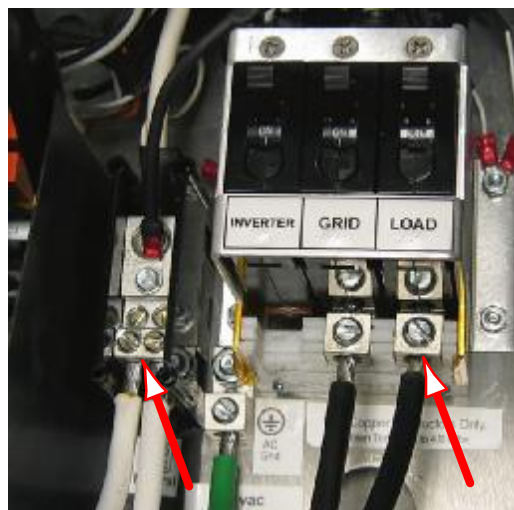


Figure 13: Voltage measurement points for external kWh meter

All wires that are connected to the external meter must leave the bottom switchgear compartment through their own output hole. Punch this hole in the bottom plate of the M5. DO NOT punch or drill a hole in the side panels of the M5, since this will void warranty and waterproofing specifications.

DC Connections

Wire Sizing

Both NEC and UL standards govern the minimum acceptable fuse and wire sizes to be used with PV systems. However, it is almost always more economical in the long run to install larger diameter wire than the minimum dictated by code, for larger wire allows electricity to flow with less resistance, minimizing internal losses and increasing the efficiency of the system. Beacon Power recommends choosing wire of a sufficient gauge to keep the sum of the voltage drops from the PV modules to the string combiner and from the string combiner to the inverter below 2%. Different PV installations will require different relative placements of the PV modules, string combiner and inverter. In some instances it may be necessary to space these components such that most of the voltage drop occurs going from, say, the PV modules to the string combiner and a very minimal voltage drop occurs in the transmission from the string combiner to the inverter. So long as the total voltage drop is below 2%, you may be assured that you are maximizing the efficiency of the PV system.

Table 3 indicates the maximum wire length that may be used for a given wire gauge and current level while still maintaining a 1% voltage drop. To use this table, determine how much current the wire must carry and find the column that contains that value. Moving down that column, find the distance that is closest to the length of wire to be used in the system. By tracing to the left from that value on the table, you will find the wire gauge necessary to hold the voltage drop to 1%. Note that this table assumes a 60-volt system and 1% losses. If the owner wishes to design for 2% voltage drop instead of 1%, the distance should be multiplied by 2; if the spec is for a 3% voltage drop, the allowable distance may be multiplied by 3, etc.

Maximum One-Way Wire Distance (FT) 1% Voltage Drop 60 Volt Circuits - Copper														
Size (AWG)	Amps													
	50	45	40	35	30	25	20	16	14	10	8	6	4	2
14	-	-	-	-	-	-	5	6	7	10	12	16	24	48
12	-	-	-	-	-	6	8	9	11	15	19	25	38	76
10	-	-	6	7	8	10	12	15	17	24	30	40	60	121
8	8	9	10	11	13	15	19	24	28	39	48	64	96	193
6	12	14	15	17	20	24	31	38	44	61	76	102	153	305
4	19	22	24	28	32	39	49	61	70	97	122	162	244	487
3	24	27	31	35	41	49	61	77	87	122	153	204	306	612
2	31	34	39	44	52	62	77	97	110	155	193	258	387	773
1	39	43	49	56	65	78	97	122	139	195	244	325	487	974
1/0	49	55	61	70	82	98	123	154	176	246	307	410	615	1230
2/0	62	69	78	89	103	124	155	194	222	310	388	517	776	1551
3/0	78	87	98	112	131	157	196	245	280	392	490	653	979	1958
4/0	99	110	123	141	164	197	247	308	352	493	617	822	1234	2467

Table 3: Maximum one-way wire distance (in feet) for 1% DC voltage drop in 60-volt systems

Wire Sizing Recommendations

For modules with rated I_{sc} less than 10A (almost all modules currently on the market), the following basic recommendations may be useful:

For module wiring within the PV Array:

—Minimum is 12 AWG; 10 AWG is recommended

For wiring from PV modules to a rooftop combiner box:

—Minimum is 12 AWG up to 40 ft; 10 AWG is recommended for distance over 20 ft.

For wiring from a rooftop combiner box to M5:

—Minimum is 4 AWG up to 100 ft; 2 AWG is recommended for distance over 80 ft (reducing lugs will be necessary at M5).

For wiring from PV modules to a combiner box at the inverter:

—Minimum is 10 AWG up to 150 ft; 8 AWG is recommended for distances of 120 to 250 ft.

PV Array Connection

The M5 has three PV input terminals that are separately protected by a 50 Amp circuit breaker. Each input may accept a maximum of 40 Amps of the rated Short Circuit Current (Isc) of the PV modules, as determined in the “System Planning: PV Input Calculations” Section.

The PV terminal connections are rated for the following maximum wire size and torque:

Terminal	Wire Size	Torque
PV - Positive	6 or 4 AWG	45 in-lbs (5.1 Nm)
PV - Negative	6 or 4 AWG	45 in-lbs (5.1 Nm)

Table 4: PV terminal information

PV wiring must be copper. Use a pair of #6 or #4 AWG minimum cables rated for 90° C such as type THWN-2 or XHHW-2, or #6 or #4 AWG minimum cables rated for 75°C such as THWN, per PV circuit. The largest wire diameter accommodated by the PV terminals is #4 AWG. When choosing wire size, follow the guidelines to minimize voltage drop. Should the need arise to increase wire diameter for long distances, you must use a reducing lug to meet the #4 AWG terminal.

Battery Connection

The M5 contains battery input terminals, but NO battery DC over-current protection or disconnects. A circuit breaker or pullout fuse block rated for 175 amperes maximum, and 60 Vdc minimum, must be located in series with the battery positive wire to the unit. It should be located as close as possible to the batteries and in an easily accessible location. Particular care must be taken to avoid creating an explosion hazard.

The following table shows the terminal wire size and torque rating:

Terminal	Maximum Wire Size	Torque
Battery Positive	4/0	120 in-lbs (13.8 Nm)
Battery Negative	4/0	120 in-lbs (13.8 Nm)

Table 5: Battery terminal information

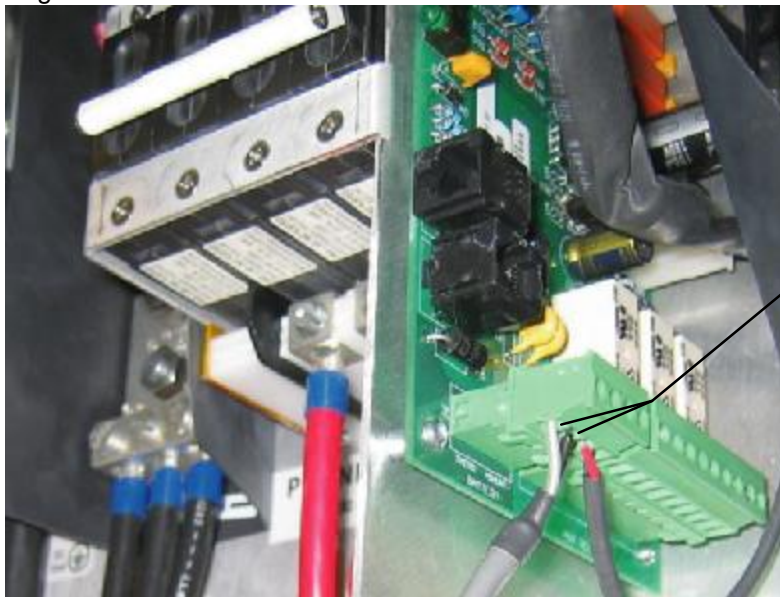
Battery cables 10 feet in length or less must be minimum #2/0 AWG flexible copper wire (hundreds of strands), such as type MTW or THW. For lengths 20 feet or less use #4/0 AWG flexible copper wire. Flexible cables as per NEC article 690-74 may be used. Crimped and sealed copper ring terminal lugs with a 5/16 or 3/8-inch hole should be used to connect the battery series cables, and final run cables to the disconnect/over-current protection and M5. Soldered cable lugs are also acceptable.

Battery Temperature Sensor Connection

The Smart Power™ M5 will not work without the battery temperature sensor connected.

A battery temperature sensor with a 20-foot cable is included with the M5, which needs to be mounted near the center of the battery bank. The sensor is only a temperature measuring device, and does not make an electrical power connection to the terminal post. The sensor will fine-tune the battery charging voltages for optimal efficiency and battery life. If a shorter cable is needed, the extra length may be coiled and secured in the battery area. The M5 battery charging system will not operate unless the temperature sensor is connected. The included cable is double insulated and rated for pulling through the same conduit as the battery cables.

Connect the battery temperature sensor cable to the two leftmost positions of the four-position screw terminal block on the terminal PC board in the lower wiring compartment (see Figure 14). Polarity does not matter. Note that the screw terminals pull out of the mating connector on the PC board for ease of wiring.



Battery Temperature
Sensor Terminals

Figure 14: Battery temperature sensor connection terminal

System Grounding

The rules pertaining to grounding are discussed in the National Electrical Code 2002, Article 690 Section V, and in the ANSI/NFPA 70-1996. Since the input and output circuits in the M5 are isolated from the enclosure, following the above rules is the responsibility of the installer. Grounding rules and regulations also vary considerably from one locality to another. If in doubt, consult a licensed electrician or electrical inspector.

Each electrical enclosure in an installation is connected together by a grounding (non-current-carrying) conductor to maintain them at the same voltage. This conductor prevents electrical shock to the user by serving as a fault current path in the event that any current-carrying wire inadvertently comes in contact with some part of a metal chassis. The wire must safely carry a fault current sufficient to trip an over current protection device (fuse or circuit breaker). A grounding system also carries transient energy, such as lightning, safely around the electrical equipment to minimize damage and risk of fire.

In all cases, the grounding wire must be bare, have green insulation, or be labeled on both ends as a ground conductor. It must always pass through the same conduit as the current carrying conductors.

The **PV array** module frames and metal supporting structure must be bonded together with copper wire and connected to the respective string combiners. Consult the manufacturer's recommended method for the grounding connections. Here you may use minimum #10 AWG wire. Neither the output terminals, nor any of the PV input connections may be connected to chassis ground within the string combiner or the M5. The PV ground terminal (labeled PV GND) in the bottom of the wiring compartment may be used to connect up to three ground conductors from three string combiners using #10 AWG wire, or two ground conductors from two string combiners using #6 AWG. Should the **batteries** or the **battery circuit breaker** be housed in a metal enclosure, that enclosure must be bonded to the battery ground terminal in the left side of the wiring compartment using a #6 AWG wire or larger.

IMPORTANT

Do NOT ground PV negative or battery negative external to the unit. Doing so will defeat the ground fault interrupter (GFI, 4-gang breaker). Refer to the DC *Ground Fault Protection* section for further details.

The common negative bus is internally connected to chassis through the photovoltaic array (PV) ground fault interrupt breaker. Opening the four-gang PV breaker disconnects PV and battery negative from chassis *ground*. **ASSUME THAT HAZARDOUS VOLTAGES ARE ALWAYS PRESENT BETWEEN: PV positive or PV negative and Earth ground, or battery positive or battery negative and Earth ground.**

Terminal	Maximum Wire Size	Torque
AC Ground	6 AWG	45 in-lbs (5.1 Nm)
Battery Ground	6 AWG	45 in-lbs (5.1 Nm)
PV GND	1/0	50 in-lbs (5.7 Nm)
GND ROD	1/0	50 in-lbs (5.7 Nm)

Table 6: Ground terminal information

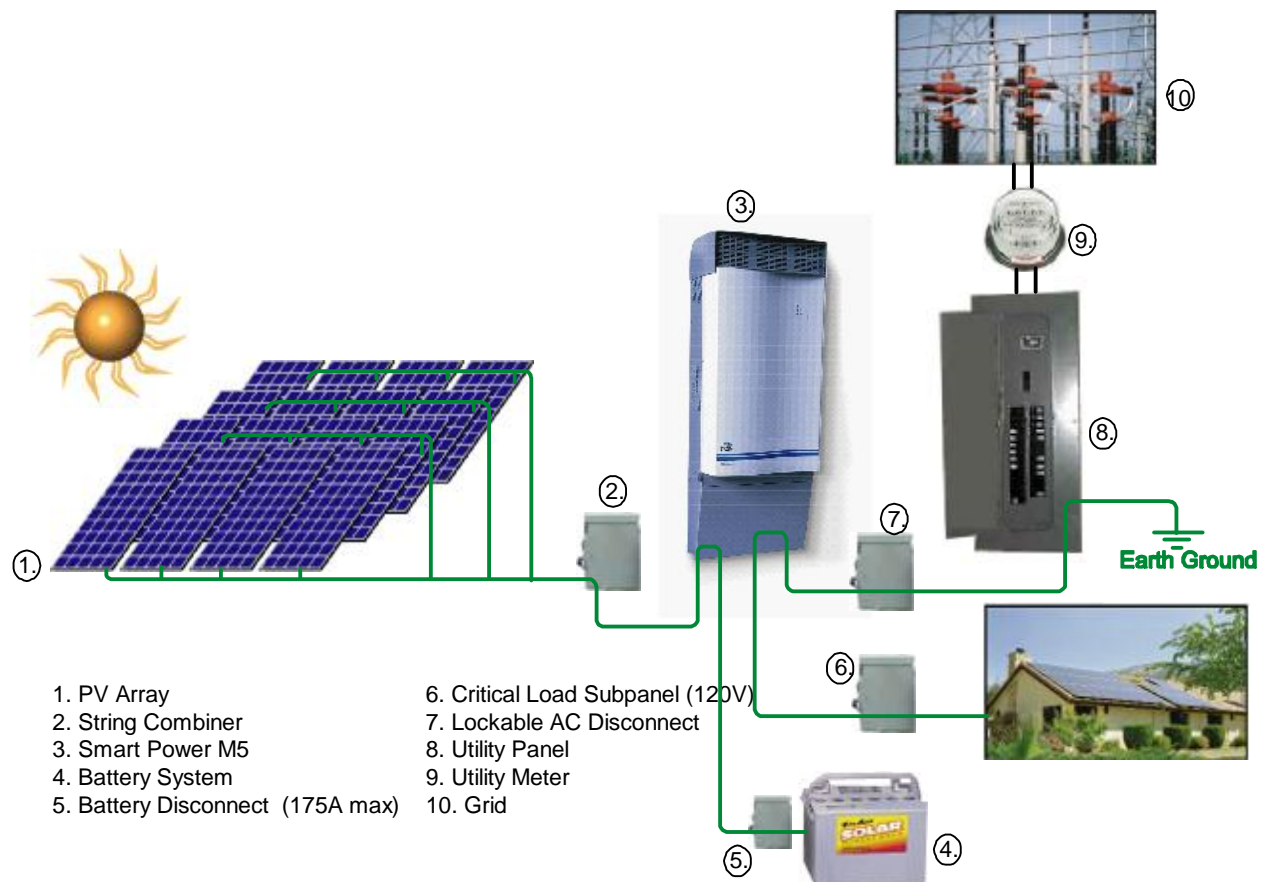


Figure 15: Ground connections, with earth ground only at utility panel

The sub-panel enclosure must be bonded to the M5 chassis using #6 AWG wire. Inside the M5 use the AC ground terminal connection to make this bond.

The M5 chassis must be bonded to the main distribution panel using #6 AWG wire. Use the AC ground terminal for this connection. This ground wire must be tied to and continue through the lockable AC disconnect enclosure. The main distribution panel is typically grounded through a metal rod in the Earth, and an additional water pipe connection. The electrical equipment must be bonded to Earth ground at a single point to prevent lightning-induced currents from flowing through the system.

The PV negative, attached to the M5 chassis beyond the GFI, should be attached through the shortest path to the grounding system. You may use the terminal labeled 'GND ROD' to run a grounding conductor directly to the grounding rod. Remember: All ground rods or grounding points in a system must be bonded together with minimum #6 AWG bare copper wire. Many local electrical regulations require that the wires, which bond multiple ground rods together, be attached to the rods with separate clamps from the clamp used to attach the wire from that rod to the main distribution panel.

For proper grounding of the False Front Cover, make sure that all screws labeled ① in Figure 9 are used to secure the cover to the enclosure.

DC Ground Fault Protection

The M5 contains an integral PV array ground fault interrupter (GFI), which protects both the equipment as well as the user. For proper operation, the chassis must be properly grounded, battery negative must not be grounded externally to the M5, and the PV array negative must not be grounded externally to the M5. The GFI consists of a 0.5 Amp circuit breaker that connects the internal DC negative bus to chassis (Earth) ground. If any part of the battery bank or PV array (other than the negative terminal) is inadvertently grounded, and greater than 0.5 Amps of current flows, this breaker will trip and disconnect all three PV input breakers.

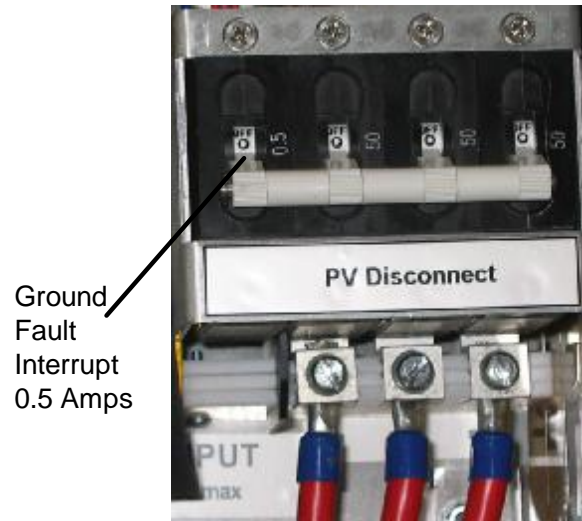


Figure 16: Ground Fault Interrupt (GFI) breaker

OPERATION

This section will cover important operational information about the Smart Power M5. This includes instructions for initial power up and functional performance tests, to make sure that the M5 was properly installed and is fully functional for the end user application.

SYSTEM CONFIGURATION (SETUP)

Should the need arise to alter certain setpoints, in case the PV array or the battery bank differ from default recommended equipment, you will need the optional monitoring package. At this point, the monitoring package is Windows based and will require a computer, preferably a laptop running Windows 98, 2000, or XP. Refer to monitoring package for setpoint adjustment instructions.

INITIAL POWER UP

After the installation has been completed, the M5 is ready for the **Pre-power up Measurements** followed by the **Initial Power Up**. Please refer to the *Functional Performance* section for full functionality tests.

The initial testing should be performed with the false cover of the wiring compartment removed.

Have all loads from the AC sub-panel disconnected, and use a small test load such as a lamp for connection to one of the branch circuits of the sub-panel.

Warning – Use extreme care when making measurements of, or near, live electrical circuits. Insulating gloves and eye protection are required.

Warning – Risk of Shock. Before replacing or removing the inner cover of the wiring compartment, disconnect all power sources from the M5: open the AC branch circuit breaker, the battery circuit breaker or pull-out fuse disconnect, and pull the fuses from the photovoltaic array string combiners (if possible). Use extreme care if the PV array wiring into the chassis cannot be de-energized. Never leave the unit or the external disconnects unattended with the lower wiring compartment open and the inner cover removed.

Pre-power up Measurements:

A number of measurements should be made before turning on the unit for the first time to ensure proper operation. **DO NOT TURN ON ANY BREAKERS TO THE UNIT.** Please measure these items and record them and make sure that they fall within the allowed window. For DC voltage values, make sure that your **POLARITY READS POSITIVE!** Negative readings may suggest reversed connection and can lead to damage to the unit.

		READING
1.	Battery Voltage (at external breaker DO NOT TURN ON)	
	a. Plus to minus	40 – 56 V
	b. Plus to chassis	40 – 56 V
	c. Negative to chassis	0 – 500 mV
2.	PV Input Strings (3 locations)	
	a. Plus to minus (3 locations)	75 – 110 V
	b. Plus to chassis (3 locations)	75 – 110 V
	c. Negative to chassis	0 – 500mV
3.	Grid Input (with external grid turned on and grid breaker in unit off)	
	a. Hot to neutral	114 – 124 V
	b. Hot to chassis	114 – 124 V
	c. Neutral to chassis	0 – 500 mV

Now that all inputs have been measured you are ready to power up your inverter for the very first time.

Initial Power up

Step 1 – Turn on the battery breaker. When DC is applied to the inverter, the top LED (RUN indicator) blinks red for one second, followed by eight flashes of all three LED's as the unit performs a self-test. The inverter should then start in Stand Alone mode; and the transformer will hum. The RUN LED will now blink GREEN once every two seconds. If this does not happen, test for the presence of battery voltage (nominally 48 volts DC) between the battery positive and negative connections on the left side of the wiring compartment.

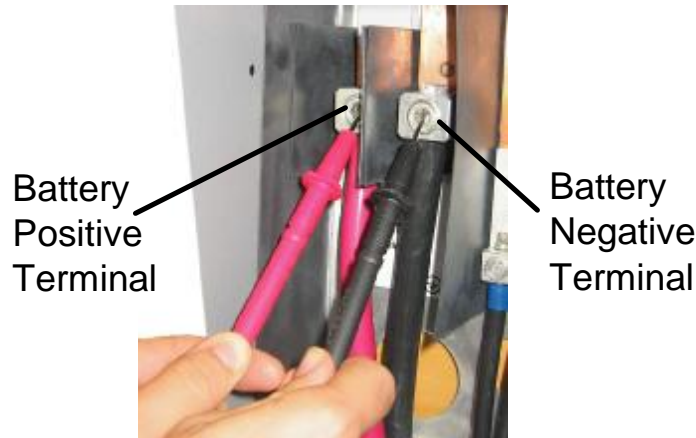


Figure 17: Battery voltage measurement location

If the batteries are extremely discharged (less than 44 volts), the inverter may not start, and if completely dead (less than 30 volts), the LED's may not flash. Charge the batteries to 48 Volt minimum.

Step 2 – Test PV input. This test must be performed when the PV array is illuminated. Ensure that string combiner fuses are in place. Optional: Check DC input voltage on the PV sub-arrays, between each PV breaker connection and the common PV negative terminal block; PV open circuit voltage should be observed: 75 to 110 Vdc, depending on module type. A “dead” sub-array indicates a wiring or fuse problem associated with one of the modules.

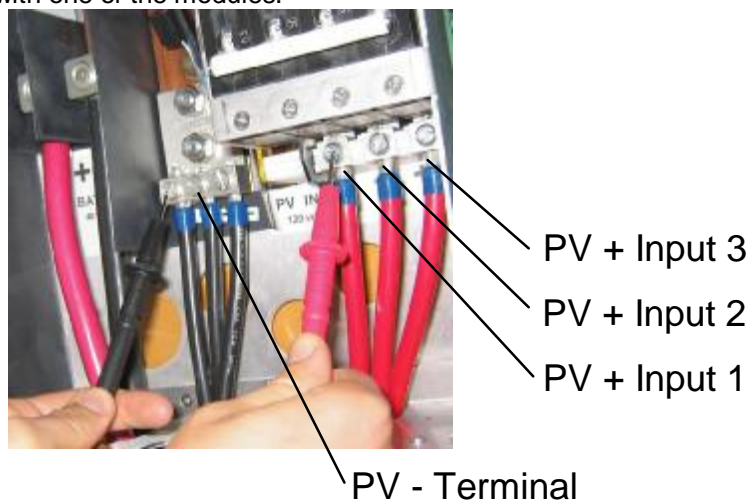


Figure 18: PV input measurement locations

Turn on the four-gang PV input breaker. Within about 15-20 seconds, the DC contactor should close with an audible “click”, and as the PV Power increases, the yellow PV indicator LED will flash. If the PV gang breaker immediately trips, there is a DC ground fault either in the PV array or the battery wiring. Find and correct the fault before restarting the startup procedure.

Step 3 – Turn on the INVERTER OUTPUT and LOAD AC breakers (and “main” breaker in the AC sub-panel, if present). Connect test lamp load to a branch circuit of the AC sub-panel; lamp should illuminate. Optional: Check AC output voltage between LOAD breaker connection and NEUTRAL terminal block; this should measure approximately 120Vac.

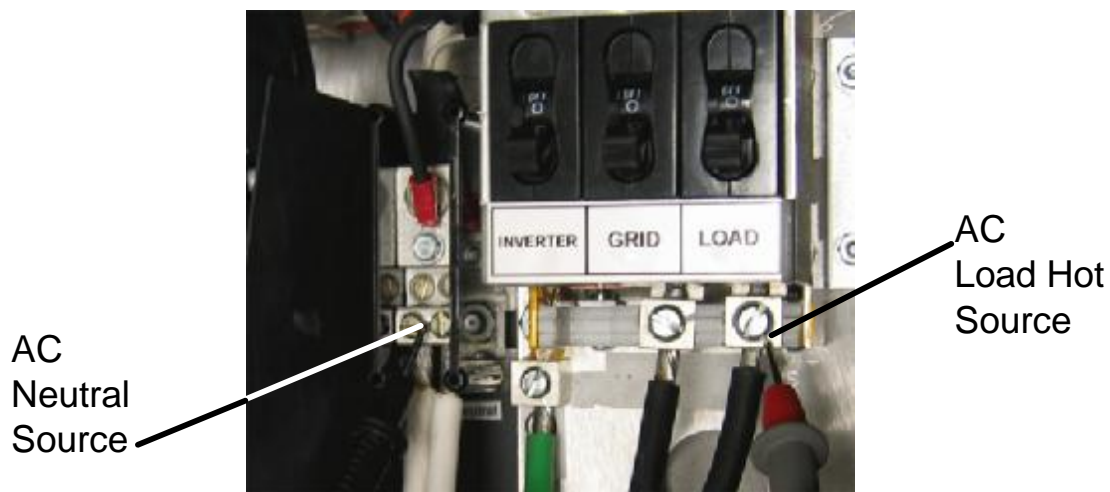


Figure 19: Load measurement location

Step 4 – Test utility parallel operation. Leave the INVERTER OUTPUT breaker ON and the test lamp connected to the sub-panel. Turn ON the M5 branch circuit breaker in the main distribution panel, and then turn on the GRID circuit breaker. Within about 15 seconds, the green UTILITY indicator LED will illuminate, and within a few more seconds the utility contactor will close with an audible click, as the M5 goes to Grid to Load mode. The test lamp will remain illuminated, with perhaps a brief blink at the transition. The RUN LED indicator will be completely OFF at this time, as the inverter itself is off-line. After five minutes, if there is sufficient PV power available, the M5 may begin to export power to the utility, and the RUN LED will start to flash green. The LED's duty cycle (i.e., ratio of OFF time to ON time) indicates the amount of power being exported to the utility line.

CAUTION: DO NOT REPLACE OR REMOVE THE FRONT COVER WHILE THE UNIT IS IN OPERATION OR EXTERNAL POWER IS SUPPLIED TO THE UNIT. USE THE SHUTDOWN PROCEDURE LISTED ON THE NEXT PAGE TO TURN OFF ALL POWER TO THE M5. THEN TURN OFF ALL POWER EXTERNAL TO THE UNIT. THIS INCLUDES AC PANEL BREAKER, DC BATTERY DISCONNECT, PV STRING BREAKERS OR FUSES. ONLY AFTER THESE ARE TURNED OFF REPLACE OR REMOVE THE FALSE COVER.

POWER-UP and SHUTDOWN Procedures

The following Table shows the Power-Up and Shutdown procedures. A simplified version can be found on the false front cover on the M5.

Operation	System Response
<u>POWER-UP Procedure</u>	
1. Battery CB	Top LED will blink red for one second, followed by eight flashes of all three LED's as the unit performs a self-test. The inverter should then start in Stand Alone mode; and the transformer will hum. The RUN LED will now blink GREEN once every two seconds.
2. PV Input CB	Within about 15 seconds, the DC contactor will close with an audible "click", and the yellow PV indicator LED will illuminate.
3. Inverter Output CB	No noticeable function
4. Load CB	The critical load / back-up circuits will now be powered through the inverter. M5 is in Stand-Alone mode.
5. Grid CB	Within about 15 seconds, the green UTILITY indicator LED will illuminate, and within a few more seconds the Utility AC-contactor will close with an audible click, as the M5 goes to Grid to Load mode. After about 5 minutes the RUN LED will start blinking green indicating Utility Export Mode.
<u>SHUTDOWN Procedure</u>	
1. Grid Breaker CB	The Utility AC-contactor will open with an audible click, and the M5 will be in Stand-Alone mode.
2. Load CB	The critical load / back-up circuits will turn OFF.
3. Inverter Output CB	No noticeable function
4. PV Input CB	No noticeable function
5. Battery CB	The main Controller and all LED's will turn OFF. The DC contactor will open with an audible click.

Table 7: Power-up and Shutdown Procedure (CB = Circuit Breaker)

LED INDICATORS

The M5 has three LED's on the top of the front cover. This section will explain these LED Indicators.



The 'RUN' LED blinks green or red, and indicates the DC to AC inverter operating state.



Green Blinks

When the inverter is operating, this indicator flashes green approximately once every two seconds. The length of the time the LED is illuminated indicates the relative output power level of the inverter. For example, a quick flash indicates no or very little inverter output. If the LED on an M5 is on for 50% of the time, the load is approximately 2.5 kW; if it is nearly always on, with a quick blink off, it indicates 5 kW load.



Red Blinks

The LED will flash red one or more times per four-second repeat cycle when the inverter is not operating or in a failure mode. Please refer to the descriptions of the flash codes below.

<u># of Blinks</u>	<u>Description</u>	
1	The inverter is in manual OFF mode, either commanded through the PC based user interface or due to an uninitiated software chip.	
2	<u>Inverter Failure Shutdown:</u>	
	Overload	Overloads can occur at varying power levels depending on conditions. If an overload occurs in Standalone Mode (during a grid failure) the inverter will attempt to restart 5 times for 10 seconds. After five retries inverter will stay off until the grid returns.
	Low Battery Voltage	Should the battery voltage drop below 46.5VDC (low battery voltage setpoint) for a period of one minute, the inverter will shutdown. The inverter will restart automatically when the battery voltage rises 2.3VDC above 46.5VDC. The battery charger will continue to operate during this shutdown.
	High Battery Voltage	Should the inverter rise above 62.0VDC (high battery voltage setpoint), the charger and inverter will shutdown.
	Low Battery Temperature	This is generally caused by a missing battery temperature sensor or bad sensor connection.
	High Battery Temperature	The battery temperature cannot exceed 70 degC, or the inverter will shutdown. A shorted sensor may also cause this failure.
	Inverter Over-Temperature	Internal inverter temperature has exceeded 85 degC. Inverter will automatically attempt to restart when internal temperature returns to normal. Persistent overheating may indicate that airflow to the M5 is restricted; ambient temperature is too high or fan has failed.
	Inverter FET Switch Desaturation	Inverter has a failed FET, or experienced an over-current in the internal shunt.
5	AC contactor failure or AC wiring fault. If the AC contactor fails for any reason, the top LED flashes 5 times. Connecting an AC power source directly to the INVERTER OUTPUT breaker can also cause this fault.	
6	Shutdown due to other hardware fault. A monitor or PC connection is required for further fault isolation.	
7	Configuration memory error. Contact Beacon Power for assistance.	

Table 8: Run LED fault indicator



No Indication

When the top LED is OFF, the inverter is in standby mode, and the loads are powered by the utility. This occurs when utility power is available and there is no PV power to export –at night, for example.



The ‘PV’ LED (yellow) indicates when there is PV Power available to be processed through the charger.



Yellow ON

When illuminated, power is being extracted from the source. Beware that this LED will not illuminate immediately when PV or other power is connected – there is a ~30 second delay. In low sunlight situations this LED may blink.



Yellow Blinks

If this indicator is flashing, there is a problem with the battery temperature sensor, or a battery over or under temperature. This condition will inhibit the charger and may rapidly lead to discharged batteries.



No Indication

There is no power available from the PV source. It is nighttime, the PV contactor has not yet turned on, or the PV Input circuit breaker is in the OFF position.



The ‘Grid’ LED (green) indicates when utility grid is available for the unit to interact with.



Green ON

It is illuminated when the inverter is operating in Grid to Load or Export mode. If the DC input indicator is also illuminated, then power may be exporting to the grid.



No Indication

The Grid is not available, either the grid / utility circuit breaker is in the OFF position, the AC disconnect has been switched, or a grid outage is occurring.

M5 BYPASS MODE

In the event that you should need to bypass the inverter, and power the loads directly from the grid, put the inverter in this BYPASS MODE.

BYPASS MODE		
STEP	CIRCUIT BREAKER	ACTION
1	GRID	OFF
2	LOAD	OFF
3	INVERTER OUTPUT	OFF
4	PV INPUT	OFF
5	BATTERY	OFF
6	GRID	ON
7	LOAD	ON

Table 9: M5 bypass mode

MAINTENANCE

Although the Smart Power M5 was designed with a life expectancy greater than 5 years, some routine maintenance will ensure a maximum life expectancy.

PERIODIC MAINTENANCE

At least twice per year, check air openings on sides of unit for blockage (foreign matter, insect nests, etc). Check for normal operation (Flashing green Run LED and constant yellow PV when sun is shining). Listen for fan operation when unit is running at high power (greater than 4kW).

REPLACEABLE PARTS

The following parts are field-replaceable by a qualified technician or installer.

Fans

The M5 contains two sets of fans. One set of fans is found in the center of the unit and the other set is found on top of the unit. Although the design life of these fans is greater than 10 years, they may need to be replaced at some point. Follow these instructions. You will be asked to reuse all the hardware you remove. Be careful not to lose or damage any screws.

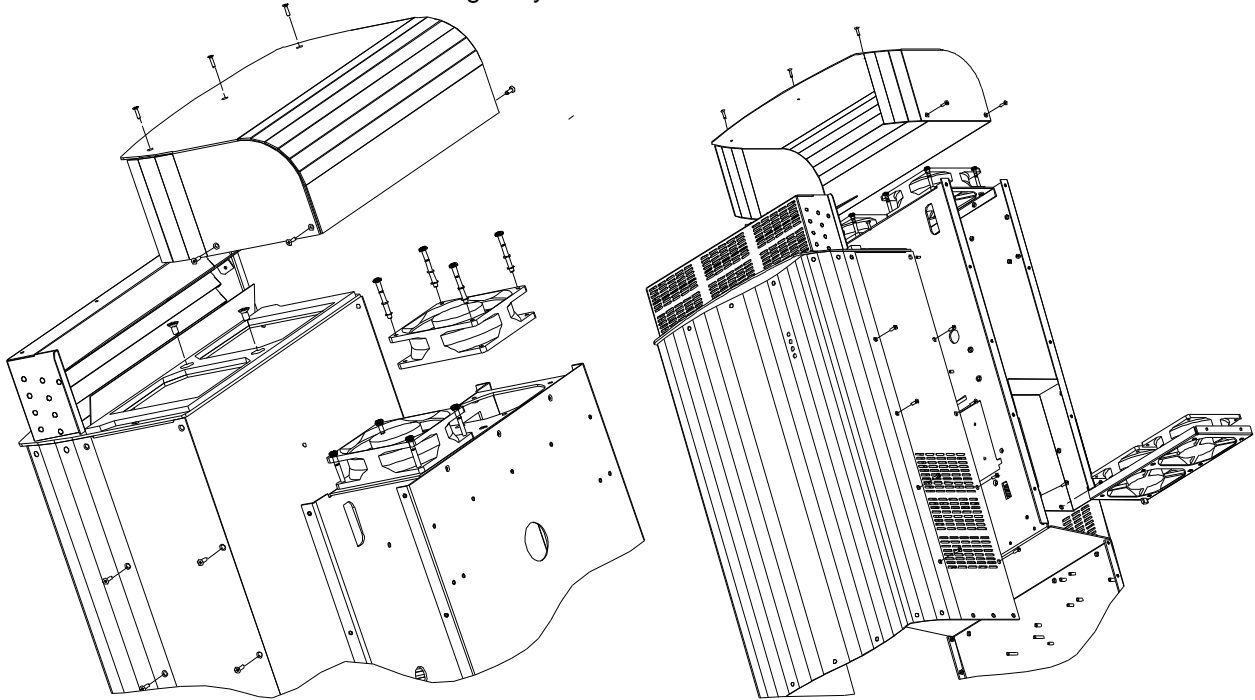


Figure 20: Top cover removal and fan replacement

Remove Front and Hood Cover

1. Remove the hood cover.
 - a. Three screws on the top of the hood (6-32 x 1/2")
 - b. Two screws on each side of the hood (6-32 x 1/2")
2. Remove the top cover.
 - a. Two screws in the center between the two AC fans
 - b. Eight screws on each side of the cover (6-32 x 1/2")
 - c. Four screws under top cover lip (6-32 x 1/2" not shown)
 - d. Open the cover by pulling the bottom out 3 – 5 inches, then lifting the cover over the two top fans. Make sure to not damage the left or right side gaskets and the two fans.

Top AC Fan Removal

1. Unplug the power connector on the side of each fan (not shown)
2. Remove four mounting screws for each fan.
3. Replace fans as needed, reversing steps 1. – 2.

Bottom DC Fan Removal

1. Remove the power connector from the fan tray assembly (one connector for both fans). It is attached to the end of a red and black twisted wire that comes through a hole on the left side of the assembly. Carefully pinch the lever on the connector to unlock it from the mating connector on the fan tray.
2. Remove two screws on each side of the fan tray assembly (right side, Figure 20)
3. Lower fan tray assembly and remove
4. Replace fan tray, and connect by reversing steps 1. – 3.

Replace Front and Hood Cover

1. Reverse steps in **Remove Front and Hood Cover** section.

APPENDIX

TORQUE SPECIFICATION

No additional terminals or lugs are required to connect the AC or DC wiring to the M5. Tighten internal terminal bolts to the torques listed below. **DO NOT OVERTIGHTEN.**

Terminal	Maximum Wire Size	Torque
Grid - Hot	4 AWG	45 in-lbs (5.1 Nm)
Grid - Neutral	4 AWG	35 in-lbs (4.0 Nm)
Load - Hot	4 AWG	45 in-lbs (5.1 Nm)
Load - Neutral	4 AWG	35 in-lbs (4.0 Nm)
Ground	6 AWG	45 in-lbs (5.1 Nm)
PV - Positive	4 AWG	45 in-lbs (5.1 Nm)
PV - Negative	4 AWG	45 in-lbs (5.1 Nm)
Battery Positive	4/0	120 in-lbs (13.8 Nm)
Battery Negative	4/0	120 in-lbs (13.8 Nm)
PV GND	1/0	50 in-lbs (5.7 Nm)
GND ROD	1/0	50 in-lbs (5.7 Nm)

Table 10: Torque Specification

GLOSSARY

AGM - Absorbed Glass Mat, battery type

CB – Circuit Breaker

CEC – California Energy Commission

EMI – Electro Magnetic Interference

GFI – Ground Fault Interrupt

PCS – Power Conversion System

PV – Photovoltaic, Solar Electric Cells

SOC - State of Charge – percentage of battery charge

SP or Setpoint – internal software memory locations that hold important operating variables

VRLA – Valve Regulated Lead Acid, battery type



- Ground

LOAD CALCULATION WORKSHEET

Battery Sizing Worksheet							
Load (Circuit)	Continuous Amps	Continuous Run Watts	Surge Amps	Surge Watts	Estimated Run Hours	Wh's	kWh's
A	B	C	D	E	F	G	H
TEXT	Value	B x 120 (V)	Value	D x 120 (V)	Value	C x F	G / 1000
Misc	0.63	75			0.5	37.5	0.04
Inverter Tare Loss	0.15	18			6	108	0.11
Total:	sum of column B	sum of column C					
Backup Loads in kW/h						sum of column H	I
Power Electronic Efficiency Factor						0.90	J
Backup Loads in kW/h						I / J	K
Desired days of autonomy						Value	L
Load battery must support in kW/h						K x L	M
System Voltage						48.00	N
Load battery must support in Amp/h						(1000 x M) / N	O
Allowable battery DOD(depth of discharge)						60%	P
Battery charge/discharge efficiency						80%	Q
Battery size to support load in Amp/h						O / P / Q	R

Table 11: Battery Sizing Worksheet Calculation Examples

Battery Sizing Worksheet							
Load (Circuit)	Continuous Amps	Continuous Run Watts	Surge Amps	Surge Watts	Estimated Run Hours	Wh's	kWh's
Misc	0.63	75			0.5	37.5	0.04
Inverter Tare Loss	0.15	18			6	108	0.11
Total:							
						Backup Loads in kW/h	
						Power Electronic Efficiency Factor	0.90
						Backup Loads in kW/h	
						Desired days of autonomy	
						Load battery must support in kW/h	
						System Voltage	48.00
						Load battery must support in Amp/h	
						Allowable battery DOD(depth of discharge)	60%
						Battery charge/discharge efficiency	80%
						Battery size to support load in Amp/h	

Table 12: Battery Sizing Worksheet blank