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A123 Systems ALM 12V7 User's Guide

End User Documentation

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Revision Control

This section describes the changes made to each revision of this document.

Revision	Change
Rev 06	In Chapter 5, corrected mislabeled diagram and discharge current value.
Rev 05	Updated images depicting series and parallel configurations in chapter 5. Replaced all cell name references with the cell short name (ANR26650).
Rev 04	Updated ALM 12V7 photo to correct labeling information depicted
Rev 03	Updated float voltage 20 13.8 V and added 13.8 V minimum recharge voltage
Rev 02	Updated Design Release
Rev 01	Initial Design Release

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Table of Contents

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Chapter 1

About this Document

This chapter includes the following sections:

Overview

A123’s ALM 12V7 Lithium Ion battery module (UL model number Series PSL000001) is designed as a drop-in replacement for the 12 volt 7 Ah lead-acid batteries that typically serve as a standby power source in many high-availability and service-critical applications. The Series PSL000001 is recognized as a standalone battery only. To ensure a seamless replacement process, the ALM 12V7 features identical dimensions to 12V7 lead-acid batteries, uses the same 0.250” faston terminal tabs and works with typical lead-acid chargers.

The ALM 12V7 battery pack consists of eight ANR26650 cells in a 4S2P configuration with integrated cell protection and balancing circuitry. The ALM 12V7 includes a user-replaceable 30 A fuse as well as a non-replaceable 120 A fuse. Furthermore, an integrated microprocessor protects the battery pack from over-voltage, under-voltage and over-temperature conditions.

Purpose of this document

This manual provides detailed specifications for the ALM 12V7 as well as guidance on the safe and effective operation and configuration of multiple ALM 12V7 modules for use as building blocks in various applications. This manual provides information to safely connect multiple modules up to a maximum configuration of four modules in series and 10 modules in parallel (4S10P), as well as how to charge and discharge the batteries.

How this document is organized

This document is divided into the following parts:

- Regulations

  Discusses the safety, EMC, environmental and transportation regulations applicable to the ALM 12V7 battery module.

- A123 Nanophosphate® Technology inside the ALM 12V7

  Discusses the Lithium Ion technology inside the ALM 12V7 and its advantages compared to traditional lead-acid batteries.

- Applications

  Discusses various applications for the ALM 12V7.

- Configuration and Operation

  Discusses how to safely connect multiple ALM 12V7s up to a maximum configuration of four modules in series and 10 in parallel. This chapter also provides details for charging and discharging multiple ALM 12V7s.

- Troubleshooting

  Discusses behavior unique to the ALM 12V7 compared to traditional lead-acid batteries, and how to operate the battery in those circumstances.

- Glossary

  Glossary of terms.

Chapter 2

Regulations

The chapter discusses the safety, EMC, environmental and transportation regulations applicable to the ALM 12V7 battery module.

The transportation material presented here is not all-inclusive of the regulations required to ship a product, but is meant to inform you of the complexity involved in doing so. Anyone involved in the integration of Lithium Ion battery packs into a host product must review the regulations cited here to meet compliance standards with industry regulations.

This chapter includes the following sections:

Safety Regulations

- UL subject 1973 - Batteries for use in Light Electric Rail (LER) Applications and Stationary Applications.
- CE — EU consumer safety, health and environmental regulations. Signifies conformity with EMC directive (2004/108/EC)
- FCC Part 15 Subpart B Class A — standards regulating unintentional emissions of radio frequencies from a digital device.
- UN 38.3 — requirements for safe transportation of Lithium Ion batteries.

Transporting Lithium Ion Batteries

This section discusses the regulations governing the transportation of Lithium Ion cells and batteries both within the United States and internationally. You should read and understand all relevant regulations discussed in this section before shipping ALM 12V7 modules. This section includes the following sections:

NOTE

The regulations discussed in this manual apply to Lithium Ion cells and batteries. Once the ALM 12V7 is integrated into a host product, the host product may be subject to additional transportation regulations that require additional certification testing. Since A123 Systems can't anticipate every possible configuration and application of the ALM 12V7, you must verify that your ALM 12V7-powered host product is compliant with all applicable regulations. Refer to Table 2-3 on page 2-4 for a list of UN numbers to reference to find applicable regulations for your application.

Overview

Rechargeable lithium ion (including lithium ion polymer) cells and batteries are considered dangerous goods. The regulations that govern their transport are based on the UN Recommendations on the Transport of Dangerous Goods Model Regulations. Transport of dangerous goods is regulated internationally by

- International Civil Aviation Organization (ICAO) Technical Instructions, and
- International Air Transport Association (IATA) Dangerous Goods Regulations and
- International Maritime Dangerous Goods (IMDG) Code.

In the United States, transportation is regulated by Title (part) 49 of the Code of Federal Regulations or CFR's. Title 49 CFR Sections 100-185 of the U.S. Hazardous Materials Regulations (HMR) contains the requirements for transporting cells and batteries. Refer to the following sections within 49 CFR for specific information.

- Section 173.185 - Shipping requirements for Lithium cells and batteries
- Section 172.102 - Special Provisions
- Sections 172.101, 178 - Further information and specifications on packaging

The Office of Hazardous Materials Safety Administration (PHMSA), which is within the U.S. Department of Transportation (DOT), is responsible for drafting and writing the U.S. regulations that govern the transportation of hazardous materials (also known as dangerous goods) by air, rail, highway and water.

Regulations by Cell/Battery Size

Lithium ion batteries and cells are considered Class 9 which is one of nine classes of hazardous materials or dangerous goods defined in the UN, US and other regulations. As a class 9 material, cells and batteries must meet UN testing and packaging requirements as well as shipping regulations. The chart below provides a synopsis of the regulations now in effect for both the US and Internationally.

Table 2-1 Shipping and Packaging Regulations by Cell/Battery Size

Regulation	Lithium Ion Cell/Battery	Shipping Classification/Testing	Special Packaging/ Markings	Battery Size
US	1.5 grams / 8.0 grams Max. ELC(1)	Excepted / T1-T8(2)	Yes(5)	Small
	5.0 grams / 25 grams Max. ELC(1)	Class 9 / T1-T8(3)	Yes(6)	Medium
	>5.0 grams / >25 grams Max. ELC(1)	Class 9 / T1-T8(4)	Yes(6)	Large (more than)
International	20 Wh / 100 Wh Max. Watt_hours	Excepted / T1-T8 (7)	Yes	
	>20 Wh / 100 Wh	Class 9 / T1-T8 (4)	Yes (8)	

(1)Equivalent Lithium Content (ELC) in grams = rated capacity (Ah) X 0.3
(2)All cells and batteries must pass UN T1-T8 Tests.
(3)Cells and batteries must pass UN T1-T8 Tests and must be shipped as Class 9 hazardous materials *unless transported by motor vehicle or rail car*.
(4)Must pass UN T1-T8 Tests and be shipped as a Class 9 hazardous material.
(5)Packages containing more than 12 batteries or 24 cells must meet certain packaging, marking, and shipping paper requirements.
(6)Requires Class 9 markings, label, specification packaging, and shipping papers *unless transported by motor vehicle or rail car*.

(7)Cells and batteries must pass UN T1-T8 Tests. Cells and batteries that pass UN Tests are excepted from regulation. NOTE: The IMDG Code contains a grandfather clause for testing "small" cells and batteries until December 31, 2013.
(8)Requires Class 9 markings, label, specification packaging, and shipping papers.

Following UN and DOT Regulations

Failure to comply with UN and DOT regulations while transporting Class 9 Hazardous Materials (Dangerous Goods) may result in substantial civil and criminal penalties. Table 2-2 outlines a process that you can follow to help ensure that cells and batteries are shipped per the required regulations.

Table 2-2 Suggested Steps for Regulatory Compliance

Step Number	Process step	Comments
1	Insure use of UN certified packaging if applicable.	All dangerous goods must be shipped in UN certified packaging.
2	Packaging of cell or Battery	Pack per regulations
3	Package labeling[a]	Insure that packaging container has all required labeling
4	Fill out proper shipping documentation	Shipper's declaration for dangerous goods, airway bill, etc.
5	Ship package	Ensure that shipping company can ship DG

a. Refer to Table 2-3 for proper shipping names and UN numbers for Lithium ion batteries

Table 2-3 Proper Shipping Names and UN numbers

Proper Shipping Name	UN Number
Lithium ion batteries	UN 3480
Lithium ion batteries packed with equipment	UN 3481
Lithium ion batteries contained in equipment	UN 3481

Environmental Regulations

The battery pack is compliant with the following environmental regulations.

- EU Directive 2002/95/EC for Restriction of Hazardous Substances (RoHS)
- EU Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators
- EU Directive 1907/2006 on the Registration Evaluation Authorization and Restriction of Chemicals (REACH)
- Management Methods for Controlling Pollution Caused by Electronic Information Products Regulation (China RoHS)

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Chapter 3

A123 Nanophosphate® Technology inside the ALM 12V7

The ALM 12V7 consists of eight ANR26650 cells using patented Nanophosphate technology, and is intended as a replacement in the high-end market for the common lead-acid battery.

This chapter details the advantages of the technology behind the ALM 12V7 in the following sections.

Nanophosphate® Technology

Based on new, highly active nanoscale material initially developed at MIT, A123's low impedance Nanophosphate electrode technology provides significant competitive advantages over alternative high-power technologies. A123's cell and electrode designs are optimized for low cost/watt and cost/watt-hour performance. They maintain a higher voltage than other long-life systems, enabling lower pack cost. This long life leads to reduced lifestyle and system costs, resulting in greater overall value.

- Nanophosphate is a positive electrode material of remarkable rate capability, which is critical to high-power systems. Our high-power products are able to pulse at discharge rates as high as 100C and deliver unmatched power by weight or volume. With their low impedance and thermally conductive design, you can continuously discharge A123's cells to 100% depth of discharge at 35C rate, a marked improvement over other rechargeable battery alternatives.
- A123's Nanophosphate technology is highly abuse-tolerant while meeting the most demanding customer requirements of power, energy, operating temperature range, cycle life and calendar life.
- A123's Nanophosphate technology delivers exceptional calendar and cycle life. At low rates these cells can deliver thousands and thousands of cycles at 100% Depth-of-Discharge, a feat unmatched by

commercial Lithium Ion cells. Even when cycled at 10C discharge rates, these cells deliver in excess of 1,000 full depth-of-discharge cycles.

Safety

A123's Nanophosphate cells are more abuse tolerant than competing cells of different Lithium Ion chemistries. For an illustration of the inherent safety of A123's Nanophosphate cells using thermal ramp testing by an independent lab, refer to Figure 3-1 and Figure 3-2.

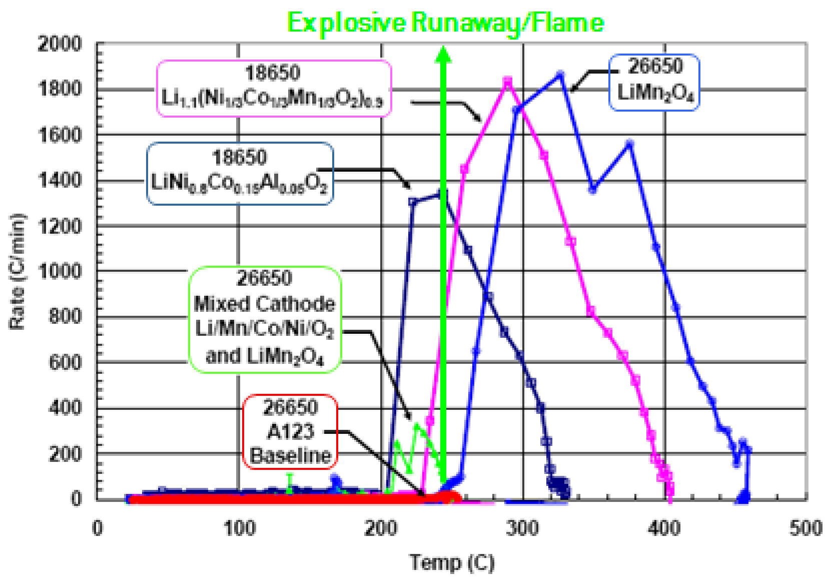

Figure 3-1 Heating Rate Profile Compared to Common Cathode Compositions in Competing Cells

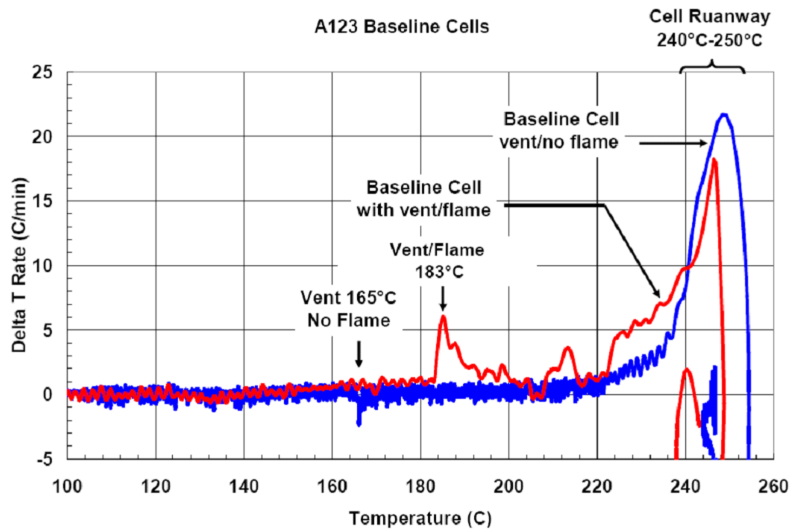

Figure 4. Heating rate profiles for two A123 baseline cells, one cell with burning vent gases.

Figure 3-2 Heating Rate Profiles for two A123 Baseline Cells

Figure 3-1 shows A123's cells have a higher onset temperature for thermal runaway than other Lithium Ion chemistries. Figure 3-2 shows a closer view of the data for A123's cells, illustrating how the maximum heat-rate for the Nanophosphate cells (20 °C/min) is only a fraction of the heat-rate for other Lithium Ion chemistries (almost 2000 °C/min).

Life

A123 Systems cells offer long cycle and calendar life, with minimal impedance growth over the life of the cells. Figure 3-3 illustrates the cells' ability to retain a high percentage of their first discharge capacity over thousands of low rate cycles. In addition, these cells also offer extended calendar life, even at elevated temperatures.

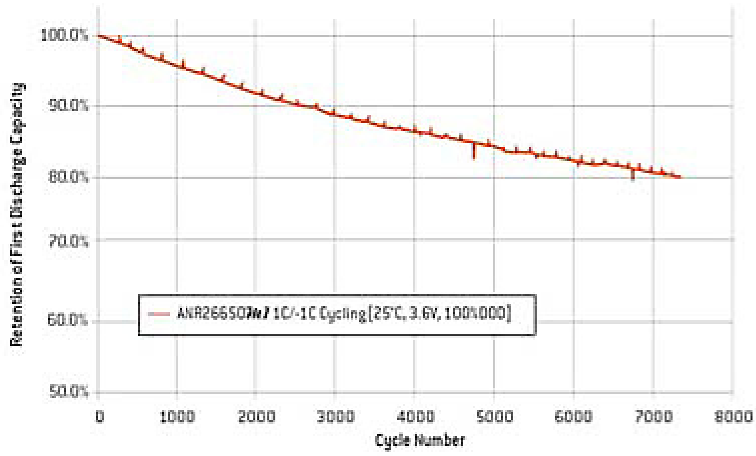

Figure 3-3 Thousands of Low Rate Cycles

The ALM 12V7

Figure 3-4 ALM 12V7 Module

The ALM 12V7 battery module consists of eight ANR26650 cells arranged in a four in series and two in parallel configuration (4S2P) with integrated cell protection and balancing circuitry. A123 Systems designed the ALM 12V7 as a drop-in replacement for the 12 volt 7 Ah lead-acid batteries that typically serve as a standby power source in many high-availability and service-critical applications. To ensure a seamless replacement process, the ALM 12V7 features identical dimensions to 12V7 lead-acid batteries, uses the same 0.250” faston terminal tabs and works with the same chargers. In addition, the ALM 12V7 leverages Nanophosphate technology for the following key advantages over lead-acid alternatives:

- Longer life in applications requiring repeated discharge and recharge cycles.
- Higher power capability, both during discharge and subsequent recharge.
- More energy during applications requiring four hours of runtime or less.
- Greater degree of safety due to the fact that the batteries are continually monitored by an integral microprocessor.
- Easier configuration of multiple modules - no external Battery Management System (BMS) required.

The advantages of Nanophosphate technology result in a powerful, safe battery pack that operates with a high rate of reliability throughout a longer useful life, reducing the overall cost of ownership over the battery pack’s life.

Functional Differences with Lead-Acid 12V7 Batteries

The integrated cell protection and balancing circuitry responsible for the durability and additional safety features of the ALM 12V7 module also cause functional behavior that differs from typical lead-acid batteries. The two biggest differences are:

- No voltage at the terminals does not necessarily indicate a bad battery.

  With a lead-acid battery, finding no voltage at the terminals often indicates the battery has reached the end of its life. With the ALM 12V7 module, no voltage at the terminals typically means the cell protection circuitry has interrupted current to protect the battery module. Simply connect the module to a charger to restore voltage to the terminals.

- State of Charge (SOC) with an ALM 12V7 appears constant, then drops suddenly.

  Voltage for an ALM 12V7 remains relatively constant throughout the depth-of-discharge, while voltage for a lead-acid battery decreases at a linear rate. Therefore, determining an ALM 12V7’s SOC using the same methods to determine a lead-acid battery’s SOC creates the impression that the ALM 12V7 has a full charge then loses power abruptly. A steady voltage across the depth-of-discharge is normal behavior for the ALM 12V7. Refer to Discharge Performance on page 3-7 for more details.

ALM 12V7 Specifications

Table 3-1 ALM 12V7 Specifications

Specification	
Maximum Discharge Current	30 A
Maximum Pulse Discharge Current	54 A for <200 ms (At 25 °C)
Ambient Operating Temperature Range	-20 °C to +58 °C
Maximum Operating Altitude	10,000 ft[a]
Operating Relative Humidity (non-condensing)	20% to 80%
Nominal Operational Voltage	13.2 V
Minimum Voltage	2 V @ any cell
Maximum Voltage	4.0 V @ any cell
Nominal Capacity	4.6 Ah
Standard Charge Voltage	14.4 V
Minimum Charge Voltage	13.8 V
Maximum Charge Voltage	14.4 V - 15.0 V
Float Charge Voltage	13.8 V
Standard Charge Current at 25 °C	3 A
Maximum Continuous Charge Current at 25 °C	10 A

a. The maximum operating temperature decreases by a factor of 1.1 °C per 1,000 ft of elevation above 7,500 ft

Mechanical Dimensions

Figure 3-5 details the mechanical dimensions of the ALM 12V7 module.

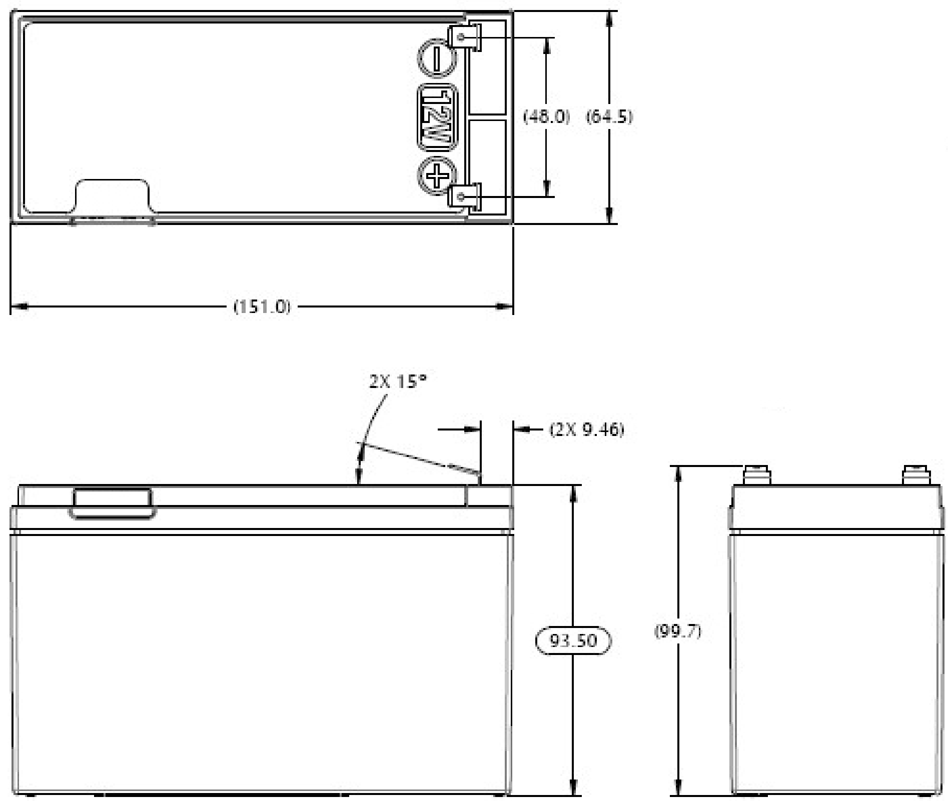

Figure 3-5 ALM 12V7 Mechanical Dimensions

The ALM 12V7 consists of the following components:

1. 12V7
2. Fuse plug
3. 30 A 58 V ATO®-style blade fuse

Discharge Performance

As shown in the typical room temperature discharge curve in Figure 3-6, the ALM 12V7's voltage remains virtually flat during the discharges and the capacity doesn't change significantly, no matter how fast the discharge is.

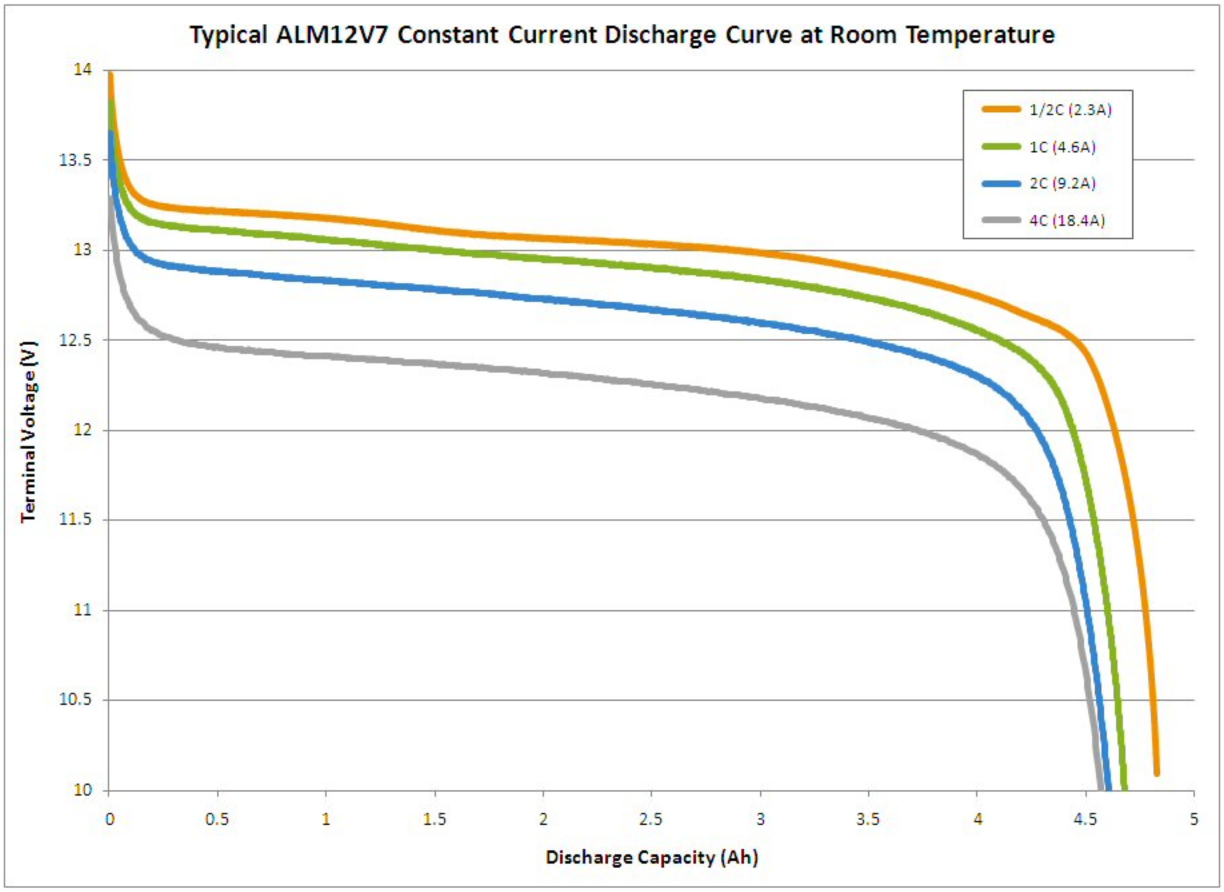

Figure 3-6 Room Temperature Discharge

Cell resistance changes with cell temperature. The warmer the ambient and/or cell temperature, the lower the resistance. Conversely, lower temperatures negatively impact the cell's ability to hold voltage under a load. Figure 3-7 and Figure 3-8 illustrate the impact ambient temperature has on the ALM 12V7's ability to hold voltage.

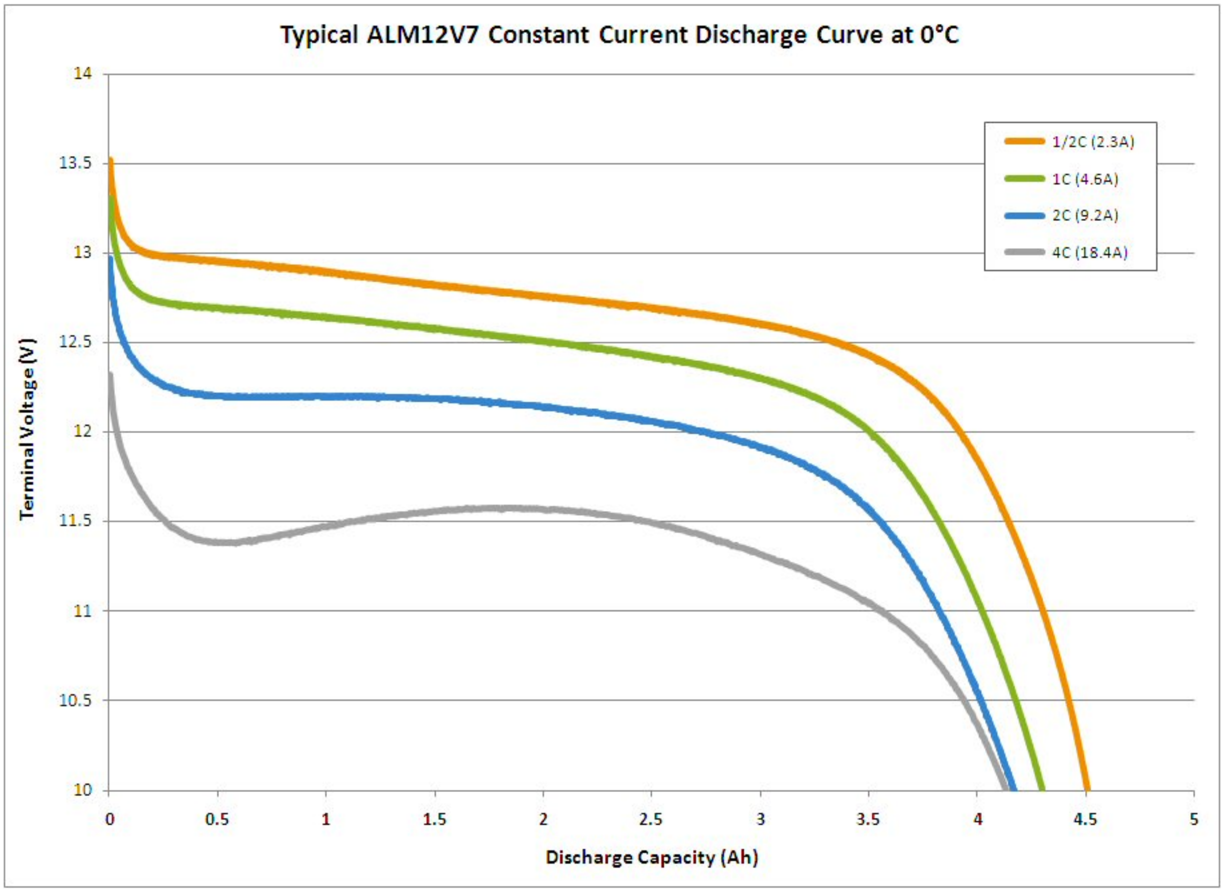

Figure 3-7 Discharge Curve at 0 °C

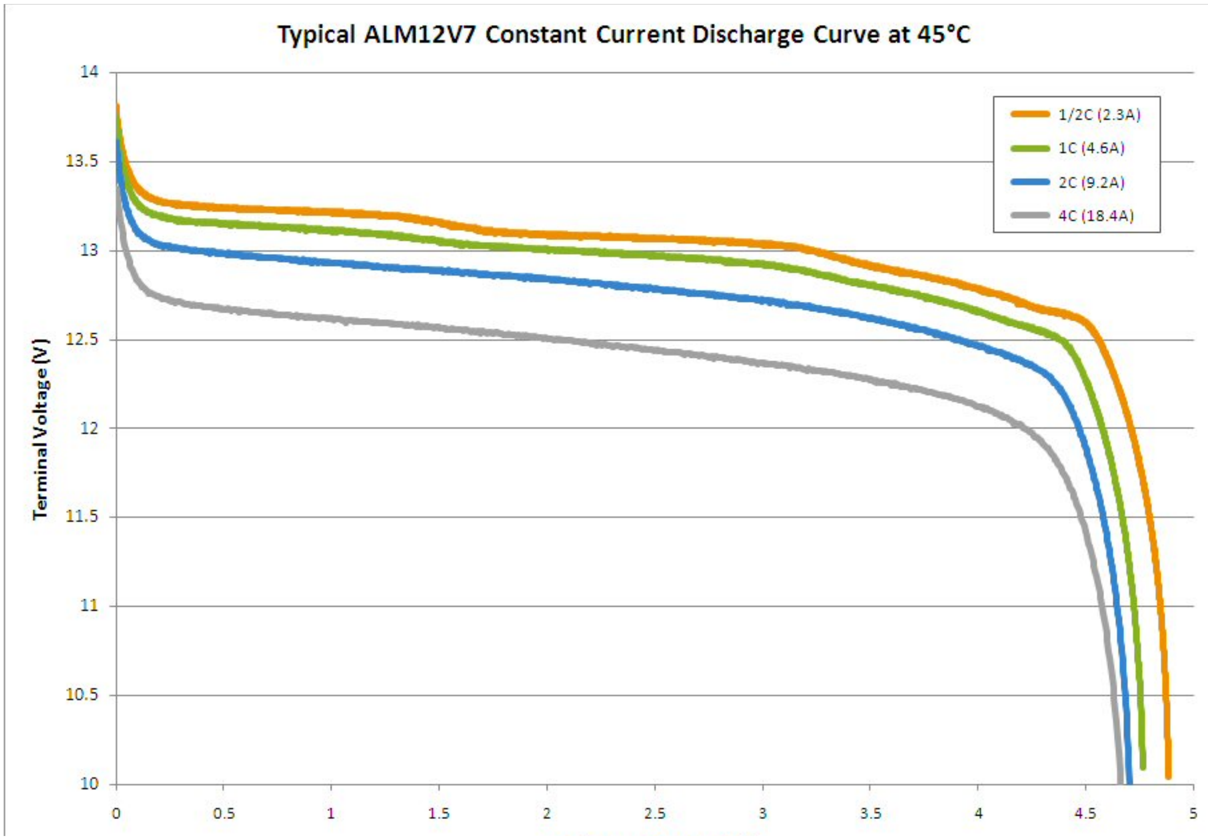

Figure 3-8 Discharge Curve at 45°C

Shelf Life

All ALM 12V7 battery packs ship from the factory at 50% SOC and can retain at least 10% SOC after 1 year of storage at temperatures not exceeding 25 °C. Note that higher storage temperatures reduce impedance and accelerate the rate of self-discharge.

Following this 1 year period the SOC falls below 10%, and the terminals become disconnected (open). The ALM 12V7 can remain in this state for a minimum of 2 more years. To reactivate the terminals, the battery must be recharged.

Cycle Life

The ALM 12V7's cycle life is determined by the 26650 cells inside it, as well as ambient temperature and charge/discharge rates. Under optimal conditions, the cells can deliver thousands of cycles at 100% Depth of Discharge (DOD). Even at 10C discharge rates, the cells can deliver in excess of 1,000 full DOD cycles. Refer to Cycle Life on page 3-10 for more details on cycle life.

Terminal Specifications

The ALM 12V7 module utilizes the same 0.250″ by 0.032″ Faston terminals found on 12V7 lead-acid batteries, and is compatible with any appropriately-sized receptacle.

Safety

A123's Nanophosphate cells are more abuse tolerant than other Lithium Ion cells; however, correct handling of the ALM 12V7 module is still important to ensure safe operation.

CAUTION

Failure to follow the following safety instructions may result in personal injuries or damage to the equipment!

- Do not expose the ALM 12V7 to heat in excess of 58 °C during operation, 60 °C in storage; do not incinerate or expose to open flames.
- Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.
- Do not charge or discharge the ALM 12V7 outside of its stated operating temperature range. Reduce charging limits for lower operating temperatures.
- Do not connect more than four modules in series. Connecting more than four modules in series exceeds the voltage limit of the integrated protection circuitry, leaving the module without critical safety features such as over-voltage and over-temperature protection.

Storage

A123 Systems ALM 12V7 can be stored in an environment with temperatures between -40 °C and +60 °C and between 10% and 90% relative humidity, non-condensing. In addition, you can store the ALM 12V7 at altitudes up to 25,000ft. For long storage periods at 25 °C, charge the battery every three years. For temperatures above 40 °C, charge the battery annually. Do not store the ALM 12V7 at temperatures above 60 °C.

Disposal

Do not incinerate or dispose of the battery. Return end-of-life or defective batteries to your nearest recycling center as per the appropriate local regulations.

Chapter 4

Applications

This chapter discusses competitive advantages and potential applications of the ALM 12V7 battery module in the following sections:

Competitive Advantages

A123's ALM 12V7 is a battery module offering tremendous value in many applications. The battery is designed to be a drop in replacement for standard lead-acid 12V7 batteries, and provide the following advantages.

Power

- Higher power capability during discharge and subsequent recharge.
- Greater efficiency due to less energy lost during high rate applications and less power required to keep the module fully charged.
- Smaller and lighter systems due to higher power and energy density.

Safety

- High degree of safety due to inherently stable cell chemistry and integrated protection circuitry.
- Limited environmental impact – lead free and no hazardous material content.

Life

- Longer useful life due to higher usable energy.
- Longer lifetime in float applications.
- Longer cycle life.
- Longer shelf, storage life due to lower self discharge.

Applications

Applications that could benefit from these competitive advantages range from sophisticated computer backup equipment and security systems to children's toys. The ALM 12V7 is particularly well suited for applications in the following categories:

- Backup Power
- Light-weight/Long-Life Solutions

While the ALM 12V7 features a sturdy case it is not designed for outdoor use or other environmentally challenging applications.

Backup Power

The occurrence of power outages, brownouts and surges are well known in business and residential environments. These power events can potentially cause havoc in any environment. Computer data loss and equipment damage are commonly avoided by installing Uninterruptible Power Supplies (UPS) that rely on lead-acid batteries for power. Replacing the standard lead-acid batteries with A123's ALM 12V7s helps users immediately benefit from A123's technology:

- Longer useful life helps avoid costly battery replacements where lead-acid batteries fail due to high temperatures or frequent UPS cycling
- Lighter weight solution helps with physical installation of UPS
- Lead free design supports environmentally friendly needs

A123 has helped many customers realize the simplicity of installing the ALM 12V7 into backup power systems to replace lead-acid solutions. Installation possibilities include:

- Home cable backup system
- Home security systems
- Single computer backup UPS
- High availability IT backup UPS
- Telecom cell tower backup UPS
- Power supplies for Computers on Wheels

Light-weight/Long-Life Solutions

Many applications today are using batteries for supplemental power. These applications typically require high-energy density and cycle the batteries frequently. Examples of these applications are:

- Electric bicycles
- Marine applications such as sonar fish finders
- Recreational camping applications such as large flashlights

- Various portable devices such as lighting

The applications listed above all look for characteristics which are consistent with the A123 value propositions. Lightweight, long cycle life and good energy density enable the A123 ALM products to provide superior performance in these applications. Comparison to lead-acid batteries quickly demonstrates the superior performance of A123 technology:

- A123 ALM batteries are less than half the weight of their lead-acid equivalents
- A123 batteries deliver more energy than lead-acid equivalent at high-rate discharges (short run time)
- A123 batteries deliver up to ten times more cycles than their lead-acid equivalents

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Chapter 5

Configuration and Operation

This chapter discusses configuring, charging and discharging the ALM 12V7 in the following sections.

NOTE

The series PSL000001 is UL Recognized as a standalone battery only and has not been evaluated for series and/or parallel configuration.

Terminology

This chapter discusses configuring and operating ALM 12V7 modules using the following terminology:

Table 5-1 Configuration Terminology

Terminology	Definition
Cell	Refers to an individual ANR26650 cell that is the basis for the ALM 12V7 battery module. Each ALM 12V7 contains eight ANR26650 cells combined in a 4S2P configuration.
Module or Battery Module	The ALM 12V7 battery module.
Series String	A string of cells arranged in series to achieve higher voltage.
Parallel String	A string of cells arranged in parallel to achieve higher capacity.

Terminology	Definition
Battery System	Battery modules connected in series and/or in parallel to achieve higher voltage and/or capacity.

Configuration Options

You can arrange A123's ALM 12V7 battery modules in series and/or in parallel to achieve higher operating voltages and capacities for your intended application, with a maximum configuration of 4S10P. An external BMS or other electronics are not required to configure multiple ALM 12V7s.

CAUTION

Do not connect more than four ALM 12V7 modules in series, as the total voltage exceeds the limits of the integrated protection circuitry. Compromising the integrated protection circuitry increases the risk of an over-voltage or over-temperature event that may damage the ALM 12V7 and the host equipment.

CAUTION

Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.

Connect the ALM 12V7 modules using 8 AWG wire and any receptacle that fits a 0.250" by 0.032" Faston terminal tab. The 8 AWG wire is necessary to carry the maximum current allowed by the user-replaceable 30 A fuse in each module. Refer to Figure 5-1 for an illustration of the components used to connect multiple ALM 12V7s.

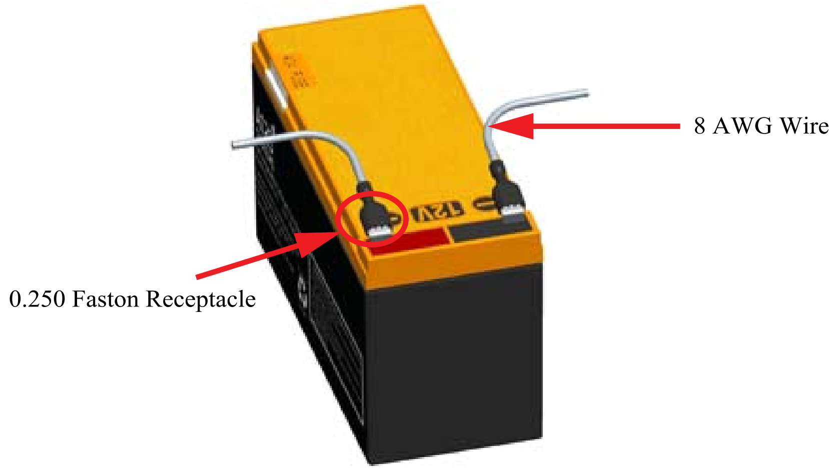


Figure 5-1 Components Used to Connect Multiple ALM 12V7s

NOTE

Do not connect ALM 12V7 modules to battery modules of other chemistries or ALM modules of different capacities. For example, do not connect an ALM 12V7 to a lead-acid 12V7 or an ALM12V35.

Series Strings

The modules can be combined together in series strings to achieve higher operating voltages by connecting the positive terminal of one module to the negative terminal of the next module. The maximum number of ALM 12V7s you can connect in a series is four. Figure 5-2 illustrates two ALM 12V7s connected in series, for a 2S1P configuration.

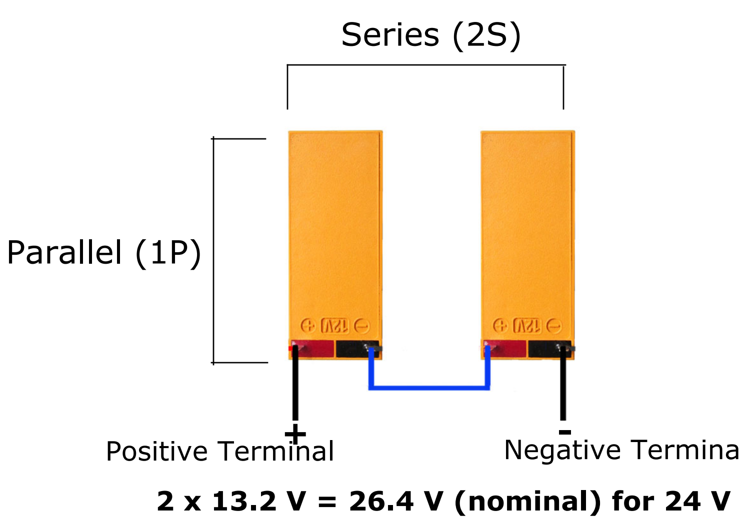


Figure 5-2 Connecting Modules in Series (2S1P Configuration)

- Two modules in series: 2 x 13.2 V = 26.4 V (nominal) for 24 V applications
- Three modules in series: 3 x 13.2 V = 39.6 V (nominal) for 36 V applications
- Four modules in series: 4 x 13.2 V = 52.8 V (nominal) for 48 V applications

Parallel Strings

You can combine modules together in parallel strings to achieve higher operating power and/or energy by connecting like-polarity terminals of adjacent modules. To combine modules in parallel strings, connect all like-polarity wires on adjacent modules to an appropriately sized terminal block for your application. Reference local electrical codes for terminal block specifications. Refer to Figure 5-3 for an example of eight ALM 12V7 modules connected together in a 4S2P configuration.

With certain restrictions, the ALM12V7 can support paralleling for added discharge current. These restrictions are described below, and depend upon accurate balancing which typically requires fairly lengthy charge periods to ensure.

If impedance, capacity, or self-discharge rates between cells vary significantly then FET failure may occur regardless of how well you adhere to these instructions. This is because the overvoltage and undervoltage protection mechanisms operate based upon individual cell voltages and unfortunately you can only monitor and respond to terminal voltages. Therefore these provisions for paralleling for added current assume that all cells the same way. Otherwise, the FETs may open unexpectedly which could lead to the failure modes previously described.

Paralleling for higher discharge currents:

1. Before wiring multiple ALM batteries together, all batteries must be individually charged to 100% SOC using a 10 A current limit. To ensure that 100% SOC is reached, a 14.4 V charge voltage should be maintained for at least 4 hours.
2. Connect batteries together in a configuration not to exceed 4s10p (4 in series, 10 in parallel).
3. The entire group of batteries should then be float charged at a 10 A current according to the number of series elements (14.4 V for 1 s, 28.8 V for 2 s, 43.2 V for 3 s, or 57.6 V for 4 s). This float should be held for at least 24 hours to allow the batteries in the system to fully balance.
4. To recharge the group, repeat the process starting at step 3. This will ensure that all cells are once again properly balanced in preparation for the next discharge.

* If operation below 23 °C is required, you should adhere to a current ramp rate of no more than 10 A per second to prevent sudden dips in pack voltage that could lead to inadvertent activation of the UVP mechanism.

Paralleling for higher charge currents:

Paralleling for higher charge currents is not supported at this time.

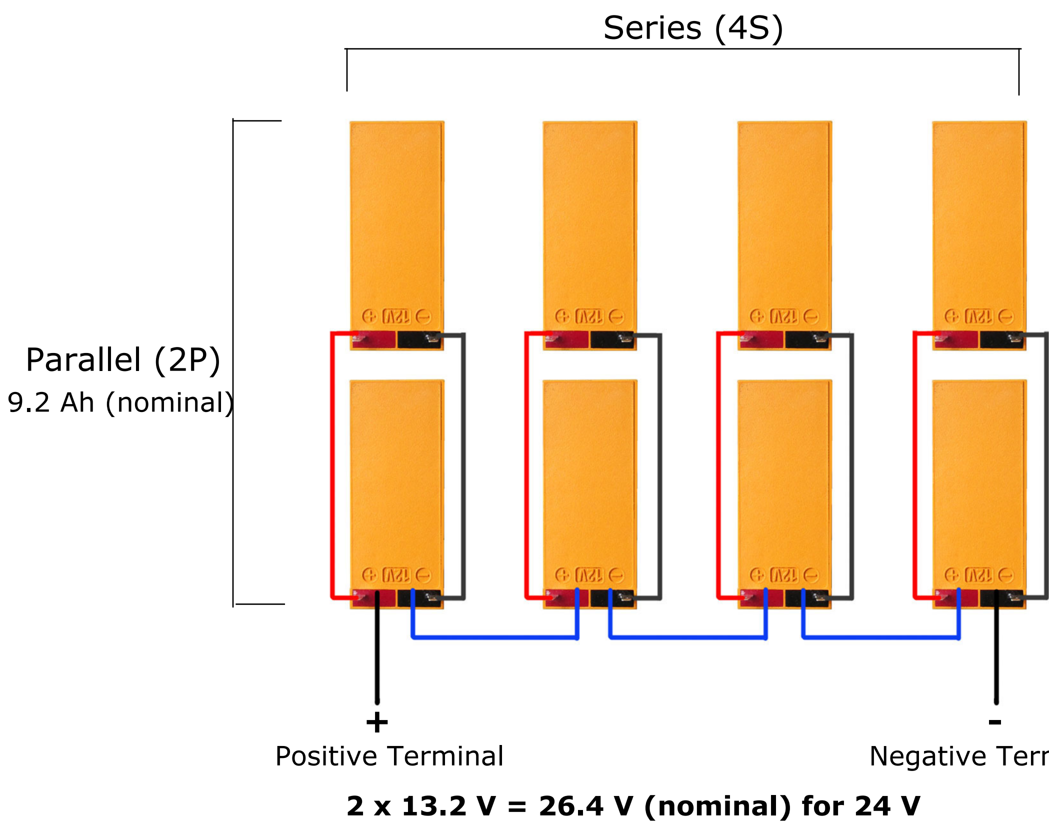
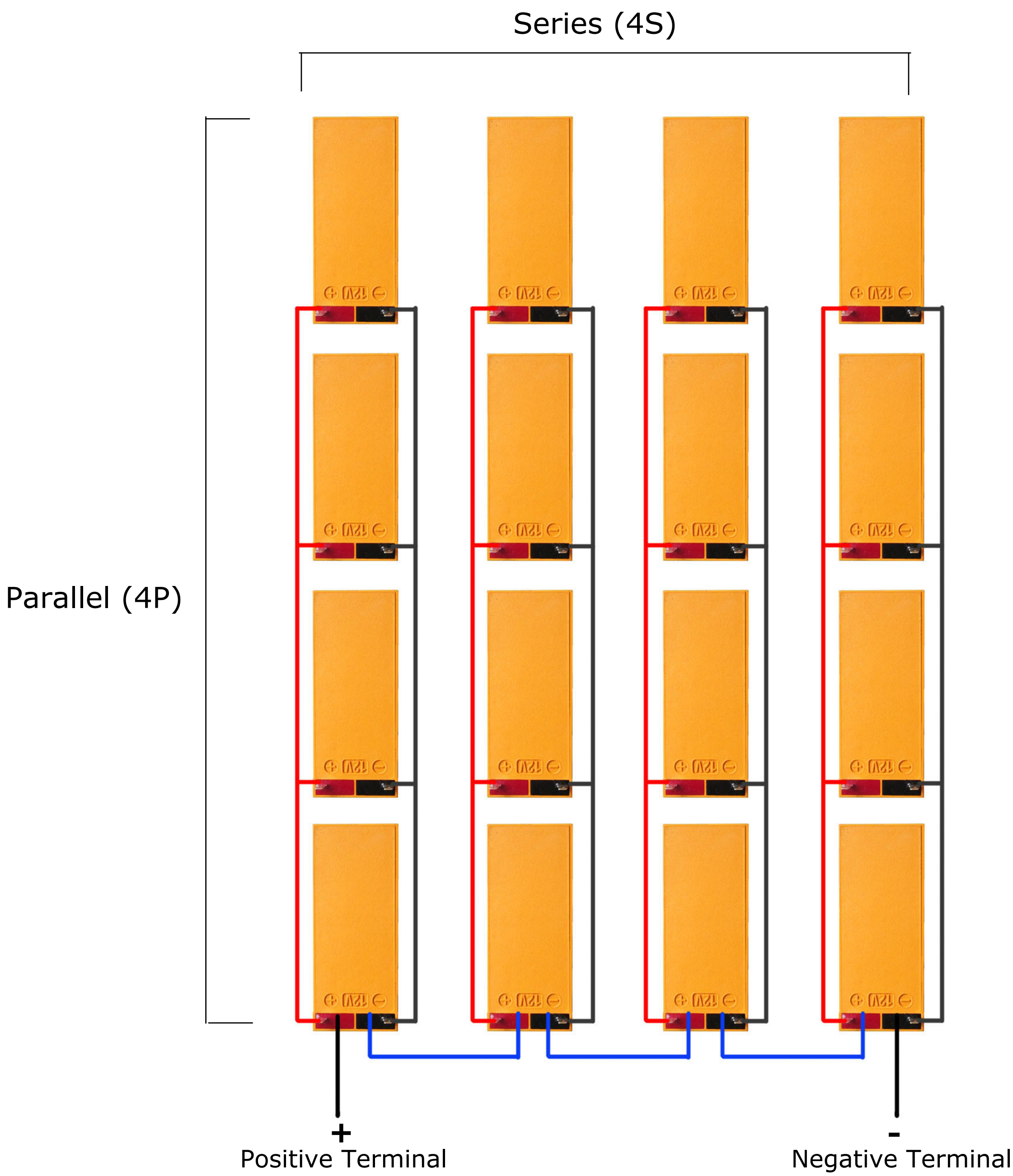


Figure 5-3 Example of a 4S2P Configuration

- Two series strings in parallel: 2 x 4.6 Ah = 9.2 Ah (nominal)
- Three series strings in parallel: 3 x 4.6 Ah = 13.8 Ah (nominal)
- Four series strings in parallel: 4 x 4.6 Ah = 18.4 Ah (nominal)

Large Configuration Example

Figure 5-4 illustrates a larger configuration of ALM 12V7 modules arranged in series and parallel. This configuration features four series strings and four parallel strings (4S4P).



4 x 13.2 V = 52.8 V (nominal) for 48 V

Figure 5-4 Example of a 4S4P Configuration

Charging Multiple Modules

This section describes how to charge and discharge ALM 12V7 modules configured in series or parallel up to a maximum configuration of 4S10P.

CAUTION

Failure to follow the following safety instructions may result in personal injuries or damage to the equipment!

- Do not connect more than four modules in series. Connecting more than four modules in series exceeds the voltage limit of the integrated protection circuitry, leaving the module without critical safety features such as over-voltage and over-temperature protection.
- Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.

Charging Modules or Battery Systems

The ALM 12V7 is compatible with any 12V7 lead-acid battery charger of 10 A or less. Chargers that automatically detect voltage at the terminals and charge accordingly may fail to wake the ALM 12V7 from a state of under-voltage protection. Constant Voltage (CV) chargers may result in an inrush of current due to the low impedance of the cells, interrupting the charge. Reset the charger and continue charging normally if the charger trips.The Total charge current for the group should be 10A.

Determine the end-of-charge voltage for the battery system by multiplying the number of modules connected in series by the maximum recommended charge voltage of a single module (14.4 V), as shown in Equation 1.

Eq. 1 (Number of modules in series) x (Recommended Maximum Charge Voltage, module) = Charge Voltage, String

To prevent damage to ALM12V7 modules connected in series from a current inrush during charging, ensure that the difference between battery system voltage and charger voltage is never greater than 10.0 V and limit the peak inrush current to 10 A. Limit the peak inrush current by minimizing charger capacitance and/or providing current limiting circuitry between the charger and battery system. To charge a single ALM12V7 module, the maximum charge voltage is 14.4 V and the maximum charge and inrush current is 10 A.

Refer to the following table for recommended charge currents and voltage.

Table 5-2 Examples for Charging

Example	Description
Example 1	If the module string has 10 modules in parallel (10P), and the recommended charge current per module is 10 A, then the charge current for this parallel string is 10 A.
Example 2	If the module string has four modules in series (4S), and the recommended charge voltage per module is 14.4 V, then the end of charge voltage for this series string is 57.6 V: (4 modules, series) x (14.4 V) = 57.6 V
Example 3	If the module string has four modules in series and 10 module strings in parallel (4S-10P), the recommended charge voltage per module is 14.4 V, and the recommended charge current per module is 10 A, then the charge current and charge voltage for the string is 100 A and 57.6 V: (4 modules, series) x (14.4 V) = 57.6 V (10 modules, parallel) 10 A

Once you reach end-of-charge voltage, apply a constant voltage hold at this voltage until the current decays to almost zero. This charges the cells to 100% state of charge (SOC). Refer to Figure 5-5 for an illustration.

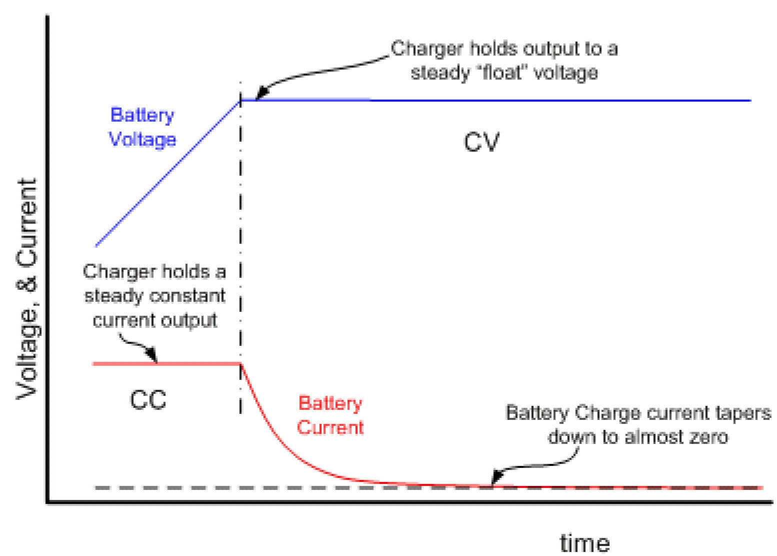


Figure 5-5 Battery Voltage and Current During Recharge

Relationship Between Charge Limits and Temperature

Due to the chemistry of Lithium Ion cells, the cells cannot accept as much charge current at lower temperatures without risking permanent loss of capacity. As the cells' temperature rises during the charging process, they can gradually accept higher currents.

To maintain optimum performance and durability of the ALM 12V7, A123 Systems recommends the following charge limits based on ambient temperature:

Table 5-3 Charge Rate by Temperature

Temperature (°C)	Charge rate
-20	C/5 (0.9 A)
-10	C/2 (2.3 A)
0	1C (4.6 A)
10	2C (9.2 A)
20	4C (10 A)[1]

1. Maximum recommended continuous charge rate is 10A

Recommended float charge method for an ALM 12V7 battery system

If you hold the voltage of the battery system at the end-of-charge voltage (after reaching 100% SOC) for prolonged periods of time, lower the end-of-charge voltage to the recommended float-charge voltage. Determine the recommended float voltage by multiplying the number of modules connected in series by the recommended float-charge voltage of a single module (13.8 V), as shown in Equation 2.

Eq. 2 (Number of modules in series) x (13.8 V) = Float Charge Voltage, battery system

Recommended fast charge method for parallel strings

Determine the fast charge current for a battery system by multiplying the number of modules connected in parallel by the maximum continuous charge current for a single module (10 A), as shown in Equation 3. You can determine the maximum recommended charge voltage by multiplying the number of modules connected in series by the recommended charge voltage of a single module (14.4 V). Charge the battery system at its maximum continuous charge current until you reach its maximum recommended charge voltage. Apply a constant voltage hold at the maximum recommended charge voltage until the total charge time reaches the fast charge time. Do not attempt a fast charge outside the recommended temperature range and stop if the battery exhibits signs of overheating, such as the battery current disappearing during a charge.

Eq. 3 (Number of modules in parallel) x (10 A) = Fast Charge Current, battery system

Discharging Battery Systems

Recommended discharge method for strings

Determine the maximum continuous discharge current for a battery system by multiplying the number of modules connected in parallel by the maximum continuous discharge current for a single module (30 A), as shown in Equation 4.

Eq. 4 (Number of modules in parallel) x (30 A) = Max Discharge Current, String

Discharge temperature limits

For optimum life, do not discharge a battery system faster than the maximum continuous discharge current or allow the batteries to self-heat beyond 110 °C. Operation above 110 °C results in accelerated performance degradation during the battery's service life. At low temperatures, the maximum available discharge current decreases due to increased internal impedance at lower temperatures. Refer to Discharge Performance on page 3-7 for more details.

Discharge Cut-Off Voltage Limits

When configuring your application stop discharges when the battery system reaches the recommended discharge cut-off voltage or any module reaches 110 °C. To determine the recommended discharge cut-off voltage for a battery system, multiply the number of modules connected in series by the recommended discharge cut-off voltage for a single module (8 V), as shown in Equation 5.

Eq. 5 (Number of modules in series) x (8 V) = Cutoff Voltage, battery system

You can discharge the battery system at greater than the maximum continuous discharge current in short pulses as long as individual modules do not exceed 110 °C. The maximum pulse discharge current for each parallel string is 54 A for less than 200 ms. During pulse discharges, the battery system voltage can safely fall below the recommended discharge cut-off voltage. Although you can safely discharge the battery system below the recommended discharge cut-off voltage, do not leave the modules below this level. Recharge the battery system to prevent permanent capacity loss and damage to the modules.

Integrated Module Protection

The ALM 12V7 includes integrated protection circuitry to prevent the battery module from exceeding its voltage limits. The module's circuitry interrupts either charging or discharging current if the battery is in danger of exceeding upper or lower voltage or temperature limits.

Over Voltage and Under Voltage

The ALM 12V7's circuitry continuously monitors cell voltage and can interrupt either charge or discharge current in the event that a cell's voltage exceeds safe operating limits.

The protection circuitry interrupts current if the voltage on any single cell rises above 4.0 V or falls below 2 V.

- If the voltage on a single cell falls below 2 V, the protection circuitry enables under-voltage protection, preventing continued discharge until you charge the battery. To avoid degradation you must recharge the battery module within 7 days. The protection circuitry disables under-voltage protection once you charge the module to the point where all cells are above 3.0 V.
- If the voltage on a single cell rises above 4.0 V, the protection circuitry enables over-voltage protection, preventing continued charging until the voltage falls. The protection circuitry disables over-voltage protection once the voltage falls below 3.6 V.

NOTE

Under-voltage protection creates an open circuit, removing voltage from the terminals. With a lead-acid battery, finding no voltage at the terminals often indicates the battery has reached the end of its life. With the ALM 12V7 module, no voltage at the terminals typically means the cell protection circuitry has interrupted current to protect the battery module. Simply connect the module to a charger to restore voltage to the terminals.

Over Temperature

The ALM 12V7's circuitry continuously monitors the battery pack's temperature and can interrupt current if the module exceeds 110 °C. Module temperature must fall below 70 °C before the protection circuitry restores current.

Balancing

Over time, the cells inside a batter pack diverge in both capacity and SOC. An advantage of the ALM 12V7 is the circuitry continuously monitors the capacity and SOC of each individual cell and balances the battery module to ensure maximum capacity. Completely balancing the battery module can take up to 48 hours.

Fusing

User-Replaceable Fuse

A 30 A 58 V, user-replaceable, ATO®-style blade fuse manufactured by LittleFuse (PN 142.6185.5302) protects the ALM 12V7 from short circuits. If required, you must replace the fuse with a LittleFuse (PN 142.6185.5302). The use of other fuses voids your warranty.

The fuse can commonly be found in automotive parts retailers as well as electronics retailers. Ensure the replacement fuse's voltage rating is appropriate for your application.

To replace the 30 A 58 V fuse:

1. Hold the fuse plug at the lower lip (indicated in Figure 5-6), then remove it and place it in a safe location. Do not lose it.

Figure 5-6 Removing the Fuse Plug

2. Remove the 30 A fuse using an ATO fuse puller, commonly available in hardware or automotive supply stores.
3. Replace the fuse with a 30 A 58 V, ATO®-style blade fuse manufactured by LittleFuse (PN 142.6185.5302).
   a. Place the top of the replacement fuse in the fuse plug. Covering the fuse with the fuse plug prior to inserting the fuse into the battery pack is the easiest way to ensure proper fitment of the fuse plug.

Figure 5-7 Fuse Fitment in the Fuse Plug

b. Insert the replacement fuse and fuse plug into the battery pack.

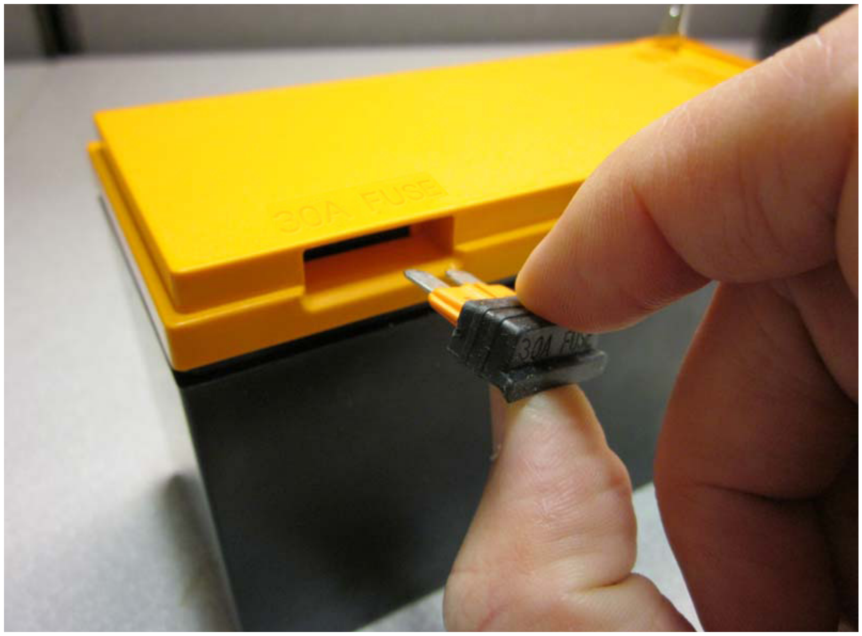


Figure 5-8 Inserting the Fuse and Fuse Plug into the ALM 12V7

c. Ensure that the fuse plug is flush with the module, as shown in Figure 5-9.

Figure 5-9 Fuse Plug Flush with the ALM 12V7 Module

4. Connect the module to a charger to wake the battery.

Secondary fuse

In addition to the user-replaceable 30 A fuse, A123 Systems integrated a secondary 120 A fuse into the battery pack’s cell connections as a safety feature in the event the user-replaceable fuse does not meet the above specifications and fails to protect the battery pack. Blowing the secondary fuse permanently disables the ALM 12V7, as it is not user-replaceable.

Chapter 6

Troubleshooting

The ALM 12V7 is an extremely reliable battery module that provides greater useful life than comparable 12V7 lead-acid batteries. Despite the high reliability of the ALM 12V7, you may encounter situations where the battery module does not operate as expected. These situations are typically the result of misuse, abuse or a non-optimal operating or storage environment. This chapter details potential issues you may encounter with the ALM 12V7 and the appropriate troubleshooting procedures.

Charger Trips using Constant Voltage

Problem

CV charger trips when charging the ALM 12V7. This is due to the low impedance of the module creating a current inrush.

Solution

Reset the charger and try again.

Terminal Voltage Absent or Low

Problem

Using a multimeter to check terminal voltage shows the terminal voltage is low.

Possible causes for this problem are:

- Blown fuse
- The voltage of a cell within the module dropped below 2 V, causing the microprocessor to enable under-voltage protection.

- The module's SOC dropped below 5% from either an extended idle period or heavy use, enabling under-voltage protection.
- The module overheated, causing the microprocessor to enable over-temperature protection.

Solution

To resolve situations where terminal voltage is absent or low:

1. Allow the battery to cool and then recheck terminal voltage.
2. Inspect the fuse and replace it if necessary. Use only fuses that meet the specifications described in Fusing on page 5-12. Ensure the replacement fuse's voltage rating is appropriate for your application.
3. Connect the battery to a charger to wake the battery and recover terminal voltage. Depending on the module's voltage and state of balance it may take up to 48 hours to completely charge and balance the module.

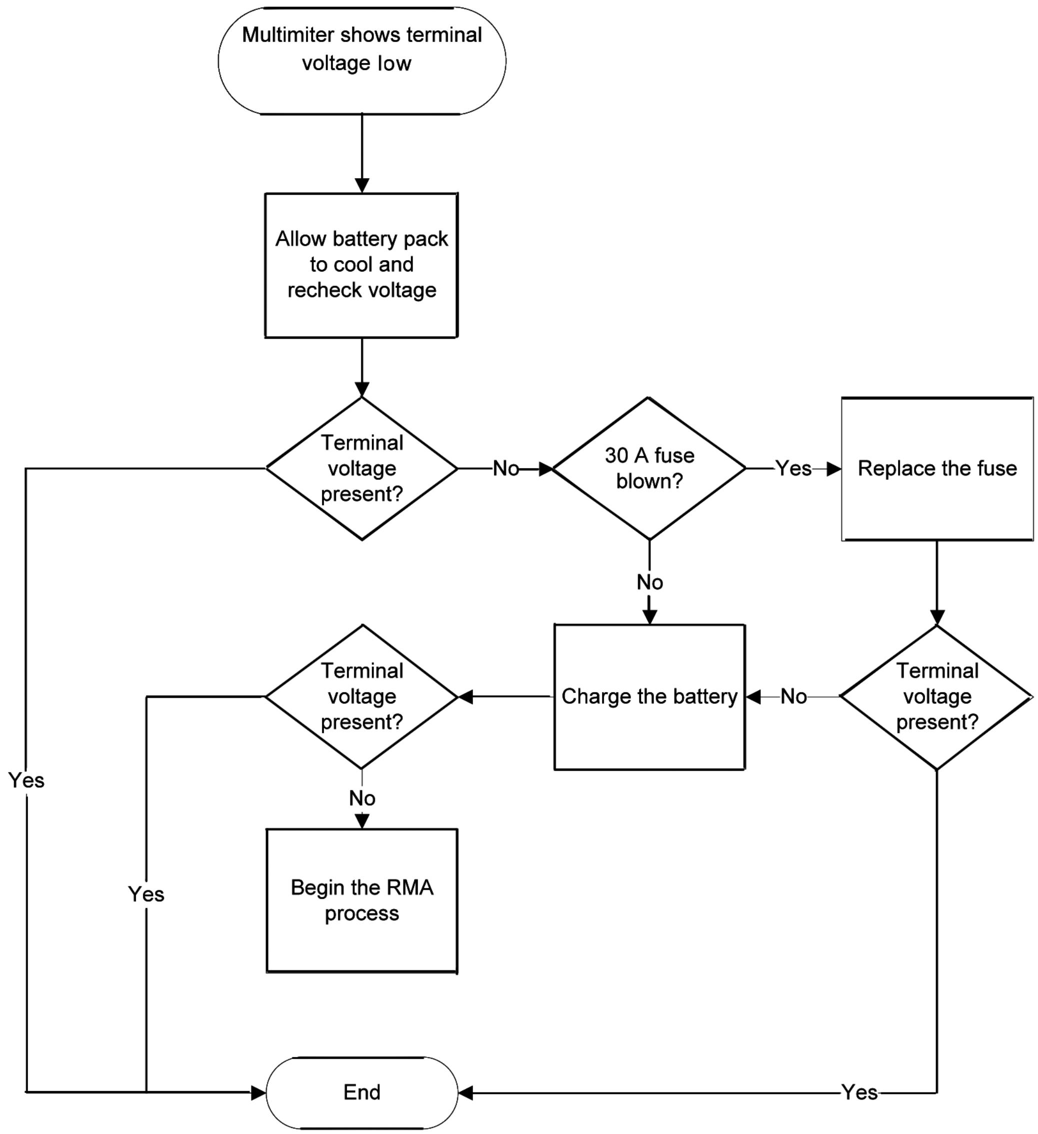


Figure 6-1 Terminal Voltage Low or Absent Troubleshooting Flow Chart

Battery Rapidly Depletes Energy between Charges

Problem

The ALM 12V7 rapidly depletes its energy between charging. Possible causes for this problem are:

- The battery pack is out-of-balance.
- The battery pack has reached the end of its useful service life.

Solution

To resolve situations where the battery rapidly depletes its energy between charges:

1. Apply a float charge (13.8 V, 10 A) for 48 hours to balance the battery pack's cells.
2. Replace the battery pack.

Battery Current Disappears when Charging

Problem

Battery current disappears when charging. Possible causes for this problem are:

- The battery overheated, enabling over-temperature protection.
- The battery pack is out-of-balance.
- Charger voltage is too high.

Solution

To resolve situations where current disappears when charging:

1. Allow the battery to cool.
2. Apply a float charge (13.8 V, 10 A) for 48 hours to balance the battery pack's cells. For more details on charging battery modules or strings, refer to Charging Modules or Battery Systems on page 5-7.
3. Reduce charger voltage to 14.4 V or less.

30 A Fuse Blows Frequently

Problem

The user-replaceable 30 A fuse blows frequently. Possible causes for this problem are:

- The fuse was replaced with a fuse that does not meet the specifications detailed in User-Replaceable Fuse on page 5-12.
- Failure to ensure correct polarity when connecting the battery pack to other battery packs or a host product's output terminals.

- The battery exceeded maximum current specifications while charging or discharging the battery.

Solution

To resolve situations where the battery's 30 A fuse blows frequently:

1. Ensure you are using a fuse that meets the fuse specifications detailed in User-Replaceable Fuse on page 5-12.
2. Verify correct polarity on all connections.
3. Do not exceed maximum current specifications while charging or discharging the battery.

Voltage Drops Abruptly

Problem

Battery voltage appears constant, then drops abruptly.

Solution

This is normal for A123's cells. Constant voltage throughout the battery's SOC ensures maximum usable life. Once the voltage of a cell within the module drops below 2 V, the ALM 12V7's circuitry enables under-voltage protection, which creates an open circuit at the terminals.

Refer to Nanophosphate® Technology on page 3-1 for more details on the cell technology within the ALM 12V7.

Appendix A

Glossary

This appendix contains the following sections:

Terminology Table

The following table describes the terminology used in this document.

Table A-1 Definitions and Acronyms

Term/Acronym	Meaning
ACR	Alternating Current Resistance.
AH	Amp-Hour is a unit of measure of charge that can be stored or delivered to/from a battery.
Battery	One or more cells which are electrically connected together by permanent means, including case, terminals and markings.
BCM	Battery Control Module – The Battery Control Module is necessary to aggregate information from modules and communicate with the system the ESS resides in.
BMS	Battery Management System – The Battery Management System refers to the collection of electronics responsible for monitoring and controlling the ESS.
C-Rate	An electrical current corresponding to that which will fill or empty a cell in one hour.

Term/Acronym	Meaning
CC	Constant Current – A method to charge or discharge a battery in which the current is held constant independent of the battery’s terminal voltage.
CE	Consultants Europe - Tests and Certifies safe and compliant product operation in Europe
Cell	A single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across two terminals.
CID	Current Interrupt Device – A small device integrated into a cell designed to interrupt the flow of current through its terminal when too much pressure or current exists in the cell.
CV	Constant Voltage – A method to charge a battery in which the terminal voltage is held constant, and the current is determined by the power path impedance or some active current limiting.
DVT	Design Verification Testing
ESS	Energy Storage System
iSOC	Current based SOC algorithm
OCV	Open Circuit Voltage – voltage reading of a battery when there is no current going in or out of it.
OEM	Original Equipment Manufacturer – in reference to this document, the maker of the equipment into which an ESS is installed and used.
FCC	RF Emissions governing body in the United States
UL	Underwriter Laboratories - Tests and Certifies safe and compliant product operation in North America
vSOC	Voltage based SOC algorithm

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