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DEVON TITUS Users Guide preliminary

End User Documentation

TITUS U1 User’s Guide

Revision Control

Revision Change Rev 05.

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Chapter 1
About this Document

Overview
The TITUS U1 battery pack consists of 48 to 64 cells in 4S12P to 4S16P configurations with integrated cell protection and balancing circuitry. The TITUS U1 includes an integrated microprocessor to provide host communication (SMBus 2.0) and pack protection. Pack protection as over-voltage, under-voltage, short circuit and over temperature conditions.

Purpose of this document
This manual provides detailed specifications for the TITUS U1 as well as guidance on the safe usage, and 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 TITUS U1 battery.

•Configuration and Operation

Discusses details for charging and discharging TITUS U1.

•Troubleshooting

Discusses behavior unique to the TITUS U1 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 TITUS U1 battery. 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.

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.
UL 2054 – Standard for safety for household and commercial 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 TITUS U1 batteries.

NOTE

The regulations discussed in this manual apply to Lithium Ion cells and batteries. Once the TITUS U1 is integrated into a host product, the host product may be subject to additional transportation regulations that require additional certification testing. Since TITUS can't anticipate every possible configuration and application of the AP U1, you must verify that your TITUS U1 powered host product is compliant with all applicable regulations.

Overview

Rechargeable lithium ion (including lithium ion polymer and lithium iron phosphate) 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.

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

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)

Chapter 3
F**unctional Differences with Lead-Acid Batteries**

The integrated cell protection and balancing circuitry responsible for the durability and additional safety features of the TITUS U1 battery, 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 TITUS U1 battery, no voltage at the terminals typically means the cell protection circuitry has interrupted current to protect the battery. Simply connect the battery to a charger to restore voltage to the terminals.

•State of Charge (SOC) with a U1 battery appears constant, then drops suddenly.
Voltage for a U1 remains relatively constant throughout the depth-of-discharge, while voltage for a lead-acid battery decreases at a linear rate. Therefore, determining a U1's SOC using the same methods to determine a lead-acid battery's SOC creates the impression that the U1 has a full charge then loses power abruptly. A steady voltage across the depth-of-discharge is normal behavior for the U1. The U1 BMS uses custom algorithms to report SOC to the user via the SM bus out put.

. TITUS U1 will exhibit 4+ times the cycle life of lead acid batteries.

Chapter 4

TITUS **U1 Specifications**

Maximum Discharge Current
20 A
Maximum Pulse Discharge Current
100 A for <100 ms (At 25 degrees C), 300A for <6ms(25 degrees C)

Ambient Operating Temperature Range
-20 °C to +60 °C

Maximum Operating Altitude
10,000 ft above sea level
a. The maximum operating temperature decreases by a factor of 1.1 °C per 1,000 ft of elevation above 7,500 ft

Operating Relative Humidity (non-condensing)
20% to 80%

Nominal Operational Voltage
12.8 V to 14.4 V

Minimum cell Voltage
2.75 V @ any cell

Maximum Voltage
4.1 V @ any cell

Nominal Capacity (depends on model)
44 Ahr 55 Ahr

Standard Charge Voltage
13.8 V

Maximum Charge Voltage
14.6 A

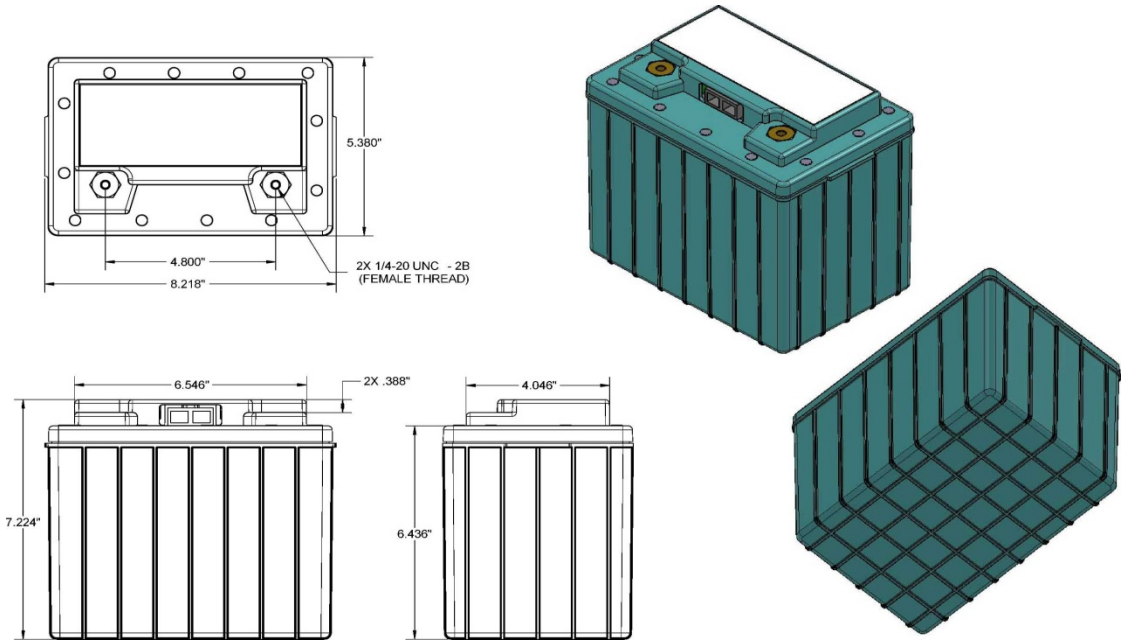
Float Charge Voltage
13.6 V

Standard Charge Current at 25 °C
Depends upon state of charge

Maximum Continuous Charge Current at 25 °C
20 A

Mechanical Dimensions

details the mechanical dimensions of the U1 battery.



The Titus U1 consists of the following components:
1. Cell packs
2. High density polypropylene case
3. Custom BMS circuit board

Chapter 5

Discharge Performance

As shown in the typical room temperature discharge curve in Figure 3-6, the U1 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 U1's ability to hold voltage.

Figure 3-7 Discharge Curve at 0 °C

Chapter 3:

Figure 3-8 Discharge Curve at 45°C

Shelf Life

All Titus U1 battery packs ship from the factory at approximately 35% SOC and can retain at least 10% SOC after 6 months of storage at temperatures not exceeding 25 °C. Note that higher storage temperatures reduce impedance and accelerate the rate of self-discharge.

Following this 1/2-year period the SOC falls below 10%, and the terminals become disconnected (open). The U1 can remain in this state for a minimum of 1/2 more year. To reactivate the terminals, the battery must be recharged.

Cycle Life

The U1's cycle life is determined by the 32700 cells inside it, as well as ambient temperature and charge/discharge rates. Under optimal conditions, the U1 can deliver thousands of cycles at 100% Depth of Discharge (DOD). Even at a 20 A discharge rate, the cells can deliver in excess of 2,000 full DOD cycles. Refer to Cycle Life on page 3-10 for more details on cycle life.

Terminal Specifications

The Titus U1 utilizes a custom metal terminal, with a 1/4-20 female thread. The terminals are capable of currents in excess of 25 Amps.

Chapter 3:

Safety

Our $LiFePO_4$ cells are more abuse tolerant than other Lithium Ion cells; however, correct handling of the U1 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 U1 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 U1.

•Do not charge or discharge the U1 outside of its stated operating temperature range. Reduce charging limits for lower operating temperatures.

•Do not connect U1, s in series. Connecting 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. (Special applications require factory application consultation)

Storage

U1's 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 U1 at altitudes up to 25,000ft. For long storage periods at 25 °C, charge the battery every 1/2 year. For temperatures above 40 °C, charge the battery every ½ year. Do not store the U1 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
Competitive Advantages, and Applications

This chapter discusses competitive advantages and potential applications of the Titus U1 battery module in the following sections:

Competitive Advantages

The U1 is a battery offering tremendous value in many applications. The battery is designed to be a drop in replacement for many standard lead-acid batteries and provides 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.
Chapter 4: Applications
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Applications

Applications that could benefit from these competitive advantages range from computer carts for hospital use, to sophisticated robots.

Chapter 5
Configuration and Operation

This chapter discusses configuring, charging and discharging the U1 in the following sections.

The U1 is UL Recognized as a standalone battery only and has not been recognized for series and/or parallel configuration

Terminology

This chapter discusses configuring and operating U1 using the following terminology:

Table 5-1 Configuration Terminology.

Definition

Cell
Refers to an individual 32700 cell that is the basis for the TITUS U1 battery module. Each TITUS U1 contains either 32 and 40 cells depending on which of the 2 models is considered.
A string of cells arranged in series to achieve higher voltage.
Series String
A string of cells arranged in parallel to achieve higher current.
Parallel String
A string of cells arranged in parallel to achieve higher capacity.
Chapter 5: Configuration and Operation
5-2
Paralleling for higher discharge currents: Contact factory.

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 Titus U1, we recommend the following charge limits based on ambient temperature: -20 degrees C to 60 degrees C

Discharge Cut-Off Voltage Limits

When configuring your application stop discharges when the battery system reaches the recommended discharge cut-off voltage or it reaches 60 °C. Discharge cutoff is also preset by the BMS, programed to not exceed limits set by the cell manufacturers data sheet.

Integrated Module Protection

The U1 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 U1 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 4.4V or falls below 2.75 V.

•If the voltage on a single cell falls below 2.75 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 4.20 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 U1, 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 TITUS U1's circuitry continuously monitors the battery pack's temperature and can interrupt current if the U1 exceeds 60 °C. Module temperature must fall below 55 °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 TITUS U1 is the circuitry continuously monitors the capacity and SOC of each individual cell pack and balances the battery to ensure maximum capacity.

Chapter 6
Troubleshooting

The TITUS U1 is an extremely reliable battery that provides greater useful life than comparable 12V lead-acid batteries. Despite the high reliability of the TITUS U1, 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 U1 and the appropriate troubleshooting procedures.

Terminal Voltage Absent or Low

Problem

Using a multimeter to check terminal voltage shows the terminal voltage is either absent or too low (below 10 V). Possible causes for this problem are:

•The voltage of a cell within the module dropped below 2.75 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.

Chapter 6: Troubleshooting

6-2

•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.Connect the battery to a charger to wake the battery and recover terminal voltage. Depending on the TITUS U1's voltage and state of balance it may take up to 48 hours to completely charge and balance the module.

Chapter 6: Troubleshooting

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

Battery Rapidly Depletes Energy between Charges

Problem

The TITUS U1 rapidly depletes its energy between charging. Possible causes for this problem are:

•The battery is out-of-balance.

•The battery has reached the end of its useful service life.

Chapter 6: Troubleshooting

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Solution

To resolve situations where the battery rapidly depletes its energy between charges: 1. Apply a float charge (13.6 V,) 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 (13.6 V,) for 48 hours to balance the battery pack's cells.

3.Reduce charger voltage to 14.4 V or less.

while charging or discharging the battery.

Voltage Drops Abruptly

Problem

Battery voltage appears constant, then drops abruptly.

Solution
This is normal for $LiFePO_4$ cells. Constant voltage throughout the battery's SOC ensures maximum usable life. Once the voltage drops below 11 V, the TITUS U1 circuitry enables under-voltage protection, which creates an open circuit at the terminals.

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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.

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

Term/Acronym Meaning

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