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Maintaining Battery Safety And Life Of Battery Are Top Priorities In Battery Charger Design

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Since they were first introduced, there have been safety issues associated with rechargeable batteries. Consider the rechargeable lead-acid battery, which has been around since 1859. These early batteries had a liquid electrolyte that could spill out. That was a potential problem until the 1930s when gel electrolyte was introduced that eliminated spilling.

Over the years, various new rechargeable battery chemistries were developed. The sealed lead acid battery (SLA) came into the market in the 1970s. Other chemistries also came along including nickel–cadmium[1] (NiCd), nickel–metal hydride[2] (NiMH), lithium-ion[3] (Li-ion), lithium-ion polymer[4](Li-ion polymer) and lithium iron phosphate (LFP or $LiFePO_4$). A relatively recent arrival, the LFP batteries were developed in 1996. All of the rechargeable battery chemistries have advantages and disadvantages, and it is because of the disadvantages that new battery chemistries were created and continue to develop.

However, one thing that these different batteries chemistries have in common is that they have all had safety issues related to charging. In the past fires have occurred when the battery was not charged properly or there was a fault in the battery construction. For example, lithium battery fires have occurred in cell phone batteries, hover board batteries and other applications. In such cases, the protection membrane that was supposed to block the ions' travel inside the battery failed. This caused the battery temperature to rise, which in turn caused a fire.

Another charging related problem, automotive lead acid batteries were known to have issues when improperly connected to a charger. The same for the NiCd, NiMH, Li-ion and Li-ion polymer batteries. The first series of Li-ion and Li-ion polymer batteries came with internal battery management system (BMS) protection circuits inside the battery case. Today cell phones, tablet computers, and laptop computers come with batteries having a BMS. Many of the cell phones, smart phones, tablets, and laptop computer batteries are not replaceable except by an authorized service technician. These batteries are charged with an internal battery charger circuit, which will not be discussed here.

In this article, we'll discuss the risks to battery safety and long operating life that are posed by charging errors, and describe the techniques used in charger design to prevent these errors. We'll also identify some of the governing standards. This information may be of value both to those designing battery chargers as well as those who are specifying battery charger products for use in various applications.

In this discussion we'll focus specifically on the charging of SLA and LFP batteries which have many applications. However, the issues and principles discussed here generally apply to the other battery chemistries. In a nutshell, safe charging of batteries requires attention to four parameters—temperature, voltage, current and time. For a given temperature, designers must determine how much current can be applied to the battery, at what max compliance voltage and for how long it may be applied. These decisions vary with the battery chemistry.

SLA and LFP Applications

SLA and LFP batteries are used to power equipment such as emergency lighting products, portable fish finders, depth finders, and battery electric starters in small gas-powered machines such as lawn mowers and snow blowers.

One of the most common battery for these applications has been the 12-V SLA battery. This battery is available in a number of capacity ratings. Generally speaking, in the applications cited, these batteries are only replaceable by trained personnel. The medical industry has used this type of battery for portable patient monitoring and fluid pumps for medications. A case outline is shown in Fig. 1, which was copied from a Panasonic data sheet. This battery has spade connectors with widths of 0.1875 (3/16) in. or 0.25 (1/4) in., which make it easy for a repair technician to replace the battery or place the battery on a charger.

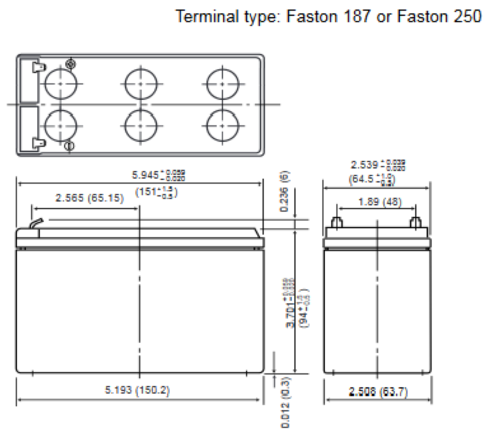

Fig. 1. Case dimensions for a Panasonic 12-V, 7.2-Ah sealed lead acid battey

In recent years, the LFP has begun to replace the SLA battery. LFP manufacturers have made many 12-V batteries in the same size case as the SLA for easy replacement. These LFP batteries have similar characteristics to the SLA including end-of-charge voltage and low voltage dropout. As a result, many of the SLA chargers can easily charge the LFP battery.

Some SLA And LFP differences

LFP chemistry batteries are capable of operating for about 2000 charge and discharge cycles while SLA has an operating life somewhere between 300 and 500 charge/discharge cycles. However, SLA batteries outperform LFP batteries at lower operational temperatures (-40C^{O}/F^{O}) and under the high-current surges needed in engine-start applications. Plus, SLA batteries have a deep discharge capability while LFP types need a hard shut off at 2.5 V per cell or 10 V for a 12-V dc system. When the LPF battery is discharged below 10 V the battery can be permanently damaged which is one reason there are electronic safety circuits added to many battery packs.

Another reason for the protection circuit is to prevent the battery from being *overcharged*. A lithium battery can explode if the lithium is plated on the electrode, as may occur during overcharging. Despite these safety concerns, the LFP battery does have a higher capacity rating for the same size as the SLA battery, is lighter in weight, has a lower self-discharge rate, and longer shelf life.

For those who want to delve more deeply into the characteristics of the SLA and LFP batteries, there are a number of helpful sources online including Battery University [5, 7, 8] and Wikipedia [7, 9]. Additional information for the charging of these batteries can also be found in the literature of the various battery manufacturers. To find some of these manufacturers you can use distributors such as Digikey,[10] Mouser,[11,12] and Newark[13] to gather additional information.

Protection Against Reverse Voltage Polarity

The first protection required for any battery charger and any battery chemistry, including SLA and LFP, is protection against a reverse-battery condition when connected to the charger. This is critical in order to prevent a fire and/or a battery explosion. This condition, which is depicted schematically in Fig. 2, occurs when the battery is connected to the charger, with or without the primary side in operation. The battery charger terminals are reversed from the charger, so the battery is discharged through the diode, circuit breaker, and transformer secondary. The same condition occurs with all transformer-based chargers including the flyback, half-bridge, full-bridge, and forward converter configurations.

The discharge current is high, it is a short circuit, and the fuse or circuit breaker must open, if the current is not stopped the charging cable can become hot and melt the wire insulation. This is where a fire happens. Often when the charging cables make a connection to the battery terminals in the reverse manner there will be a spark or an arc.

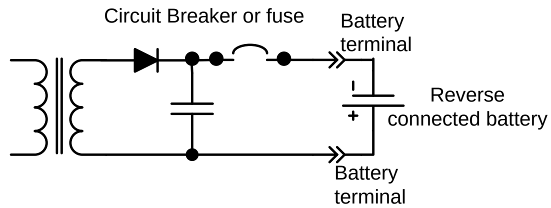

Fig. 2. Reverse battery connection for a battery misconnected to a charger. Other transformer configurations such as half-bridge, full-bridge, and forward converter are not shown but the results are the same.

The UL 1236 Standard for Battery Chargers for Charging Engine-Start Batteries[10] requires the reverse cable test for automotive battery chargers. Under this test, the circuit breaker can open and click but there must not be a fire. For a list of other standards for battery chargers, please see, the table which is from the scope of the UL 1236 where other relevant UL standards are listed.

Other techniques, besides the use of a circuit breaker, can be used to prevent discharge current from flowing if the charging cable is reversed. One simple method for 12-V batteries is to insert a relay or contactor in series with the circuit breaker that will not allow the reverse current to flow. The relay pull-in coil is energized only with the correct battery connection (see Fig. 3). Polarized connectors are a third method employed to prevent reverse-battery connection.

Table. Scope of UL 1236 and other UL battery charger standards.

1.1 These requirements cover battery chargers rated 600 volts or less and intended for household or commercial use to charge lead-acid engine-started and other starting, lighting, and ignition (SLI) type batteries, in accordance with the National Electrical Code, NFPA 70. The requirements also cover a battery charger intended to be permanently installed on a boat.
1.2 A battery charger for use with an internal combustion engine driving a centrifugal fire pump shall comply with the requirements of this Standard and the applicable requirements for the end product.
1.3 These requirements do not cover the following types of battery chargers: *a) Battery chargers for use in industrial applications as covered by the Standard for Industrial Battery Chargers, UL 1564;* *b) Battery charger systems for use in electric vehicle applications covered by the Standard for Electric Vehicle (EV) Charging System Equipment, UL 2202;* *c) Battery chargers for use with portable tools or household appliances as covered by the Standard for Power Units Other Than Class 2, UL 1012, or the Standard for Class 2 Power units, UL 1310; and* *d) Battery chargers for fire protection signaling service.*

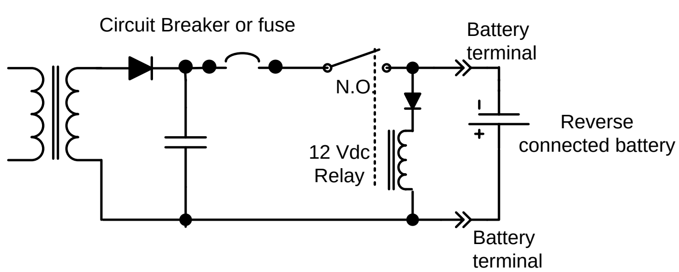

Fig. 3. Reverse battery protection using a relay.

Relay Safety Protection For Reverse Battery

The use of a 12-Vdc relay has a number of added features not apparent to the causal designer. First, the relay should have a 12-Vdc coil. Then, the contact(s) need to be rated at a dc current greater than the current that is used for charging the battery.

For example, if using an 8-Adc charging current use of a 10-Adc or higher current contact rating is recommended. It is also recommended that an automotive 12-Vdc rated relay be used which has good quality. If possible the authors recommend the relay have an automotive PPAP rating.

Some design tips to keep in mind:

- The pull-in voltage of a 12-Vdc relay is approximately 8-Vdc. The designer can add a number of small-signal diodes in series with the pull-in coil, such as the BAV199, to raise the battery pull-in voltage to approximately 10 Vdc.
- Raising the pull-in voltage prevents charging a deep-discharged battery. The lowest voltage of a 12-V LFP is 10 V.
- The 12-V SLA can be deeply discharged but the battery voltage will recover to above 10 V if left in an open-circuit condition. This approach prevents charging a deep discharged battery until the battery can accept a charge current.

Polarized Connectors

The industry solved the issue of reverse battery connections by using polarized connectors. These male and female connectors and connectors with keys solved many applications. But not all applications are solved using these connectors.

Emergency lighting applications, portable fish finders, and depth finders, and battery electric starters in small gas-powered machines such as lawn mowers and snow-blowers, often use SLA and now LFP batteries with 0.1875 (3/16) in. or 0.25 (1/4) in. spade connectors. Many of the chargers for these applications need to have additional reverse-battery protection like that listed above. Designers can use power MOSFETs in place of relays in some applications.

Cell-phone, notebook computers, tablet computers, etc. that use lithium-ion batteries have addressed this issue in the safety circuit built into the battery packs. This article will not address the safety circuits and control ICs used in the battery packs. The medical industry uses many battery power monitoring devices. Medical devices are used for patient monitoring, including blood pressure, heart rate, and intravenous monitoring; such battery-powered systems are covered under the UL/IEC 60601 standard.

What Is Needed For The Safe Charging Of SLA And LFP Batteries?

Temperature

The battery needs to be between -20˚C and +50˚C to be able to accept a charge current safely. The various battery manufacturers have differing specifications on the acceptable battery case temperature for charging. At cold temperatures the battery may not accept a charge and at hot temperatures there is a danger of battery explosions.

The automotive industry has its special battery requirements, which are requirements beyond the scope of this article. However, it’s worth noting that certain automotive requirements have influenced battery development. In response to these requirements, the battery manufacturing industry has continued to make improvements to both SLA and LFP batteries. For example, there are requirements for engine-start systems to operate at -40˚C (-40˚F). Fig. 4 shows the capacity of a lead acid battery over a wide range of temperature from -40˚C to +60˚C.

When the battery case is above +40˚C, a lead-acid battery has high internal chemical activity and high self discharge. To have a long battery life, the battery temperature needs to be lowered to the recommended battery temperature range set by the battery manufacturer. Many of the characteristics of automotive lead acid batteries used for vehicle starting can be applied to other SLA batteries.

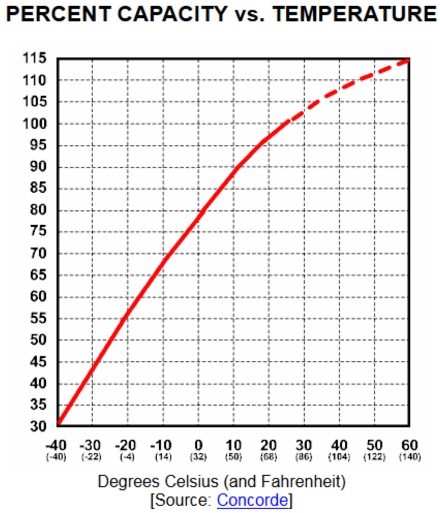

Fig. 4. Battery capacity versus temperature.

End Of Charge Limits

The charging method typically recommended for charging batteries is called a constant current-constant voltage (CCCV) control algorithm. This type of control algorithm is used for many battery chemistries. The current is constant going into the battery and is limited to the recommended value defined by the battery manufacturer, in this article 3 Adc for the 12-V SLA or LFP. The battery voltage is monitored and when the battery terminal voltage is obtained, the voltage is held at that value. In this article, the voltage is 14.5 Vdc for the 12-V SLA or LFP. Once the battery voltage limit is reached the charger goes into the constant voltage mode and current is decreased as the battery becomes charged.

A 12-V battery is considered to be fully charged when the battery terminal voltage reaches 14.5 Vdc and the charging current is less than 0.02 of the "C-rate", where "C" is the discharge rate of the battery equal to the specified capacity value for 1 hour. In the case of a 10-Ah battery the "C" rating is 10 A. The end of charge is when the charging current is 0.2 A or 200 mA dc. Both SLA and LFP 12-V batteries can use the same charger algorithms as shown in Fig. 5.

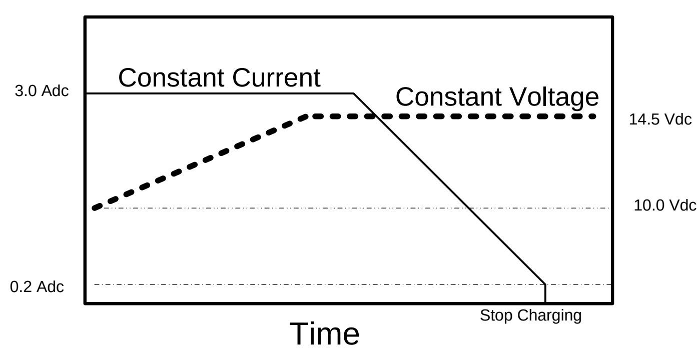

Fig. 5. Constant-current constant-voltage graph for a 10 amp-hour battery.

The battery charger for both SLA and LFP batteries can stop charging at this point. There are products that have a battery monitoring system, either external or embedded in them. These have a maintenance algorithm that keeps the charger connected to the battery in an attempt to keep the battery at full charge.

These types of chargers may have a microprocessor as a controller where the state of charge is maintained. This type of charge system has been associated with SLA batteries. The SLA battery voltage decreases over time down to a 13.2 V to 13.5 V level after the charging current stops. LFP batteries do not decrease their voltage, but maintain their end-of-charge voltage. This type of charging is shown in Fig. 6.

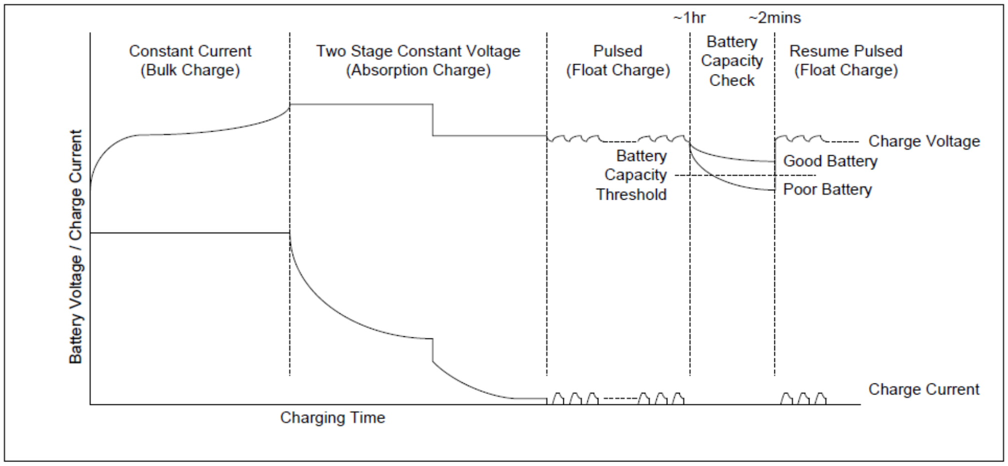

Fig. 6. SLA battery charging profile.

Over Charge Protection

The SLA and LFP batteries should not be continuously charged. In the case of SLA batteries the electrolyte can dry up due to outgassing. The vents in the SLA battery open and the battery dries out.

In the past this has been an issue with emergency lighting systems. LFP batteries are lithium-ion batteries and if the current is not stopped the lithium can be plated to the electrode. The exact voltage level where the charger can return to charging is defined by the battery manufacturer and beyond the scope of this article.

Many BMSs have circuits placed inside the battery case. This has been used by many of the batteries packs found in laptop computers, tablets, and cell phone batteries. These are needed to protect the consumer from battery fires.

Department Of Energy Rules For Battery Chargers

The United States Department of Energy (DOE) has mandatory rules for battery chargers.[15] Many battery chargers are placed inside the product and the chargers use electrical energy constantly. It is the standby energy that is of concern to the DOE. The California Energy Commission has similar rules.[16] Please refer to these documents for additional information.

Summary

This article explains some of the safety and compliance issues related to battery charging. The article focused on the SLA and LFP type batteries. The most important issue is safety as related to battery charger systems. The reverse-battery connection is the most important issue. The second most pressing concern is the end-of-charge needed to maintain good battery health.

The third item discussed was overcharge protection against both overcurrent and overvoltage. The fourth and final item is government mandates for energy efficiency from both the U.S. Department of Energy and the California Energy Commission. The references provide only some of the additional information that may be needed when investigating these topics.

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Kevin Parmenter is an IEEE Senior Member and has over 20 years of experience in the electronics and semiconductor industry. Kevin is currently director of Field Applications Engineering North America for Taiwan Semiconductor. Previously he was vice president of applications engineering in the U.S.A. for Excelsys, an Advanced Energy company; director of Advanced Technical Marketing for Digital Power Products at Exar; and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division.

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For further reading on power supply-related safety and compliance issues, see How2Power's special section on Power Supply Safety and Compliance.