Application Note

LiFePO4 Design Considerations

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ABSTRACT

Lithium Iron Phosphate (LiFePO4) batteries are one of the plethora of batteries to choose from when choosing which battery to use in a design. Their good thermal performance, resistance to thermal runaway and long cycle life are what sets LiFePO4 batteries apart from the other options. However, LiFePO4 batteries require special considerations and this document discusses these considerations and how they compare to more traditional Lithium ion (Li-ion) batteries.

Table of Contents

List of Figures

List of Tables

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1 Introduction

When choosing between batteries there are many tradeoffs to consider: cost, size, weight, energy density, cycle life, stability, etc. In general, Lithium Iron Phosphate (LiFePO4) batteries are preferred over more traditional Lithium Ion (Li-ion) batteries because of their good thermal stability, low risk of thermal runaway, long cycle life, and high discharge current.

However, LiFePO4 batteries have a lower energy density and lower charge voltage, so they typically have to take up more area compared to a Li-ion battery. Furthermore, due to the lower charge voltage, a LiFePO4 battery may need a boost converter when a Li-ion may not. Table 1-1 shows a general comparison between typical low power multi-chemistry charging designs.

Later sections will focus on the differences between LiFePO4 and Li-ion's charge profiles and thermal performance and the design implications these differences cause. We will then provide potential charger designs that are suitable for LiFePO4 batteries.

Table 1-1. Tradeoffs Between Typical Low Power Multi-Chemistry Batteries (1)

	Li-Ion	LiFePO4	Ni-MH	SuperCap
Energy Density	High 150-180 Wh/kg	Medium 90-120 Wh/kg	Low 60-120 Wh/kg	Low 4.5Wh/kg
V(nom)/cell	3.6 V	3.2 V	1.2 V	2.7 V
V(charging)	3.9 V-4.2 V	3.5 V-3.65 V	1.4 V-1.6 V	2.7 V
Area	Low	Medium	High	High
Price	High	Medium	Low	Medium
Benefits	• High Energy density • High voltage/cell at 3.6 V can lead to single cell use and space savings • Long cycle life 500 cycles	• High current rating 3°C • Long cycle life 2000 cycles • Good thermal stability • Safer Li-Ions: enhanced • safety/tolerance if abused • Tolerant to full charge conditions	• Reliable and Durable • Safe: Overcharge and discharge do not create high temperatures • More cost effective	• Safe: No volatile chemicals, Overcharge and discharge do not create high temperatures • Long life, no wear out mechanism 500k cycles
Limitations	• Fragile: requires protection circuit for safe operation • Peak voltage limited during charge • Temperature needs to be monitored	• Lower voltage of 3.2 V/cell • Higher self-discharge which can cause balancing issues with aging	• Quick self-discharge, needs to be charged more frequently • Lower voltage 1.2V/cell require multi-cell packs and larger designs	• Voltage can have large change with discharge, SOC. • Low cell voltage can require series cell and possible balancing circuit.
Charge Temp	0°C to 45°C	0°C to 45°C	0°C to 40°C	-40°C to 65°C
Discharge Temp	-20°C to 60°C	-20°C to 60°C	0°C to 50°C -20°C to +85°C Possible	-40°C to 65°C

2 Charge Profile and SOC vs OCV

LiFePO4 and Li-ion batteries share the same charge profile shown in Figure 2-1. This charge profile is a standard Pre-charge, CC, and CV charge profile, however, since LiFePO4 and Li-ion batteries have different voltage profiles, these stages in the charge profile happen at different voltages. For Li-ion batteries, $V_{OREG} \approx$ 3.9-4.2 V, $V_{Precharge} \approx$ 3.0 V, and $V_{Short} \approx$ 2.0 V. For LiFePO4 batteries, $V_{OREG} \approx$ 3.5-3.65 V, $V_{Precharge} \approx$ 2.0 V, and $V_{Short} \approx$ 1.2 V.

Furthermore, LiFePO4 and Li-ion batteries have similar charge rates, but Li-ion typically has a discharge rate of 1C whereas LiFePO4 can have discharge rates of 3C. This makes LiFePO4 good for higher current applications.

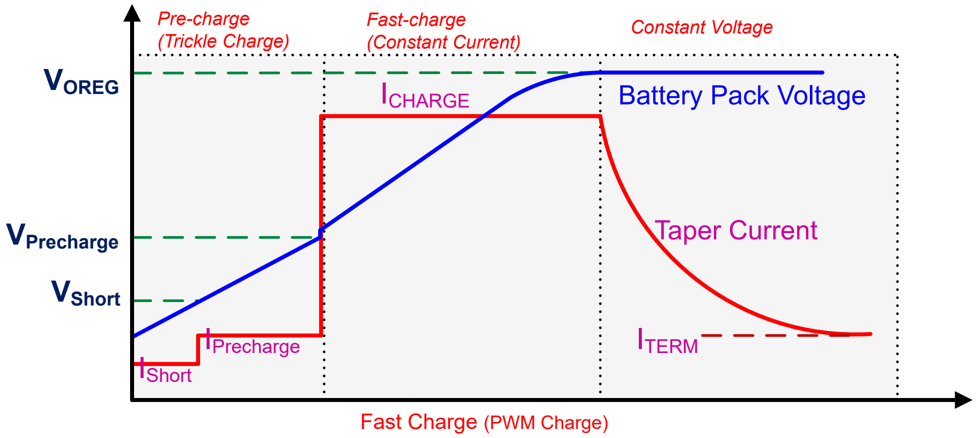

Figure 2-1. Standard CC/CV Charge Profile

Another key difference between LiFePO4 and Li-ion batteries are their SOC (State of Charge) vs OCV (Open Circuit Voltage) profiles. As can be seen in Figure 2-2, Li-ion batteries have a fairly linear SOC vs OCV profile whereas LiFePO4 batteries are fairly linear for the approximately 85% to 100% SOC range, but has an abrupt change in slope for the approximately10% to approximately 85% SOC range. This becomes significant when choosing what charge voltage accuracy is needed in a design and the SOC the battery will be charged to [1].

[1] A designer can choose to charge their battery at a lower SOC to reduce the capacity degradation due to decomposition of the graphite on the anode.

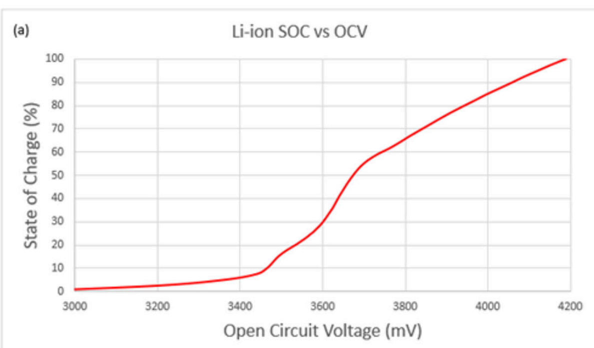

Figure 2-2. Li-ion SOC vs OCV Profiles

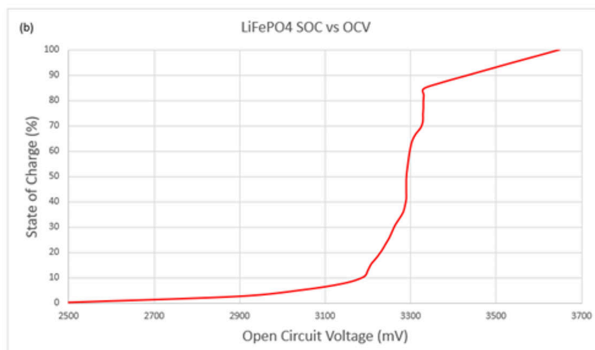

Figure 2-3. LiFePO4 SOC vs OCV Profiles

Small charge voltage inaccuracies can cause a large percentage of the battery's capacity to go unused especially if the designer decides to try to preserve the cycle life of the battery by charging the battery to a SOC lower than 100%. Table 2-1 and Table 2-2 illustrates this quite well by showing how much battery capacity you can lose for Li-ion and LiFePO4 batteries due to charge voltage inaccuracy. Table 2-1 this when charging to a SOC 100% and Table 2-2 illustrates this when charging to a SOC of 80%.

To explain how we got the results from Table 2-1 and Table 2-2, we give the following example from Table 2-1. If the designer uses a charging design with a charge voltage regulation accuracy of +/-2% to charge a Li-ion battery, then the charge voltage needs to be set at 98% taking in consideration of the +2% tolerance if the design target is not to let the battery voltage surpass 100% of charge voltage. As a result, the minimum V_{bat} can be 96% of the maximum charge voltage because of the negative end of the charge voltage accuracy. So, with a charge voltage accuracy of ±2%, The battery is possible to be charged 4% below the maximum charge voltage and this can result in up to 13.2% of the battery's capacity to go unused.

As can be seen in Table 2-1, even a charge voltage accuracy of ±0.5% can result in a 3% loss of battery capacity. This only gets multiplied more with worse charge voltage accuracies. When comparing LiFePO4 to Li-ion batteries, LiFePO4 perform better when they are charged to a SOC of 100% because LiFePO4's SOC vs OCV profile has a smaller slope for higher SOC compared to Li-ion batteries.

However, as can be seen in Table 2-2, charging LiFePO4 to a SOC of 80% to preserve its cycle life becomes essentially impractical. Even with a charge voltage accuracy of ±0.5%,you can be losing up to 41.4% of the battery's available capacity. This is an additional 21.4% of battery life on top of the 20% you are losing by deciding to charge to a SOC of 80%.

Table 2-1. Charge Voltage Accuracy vs Lost Battery Capacity Compared to TI Designs With Charging to a SOC of 100%

Charger design	Charge Voltage Accuracy	Battery	Minimum V_{bat} (mV)(1)	Capacity at V_{bat}	Maximum Capacity Loss	Capacity Loss Compared to TI design
Texas Instruments	±0.5%	Li-ion	4147	97.0 %	3.0 %	-
		LiFePO4	3612	98.3 %	1.7 %	-
Competitor	±1%	Li-ion	4342	93.6 %	6.4 %	3.4 %
		LiFePO4	3576	96.6 %	3.4 %	1.7 %
Discrete	±2%	Li-ion	4298	86.8 %	13.2 %	10.2 %
		LiFePO4	3503	93.2 %	6.8 %	5.1 %
Discrete	±3.5%	Li-ion	4232	75.5 %	24.5 %	21.5 %
		LiFePO4	3393	87.9 %	12.1 %	10.4 %

(1) Minimum V_{bat} refers to the minimum charge voltage when considering the negative end of the charge voltage percentage. This value is calculated with the following equation: Minimum V_{bat}= $V_{SOC(100\%)}$ *(1-2*CVA) where $V_{SOC(100\%)}$ is the voltage associated with a SOC of 100% and CVA is the charge voltage accuracy.

Table 2-2. Charge Voltage Accuracy vs Lost Battery Capacity Compared to TI Designs With Charging to a SOC of 80%

Charger design	Charge Voltage Accuracy	Battery	Minimum V_{bat} (mV)(1)	Capacity at V_{bat}	Maximum Capacity Loss	Capacity Loss Compared to TI design
Texas Instruments	±0.5%	Li-ion	4111	75.8 %	24.2 %	-
		LiFePO4	3297	58.6 %	41.4 %	-
Competitor	±1%	Li-ion	4091	71.8 %	28.2 %	4.0 %
		LiFePO4	3263	30.6 %	69.4 %	28 %
Discrete	±2%	Li-ion	4049	63.6 %	26.4 %	12.2 %
		LiFePO4	3197	12.5 %	87.5 %	46.1 %
Discrete	±3.5%	Li-ion	3987	47.2 %	52.8 %	28.6 %
		LiFePO4	3096	6.7 %	93.3 %	51.9 %

(1) Minimum V_{bat} refers to the minimum charge voltage when considering the negative end of the charge voltage percentage. This value is calculated with the following equation: Minimum V_{bat}= $V_{SOC(80\%)}$ *(1-2*CVA) where $V_{SOC(80\%)}$ is the voltage associated with a SOC of 80% and CVA is the charge voltage accuracy.

When considering that LiFePO4 batteries already have a long cycle life compared to other battery chemistries, most designers charge their LiFePO4 batteries to a SOC of 100% because they are limited by the lower energy density. On the other hand, Li-ion batteries do not have as significant capacity loss when charging at a SOC of 80%, so it can be practical for the designer to try to preserve the cycle life of their Li-ion batteries by charging the batteries to a SOC of 80%.

Nevertheless, any unused capacity of the battery means that the designer has to buy an even bigger battery to support their needs. This means that if your design truly needs a 10Whr battery for your application, and your design doesn't utilize 15-30% of the battery, either by charge voltage inaccuracy and/or in order to preserve the cycle life of the battery, you will need to buy a 15-30% bigger battery. And, since the battery is usually one of the most expensive parts of the system, the tradeoffs to save a few cents on the battery charger and/or the potential increase in cycle life typically do not outweigh added cost of having to buy a bigger battery. Furthermore, when you consider the additional features that a battery charger design can provide, the benefits of a good charger design outweigh the costs.

3 Thermal Runaway and Temperature Characteristics

Thermal runaway is the catastrophic failure of a battery that can damage the battery and can lead to a violent explosion. Thermal runaway can be caused by battery penetration, over charge, over current, and excessive thermal abuse. Li-ion batteries are of particular concern because they are not as stable as other options, which is why they have so many shipping restrictions. This is why protection circuitry is needed to prevent overcurrent, overvoltage, undervoltage, and others.

LiFePO4 batteries have a stable chemistry composition which make it less prone to thermal runaway. The thermal runaway temperature for LiFePO4 batteries is much higher than Li-ion batteries and it is very hard to enter this fail mode. Because of this, LiFePO4 batteries perform well in higher ambient temperature applications and can typically handle higher discharge currents. Additionally, protection circuitry can be added to have an additional layer of security, but it does not necessarily require protection circuitry.

Aside from thermal runaway, higher temperatures can degrade the capacity of the battery. But, with LiFePO4's characteristics, they typically experience less degradation at higher temperatures compared to Li-ion batteries.

4 Applications

As previously mentioned, the main advantages of LiFePO4 are their thermal stability, low chances of going into thermal runaway, longer cycle life, and higher discharge current. However, due to their low energy density, LiFePO4 batteries typically take up more space compared to Li-ion batteries. This makes LiFePO4 batteries good for applications that need good thermal performance and can afford to take up more space. They are also good for applications that need a higher discharge current and/or need higher cycle life.

LiFePO4 could be a good choice for personal devices due to their safety characteristics. The designer would be less concerned about thermal runaways potentially harming their consumers. LiFePO4 batteries can also be a good choice for start up circuits due to their higher discharge currents. Furthermore, any application where cycle life is the main concern, LiFePO4 would be the better choice over Li-ion batteries.

Table 4-1 shows various TI charging designs that are compatible with Li-ion and LiFePO4 batteries. The designs provided here should satisfy a large variety of applications, there are examples of standalone designs, buck-boost, buck, and linear design and with various cell configurations. All of these designs have very good charge voltage accuracy and have thermal regulation.

Most of these designs have power path management which will automatically switch the power path from adapter to battery and vice versa. Furthermore, all of these designs provide dynamic power management (DPM) with the majority of these designs allowing the battery to supplement the system load if it becomes too much for the adapter. All of these designs also provide overcurrent and overvoltage protection.

Table 4-1. Charging Designs

	BQ25798	BQ25730	BQ25620	BQ25300	BQ24630	BQ25180	BQ25170
V_{IN} Max Rating	30 V	32 V	26 V	28 V	33 V	25 V	30 V
V_{IN} Operating Range	3.6 – 24 V	3.5 – 26 V	3.9 – 18 V	4 – 17 V	5 – 28 V	3.0 – 5.9 V	3.0 – 6.65 V
Battery Configuration	Li-ion, LiFePO4	Li-Ion, LiFePO4, NiMH, Supercap	Li-ion, LiFePO4	Li-ion	Li-ion, LiFePO4	Li-Ion, LiFePO4	Li-Ion, LiFePO4
Cell Configuration	1s – 4s	1s – 5s	1s	1s	1s – 7s	1s	1s
Topology	Buck-Boost	Buck-Boost	Buck	Buck	Buck	Linear	Linear
Charge Voltage	3 to 18.8 V	1.024 to 23 V	3.5 to 4.8 V	4.1 to 4.4 V	1.8 to 26 V	3.5 V to 4.65 V	3.5 V to 4.4 V
Charge Voltage Accuracy (Over Temp)	-0.25 to +0.65 %	±0.5 %	±0.5 %	±0.5 %	±0.5 %	±0.5 %	±0.5 %
Max Charge Current	5 A	16.2 A	3.5 A	3 A	10 A	1 A	0.8 A
Control Interface	I2C	I2C	I2C	Standalone	Standalone	I2C	Standalone
Power-Path Management	Yes	Yes	Yes	No	Yes	Yes	No
Fast Charge Timer	Programmable	Programmable	Programmable	Fixed	Programmable	Programmable	Fixed
Package	4.0x4.0mm QFN-29	4.0x4.0mm WQFN-32	2.5x3.0mm WQFN-18	3.0x3.0mm RTE WQFN	4.0x4.0mm VQFN-24	1.6x1.1mm WCSP-8	2.0x2.0mm QFN-8
Additional Market Application	Video Doorbell, Smart Home Control, Vacuum Robot	Tablet, Wireless Speaker, Ventilators, Vacuum Robot	Tablet, Computer Accessories, IP Camera, EPOS	Wireless Speakers, Barcode Scanner, Cordless Power Tool	Power Tools, Netbook, Medical Equipment	TWS, Wearable, Medical, Building and Retail Automation	TWS, Wearable, ePOS, Camera

5 Summary

LiFePO4 batteries have many advantages over more traditional Li-ion batteries. These advantages include longer cycle life, better thermal performance, resistance to thermal runaway, and higher discharge currents. This makes LiFePO4 batteries good for applications that need a long cycles life, higher safety requirements, or higher discharge currents. However, due to their voltage difference and lower energy density, LiFePO4 should not charge their batteries to a SOC 80% to preserve its cycle life because it will not utilize a large percentage of its capacity. Since, LiFePO4 batteries have a longer cycle life, they can be charged to 100% SOC and still have a much longer cycle life than Li-ion batteries.

6 References

1. Texas Instruments, *Multi-Chemistry Charger in Low Battery Power Applications*, application note.
2. Texas Instruments, *Using battery charger ICs to shrink your design for vacuum robots*.