Discussion on Lithium Iron Phosphate Batteries Used for IDCs Compared with VRLA Batteries

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Abstract
Characteristics and performance of Lithium Iron Phosphate (LFP) batteries were compared with that of VRLA batteries. The advantages and disadvantages of LFP batteries that relate to the requirements of Internet Data Center (IDC) were discussed. Although the cost of LFP batteries is much higher than that of VRLA batteries for the same energy, they can still be used for some special applications economically.

Introduction
Modern IDCs (Internet Data Centers) require large quantities of batteries for UPS backup power supplies. The investment for facilities and the cost for operation of IDCs are huge. There are different battery technologies in existence; however, their performance, cost and behavior are quite different from each other. Proper selection of suitable battery technologies cannot only lower the initial investment but also reduce the cost of operation in IDCs.

Valve regulated lead acid (VRLA) batteries are currently the dominant battery technology used for UPS in IDCs, renewable energy storage systems, telecom, etc. The LFP battery is a new but promising candidate for the above mentioned applications. It's considered one of safest lithium ion battery chemistries available now.[1] It's believed that the only obstacle for large-scale adoption of LFP technology is its high cost, which is approximately three times that of VRLA batteries for the same kWh energy.

In this paper, the advantages and disadvantages of LFP batteries used for UPS at IDCs are reviewed and compared with that of VRLA batteries. In addition, the possible applications of LFP batteries is discussed.

Size and Energy Density
The LFP battery is smaller in size and weight in comparison to the same energy rated VRLA battery. In Table 1, the main features of LFP and VRLA batteries, such as volume, weight, energy and power density, are compared. The referenced batteries were a 12V, 40Ah VRLA battery and a 12V, 40Ah LFP battery. Hereafter, if not specified, all the results were made from these two battery models.

Table 1. Comparison of Main Features of LFP and VRLA Batteries.

Item	VRLA	LFP	%LFP/VRLA
Dimensions (L x W x H) (mm)	197 x 166 x 170	136 x 115 x 160	
Weight (kg)	14.7	5.9	40.00%
Volume (L)	5.52	2.5	45.00%
Power density @ 15 min (W/kg)	50.6	144	285.00%
Energy density @ 10hr (Wh/kg)	32.6	81.3	249.00%

It’s seen that the weight and volume of an LFP battery without a BMS (Battery Management System) is smaller than that of a VRLA battery. If LFP batteries were chosen for use in IDCs, the owner may save installation space, and lower the floor load-bearing level. In other words, existing IDCs could be upgraded with doubled energy or power capacity but would not need to expand the battery room space or worry about the floor-bearing issue.

Electrical Performance

LFP batteries are made using aluminum foil for the positive electrode current collector, coated with a mixture of lithium iron phosphate, conductive carbon and adhesive to form the positive electrode. The negative electrode is made using copper foil as a current collector, coated with graphite, conductive carbon and adhesive. The aluminum and copper are better current conductors than lead. Furthermore, the active material coating for LFP batteries is usually very thin. The thickness of a typical LFP electrode sheet is about 0.45 mm and that of a VRLA plate is around 2.0mm to 3.0mm. This makes the internal resistance of an LFP battery much lower than that of a VRLA, usually 20% of the latter. So, the discharge performance of LFP batteries is better than VRLA batteries, especially at high rate, short duration discharge. Figures 1 and 2 show the typical discharge performance of VRLA and LFP at different rates.

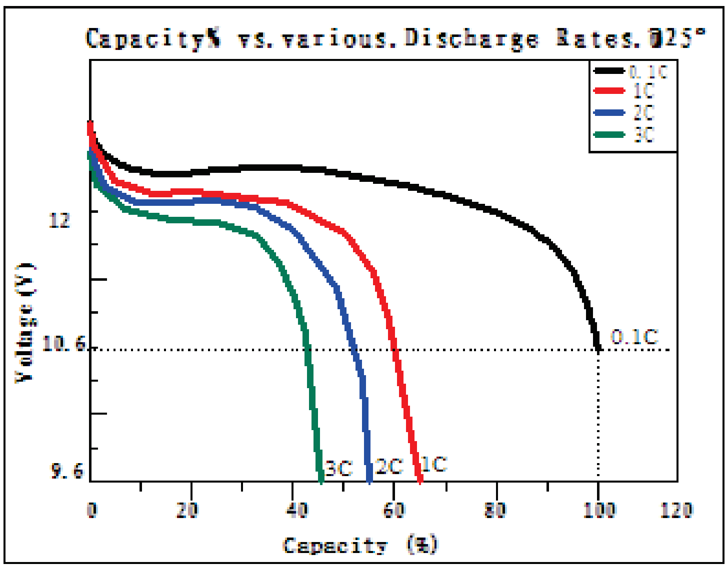

Figure 1. Rate Discharge Characteristics of VRLA battery.[2]

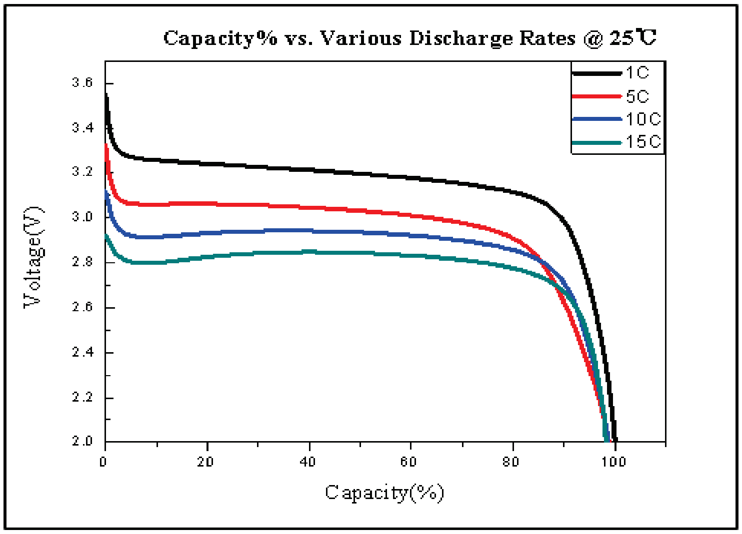

Figure 2. Rate Discharge Characteristics of LFP battery.[3]

It's seen that at a discharge rate of 15 C, an LFP battery can still deliver its 95% nominal capacity, but a VRLA counterpart can only give out about 50% of its nominal capacity at a rate of 3 C. In other words, it is possible to use a small size LFP battery to replace a large VRLA battery for the same backup time in short duration applications, for example, for an installation where the backup time is less than five minutes.

Although the delivered capacity percentage at high rates was very high, the voltage platform at high rates is much lower than a low rate. For example, at a 1 C rate discharge, the voltage platform is higher than 3.2 volts per cell, but it's only 2.8V per cell at 15 C. When considering a 12 volt block, the voltage platform is about 1.2 volts lower. This feature should be paid close attention when designing electrical systems with LFP batteries operated at high discharge rates.

For the same reasons as discharge, LFP batteries can accept high charge current and be fully charged in short time. Figures 3 and 4 show the typical charge characteristics of VRLA and LFP batteries.

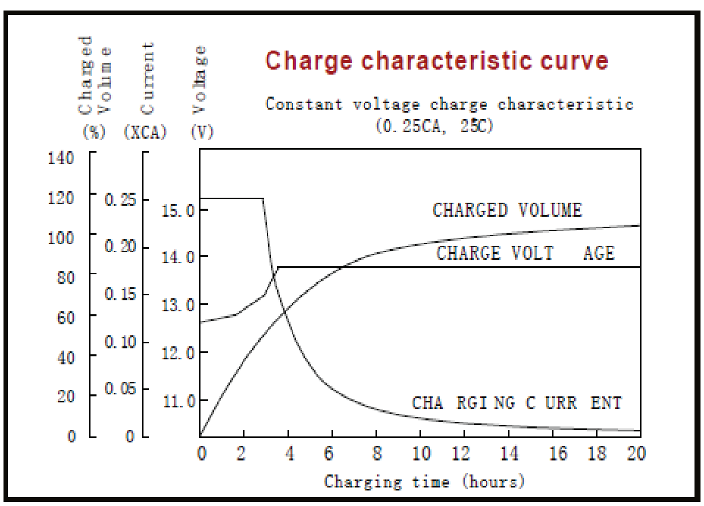

Figure 3. Charge Characteristic of VRLA battery.[2]

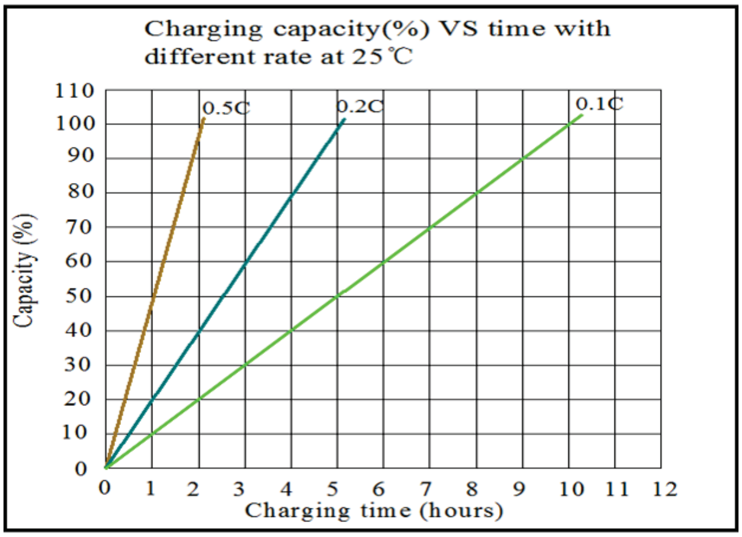

Figure 4. Charge Characteristic of LFP battery.[3]

The LFP battery can be fully charged in a little more than two hours at a rate of 0.5 C. The discharge/charge efficiency is very close to 100%. In fact, LFP batteries can be charged at a charge rate up to 2 C in less than one hour, depending on the design of the battery and the charger's capability. In comparison, VRLA batteries typically take longer to fully recharge, depending on charging parameters. The return on the last 20% to 30% of the previously discharged capacity is not coulombically efficient and takes a relatively long time. The feature of fast charge of LFP batteries is very useful for applications where power failures come frequently and there is not enough time for the recharge of VRLA batteries.

Service Life

The outstanding feature of Lithium batteries is their very long service life, both under cycling and floating applications. Figure 5 shows the optimal floating life of a 10-year design life VRLA battery at 25°C, and Figure 6 shows the calendar aging characteristic of LFP cells under different temperatures and SOCs.

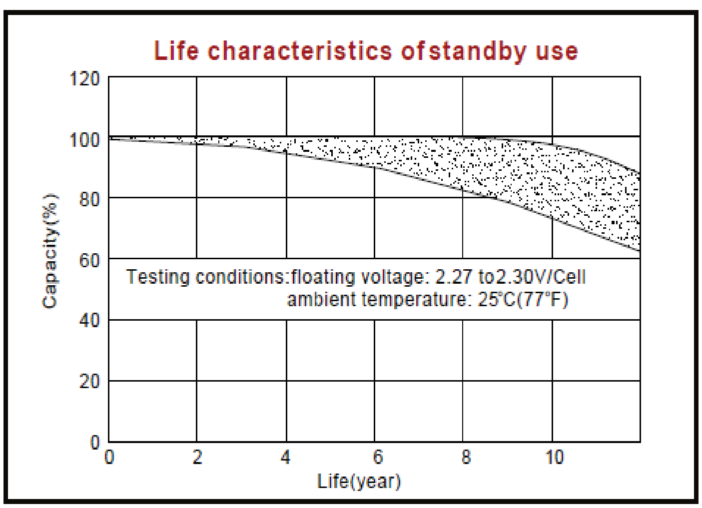

Figure 5. Optimal Floating Life of a 10 year design life VRLA battery at 25°C.[2]

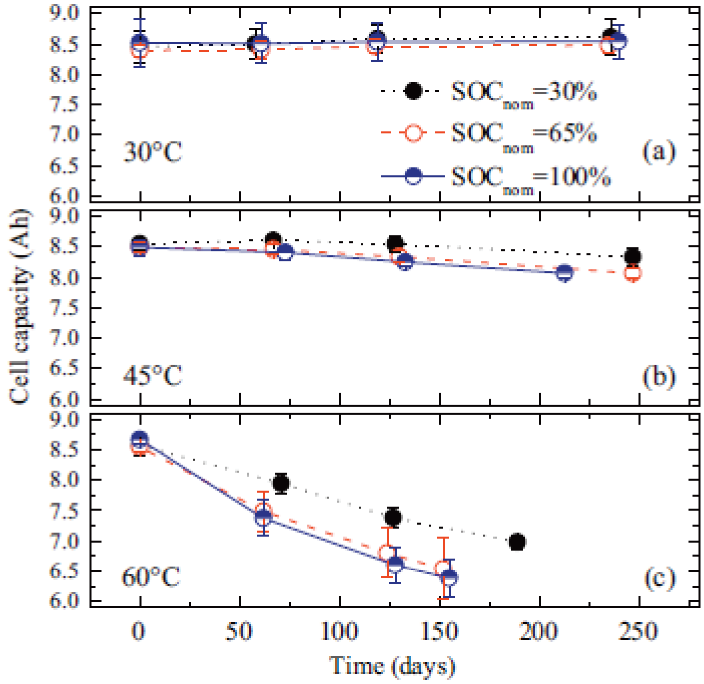

Figure 6. Calendar aging of LFP battery at different temperatures and SOCs.[4]

The main aging mechanism for lithium ion batteries under floating or storage is loss of active lithium in the cells.[5] From Figure 6, it's concluded that at mild temperature, or even at 45°C, the aging of LFP cells was very slow. Although the field floating life of LFP batteries has not been verified, laboratory test results show favorable anticipation that LFP batteries could be operated at higher temperatures than 25°C and still meet the service life requirement in IDCs where there are no air-conditioners. But for VRLA batteries, air-conditioners are usually required by the manufacturers to keep the ambient temperature in a favorable range, which is around 25°C. Air-conditioners consume a big part of energy in the operation of IDCs. If LFP were selected for the energy storage technology, the room temperature could be set at temperatures higher than 25°C and energy saved from A/C operation.

Under cycle applications, LFP batteries behave even better. Figures 7 and 8 show the cycle life characteristics of VRLA and LFP batteries.

From Figures 7 and 8, it can be seen that the cycle number of LFP batteries is around ten times of that of VRLA batteries. For daily, deep discharge application (80% DOD or more), LFP batteries can serve ten years or more, but VRLA can only serve around one year under the same conditions. It's more economical to use LFP batteries in such cases, rather than VRLA batteries. For example, in Africa and India, areas where power failure is very frequent, for renewable energy storage, solar, and wind systems, LFP batteries are also a good choice, as they have lower service costs and can be installed outdoors without air-conditioning. Long life and lower operating costs are expected under such applications.

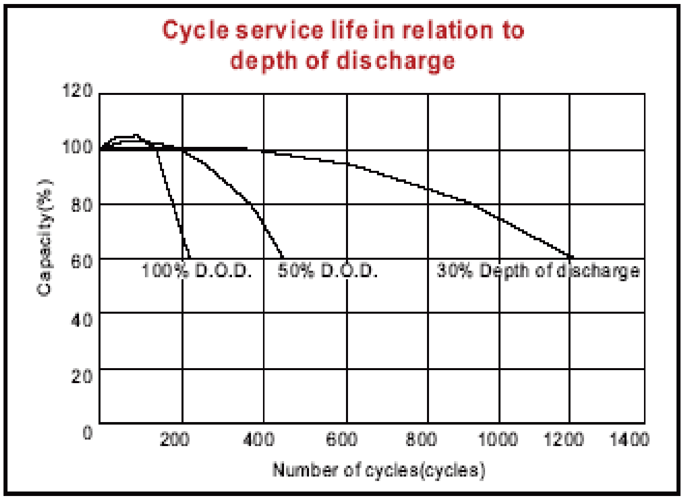

Figure 7 Cycle Life of VRLA Battery.[2]

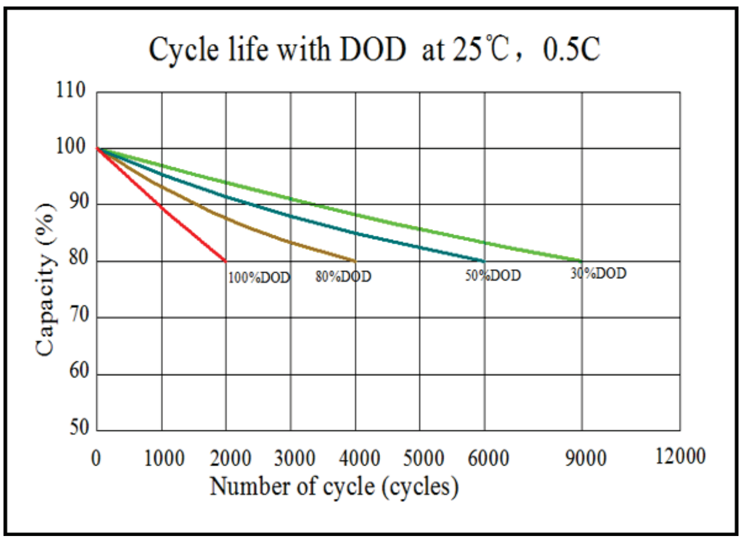

Figure 8 Cycle Life of LFP Battery.[3]

Another merit of LFP batteries is the high energy efficiency. During charging, there are no side reactions inside an LFP battery. The energy efficiency of charge-discharge for an LFP battery is as high as 95%. However, this figure is less than 90% for a VRLA battery, because the water would decompose at the final stage of charge in a VRLA battery. This is a side reaction that consumes charge current and energy. For long terms of operation, LFP batteries can save operating cost due to this advantage.

Drawbacks

However, some drawbacks hinder the large scale application of LFP batteries. The first and most important one is the high cost. The average cost for LFP batteries is $250 USD per kWh, while it's only $77 USD per kWh for VRLA batteries, the former being more than three times of the latter.

Cost can also increase due to the BMS (Battery Management System). A BMS is necessary for all LFP batteries, to protect the cells from overcharge, overdischarge, and overtemperature; otherwise, the cells and batteries may be damaged or a safety issue may arise. If there is no BMS, there is the risk of fire or even explosion during operation of LFP batteries. For some cases where high current or high power is required, the cost of the BMS is even higher than the batteries.

For LFP batteries, the reliability of the whole battery system is affected by the weak cells in the string. During discharge, the circuit must be disconnected when the low limit of voltage reaches the set value; otherwise, the cell may be overdischarged. From this point, VRLA batteries are more forgiving and reliable than LFP batteries.

Another concern for use of LFP batteries is safety, because the electrolyte and separator in the cells are flammable. With adequate design, processing and protection of the BMS, LFP batteries can be as safe as VRLA batteries. Actually, stationary batteries are less apt to cause safety issues, because the main cause of a fire or explosion is the damage to the battery case, which leads to electrolyte leaking.

Possible Applications

LFP batteries with excellent performance are being used in more and more applications. From an economic view, LFP batteries are strong competitors of VRLA batteries in applications such as standby power supplies for the Africa and India markets, where power failures are frequent, because the batteries can be cycled several times. And for renewable energy storage, solar, and wind systems, the applications are also high cycling.

A comparative application area is in UPS systems in IDCs when the discharge power is high and duration is short. For example, where backup time is from one minute to three minutes, LFP batteries are comparable in cost to VRLA batteries. See Table 2. The prices were compared for a 500kVA UPS using VRLA batteries or LFP batteries.

Table 2. Price Comparison of VRLA and LFP with BMS.

Battery Type	**VRLA**	**LFP**
Nominal Voltage	540V	537.6V
Voltage Window	607.5 - 432.0V	613.2-378.0V
Backup Time (min)	1.0	1.0
Battery Model and Number	12V 100Ah 90 pcs (two strings)	3.2V20Ah 336 pcs (two strings)
Battery Cost ($)	8,307.00	6,200.00
Total Battery Weight (kg)	2,900	360
BMS and Price (USD)	N/A	1,230.00
BMU and Price ($)	N/A	24 pcs 3,890.00
Total Price ($)	8,307.00	10,090.00
Price w/o BMS ($)	8,307.00	8,860.00

In this case, the excellent high power discharge performance of LFP batteries was shown. A 20Ah cell could deliver as much power as a 100Ah VRLA cell for a backup time of one minute. The total cost for the LFP cells is even lower than that of VRLA batteries. With the BMS cost added to the total cost, it’s still comparable with that of VRLA batteries. So under certain circumstances, the application of LFP batteries can be economical.

Summary

Compared with VRLA batteries, LFP batteries possess some outstanding advantages, such as small volume, light weight, high discharge power, fast recharge, and very long service life. For big UPS systems in IDCs, where large quantities of batteries are needed, LFP batteries could replace VRLA batteries. When the backup time of UPS is short, LFP batteries can be as economical as their counterpart VRLA batteries.

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