pbq ®

Lithium Ferro Phosphate

Leading in quality

$LiFePO_4$ Batteries

GENERAL FEATURES

High Quality & Reliability
The **pbq** $LiFePO_4$battery or lithium iron phosphate has a constant and reliable performance. It can be easily maintained to provide proper operation of the equipment that it powers.

Construction
A lithium iron phosphate cell has a nominal voltage of 3,2V.
In order to build up 12V batteries, 4 cells are connected in series.
Each cell is a spiral wound construction of a positive and negative plate devided with a separator. The cells are wound so that they can easily processed to prismatic batteries.

Flame retardant casing
The concept of the pbq $LiFePO_4$ battery range is to have battery types that are useful for a wide range of applications.
For some applications it is adviced to have flame retardant, but in some occasions a flame retardant casing is mandatory.
Therefore all pbq $LiFePO_4$ batteries are supplied in flame retardant casings (V0), of course without affecting the RoHS compliancy.

Safety
The pbq $LiFePO_4$ underwent different tests to investigate the safety of the battery. These tests have demonstrated that this battery has a high standard of safety.
F.e. a PTC insertion converts the electrolyte into a stable fluid if the internal temperature of the battery exceeds 80°C. Although this is an irreversable process, a thermal runnaway is avoided in an early stage.

Lifetime
The **pbq** $LiFePO_4$ battery has long life in float or cyclic service. The expected life of float service exceeds 10 years depending on the model and working temperature. The expected life of cyclic service, each time 100% DoD, reach over 2000 cycles (80% remaining capacity).

Venting System
pbq $LiFePO_4$ batteries are equiped with a safe, pressure venting system, which is designed to release excess gas. Thus, there is no excessive build-up of gas in the batteries. This makes the battery operate safely and avoids exploding of the battery in the unlikely event of accumulating gass internally, caused by misuse of the battery. The release of gass from the battery results in a permanent damage.Therefore the break vent wil l not close after the overpressure is released.

Self discharge
The pbq lithium battery has a selfdicharge, equivalent to a lead acid battery. The selfdischarge is around 3% to 5% per month depending on the environmental temperature. The safety features avoid deep discharging, but cannot avoid the selfdischarge. Retired and unused batteries must be disposed according to regulations of the local authorities.

Maintenance free
During the service life of **pbq** $LiFePO_4$ batteries, there is no provision for maintenance functions to be carried out.
The open circuit voltage of stored batteries however need to be checked frequently is order to avoid deep discharging due to self discharge. A three monthly check up will keep your stored pbq $LiFePO_4$ battery fresh.

Charging abilities
The pbq lithium batteries allow high charge currents up to 1C. This is three times faster compared to lead acid batteries, and reduces the charge time to approximately one hour.

Environmental care
The $LiFePO_4$ battery is generally known as the green battery. Other than most popular chemistries, the lithium iron phosphate does not contain heavy metals. The production of the battery is not a load to the environment.
Additional to these standard features of the lithium iron battery, pbq constructed the so battery that the battery is easy to dismantle, in order to devide all the different components during the recycling proces.
pbq uses a distinguished blue colour for the casing sothat recyclers regognize the battery as such, gaining the recyclebility **and safety of the workers**

APPLICATIONS

A **partial list** of some of the more common applications includes, but is not limited to, standby or primary power for:

- Windmills
- Marine Equipment
- Medical Equipment
- Communications Equipment
- Office machines
- Solar Powered Systems
- Electric powered Bicycle
- Telecommunications
- Emergency Lights
- Fire & Security Systems
- Robots
- Geophysical Equipment
- Power Tools
- Uninterruptible Power Supplies (UPS)
- Wheelchairs
- Electric vehicles

TECHNICAL TERMS

1. Battery capacity for LiFePO$_4$ batteries is described in "Ampere Hour" at the one hour rate (C_1) when discharged at 25°C. For a **pbq** 4-12 at C_1 this battery will deliver a current of 4A during 1 hours to a cut-off voltage of 2,5 volts per cell (10 volts per battery).
2. Battery load, by convention is described in terms of a multiple of C in amperes, where C is the capacity at 25°C, so for a 4.5Ah battery 1C equals 4.5A while 2C equals 9A.
3. Battery cut-off voltage is the voltage per cell to which a battery may be discharged safely. When a Lithium iron batteries is 100% discharged, the voltage is 2.5V/cell in that case we the battery is deep discharged. The protection feature does not allow to discharge the battery deeper than 2,5V/cell.
4. Close to the battery cut-of voltage is the depth of discharge. The depth of discharge is the voltage to which the application draws power from the battery, before the application switches off or is switched off.
5. U_{OC}= Open circuit voltage is the voltage of the battery, while the battery is not loaded. For measuring the U_{OC} only use a high impedance multi-meter or similar device.
6. Vpc = Voltage per cell. Each cell in a LiFePO$_4$ battery generates around 3,2 volt. Therefore a 12 volt battery is made of 4 cells.
7. A cell is a single electrochemical combination generating a certain voltage, 3,2 volt for lithium iron phosphate (U_{OC} @ 100% SoC), while a battery is a combination of 2 or more cells. However, in everyday speach, one usually refers to batteries even if it is actually a cell.
8. Over charging a lithum iron battery will lead into unrecoverable damage to the battery. The internal battery protection board of the pbq LiFePO$_4$ avoids deep discharging by terminating the output when the battery voltage reaches 2,5V/cell
9. Over current, either during charging or discharging, will damage the battery. The internal safety features prevent the battery from damaging by switching off the (dis)charge current.

BATTERY STORAGE

It is recognized that **pbq** LiFePO$_4$ batteries exhibit excellent charge retention characteristics. That is, their self discharge rate is low and is typically 3%-5% per month at 25°C. Although the self discharge rate is low, specific precautions must be taken to guard against the battery over discharging due to self discharge when in storage or in a non operational mode.
Other than Lead Acid batteries it not necessary to recharge a battery after it is discharged. However if the battery is fully discharged, it is highly recommended to recharge the battery, to avoid deep discharge due to self discharge.

Storage temperature for LiFePO$_4$ batteries

The **pbq** batteries can be stored in an ambient temperature between -20°C to +60°C.
Please note that the capacity of the battery reduces if the temperature degreases. At -20°C a fully charged battery can only provide 55% to 60% of its rated capacity.

Mechanical precautions

Storage at low temperatures is possible providing the battery is handled with some extra care, since most plastics hardens at low temperatures, the risk of damaging the battery container through shock or dropping will increase. When stored at high temperatures ensure that the battery is on a flat and horizontal shelf to prevent deformation of the plastic container.

Electrical precautions

Note that the electrochemical processes in any battery will be influenced by the temperature. When taking a battery out of storage ensure proper functioning before connecting it to your equipment. Check that the delivered voltage and current drain of your applications meets the specifications at the given temperature. The electric characteristics will be reduced at low temperatures, so in order to reach the full capacity, let the battery warm up before use.

Storage at different temperatures will influence the self discharge. If the temperatures is below 20°C every 9 months the battery should be checked and recharged, above 30°C this should be done every 3 months. Storage at temperatures above 40°C will reduce the functional life of the battery. When charging batteries that are stored at temperatures other than room temperature, a charger that accordingly compensates the charge voltage should be used.

A program of stock control must be introduced to ensure that batteries are recharged well before the self discharge below 2,5V/cell. A FIFO usage system is also recommended.

Supplementary Charge Advice

Storage Temperature	*Charging Interval*
20°C or less	Every 9 months
20 - 30°C	Every 6 months
30 - 40°C	Every 3 months

Precautions Against Over Self Discharge

- **Never** subject batteries to an external heat source.
- **Always** store batteries in a cool, dry place
- **Never** store batteries in direct sunlight.
- **Always** regularly check the voltage of batteries in stock.

Precautions for Pre-Installed Batteries

When batteries are installed in a product the following precautions to avoid over discharge during storage must be taken:

- Only new or freshly recharged batteries should be used.
- Any load that is on the battery in the product must be FULLY DISCONNECTED. Any discharge on the battery other than self-discharge will quickly flatten the battery.
- The first operating instruction for equipment fitted and sold with a rechargeable battery must be: "The battery must be fully charged before use.
- Do not mix batteries with different capacities and/or production dates in a single application.
- Do not connect more than four batteries or strings of batteries in parallel without consulting a pbq engineer.

Extremely Low Temperatures

The **pbq** LiFePO$_4$ batteries can be exposed to sub-zero (°C) temperatures without serious damage. However, temperatures below -20^{0}C will damage the battery.

The charging voltage should be temperature compensated when temperature extremes are anticipated. As a guideline, a co-efficient of 5mV/^{0}C/cell with an upper limit of 3.9V is adviced.
Therefore, always charge batteries 100% when extreme low temperatures are expected and never leave discharged batteries at low temperatures. When charging a battery that has been stored in a discharged state at low temperatures, make sure that the battery is fully warmed to room temperature before charging the battery.

DISCHARGE CHARACTERISTICS

General Comments

The discharge curves show the minimum design parameters for each fully charged **pbq** battery after installation. Full capacity is reached after initial service as follows:

- Float Service:
- One month after installation and recharging.

- Cycle Service:
- Within three to five cycles after initial charge and
- service entry.

Capacity

Different from lead acid batteries, Lithium Iron Phosphate batteries do not loose capacity when the drain current increases.
In other words, the product of the service time and the drain current are always close to the rated capacity (C = I x t)

Temperature

The pbq LiFePO$_4$ has a wide temperature range. It operates between -20^{0}C and 60^{0}C. SInce a battery is a chemical process, the performance will reduce under cold (-20^{0}C) circumstances. A lithium iron battery has approximately 55% to 60% remaining capacity when it is fully charged.

Aging

Although pbq LiFePO$_4$ batteries have a respectable float and cyclic life, the batteries get old. Depending on the use like Depth of Discharge and environmental conditions the batteries may last up to 3000 cycles or 10 years in float use.
The aging is caused by the intercalating (falling apart) of the moluecule structure of the negative plate.

Load

The discharge current is expressed in a ratio to the capacity of the battery, the so called C-rate.

F.e. if a 30Ah battery is discharged with a constant current of 6A the c-rate of the discharge current is:

(I / C =) 6A / 30Ah = 0.2C

Protection

The maximum continu discharge current for pbq LiFePO$_4$ batteries is 10C. It allows up to 20C peak discharge current.
The battery is protected against over current. When the voltage drop, caused by a high discharge current, falls under the 2,5V/cell, the protection board switches off the battery power.
If the discharge current causes extreme internal heat, the so called PTC insertion converts the electrolyte in a stable fluid and stops the battery from functioning. This, however, is an irreversable proces.
The protection board also switches off the power if the minimum discharge voltage of 2,5V/cell is reached.
The protection board is reset when a charge voltage is applied to the poles of the battery.

BATTERY SELECTION

Since the capacity of the pbq LiFePO$_4$ battery is hardly affected by the height of the discharge current, the capacity of the required battery simply can be calculated by multiplying the application drain current by the required service cycle time (C = I x t). It is suggested that a review is made together with your **pbq** distribution partner in case of any questions.

Effect of Temperature on Battery Capacity

The nominal battery capacity is based on the temperature of 25°C. Above this temperature the capacity increases marginally but it must be noted that the working battery should be kept within the temperature design limitations of the product. Below 25°C the capacity decreases. This decrease in capacity becomes large at temperatures below 0°C.
The pbq LiFePO$_4$ battery is functional in a temperature range between -20^{0}C and +60^{0}C.
Please be aware that the remaining capacity at -20^{0}C is 55% to 60%.
Also note that the PTC insertion becomes active at an internal temperature of approximately 80^{0}C, causing permanent termionation of the battery output power.
The purpose of the PTC insertion is to avoid a thermal runaway in an early stage. SAFETY FIRST!.

BATTERY CHARGING

Correct battery charging ensures the maximum possible working life for the battery. There is one major method of charging a pbq LiFePO$_4$ battery.

Also read "Connecting batteries ".

Constant Current / Constant Voltage Charging

Constant Current/Constant Voltage charging is the recommended method of charging, also known as CC/CV charging. This is the same recommended method used for charging lead acid batteries
Other then VRLA batteries, there is no difference in the charge voltage for cyclic and float use. The maximum charging voltage is 3,7V/cell. If the applied charge voltage is too low, the battery may not get 100% charged. If the charge voltage is higher than 3,7V/cell, the safety board disconnects the battery.

The battery allows charge currents up to 1C (=1 x capacity of the battery).
The protection board does not limit the charguing current. A too large charging current results in haeting up the internal battery. The PTC insertion will avoit a thermal runaway by neutralizing the electrolyte, and switching off the battery permanently.

Because the battery is not 100% efficient, it is necessary to charge a greater amount of energy into the battery than what was taken out of the battery on discharge. When the remaining charge current is less then 0,01C at a charge voltage of 3,7V/cell, the battery is concidered as 100% charged.

If the charge current contains an AC (Alternating Current) component, the battery can heat up insite. This effect may shorten the lifetime of the battery.
Ensure that the charge current is ripple free.

Effect of Temperature on Charging Voltage

As temperature rises, electrochemical activity in a battery increases. Similarly, as temperature falls, electrochemical activity decreases. Therefore, conversely, as temperature rises charging voltage should be reduced to prevent overcharge, and increased as temperature falls to avoid undercharge. In general (especially where battery temperature changes are greater than 25°C ± 5°C), to assure optimum service life, the use of a temperature compensated charger is recommended.
The recommended compensation factor for **pbq** batteries is:

- -5mV/°C/Cell with a maximum of 3.9V per cell

The following recommendations show general guidelines to optimize the charging process and assure safety of the installation:

- Charge the **pbq** LiFePO$_4$ battery at the recommended 3,7 Volt per cell at 25°C.
- Adjust the charging voltage in accordance to the requirements of operating temperatures other than 25°C when the ambient is expected to be more than 5°C different from this temperature.
- Use a temperature compensated charging voltage if frequent variations of the ambient are expected.
- Do not charge the **pbq** LiFePO$_4$ battery at temperatures above 60°C.
- Make sure there is free flow of air around the individual batteries (At least 2mm spacing between batteries).
- Natural or forced ventilation of the battery area to avoid any accumulation of gas over long periods of time is recommended.

Connecting batteries

When batteries are used in series or in parallel, it is important to have the batteries balanced. Imbalance in the string may result in reduced performance or even damage of - individual - batteries.
Imbalance can be caused by:

- Batteries with different state of health (mix of old and new batteries or production code)
- Batteries with a different state of charge (charged and uncharged batteries)
- Differences caused by temperature (mix of cold and warm batteries
- Different types or brand of batteries.

Avoid the above mentioned occassions by not mixing batteries. Select batteries from the same age, production code, state of health, etc. Acclimatize batteries before connecting.

The best charging performance is reached if a balancer is used while charging when batteries are connected in series.

Series connection
Similar to lead acid batteries, pbq LiFePO$_4$ easily can be connected in series in order to increase the total battery voltage to the required level.
It is obvious that the voltage limitations increase liniar with the number of cells/batteries connected in series.
It is important to understand that there are only 4 cells to create a 12V battery.
The table below outlines the voltage limitations when pbq LiFePO$_4$ batteries are connected in series.

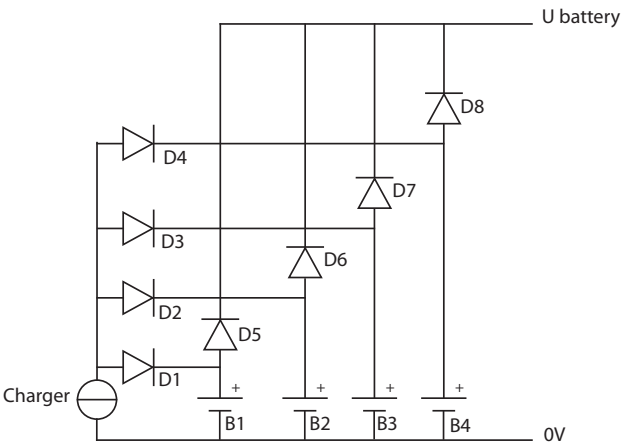
Values in Volts	1S	2S	3S	4S
Nominal voltage	12,8	25,6	38,4	51,2
Charge voltage	14,8	29,6	44,4	59,2
End of discharge voltage	10	20	30	40

When charging batteries in series, it is important to understand that imbalance between the batteries will cause that not all batteries are charged 100%. The imbalance creates the largest voltage drop over the battery with the largest impedance. If the voltage over this particular battery is larger than 14,8V, the safety board will switch off and interupt the charging process.

To work aroud this phenomenon there are two options

- Use a balancer; it will take care that all batteries are charged equally.
- Charge each battery individual; there is no need to disconnect the batteries, if all batteries are charged individual at the same time. DO NOT connect one charger over each battery simultaneously.

Parallel connection
You can connect pbq LiFePO$_4$ batteries in parallel if you require larger capacities.
When batteries are connected in parallel, they may charge eachother if there is imbalace between the cells. Respect the advices above to avoid imbalance. Still then imbalance is possible. F.e. one battery may age quicker than the other one.
If there is a major difference between the batteries, thay may damage eachother.
The key to intercept this problem is to apply diodes.
The image below demonstrates how a group of parallel switched batteries are protected agains reversed currents from other batteries in the string.



Diodes D1 to D4 must allow a forward current (I_f) that is at least as high as the charge current.
Diodes D5 to D8 must allow a forward current (I_f) that is at least as high as the maximum discharge current.

All diodes (D1 to D8) must hold a reversed current as high as possible.
Since diodes claim a fixed voltage (V_f) it is adviced to select a diode with a low forward voltage. Schottky diodes typically have a low forward voltage.

The typical forward voltage of diodes D1 to D4 is subtracted from the charge voltage.
F.e.: The V_f of selected diodes D1 to D4 is 0,4V. If the charger voltage is 14,8V, the batteries are charged with (14,8V - 0,4V =) 14,4V.
The typical forward voltage of diodes D5 to D8 is subtracted from the battery voltage (U battery).
F.e.: The V_f of selected diodes D1 to D4 is 0,4V. If the battery voltage is 12,5V at a certain moment, the output voltage of the batteries string is (12,5V - 0,4V =) 12,1V.

Handling precausions

Safety board

The pbq LiFePO$_4$ battery is equiped with a safety board. The purpose of this feature is to protect the user and the battery. The safety board mainly restrict the voltage limits. The maximum voltage for the pbq LiFePO$_4$ battery is 3.7V while the minimum voltage is 2,5V.

The safety board does not limit the current. The battery itself does have current limits. The maximum charge current is 1C and the maximum discharge current is 10C.
Silimar to any other chemistry misuse of the battery may result in permanent damage.
Exceeding the current limits may result in

- Voltage drop; the safety board will switch off on the preset voltage limits.
- Internal heating; the PTC insertion will neutralize the electrolyte at 80^{0}C and paralize the battery permanently to avoid thermal runaway
- Extreme heat on the poles (f.e. shortcutting the battery); the aluminium tabs have a relative low flamepoint and burn away in fractions of a second, the current flow is interupted permanently.

Additionally to the mentioned safety features above, the contruction of the battery and the implemantation of the chemistry dots the i's and crosses the t's where it concerns safety. It is obvious that the pbq LiFePO$_4$ battery is an extreme safe battery to use.

Balancing

Beside the safety features of the protection board, the internal electronics take care that all the cells inside the casing remain on a same voltage level. This avoids reversed currents and extents the life of each individual cell in tha battery.
Leveling the voltage of the cells is called balancing.

Supplementary advice

1. Don't leave a battery in a discharged condition.
2. Never allow a battery to fall below 2.5Vpc in storage. If the Voc is less than 2.5Vpc, the nominal battery capacity may not be achieved and the actual service life decreased.
3. Maximum continuous discharge current is 10CA.
4. Avoid over discharging the battery.
5. Stored batteries should receive a supplementary charge if they are to achieve their service design life.
6. Ensure the operating temperature is below 60ºC.

Storage

1. When storing the batteries, be sure to remove them from the equipment or disconnect them from the charger and load. Keep them in a place where the air is dry and the temperature is sufficiently low.
2. Charge the batteries, at least once, every six months during storage.
3. The batteries gradually deteriorate even during storage.

Other Precautionary Measures

1. When cleaning the batteries, use soft cloth only. Use of organic solvents such as gasoline or thinner and application or adherence of oil to the batteries must be avoided. Do not clean the batteries using a dirty or an oily cloth. Also contact with PVC material must be avoided.
2. Batteries may generate flammable gas in some cases. Do not expose them to flame or excess heat. Do not short out batteries.
3. Do not attempt to disassemble the batteries. Avoid contact with electrolyte that may leak from physically damaged batteries. If contact is made with skin or clothes, rinse the area generously with water. If contact is made with the eyes, wash them thoroughly with large amounts of clean water, and consult a physician immediately. Consult the MSDS for immediate assistance and a doctor for medical care.
4. Batteries can explode if put into a fire. Never dispose batteries in a fire.
5. Mixed usage of batteries differing in capacity, type, manufacturer or history of use (charge/discharge operation) may damage the batteries and the equipment due to the difference in their characteristic values. This practice must be avoided at all costs.
6. While our batteries are exceptionally dependable, we do not recommend use in life support medical applications unless there is an alternate battery or back-up power supply.
7. When the batteries come to their end of life, discharge duration time becomes drastically reduced. And finally, batteries lose their available capacity by intercalating of the plates and electrolyte. Therefore, please consider the design of the charger with regard to the above battery damage modes, such as short-circuit protection for the output.

Disposal

The disposal of batteries is regulated by the European community and local authorities.
Accredited recycling companies are responsable for proper recycling of the batteries and have to deal with all the different types of batteries and chemistries.
pbq feels, it is part of her responcibility to support to all parties in the chain, including recyclers.

Of course pbq LiFePO$_4$ batteries are labeled according to the battery directives.
Additional to that the pbq LiFePO$_4$ battery container has a distinguished blue container color. Recyclers will regognize the casing rather than searching for data on the label.
The pbq LiFePO$_4$ battery container is relatively easy to dismantle. The different components, like casing, lid, electronics and retired cells can easily be separated. The battery does not have to be shreddered which is a risky operation with Lithium batteries in general.

DO NOT DISMANTLE THE BATTERY.
Retired and disposed batteries should only be dismantled by official recycling companies.

Dismantleing the battery may lead to:

- injury, burns, contact to chemicals, etc
- smoke, fire or explosion
- internal damage of the battery

Statements

WEEE
The WEEE is the European directive 2002/96/EC discribing how waste of electrical and electronic equipment should be treated.

RoHS
Directive 2002/95/EC is the restriction of hazardous substances in electric and electronic equipment.

CE
CE is the abbreviation for Conformité Européene. The CE mark is mandatory for different product groups.Electric and electronic components must comply to the EMC, ESD and Low voltage directive to carry the CE marking.

The above mentioned directives are not applicable on batteries. pbq LiFePO$_4$ however contain a safety board. The directives are applicable on the safety boards inside.
For batteries there is a separate battery directive

Battery directive
Directive 2006/66/EC is the battery directive and is aplicable on batteries and accumulators and waste batteries and accumulators. CE marking is not mandatory under this directive.

REACH
REACH is European regualtion and the abbreviation for **R**egistration, **E**valuation, **A**uthorisation and restriction of **CH**emicals.

Downloading of the statements
pbq batteries comply to all the above mentioned directives. Should you require a printed copy of the statement, please visit **www.pbq-batteries.com** and follow the route to the different downloadable statements.
You will also find **MSDS sheets** for the different chemistries.

UN38.3 T1 to T8
For transportation of lithium batteries a declaration that the battery comply to the UN 38.3 test is required.
The MSDS of the pbq LiFePO$_4$ states, under point 14. Transportation, that the batteries are in compliance with the UN38.3 requirements.

Before using the first time

For safety reason during transportation, the battery is charged for approximately 50%.

Before using the battery for the first time, charge the battery to 100%.