# Solar Stik® Technical Bulletin 5

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## Lithium Batteries, Expander Pak 2400s, and Their Battery Management Systems

**This Technical Bulletin is focused on the individual battery cells that are integrated into the Li Expander Pak 2400. The multi-tiered Battery Management System (BMS) that maintains the batteries and the cascade of events that could lead to worst-case scenarios are explained. Additionally, safeguards to prevent failure are discussed.**

### $LiFePO_4$ TECHNOLOGY:

The Solar Stik Li Expander Pak 2400s contain a custom, Ultralife $LiFePO_4$ battery module that was designed, tested, and UN certified for use in the Solar Stik System.

There are significant advantages to using $LiFeP0_4$ batteries:

- Very high cycle life > 3000 cycles
- Rapid and deep discharges (can go to near 0% without hurting the cells*)
- Very rapid recharge
- Very high energy density: twice that of lead-acid; double the energy for its weight
- $LiFeP0_4$ battery chemistry is as safe as lead-acid
- Other than air cargo, transport regulations that are the same as for lead-acid

*Batteries must not be stored in a discharged state or they may become permanently damaged.

In most respects, $LiFeP0_4$ batteries are very durable, but they do not tolerate abuse well. “Abuse” can be defined as:

- Being stored in a discharged state
- Extreme high heat environment

Either one of these forms of abuse alone could cause damage while the battery is not in service. A combination of these abuses will (most likely) cause damage while the battery is not in service. The duration of exposure to high heat will be directly correlated to the amount of damage done. These phenomena are not unique to $LiFeP0_4$ batteries.

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Storing the Li Expander Pak 2400s in a hot container is unavoidable at times; however, the damage can be mitigated in two ways:

1) ALWAYS charge the Expander Paks fully before storage.

2) If the Li Expander Pak 2400s are stored in a high-temperature environment for more than 3 months, perform a maintenance charge on the system at 3 months. The maximum time between services (FULL-recharging) for a system stored in a climate-controlled environment is 6 months. If it is stored in a high-heat environment, then more frequent inspection/ charging is absolutely necessary.

Unlike lead-acid batteries, THE VOLTAGE OF A $LiFePO_4$ CELL IS NOT AN INDICATION OF THE BATTERY'S STATE OF CHARGE! This is a very important factor in understanding how to diagnose and maintain these batteries properly. $LiFePO_4$ chemistry batteries maintain high voltages up to the point that they are fully discharged, at which point the voltage will drop rapidly. This makes it difficult to use the battery's voltage to determine the actual SOC. This is precisely why regimented maintenance charging is vital.

**OVERVIEW - Li Expander Pak 2400 PROTECTION CIRCUITS:**

Lithium batteries operate in a much more confined spectrum of voltage and current than lead-acid batteries. Under/Over-voltage conditions are tightly regulated by an internal protection circuit. However, just as with lead-acid, irreversible damage can occur to a lithium cell when it is discharged below a certain voltage (Li Expander Pak 2400 is 2.5 V/cell) for an extended period of time.

The Ultralife battery modules installed in the Li Expander Pak 2400s consist of eight (8) $LiFePO_4$ "super-cells". These cells require a complex BMS, which manages the super cells and their protection circuits. The BMS is solely responsible for enabling or disabling the battery "terminals" where any external circuit is connected (i.e., load, PRO-Verter, solar charging source, etc.), and through which all current flows in and out. Each super-cell has a cell-balancing device to make sure all of the cells in a battery are charged evenly and are synchronized with the other cells as they charge and discharge.

NOTE: Eight (8) super-cells wired in series that are each at 2.5 V means that the "battery voltage" is 20 V, which is the "terminal disconnect voltage" or low state-of-charge threshold. If the eight (8) super cells are all at 2.9 V, then the battery voltage will be 23.2 V (terminal connection voltage). For the purposes of this discussion, we will be referring to the individual cell voltage because one cell alone at 2.5 V can cause the entire battery module to stop working.



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**THE BATTERY MANAGEMENT SYSTEM (BMS)**

The Li Expander Pak 2400 battery BMS has two controller boards: one for PROTECTION and one for the BATTERY STATUS LED located on the outside of the Expander Pak 2400 case.

- The PROTECTION circuit monitors the cell voltages (balancing), temperatures, and current going through the battery. It also controls the input/output of the battery; when all of the conditions are good, current can flow in/out of the battery terminals. If the temperature, voltage, or current are outside of their preset limits, then the battery terminals are disabled and no current can flow in/out.

- The BATTERY STATUS LED circuit monitors the output of the battery. If the STATUS LED controller senses the output has been disabled, for any reason, it turns the LED to RED. The Battery STATUS LED is not connected to the BMS-computed SOC; it is only monitoring the output of the battery and indicating to the user if the terminals of the battery are active or not.

Without the BMS PROTECTION circuit, there would be a significant safety risk. For example, if charging voltage and current are applied to a battery with dead or damaged lithium cells and no BMS, the remaining (functioning) cells would be exposed to higher individual voltages in order to compensate for the loss of dead cells in the battery. The external charging circuits would attempt to function by keeping the battery at its prescribed operating voltage, completely unaware that individual cells in the battery were being over-charged. With a BMS installed, however, the failure of a cell will trigger the PROTECTION circuit; thus the battery can (and will) protect itself (and the operator).

Charging mechanisms used with ANY Li Expander Pak 2400 do not have the ability to recognize when a cell in a battery module has failed, or by extension, when a battery has removed itself from service. In any lithium battery that is made of multiple cells, that is the exclusive role of the BMS. External charging sources such as solar, vehicular, and the AC circuit will continue to attempt to charge at their set charging voltage values (in this case, at about 28 V) regardless of an individual cell's health or SOC.  If one battery drops out of service, the system voltage is not affected, and the loss of one battery will have minimal impact on the overall system performance. If this situation is amplified, and multiple Expander Pak 2400s are removed from the system, then the system's performance will progressively degrade.

Additional notes about the BMS:

- The BMS is the key feature enabling the battery to handle high charge and discharge rates (up to 50 A each), and also allows multiple batteries to be used in concert (in a scaled configuration).

- In order for a scaled battery bank (multiple Li Expander Pak 2400s in a parallel connection) to function properly, the individual battery BMS must be synchronized with each other.  This is accomplished by fully cycling the bank 2-3 times after the batteries are connected together.


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**Li Expander Pak 2400 IN AN OVER-DISCHARGED STATE:**

It only takes ONE super-cell to reach a voltage of 2.5 VDC in an Li Expander Pak 2400 to cause an over-discharged condition. This is also considered 0% SOC for the whole battery... If the BMS senses that one cell has breached this low-voltage threshold, the PROTECTION circuit will immediately deactivate the battery terminals. This will protect the cell from going into a deeply discharged state, which can cause damage to the individual cell.

The STATUS LED will go RED because the output is disabled, and it will remain RED as long as this condition exists.

If the BMS has disconnected the battery terminals from service due to low SOC, it will continuously scan the terminals to see when charging voltage is being applied so that it can reconnect the battery into service. This “sense” circuit is very active when the battery is first disconnected at the terminals due to low SOC If the discharged condition persists and the cells are not recharged in a timely fashion, the cell voltages continue deteriorate.

**BMS OPERATION WHILE IN OVER-DISCHARGED STATE:**

$LiFePO_4$ battery cells, as discussed earlier, will drop in voltage very quickly when they have reached low SOC. The BMS will disconnect the terminals to prevent further discharge by an external component, but the BMS itself requires power to operate.

THE BMS WILL CONTINUE TO USE POWER FROM THE CELLS TO PERFORM ITS PRIMARY FUNCTIONS, even if the battery has disconnected itself from service. The cells will continue to discharge internally in support of the BMS functions, and the voltage can fall very rapidly to the point of non-recovery.

If the battery PROTECTION circuit is engaged due to low SOC, you can be sure there is precious little energy left in the battery, so timely recharging is of UTMOST importance at this stage.

As time passes and the cells continue to lose voltage, the BMS will slow down its functions to preserve as much energy in the cells as is possible.

One of these functions is to search for charging voltage at the battery terminals. Once the battery terminals are disconnected from service, the BMS uses a sense circuit to pulse the terminals, sensing for voltage. Once the presence of higher voltage (greater that 23.2 V) is sensed at the terminals, it will begin allowing charging current into the cells.

The longer the battery has been in the discharged state, the greater the interval between the pulses; thus, the longer the charge voltage must be applied in order for the BMS to sense the voltage. In extreme cases where the cells have remained at the “over-discharged” state for an extended period, the BMS will only sporadically pulse the terminals; therefore, the Li Expander Pak 2400 may need to remain connected to a charging source for multiple days in order for the BMS to allow enough power back in through the terminals to effect a recovery.

**“BRICKING” A $LiFePO_4$ BATTERY**

As soon as the BMS senses the cell voltage is too low to discharge further, time is of the essence to place the batteries on charge. Failure to do this may cause a fatal error known as “bricking”.

Once the batteries reach their internal “disconnect” voltage, the voltage can fall very rapidly in the internal cells, causing the battery to “brick”. This means that the battery cells are non-recoverable, and the battery module must be replaced.

**DISPOSAL OF A “BRICKED” BATTERY**

When a $LiFePO_4$ battery is 100% discharged, the cells lose any hazardous properties. They are inert and safe, and can be disposed of properly and safely using any common method. The ingredients used in the creation of the $LiFePO_4$ cells are fully biodegradable.

Alternately, the batteries can also be shipped back for cell-replacement using standard shipping methods. If they are truly discharged, there are no hazardous properties and therefore there are no shipping restrictions or labeling required.

**SELF-RECOVERY FROM AN OVER-DISCHARGED STATE**

It is possible for a battery to “self-recover” from an over-discharged condition.

If the battery is discharged slowly (low current) there is a small chance the STATUS LED will turn GREEN again, as the voltage will not recover as much. However, there is a high chance the STATUS LED will turn GREEN again if the battery is discharged quickly (high current) to the point where the terminal disconnect voltage is reached. When they are allowed to rest from a rapid discharge, the cell voltages will start to rise. When the cell voltage recovers back above 2.9 V, the PROTECTION chip will enable the output of the battery, as it has determined there is some energy left in the cells and they are not in danger of being damaged. When the output is enabled again, the STATUS LED circuit will sense this and turn the LED GREEN since there is power at the terminals.

If this condition occurs, the battery should immediately be put into charge mode.