APPLICATION NOTES

Circuit Protection for Lithium-Ion and Lithium Polymer Rechargeable Battery Applications

The introduction of portable devices with advanced features and the demand for longer run times and has resulted in innovations in the battery technologies used for portable applications. The latest generation of battery technologies has met these needs by increasing the energy density of the battery cell. The increase in energy density allows low voltage applications such as mobile phones to operate off of a single cell, and multiple cell applications to achieve longer operating times. The energy density change has also required that protection circuits be included with all rechargeable Lithium-Ion and Lithium Polymer battery packs. Protection circuits in packs include a control IC, MOSFET switch, external capacitor for IC timing to prevent inadvertent MOSFET operation, capacitors or varistors to protect against ESD and system transients, and secondary protection devices. The control IC and MOSFET provide primary protection for the pack during both charge and discharge cycles. This protection circuitry is offered in a single package solution for battery pack protection. While the primary protection circuit is reliable, to ensure complete user safety secondary protection devices are included to protect in situations outside of the normal range of operation. The secondary protection is provided by the use of overcurrent protection devices.

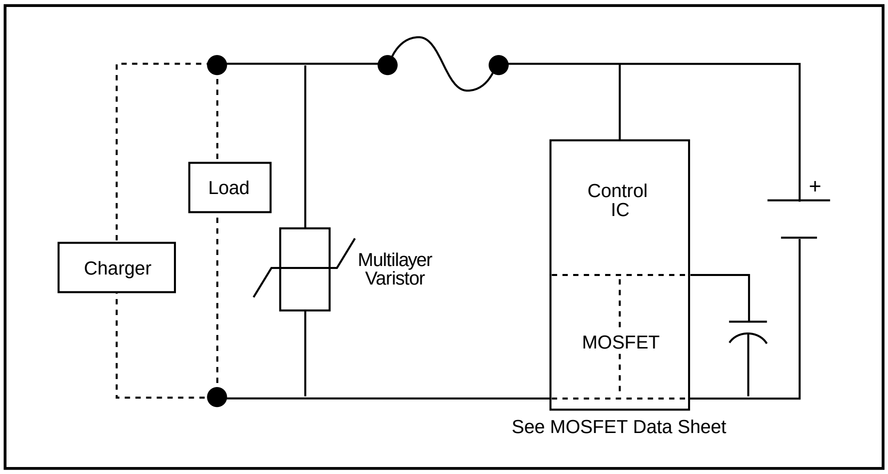

Figure1. The overcurrent device is placed in series with the primary protection circuit.

Battery Pack Circuit Protection Requirements

Lithium-Ion and Lithium Polymer battery technologies require protection from short circuit discharges, improper charging and overheating. A short circuit condition can occur when the output terminals of the battery pack are bridged by a conductive object. This could be caused by items as simple as coins or keys touching the terminals of the pack. A short circuit condition in a fully charged multi-cell pack can generate short circuit currents in excess of 50 amperes. This can result in fire to the pack or surrounding materials. The primary protection circuit is designed to allow for peak discharge currents without interrupting the circuit but will operate to limit the current when the discharge exceeds a predetermined current level for a specified time period (1-15 ms).

The charging conditions for Lithium-Ion and Lithium Polymer cells use constant current/constant voltage. The charge circuits are designed to monitor the pack voltage to determine state of charge and cease charging once the specified voltage has been reached. The primary protection circuit in the pack senses the voltage level and is designed to disable the charge circuit after a predetermined voltage level is exceeded for a specified time period. In the event that the cell voltage exceeds its maximum level, the cell can enter a thermal runaway condition where the cell temperature can exceed 125°C. At this temperature the cell may explode and erupt into flames.

In many battery packs, the primary protection circuit will disable the charge circuit upon reaching the maximum voltage but the discharge circuit is still enabled. This is the most dangerous condition for a short circuit as the battery is fully charged.

During the charge cycle the primary protection circuit in the battery pack is designed to allow charging until the maximum voltage is reached. Under the condition where a fully discharged cell is subjected to an excessive charge current the IC and MOSFET will not operate until the voltage exceeds the maximum level. This may not occur until significant damage is done to the battery pack. The use of a properly sized overcurrent device as secondary protection in the battery pack will result in the limiting the current before damage is caused and long before the primary circuit reaches the maximum voltage where it will operate to interrupt the charge cycle.

The secondary protection circuits are required to prevent both the short circuit and thermal runaway conditions in the event the primary circuit does not operate properly. The primary circuit is susceptible to ESD damage and thermal overstress. The silicon structures of the primary protection circuitry have a potential for failing in a shorted condition allowing energy to flow in the event the protection circuit is damaged. In the event that the primary circuit has been damaged by ESD or thermal overstress secondary protection from an overcurrent device will provide protection from both overcharge and overdischarge. During discharge the overcurrent device will limit a short circuit current, which an undamaged primary circuit would have handled, before excessive temperatures can occur in the pack or external damage is caused. On charging excessive currents that have damaged the primary protection circuit will be interrupted by an overcurrent device. Packs designed for applications where they can be charged by an automotive charger should always implement secondary overcurrent protection. The charge currents from the automobile can exceed 50 amperes causing immediate damage to the primary protection circuitry and the battery cells.

3rd Party Charger Hazards

The battery chargers supplied with portable devices are typically designed by the original equipment manufacturer (OEM) and are tested to ensure safe operation with the portable device and battery pack. Unfortunately the use of chargers purchased separately may result in improper charge cycles. The end user may have selected the wrong charger or the charger selected may not have been designed to properly coordinate charge protection. The proliferation of charge adapters for the automobile and airplane have increased the risk for improper charge conditions.

The use of an overcurrent device as a secondary protection circuit will provide protection from excessive current early in the charge cycle, in a short circuit condition that exceeds the power handling capability of the primary protection circuitry and in the event of circuit failure.

Selection of Secondary Overcurrent Protection

The two primary methods for providing secondary overcurrent protection in Lithium-Ion and Lithium Polymer battery packs are one time fuses and resettable polymer PTC devices. Both devices provide protection from current surges but operate in different methods.

The polymer PTC devices are made from a mix of conductive particles and polymer, which are designed to separate upon heating and result in a non-linear shift in resistance. The heating occurs when the device is subjected to an overcurrent event beyond its specified operating range. The shift to a high resistance state limits the current until the source of the fault is removed. A one-time fuse uses a conductive metal that is designed to melt at a specified current level and interrupt the circuit.

The most obvious difference between the two technologies is resettability but there are other factors to consider when selecting an overcurrent device for battery pack protection. A critical factor is the resistance of the protection device. The resistance of polymer PTCs for battery protection can range from 0.015 to 0.250 ohms depending on the rating and terminal configuration. The polymer PTC resistance also will normally shift upwards upon initial operation. The resistance of fuses for battery pack applications is between 0.005 and 0.035 ohms and will be maintained over the life of the device. The lower resistance can have a significant impact on battery life in many applications.

In addition the size and configuration of each technology may dictate which solution is used. The PTC products are available in either a strap configuration or surface mount. Due to limitations in the PTC technology the smallest strap devices are over 12.7 mm (.500") in length. The strap devices must be welded to the battery pack terminals for proper assembly. Surface mount versions of the polymer PTCs are available but the ratings required to prevent nuisance tripping are still 4.57 × 3.04 mm (.180 × .120") in size. High amperage fuses, up to 7 amperes, are available in surface mount packages measuring as small as 3.18 × 1.52 mm (.125 × .060"). Both surface mount fuses and polymer PTCs require a substrate to mount to. While previous battery pack technologies such as Ni-Cd or Ni-Mh were not suited for surface mount solutions the Lithium technologies require a primary protection circuit which is surface mounted. This provides the option of using a surface mount device for secondary protection, which can be placed using automated equipment to lower the overall pack cost.

While the resettability is a desirable function in many applications where there is significant user contact, such as computer ports, the use in a safety critical application requires some additional considerations. Because the overcurrent device is providing secondary protection in the case of primary protection failure the resettable feature may be a disadvantage. The primary protection circuit uses a control IC/MOSFET that is resettable. It monitors the circuit conditions as resets when the voltage and current return to normal operating levels. In the event the secondary overcurrent device operates this would signal a condition where the primary was not able to trigger properly. A polymer PTC solution would resume conducting current once the fault is removed. In this situation it is likely that a damaged protection circuit is put into operation. The advantage of a one time fuse is that the circuit is permanently disabled and the pack will be inoperable until replaced. It eliminates the possibility of a damaged safety circuit being put into operation.

Model and Rating Selection

Based on form factor, resistance and safety level analysis the device selection can be conducted. The key circuit parameters which must be determined is the normal operating current of the circuit under both charge and discharge, the maximum fault current, any current pulses and the primary protection circuit response time to an overcurrent event.

The overcurrent device selected must have a normal operating current above the charge and discharge current levels. The rating selection must take into account any ambient temperature conditions and appropriate device rerating should be conducted using the manufacturers' recommendations.

Once the appropriate normal operating rating is determined the form factor desired will present a number of models which may meet the parameters of the circuit. The model selected must have an interrupting rating greater than the maximum fault current of the application. This will allow the secondary protection device to safely interrupt the overcurrent event.

After the model and normal operating rating have been determined the device must be checked to verify that it will withstand surge currents which may occur. The surge currents are normally caused by start up pulses, or in some applications transmit pulses such as a mobile phone. In addition to the normal pulses, the use of the device as a secondary protection circuit requires that it be coordinated with the primary protection circuit. Circuit designers will normally specify a secondary protection device that is sized to open only under primary protection failure or very large current surges. Because the IC control/MOSFET solution is resettable it will be sized to operate under all normal fault conditions. Under a short circuit the IC/MOSFET circuitry has a built in delay time before it operates. This delay time in a short circuit condition creates an additional pulse that must be compensated for when selecting a fuse to prevent nuisance opening. The delay pulse is usually the largest pulse that the circuit will see and the fuse should be selected to withstand repetitions of this pulse. Consult the I2t rating of the fuse selected and the pulse cycle withstand calculations to ensure proper coordination with the primary protection circuitry.

For single cell battery pack applications the Littelfuse 429 series 4 to 7 ampere ratings provide coordinated protection for many primary protection circuits. For single cell applications where the IC delay time is minimized lower ratings and smaller sizes may be appropriate. The 435 series is available up to 2 amperes in a surface mount package as small as 1.04 × .51 mm (.041 × .020") and the 434 series is available up to 5 amperes in an 1.60 × .813 mm (.060 × .032") package.

For applications where higher energy surge currents are likely to occur, Slo-Blo® Fuses are available, including the 430 and 452 series.

For multiple cell packs the 451 series is available in ratings up to 15 amperes to meet the higher discharge currents.

Conclusion

The use of an overcurrent device as a secondary protection circuit will provide protection from excessive current early in the charge cycle, in a short circuit condition that exceeds the power handling capability of the primary protection circuitry and in the event of circuit failure. With the increased use of Lithium-Ion and Lithium Polymer battery packs in applications where user safety is critical the implementation of secondary protection circuits will ensure an unsurpassed level of safety with minimal cost impact.

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