FAULT PROTECTION FOR BATTERY MONITORING SYSTEMS

Charles E. Burns
Senior Electrical Engineer
American Power Conversion Corporation

INTRODUCTION

Battery monitoring systems have been in use for several years and have gained acceptance in a variety of applications. The battery terminals to which these monitoring systems are connected can potentially deliver thousands of short circuit amperes at voltage potentials equal to that of the entire string. This paper will present some considerations regarding personnel safety and selection of devices for clearing faults successfully and safely. Examples of various protection devices that are commonly used will be shown and oscilloscope traces showing the current and voltage versus time using both correct and incorrect voltage rating fuses to clear short circuit DC faults.

THE BATTERY STRING AND THE CONNECTED CIRCUITS

In certain applications, many individual cells are connected together in series to provide the desired string voltage. A series circuit consisting of batteries, monitoring equipment, connectors, cables, load switches and the attached loads are shown in Figure 1. There may be parallel load devices, such as the charging equipment, monitoring systems, indicator lights and test equipment that remain connected directly to the string resulting in a situation where the main load switch does not completely open the battery circuit.

When a battery circuit is terminated by even a very small load path and then opened at any point within the circuit, the entire string voltage will appear across the open part of the circuit that has been created. In this case, it is the main load switch. For example, the full string voltage will be present between the battery post and the strap, the moment that it is disconnected. Thus, the entire string voltage will also appear across the terminals of a single cell if the electrolyte has leaked out. The string voltage can be 540 volts on large UPS applications where 240 or more cells are connected in series. Refer to Figure 1.

PERSONNEL SAFETY

Personnel who work around battery strings must be made aware of the possibility of the potential hazard that exists when working near any battery terminals. Lethal voltages can appear between an open strap and the battery terminal as discussed above and from the terminals to earth ground if the charging system is not powered from an isolation transformer. A technician could be electrocuted after removing one end of an inter-cell strap from a seemingly “safe” two volt cell or by touching a battery terminal with one hand and a grounded battery rack with the other. Even when the battery disconnect switch is open, a parallel current path might remain attached across the battery’s output and even a small power device can conduct enough current at this voltage to electrocute a person.

EQUIPMENT DAMAGE

Monitoring and test equipment connected to the batteries can also be damaged if the circuit is opened as described above. Because it is not possible to prevent the battery itself from becoming an open circuit, equipment of all types that is attached at any place on the battery circuit must be capable of withstanding the full string voltage under these conditions, otherwise serious damage may occur.

CLEARING OR LIMITING FAULT CURRENT

There are several approaches to dealing with unintended short circuits to ground and from wire-to-wire. These faults can result from a wide range of problems such as damaged wire insulation and short circuits within the connected monitoring and test equipment. It is essential that either fuses to clear the circuit completely or some other means be provided to limit the fault current to a level that will protect the wires and associated equipment from damage, as well as personnel.

CLEARING ALTERNATING CURRENT (AC) AND DIRECT CURRENT (DC) FAULTS

DC systems require special consideration when selecting a fuse device because it is continuous and there is no zero voltage crossover point. Whereas an AC system permits the voltage developed across the clearing gap to gradually reduce to zero and then gradually increase. The zero crossing characteristic of a sine wave in an AC circuit permits a lower device voltage rating than is possible with DC. This is because with AC the arc that is created at the open part of the fuse element is allowed to clear the circuit at a much lower voltage than the continuous voltage and current that is present with DC.

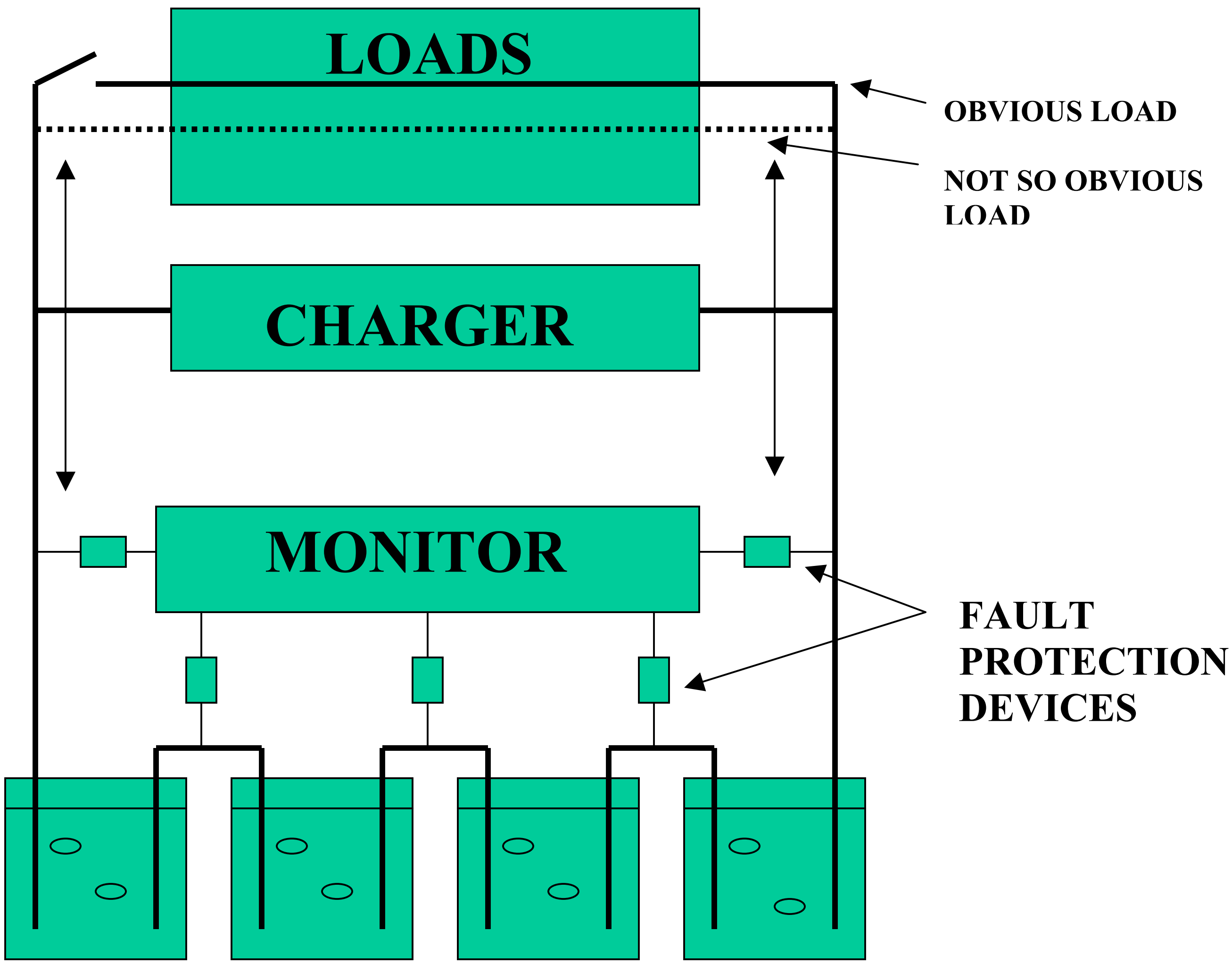

Figure 1
Basic Battery Circuit with Monitoring System

DEVICE VOLTAGE AND POWER RATING

Each fuse or current limiting device that is connected to a battery at any point in the circuit must be rated at the highest voltage found in the string that is to be protected. This means that each fuse or resistor connected to a battery string must be rated at or above the voltage of the entire string in a float charge. For example, a UPS that is floating at 540 volts needs a fuse rating of 600 volts. If the protective device is a resistor designed to limit the current to a safe level, it must also be able to dissipate the power that is developed across it. Using Ohms law at 540 volts, a 1000 ohm resistor would require a power rating of at least 291.6 watts, a 10,000 ohm resistor would require a power rating of at least 29.16 watts and a 100,000 ohm resistor would require a power rating of 2.916 watts. The voltage rating of a fuse is the highest voltage circuit that the devices can safely open under fault conditions. The voltage rating also determines its ability to suppress the internal arcing that occurs when the fuse element melts and an arc is produced across the gap. If a fuse is used with a voltage rating lower than the circuit voltage, arc suppression will be impaired and under some fault current conditions, the fuse may not clear the over-current safely. The "interrupting rating" of a fuse defines the capacity of the protective device to maintain its physical integrity (not break or explode) when reacting to fault currents. Section 110-9 of the National Electric Code requires equipment intended to break current at fault levels to have an interrupting rating sufficient for the current that must be interrupted.

Figure 2 shows a 250 volt rated fuse during a fault condition in a 500 VDC circuit. In this example, the system voltage was twice that of the fuse voltage rating. Both the arc voltage and the fault current are shown. (The bottom trace is inverted)

As the fuse begins to open the fault, a dip is observed. As the fuse starts to clear the complete current, it is followed by a re-strike. The fuse exploded and the level of current actually returned to the full short circuit value.

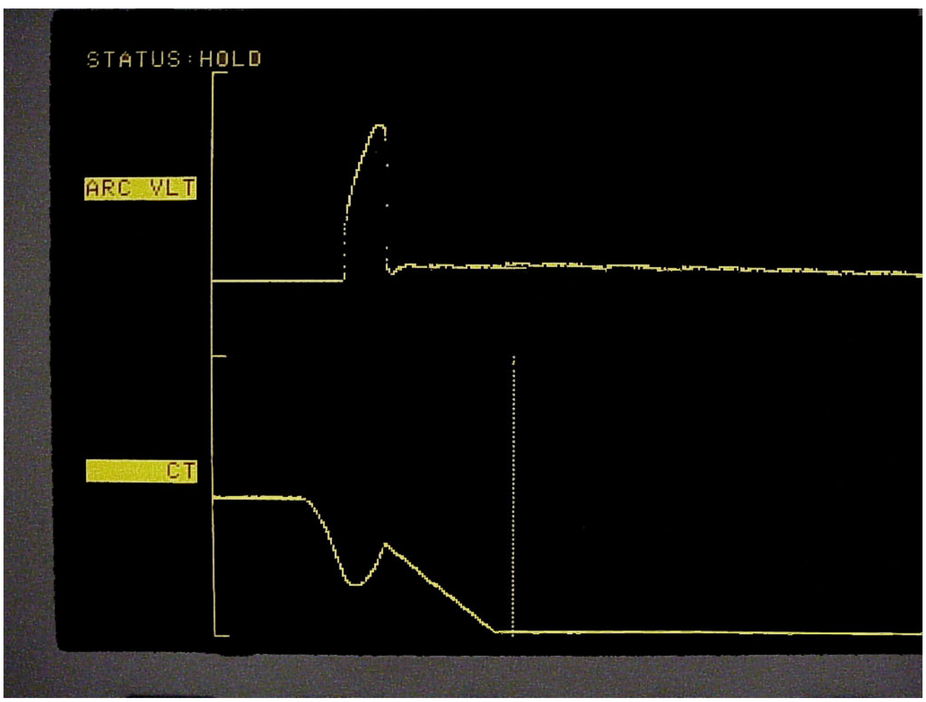

Figure 2 **Courtesy Cooper-Bussman**

250 V Fuse Attempting to Clear a 500 V Circuit Fault

FAULT CLEARING DEVICES USED IN BATTERY MONITORING

Both resistors and fuses will be found in battery monitoring equipment. Figure 3 shows an example of a resistor that is contained inside of a ring terminal assembly. The ring terminal is bolted to the battery post and the resistor is sized to prevent damage if a fault occurs. Unlike a fuse, the resistor should not require replacement after the fault is cleared. Some monitoring systems use fuses in the connections that carry significant discharge current from the battery and resistors in the separate connections and leads that only sense voltage.

MONITORING SYSTEM TEST CURRENTS AND DEVICES

Impedance monitoring requires that a significant fixed alternating current from the monitoring device be applied to a group of cells while the AC voltage drop is measured across each individual cell in the group. The fixed AC current value is divided into the AC voltage drop to derive the impedance value of the cell circuit.

Resistance monitoring requires that a significant fixed direct current be discharged from a group of cells while the DC voltage is measured across each individual cell in the group. The cell voltage during the discharge is subtracted from the voltage before the discharge. This difference value is divided by the fixed discharge current value to derive the circuit resistance.

In both of these cases, the leads that must carry significant test current use fuses while the voltage monitoring leads use resistors to simply limit the fault current. It should be noted that the magnitude of the test currents used by both methods are sufficient to actually cause the circuit they are testing to open. For example when a conductor within the battery is extremely corroded but is still "holding on by a thread", the very small float charge current is not sufficient to break it loose and open the circuit. This is the kind of failure that occurs when the battery is suddenly placed under a significant load and the circuit opens immediately. This means that the full string voltage can likely appear across the input of a monitoring system immediately after a test is initiated.

Battery management systems use fuses exclusively because the same leads are used for both individual charging and monitoring. Since the testing and charging current is small, it is much less likely to cause a corroded battery circuit to open. Whether the monitoring system causes the battery circuit to open or if the load current causes it to open, the monitoring system device must be able to safely open or limit the full string voltage that will suddenly appear as described earlier.

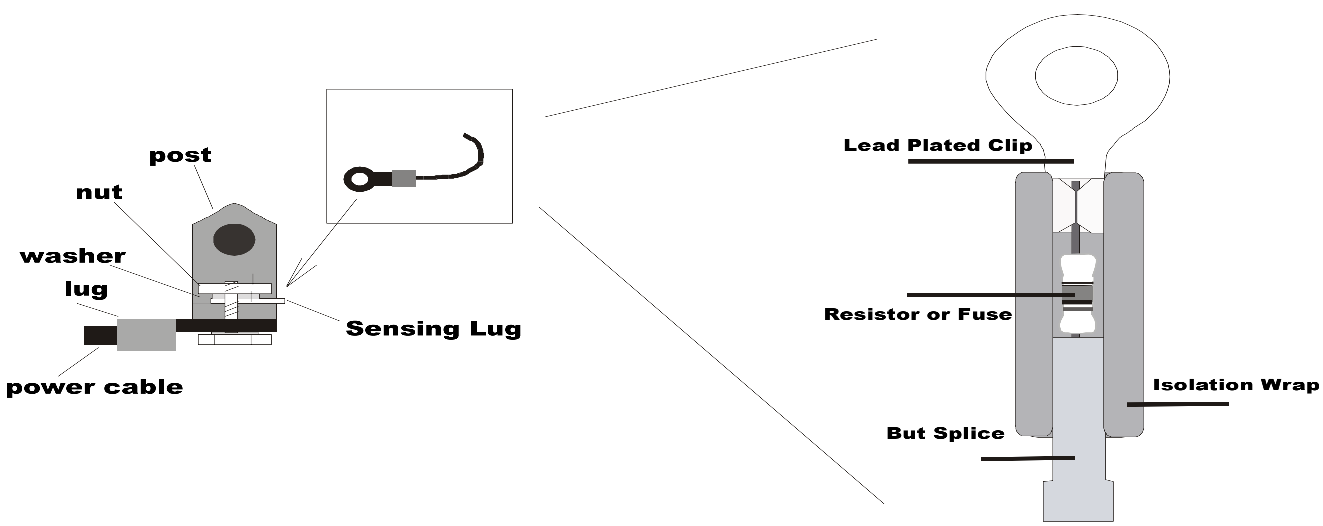

Figure 3
Fused Ring Terminal

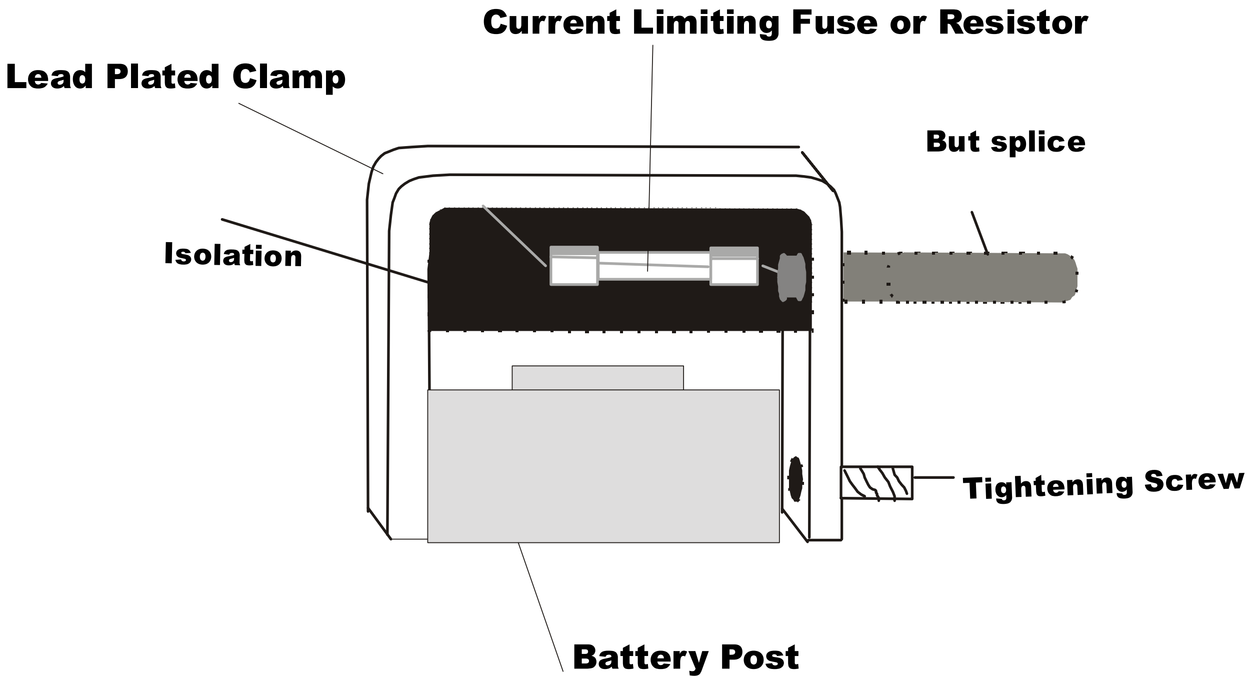

Figure 4
"C" Clamp with Fuse

Figure 5
600V Fuse Assembly with Quick Disconnects

Figure 4 shows a C-Clamp arrangement with an integral fuse included.
Figure 5 shows a 600 volt fuse assembly with quick disconnect terminals mounted on each end. Battery and UPS manufacturers are now pre-installing the mating "tab washers" on battery terminals to accommodate monitoring equipment that use these ¼" "slide on" connectors.

A SHORT CIRCUIT TEST USING A FUSE WITH THE CORRECT VOLTAGE RATING

Figure 6 is the test arrangement that was used to perform a short circuit test using the 600 volt fuse shown in Figure 5. The device was connected and the circuit breaker closed to create the fault. The current waveform was captured on a storage oscilloscope and is shown in Figure 7.

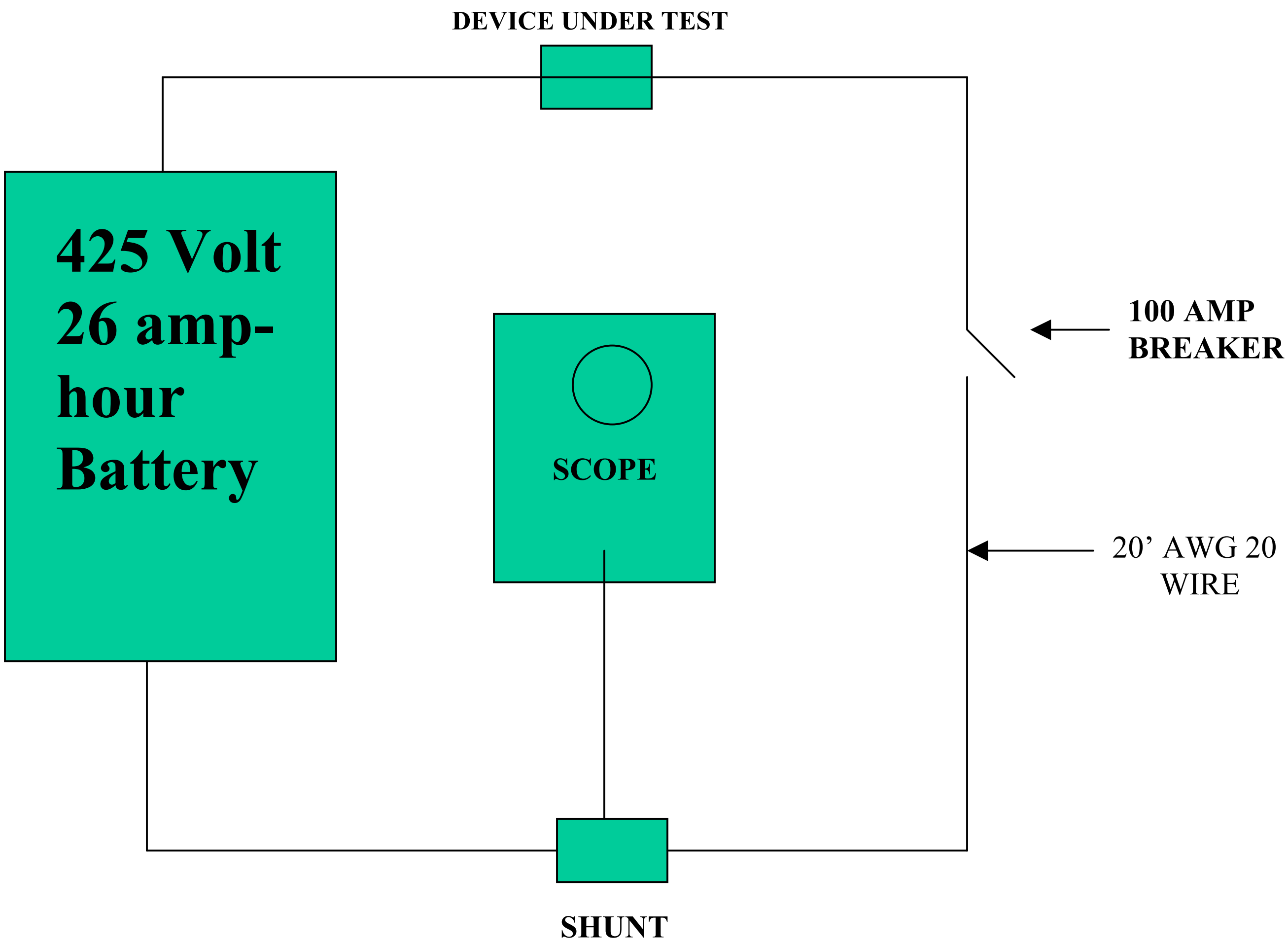

Figure 6
Short Circuit Test Setup Diagram

Fuse device under test: 2 ampere, 600 volt as shown in Figure 5.
Voltage source: 32, 12 volt batteries (26 amp-hours each) in series yielding a total string voltage of 425 volts.
Average internal resistance of each battery was .007 ohms.
Horizontal time base: 50 microseconds per division
Vertical sensitivity: 5 volts per division.
Measurements were taken across a current shunt with a resistance of .0394 ohms.
Signal shown represents a 10 volts/.0394 ohms = 253.8 amperes when the circuit was cleared by the fuse opening.

Note that the opening time was only 100 microseconds and the current development was smooth until the peak and after the circuit opened, no secondary flashes or re-fusing as was seen in Figure 2.

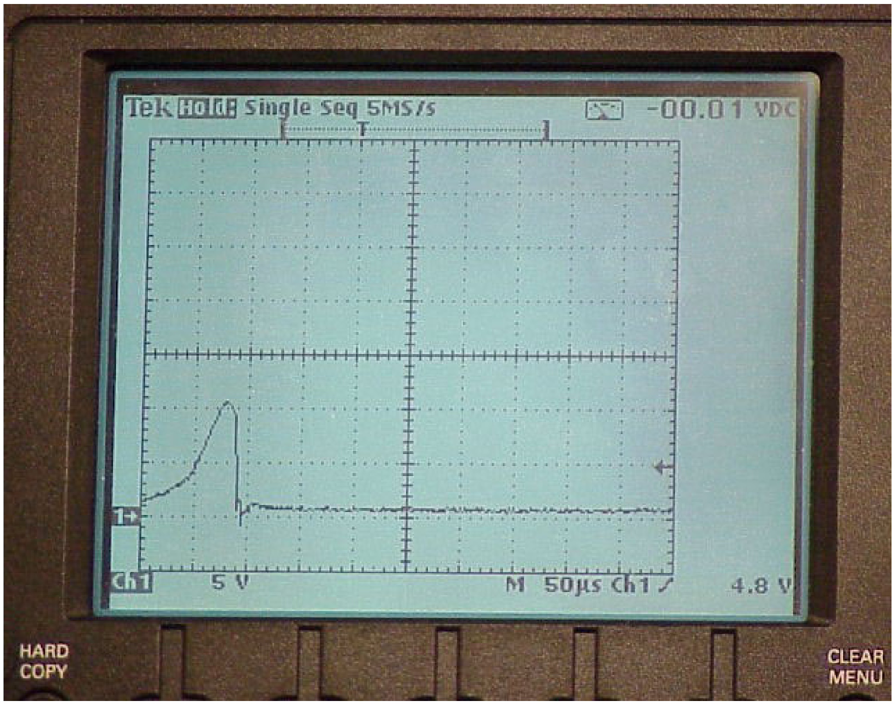

Figure 6
Interruption Event Capture with Properly Rated Fuse

SUMMARY AND CONCLUSIONS

Since the entire string voltage can appear across an open circuit at any place along the battery string, precautions should be taken when working with the battery and connecting equipment to it.

Selection of fault clearing and current limiting devices involves including the voltage that will be present when the battery circuit opens at the connection point. The fault current and voltage at the connection points can be many times greater than would be normally expected.

REFERENCES

Electrical Protection Handbook, Cooper-Bussman Publication #3002
National Electric Code Handbook
IEEE PAR-1491, Guide for Selection of Battery Monitoring Equipment for Stationary Batteries

CONTRIBUTORS

Ed Koepke, Cooper-Bussman
J.P. Yagelowich, American Power Conversion Corporation