DC GROUND FAULT DETECTION PROVIDED FOR UNINTERRUPTIBLE POWER SUPPLIES

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INTRODUCTION

There are concerns among owners and mangers of Uninterruptible Power Supplies (UPS) in the operation of their UPS battery plant(s) to the risk of DC ground faults and to the timely detection and alarming of a ground fault before it can escalate into a serious or catastrophic event.

This paper will address the various mechanisms that can develop into a DC ground fault, the types of batteries that are associated with these faults and the various architectures of UPS, including the various methods of detecting DC ground faults. The paper will present graphical representations of these architectures and the circuits employed in the detection and annunciation of a fault and the apparent level of risk to an event and the sensitivity in the detection of a DC fault.

Four leading UPS manufacturers were contacted as part of this review and are considered to be representative of the industry. The focus of the inquiry is to identify the detection philosophy and circuit design used in UPS systems rated 150 kVA and larger. The paper includes information collected from each manufacturer, both verbal and written, as well as discussions with engineering associates, empirical data, as well as historical data review and analysis.

The primary concerns with any Battery Ground Fault include three principle areas:

1) Risk that the ground fault will develop into a fire.
2) Risk to personnel who must work on or near the battery.
3) Risk to system reliability.

For the purposes of this paper, we shall consider items 1 and 2 resulting from a battery ground fault and the ability to detect such a fault. Consideration for system reliability is beyond the scope of this paper.

CAUSES OF BATTERY GROUND FAULTS

There are several causes for introducing a ground fault into a battery system. The following presents the most common causes for ground faults.

- Dirt on the surface of the container- Dirt and debris left on the surface of the battery can develop paths for tracking to the battery rack. Residual electrolyte left on the container due to maintenance activities can enhance the conduction path created by the dirt exacerbating the level of ground fault.
- Penetration in the container- Any penetration in the container, such as a hole, will allow electrolyte to seep out of the container and contact the battery rack.
- Cracks or crazing of the container-Cracks caused by stress or crazing caused by the use of non approved cleaning materials on containers can result in seepage of electrolyte making contact with battery racks.

UPS TOPOLOGIES

Isolated Input

The long-established UPS topology includes an input isolation transformer used to regulate the desired rectifier/charger input voltage and for isolating the rectifier/charger components from the power source. In the larger UPS modules, typically greater than 500 kVA, the rectifier design is a 12-pulse SCR or IGBT full wave bridge and requires six inputs, three from a Wye configured and three from a Delta configured input transformer that is provided as part of the UPS module. The 3-phase supply realizes a 30° phase shift through the Delta to Wye transformer windings. The result is a "12-pulse" full wave rectified output. Three immediate advantages exist in this design. First the DC ripple voltage is reduced to approximately 3% at a ripple frequency of 720Hz (as opposed to approximately 14% ripple at 360Hz for 6-pulse). This makes DC filtering more efficient and relatively less expensive. The above example is based on a 60 Hz application.

The second advantage is that the reflected distortion introduced onto the incoming supply is reduced by a factor of 4. Should the distortion have been 6% under 6-pulse, this is now reduced to 1.5% with a 12-pulse system. Note that the Input Isolation transformer secondary Wye windings are not grounded.

A third advantage with this design is that the UPS battery string is essentially floating. There is no intentional electrical connection on the DC power path to ground. Figures 1 and 2 represent Isolated Inputs for 12 pulse and 6 pulse rectifier systems. Note that the resistive bridge circuit represented in each is the ground fault detection circuit and is comprised of high value resistors or other components providing isolation of the circuit common ground reference from the battery.

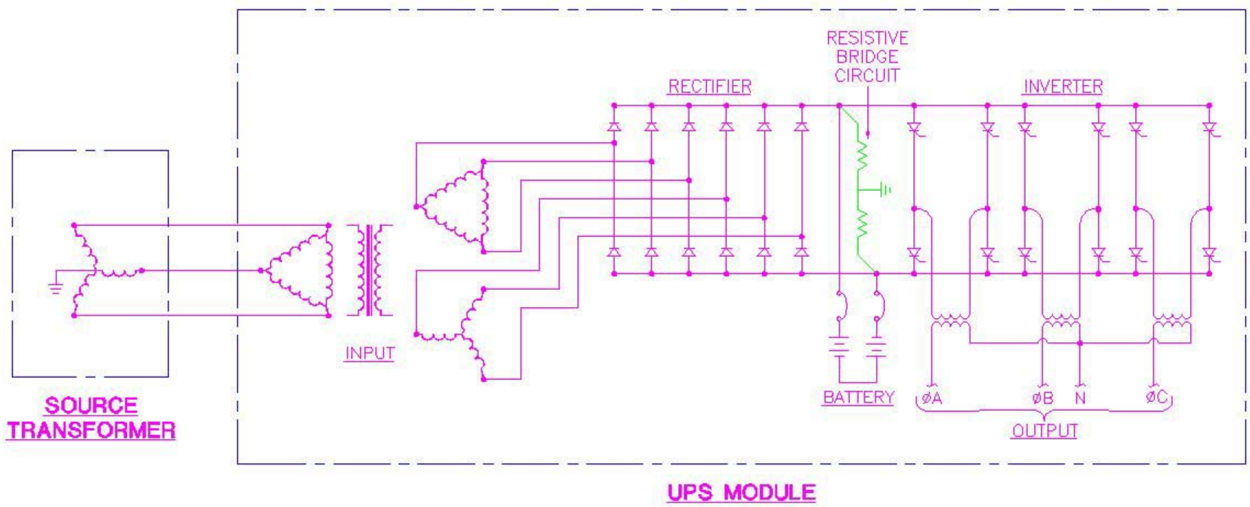

Fig. 1 - Isolated Input for 12 Pulse Rectifier with Resistive Bridge Detection Circuit

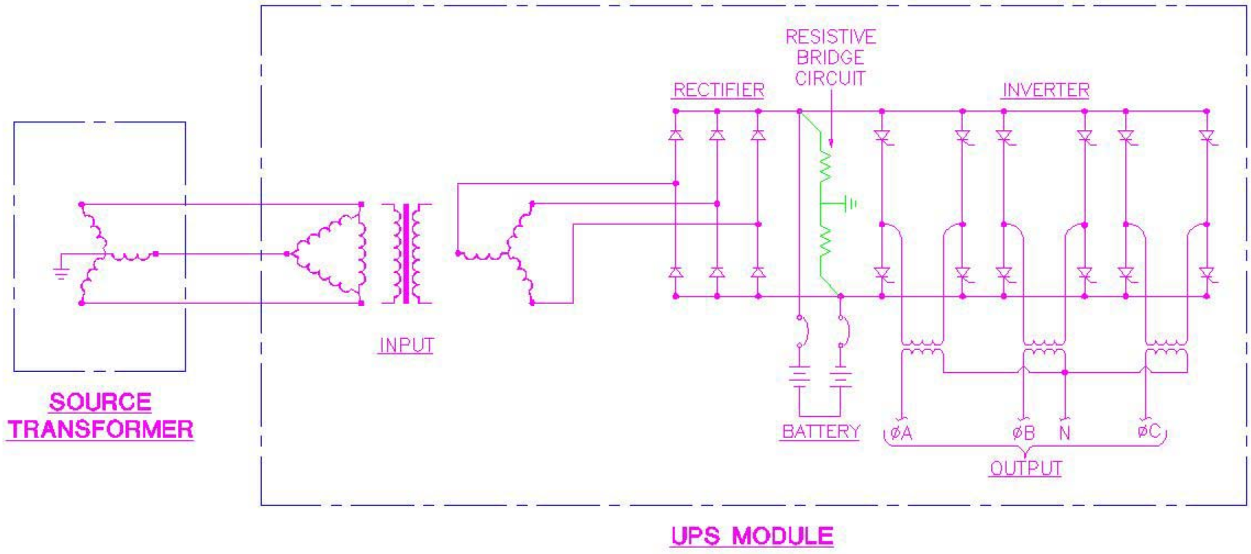

Fig. 2 - Isolated Input for 6 Pulse Rectifier with Resistive Bridge Detection Circuit

Non-Isolated Input

The advances in power electronics have resulted in components that no longer are held to the tolerances required in earlier equipment. The Non-Isolated UPS does not provide an input isolation transformer as part of the standard offering with 6-pulse rectifiers. The rectifier functions without requiring regulation of the input voltage and without the need for isolating the rectifier/charger components from the power source. Advantages to this design include smaller foot print, greater efficiency and lower cost as compared with an equivalent system having an input isolation transformer. One of the primary disadvantages in this configuration is that the lack of an input isolation transformer presents an electrical ground reference at the UPS battery, thereby presenting challenges to DC monitoring and to personnel performing maintenance activities. The normal switching operations of the rectifier SCR's or IGBT's present a circuit path to the system grounding location of the 3-phase source supply.

The use of Non-Isolated input is generally limited to UPS capacity ratings less than 500 kVA however; the UPS manufacture may offer 6-pulse rectifier systems without input isolation if specifically requested by the customer. Figure 3 represents a Non-Isolated UPS.

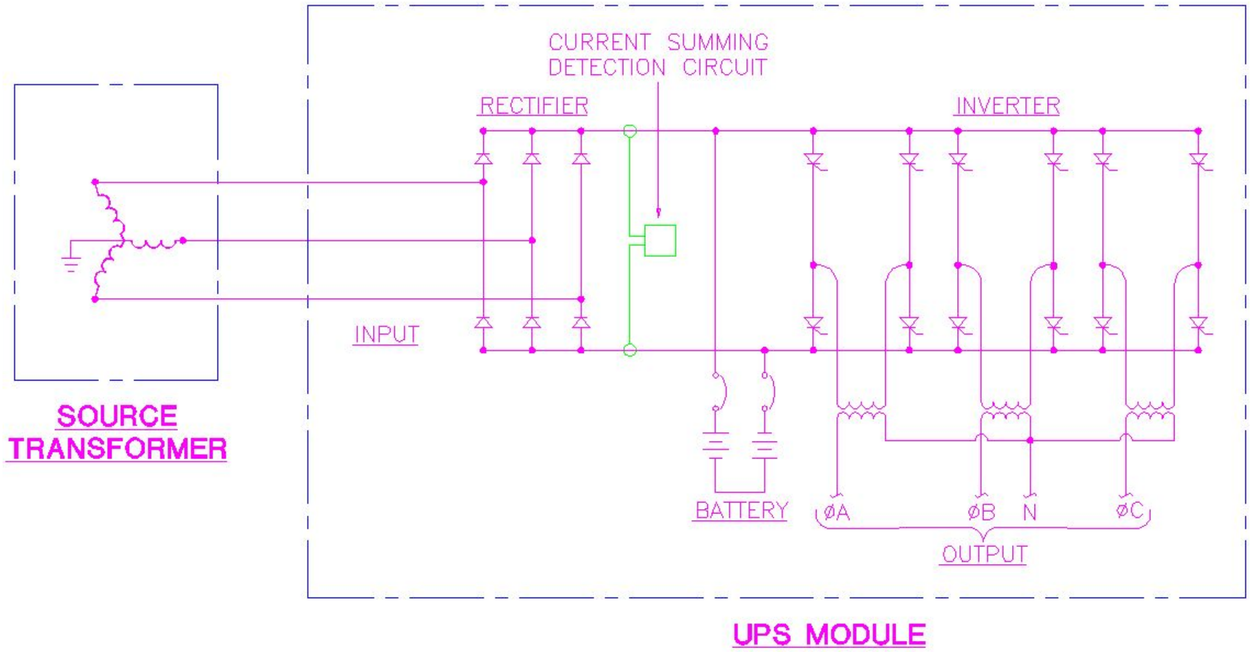

Fig. 3 – Non Isolated Input with DC Current Sensing Summation Circuit

DC GROUND FAULT DETECTION CIRCUITS

Bridge Circuit
The traditional DC ground fault detection circuit is comprised of a voltage divider network, represented as a resistor network R1 and R2, where the common connection is grounded electrically at the mid-point of the battery. The common connection references the battery to ground while still providing a measure of isolation from ground. Under normal operation, R1 and R2 each support a voltage equal to half the total battery voltage. An inadvertent ground on the + or – DC bus shorts out the respective R and the DC bus drops to a ground potential. The Bridge Circuit is widely used with the Isolated Input UPS configuration. Graphical representation of the bridge circuit is presented in Figures 1 and 2.

DC Current Sensing Summation Circuit
DC Current Sensing Summation (Residual Current) measures both the positive and the negative bus currents in a Hall-element current sensor. DC current in the positive leg and DC Current in the negative leg are summed. The normal condition is that the instantaneous sum of the positive and negative current flow will equal zero. The circuit alarm on a current threshold setting that is greater than zero. The assumption is that if the current sum is not zero it must be outside of the normal condition path, i.e. a ground fault on the battery. The DC Current Sensing Summation Circuit is used with the Non-Isolated UPS configuration. Graphical representation of the DC Current Summation circuit is presented in Figure 3.

Hybrid and Proprietary Circuits
There reportedly are variations on the circuit designs described above as well as alternative detection circuit configurations. In addition to the DC Current Summation circuit, it is reported that the AC Ground Fault detection provided with module input circuit breakers offers an alternative means of detecting a battery ground fault on Non-Isolated input systems. The limitations to this method are discussed later in this report.
A proprietary detection circuit design described by one of the UPS manufacturers applies an AC potential across the battery. A ground fault in the battery will result in an AC current which is then detected and an alarm is activated.

DETECTION CIRCUIT SENSITIVITY

Detection circuit sensitivity levels are somewhat ambiguous given specific methodologies. The following presents a description of the relative sensitivity for each of the detection circuits provided.

Resistance or Impedance bridges are common for ungrounded battery systems and specifically Isolated Input UPS module. These detection circuits are reportedly the most sensitive and most prone to nuisance alarms. Consequently the UPS manufacturer may set alarm trigger levels to limit nuisance alarms. Additionally, the location of the ground fault and the resistance of the fault path can affect the detection and alarm capability of the circuit.

DC Current Summation circuits using a Hall Effect CT enclosing the positive and negative circuit conductors, and not the equipment grounding conductors. This methodology is applicable to grounded battery systems, specifically Non-Isolated UPS modules. Any leakage/fault current to ground will appear as an output from the CT. On the smaller UPS modules with very low battery load levels these can be effective and reliably detect very low leakage/fault current levels, i.e., less than 100ma. In larger UPS systems, as the battery system power levels go up, so do the detection current levels. This is due to the size of the Hall Effect CT's required and their corresponding error tolerance. A 1200A battery ground fault detection system with a properly rated Hall Effect CT may not be able to reliably detect less than 20A of battery ground fault current.

AC signal injection is used for an ungrounded battery system, and uses an AC signal source to impose an AC voltage to ground on the ungrounded battery string. This AC voltage between the battery and ground has no detrimental effects to the battery system. Consequently a battery ground fault will create a corresponding AC fault current which can be detected using a conventional AC current CT. The fact that an AC current signal is used for detection purposes makes this an attractive option for larger battery systems, i.e. an AC current CT is used for detection and the detection level is independent of the DC battery power level. The success of such a detection method has not been verified to date.

AC ground fault detection is reportedly used by some UPS manufacturers as an alternate means of detecting a battery ground fault condition primarily on the Non-Isolated Input UPS. This methodology relies on the ground fault protection provided with a UPS module input circuit breaker. The application relies on the fact that in a battery fault to ground there is an AC characteristic to the fault current reflective of the rectifier switching activity. The sensitivity of an AC ground fault circuit to detect the levels of DC fault current discussed above is questionable. The primary function of the AC ground fault circuit is to detect questionable levels of AC ground fault current while avoiding unwanted nuisance tripping if set too low. Ground fault protection is not a standard offering with all UPS modules and my not be an option.

UPS MANUFACTURER DETECTION METHODS

The following is a summary of the detection circuits employed by each of the four UPS Manufacturers surveyed:

Manufacturer ‘A’

- Uses both the Bridge Circuit on Isolated Input modules and the DC Current Sensing Summation (Residual Current) method of ground fault detection on Non-isolated Input modules.
- In addition, the manufacturer employees a third method whereby an AC potential is applied. In the event of a ground fault, AC current flow will initiate an alarm.

Manufacturer ‘B’

- Uses both the Bridge Circuit and the DC Current Sensing Summation (Residual Current) method of ground fault detection.
- Larger UPS systems that utilize a "12-pulse" full wave rectifier are equipped with an Input Isolation transformer and use the Bridge Circuit.
- Non-isolated UPS modules use the DC Current Sensing Summation method of ground fault detection. A battery ground fault may also be detected by the module input circuit breaker if equipped with ground fault detection.

Manufacturer ‘C’

- Does not provide DC Ground fault detection on their *Non- Isolated* UPS module line of products. In UPS modules rated less than approximately 500 kVA, the Isolation Transformer is an option. On all modules rated approximately 500 kVA and greater an isolation transformer is provided and the Bridge Circuit ground fault detection is utilized.
- Does not use the DC Current Sensing Summation (Residual Current) method of ground fault detection.

Manufacturer ‘D’

- Uses the Bridge Circuit method of ground fault detection. Manufacturer does not use the DC Current Sensing Summation method of ground fault detection on a *Non-Isolated* Input UPS and recognizes that the Bride Circuit method of measuring battery ground faults is not feasible in such an application. It is recognized that the Bridge Circuit is only valid with the *Isolated* Input UPS.

BATTERY GROUND FAULT MODEL

Preparing a model for a Battery Ground Fault and the development of conditions favorable to starting a fire requires an understanding of the many variables that are involved. A fire requires three elements; Fuel, Oxygen and Heat. There are three phases in the start of any fire: preignition/preheating, ignition and combustion. In order for a fire to start, energy must first be added in order to bring the fuel up to combustion temperature. Surface water and water within the fuel itself must be driven off before pyrolysis can occur. Pyrolysis is the breakdown of substances in the fuel by heat to release flammable gasses. The initial reaction is endothermic (i.e. it requires an external source of heat) and will merely char the fuel, but once temperatures reach a critical point and the flammable by-products of pyrolysis ignite the heat released will drive a runaway exothermic reaction.

The fuel in a battery fire may initially include the battery jar or case material as well as paint on surfaces of racks or enclosures. Oxygen is readily available. The heat source required as the third element is provided from the current flow in a battery ground fault and therefore a circuit path and a potential difference must be available for current to flow.

Evaluating the various battery applications indicates that the lack of an Input Isolation transformer on the UPS module presents a ready circuit path for battery ground fault current via a common ground path to the Neutral-to-Ground bond at the upstream supply transformer which powers the rectifier. The normal switching operations of the rectifier SCR’s or IGBT’s completes a circuit path to the battery. Graphical representation of battery ground fault in the Non-Isolated Input UPS is presented in Figure 4.

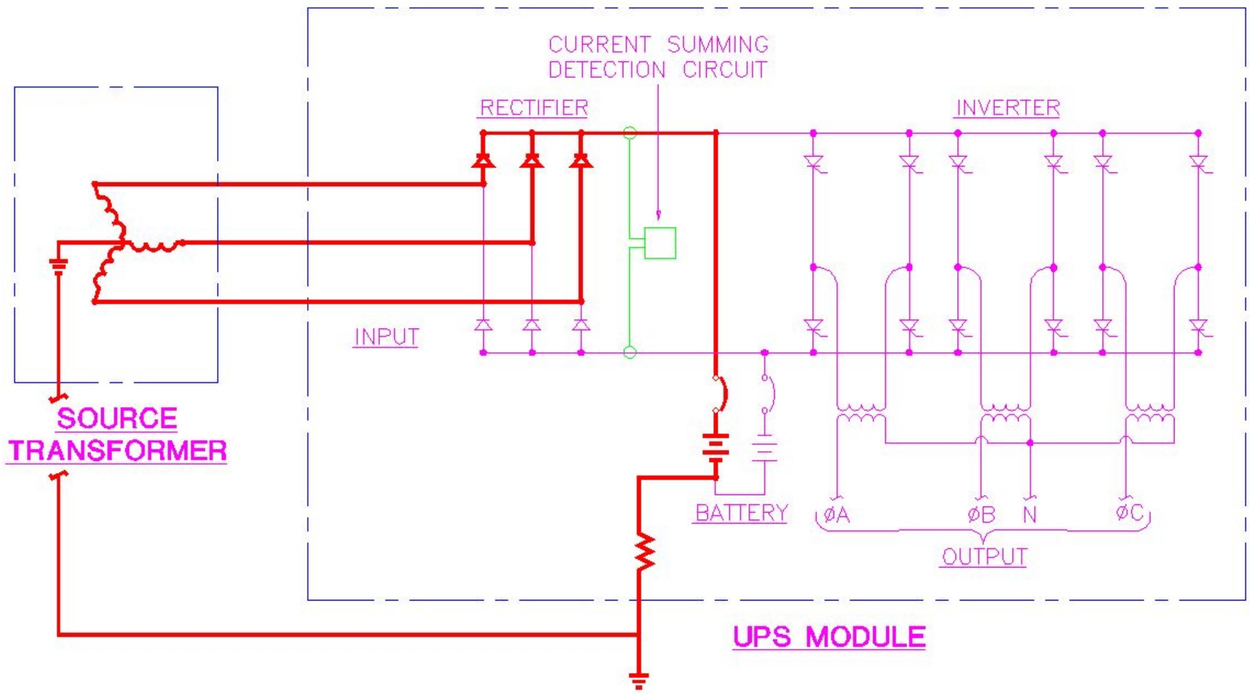

Figure 4 – Graphical Representation of Battery Ground Fault

A second order of risk to a battery ground fault can exist within the battery itself where multiple cells are breached presenting a path for ground fault current via the rack or enclosure. The ground fault can be exacerbated by leaking electrolyte from the affected cells enhancing fault current flow. The circuit is completed though the battery terminals post intercell connections. Unconfirmed reports suggest a fault potential as low as 18 volts may have been involved in battery ground faults that have escalated into a battery fire.

Efforts to model the expected heat generated from a 2 ampere ground fault in a large UPS application suggest a Fault Power level of approximately 500 watts. The following table represents this calculation process.

Fault Current Calculation			
Cell Quantity	240		
Cell Potential	2.25	volts	
Faulty Cell	1		Cell 1 is worst case fault potential
Galvanic Differential	-0.4	volts	Low Alloy Steel - Lead
Fault Potential	269.6	volts	
DC Potential	540	volts	
Capacity Apparent	1000	KVA	
Power Factor	0.9		
Capacity Power	900	KW	
Inverter Efficiency	95.00%		
Full Load Current	1754.38596	amps	
Full Scale Current	2000	amps	Round up to standard size
HallAccuracy	0.10%		Hall-Effect current sensor
Sensitivity	2	amps	minimum detection level
FaultPower	539.2	watts	at minimum detection level
FaultResistance	134.8	ohms	at minimum detection level

Table 1 – Fault Current Calculation

The initial conclusion is that there is insufficient heat generated to initiate a fire. Recent laboratory investigations such as conducted by Mr. Herbert K. Giess, Oerlikon Stationary Battery, Aesch, Switzerland suggest that the ignition process in a battery ground fault condition is such that a fire can ensue even at low fault current levels with minimum heat generation. The investigation highlights the risk when flammable material is used in the construction of battery jars and cases. Plastics often do not pose good heat transfer characteristics. Spot heating caused by even low fault current levels may escalate into conditions that favor ignition of this material.

CONCLUSION

There is no standard methodology used in the UPS industry to detect battery ground faults. The effectiveness of detecting all battery ground fault conditions before escalating into a fire is questionable given recent data that suggests that a battery ground fault of 1 ampere or less can precipitate a fire hazard.

The UPS design that presents the greatest risk to a battery ground fault as well as to safety to maintenance personnel is the Non-Isolated Input UPS in which a single leakage path between a cell and ground can result in establishing a fault current path. The UPS industry has established a market for the Non-Isolated UPS and it is unlikely that this design option will lose its appeal to the UPS consumer without significant investment in information sharing and education regarding the risks presented with this design.

The installation and commissioning programs that are recognized today should be expanded to include *insulation resistance* testing of all newly installed battery plants. Insulation testing should be performed of a completed battery between the post terminal and ground to ensure adequate insulation integrity. Preliminary test parameters under consideration include a 1000 VDC Megger applied for one minute with an acceptable minimum resistance value of 2, 000 Megohms. This will help identify and jar or case weaknesses, fractures or penetrations. The conditions under which this test is performed will require a thorough cleaning of all battery surfaces. Periodic testing performed on an annual basis will help identify any subsequent insulation degradation. This will require the isolation of the battery from the UPS and any monitoring system prior to testing. Proactive insulation resistance testing and maintenance will help identify any problems in all variations of battery plant types and configurations.

Additionally, the industry should pursue the UPS manufacturers to implement dedicated monitoring of the positive, negative DC bus for the Non-Isolated UPS using high precision current sensors capable of measuring milliamperes of current without being adversely affected by the high discharge current required by the load. Where the battery rack or cabinet is bonded to system ground by specific grounding conductors, these conductors may also serve as a location to monitor ground fault current. In lieu of manufacture provided monitoring equipment as described, a separate system may be installed.

REFERENCES

H. K. Giess, Oerlikon, Aesch, Switzerland *Ground Short Phenomena Involving VRLA Batteries, Stationary Batteries*, Proceedings Intelec 2005, Berlin, Germany

ACKNOWLEDGEMENTS

The author gratefully acknowledges the UPS industry equipment manufacturers and C&D Technologies as resources for the technical information used in the preparation of this paper.