BATTERY AND SUBSYSTEM ELEMENTS OF A HVDC SYSTEM FOR THE TELECOMMUNICATIONS AND DATA NETWORKS. FIRST, DO NO HARM.

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INTRODUCTION

Traditional telecommunications facilities and data centers both rely on dc battery systems to provide interruption free power to critical equipment. In the telecommunications world, lower voltage dc power is distributed directly to the equipment, while in data centers the loads typically require ac power. Over time, data center and telecommunication loads have become very similar, essentially computer based equipment. Since both telecommunications centers and data centers require high reliability, some have questioned why there are two distinct architectures. At the same time, both data center and telecommunications industries are examining higher voltage dc (HVDC) as an alternative means to distribute power.

The concept of dc for data communications facilities is not a new one. The concept was discussed at length during INTELEC ’97 in Melbourne Australia, and the first of many papers was published at INTELEC 98 in San Francisco, California (Åkerlund, et al)[i ii]. Recently, interest in higher voltage dc has expanded to include traditional telecommunications applications. While there are proven benefits to using HVDC, the practical implications are not all fully understood. Low voltage dc systems have been deployed for nearly a century during which time the reliability and safety of these systems has been proven. Traditional double conversion UPS systems have a large installed base where safety and reliability is well known. On the other hand, HVDC systems are still in their infancy and the architecture, voltage level and grounding schemes have not been standardized. There is arguably insufficient data to assess the reliability of distributed HVDC systems. This is not to state that HVDC systems are unreliable; there is just insufficient data to draw any conclusions at this time.

This paper proposes an HVDC architecture designed with the intention of minimizing risk to operations and maintenance personnel, while maximizing the system uptime and reliability. Details on the selection process of the proposed design concepts will be included along with a comparison of the various considered options.

PLANT ARCHITECTURE

Due to the voltages anticipated, reliability would be enhanced and safety for maintenance workers improved dramatically if the HVDC plant could be deenergized for routine or unplanned maintenance. A 2N architecture can provides a high level of uptime availability and maintenance accessibility. Such a system might look like Figure 1.

The “load” for such a system are the dual inputs of servers and the like that are equipped with power supplies suited for 384 Volt dc inputs. Each server would be cord-connected to a pair of secondary dc distribution modules, typically outlet strips arranged with receptacles designed for arc-flash resistant plugs.

The bus between primary and secondary dc distribution could be a busduct arrangement or could employ traditional wiring methods in raceways suitable for the application. The battery for each plant would consist of two or more parallel strings of 180 Vented Lead Acid (VLA) or Valve Regulated Lead Acid (VRLA) cells.

Ideally, the rectifiers would be of a modular type to facilitate growth and eliminate costs associated with over capacity. The rectifiers should operate with high efficiency across a broad range of output loading.

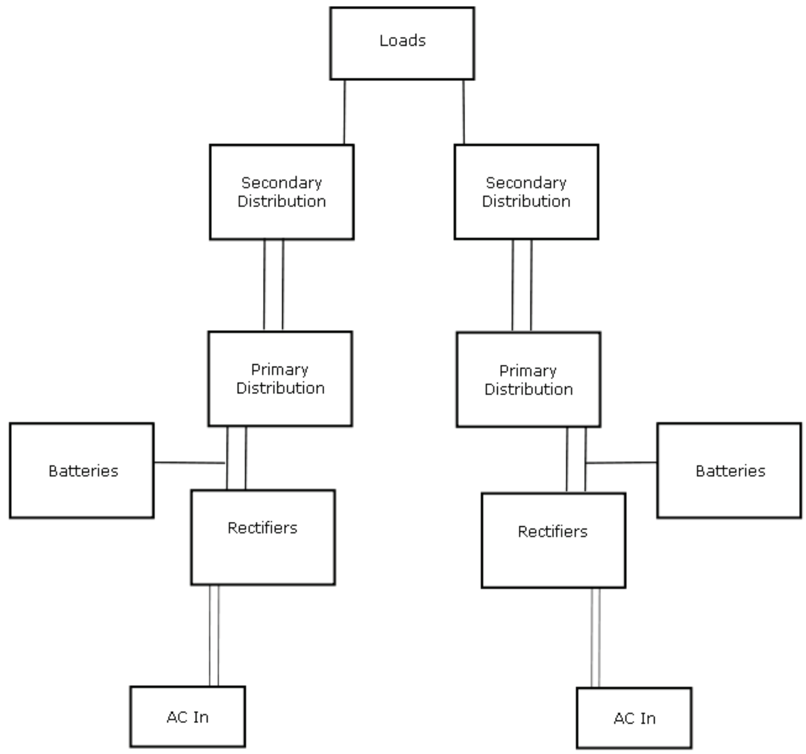

Figure 1 a 2N plant architecture for HVDC plant in critical applications

BATTERY ISSUES

Virtually all ac UPS and dc power plants use a storage battery, usually a lead acid battery of either the vented or the valve regulated technology. With a nominal voltage below 50 volts, traditional -48 volt battery systems have been placed in good stead with the various code articles that otherwise might require numerous protective devices such as disconnects and design constraints such as separation distances, etc. Arguably, HVDC systems will have to comply with all safety aspects of codes and standards that go far and above those required for -48 volt systems. Additionally, telephone company technicians, long accustomed to working around -48 volt power plants and batteries will need training and appropriate Personal Protective Equipment (PPE) adequate for the elevated shock and arc-flash hazards; otherwise, they have no legitimate authority to enter the battery room. Companies will need to determine whether they choose to train and equip their technicians accordingly or contract such work to properly trained and equipped electricians and/or battery technicians.

With codes and standards as minimum requirements, we believe that there are relatively low-cost features and engineering guidelines that would make a HVDC battery system safer to install and maintain. Traditional ac UPS systems can employ an ungrounded battery system because ground for the servers or other “load” is provided by a separately derived neutral, either at the inverter section of the UPS, or downstream at the transformers housed in power distribution units (PDU). Because the battery is ungrounded, UPS systems typically use ground fault detection monitors to protect technicians servicing the battery, and identify situations where a second ground fault could precipitate a battery fire. Further, with an ungrounded battery, there is little risk for technicians who might come into contact between some energized part of the battery and the grounded battery stand.

HVDC systems cannot use transformers, and other means of isolating the battery are encumbered with equipment costs and reduced system efficiency, so the entire system, including the battery, will be grounded. With a grounded battery installed on a grounded stand, or inside a grounded cabinet as might be the case of a VRLA battery, it is appropriate to reduce the battery voltage with respect to ground. One option, using a 180-cell battery, would be to arrange the cells into two 90-cell strings with a midpoint ground. This would reduce technician voltage exposure by half. Figure 2 is a sketch of such a topology.

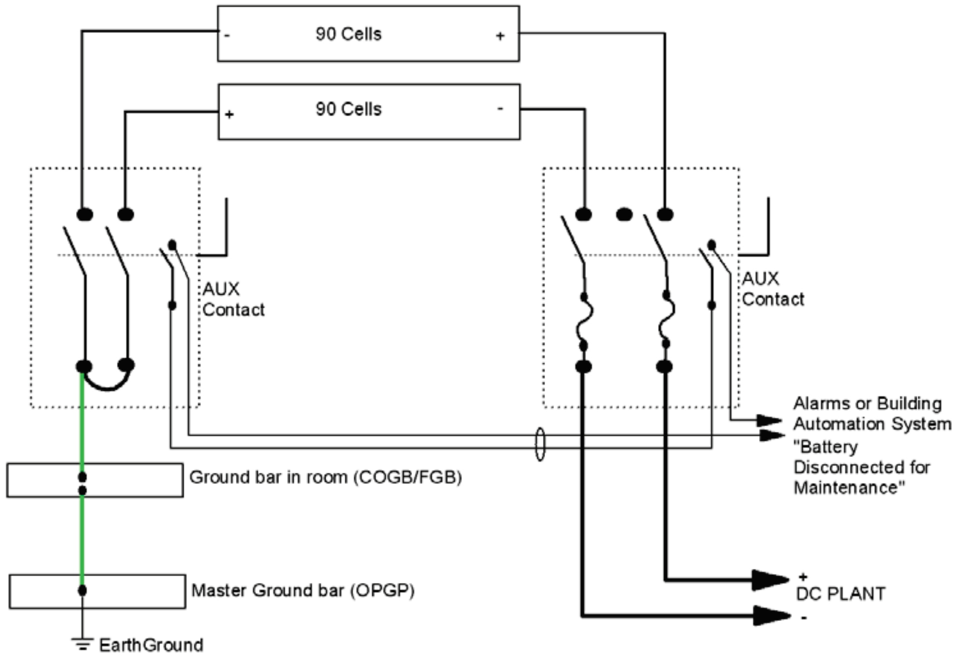

Figure 2 A 2-pole disconnect switch is used to isolate a 180-cell battery into two 90-cell strings and remove the ground for system maintenance.

One drawback of the design shown in Figure 2 is that when the battery disconnects are opened, the system may be left ungrounded. A more attractive approach is to use a "floating" battery, where the battery is implicitly grounded by arranging the rectifiers to be center-grounded between positive and negative 200V outputs (Figure 3).

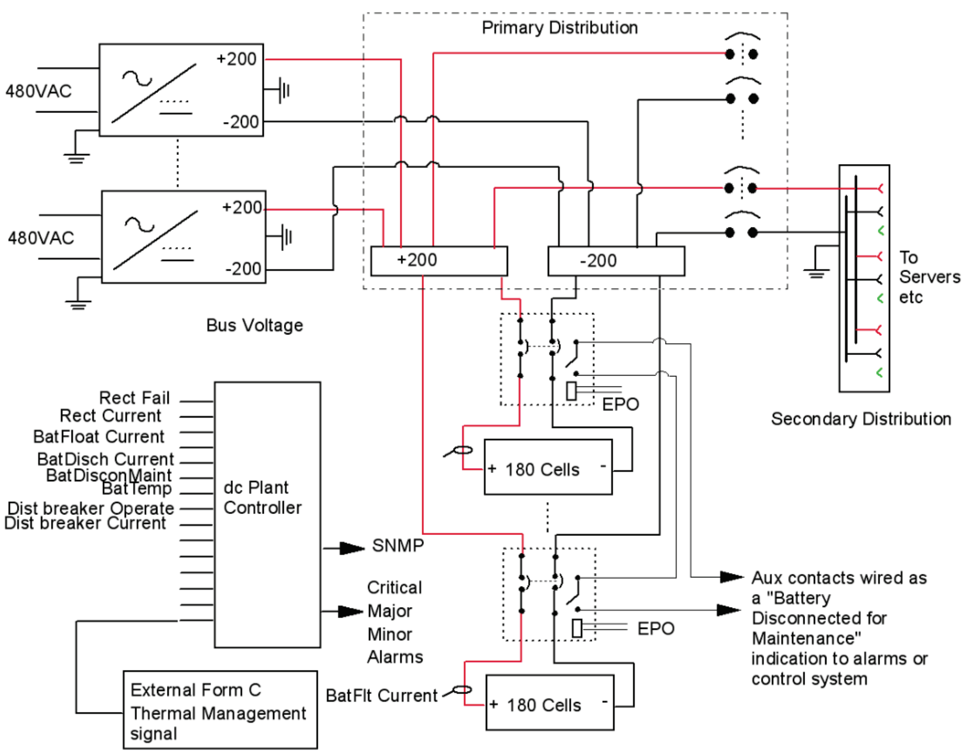

Figure 3 depicts a center-grounded 400V rectifier plant arrangement with a "floating" battery.

With this arrangement, a 400 volt ungrounded battery is connected to the plant via fused safety switches or other overcurrent protection with auxiliary contacts used to signal the plant controller and/or the alarm system that the battery is disconnected. The reason for this alarm event is that occasionally, battery technicians actually forget to reconnect the battery leaving the plant vulnerable to failure.

During battery maintenance the OSHA Lockout/Tagout[iii] procedure covered in 29 CFR 1910.147 should be followed. This arrangement is not considered a single point of failure because the overall topology is based on at least two battery strings per plant and a 2N plant architecture as was covered previously and in Figure 1.

Although traditional metallic grounded battery stands have been used successfully for low voltage dc systems and ungrounded high voltage systems, they may be problematic with high voltage grounded systems. Batteries that develop small leaks can create a path to ground via conductive electrolyte. For ungrounded battery systems these ground paths can be detected by a ground fault detector. Even on low voltage systems it is possible for these types of ground paths to cause fires and/or thermal runaway, but likely due to the lower voltage to ground, the issues are not wide spread. With the higher voltage dc systems, these potential paths to ground may quickly develop into serious issues.

The other problem with building HVDC systems using traditional grounded metallic battery stands is that they introduce significant shock and arc-flash potential. Although the plan is to isolate the battery strings during routine maintenance, there may be times when the battery has to be worked on while energized.

A potential fix to these issues is to use insulated and/or non-metallic battery stands. In the 1970's Lucent Technologies (Formerly AT&T Network Systems/Western Electric Co.) and now called Lineage Power Division of General Electric designed a nonmetallic battery stand for their legendary KS-20472 Round Cell Battery. The battery stand was designated KS-20760 and it is a polyester-glass design intended for both non-shock/vibration areas and seismic area deployments. If facility space permits, and the battery loading will be a relatively low-rate discharge, the KS-20472 battery mounted on KS-20760 polyester-glass stands would provide a demonstrated long battery life[iv] and a nonconductive battery stand that enhances safety. Because this particular battery has a 40 to 70 year design life at 25^{o} C (77^{o} F), one could capitalize on that abundant life and reduce the facility air conditioning cost by operating the battery area as high as 35^{o} C (95^{o} F), and still yield a 20 year or more battery life.

Figure 4 Lineage Power Round Cell battery cells on polyester-glass stands

The down side of the Round Cell is its high floor space requirements. If one must deploy rectangular cells for purposes of battery room density, are nonconductive stands still a possibility? HVDC might well create a market for a nonconductive battery stand that would support rectangular vented batteries.

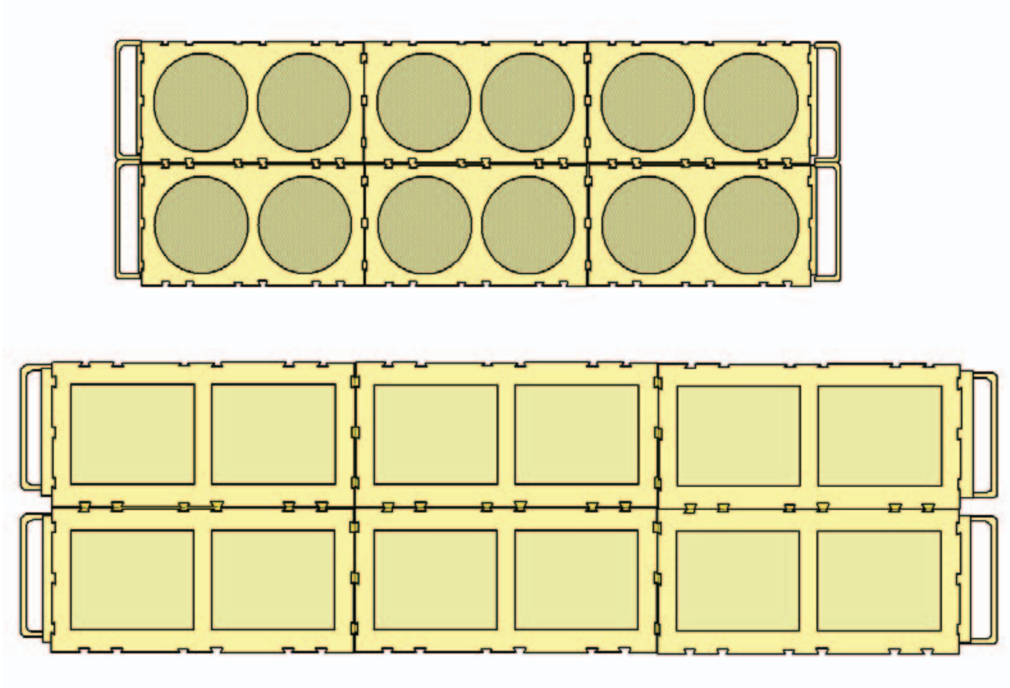

Figure 5 Approximate footprints of traditional Round Cells (top) on polyester-glass stands and a poly material stand that could be designed for rectangular vented battery cells (bottom).

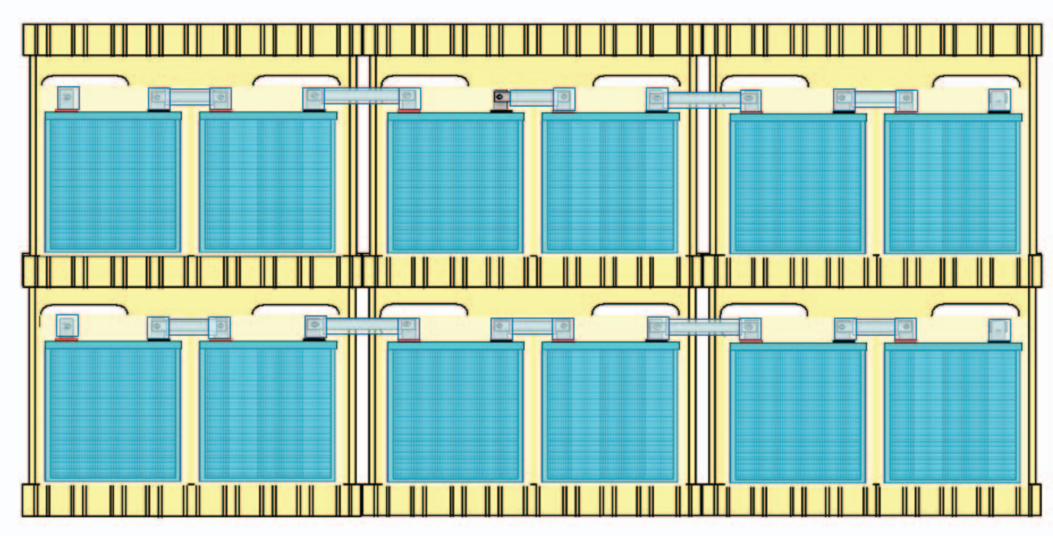

Figure 6 Side view of a rectangular vented cell arrangement on polyester-glass.

One possibility is a polyester-glass system similar to that of the Lineage Power design. Basically, the stand might consist of bases that fasten together by means of keyed wedges. Vertical panels would provide support for a second or third tier and no conductive parts would be used. It remains to be seen whether or not such a stand would meet seismic zone 4 requirements. Regardless, there are many data centers and central offices in seismic zones 1 – 3, so the potential market for a battery stand with a limited seismic rating could still be substantial.

The existing polyester-glass system ships in small containers and assembles quickly with wedge keys that require no special tools or torquing of fasteners. The wells in which the cells sit are spaced so that there is no need to shove or pry cells back and forth on the battery stand to make the intercell connectors align. These advantageous features could be incorporated into an updated battery stand design.

Alternatively, traditional seismic rated metal stands could be made nonconductive by the application of dielectric epoxy or similar product in place of powder-coat paint. Such a conformal coating would be both acid-resistant and provide an insulating barrier between the grounded battery stand and the energized parts of the battery cells and intercell connections. Figures 7, 8 and 9 provide sketches of a conformally coated battery stand arrangement. The grounding arrangement shown in Figure 9 is intended that the ground lead would be disconnected during battery maintenance further enhancing safety from shock or arc-flash event. Insulation dielectric should be determined from IEC60950[v]. Using the general rule of thumb, 2U + 1,000V the appropriate dielectric for a 400V battery system would be 1,800 Volts.

A potential problem with insulated or non-metallic racks is that there is an increased possibility of a static discharge when a technician touches a cell. With an increased possibility of a static discharge comes an increase possibility of igniting hydrogen gas emanating from the cell. Maintenance procedures would have to be carefully written as to minimize this increased risk.

Spill containments should be provided for vented battery arrangements per local requirements.

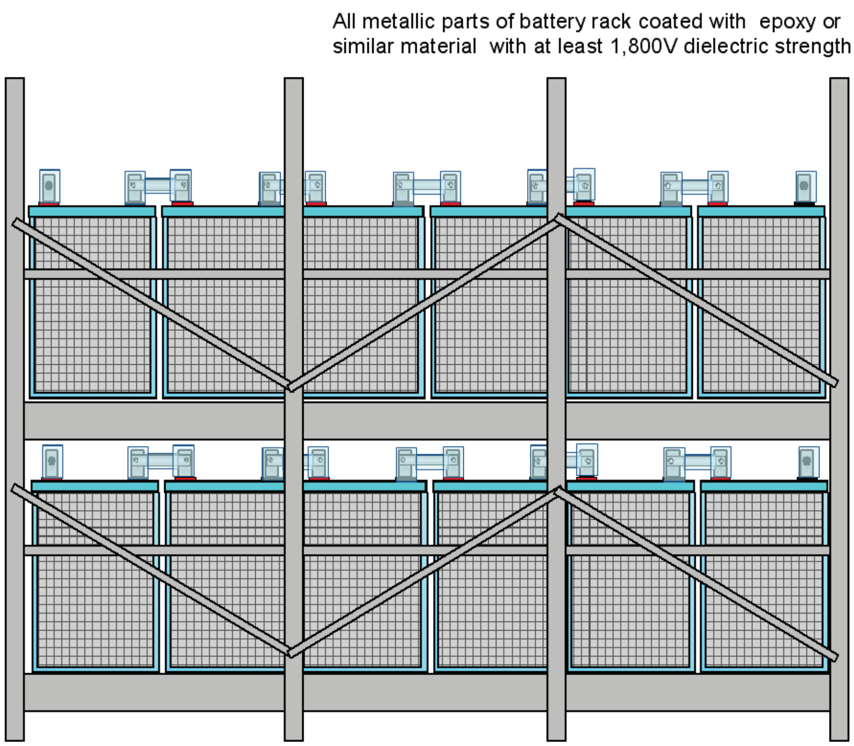

Figure 7 Side view of a rectangular vented cell arrangement on a conformal coated steel battery stand

Covering all energized parts of the intercell connections and posts are a requirement under NFPA 70E and it's likely that a market could emerge for safer coverings for intercell to post connections. Transparent coverings are highly desirable, since they facilitate inspection for damage from electrolyte leakage or seepage. Figures 10 and 11 offer some thoughts on how such products might appear. To comply with fire resistance requirements, such insulating materials should be UL 94V-0 rated.

If cabinets are used to house VRLA cells, it is advantageous the interior of the cabinet have no exposed metal in the areas of the battery posts or intercell connections. Such surfaces should be lined with a GPO-3 non-tracking mineral filled, continuous strand, fiberglass-mat-reinforced thermoset unsaturated polyester material, such as the trade name "Glastic" or its equivalent. Cabling supports should be structural assemblies of similar material. The dielectric rating should be at least 1,800 volts.

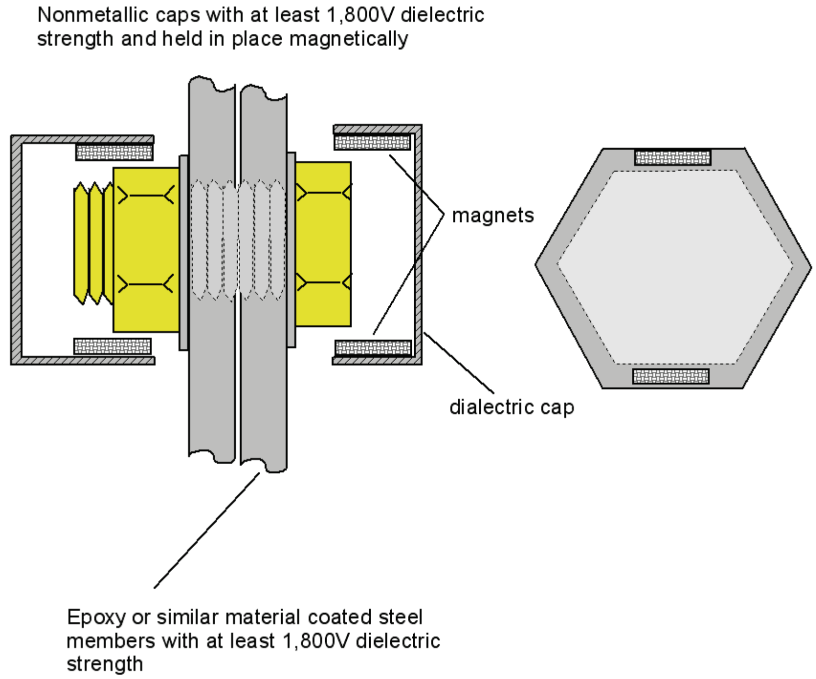

Figure 8 Insulating caps for all bolts or other conductive fasteners on a conformal coated steel battery stand

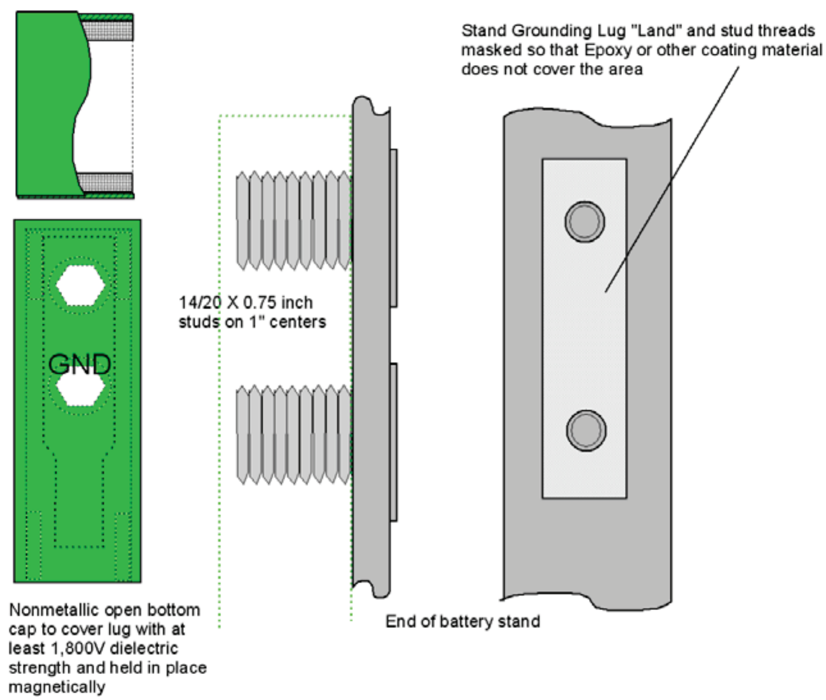

Figure 9 Grounding arrangement and insulating cap for steel framework on a conformal coated steel battery stand

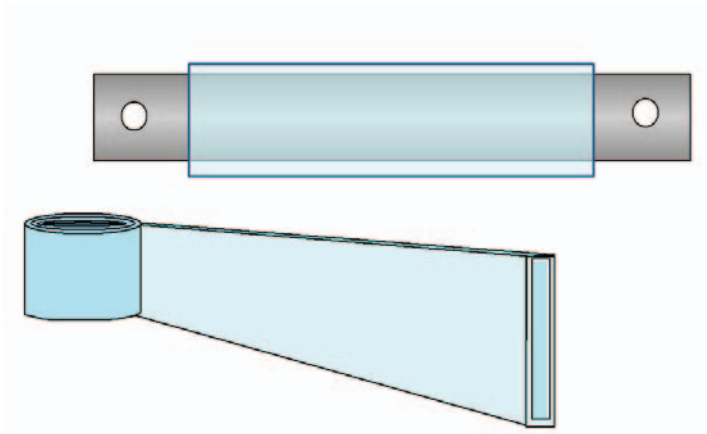

Figure 10 shows a cut to fit transparent insulating cover that would slide onto intercell connections. The dielectric rating should be at least 1,800 volts.

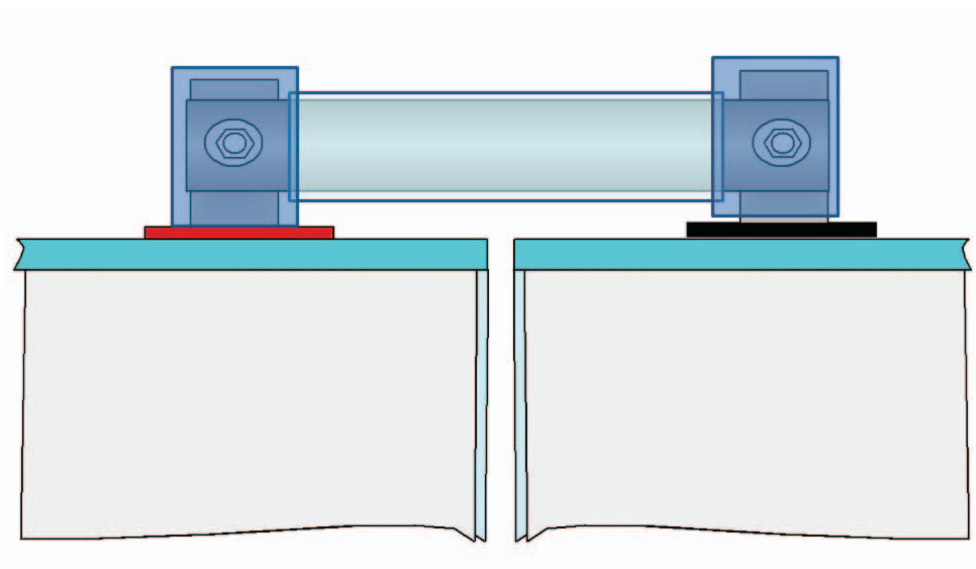

Figure 11 shows covered intercell connector and cube shaped transparent battery post covers. The dielectric rating should be at least 1,800 volts.

Monitoring is an important part of such a system, particularly if the battery reserve time is less than one hour. Because individual cell or jar monitoring is relatively cheap these days, it's prudent to provide such monitoring so that weak cells are quickly identified and corrected before they can contribute to a system failure. Cell voltage, per string current, total battery current and ambient temperature should be monitored. Further, if VRLA cells are deployed, the International Fire Code requires that Thermal Runaway conditions be detected and rectifiers backed down to prevent such conditions or other potentially catastrophic events either caused by elevated temperature or resulting in elevated battery temperature.

Oddly, in the telecommunications business it is often the case that alarm events become mismanaged due to poor communication that results in technicians misinterpreting alarm events. Major failures have occurred when, for instance a BD (Battery on Discharge) alarm indication was interpreted to mean, "Building on Diesel." Accordingly, given the relatively cheap cost of digital memory and display and the dramatically high cost of a system failure, alarm events should be spelled out and not be abbreviated. A Battery on Discharge alarm should read exactly that on any local display or remote monitor display at a surveillance center. A Discharge Fuse Alarm should read just that and so on for all alarm reporting events.

BATTERY MONITORING

As is the case with any UPS, whether ac or dc, the overall uptime availability is only as reliable as the battery backing the system. A permanently wired battery monitor capability should be a requirement. Ideally, battery monitoring that is built into a manufacturer's HVDC product is prudent. If the feature isn't available, the ability to interface with a commercially available battery monitor should figure prominently in the overall design specification, particularly if the battery will be VRLA. The International Fire Code, Section 609.3 requires that VRLA battery systems be equipped with a listed or approved means of preventing thermal runaway. Thermal runaway is best prevented by monitoring float current and temperature. If the HVDC plant controller isn't capable of meeting the IFC 609.3 requirement internally, it should be arranged for an external Form-C contact 'open' condition to cause the rectifiers to treat the event like an impending Thermal Runaway and reduce output. Additionally, monitoring cell or monobloc voltages should be a minimum requirement. Ideally, intercell resistance and cell Ohmic testing also is valuable. Finally, the battery system must be equipped for Ground Fault monitoring utilizing either a resistive bridge arrangement or a Current Summing type of detector [vi].

DISTRIBUTION

Several dc distribution architectures are practical, cable bus architectures, busducts and the like. The industry has seen critical failures where through error, data center technicians have plugged both inputs of a dual power supply server into the same feeder of a redundant source. The fact that several manufacturers have developed suitable plugs and receptacles for 400 Volt applications provides a simple distribution architecture to solve that potential problem by using two different types of connector and cord as shown in Figure 12.

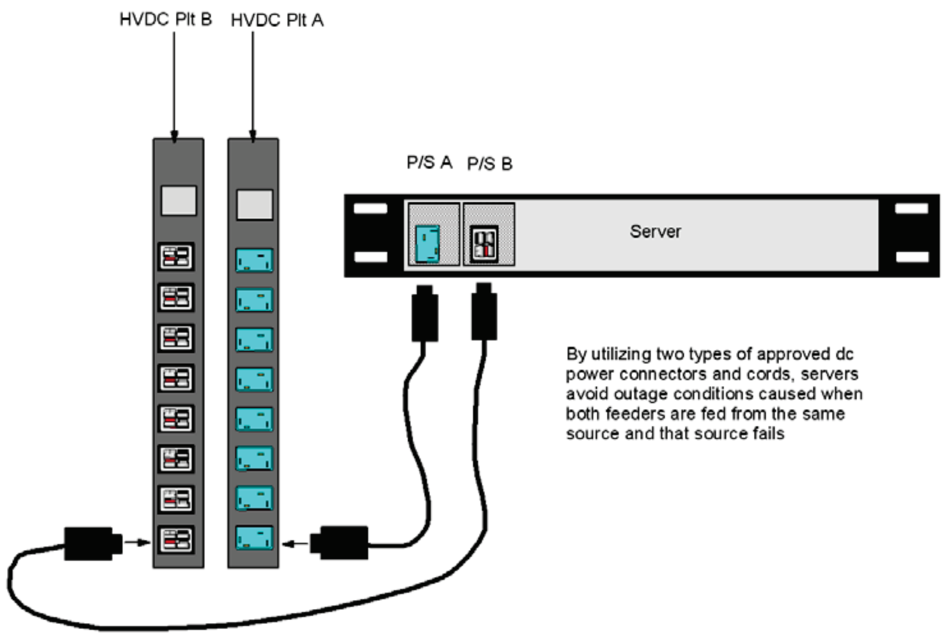

Figure 12 shows a plug, cord and receptacle arrangement to improve network reliability.

EMERGENCY POWER OFF (EPO)

Although shunt-trip devices were sketched into the battery disconnects shown in Figure 3, to EPO or not to EPO is a huge question that begs consideration across the telecommunication industry as Internet Protocol (IP) based systems expand almost limitlessly. From a standards viewpoint, three NFPA standards apply to the discussion. NFPA 75[vii] Standard for the Protection of Information Technology Equipment clearly covers the data center environment in which an EPO is a requirement and also Article 645 of the National Electrical Code[viii] speaks to it as well. Telecommunications facilities fall under the purview of NFPA 76[ix] Standard for the Fire Protection of Telecommunications Facilities. Important, is the fact that NFPA 76 does not require an EPO. With the wide proliferation of IP-based backhaul systems for telecommunications services – wireless service in particular – the nature of the data passing through the many routers, servers and other elements comprising the electronic fabric of a facility, is clearly telecommunications traffic. Article 1.1 of NFPA76 covers the scope and reads:

Scope. This standard provides requirements for fire protection of telecommunications facilities where telecommunications services such as telephone (landline, wireless) transmission, data transmission, internet transmission, voice-over internet protocol (VoIP) transmission, and video transmission are rendered to the public.

Accordingly, it's important that telecommunications companies make a clear distinction that although their facility might look like a data center and employ many of the same systems as a data center, it is in fact a telecommunications facility. Therefore, as a telecommunications facility it should cleave to NFPA 76 in order to protect the public safety aspects of telecommunications services. If an AHJ rejects that argument, an alternate approach to avoiding an EPO is to declare the facility a Critical Operations Data System under NEC® Articles 645.2 and 645.10 provided that the five conditions in 645.10 are met. These conditions include, an approved plan for equipment zone power and airflow depowering, 24/7 availability of qualified technical staff, smoke sensing fire detection, a fire suppression system, and proper use of plenum rated cabling in such spaces[x].

THE HIGH COST OF SAVING A BUCK

If human altruism isn't enough to make us realize that the safety of those who install and maintain the systems we design is important, then the hard facts of business life in an increasingly regulated industry and litigious society should remind us that it also makes good business sense. Injuries and their related costs are very real Operational expenditures (Opex) that must factor mightily into the engineering judgment weighed as design plans roll out. Can HVDC save Opex and even perhaps some capital money? We think so. Would the cost of the first serious injury consume any savings realized? Probably. Accordingly, safety must be designed into the product and into all procedures for installing, operating and maintaining it. Any such deployment though, needs to bring safety to the 'drafting table' first, and then to the power room. The principal elements of personnel safety rely heavily on:

- Reducing the voltages to ground to which a technician might be exposed
- Isolating the system to the extent practicable
- Providing adequate training, documentation and procedures to the technicians
- Providing appropriate tools and PPE and having a formal program in place to enforce their proper use
- Maintaining an attitude of professionalism in all aspects of the HVDC deployment and plant operation

CONCLUSIONS

HVDC shows promise – lots of it. The keys to exploiting dollar savings from the technology include maximizing system efficiency across a varying load profile, good service life, system modularity, ease of site engineering and product ordering, cabling management, installation, operation and maintenance. Solid, reliable system documentation is important to avoid engineering and procedural errors, which remain a big problem in the industry and often lead to safety concerns. The extent to which the industry is able to deliver on all these factors and designed-in safety will determine whether in fact HVDC is a winning technology.

REFERENCES

[i] Intelec Adhoc group, the INTELEC® white paper, "Powering the Internet, Datacom Equipment in Telecom Facilities", IEEE INTELEC® 1998, Session 1-3.

[ii] Case Studies Supporting -48VDC as the Power Input of Choice for Computer Equipment Deployed in the Telecom Network D. McMenamin INTELEC® `98 Session 12-2

[iii] 29 CFR 1910.147 The Control of Hazardous Energy

[iv] The Round Cell: Promises vs Results 30 Years later D.O. Feder et al INTELEC® 2004 Session 23.2

[v] IEC60950 Safety Standard for Information Technology Equipment

[vi] DC Ground Fault Detection Provided for Uninterruptible Power Supplies Edward P. Rafter, P. E. Battcon 2006 Session 5

[vii] NFPA 75 Standard for the Protection of Information Technology Equipment

[viii] NFPA 70 National Electrical Code

[ix] NFPA 76 Standard for the Fire Protection of Telecommunications

[x] 2011 National Electrical Code® Changes of Interest to Data/Comm Cabling Contractors, Users and Code Enforcement Officials - Stanley Kaufman, Ph.D. Communication Cable and Connectivity Association, Inc. ("CCCA")