How to Avoid a Starring Role in a Really Ugly Case Study.
Stupid errors easily avoided.

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Abstract

Despite advancements in equipment design, a significant incidence of personnel injury, network failures and equipment damage events are a direct result of procedural errors performed during battery and associated UPS or dc power plant installation and maintenance activities.

A variety of failings contribute to the root causes of such incidents, some of them systemic and others endemic. Potentially perturbing conditions play out in terms of missing or inadequate instructional documentation, technician training, supervision, tooling, fatigue, inattention, boredom and other factors that result in fires, accidents, lost productivity, disciplinary actions and distinctly unflattering reports.

Planned for inclusion herein are case studies of high current faults, ESD events, erroneously cut cables and near-miss incidents. In each case, the simple, inexpensive steps that could make the difference between a well-executed, quality job and a potentially career-altering debacle will be covered.

Introduction

The intent of this paper is to share analyses of power incidents that easily could've been avoided. In many of these incidents, verification of a planned action would have taken only seconds to perform. For the lack of such verification steps, however, unwanted results occurred with loss of telecommunications service, personnel injuries, equipment damage or a combination of these activities.

Mishandled Temperature Alarms: Not cool

Figure 1 is a photograph showing irreparable damage to a flooded string of 1,680 ampere hour cells that was caused by a mishandled HVAC system failure in a telecommunications installation. Over a span of approximately 60 hours, the room temperature climbed to approximately 130 Degrees (F) (54.4^0 C).

Note the bulging evident on the sides of the battery jars. The jar material was PVC which softens at approximately 160 degrees (F) (71^0C). Accordingly, the battery itself became an electric heater to some degree, as a result of energy from the dc power plant rectifiers dissipated across the battery's decreasing internal resistance. Under such overcharge conditions, electrolyte water is electrolyzed, producing copious amounts of hydrogen.

Note also, that as the jar sides bulged out, the electrolyte level dropped well beneath the distal end of the fill-funnel tube of the explosion-resistant vent atop each cell. These abnormal conditions placed the cell head-space (if not the facility itself) in a very serious threat of explosion once the hydrogen concentration in a given volume of air would reach 4% or greater.

Figure 1. Lead calcium battery cells with jars that bulged due to an overheat condition in the wake of an HVAC system failure. Note the drastic electrolyte level drop (Arrows) that resulted from jar bulging.

Take-away: Facility high temperature alarms should be responded to promptly. Either something bad has already happened or will in time.

Battery ESD Issues: One spark away from a boom

As often as we use the term, "This isn't rocket science," when hydrogen, oxygen and heat reach the right proportions, the expression becomes a distinction without much difference.

In this case, as is shown in Figure 2, the head-space of a mishandled 4,000 Ampere Hour cell exploded. At the time, a group of 24 cells held in warehouse storage was temporarily wired in series for a 150 hour, 60 volt 'Freshening charge."

At some point, a technician removed the explosion- resistant vent cap from one cell and a resultant ESD event caused ignition of hydrogen in the cell headspace which exploded.

The product literature[i] specifies that "**For maximum safety, do NOT handle cells during or after boost charge for 24 to 48 hours.**"

Another cell headspace explosion occurred (Figure 3) when a technician touched the top of a 3,900 Ampere Hour cell in Float charge operation. In this case, rather than place a step ladder to reach the upper tier of the string, a technician dragged a plastic chair across a tile floor and then stood upon it to service the battery. Dragging the chair generated a triboelectric charge sufficient to initiate the event.

It is critical that persons working on battery cells are trained and familiar with the tasks at hand and that they discharge accumulated triboelectric (static) charges to a metal object before touching any part of the top of a battery cell. IEEE Standard 1657[ii] is an accepted industry document that catalogues the qualifications needed by technicians working on or around stationary batteries.

Figure 2. A 4,000 AH cell being boost-charged exploded as a result of an electrostatic discharge.

Figure 3. A 3,900 AH cell exploded when an electrostatic discharge as a result of a technician's errors.

Take-away lesson: It's important to follow manufacturer's literature when handling any kind of battery.

Container Damage: Taking a leak along the road to perdition

Cell containers that leak due to mishandling damage, aging or manufacturing defect can initiate fires because each cell is at some electrical potential in a string. The cell in Figure 4 has a leaking container-to-cover seal and is cell 17 in a 48 Volt string. With a float voltage of 2.2 volts per cell, cell #17 would be at approximately a 37 volt potential with respect to Ground at cell 1. As electrolyte leaks from the cell and forms streaks or "patches" of dried electrolyte, the result can be a short circuit to Ground that can initiate a battery fire.

Figure 5 shows two of twenty-four 4,000 Ampere-hour cells that were damaged by an external fire that began with a small crack that occurred during installation. Electrolyte seeped from a small crack in the corner of a cell and initiated a fire. The fire propagated along spill containment bags beneath the cells and the heat from that fire charred the plastic containers above them.

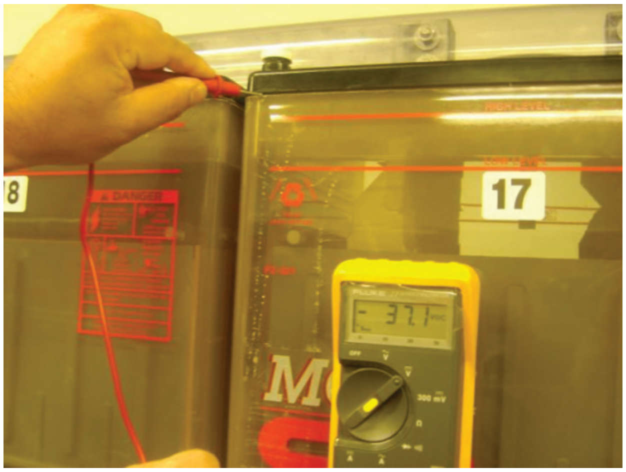

Figure 4. A leaking jar-to-cover seal could become the energy source that results in a battery fire.

Figure 5. A leaking jar resulted in fire to spill containment bags beneath a battery.

Remote telecommunications facilities such as cell and microwave sites usually have coarse gravel ground cover. When battery cells are unpacked for installation in a cabinet or shelter at such sites, it is critical that installation technicians provide temporary sheets of plywood or other substrate upon which to unpack the cell(s)[iii].

To place unprotected cells on gravel or steel walking surfaces can cause overstress point-contact damage to the containers of those cells. Such damage can result in electrolyte leakage and fire as well as early failure due to loss of internal pressure in VRLA cells. VRLA cell containers (also called jars) are pressure vessels. During normal float operation, water in the electrolyte is electrolyzed to produce oxygen at the positive plate. In a pressurized environment, this oxygen passes through to the negative and recombines back into water that becomes absorbed into the electrolyte within the cell. If this pressure vessel becomes compromised, oxygen leaks out into the atmosphere and cannot then recombine into water within the damaged cell.

If the pressure vessel becomes compromised, these gasses leak out into the atmosphere and cannot recombine within the cell. As a result, the absorbent mats within the cell that immobilize electrolyte and 'hold' it to the plates, become increasingly dry. Electrolyte dry-out is a condition that results in reduced battery reserve capacity and service life.

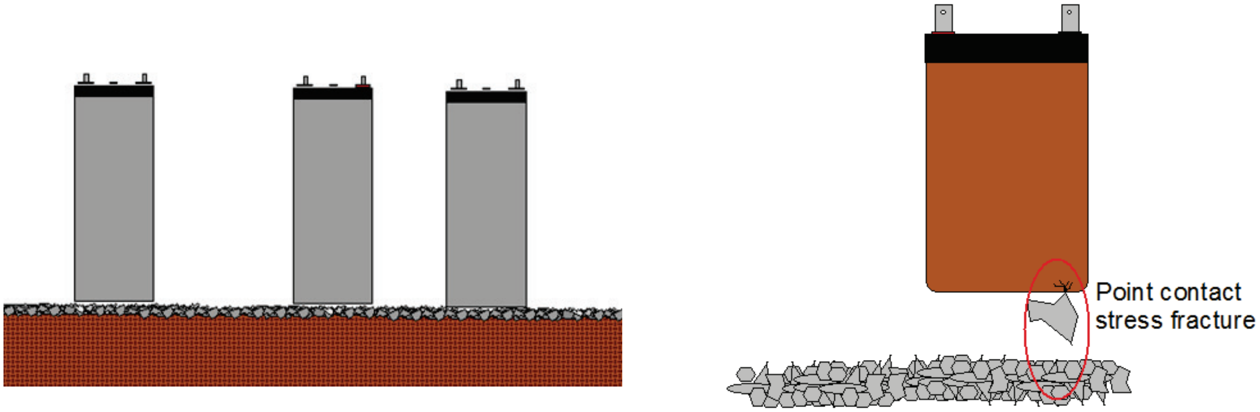

Figure 6. Placing cells on gravel or other surfaces with sharp, pointed edges can result in container failure due to stress cracking.

Take-away lesson: Plywood is cheap; battery fires are not.

VRLA battery cells can leak from overcharge because under such conditions, the pressure vents can open and release a small mist of electrolyte that can accumulate on the tops of battery containers. Maintaining battery cleanliness is important because a variety of contaminants on the top of a battery can cause misdirected energy (short-circuits) that can compromise battery capacity, at best, or initiate combustion. Figure 7 shows a twelve (12) volt monobloc battery with a film of electrolyte that spread along the top cover, probably a result of misting from vent release during an overcharge condition. This unit is in need of neutralization and cleaning followed by Ohmic testing to see if its condition is suitable for continued service.

Figure 7. As is seen, there is a two (2) volt loss across the top of the cover as a result of electrolyte leakage.

Take-away lesson: It's important to respect the necessary precautions during installation to avoid container cracks and to discover them during maintenance and take appropriate remediation action.

UPS Oops: Mental inertia and fleeing occupants

A technician replacing the battery in a 40 KVA UPS cabinet made a critical error that resulted in battery damage and the temporary evacuation of more than a hundred building occupants in a major telecommunications facility. The battery was housed in a steel cabinet and was comprised of a number of Monobloc units each with a short connection lead equipped with single pole Anderson type connector at the positive and negative posts. All but one of the red positive leads normally connect in series to the black negative leads, putting the Monobloc units in series. The last two leads, one positive and one negative normally plug into mating connectors in the UPS.

The technician apparently lost concentration while plugging red-to-black, red-to-black and instead of connecting the last two to the UPS, he plugged them together short-circuiting the entire battery (see Figure 8). When he misconnected the two connectors their contact surfaces welded together. For a time, he struggled to separate the welded connectors during which the battery units overheated and produced sufficient smoke to trigger early warning detectors that brought in fire alarms. The building was evacuated as a matter of procedure. A telephone company technician passed by while evacuating and suggested that the panicked technician disconnect a pair of connectors that had not welded. The battery technician did so but by then the battery was badly damaged and in need of immediate replacement.

Studies have shown that repetitive actions often herald a lapse of mindfulness and it seems that such was the case at hand. This significant accident could easily have been prevented by tagging the leads that were intended to plug into the UPS (see Figure 9).

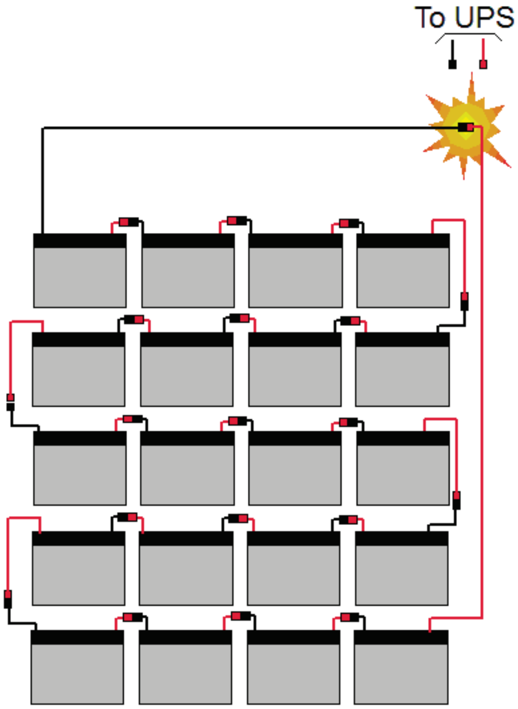

Figure 8. A technician inadvertently dead-shorted a string of monobloc units by plugging together connectors that were intended to connect to a 40 KVA UPS.

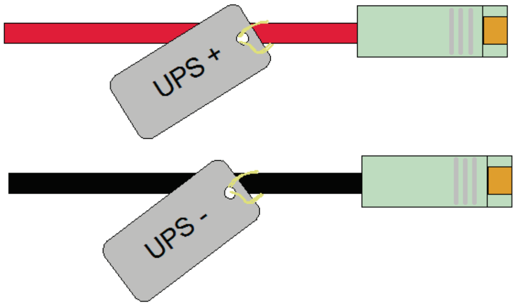

Figure 9. The use of inexpensive tags early in the installation would have prevented the accident discussed above.

Take-away lesson: Tagging leads to avoid mistakes is fundamental to reliability on electrical tasks.

INs and OUTs: INattention + INsufficient training + INtential neglect of PPE = OUTage and INjury

An accident with two installers injured occurred as a result of cascading errors during the addition of two (2) strings of 1,600 ampere-hour vented cells to a -48 volt dc plant with four (4) existing strings, thus bringing the total to six (6).

The cabling plan utilized a pair of copper splice plates as the interface between very flexible cables to the battery strings to larger cables intended to connect to the existing battery bus as is seen in Figure 10.

The first contributory error was that an installation technician mistagged the leads between the splice plates and the battery bus. As a result of the tagging error, the two additional battery strings would be connected to the battery bus in the opposite polarity with respect to the existing strings.

Just prior to the accident, one polarity of the two new strings was connected between the splice plate and the bus and the second polarity was about to be connected at its splice plate.

To prevent battery bus voltage perturbations, most carriers specify that a battery charger be connected to the string(s) being added and its output voltage adjusted so that the open circuit voltage of the “incoming” strings is close to the bus voltage, usually within a quarter-volt. The voltage on the “loose” end of the battery cables with respect to the bus are monitored with a voltmeter as the charging unit is adjusted. When the voltage is within the specified parameter, the remaining cable is landed and the connections, safely completed.

(the plot sickens…)

Because the two new strings were, in fact, connected in reverse polarity, the voltmeter measured 104 volts. As is shown in Figure 11, the technician’s helper either didn’t look or didn’t grasp the significance of 104-point-*something* volts on his meter. He adjusted the charger until the meter displayed what he thought was less than 0.250 volts, when in fact the difference in potential was 104.something volts.

When the helper believed that the “incoming” battery strings were at the correct voltage, he told the installer to go ahead and “land” the lead already connected at the bus end, to the splice plate. When the lead touched, the resulting arc caused flash burns to the installer’s arm and hand and damage to the lug. The helper working beneath him incurred corneal burns because he failed to wear required Personal Protective Equipment (PPE) in this case, safety glasses.

The transient short-circuit initiated by the arcing fault caused the bus voltage to "bobble," which in turn, caused network equipment to shut down.

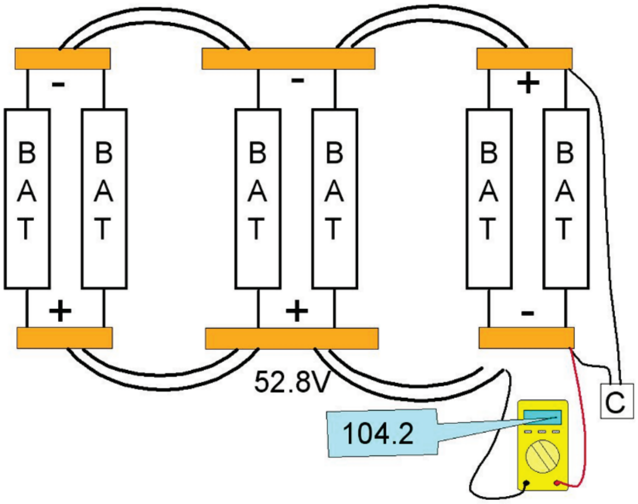

Figure 10. Anatomy of this accident. The two strings to the right were being added and accidentally were connected in reverse polarity.

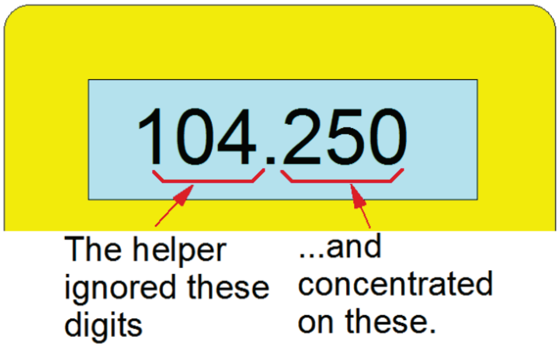

Figure 11. How the helper misread the display on his voltmeter and caused the accident described above.

Take-away lesson: Training, supervision and attention to safety are non-negotiable requirements for any power job.

People make mistakes: Sleepy people make the most interesting ones

A central office was soon to grow with approximately 1000 amperes of switching equipment and the existing dc plant had a bus that already was somewhat overloaded. The entire central office would be rehomed to a larger facility in approximately two years. A plan was developed to provide a new dc plant large enough for the existing switching equipment and the planned addition. The switching system would be repowered from the new dc plant and then grown. The transport and miscellaneous systems would remain on the legacy dc plant which at that point, would no longer be overloaded.

As is shown in Figure 12, the switching system was located on a raised floor in a room adjacent to a storage room. The existing dc cabling came across the storage room and then dropped on a vertical cable rack to the floor level and then entered the switchroom via a cable hole in the partition wall.

The plan was to enter the storeroom with cabling from the new dc plant and transition the switching system to it by using "H-taps" between the new and existing cables and then cutting the existing cables. The procedure is often referred to as a "Cut & Cut" in the industry.

The cabling was run from the new dc plant and connected in parallel with the cabling from the legacy dc plant. During a midnight to 6 AM "Maintenance Window", the installer erroneously cut the leads on the wrong side of the H-taps, thus accidentally depowering the switching equipment.

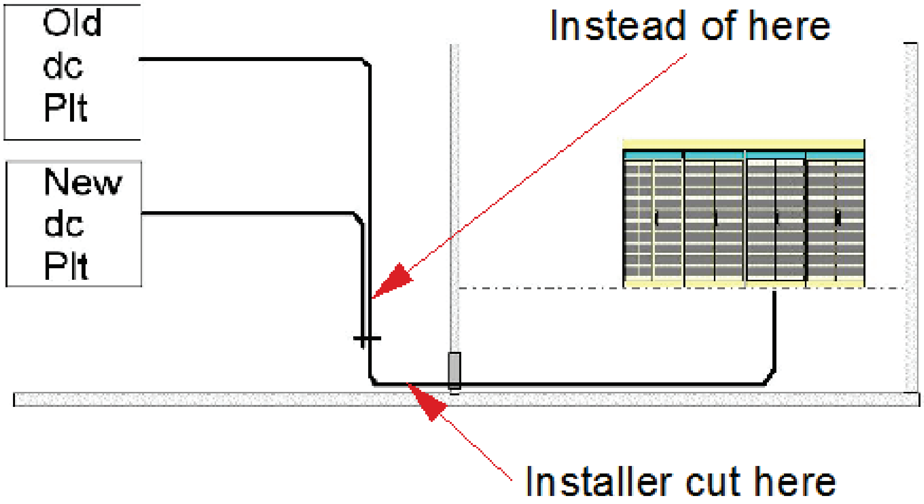

Figure 12. Installer error.

Had the lead to be cut been checked, verified and tagged (Figure 13) in the Method Of Procedure (MOP) process, it's likely that the accident wouldn't have occurred. Also, if a clamp-on dc ammeter was employed during the transition, the correct load "rollover" would be accomplished.

Procedurally, with the existing feeder energized and the new feeder deenergized, 100% of the load would be on the existing feeder and should be so verified. When the new feeder is energized, each side should now carry 50% of the load and should be verified. At that point, the existing feeder would be deenergized and the verification would be that 100% of the load is now on the "new" feeder and none on the existing feeder.

A suitable clamp-on dc ammeter costs approximately $400.00. The verification steps outlined herein add fewer than five (5) minutes to the transition and avoids a potential error that could injure someone, disable service and perhaps damage equipment. The investment seems a prudent one.

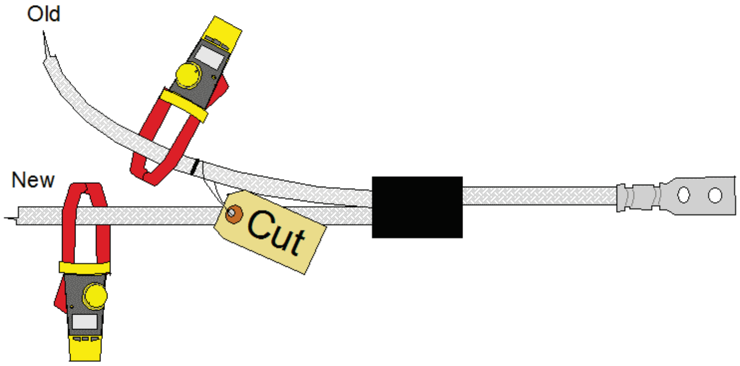

Figure 13. Simple ways of avoiding the problem

Take-away lesson: Every step of a Detailed Method Of Procedure (D-MOP) needs a verification step and any leads to be cut need to be well identified beforehand.

Skill: It's not just for brain surgeons anymore
Most carriers follow the precepts of Telcordia GR-1275[iv] for installation work and in particular, the requirement that people doing power work be at a skill level 4[1] (fully qualified) and that helpers on such a job be at least a skill level 2[2]. What can happen sometimes is that a helper is placed under the direction of a level 4 installer but that person is physically working in some other part of the central office and the helper is working undirected.

In the case being presented herein, a helper with two weeks on the job and no training was told to disconnect and remove an obsolete string of vented batteries in a central office. His Level 4 installer – a 'Lead man' in some parlance – was working elsewhere in the building[3].

Most people want to do a good job and they bring to bear the totality of their learning and experience to their tasks. In this case, one of the few facts this helper knew about lead acid batteries of any kind were words of advice from his father about safely working on the electrical system of an automobile. His father's advice was to first disconnect the negative battery cable and then no matter what else he does to the car's electrical system, it is safe. And, in a negatively grounded system such as a car, that advice is generally valid.

Unfortunately, this helper was working on the battery of a -48 volt power plant and therefore the positive poles of the battery strings are grounded. Further, the string he was removing was only one of many parallel strings in the dc plant. By taking his father's advice and disconnecting the plant cables from the negative side of a battery string and then letting those cables drop against the framework (a ground source) a major arcing event ensued and caused the failure of telecommunications systems in the central office.

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[1] R23-9 [1186]The Installer shall be assessed and classified by skill level associated with Common Systems; and for Skill Level 3 and 4 Installers, manufacturer-specific Switching, Transport, or Power Equipment.

[2] R23-11 [1188]Skill Level 1 and 2 Installers must be directly supervised and be directed by a Skill Level 3 or 4 Installer or Installation Supervisor. The Skill Level 3 or 4 Installer or Installation Supervisor shall be "on-site" to direct Skill Level 1 or 2 Installers.

[3] R23-12 [1190]A Skill Level 4 Installer shall be the only person who performs the work operations/job activities associated with the Critical Work Activities detailed in the MOP. However, a Skill Level 2 or 3 Installer may assist, as required.

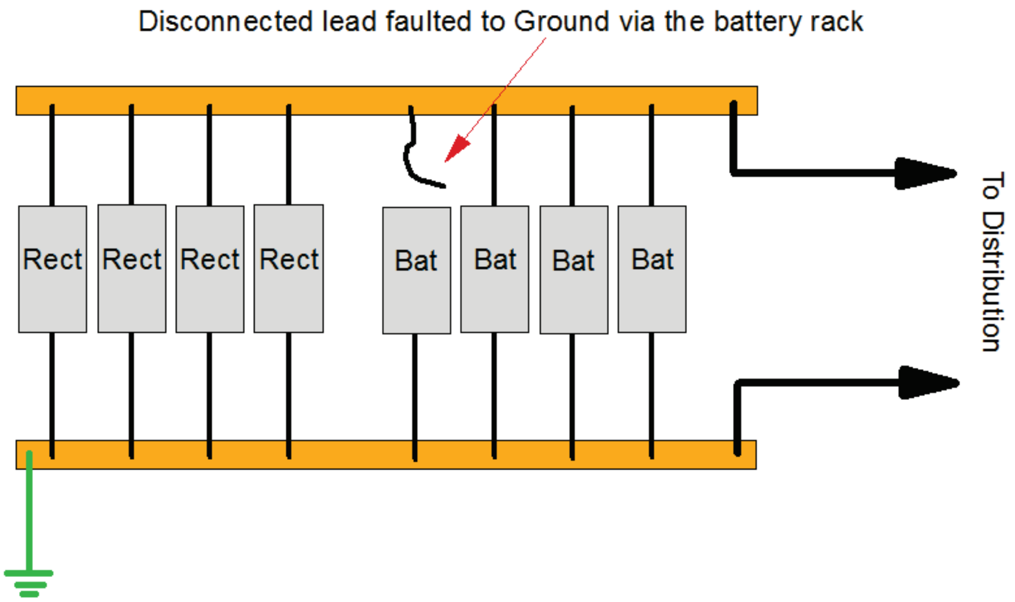

Figure 14. Illustrates the accident discussed above.

Take-away lesson: All persons performing work on power equipment must be of a skill Level appropriate for the task. The specific installer names and their skill levels should be identified on the D-MOP.

Transitions: One picture is worth 400,000 Amps of fault current

In this writer's opinion, the MOP process is key to a successful installation or removal. For jobs in which a transition from one power source to another is involved, not only is the detailed MOP critical, but a single-line diagram depicting the key elements of the transition work should be drawn, included in the MOP and plainly posted on the job site. The reason is, that sometimes in MOPs, the words get in the way of understanding the activity. Further, even experienced installers rarely have a solid understanding of how the equipment that he or she is installing actually works. When there is insufficient training, power equipment becomes a "black box" that ac volts and amps go into and dc volts and amps come out of and what takes place in between is magic.

Though a dated incident, a major loss in 1994 illustrates the criticality of transitional sketches. An event in a California central office is outlined in a national Fire Protection Association (NFPA) report titled, Telephone Exchange Fire, Los Angeles, CA March 15th 1994[v]. The event caused a loss of telephone services, including 9-1-1 traffic for more than twelve (12) hours. The dollar losses have been estimated at approximately $400M, a sum worth roughly $1B in today's dollars. Fortunately, there was no loss of life or serious injury during the event.

The intent of the job that experienced difficulty, was to modify a dc plant equipped with eight (8) 27-cell strings into nine (9) 24 cell strings. The particular plant was a Western Electric 302 plant, which was a standard offering of the era for large electromechanical switching systems and associated transport systems. As the network evolved, electronic switching systems became the standard. Twenty-seven (27) cell plants were arranged with twenty-three (23) cells in series and then two (2) groups of two (2) cells each that were added into series during discharge by means of a large motorized switch. The twenty-three (23) cells floated at 49.9 volts (2.17 volts per cell times 23) and the groups of "end cells" utilized trickle chargers to maintain their readiness.

During battery discharge conditions, the motor operated switch would add two cells into series with the twenty-three cells for a time. When the bus voltage reached a low limit point, the motorized switch would add the last two cells into series and the twenty-seven cells would discharge until a return of float operation, or battery exhaust. In the event of a motor failure, the switch could be manually operated with a hand crank. Newer electronic systems that would be powered by a -48 Volt power plant were not compatible with a dc plant with cells switched in or out because of transients caused by the switch action. Accordingly, this job was undertaken to modify the plant for a twenty-four cell operation with no motor operated switch.

Figure 15 shows the normal operation of a twenty-seven cell plant. Not shown are large resistors that ensure continuity while the motor driven switch moves from one position to another.

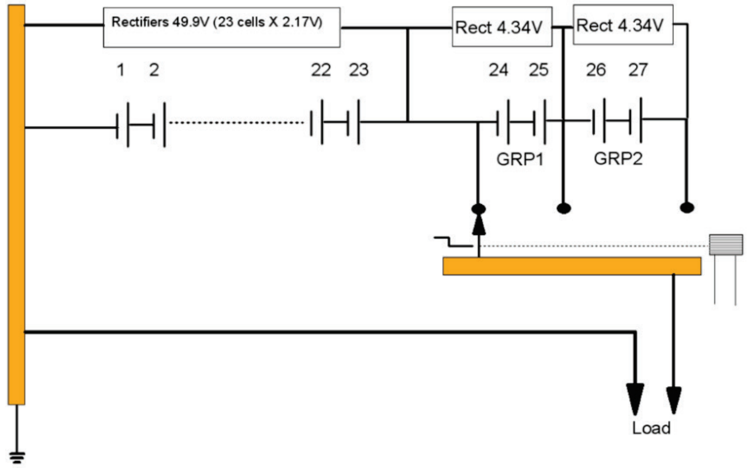

Figure 15 Shows the normal operation of a twenty-seven cell plant.

Figure 16 is of a motorized End cell switch, typical of what was in place at the job under discussion. The unit is a 3-position switch that under normal conditions is motorized or can be hand cranked if necessary.

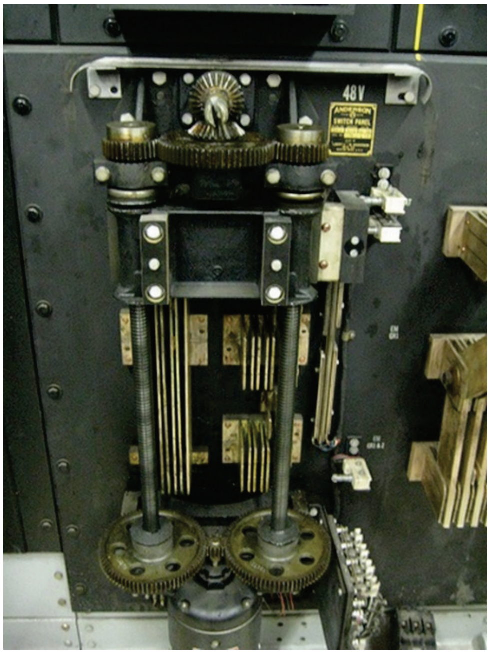

Figure 16. An End cell switch (cover removed)

Figure 17 depicts a sketch of what was intended to be the completed job. The motor-driven switch would be removed and cells from the eight (8) parallel twenty-seven cell strings would be rearranged into nine (9) parallel 24 cell strings.

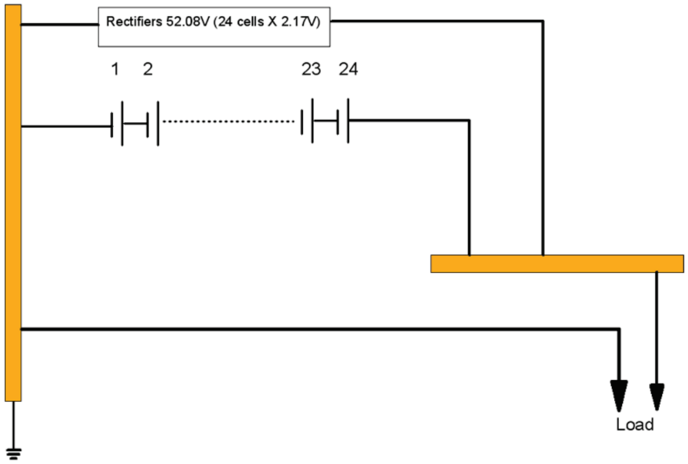

Figure 17 Sketch of what was intended to be the completed job.

Figure 18 is an excerpt from the NFPA report from the incident and it shows the placement of "Transitional Cables". Their purpose was to bypass the motor operated switch for the transition from twenty-seven to twenty-four cell operation. Figure 19 has a better illustration of the transitional cables (drawn in red) showing their relationship to the dc plant elements.

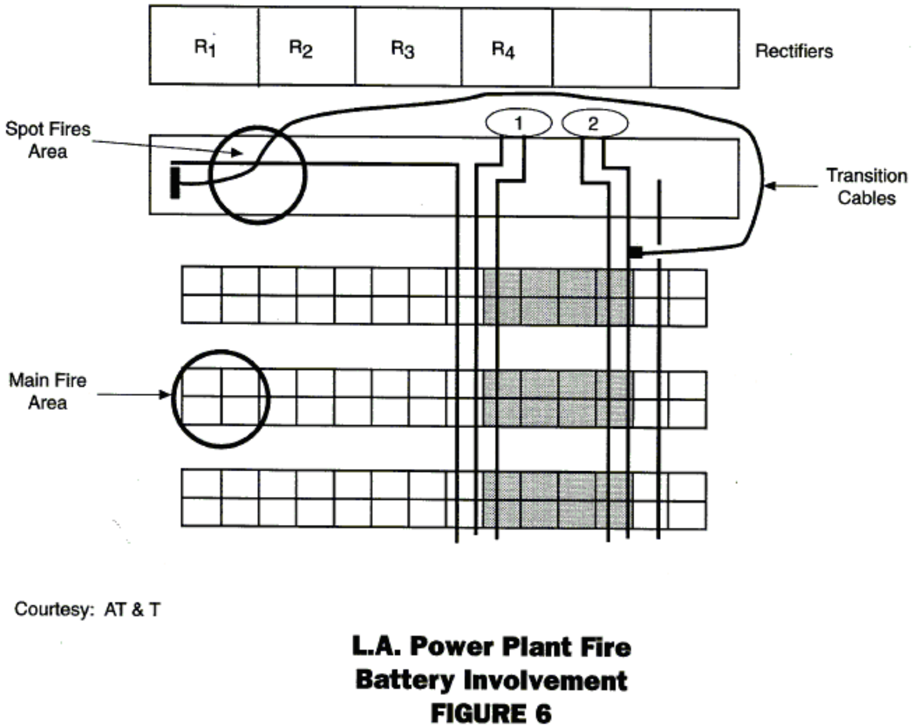

Figure 18. An excerpt from the NFPA report.

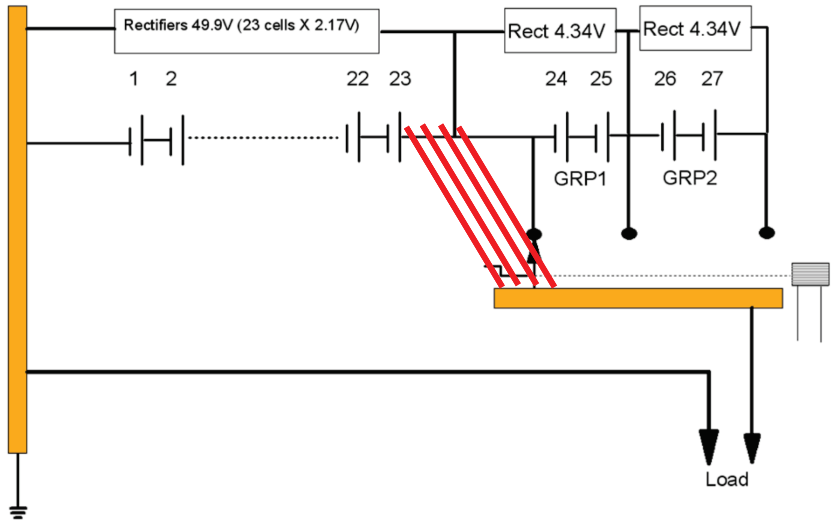

Figure 19. Shows the transitional cables (drawn in red) showing their relationship to the dc plant elements.

When things go wrong, they do so very quickly. At the time of this accident, the transitional cables were in place and the fuse for the switch motor was removed to prevent its operation. During work activities, the dc plant controller falsely operated a relay that caused all rectifiers to shut down. The particular relay was a high-voltage shutdown feature that signals all rectifiers to shut down until a manual intervention took place. At that point, all the installers needed to do was to press a reset button on the front of the power board and the High Voltage Shutdown relay would have returned to a normal state and rectifiers would have restarted. Unfortunately, the installers didn't understand the problem or the particular button[vi] and so they tried numerous other means to restart the rectifiers all of which failed.

At that point, the telephone equipment was operating from a twenty-three cell battery that was draining quickly and the low bus voltage was causing telephone equipment problems. In an frantic, though erroneous, attempt to put more cells into series with the twenty-three cell strings, the fuse for the motor driven switch was reinstalled and the switch then moved to the Group 1 position. As can be seen in Figure 18, doing so created a dead-short circuit via the Transitional Cables for two cells in series times eight strings in parallel of 7,000 ampere hour End cells. The transitional cables began to heat rapidly. Further, because the plant voltage didn't raise due to the shorted Group 1 End cells, the motor operated switch moved to the Group 2 position. At that point, the fault energy into the transitional cables became four cells in series times eight strings in parallel with current well in excess of 100,000 amperes.

The transitional cables were temporary and as such they were supported by canvas straps which burned through fairly quickly. Once the support straps burned through the transitional cables fell onto grounded framework and also onto a busduct carrying three phase 480 Volt bars fused at 1,600 amperes from an ac switchboard. In addition to the electrical faults caused by energy from the shorted End cells, once the transitional cables touched a ground source, the eight strings of twenty-three cells also fed into the fault. The available fault current rose to something approaching 400,000 amperes. The sheet steel housing surrounding the busduct burned through quickly adding a high-power ac fault component to the harrowing dc fault for the clearing time of the ac circuit breaker.

Because battery cables are unfused in telecom applications, clearing the fault required cutting cables, disconnecting battery strings and opening distribution fuses to stop the electrical fault. There is more to this story but the key point is that had a transitional sketch shown the Transitional Cables bypassing the motor-operated End Cell switch, it would have been obvious to the nearly-panicked installers that permitting the motor operated switch to operate would be a disastrous response. Transition sketches should be included in a Detailed MOP and also posted prominently on the job site and the steps checked off as the work proceeds.

Take-away lesson: (1) As in many documents, sometimes the words get in the way and a simple sketch paves the way to understanding. Transition sketches should be part of any D-MOP covering power or major Grounding transitions. (2) Don't assume that an installer knows how equipment operates just because he or she is experienced at installing it. Many system elements are a "Black Box" to installers. Require a Skill Level 4A technician or vendor field engineer for transitions or major plant or Grounding modifications.

Witness for the Defenseless: Adding a set of trained eyes to critical jobs

Because power source transitions risk network reliability and people make mistakes or take shortcuts, a prudent approach is to assign a power specialist on the job with no other tasks than examining the Detailed-MOP in a granular fashion to be certain that the verification and execution steps planned are correct and in the proper sequence. The same specialist should oversee each step of the actual transition to assure that every action is taken in the proper sequence and that the work is proceeding in a safe and sane manner. This specialist could be internal talent to the telco or a contracted third-party specialist. The specialist should not be an employee of the company performing the installation work. Providing a specialist for this role adds trivial expense to the job, probably a good deal less than 0.5% on most power or major Grounding projects.

Take-away lesson: When a significant injury network failure occurs, people on all sides of the Purchase Order are left with dirty hands or at best a dark cloud. Utilizing specialist oversight is prudent approach to transitions and possibly a lifeguard to one's career.

Summary

The devil is in the details of any task involving a dc power plant and its battery or Grounding system. Without reliable equipment documentation, installer training, adequate supervision[vii] and an unblinking focus on the MOP process, it's only a matter of time before a routine job becomes the subject of an unflattering report.

The preparation and verification steps to assure a safe and solid job generally are not expensive. Such in-process tools are somewhat like buckling the seat belt when entering a vehicle. Both take relatively little time or effort and can prevent haunting problems or unwanted forks in your career path.

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