A Maintenance Engineer's Perspective on Battery Performance Relative to Network Reliability

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Abstract

This paper is intended to share the experience of an American operating telephone company relative to storage battery and battery plant performance. While, overall, battery performance is fairly good, some engineers still consider lead acid batteries an emerging technology. The fact that electrochemical research is more than a century down the road and we haven't got it right yet, draws comparison to the healing arts of the medical profession - which are a good deal older and still have a long way to go.

As dependant as the telephone network is on batteries, there are numerous problems which must be overcome and many specific incidents which might have been avoided. A number of these are presented in the paper as case studies. Included are the specific problems and preventive possibilities.

Forward

"Where were you when the lights went out?" is a phrase which took on momentous meaning when it was coined following a massive power failure in the northeast United States in the early 1960's. Blacked out were major portions of New York, New Jersey, Connecticut and other American territories even being felt in parts of Canada. The phrase became the title to a pop song and a successful situation comedy motion picture which explored the lighter side of people suddenly without the many appliances upon which we depend for health and safety, mobility, recreation and other quality of life issues.

Government officials, military leaders and telecommunications engineers saw nothing in the blackout to take lightly. At the peak of a cold war, a nation or territory without electrical power is vulnerable to political disgrace or even direct attack. Defense strategies and city management are virtually addicted to instant communications.

Remember that this grid failure was more than thirty years ago. Homes today are even more appliance dependant than back then. In today's residential kitchen, for example, the homeowner would be hard pressed to open a can without electricity, even gas ovens won't light because they depend on electrical ignition systems and control valves. Not only telephones, but voice-mail, FAX machines, computer links, personal pagers (beepers) and cellular systems link a modern society literally held together by instant communications.

Of course, commercial power generation is fairly reliable. Advances in automated processes and controls have done much to improve the reliability of electrical generating stations, whether hydroelectric facilities, fossil fueled, nuclear plants, or the emerging wind and solar facilities. Across the power grid, plant managers give unabashed worship to the maxim that "Time is money." Generating station downtime is rare and usually carefully planned. Philadelphia Electric company recently achieved 533 days of continuous running in Unit 2 of their Limerick, PA nuclear facility. The extended run of this 1,052 megawatt plant, set a world record for that class of reactor facility. A recent fuel rod change in this same plant, surpassed all estimates for swiftness and accuracy. Their industry simply cannot afford idle plant.

Unfortunately, transmission and distribution systems remain vulnerable to the elements and to other perils. Events, large and small can disrupt power to a community. Certainly seismic activity around the world has wreaked havoc with electrical grids. Earthquakes disrupt feeders on a broad scale. Further along the distribution system, wind and lightning remains a common threat, as do motorists knocking down utility poles and careless equipment operators digging up underground cabling.

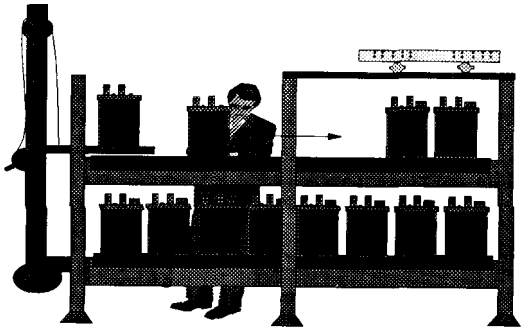
Obviously standby generators play a major role in assuring a reliable telecommunications network. Their role is limited, though, because the distributed telephone network now requires energy sources out in neighborhoods, when in prior systems the central office provided the energy right to the telephone set.

Flywheel and other technologies are emerging for the distributed network and fuel cells continue to entice us, however, it looks like batteries are going to be around for awhile yet. Of course with any technology there are problems and a number of case studies follow:

Battery Explosion

Few events capture network attention like a fire or explosion. Batteries evolve hydrogen which is explosive in certain concentrations - that's nothing new. Installing batteries doesn't require a rocket scientist, however both careers require a certain familiarity with what actions and reactions turn hydrogen and oxygen into heat and noise. In a medium sized central office (about 35,000 lines), an installer was replacing several strings of 1680 Ampere Hour (AH) batteries. Because the load was significant the job was planned to place the new batteries into service with minimum string downtime on the bus. Accordingly, the new strings were boost charged on the floor and then, one string at a time, the old strings were removed from their stands and the new ones quickly installed.

Either through ignorance or to save time, the installer waived a requirement for gassy cells to vent for 24-hours before moving them. Then, because it was easier, he put shipping plugs into the battery ells in place of their anti-explosion vents. Central office geometry prevented the installer from moving the battery hoist along the stand, so he opted to hoist the cells to one end of the stand and then slide them into place along a PVC (PolyVinyl Chloride) cover mat installed to protect the rack from minor acid spills over its service life. The relative humidity in the room was fairly low - approximately 25%, which is typical of winter RH levels in the vicinity.



Technician sliding batteries into place along PVC rack protector experienced two battery explosions.

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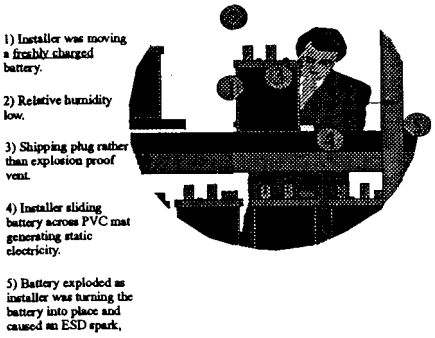
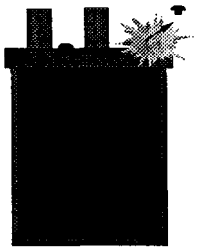
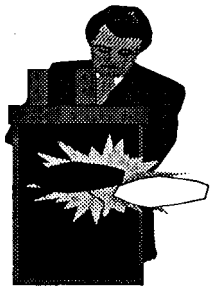
Anatomy of an accident





The first gas ignition caused the shipping plug to break its "ears" from the bayonett-type fastener, and the top cover of the battery jar cracked.



Large portion of jar blew out in a jagged piece.

The second gas ignition was more dramatic. Fortunately, the side opposite the installer exploded and his injuries were minor.

While sliding batteries into place and turning them to align their posts, a cell experienced a very small explosion which cracked the top of the jar and "launched" the shipping plug like an oversized champagne cork. After a consultation with his supervisor, and others in his company, they concluded that the event was unlikely to occur again so they resumed the work as before. A short time later, a 1680 AH cell weighing approximately 350 pounds (159 KG) exploded in the installer's arms, showering him with electrolyte and bits of plastic jar material. The installer was very fortunate, because the battery fragmented on the side opposite his body. One jagged piece of plastic jar material some 10 inches by 6 inches (25 by 15 CM) was found approximately 6 feet (2 meters) from the cell. It could have been a lethal projectile. As it was, the installer's principal injuries were minor burns caused by approximately a half-liter of electrolyte which struck his skin and clothing.

Valve Regulated Problems

Valve Regulated Lead Acid (VRLA) batteries are getting lots of hype from vendors and bad press from unhappy customers. Indeed, papers and workshops relating to the care and feeding of VRLA cells are an INTELEC mainstay. Several years into production, now, the industry still has customers who want the impossible and vendors who will enthusiastically promise it.

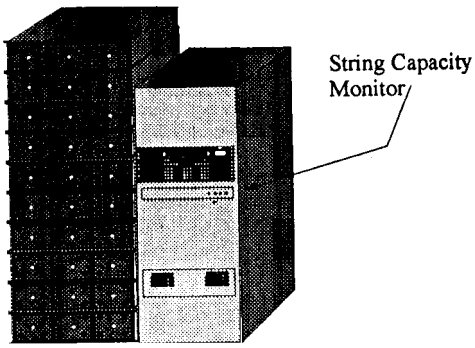
Generally, the problems experienced in the field fall into the broad categories, of low capacity and short life. Some of the factors causing the failures are design problems and some are operational issues.

"Diminished Capacity" is an American legal term which expresses the notion that someone did not possess the faculties to adequately predetermine the consequences of their actions. Thus, someone mentally imbalanced or under the influence of mind-altering chemicals may have a "Diminished Capacity" to understand or even consider that a contemplated action is criminal, perhaps heinous.

VRLA batteries are a little like that. Often, they simply don't perform, and suffer a diminished electrical capacity, and the manufacturers often haven't the slightest idea why. Or, customers accustomed to the long service life of flooded cells are desperately seeking "Maintenance Free" batteries for high density packages in extreme environments.

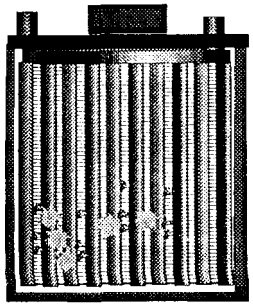
Battery vendors around the world are struggling with these issues. One American battery firm (GNB) has concluded that injecting a small quantity of water into their batteries some years into service life will restore lost capacity. Their reasoning is sound and the industry is looking at this with great interest. Of course, the ability to replace the valve or provide another "injection port" is the key to whether this would work for other vendors. Together with improved electrical post connections, the hype term "Maintenance Free" might be replaced by an attainable term "Extended Service," and describe a battery serviced at five year intervals. One wonders if fluid addition/replacement could be "built-in" with water or electrolyte stored in a capsule designed to dissolve in five years or so?

Another American firm (Midtronics) has offered an interesting product for measuring battery capacity. Their conductance-based metering instrument has evolved into a small, relatively inexpensive rack mounted unit which automatically monitors a battery and generates an alarm if capacity falls below a user defined threshold.



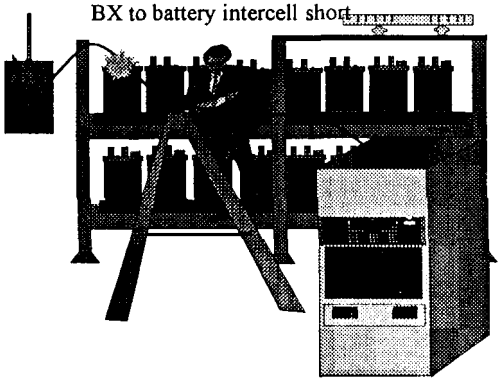
The failure of the battery for a 150 KVA UPS in Pennsylvania was traced to crystalline dendrites which grew from the plates and pierced the separators shorting several cells. Fortunately, the problem was discovered without a battery fire. The condition is thought to be a polarization defect, however, it underscores the need to watch battery operating temperatures. In this case, the battery was so hot it was heating the room.

Severe burn on installer's face



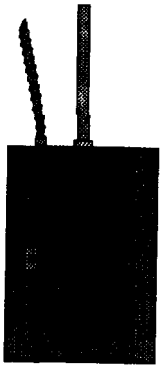
Shorted cells due to dendril growth penetrating separators.

BX to battery intercell short

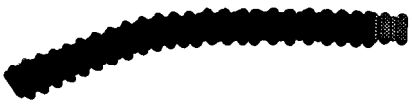


Other battery internal shorts are a result of too much shelf time. Batteries should not be stored off charge for more than six months. Batteries stored for longer than that often fail prematurely because they form small (fingernail sized) scales which slough off the plates and accumulate on the cell floor until enough pile up that they short the cell. Engineers should audit the manufacture dates on incoming cells and reject any that are more than six months old unless the vendor can prove they were charged during that interval. Some vendors use cold storage to slow the shelf aging process. This is marginally acceptable but certainly not desirable. Sometimes cells shorted this way can be salvaged for awhile by stirring or agitating the electrolyte, thus redistributing the debris, clearing the short until it piles up again.

Armor is at ground potential

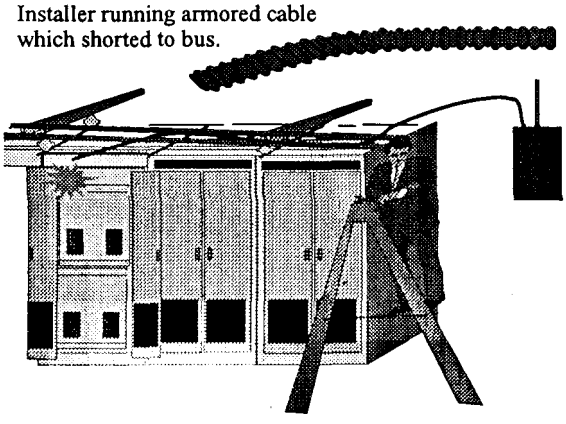


Shorted battery busses account for many telephone service lapses and installer injuries. Some years ago, an installer was injured while adding a 100 amp rectifier to a 6,000 ampere plant at a Pennsylvania central office. He was using armored cable, often called BX, to provide AC to the rectifier. The installer had connected the circuit breaker end of the cable and was pushing the cable along a 5-inch cable rack when it poked off the rack and through the top of a rectifier cabinet which had a cover missing. The BX struck the -48 volt bus and welded to it, becoming incandescent. Wearing gloves, the installer tried to pull the cable off the bus. When the cable broke free it whipped back, slapping the installer in the face, burning him severely.



Jacketed metal-clad cable

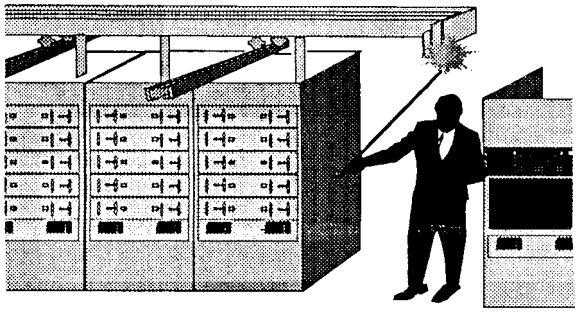
Installer running armored cable which shorted to bus.



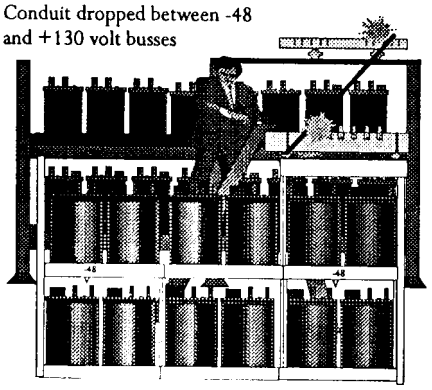
Another installer caused a service lapse in a central office when a run of BX fell across the intercell connectors of a +130 volt string, burning the battery post and the intercell connector.

We no longer use common BX for AC service. Instead, we specify jacketed metal-clad cable or jacketed flexible raceway (Seal-tite) for such cabling runs. the jacket is intended for waterproofing but it is a credible insulator preventing accidents. Additional factors in both accidents is that mechanically connecting the cable to the AC service cabinet placed the cable armor at ground potential. Cables should not be run with potential on them. In the first incident, the missing cover allowed the cable to snake into the bus. Missing covers should be replaced or the area made safe. Lastly, it was imprudent to yank the cable from the bus once it had welded on. Cutting the cable would have opened the circuit allowing a more studied approach to the problem.

A 6,000 ampere battery bus became shorted to ground in Delaware. The DC distribution cabinets were in the same equipment line-up as several other power plant cabinets. A four foot (1.2 M) main aisle separated them. Someone installed a pipe railing between the cabinets to force foot traffic out of the power area of the central office. The railing was not hard-fastened, and an equipment installer pushed it up out of his way to pass through. Pushing the pipe up like a gate, brought it into contact with overhead bus bars.

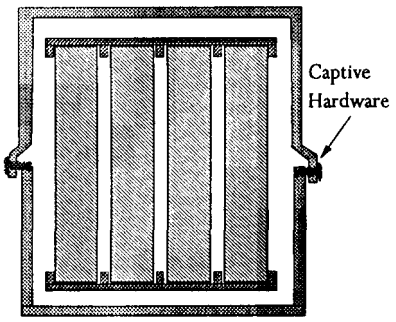


Conduit dropped between -48 and +130 volt busses



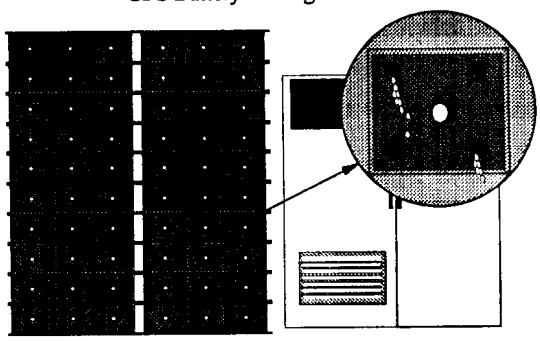
A similar incident occurred recently in New Jersey when a an electrical contractor dropped a length of conduit between the bus assemblies of a -48 volt plant and a +130 volt DC plant. The two accidents underscore a need for bus covers. There really is no place in a power room for exposed bus components. I imagine there is a significant market in America for insulating bus covers fashioned of fiberglass or similar materials, and arranged for installation with captive hardware. Likewise, insulating covers for battery intercell connectors would be an inexpensive way to increase the reliability of the power plant.

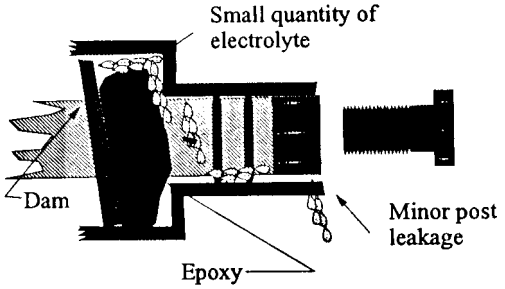
Bus protected with insulation



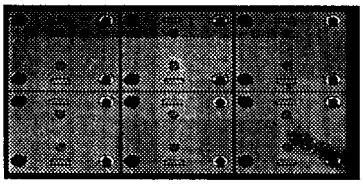
A VRLA battery failed in a 15 KVA UPS system, recently, in a Delaware central office. Approximately 25 cells of a 68 cell battery leaked electrolyte from their posts. The cells were only a few months old so the vendor was forced to replace the string. Upon tear-down, in the vendor's lab, we discovered a minor manufacturing flaw which he is correcting. A dam didn't fit quite right and allowed a small amount of electrolyte to become trapped in the post area during manufacture. Our principal concern was a potential for a battery fire if multiple ground faults established a fault circuit across a sufficient number of series cells. In this case, frequent cleaning until the defective cells were replaced prevented further trouble. UPS systems, with their high DC voltages, should always be equipped with isolated batteries and ground-fault alarms.

UPS Battery Leakage

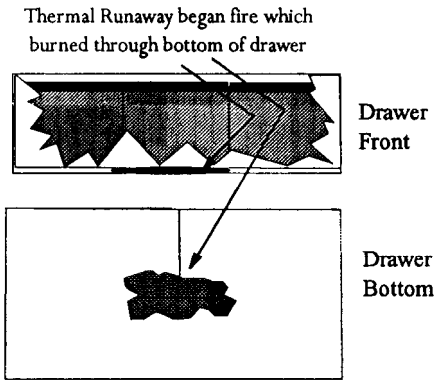


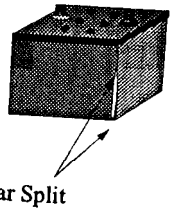


Thermal Runaway
Batteries are part of a system. Any battery can experience thermal runaway, however it is rare in flooded cells because excessive heat build-up is unlikely. Valve regulated cells, however, often are placed in very confined locations where heat becomes trapped. Additionally, thermal runaway, often is associated with a 10 to 15% dry-out in a VRLA battery. Flooded cells usually receive enough maintenance that water is replaced. Some of the thermal runaway experiences in my company have resulted in dramatic fires, some burning through the drawers which house the cells. Others simply split the battery jars.



Drawer is a confined space with no ventilation





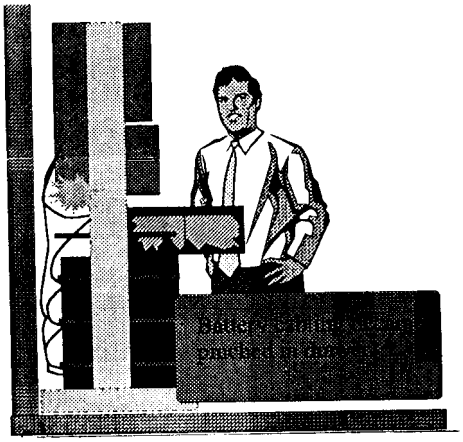
Jar Split

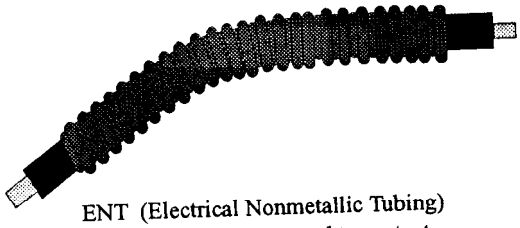
Some remedies include housing designs which allow spacing the cells. Others include thermal management of battery charger output voltage, and fluid replacement as noted above (the GNB approach) and as suggested by this author in a paper published in the 1992 INTELEC proceedings.

Battery life is also a function of operating temperature. A highly respected engineer from US West presented a paper at INTELEC '94 and shared his experiences with VRLA batteries used in outdoor equipment cabinets exposed to desert climates. The shared data from batteries operated at temperatures approaching 150 degrees Fahrenheit correlate closely with the formula which declares every 15 degrees (F) above 77 as a half-life for a battery. At 150 degrees a battery designed for a ten year life will last eleven months. Accordingly, providing some form of cooling by geothermal or other means to keep a battery at or near 77 degrees fahrenheit maximizes operating life.

How well a battery performs in float service also is temperature dependant across the series cell string. From one end of a string to another, a temperature gradient exceeding 5 degrees Fahrenheit can create a charge imbalance where some cells charge and some don't.

Battery cabling in small cabinetized plants is very vulnerable. In a remote site in western Pennsylvania, an additional string was being added to accommodate growth. During the installation, a cable slipped and shorted to the framework. The other end had already been connected to the battery bus. In another accident, in eastern Pennsylvania, a cable became pinched in a rolling dolly type rack in a UPS battery cabinet and burned off.

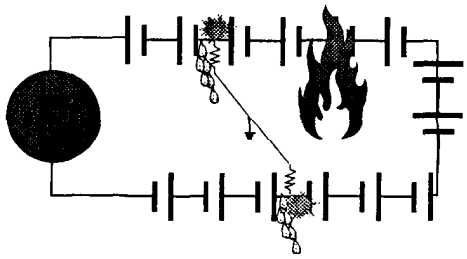




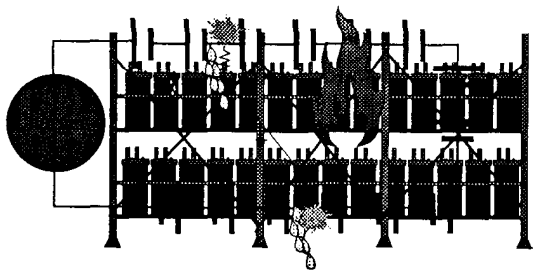
ENT (Electrical Nonmetallic Tubing) Flex Conduit may be used to protect battery cables from being cut or pinched.

Protective insulation would have prevented both accidents. ENT (Electrical Nonmetallic Tubing) is a sturdy flexible conduit. Of course, the particular plastic must meet or exceed fire retardancy ratings (Limiting Oxygen Index greater than 28% or passing UL 94V-0 Underwriter's Laboratories vertical flame spread test). Flexible conduits are a very inexpensive means to increasing plant reliability.

Multiple Ground Faults



Multiple Ground Faults



Conclusion

Despite the failures noted herein, my company has more than 1,400 central offices and thousands of huts, remotes, underground vaults, and outdoor cabinets. There are lots of batteries in those locations and our overall performance is very good. At the same time, virtually every problem noted herein in the case studies is preventable. Our challenge is to do just that - to prevent power problems from affecting the telephone network. From a network perspective, a telecommunications facility, whether centralized or distributed, is a process and a place where we pour commercial AC into one end and dial-tone comes out the other. There are grave economic and social consequences when that process is interrupted, even for tiny intervals. A modern digital switching machine will shut down with power interruptions measured in milliseconds, and take hours to reboot. For as long as we still have them in the network, batteries must be considered part of a system and designed and maintained as such. Little details like insulation and following proper procedures make the difference between a faulty network and a fault tolerant one.