Parameters to Address When Considering a Distributed DC Topology
It's All About Reliability and Cost

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ABSTRACT

Skyrocketing commodity costs for copper, and the cost of physically supporting cable trays chock full of the stuff are bringing energy users to give serious thought to distributed architectures. The concept isn't new but there were significant problems experienced in the first go-around in the early to mid 1980's. Another approach was using smaller centralized plants closer to the load but those architectures also met with problems. Other approaches and emerging battery technologies offer promise of realizing a true distributed system with fewer headaches.

But the marketing lizard said…

We've heard all that already and exciting promises often collapse under the staggering weight of their marketing hype. The purpose of this paper is to discuss a number of distributed architectures, past, present and future and speak candidly to some of the many parameters that should be weighed and thoroughly vetted before making a wide deployment of a system with inadequately demonstrated reliability.

Early on… In the early to mid 1980's, British Telecom led the industry in distributed architecture dc power systems for central office applications. At that time, much of their equipment was cabinetized crossbar type switching systems. Small dc plants and valve regulated lead acid (VRLA) batteries powered them similar to the sketch in Figure 1.

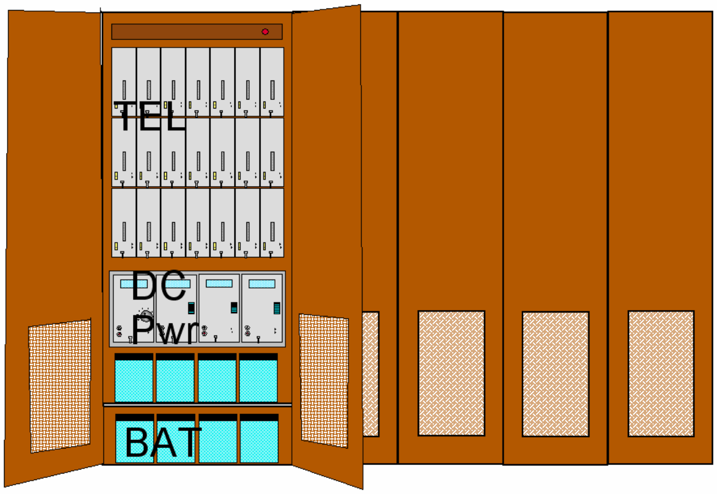


Figure 1 – Distributed dc power for central office applications on a per cabinet basis.

The topology met the goal of reducing copper cost by avoiding large, centralized battery and distribution busses. Initially, there were concerns that misting could spray electrolyte inside the cabinets and create corrosion damage. Soon after, they went to a slightly different architecture with battery cabinets at the ends of aisles and rectifier and distribution cabinets adjacent to them as is shown in Figure 2, and that remains their topology today.

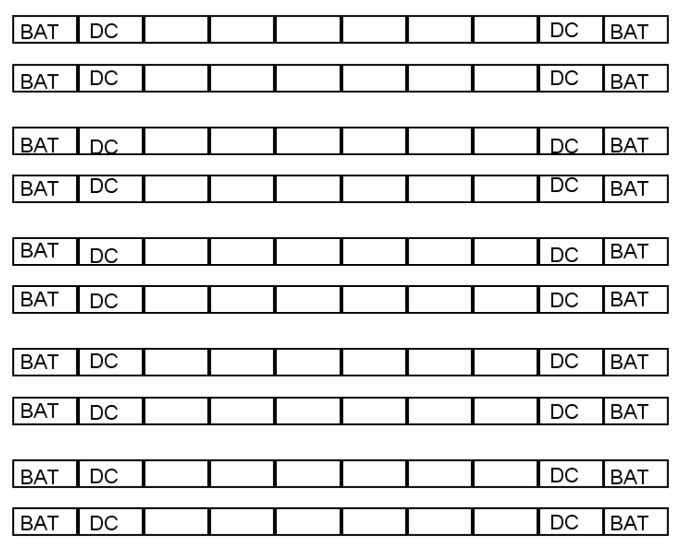


Figure 2 – Distributed dc power for central office applications on a per aisle basis.

Another distributed architecture dc system was developed by Western Electric, (now Alcatel Lucent) in the design of their Subscriber Loop Carrier SLC-96 terminals. (Figure 3)

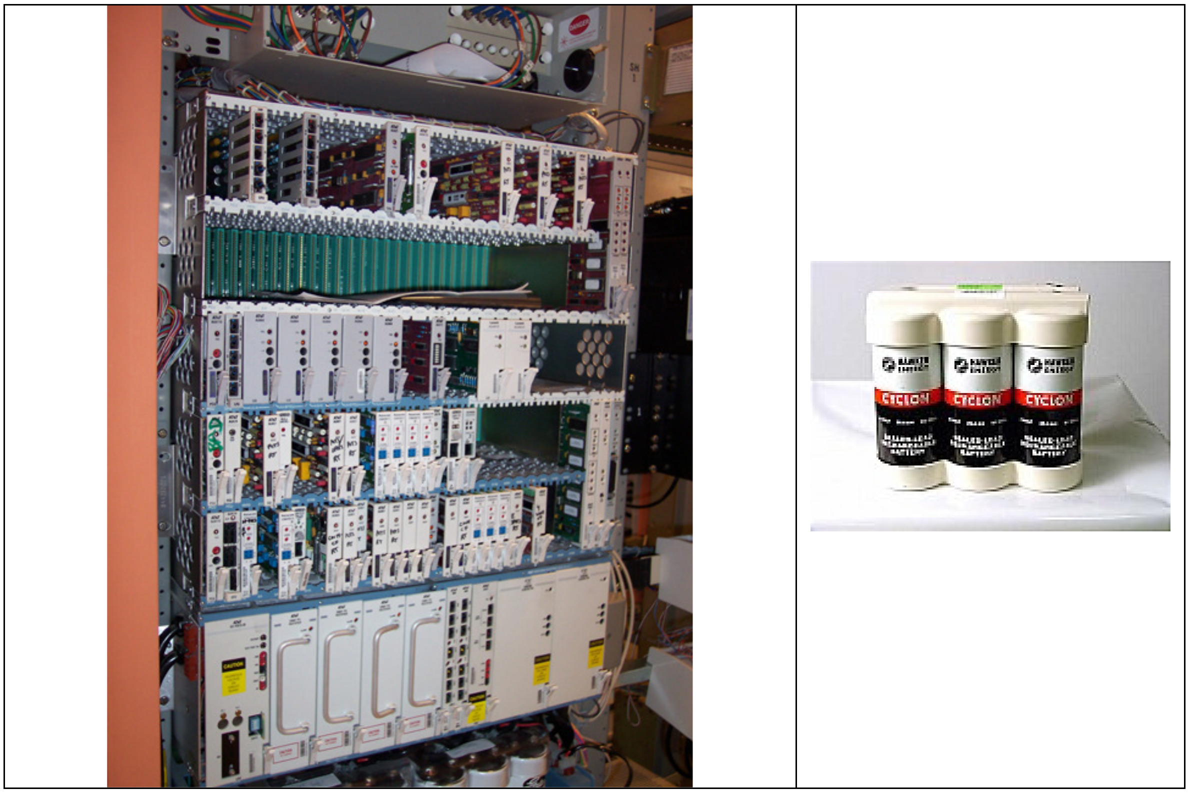


Figure 3 - depicts a SLC-96 bay with integral dc power plant and batteries just barely visible at the lower part of the bay. The photo on the right is typical of the battery used in SLC bays, a 12 volt array consisting of six 2 volt lead-acid cylindrical cells. Four (4) such battery packs provided a -48Volt reserve capacity.

SLC was a digital loop carrier system intended for two broad applications, pair-gain and delivery of telephone services to housing developments greater than 18,000 feet (5,486 meters) from a central office. Basically, the system was an advancement of the T-1 digital carrier system originally developed in 1964. SLC-96 used four (4) T-1 digroups of twenty-four (24) channels each for a total of ninety-xix (96) telephone circuits per bay. Only eight (8) pairs in a telephone cable were needed to service ninety-six (96) subscribers. Typically, SLC-96 was placed in street corner cabinets. For large developments, multiple bays of SLC-96 were deployed in underground housings called Controlled Environmental Vaults (CEV). Such bays initially came with a small dc power plant and integral battery in each bay. The photo in Figure 3 shows a SLC-96 terminal with a small dc power plant below the channel bank equipment. The batteries are just visible in the lower edge of the photo.

In time it was learned that for CEVs or huts with more than a few bays, there was improved space utilization if a bulk power plant and centralized battery were used, permitting more carrier digroups in the bays and so distributed power fell out of favor for such applications.

A distribution scheme that came from the ac UPS industry was that of one or more cabinetized UPS systems per aisle as is shown in Figure 4. The advantage was copper savings. The disadvantage was that as UPS has a significantly lower availability than dc and so there is a penalty in overall system reliability.

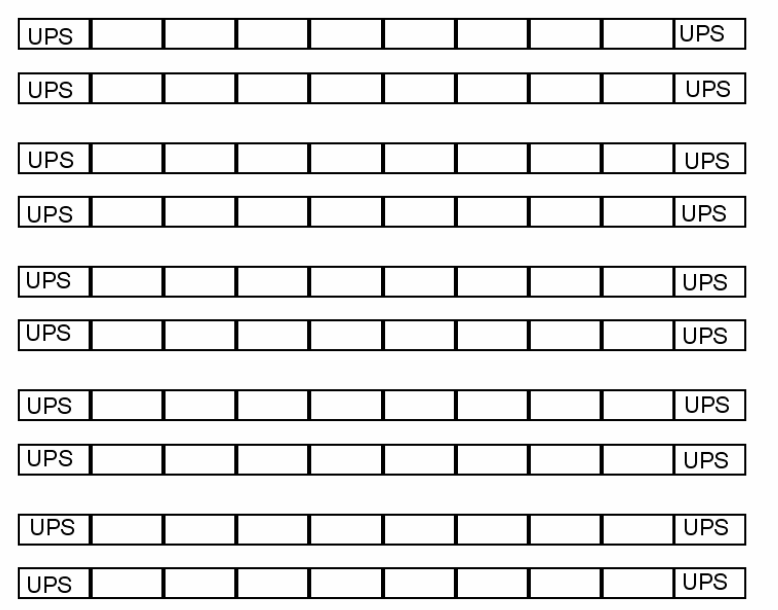


Figure 4 depicts a floor plan for a central office or small data center with one or two cabinetized power systems per aisle. Originally this topology was intended for ac UPS systems feeding ac powered telecommunications or IT equipment.

The so-called second round of the "Battle of the Currents" began in 1998 at the INTELEC conference with a jointly written paper titled "Powering the Internet: -48 V DC Equipment Topology – an Emerging Technology." [i] The paper ignited a firestorm of controversy between the ac UPS world and dc power systems providers. The paper demonstrated an availability of some twenty times that of ac UPS due to system simplicity. The model used was provided by Seichii Muroyama of NTT and is shown in Figure 4 where:

CS= Commercial Power Source
RF = Rectifier
Bat = Battery
EG= Engine Genertor
SWe= Electronic (Static) Switch
SWm= Manual Switch
DC/AC= Inverter
Cont=Control Circuit for Static Switch

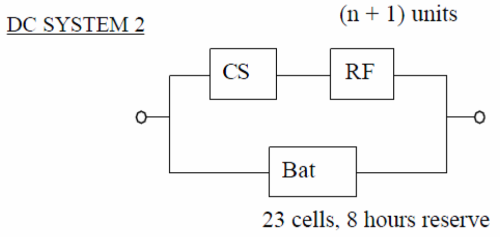
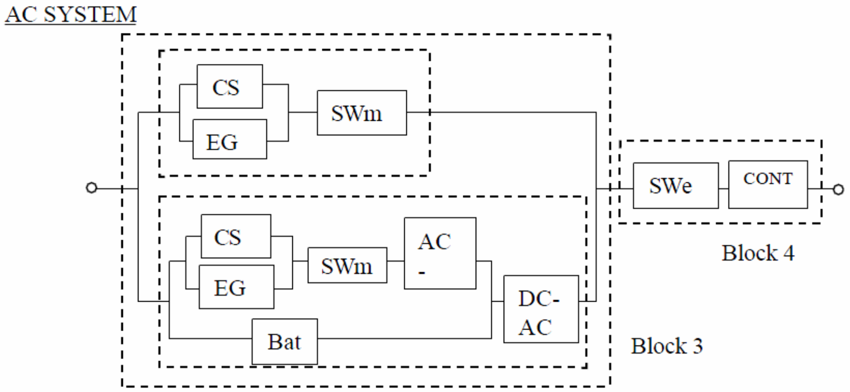


Figure 5-5. Reliability Model for DC Power Supply without Engine-Generator Set



The unavailability for:

DC System 2 is calculated as:

WDC2 = WCS _ exp(-µCS _ T) + WRF _ exp(-µRF _ T) + (WCS + WRF) _ (WBat)
Using values from TableÊ5-1:
WDC2 = 9_10-10 (for T = 8 hours)

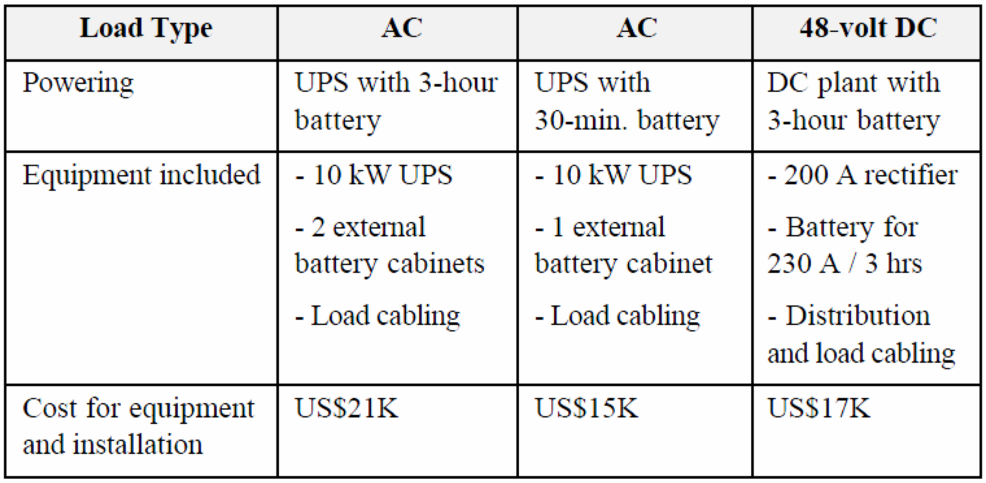
AC System

The unavailability for AC System is calculated as:
WAC = (WCS/EG + WSWm) _ (WCS/EG _ exp(-µCS/EG _ T) + WSWm _ exp(-µSWm _ T)
+ WAC-DC _ exp(-µAC-DC _ T) + WDC-AC) + (WSWe + WCONT)
(1) In the case of T = 3 hours (WAC1):
WAC1 = (1.57 _10-6) _ (3.89 _10-5) + (7.4 _10-6) = 7.4 _10-6
(2) In the case of T = 10 minutes (WAC2):
WAC2 = (1.57 _10-6) _ (6.18 _ 10-5) + (7.4 _10-6) = 7.4 _10-6

Figure 5 is excerpted from the referenced paper the conclusion of which, telecom type dc power systems have twenty times the availability of ac UPS systems.

Because telephone companies were deploying a mix of Information Technology (IT) type equipment such as Modems, Routers, Servers and related systems into their networks, they began pushing manufacturers to provide a -48 Volt version of the theretofore ac powered systems.

Cost usually wins the "contest." What is the cost of adding – say – 10KW of load to a central office or a data center in both the ac and dc worlds? Table 6-1 from the INTELEC paper referenced above showed that dc with a three hour backup was significantly less expensive (in 1998 U.S. Dollars) to provide.



Load Type	AC	AC	48-volt DC
Powering	UPS with 3-hour battery	UPS with 30-min. battery	DC plant with 3-hour battery
Equipment included	- 10 kW UPS - 2 external battery cabinets - Load cabling	- 10 kW UPS - 1 external battery cabinet - Load cabling	- 200 A rectifier - Battery for 230 A / 3 hrs - Distribution and load cabling
Cost for equipment and installation	US$21K	US$15K	US$17K

In time, IT based systems became whole data centers that processed telecommunications and related traffic and therefore large – typically 10,000 Ampere centralized plants were feeding these systems. While the advantages loom large, so did the cost of conveying 48 Volts several hundred feet from Primary Distribution bays in centralized power rooms to Secondary Distribution bays in the switchrooms and on to individual bays or cabinets of equipment.

Bob Burditt[ii], then working for PECO-II introduced the idea of placing multiple dc plants with the telephone /IT equipment connected together via a CAN bus or similar arrangement. Batteries would be housed in the basement and cabled straight up through the floor into the bottom of Primary Distribution bays or cabinets to reduce the copper losses dramatically. Some folks liked that idea. Others didn't like the topology because they didn't want the cost of a basement and columns impeding aisle placement in the data center environment. For unknown reasons, data center designers don't know or understand that telephone systems engineers have worked around building columns quite successfully for more than a century.

As IT equipment became more power-dense, the power demands of data centers increased almost logarithmically and so it would take more than a single 10,000 Ampere 48 Volt plant and centralizing them would result in huge amounts of large distribution cable. Regardless, the same philosophy shown below would work well in such an application. Because high frequency switchmode rectifiers have advanced to high efficiencies, typically around 97 percent, the added heat load in the switchroom is tolerable. A 10,000 Ampere dc plant typically would be loaded to 7,000 Amperes or 336 kW. The added heat from 97% efficient rectifiers delivering 7,000 Amperes to the load would require only 1.7 tons of cooling capacity on top of some 57 tons for the telephone or IT heat release plus whatever is needed to overcome solar gain heating.

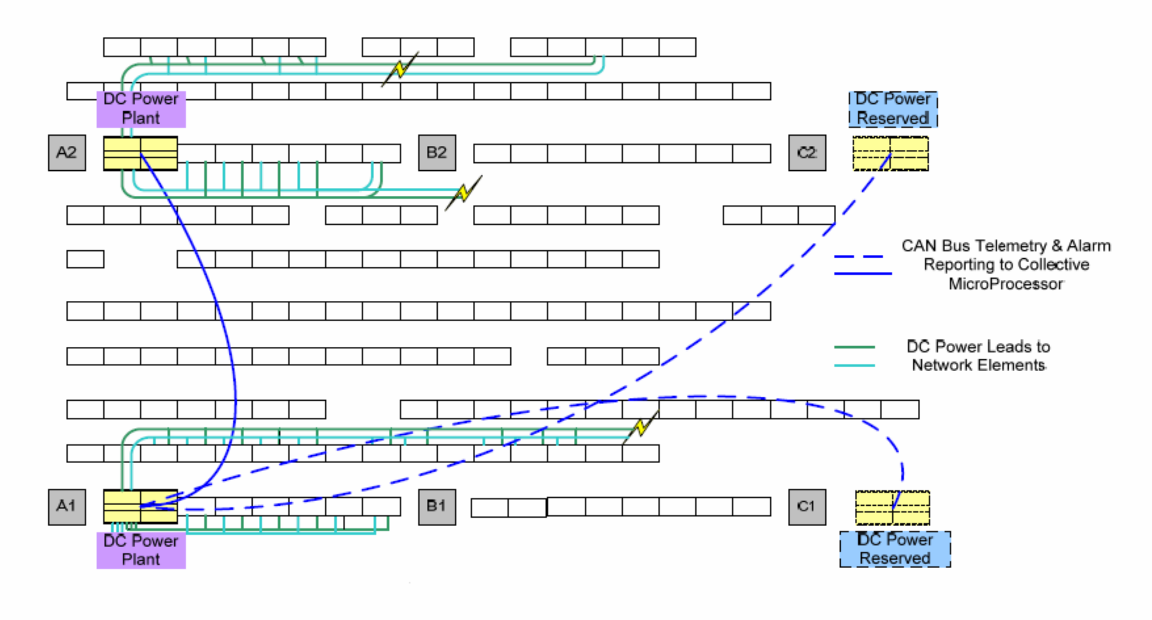


Figure 6 depicts a figure offered by Bob Burditt at Battcon 2007 for a multiple -48 Volt plant every few building bays. The rectifiers etc are collocated with the telephone/IT equipment and the batteries are on the floor below, cabled up through the floor slab. (Used with permission)

As the technology world moved on, the voice, data and video worlds converged still more and a greatly increased proportion of the equipment used to deliver those services are based on server and router type systems. During that time, Moore's Law[iii] remains the law of the land in a technical world and so energy density has taken quantum leaps and with that, the heat release of telecommunications equipment has soared. The upshot of that increase is that the term "Pizza Box' used to describe 1U high equipment shelves is now being called "pizza ovens" in recognition of the high heat output dumped into the space. This high heat release gives pause to the notion of three, four and even eight hour battery reserves when equipment would shut down on over-temperature in fifteen to twenty minutes. Accordingly, the demand for high battery availability gives way to high generator reliability and/or schemes for parallel geo-redundant switching centers.

In either case, the bottom line to that discussion is that the battery reserve time comes down to something like one hour. This reduced interval covers the contingency that someone can open enough doors to move hot air around for an extra few minutes while technicians scramble and solve whatever ill prevented the standby engine from running. Or, commercial power restores. In either case, the important factor is that the HVAC equipment is once again on-line and pumping unwanted heat outdoors.

Given these conditions and trends, just as fashion trends often come full circle, it might just be that distributed power architectures come back into favor by cost conscious engineers. This author believes that the battery is the key to distributed power systems. Clearly, VRLA batteries have improved, as have the charging regimes used to maintain them in a readiness state of charge. Despite the problematic misting experienced by British Telecom in the 1980's, such cells have provided reliable service, even in outdoor cabinets subject to harsh environmental conditions.

The telecommunications equipment voltage limits in ATIS ATIS-0600315.2007 and the 2011 draft of that same document is 40.0 to 56.7 volts for systems that do not use loop signaling. Accordingly, 48 Volt data centers or any other 48 Volt system not connected to telephone instruments could use this voltage range. Increasing the 48 Volt battery by one additional series cell still falls within the acceptable voltage limits and permits either expanding the dc voltage drop permitting the use of smaller copper conductors, or increasing the battery reserve time for a smaller Cabinetized battery.

An example is an aisle-fed topology similar to Figure 7, arranged with two, small 25 cell, 48 Volt dc power systems per line-up. The A and B redundant inputs for the data or telecommunications equipment inn cabinets 100.02 through 100.10 are fed from branch circuits from the power plants at each end of the lineup. When designed with a one volt drop in distribution wiring, the result is adequate power for a discharge down to 1.64 Volts per cell. This potential is much better battery utilization than the 1.84 Volts per cell typical of telecom applications and produces a significantly greater reserve time for a given ampere-hour cell capacity.

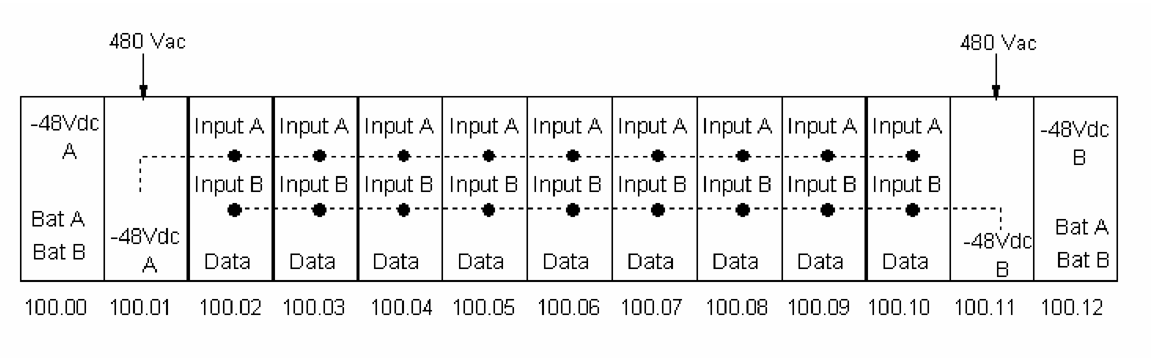


Figure 7, Top view of a distributed dc architecture using dual dc plants for A/B redundant input systems.

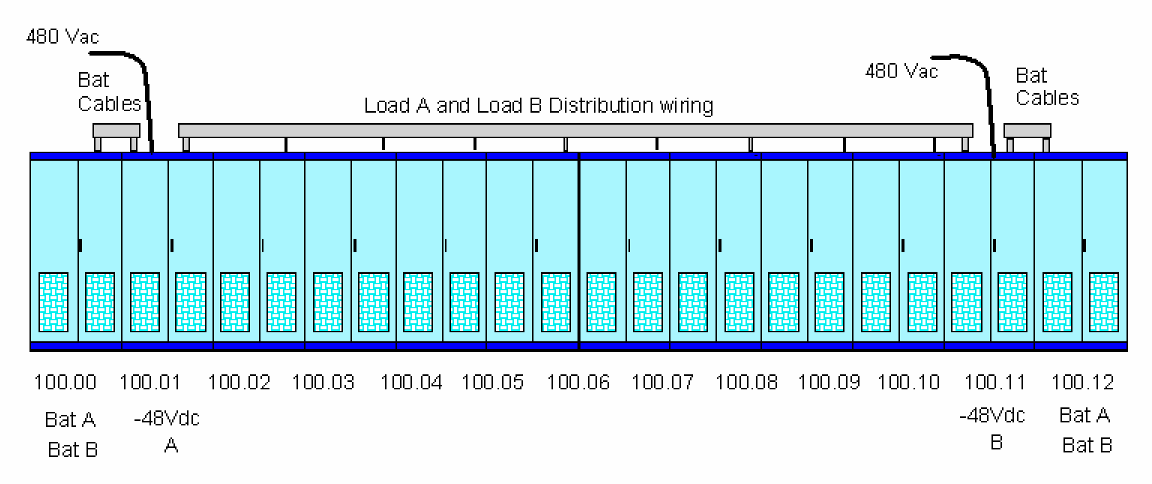


Figure 8, Front view of a distributed dc architecture using dual dc plants for A/B redundant input systems. Dist wiring is in a simple 4” overhead or underfloor raceway.

At least two new battery technologies show promise that could improve the power density of distributed dc power topologies.

Please pass the salt

Fiamm Corporation is marketing a Sodium Nickel Chloride battery for 24, 48 and 380 Volt applications that drastically reduces battery footprint. In this technology, the Negative electrode is molten sodium and the electrolyte is a formed ceramic tube placed within steel square tube sections. The Positive electrode is a Sodium and aluminum compound and ion transfer through the ceramic electrolyte causes current flow. An internal controller circuit maintains safe operation. The technology boasts a power density five times that of lead, a cycle life > 1,000 discharge cycles and a high tolerance for short circuits. Some of the down-sides to this technology is that it has a high internal operating temperature 270^{o}C, necessary to keep the sodium in a molten state. From a cold state, it can take as long as 24 hours to reach operating temperature. The battery consumes as much as 100 Watts (typically about 55) to keep itself heated.

Figure 9 (left) is Fiamm's Sodium Nickel battery offering. The unit is in a highly insulated stainless steel case to contain the nearly 300 degree (C) operating temperature. The two circles on the upper left are the output connections. The small door at the lower front-left is access to connectors for control and monitoring. The figure to the right is a rack of Sodium Nickel cells delivering 3,200 AH.

But hold the sulfur, it doesn't smell good right now…

Another Sodium battery being offered is the Sodium Sulfur cell which is similar in concept to that described above. A significant downside to this technology is that if the sodium hydride cools too much during a prolonged power loss, the material settles to the bottom of the cell and solidifies, thus ruining the cell. While the technology is being watched, at this moment in time Sodium Nickel has more interest from telecom than does Sodium Sulfur.

And Lithium?

Lithium Ion batteries are an energy-dense technology that's gaining interest among battery people. Several white papers were presented on the subject at Battcon 2011, The electric vehicle industry is looking to Lithium as the Holy Grail because the battery is packed with power, relatively low in weight and has a very rapid recharge time as compared with heavier, slower to recharge VRLA technology. On the other hand, engineers fret over the possibility that under catastrophic conditions Lithium cells result in dramatic fires. In the electric vehicle realm this threat is a balanced risk when compared with a gasoline tank vulnerable to rear-end collisions.

For telecommunications engineers are wary, though encouraged by control system improvements in this emerging technology. Some of the wariness comes from negative experiences seen when Avestor, blitzed the industry with a highly touted Lithium Metal Polymer battery. Initially, the battery showed promise despite a fire in an Atlanta lab. Even the smallest fire events get big press in Telecom. Later, after publishing a white papers[iv] [v]at Battcon 2003 and 2004 saying in essence that all the safety and control problems were solved, a couple major players in telecom, initiated field trials and one service provider bought in for a wide deployment. Despite modest sales, the company failed. Some opine that the product was rushed to market, a corporate gamble that doomed that company.

Lithium Ion batteries are getting interest for stationary battery applications and there are a number of companies offering their version of a product. Lithium Ion technology differs markedly from the Lithium Metal Polymer technology that failed. With Lithium Ion, both the positive and the negative electrodes act as host structures for the Li ions and the Li+ as may be seen in Figure 10.

A daunting concern among stationary battery users is thermal runaway which was a nettlesome problem in Valve Regulated batteries but would be disastrous in Lithium-ion. The reason is the flammable nature of the electrolyte and the generation of heat between the electrodes. Fires involving lithium batteries are dramatic, high wattage events!

All battery cells have Anodes and Cathodes with a separator between them. The flow of ions across that separator is what makes the unit an electrochemical cell. In the case of Lithium Ion, if too little resistance exists in that path either due to an internal or an external short-circuit, an exothermic chemical reaction will occur and the cell temperature will rise dramatically.

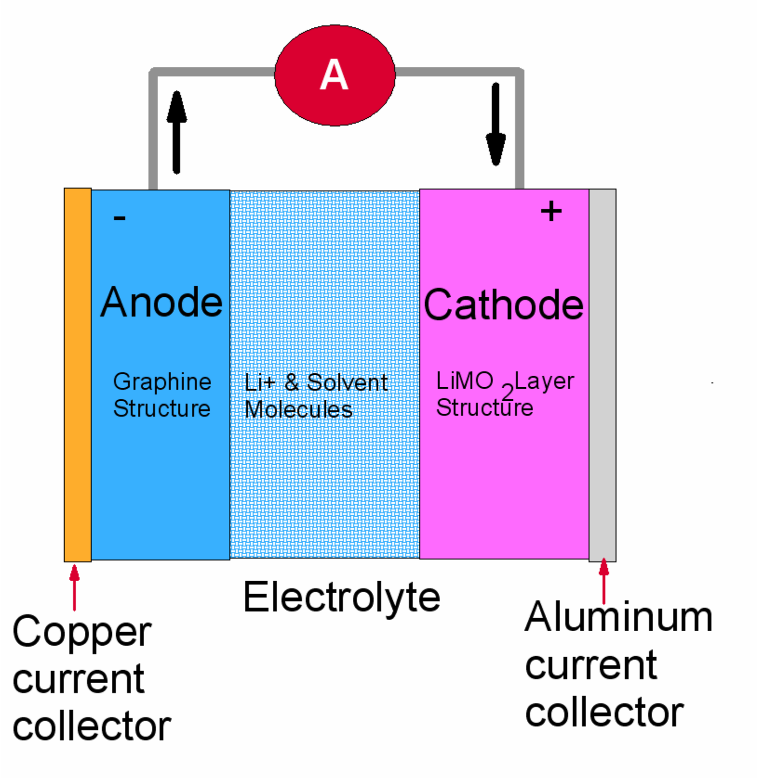


Figure 10, Lithium Ion technology

Lead acid or Ni-Cad batteries use water-based electrolytes, whereas the electrolyte in a Lithium-Ion cell is quite flammable. If electrolyte leaves the cell, exposure to atmospheric air increases the reaction causing the electrolyte burn. Because the energy density of a Lithium cell is greater than that of its competing technologies, the resulting fire also is much larger in terms of energy[vi].

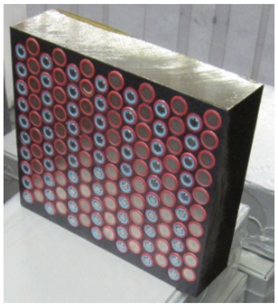


Figure 11, lithium ion cells mounted in a thermal management enclosure formed of phase change materials that tend to even-out cell heating. (Photo courtesy: Ultralife Corp./AllCell Technologies)

The electronic protection systems built into Lithium Ion batteries are intended to control thermal reactions and thereby reduce the incidence of fire. In addition, in an effort to address flammability concerns, some manufacturers are differentiating their product by encasing cells within battery modules in a thermal management material to inhibit, retard and in some cases potentially prevent the propagation of thermal runaway (Figure 11). Regardless, quality control issues and operational conditions will rank highly in telco vetting processes.

So…?

The high power density of the Sodium Nickel and Lithium Ion battery offerings are soon to be vetted in telecommunications. Obviously, high power density bears more intensive risk of fire, the smoke from which could have very serious cost penalties for telecom users due to equipment contamination and of course, loss of service for a time. If either or both of these technologies pan out, however, they could herald a rebirth of the distributed architectures shown in Figures 1, 3 and 5 without a need for basements. The batteries easily could be cabinetized and provide sufficient energy for a one hour reserve time as is dictated by newer equipment heating profiles discussed previously.

Conclusions

What has gone around just might come around again. Remember that the mathematical models for the cellular telephone network originally were developed in the 1930's and it took nearly forty years and some false-starts to gain traction and reach fruition. Newer battery technologies and conditions ripe for a reduced battery reserve time are converging. As these factors coalesce, distributed dc architectures could emerge like a Phoenix to exploit the inherent uptime of dc systems while facilitating dramatically reduced copper purchases and the physical plant needed to support massive conductors. That's a win-win.

Further, equipment rooms with high heat loads often employ raised access plenum floors. The ac feeds for distributed dc plants are small enough to be placed in conduits in those plenums, where large dc conductors could not be placed. No manufacturers produce a plenum-rated dc power cable. Accordingly, ac to the rectifiers could be run in the plenum space and the relatively small conductor runs for dc to the equipment would be easily manageable in overhead cable trays. A win-win scenario just became a win-win, win some more.

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[i] Powering the Internet: -48 V DC Equipment Topology – an Emerging Technology (1998) John Åkerlund – Telia, Bo Lindemark -Ericsson Components AB, Dan McMenamin - Bell Atlantic, Seiichi Muroyama – NTT, John Parsons – British Telecom, Jacques Poulin – Nortel APS, Chris Riddleberger - Consultant, Katsuichi Yotsumoto – NTT. IEEE Proceedings, INTELEC '98 San Francisco, CA

[ii] DESIGN CONSIDERATIONS FOR DISTRIBUTED DC POWER APPLICATIONS IN TRADITIONAL TELECOMMUNICATION FACILITIES (2007) Robert Burditt – PECO-II Proceedings Battcon '07

[iii] The Future of Integrated Electronics" Gordon Moore (1965) An internal paper at Fairchild Semiconductor, republished as "Cramming more components onto integrated circuits" in Electronics Magazine in 1965 and then updated in 1975

[iv] Vallee, A. et al, "Lithium-Metal-Polymer Batteries: From the Electrochemical Cell to the Integrated Energy Storage System: Battcon 2004

[v] Gow, P. et al Designing Lithium-Metal-Polymer Batteries for Safety Battcon 2003

[vi] Arora, A. Lithium Ion Batteries for Stationary Applications: A Safety Perspective Battcon 2011

About the author:

	Dan McMenamin is an internationally recognized telecommunications consultant following a 36 year career with Verizon Communications (formerly Bell Atlantic). His background includes network equipment engineering and maintenance engineering posts covering a gamut of technologies including analog and digital switching systems, transport and radio/microwave systems, cellular systems, data centers, power systems and grounding. Dan has served on both national and international standards teams and is a member of the Lightning Protection Institute (LPI), United Lightning Protection Association, Power Sources Manufacturer's Association, Alliance of Telecommunication Industry Solutions (ATIS) Protection Engineer's Group (PEG), National Fire Protection Association, International Code Council and a Senior Member of the Institute for Electrical and Electronic Engineers (IEEE). With extensive experience at organizing and presenting technical seminars, Dan also has authored more than thirty technical papers and articles, and has served on the Technical Program Committees of the 1990, 92, 94, 96, 98, 2000, 2002 2004, 2008 and 2010 International TELecommun-ications Energy Conferences (INTELEC) and General Chair of INTELEC 2006. Dan has served as a featured speaker for seminars hosted by Verizon Communications, Verizon Wireless, Verizon Global Networks Inc., Marconi Corporation, Nortel Networks, Astec Corporation, Prentiss Properties, Lucent Technologies and Emerson / Liebert Corporation.