DC PLANT MODIFICATION MISHAPS
(AND HOW TO AVOID THEM)

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Abstract

During last summer's IEEE Energy Storage and Stationery Battery Committee meeting, there was considerable interest in a presentation by Telcordia's Service Line Director, Richard Kluge. A large part of his discussion centered around several major incidents in the telecommunications industry. Due to time constraints, Mr. Kluge covered only high level details about any of the events. The lessons to be learned from those and similar incidents bear sharing because many older plants are still in service. The purpose of this paper is to cover several such incidents in greater technical detail and show 'take-away' learning concepts to prevent such failures going forward.

Covered will be:

- A large battery fire
- Vibrating bus bars in a dc plant
- Countercell modification error
- EPO error
- Take-Away Lessons

Large Battery Fire

A significant fire occurred in a large dc power plant, one of six dc plants on the 13th floor of a central office building. The information presented herein was gleaned from a review of the NFPA report[i] on that fire and from a discussion with a Maintenance Engineer very familiar with the incident.

The dc power plant that experienced a fire was a 48Volt, twenty-seven (27) cell Western Electric 302A plant[ii] with six (6) parallel strings of KS-5582 List 07[iii], 7,200 Ampere-hour floor-mounted lead antimony cells known as 'tank cells' or 'submarine batteries' in the industry. The twenty-seven cell topology was common to central offices with electro-mechanical switching systems. Under normal operating conditions, twenty-three cells are float charged at 49.9 VDC (2.17V/cell X 23 cells).

Two groups of two cells called 'End cells' are charged by trickle chargers. In discharge conditions, a motor-driven end cell switch adds the first group of two End cells into series with the twenty-three and then the second group of End cells as the bus voltage declines further. The twenty-seven cells become discharged to 1.75 volts per cell (47.25 Bus Voltage) at the end of the designed reserve time.

While electromechanical switching systems easily tolerate transients that accompanied End cells switching in and out, electronic switching systems do not. To prepare for the provision of an electronic switching system, a decision was made to avoid the cost of a new twenty-four cell dc power plant by modifying the 302A plant. The modification would remove the End cell switch and reconfigure the battery. From the existing pool of End cells, one cell would be added to each string of twenty-three. The 49.9 Volt SCR type rectifiers (chargers) would be replaced by 52.8 Volt controlled Ferro resonant units which were state of the art at that time. The modifications were performed by experienced installers who had previously performed the task on other plants.

Among the first steps in the modification, a fuse was removed that disabled the End cell Switch. Then, several 750 Kcmil copper conductors were run as shown in Figure 2. These conductors were considered temporary and were supported by canvas shipping straps.

Approximately forty-seven minutes into the midnight work shift, all the existing 49.9 Volt rectifiers shut down suddenly. Because the End Cell Switch was disabled the bus voltage went to something less than 46 Volts (23 cells times 2 V, minus the coup-de-fouet dip).

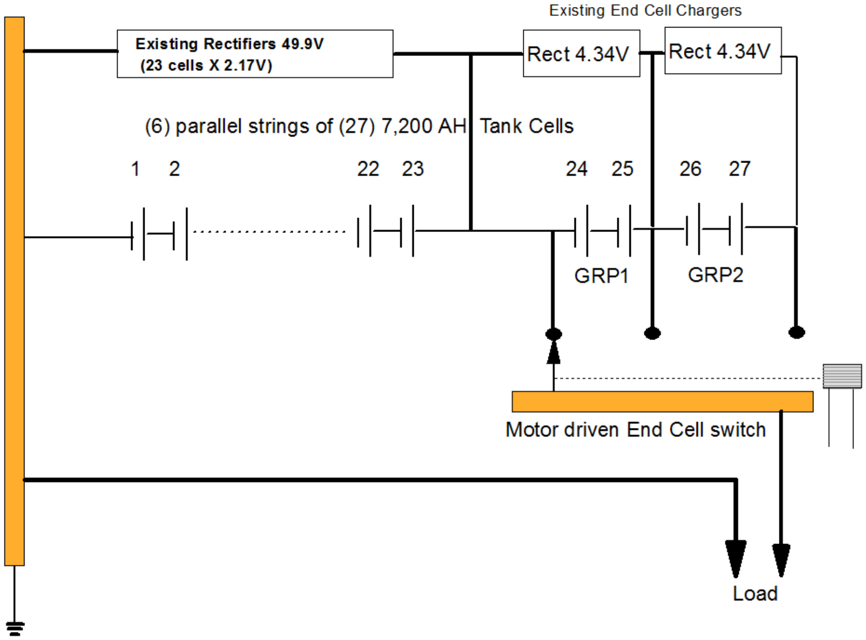

Figure 1: Simplified sketch of a 302A Plant before modification

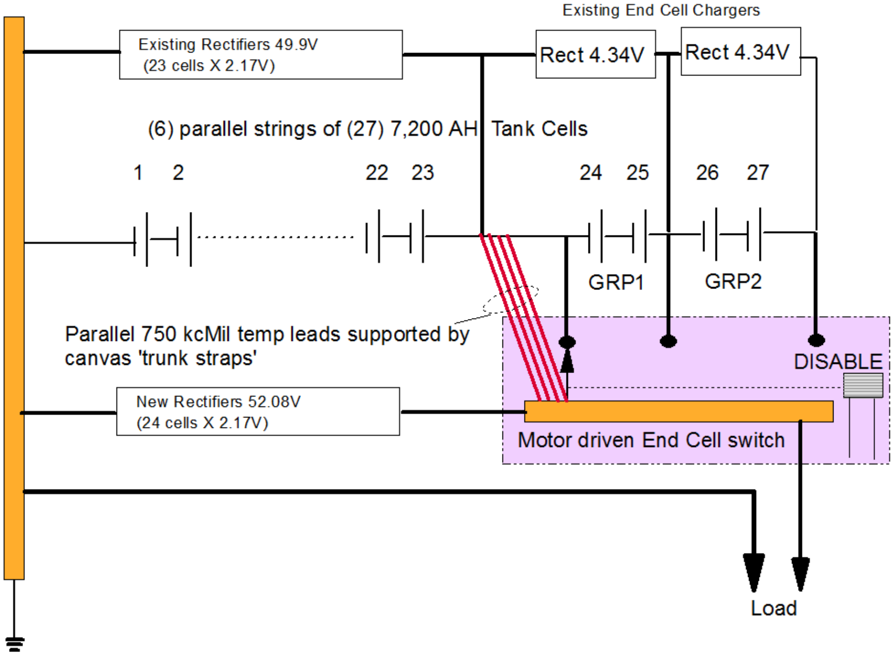

Figure 2: Interim modification of the 302A Plant

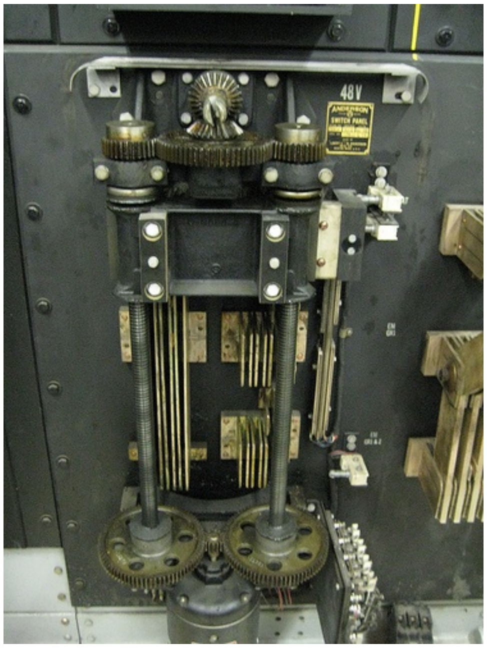

Figure 3: A typical End Cell Switch (cover removed)

Although unknown at the time, the reason the rectifiers shut down is that a High Voltage Shutdown Relay in the plant controller had operated. All that need be done to correct the condition was to push the 'Reset" button on the controller. When operated, the HVSD Relay, applies Ground to the TR leads to each rectifier which in turn, causes the rectifier to shut down. Absent that bit of knowledge, the installers checked the rectifiers for ac power and other conditions that might prevent their operation. At some point, the installers turned on the new 52.8 Volt rectifiers but none of them started because they too had Grounded TR leads from the plant controller HVSD circuit.

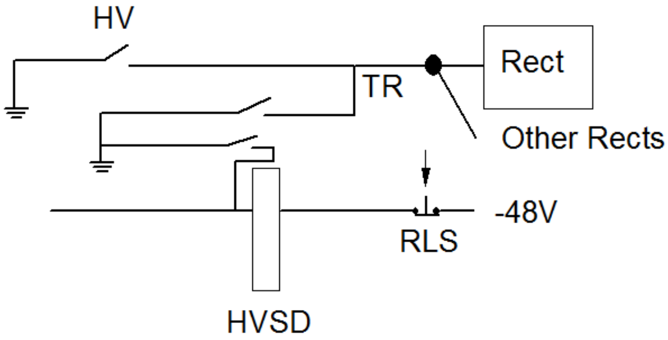

Figure 4: HV Shutdown Circuit

By this time, the battery was somewhat discharged and telephone equipment was reacting to the low voltage condition. A critically bad decision was made to reactivate the disabled End Cell Switch in the belief that doing so would add End cells to the twenty-three. Apparently, the installers didn't realize that the temporary transition cables they had run created a short-circuit path around the End cells. When the End cell Switch moved to the Group 1 position, six 7,200 Ampere-Hour cells times two cells in series dead shorted across the transition cables. The available fault current was approximately 300,000 Amperes. Because of the short-circuit, the plant voltage didn't increase and so the End Cell Switch immediately moved to the group 2 position and so four cells in series times six in parallel now fed into the transition cabling.

The transition wiring began to burn and the canvas support straps burned through. The transition wiring fell onto the housing of a 480 Volt three- phase busduct thus adding the energized side of the twenty-three cell strings into the burgeoning fault. The sheet metal busduct covers burned through quickly and the conductors then faulted the ac busbars. The ac bus was protected by a 1,600 Ampere circuit breaker that quickly operated but the huge dc fault remained.

With extreme levels of current raging from the battery, the hard-rubber battery containers began to melt and leak electrolyte onto the floor. By then the facility was evacuated. The fire department arrived. Not understanding the actual cause of the fire, they tried operating the switch and fuse units to disconnect the telecommunications equipment load in the mistaken belief that deloading the battery would suppress the fire.

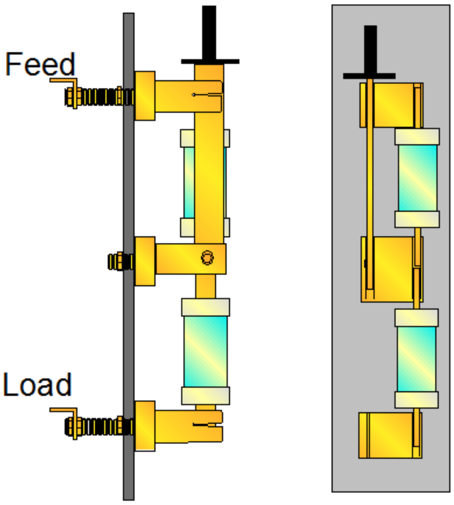

Figure 5: Knife Switch Type Switch & Fuse Unit: Fuses are typically 250 to 600 Amps

Because they didn't understand switch and fuse units, such efforts were futile. As may be seen in Figure 5, a switch and fuse unit comprise two fuses connected in series with either one of them shunted by a switch. The purpose of this design was to permit either fuse holder to be bypassed for routine maintenance. When firemen operated the switch from one position to another, nothing changed in terms of connected load.

The deleterious reaction to telecommunications services was vast. Between the cost of the repairs, cleanup and decontamination and revenue losses, estimates at the time place the overall cost at $400 million USD in 1994. To consider the impact in 2019 terms, based on the U.S. Consumer Price Index inflation calculator[1] 400 Milllion U.S. Dollars in 1994 has a value of $682.25 Billion in today's currency.

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[1] http://www.in2013dollars.com/us/inflation/1994?amount=400000000

Vibrating Bus Bars

Like the incident above, this matter was in a fairly large 302B End Cell switched power plant carrying approximately 6,000 Amperes of transport equipment load. There was no switching equipment fed from the plant and so the End Cell Switch was not a problem. The plant was equipped with five (5) 1,600 ampere SCR type rectifiers which were obsolete and obtaining repair parts was problematic. The plant's manufacturer suggested replacing the five large rectifiers with thirty-two of their current model 200 Ampere Controlled ferroresonant units.

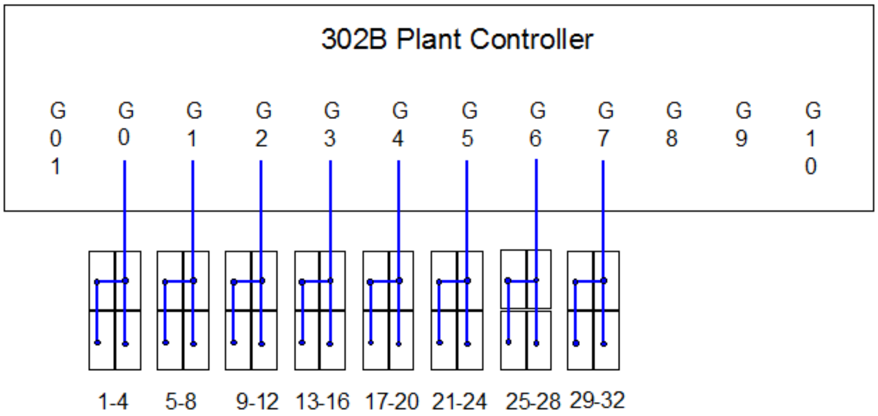

Figure 6: controller wiring modification done at the time

The relay type plant controller is not capable of so many rectifier units and so the manufacturer's engineers specified that the control leads for groups of four (4) 200 Ampere rectifiers be multipled together as depicted in Figure 6. Accordingly, the thirty-two rectifiers appeared as eight (8) 800 Ampere units to the controller.

Not long after the replacement was completed, the plant began to behave strangely. The aluminum busbars began to vibrate with the whole assembly shaking approximately a quarter-inch (6.4mm). Additionally, a 20 Hz sinewave at 2V peak-to-peak developed on the dc bus and many relays in telecommunications systems began chattering at a 20Hz rate.

So much magnetic flux appeared on the bus that the steel bolts that clamped together layers of busbar, a length of 5/8-inch threaded rod (roughly 5 pounds (2.3 kg)) easily hung from a bolt head. Further, some technician's wristwatch movements became damaged by magnetism.

An intense investigation began to determine the cause and provide a solution to the problem. The investigation revealed that the problem was two-fold:

Each rectifier had an L/C type output filter assembly (Figure 7) and with so many rectifiers in parallel the filters took on unusual properties. Capacitors in parallel tend to add in their value. For example, three (3) 30,000 microfarad capacitors in parallel add to produce 90,000 microfarads of capacity. Inductors in parallel tend to divide so that three, 18,000 microhenry inductors in parallel equal 6,000 microhenries. With some thirty-two rectifiers in parallel on a bus, the parallel output filters behaved like a resonant tank circuit with the tank's Q factor being determined by the small amount of resistance in the circuit. For a parallel RLC circuit, the Q factor is the inverse of the series case: $Q = R\ C\ L = R\ \omega 0 = \omega 0\ RC$ Consider a circuit where R, L and C are all in parallel. The lower the parallel resistance, the more effect it will have in damping the circuit and thus the lower the Q.

In other words, this dc power plant became a very expensive 2 Volt peak to peak, 20 Hertz, 6,000 Amp oscillator that also happened to feed telecom transport equipment.

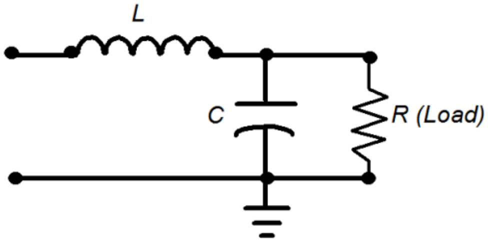

Figure 7: Rectifier Output Filter (also a resonant tank in the case under discussion)

Like most pulsed rectifiers, these units used firing boards to pulse the control leads of triacs in the voltage regulation circuitry. The input impedance to the firing boards used was somewhat high. The firing boards were reacting to the resonant tank behavior of the paralleled output filters and imposing the 20 Hertz sinewave onto the dc bus. The solution was to add a small capacitor to each rectifier to detune the firing board and sufficiently reduce its frequency response.

Countercell Issue

A digital switching system was planned for a small central office. A frugal engineer decided to keep an obsolete 110 Type plant[iv] and modify it to feed the new switch. Sometime after the new switching system was in service, the modified power plant reacted badly to a minor anomaly in the ac mains. Dc power was interrupted for approximately 500 milliseconds and all fuses in the switching modules operated (blew).

Before modification, the dc plant had an electrochemical Counter-EMF cell to reduce the dc voltage to the telecommunications equipment while on float operation (Figure 8). During a battery discharge condition, a large contactor would operate to shunt out the Counter-EMF cell in order to apply the full battery bus voltage to the load. During the modification the Counter-EMF cell was removed and the installers were supposed to run a short run of 750 Kcmil power wire between the splice plates where the Counter-EMF cell had connected.

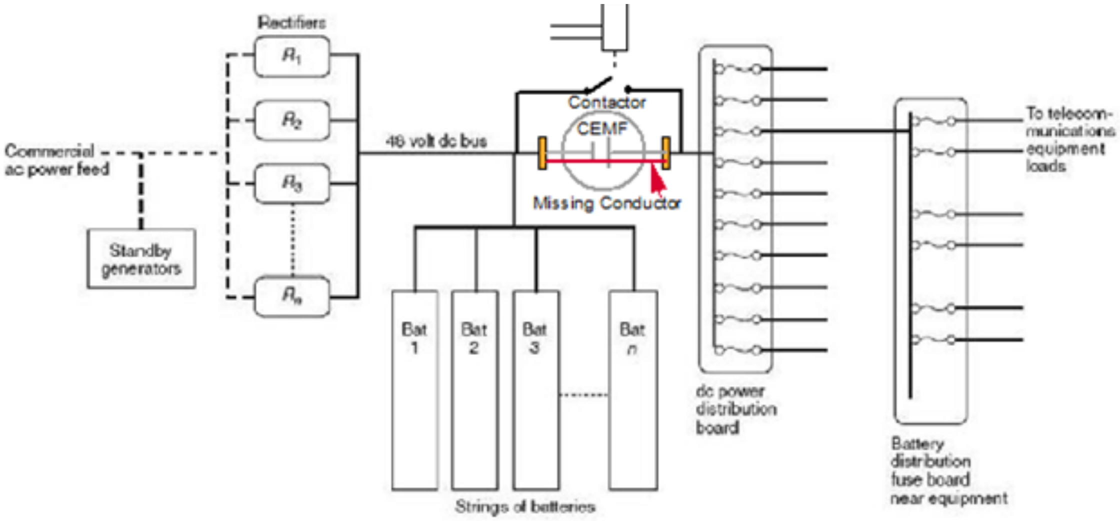

Figure 8: Block diagram of a 110 type plant depicting the CEMF cell that was removed but not bypassed.

During an investigation of the incident it was learned that the conductor intended to bridge the removed CEMF cell was somehow omitted. The contactor that would normally short-out the CEMF in a battery discharge was in a normally operated state because the plant Float voltage had been raised. When commercial power failed momentarily, the rectifier shutdown and restart caused a bus voltage 'bobble' that caused the CEMF contactor to fall to a non-operated state denying dc to the telecommunications systems for the brief time until it reclosed. The removal and reconnection of dc caused the electrolytic capacitors in the telecommunications systems to discharge and then quickly recharge. Excessive recharge current to the electrolytic capacitors caused their upstream fuses to operate.

EPO Matter

A central office was initially equipped with a three (3) bay Distributed Architecture power plant. The contracted engineer who did the initial job found him/herself confronted by a local ordinance[2v] that required a Battery Disconnect Switch external to the building. In order to comply, the engineer ordered the plant with a Battery Low Voltage Disconnect (LVD) feature (a disconnect contactor). On installation, the engineer specified that the low voltage controls be eliminated and external wiring provided to a switch in a Riser Room (Figure XX).

As the telecommunications load grew, another engineering firm won the contract to add bays to the original plant. This firm apparently didn't know about the requirement or the modification and therefore didn't order the bays equipped with the LVD option. That job and a later one went in without LVDs. The shortcomings of this predicament are:

- The Fire Department believes that they can disconnect all battery strings with a single button and they cannot.
- The non-standard wiring creates troubleshooting difficulties because the undocumented as-built wiring is different.
- Because the circuitry is not alarmed, the EPO switch could be operated and some battery string sitting on open circuit for an indeterminate period. In such a case, the load on the remaining battery strings could overload the inter-bay equalization links and cause them to overheat and perhaps burn open.

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[2] Southern Nevada Amendments to the 1999 National Electrical Code, 230-70 "Exterior means shall be provided to disconnect all conductors in a building or other structure."

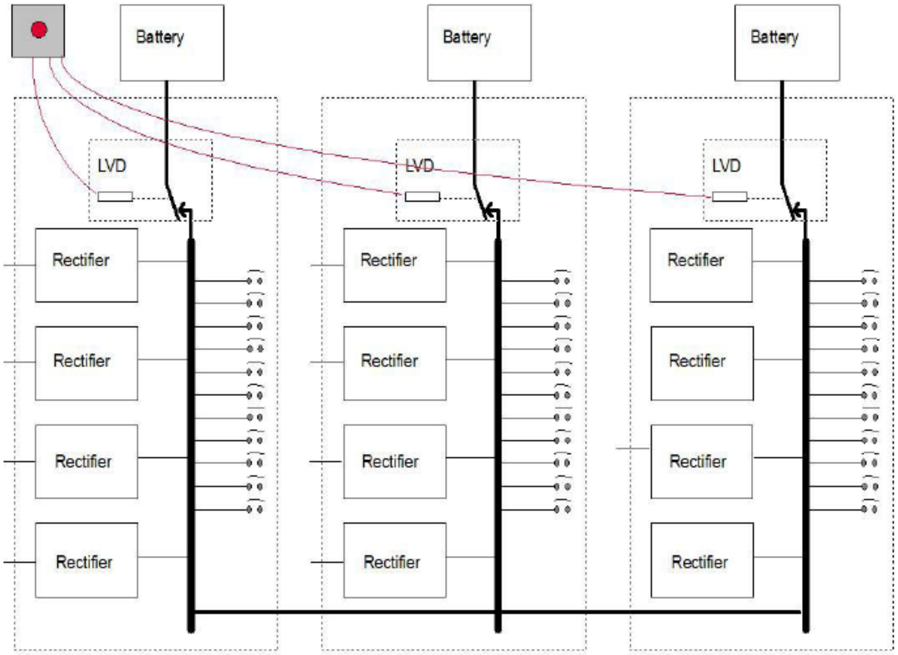

Figure 9: Local modifications to a Distributed Architecture dc power plant to make the LVD function as an EPO.

The matter was resolved by meeting with the local fire department and showing the large territory that would be without communications if the EPO switch was activated accidentally or with malice and the many fire detection and protection arrangements for the facility. Once they understood the issues, the fire professionals approved a variance to the county requirement.

Lessons

In the case of the failures identified herein, and the risk posed by the modifications in EPO matter, it should be evident that modifications to standard dc power plants invite problems and perhaps disaster:

1. Because the modifications tend to be undocumented, on-site or contracted technicians easily make counter-practical decisions about troubleshooting, plant operations and emergency responses.

2. Generally speaking, very few installers have detailed knowledge about product operation. They know where and how to land wiring and muddle through start-up procedures but if something goes awry they are often unqualified to make good decisions regarding the troubleshooting and repair.

3. Technical support from manufacturer representatives will be inaccurate because they are familiar with standard equipment not modified models.

The incidents covered herein and any number of power-related failures around the industry underscore that telecommunications systems are extremely vulnerable to power anomalies. Additionally, power jobs tend to be significantly more expensive than most other installation work in a central office. The way failures are trending, procedural errors remain a nettlesome threat to network reliability.

Erstwhile relay based power plant controllers are grossly obsolete and the last technicians ever to maintain them have retired, moved to Florida and taken up golf or part time jobs at Disney World. Microprocessor based controllers are inexpensive, ubiquitous and easily capable of governing large numbers of rectifiers.

In the case of End-Cell switched dc plants that still feeds transport systems, a safer approach is to construct a new dc plant and then tie the bus directly to the Distribution busses on the obsolete plant. At some point the distribution board will be spare or nearly so. At that time, relocating the few remaining circuits to the new plant and removing the old board make practical engineering sense.

Finally, there is a compelling case to be made that installation jobs in the power sector be overseen by qualified expertise that is external to the company performing the installation. The role of this person is to determine the impact of work steps proposed on Methods Of Procedures (MOPs) and to assure that no shortcuts are taken. Due to the high cost of power jobs, inclusion of a subject matter expert adds only a fraction of one percent to the job budget. Given the cost of power related problems, expertise is a prudent investment.

References / Bibliography

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[i] **Fire Investigation Report: Telephone Exchange Fire – Los Angeles California March 15 1994, Michael S. Isner, National Fire Protection Association – Quincy MA**

[ii] **Power Plant 302A (J86343) Operating Methods 167-621-301 Issue 10 March 1974 Bell System Practice**

[iii] **Lead Acid Type Storage Batteries theory and Definitions 157-601-101 Issue 7, August 1976 Bell System Practice**

[iv] **Power Plants 110A and 110B Operating Methods 167-215-301 Issue 7, February 1969 Bell System Practice**

[v] **Southern Nevada Amendments to the 1999 National Electrical Code – Southern Nevada Building Officials**

Acknowledgement: The late Bob Kakalec, a former Bell Labs engineer and ferroresonant guru was the gentleman who solved the vibrating busbar issue in Philadelphia and that ‘fix’ was applied to numerous other central offices with large numbers of ferros.