A SERVICE PROVIDER'S DECISION TO MOVE FROM 48V TO 380V POWERING

THE PROBLEM STATEMENT, TECHNICAL ASSESSMENT, FINANCIAL ANALYSIS AND PRACTICAL IMPLEMENTATION PLAN

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Abstract - The continuing evolution of servers and other information and communications technology (ICT) equipment has resulted in greatly improved capacity and performance. These advancements are accompanied by a significant increase in the power required to support a rack of ICT equipment, with projections of per-rack power requirements approaching 15kW or more. This increasing power density represents a significant challenge for Level 3 Communications and many other service providers. Level 3 has come to the realization that this magnitude of power density cannot be practically achieved with its current 48V powering architecture at a great number of its gateway facilities. A new powering approach is required to extend the life of those facilities and infrastructure for the coming decades. This paper will discuss the problem facing the company, its technical and economic assessments; and the laboratory and field experiences that resulted in its decision.

INTRODUCTION

Level 3 Communications, headquartered in Broomfield, Colorado, is a premier global provider of data, voice, video and managed services. Level 3 has achieved strong growth fueled by the reliable and cost-effective delivery of content-based services enabled by its advanced information and communications technology (ICT) infrastructure. The continuing evolution of ICT equipment has greatly improved its capacity and performance. These advancements are accompanied by a significant increase in the power required to support a rack of ICT equipment. A few short years ago, planners could assume a power level of 750W to 1,250W per rack for the deployment of state-of-the-art servers. Today's planners project power levels as high as 15kW or more for the server racks that will be delivered in the coming years.

This increasing power density represents a significant challenge for Level 3. Like most service providers, Level 3 utilizes traditional -48V power plants in its network. A typical gateway location will have several plants ranging in capacity from 4,000A to 10,000A. Many of the plants are already operating near capacity and have been in service for many years with aging (ferroresonant) rectifiers experiencing failures. It would appear that the challenge could be addressed by upgrading, replacing or supplementing the existing plants with new 48V power equipment; however, that was not the case.

The most significant issue facing Level 3 was that extensive cable congestion restricts power delivery into the ICT areas from the 48V systems. These extremely large stacks of cable are the result of the high current levels associated with 48V powering, the requirement to support worst-case load projections and the need to adhere to tight voltage drop considerations. As a consequence, the anticipated power needs cannot be adequately met by growing and modernizing the existing 48V plants or by adding new 48V plants.

Relocating the gateways to new, larger facilities was not a financially attractive alternative because of the enormous investment associated with transitioning the interfaces to its customers and to its own network. Level 3 faced this problem at a large number of its gateway sites. The reality of the situation was that a new powering architecture was required to extend the life of its existing facilities and infrastructure for the years to come, and to enable continued growth.

Level 3 has chosen a transition to 380V powering as its path forward, making the company the first U.S.-based service provider to adopt this approach. This paper discusses the technical and economic assessments that led to this decision and the implementation plan for transitioning to 380V powering at its existing sites.

380V POWERING APPROACH

Papers have been written in recent years that discuss the benefits obtained from the utilization of 380V powering in various case studies. These benefits include improved energy efficiency; a simplified architecture with reduced CAPEX and OPEX costs, smaller footprint and higher reliability; and the facilitation of microgrids to supplement the electric grid with distributed generation resources.

Certainly, all of these are valued objectives in Level 3's planning. Realistically, however, the most important near-term benefit of 380V powering is depicted in figure 1.

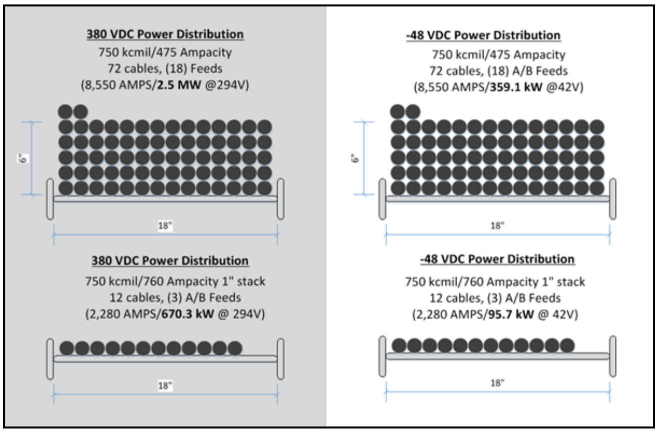

Fig. 1 - Power Distribution Comparison

The upper half of figure 1 show seventy-two 750MCM cables stacked on an 18" cable rack. In that configuration, the capacity of each cable is 475 amps [1]. This reflects derating of the cable's current-carrying capacity due to thermal considerations. That cable stack can deliver 359kW of 48V power. When that same cable configuration is used for 380V powering, it can deliver 2.5MW.

The lower drawings depict a single row of twelve 750MCM cables on an 18" cable rack. In this configuration, each cable has a current-carrying capacity of 760 amps [2]. The 48V configuration can deliver 96kW. At 380V, those same cables can deliver 670kW. In fact, the 380V stack at the lower left can deliver 87% more power than the 48V stack at the upper right.

The use of 380V provides a dramatic improvement in the power density of the distribution system. Recognizing its value as a potential solution to the serious challenge it faced, Level 3 initiated an assessment of a 380V powering approach. The proposed strategy for transitioning from 48V to 380V at existing facilities is depicted in figure 2.

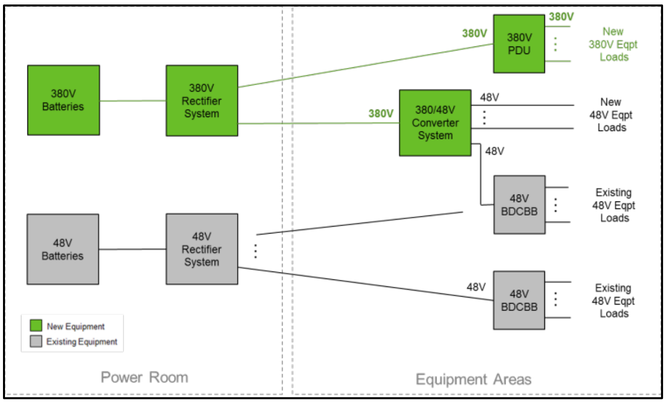

Fig. 2 - 48V to 380V Transition

As is the case with most service providers, Level 3's existing powering architecture provides a 48V rectifier plant and batteries in a power room. Because the current is high at 48V, it was desirable to minimize the distance between the rectifiers and the batteries. The 48V power was distributed to the loads through battery distributing circuit breaker boards (BDCBBs), which are located in the ICT equipment area. It was the large cable bundles between the rectifier system and the BDCBBs that are creating the congestion issues.

It is Level 3's intention to install a 380V rectifier plant and batteries at the site. Since the existing loads and most of the new loads will operate from 48V for some time, phase 1 of the strategy was to install a high-efficiency 380V/48V converter system in the ICT equipment area. The plan was to reuse existing cable to make the connections between the 380V rectifier system and the converter system. Because the current levels are low at 380V, this can be accomplished by using a few spare cables, which might exist at the 48V rectifier bay or by creating the necessary spare cables by consolidating some BDCBB panels.

In order to reuse those cables, it will be beneficial to install the 380V rectifier bays near the 48V plant. Because those bays do not require much floor space, Level 3 expects that this will be possible at most or all of its gateways. It was not mandatory that the 380V batteries be close to the rectifiers. The new batteries can be located in other parts of the facility where space may be available. In worst case situations, the batteries can be deployed in outdoor containers that can be installed at the site. It is important to remember that 380V power requires one seventh the current of 48V power and allows seven times the voltage drop in cable sizing.

Once operational, the 380V/48V converters will support any new 48V loads being added at the facility. A portion of the existing 48V load will also be transferred to the converter system by re-terminating the input to some of the BDCBB panels. The 380V system will thereby provide additional capacity for the facility as well as provide relief for heavily loaded 48V plants.

In phase 2 of the transition, Level 3 will deploy ICT equipment operating directly from 380V power. At this point, a 380V power distribution unit (PDU) will be utilized in place of the 380V/48V converter bays to support the new loads. These PDUs will be connected to the 380V rectifier bays using existing cables made spare through the on-going transition of loads from the 48V plants. The 380V plants will grow over time and the 48V plants will be eliminated as they reach end of life.

TECHNICAL ASSESSMENT

Level 3 was anxious to implement a proof of concept laboratory trial of an Eltek 380V rectifier system and 380V/48V converter system. However, that step would not be made until an in-depth paper analysis of the architecture could be undertaken. Of primary interest were the areas of personnel safety and operational performance.

A key aspect of safety was the concept of ±190V powering with high-ohmic midpoint grounding depicted in figure 3 and specified in an ETSI standard [3]. In this configuration, the 380V rectifiers are operated as an ungrounded system. Between the positive and negative terminals of the rectifier output are two large value resistors connected in series with their center point grounded. There are two purposes for those resistors. If one of the polarities should experience a fault to ground, the current flowing in the circuit is forced through the high-ohmic resistors limiting its value to milliamps. This is an essential personnel safety feature. Additionally, the resistors are part of a ground fault detection circuit built into the system's controller to ensure that the presence of any such fault is quickly identified. Because of the safe current levels involved, the system is allowed to continue its operation while the source of the ground fault is located and ultimately corrected.

It should be noted that Level 3's investigation into this area of the system included ground fault location technology. Since telecom applications generally involve grounded systems, Level 3 had limited experience in this domain. The eventual laboratory application of the 380V system afforded an opportunity to conduct a successful demonstration of a third-party ground fault location product, which could be permanently deployed at a site or used as a portable tool.

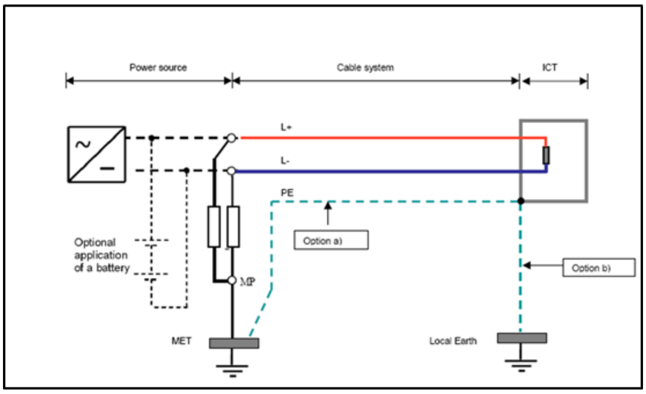

Fig. 3 – High-Ohmic Midpoint Grounding [3]

There have been articles written about ungrounded AC systems and their ability to dissipate the energy associated with induced transients [4]. This topic led Level 3 to pursue a more detailed understanding of how the Eltek 380V system would perform in this respect. The specific concern was that an ungrounded system deploying a high-ohmic ground at its midpoint might be unable to effectively eliminate that transient energy to ground and instead might pass it through to server power supplies, which could then be damaged and fail. This was a reliability concern.

A considerable amount of discussion and activity ensued. The outcome established that the 380V rectifier system mitigated the impact of any induced transients for several reasons: (1) the rectifier modules have EMI circuits that effectively dissipate transient energy (2) AC surge protection devices are provided on the input to the rectifiers, (3) DC surge protection devices are provided on the output of the system and most importantly, (4) extensive induced transient testing was performed on the system, which validated its surge immunity (based on IEC 61000-4-5: Electromagnetic Compatibility requirements [5]).

It was mandatory to Level 3 that the rectifier and converter systems were designed and tested to UL standards, that tools be available for calculating and labeling arc flash and shock hazard per NFPA 70E requirements [6], and that the equipment would be implemented in accordance with all applicable National Electric Code (NEC) articles. The latter point included an investigation to confirm that 48V and 380V cables were allowed to co-exist on the same cable tray. This was a critical consideration since the transition plan specifically was designed to repurpose existing 48V cables for 380V runs. NEC Article 300.3 [7] confirmed that mixed voltages are permitted as long as all voltages are 1000V or less and that all cables are rated for the highest of the mixed voltages.

LAB EVALUATION

Upon completion of the "paper" analysis of the Eltek system architecture, Level 3 immediately implemented a laboratory evaluation of the 380V rectifier system and its associated 380V/48V converter system at its Interoperability Lab in Broomfield. This environment enabled Level 3 to conduct the proof of concept under conditions that are very similar to those found in its gateways.

The lab evaluation began in July of 2015. The company installed a 380V rectifier system with a capacity of 120kW which was populated with 60kW of rectifier modules. One 30kW 380V/48V converter system was provided initially and a second 30kw system was subsequently added. An important consideration for this application was the fact that the converter modules are over 98% efficient. This greatly mitigates the efficiency impact of having a conversion back to 48V. The system was equipped with a 380V battery string that provided between 15 and 30 minutes of reserve power.

The system has operated extremely reliably since its installation. The evaluation system has been installed to power the equipment in the interoperability lab and plans are underway to add 60kW more capacity to the system, which will remain an important and evolving component of the facility's power infrastructure. In the spring of 2016, Level 3 determined that this evaluation had served as proof of concept for the 380V system. That declaration initiated two important events. The first was a detailed economic assessment of the 380V architecture and the second was the planning for the network readiness test (NRT), which was the final validation of the power system in an actual network facility with revenue-generating loads on the system.

ECONOMIC ASSESSMENT

Understanding the costs of implementing a 380V system was an extremely important part of Level 3's decision-making process. Towards that end, a detailed study was undertaken to compare the cost of a 380V solution to that of a comparable 48V alternative. Every effort was made to do modeling that used realistic study parameters, followed Level 3's engineering practices and was based on completely objective cost information.

The 380V rectifier system was Eltek's Ecotower product. Each rectifier bay provided a capacity of 144kW and was equipped with four 250A double-pole breakers for 380V load distribution. The 380V/48V converter system was also an Eltek Ecotower product. Each converter bay provided 60kW of capacity, along with 96 plug-in breaker positions for 48V load distribution. The value of close collaboration between Level 3 and Eltek throughout the entire evaluation process should be noted. The Ecotower products that were ultimately developed for general use reflected the insights gained during the lab trials and the modeling process.

Level 3 determined that a system with two rectifier cabinets (288kW capacity total) was an appropriate size for initiating the transition from 48V to 380V powering at its existing gateways. This would provide relief for highly loaded 48V plants as well as capacity for growth. The plan was to utilize separate A and B converter bays to provide diversity of distribution to the 48V loads. The model included a total of eight converter bays. The requirements also included the provision of four hours of battery reserve using Unigy II 3AVR95-33 battery strings, which are widely deployed in the Level 3 network. A 380V battery string is essentially seven 48V strings connected in series.

The study compared the cost of the 380V approach with that of an equivalent 48V alternative. The 48V system modeled was Eltek's Scalable system which is a product that had been deployed in Level 3's network. The 48V distribution was provided by four new BDCBBs. It is important to note that Level 3 understood that in many cases the cabling issues will make the 48V solution virtually impossible to implement. However, for the purposes of the cost study, it was assumed that the cable access was available. The study parameters are summarized in figure 4.

PARAMETER	48V SYSTEM	380V SYSTEM
48V Equipment Load on System	*216kW*	*216kW*
Equipped Rectifier Capacity	*264kW*	*288kW*
Number of BDCBBs	*4*	*n/a*
Number of Converter Bays	*n/a*	*8*
Number of Battery Strings	*20*	*3*

Fig. 4 – Study Parameters

Cabling costs were a major factor in this analysis. It was assumed that the average distance between the power system and the BDCBBs or converter bays was 100 feet (one way) for both the 48V and 380V cases. The distance between the 380V system and its batteries were also assumed to be 100 feet (one way). The 48V batteries were 25 feet (one-way) from their associated rectifiers.

The normalized results of the cost study are provided in figure 5, with the 380V costs expressed as a percentage of the 48V costs. The analysis showed a 27% cost reduction by utilizing the 380V system versus the 48V alternative. That represented a savings of $318,000 for the application studied. Some items to note:

- The costs of the equipment and its installation for the two alternatives were within about 8% of one another. The 380V system costs were higher, largely attributable to the converters required to provide 48V to the load.

- The savings result from the dramatically reduced amount of cable and its installation in the 380V architecture. Existing cables have been repurposed to feed 380V power to the converter systems (the costs include some BDCBB panel consolidation to create spare cable). In the 48V model, new cabling was required to feed the BDCBBs. The 380V batteries were connected to the system using four 350MCM cables and some overhead bus duct. The 20 strings of 48V batteries required a total of 80 750MCM cables.

- The converters enabled an additional cost savings that was not captured in the model. The converters provide a regulated 54V output to the load, even as the 380V batteries are discharged down to 294V end voltage. The BDCBBs, however, provide a voltage as low as 41V at the load when the 48V batteries discharge. Since the load cables must support the worst-case condition, it is reasonable to expect that the 380V approach will reduce the amount of copper required by about 30%. This load cable was <u>not</u> part of the study model.

CATEGORY	COMPONENT	48V SYSTEM	380V SYSTEM	380V vs. 48V Δ	COMMENTS
EQUIPMENT	*Rectifiers and Distribution*	*1.00*	*0.54*	*(0.46)*	*48V requires separate distribution cabinets*
	Secondary Distribution	*1.00*	*5.86*	*4.86*	*48V: four BDFBs* *380V: eight converter cabinets*
	Batteries	*1.00*	*1.03*	*0.03*	*Both include disconnect switches; 380V includes bus duct*
	Equipment Total	*1.00*	*1.13*	*0.13*	
EQUIPMENT INSTALLATION	*Rectifiers and Distribution*	*1.00*	*0.26*	*(.74)*	*48V: five cabinets; 380V: two cabinets*
	Secondary Distribution	*1.00*	*6.80*	*5.80*	*380V consolidates some existing BDCBB panels to create spare cables*
	Batteries	*1.00*	*0.92*	*(0.08)*	*48V involves 20 disconnect switches*
	Equipment Installation Total	*1.00*	*0.91*	*(0.09)*	
POWER CABLING	*Material*	*1.00*	*0.10*	*(0.90)*	*Does not include cabling from BDFBs or Converter Cabinets to the 48V loads; 380V will be ~30% less*
	Labor	*1.00*	*0.07*	*(0.93)*	
	Power Cabling Total	*1.00*	*0.09*	*(0.91)*	
	OVERALL TOTAL	***1.00***	***0.73***	***(0.27)***	***27% Savings with 380V***

Fig. 5 – Normalized Cost Comparison

The magnitude of the cost savings served as an additional impetus for Level 3 to move ahead with its transition to 380V powering. Aside from its value in sites that are constrained by cable congestion, the analysis showed that 380V solutions were also a fundamentally more economical alternative to the traditional 48V approach for any gateway site.

NETWORK READINESS TEST

The final step in Level 3's evaluation process was the network readiness test (NRT). The Dallas gateway was selected as an example of a facility with heavily loaded 48V power systems and constrained by cable congestion. The 380V system was installed and put in service during a three-week period in June of 2016. It was carrying revenue-generating traffic.

The economic assessment presented above was based largely on the Dallas facility. The NRT provided an opportunity to validate those projected costs in an actual deployment. While there was understandably a bit of a learning curve associated with these new products, the conclusion of the project team was that the costs estimated in the study were accurate, reasonable and repeatable for other gateway locations.

The process of transitioning load from the 48V systems onto the 380V system and converter bays went well. By the end of the three-week period, about 2000A of load had been moved to the new system. Once that work was completed, a significant amount of cable was made spare. This could be used for future 380V distribution or could be mined for copper recovery value if that space is needed.

Level 3 had allocated a 90-day soak period for the site, which also allowed the company the time to create the remaining documentation that must be available for network-wide deployment. Following that period, Level 3 expected that transitioning to 380V powering would be a standard process across all its gateways.

CONCLUSION

Facing a serious power cable congestion issue that threatens the long-term viability of many of its gateway facilities in key markets, Level 3 identified 380V powering as a potential solution. It established a close, collaborative relationship with Eltek aimed at facilitating an investigation of that approach. Using a thorough and methodical process over more than two years, the company has determined that a transition to 380V powering can be implemented practically, economically and reliably to enable it to achieve the power densities required as its infrastructure evolves.

Having made that decision, attention now turns to forward-looking initiatives to further enhance its powering infrastructure and reliability. Included among these are utilizing the 380V bus to directly power ICT equipment, HVAC systems and lighting; upgrades to improved cooling systems; investigation into the use of microturbines to supplement the electric grid; and the reduction of battery reserve time while still enhancing reliability. These are potential topics for a future paper.

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