Single-Conversion Power Distribution

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Abstract

Each voltage conversion step increases complexity, space requirements and cost while decreasing reliability and efficiency. With a single voltage conversion strategy these characteristics may be significantly improved.

Introduction

As equipment power density requirements continue to increase, it is necessary to find higher capacity power distribution methods to support modern equipment. Thus far, power density has been improved with much smaller power conversion units and alternative battery technologies but a continuation of power density increases is projected that will exceed existing design limitations. Reduced copper interconnect cabling has revealed the opportunity to increase server cabinet height from 42 to 52 RU which further increases the power requirements per cabinet

There is now an opportunity to eliminate all but one voltage conversion. Almost all modern servers and routers use a single voltage power rail. Most server manufacturers provide many power input options but the power supply simply converts whatever the office distribution power is to a single voltage for the common power rail. This power rail voltage is typically 12VDC in equipment used today but this voltage will need to increase soon. The design proposed herein will accommodate any rail voltage to meet future requirements.

480V3Φ power may safely be distributed to each cabinet using an overhead bus. The vertical space outside the server rails and within each server cabinet may be used to house a UL listed 480V3Φ to 12VDC power conversion assembly. The vertical power distribution would have 100A power connection terminals at each Rack Unit (RU) providing enough ampacity for up to 960W to each RU. These terminals may be coupled together to support multi-RU server chassis with higher power requirements. This would eliminate the need for the power supply within each server/router chassis which is required to reach the single-conversion goal. The wiring in this design sounds bulky but even at this low voltage (12VDC) the total cabinet capacity is 45kW (with a 2n+1 redundant rectifier) per 52RU cabinet. A higher rail voltage would reduce conductor ampacity requirements and improve power capacity.

There are many options for the battery plant. If four minutes of run-time meets the requirement, then the battery module can fit into slots that are common to the power conversion unit within the server cabinet.

Power delivery to all cabinets can be via redundant 480V-3Φ power bus ducts. Power connection from the bus to each cabinet can be made with flexible cables terminated with twist lock connectors to avoid the cost of specialized electrical personnel. This also substantially reduces the cable and conduit bulk of underfloor power whips. The resulting congestion reduction improves subfloor airflow and may reduce the subfloor clear-height design requirement.

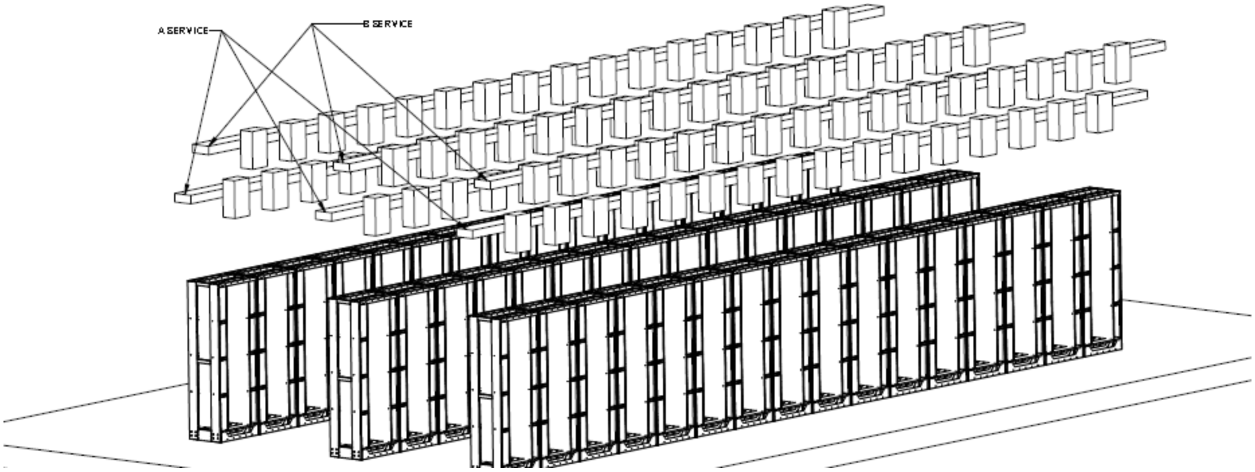

Figure 1. Room View

The simplified block diagrams below compare typical power distribution methods with the proposed design. Typical power losses are approximated for each conversion step. Conductor losses are omitted.

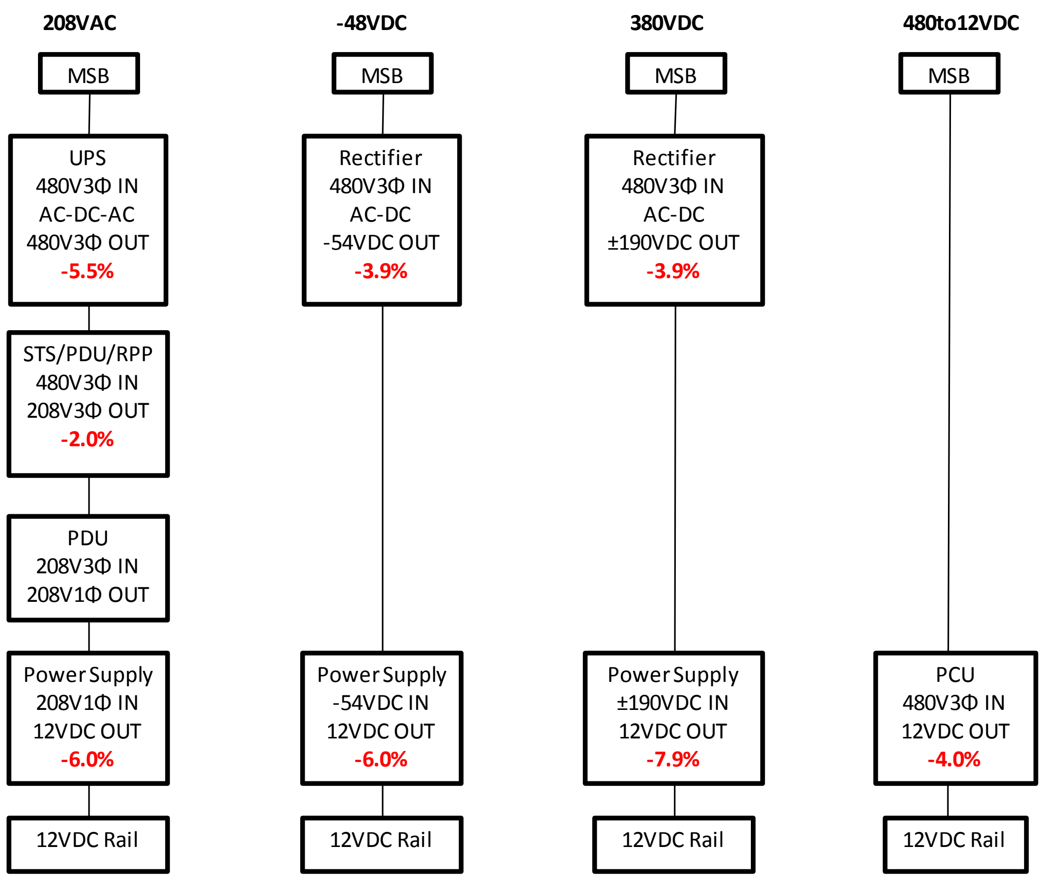

Figure 2. Block Diagram Comparison

Efficiency

Since several elements of the power distribution are different, the circuit must be examined all the way from the power meter through to the power rail. The most substantial reduction in losses is due to the elimination of other power conversions, but there are some other factors that contribute to the final result. In the table below, designs and loading perceived to be typical based upon personal observations were used. It is noted that there are many other designs which perform better than these listed. There are some that eliminate conversions nicely but they require custom equipment. It was assumed the UPS is in dual-conversion mode, but the result would still be near 10% total system loss even if not.

Table 1[1,2,3,4] Block Diagram Comparison

Assumed Load	Distribution and Conversion	Typical 208-277VAC	Typical -48VDC	Proposed 380VDC	Proposed 480to12VDC
25%	Primary Switch Gear & Cabling	0.5%	0.5%	0.5%	0.5%
65%	UPS, double-conversion	5.5%			
25%	SPDU with Stepdown Transformer	2.0%			
25%	RPP / BDFB	0.2%	0.2%	0.2%	0.3%
50%	Rectifier		3.9%	3.9%	
25%	Secondary Switch Gear & Cabling	0.5%	1.0%	0.14%	0.20%
	Total Loss, Meter to Cabinet	**8.7%**	**5.6%**	**4.7%**	**1.0%**
50%	Chassis Power Supply, Typical Case	6.0%	6.0%	7.9%	4.0%
	Total Loss, Meter to Power Rail	**14.7%**	**11.6%**	**12.6%**	**5.0%**

There are an extremely wide variety of server chassis power supplies[4c]. The reduction of this variable improves the ability to actually know the system efficiency. This analysis assumes this is not a retrofit but rather new servers; so the best, widely available power supply specifications were used. This really hurt the value for the 380VDC input power supplies since so few are now available[4]. Presumably, the efficiency of these units will improve but the total system efficiency would still fall well short of the single-conversion strategy because of the additional conversion required.

There has been much effort put toward improving the efficiency of server and router power supplies. While it's possible to get 208VAC input power supplies that are 96% efficient[4C] (4% loss), they are not widely available today as shown on the chart below. It has been a challenging task to get widespread support and adoption.

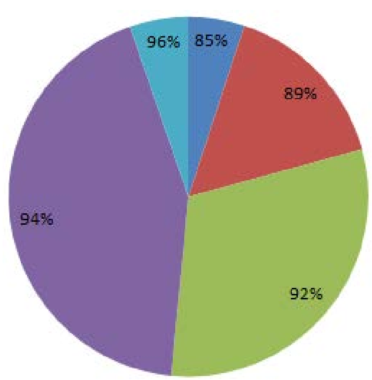

Figure 3. 208 VAC Input Power Supply Efficiency Availability

The 80 Plus[4c] program, started in 2004, publishes standards and independently certifies each design to ensure performance meets specifications. The highest efficiency standard today is "Titanium" which is 96% efficient at 50% load at >0.95 PF. This specification is comparable to typical rectifier performance but these power supplies are not available for most devices. The most widely available power supply is the "Platinum" specification. This specification was used in assumptions since this is the power supply one would typically get if ordering the best efficiency models available. Accordingly, 94% efficiency may be assumed if one is diligent in the ordering process to ensure compliance.

Eliminating the power supply from the server vastly improves the consistency and quality of the power supplies. The proposed power conversion units use a true 3-phase input which keeps the phase balance correct and the power factor conversion circuitry consistent.

Reliability: Power conversion and battery failure exposure reduced to single cabinet

Every device added in series in a circuit reduces reliability. In this design the power is delivered all the way from the utility transformer to the cabinet with only copper conductors, circuit breakers and switch gear in the path. The power conversion module can be configured in any redundancy scheme depending on budget limitations and failure tolerance. The system redundancy is distributed to each cabinet so if an extremely rare failure sequence occurred, or if an operator made a catastrophic error, the failure would only affect a single cabinet.

Server power supplies are often pulling air through the server so its intake air temperature is really the server's output air temp. These power supplies are in a sacrificial position because they are low cost, redundant and easy to replace. The elevated temperature does significantly reduce the life expectancy of the power supply. The single-power conversion design gives the power conversion units the cool air supply from the front of the cabinet and exhaust out the back, in parallel rather than in series with the servers. The chart below shows a typical reduction in MTBF of ≈30% for every 10 degrees C increase in temperature.

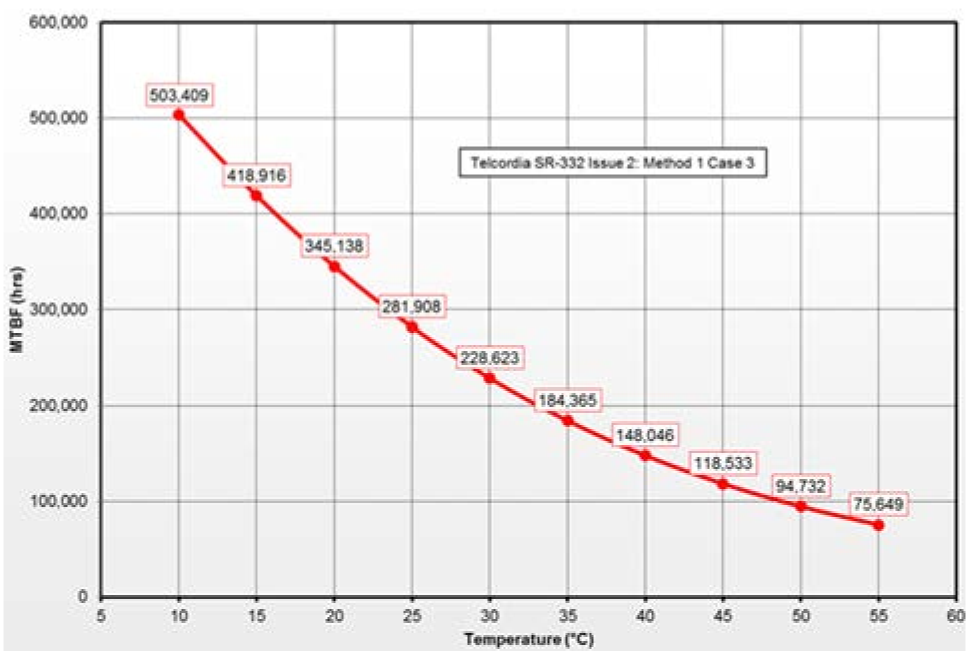

Figure 4. MTBF of Typical Rectifier versus Intake Air Temperature

Capital Cost reduction

Of the examined models, the most efficient way to transfer power through the office is via 480V3Φ. The following chart compares power transfer using 100A circuits.

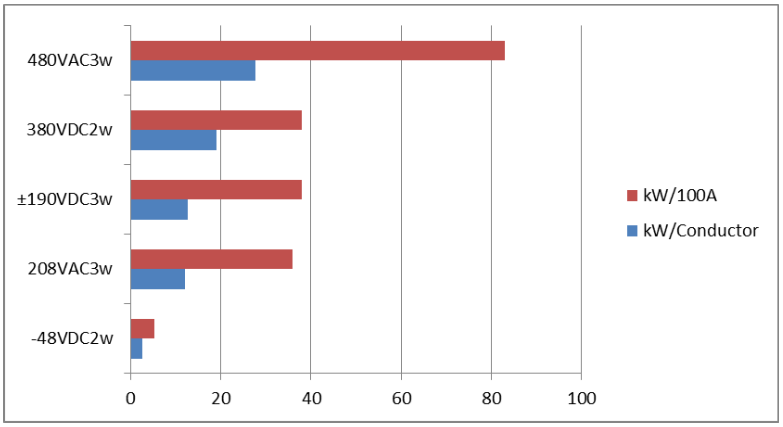

Figure 5. Power Transfer Comparison

Clearly, the higher voltage and advantage of 3-phases provide the most effective power transfer system. Much less obvious yet more consequential are other cost issues. Lower current often allows a smaller breaker frame size. 480V3Φ circuit breakers are readily available from any electrical supply but 380VDC circuit breakers can be hard to locate, and expensive. Today's higher power requirements exceed the practicality of the -48VDC systems due to high current.

The circuit breaker cost issue mentioned above is not shown in the chart below due to inability to obtain typical pricing for 380VDC breakers so the cost of breakers was omitted on all of the systems. The prices shown in the chart below were gathered from typical quotations based on a fully redundant 1.5MW design intended to be loaded at 1.2MW spread over 240 cabinets. This scenario is actually the worst possible case loading distribution for the proposed system. As the load density increases, the capital cost savings improves. Chart range scale is $K.

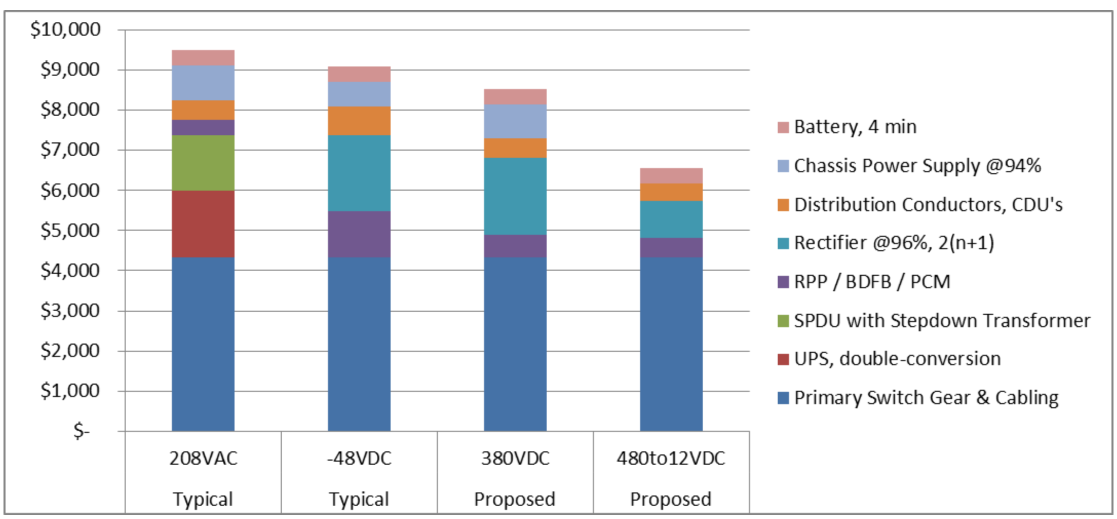

Figure 6. Capital Cost Comparison $1=$1,000

Stranded vertical space within cabinets reclaimed

In most server cabinets the area between the servers and the sidewall of the cabinet is vacant. The recent compaction of power rectifier modules opens the opportunity to use this space for the power conversion module, even including some battery capacity. Here are a few configurations showing the flexibility of the proposed design.

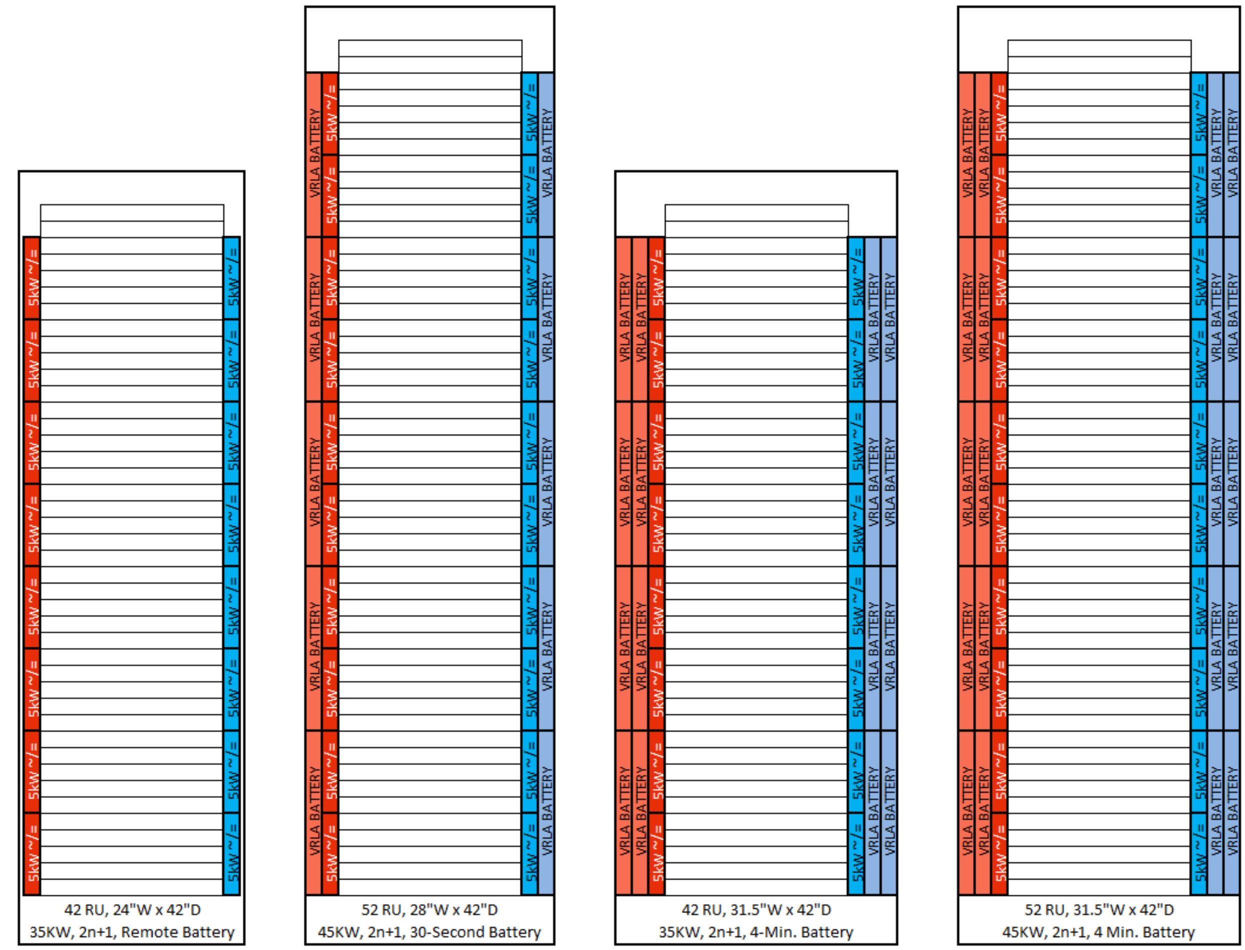

Figure 7. Front Cabinet View, various configurations

These configurations are all based on using 12VDC for the server rail. The high current requirement at 12V restricts each rectifier's output power causing the limit to be 5kW each. If the output voltage were 24VDC, each rectifier would be rated at 6kW, instead of 5kW, and each power terminal would be rated at 60A instead of 100A. The 52RU cabinet would then be rated at 54kW rather than 45kW albeit with a corresponding reduced battery holdover time.

Battery holdover time configurations from 30 seconds to 4 minutes are available in each cabinet to accommodate generator transfer. A higher voltage, 4 to 8 hour time duration battery may be located along the wall, power room or out of doors to allow time for transportable generator power recovery.

These are shown with VRLA battery packs. If we used Lithium-ion battery packs the runtimes would be much higher. While unable to verify high discharge rate Lithium-ion specifications in time for publication, approximately 5-minutes runtime on the single battery column model showing 30-Seconds compared to VRLA technology is expected.

The 12V power distribution is oriented vertically within the cabinets with a power connection for each RU. This distribution method enables the shortest possible power connectivity minimizing I^2R power loss. It also positions the conductors out of the airflow path from the rear of the server to the cabinet rear door vent. This arrangement can provide ampacity to supply 960W per RU at 12VDC.

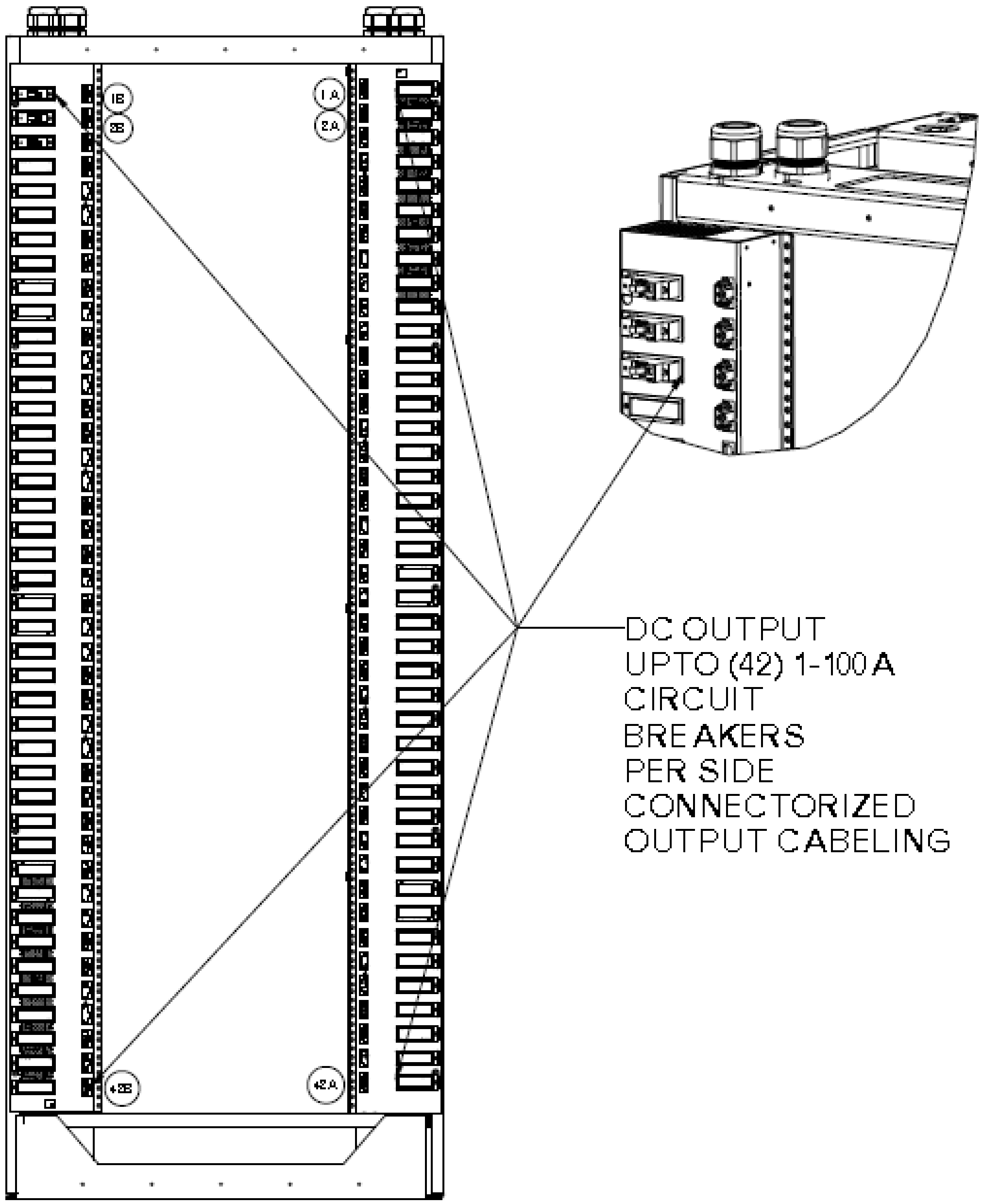

Figure 8. Rear Cabinet View

Personnel Safety

All electrical energy is isolated from personnel within electrical panels, bus duct and cabinet power containment areas. Since all power systems are fully redundant, one side can be de-energized and fully locked-out prior to service. Safety interlocks may also be used to help prevent accidental exposure.

Maintenance cost reduction

The power conversion units are maintained similarly to the way server power supplies are today. When a module fails, it will alarm to indicate replacement is necessary. The units are all plug-n-play, small and lightweight. They are easily replaced by the typical craftsperson. Routine maintenance is eliminated. Almost every repair would be a module replacement but extraordinary repair would still require a specialist.

The battery system proposed is also designed as plug-n-play modules. They are continually monitored and will alarm when replacement is required should the unit fail to reach the scheduled replacement age. The units are small, of manageable weight and actually fit into the same slots as the rectifiers. If traditional battery systems are used, maintenance of the battery plant will remain status quo.

Since there are not any large power conversion machines, the requirement for annual and semi-annual routine maintenance is eliminated because the equipment does not exist.

Flexibility

Since 480V-3Φ is available to all cabinets and the same form-factor power supply can have an output voltage of choice, Rail Supply voltage can be unique for each cabinet. Some super computer servers are already using 48VDC Rail voltage to reduce losses and bulk. The latest 8 to 24 Terra-bit MAD routers now use a power equalizer module instead of a power supply. They drive the power rail with -48V and limit the energy, filter and distribute the incoming voltage to avoid a conversion. It's likely other server and router manufacturers will need to increase their Rail Voltage as power density increases. This system allows selection of any rail voltage needed, per cabinet as shown below.

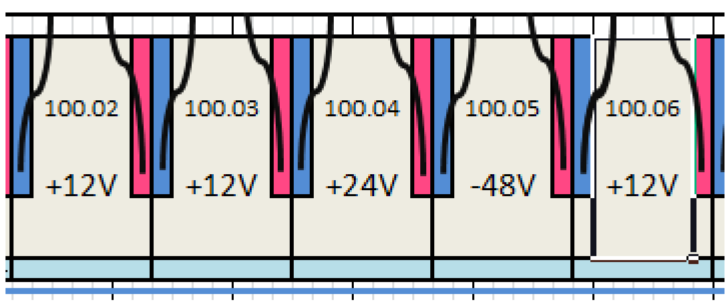

Figure 9. Various Power Rail Voltage Flexibility

While most new cabinets would be able to take advantage of the single conversion, some legacy gear may be needed in the 480V row. This can be accommodated by installing -48VDC rectifiers in the vertical power conversion assembly instead of the 12V units. Future servers may require +24V or +48V but this design can already fully support these voltages even easier than 12V since the output current is substantially reduced.

Battery

The battery cannot be connected directly to the Power Rail for safety reasons. The total energy available on the chassis power rail is limited using small DC-DC converters in each battery module. The Rail Voltage spec is 12V±0.1V so the battery voltage must also be regulated. Because a conversion is necessary on the battery discharge circuit, the door is open for higher voltage batteries which would reduce battery distribution material cost.

The design shown uses 48V battery packs with the 12V converter within the battery pack. If hours of extended battery runtime are required, a 540V battery system with a minimum discharge voltage of 420V would allow full power holdover with two DC Battery circuits identical in ampacity to the AC bus.

$$(45kW / 480V / SqRt\ 3) = 54.1\ Amps \approx (45kW / 420V / 2\ circuits)$$

Challenges

There are a few obstacles challenging implementation of this system. The server and router manufacturers will need to allow an external power supply to drive their internal power rail. We expect they will want to remove the power supply from their device since others provide the power supply already. There should be considerable motivation to do so since they would be able to reduce their input power specifications relative to the work performed and slightly reduce their total cost. Also, the very high power density equipment manufacturers are already doing so.

I’m not sure placing batteries into the server cabinet is the best idea. I think we’d opt for the remote battery solution with the con being that we’d need to carry a separate battery bus over each row for that.

Conclusions

This design does have some issue to overcome so we have to ask if it is worth the effort. I calculated a 6.6% power reduction due to reduced losses when compared to our typical -48VDC distribution design. This alone would likely be enough justification to proceed. Additionally, the design cost significantly less to build and wins most other comparable characteristics.

Any design that reduces the number of conversions would yield substantial efficiency improvement and claim a subset of the benefits of a single-conversion design; reduction to a single conversion is the most elegant solution. There are so many benefits that it actually requires a list to show the benefits: efficiency gain, complexity reduction, reliability leap, capital and maintenance cost reduction, reclaimed cabinet space, power density increase, reduced component count, improve safety, reduced heat, etc.

The most significant three can be summarized as cut power losses by half, reduce capital spend by 20-30% and increase reliability by an order of magnitude. These are all very significant improvements sans any other ill effects.

The limiting issue is really availability of servers ready to accept the power connection. Server cabinets with this vertical power conversion assembly system are in prototypical development now. I do not expect any delays because all the pieces are from existing from existing modules.

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