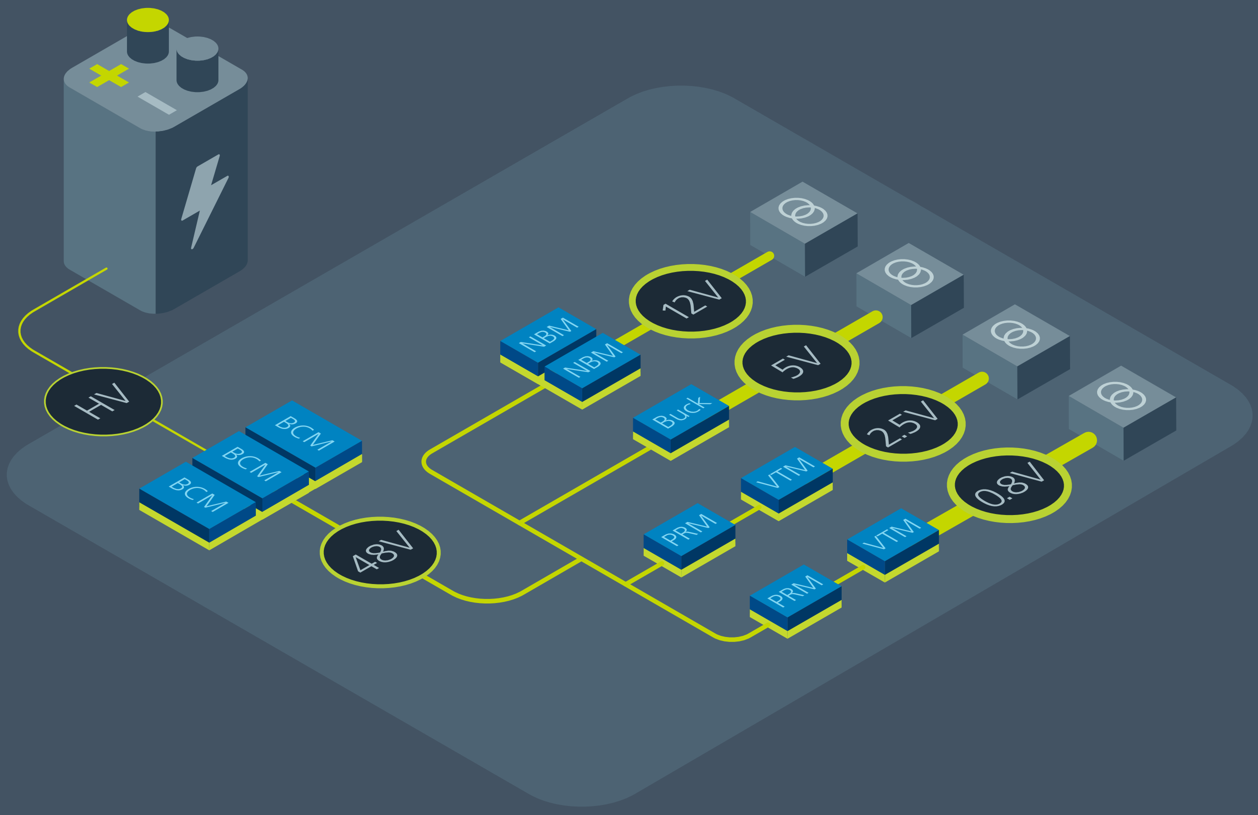


白皮书，作者：Tom Curatolo，首席应用工程师

创新供电网络

VICOR

设备或系统的每一个电子组件都有一个由线缆、母线排、连接器、电路板铜箔电源层以及 AC 至 DC 及 DC 至 DC 转换器及稳压器组成的供电网络 (PDN)。控制 PDN 性能的是其整体架构，例如对 AC 或 DC 电压配电、特定电压电平和电流强度的使用，以及网络需要进行电压转换和稳压的时间与次数。许多 PDN 经过多年的发展，已在特定行业中实现了标准化，例如国防与航空航天工业中的 270V 和 28V、通信基础设施应用中使用的 -48V 以及汽车中使用的 12V PDN，这些后来都成了计算机服务器和工业应用中的标准。因此，围绕标准 PDN 建立起了数十亿美元的产业。

当标准 PDN 再也无法满足系统电源的需求时，就会出现严重混乱。这种混乱的出现，为电源系统设计人员带来了巨大的机遇，可以在以 48V 为基础的最新 PDN上实现创新，48V 标准现已出现在混合动力汽车、数据中心、人工智能 (AI) 加速卡、照明以及无人驾驶汽车行业。随着各行各业向最新 PDN 过渡，通过新型 PDN 和技术来实现性能突破的机会越来越多。

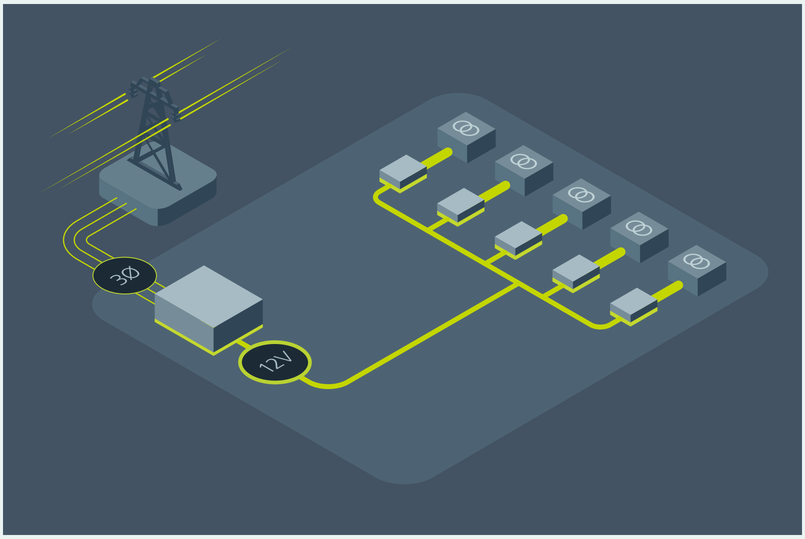


图 1：离网应用中的传统三相电至 12V 转换器，由12V 总线为下游负载供电。

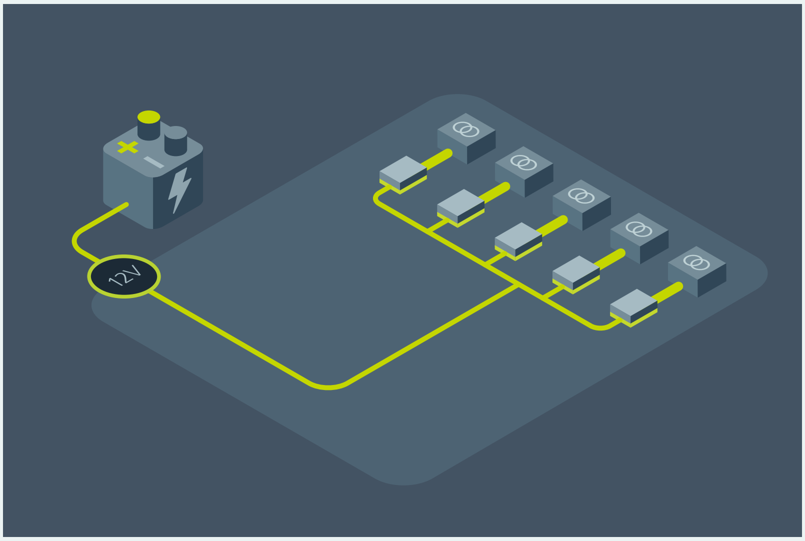


图2：典型的 12V 蓄电池到点负载的转换器。因为 12V 铅酸蓄电池的增长，该配置常见于汽车应用。

PDN 的功能

PDN 旨在将大功率电源转换成特定的电压和电流，从而为系统中的多个负载供电。变换器的工作需要在特性的温度范围内，满足负载的稳态和峰值供电需求。当电能从电源传输到负载时 ，PDN 的性能按照功耗、其物理尺寸、重量和成本来衡量。

> “高级供电系统的负载数量，负载功率在前所未有的增长。基于12V的供电系统要实现高性能，设计上面临着复杂的挑战。”

企业及高性能计算的高级系统、通信与网络基础设施、自动驾驶汽车以及大量交通运输应用只是需要更多电源的高增长产业中的几个。当 PDN 采用 12V 时，这些负载及负载功耗不断增长的系统为实现高性能带来了复杂的设计挑战。将较高电压整合在PDN 中，会带来巨大的挑战，而且抵制变革的理由很充分。在某些情况下，几十年来已经建立了庞大的生态系统来支持行业的 12V PDN。

主要的半导体、连接器及线缆产业与公司已围绕 12伏 DC 网络的组件供应纷纷建立。这种供电网络出现在上世纪 60 年代的汽车市场。在汽车电源很快超过了 6V 电池所能提供的电源后，PDN 改用 12V 电压。最初使用的是两个串联的 6V 电池。随着 12 伏电压成为大容量乘用车的标准，12 伏 PDN 组件迅速商品化，现已成了数十亿美元的市场，进入门槛很高。12 伏组件的大量供货，为 12 伏标准进入工业和计算机服务器市场起到了推波助澜的作用，而卡车市场则推动了 24V 标准进入更高功率的工业应用领域。

这段简短的历史，介绍了系统功率的提升推动了高性能供电网络的发展情况。供应链的成本要求、多电源供电和风险带来了改变 PDN 的阻力。然而，这种阻力可能会成为系统性能以及保持竞争优势的限制因素。

的

电 PDN 了。 的 ，因为

电 (SELV)

Small-gauge wire could carry the current that had to run long distances with minimized voltage drops

An “always on” requirement drove the industry to utilize large lead-acid rechargeable 48V battery banks

As communications networking infrastructure grew in complexity with the advent of the Internet, laptops and mobile phones, leveraging the existing 48V PDN infrastructure to power new equipment made a great deal of sense. However, powering the many new and complex loads consisting of arrays of network processors, memory and control system loads from 48V posed a challenge because the bulk of the available technologies were centered on 12V capabilities with semiconductor converters and regulator components optimized for this operating voltage.

To solve this 48V-to-12V problem, an architecture called Intermediate Bus Architecture (IBA) was deployed and quickly became the de facto standard in communications and network infrastructure applications. The type of bus converters used are non-regulated fixed-ratio 1:4 isolated devices and built on an open-frame package that met DOSA and POLA pinout standards to enable multi-sourcing. Isolation was not a safety requirement for the SELV IBA because positive battery terminals were tied to ground to stop galvanic corrosion, resulting in a negative 48V voltage. By using an isolated fixed-ratio bus converter as a DC-DC transformer, a –48V input can be used to deliver a +12V output for the downstream point-of-load (PoL) regulators.

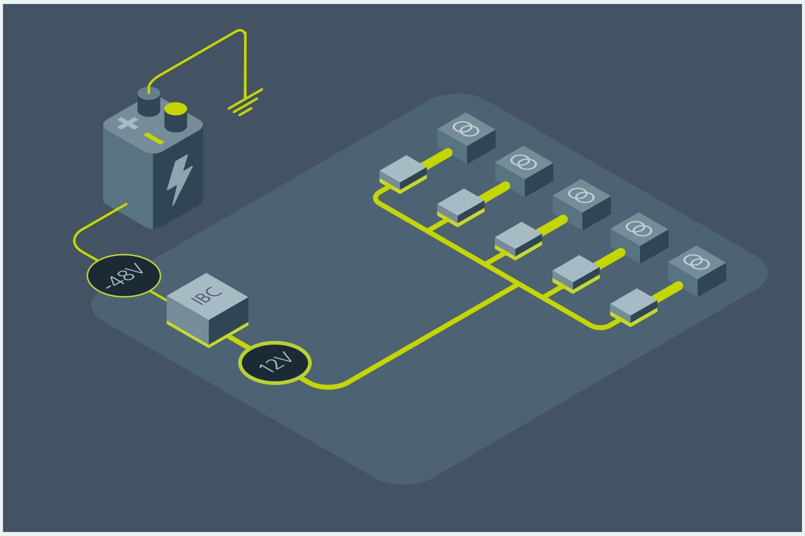


Figure 3: Intermediate Bus Architecture (IBA) with the IBC™ Module intermediate bus converter stepping down the 48V battery voltage to an isolated 12V bus for powering PoL converters. This is a typical PDN for communications and network equipment that became commonplace in the 90s after niPoL buck converters became widely available from a multiplicity of sources.

Power system engineers spend a great deal of time architecting and optimizing power delivery networks to deliver high system performance and reliability. If the system load power is high, designing bulk power delivery with a higher voltage for the intermediate bus reduces the current (I = P/V) the voltage drops (V = I • R) and the power losses ($P_{LOSS} = I^2R$) which reduces the size, weight and cost (cables, bus bars, connectors, motherboard copper power planes) of the PDN. Architecting the system to maximize the length of the higher-voltage runs before converting down to lower voltages and higher currents is a big advantage.

Every industry (and application) is different, but standardization around a specific PDN voltage or architecture such as IBA can restrict improving the performance of a PDN. Most often, the need to excel and gain a competitive advantage through new features and functions drive changes to a PDN. For example, advanced applications such as artificial intelligence (AI) in data centers are driving the move from 12V to 48V PDNs and away from IBA to new architectures. The significant rise in processor and associated server-rack power levels have simply exceeded what 12V can deliver.

For the automotive market, the need to meet regulatory standards that required a reduction of CO2 emissions in vehicles was a catalyst to explore vehicle electrification. Regulatory pressure combined with a demand for higher vehicle performance has resulted in the emergence of 48V batteries to support new mild-hybrid powertrains, safety system and entertainment system designs.

In large LED-display systems, the classic problem of long cable runs, higher power and the need for SELV has made 48V PDNs the standard in this emerging industry.

New higher-voltage PDNs

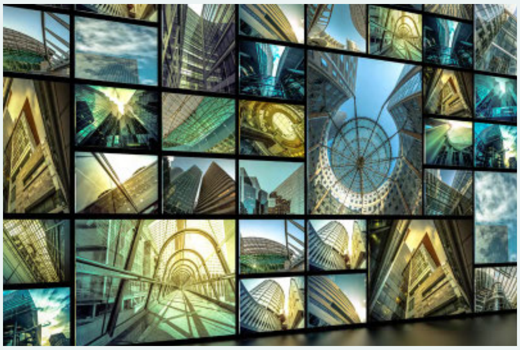
Many 12V PDNs are designed with a very simple dual structure of AC-to-12V and then 12V-to-PoL. In the case of 12V battery power sources, bulk 12V power distribution feeds 12V PoL converters and regulators.

With the advent of higher system power requirements, PDNs based on 380V and 48V are more complex as many industries are still trying to retain legacy 12V PDN infrastructure at the point-of-load. Additional PDN challenges come in the form of new high-voltage bulk power sources such as 800V batteries in electric vehicle (EV) and high-performance vehicles.

In these new systems and applications, the PDN can be broken down into three basic segments:

- Bulk power conversion to 48V
- Intermediate bus power delivery at 48V followed by conversion and sometimes regulation to 12V
- Point-of-load (PoL) power delivery with conversion and regulation at 12V

The addition of the extra 48-to-12V conversion step is an added cost with additional power, efficiency and board-space loss. However, the advantages of high-voltage power delivery to the PDN and the overall power savings associated with a high-voltage PDN outweigh the extra conversion-step losses. Furthermore there are alternative topologies, architectures and modular power solutions for direct 48V-to-load conversion and regulation that enable the best of both worlds.



Innovating bulk power delivery

The opportunities for innovating bulk power conversion to an intermediate 48V PDN lie in the following areas:

- Achieving higher power density
- Deploying a modular approach to achieve redundancy and simplifying thermal management
- Enabling advanced cooling techniques with thermally adept planar packaging
- Using fixed-ratio converters

As power levels continue to rise, the challenges on a bulk power system design get increasingly more complex. Managing the size and weight of the bulk power converter and cooling it due to higher power losses are the primary areas of focus in the majority of applications. If size and weight is not an issue then very high efficiency can be achieved and thermal management can be achieved with fan cooling.

However, most applications demand higher power density. Power systems engineers should consider the benefits of using power modules for designing and building these large converters, rather than creating one-off discrete designs. Power modules in conjunction with innovative architectures, topologies, control systems and packaging offer new ways of improving bulk PDN performance.

If the bulk power source is AC or high-voltage DC, isolation is required. An isolation stage adds power loss in any converter, but regulation may not be necessary if the intermediate-bus PDN contains regulation for the PoL stage (i.e., 48-to-12V). The two considerations for this approach are:

- Input range of the power source: the fixed-ratio converter will reflect this input voltage to the output based on its turns ratio or K factor, just like a transformer, and
- The need for power factor correction (PFC) in the cases of three-phase and single phase AC power sources.

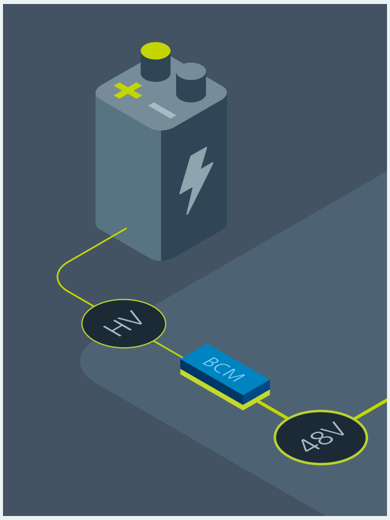


Figure 4: Lithium-ion and other variants of new battery chemistries provide advantages for producing a high-voltage source. The BCM® Bus Converter maintains industry-leading efficient power conversion for a fixed-ratio converter that is compatible with the high voltages from a battery to an isolated 48V bus.

Another approach for capitalizing on the high power density and efficiency of a fixed-ratio converter to improve the size and weight of a large bulk power converter is to use it as the conversion and isolation stage function where the PFC and regulation is done by a preliminary stage. he fixed ratio converter is easily paralleled to deliver very high power due to the positive temperature coefficient of the BCM's output impedance.

Data centers and exascale computing commonly require maximum processing power in a confined space, so they benefit greatly from high-density component and advanced cooling techniques. In some cases, full-immersion cooling is being implemented where the entire server is placed in a bath of Fluorinert. Alternatively, other high-performance computing applications are using cooling techniques with heat-pipe and coldplate technologies. In these applications a low-profile planar package is required for the power-conversion and regulation stages of the bulk power system.

Innovating intermediate bus and point-of-load power delivery

The opportunities for innovating 48V intermediate bus PDNs lie in the following areas:

- Utilizing non-isolated, fixed-ratio bus converters for 48-to-12V conversion
- Deploying high-power-density, regulated power module converters
- Incorporating a different architecture from IBA, called Factorized Power Architecture (FPA™)

Moving from a 12V intermediate bus PDN to a 48V PDN presents some challenges but also offers significant advantages. Extending the 48V runs to be as close as physically possible to the PoL regulators will reduce power cable connector and PCB copper power plane, size, weight and cost. PoL space constraints are often problematic, so the converter needs to have a high power density and efficiency. A non-isolated fixed-ratio bus converter is the best option as long as the PoL regulators can handle the voltage variation on their input which is determined by the voltage input range to the bus converter divided by the turns-ratio or K factor ($V_{IN}/K = V_{OUT}$). If the bulk power converter is designed with reasonable regulation tolerances, then this design approach is both feasible and advantageous.

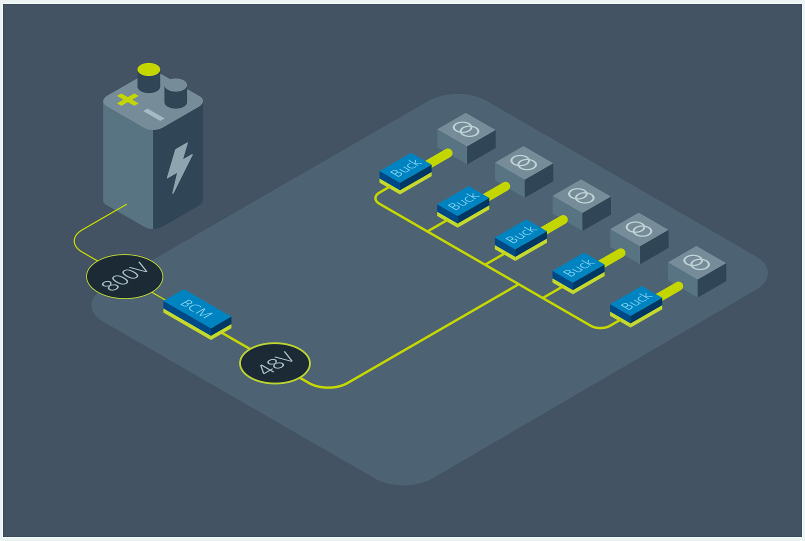


Figure 5: The 800V DC bus voltage is gaining acceptance in the EV market due to significant advantages in weight savings and battery charging time. The flexibility of the BCM® Bus Converter provides synergy with the 800V battery source to convert to an isolated 48V intermediate bus.

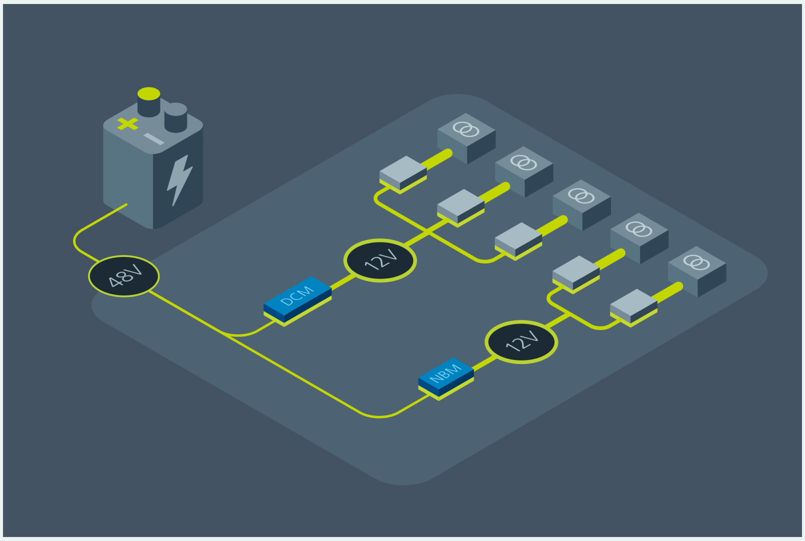


Figure 6: This is typical of recent developments in automotive PDN design in regards to maintaining compatibility with legacy 12V electronics in new vehicle systems. The 48V battery voltage is efficiently converted to 12V with the DCM™ DC-DC Converter and the non-isolated NBM™ Bus Converter to address size, weight and power density challenges.

For designs where the bulk power converter or bulk power source (such as a 48V battery) has a wide output voltage range, regulated DC-DC converters may be required depending on the PoL regulator input voltage specification. Adding regulation to the 48-to-12V stage reduces the efficiency of the converter by 2 to 4% depending on its topology. Regulation also reduces overall power density and increases the thermal management challenge of handling power losses in very high-power applications. Finding a regulated 48-to-12V converter with high efficiency and power density in a thermally-adept package is the best option.

But to really advance the PDN design with significantly improved performance and high current density at the PoL, a new architecture to consider is the Vicor Factorized Power Architecture (FPA). With FPA, a new type of converter called a current multiplier, capable of direct 48V-to-load voltage conversion with high efficiency and density, is placed very close to the load. In high-current applications this is very advantageous as it reduces the PDN impedance from the converter to the load which can be a source of very high power losses and also impact di/dt transient performance. Because the current multiplier is a fixed-ratio converter, its input must be regulated by an upstream regulation stage. To maximize efficiency and density and minimize power losses, the regulator module (PRM) provides 48V-to-48V regulation while the current multiplier's K factor is chosen to provide the required output voltage level for the load.

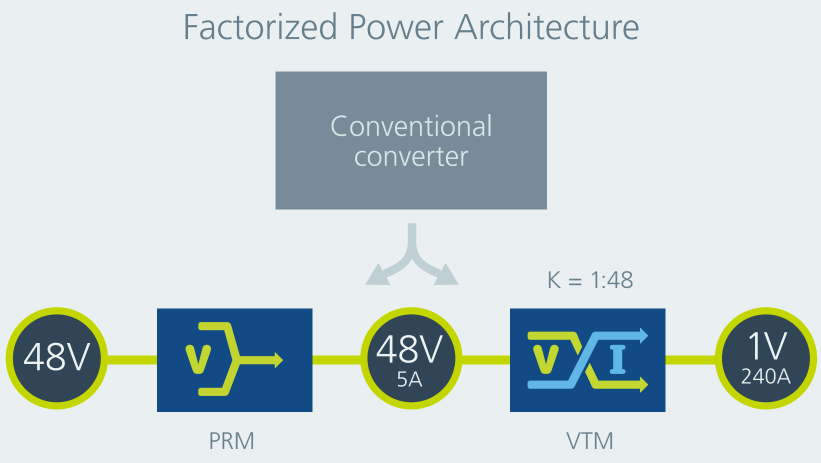


Figure 7: The Factorized Power Architecture™ separates the building blocks for regulation and current multiplication to improve performance over a conventional converter. The concept of a dual chip set that is optimized for specific functions has significantly raised the bar on key figures of merit. The PRM™ Regulator is designed for tightly regulating the 48V bus feeding the downstream VTM™ Current Multiplier that provides high-efficiency transformation at the load.

Conclusion

Adopting a higher voltage PDN eases the numerous challenges power systems engineers face as power levels continue to rise across many industries. Power system engineers should evaluate new topologies and architectures from new suppliers that can deliver appreciable system performance benefits. Progress, advancement and innovation invariably require new thinking, new ideas and new approaches. As your business requirements change, be open to possibilities. Exploring and researching alternatives can be rewarding in many ways.

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