


UAV eBook

Leverage high density power conversion in 48V architectures to build better UAVs

VICOR

Contents

UAV eBook Introduction

The proliferation of unmanned aerial vehicles (UAVs) and drones has revolutionized industries from agriculture to emergency response. As UAVs take on increasingly complex tasks, the demand for higher performance, longer flight times, and increased payload capacities has surged. However, achieving these goals often necessitates innovative approaches to power distribution.

UAV performance is a combination of range, flight time, payload capacity, and the ability to maintain fast communications. While higher power levels are necessary to increase range and payload capacity, they often conflict with the need for lightweight and compact designs. Whether it's a tethered drone, a vertical take-off and landing (VTOL) drone, or a high-altitude long-endurance (HALE) drone, UAV developers are looking for ways to achieve highly efficient, lightweight and compact power solutions.

> This eBook will help engineers developing UAVs to find a better way to distribute power in their designs.

This eBook empowers UAV engineers to optimize power distribution within their designs. We delve into real-world case studies, showcasing how industry leaders have successfully implemented Vicor power modules to achieve groundbreaking results using high density power conversion in 48V architectures.

Next, in-depth articles and whitepapers will guide you through the key advantages of power modules over traditional discrete power solutions, how packaging impacts PDNs, approaches to overcome typical tethered UAV challenges, and how high-density, high-performance fixed ratio converters can improve your PDNs.

Lastly, you'll be provided with links to a variety of sophisticated online tools for easy adoption and integration of these innovative power modules.

Whether you wish to improve features and functionality, scale for the future or shorten your time to market, this eBook will help you identify ways to improve your design by taking a better approach to power delivery networks.

Case studies

VICOR

Case study: Delivery UAVs

Extending delivery missions and saving space for greater payloads

Customer's challenge

Delivery UAVs must safely and securely deliver goods to their intended recipients wherever they are located. The longer the range and ability to handle heavier and larger loads, the more productive these UAVs can be. Because they can operate in congested and complex areas, they must be absolutely safe. They need to incorporate redundancies on multiple layers to avoid harming people, damaging property, or losing their valuable cargo. That means motors, GPS for navigation, vision systems, and other sensors for flight and flight termination require redundant power with incurring significant weight gain. The key goals were:

- Increase flight time to reach greater distances
- Compact and lightweight solution to carry heavier loads
- Supporting a variety of point-of-load voltages

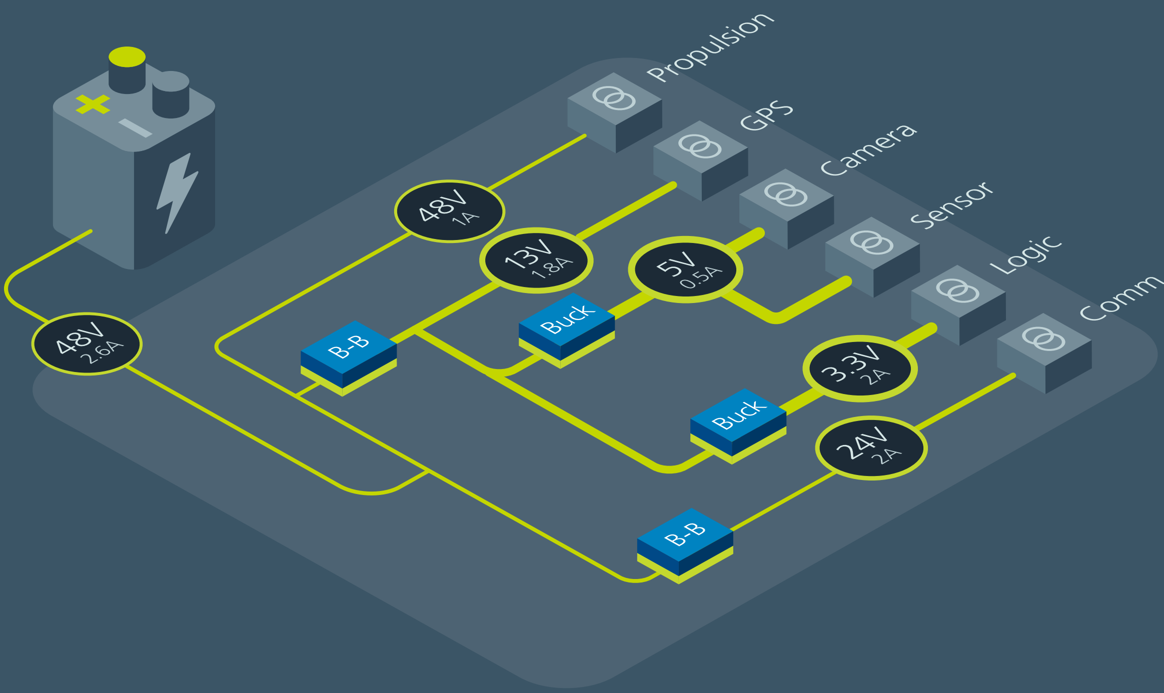
The Vicor solution

Weight is a critical factor for delivery drones. They must maintain a low overall weight in order to increase their payload capacity and fly smoothly to the destination without overstressing the battery. Vicor high power density modules help to reduce the weight of the drone and save on-board space for the sensors needed for safe and effective operation. Key benefits were:

- High-power density enables smaller form factor and lower weight
- Higher efficiency to extend flight times and range of operation
- Easily used in Vicor ZVS buck and buck-boost regulators

The Power Delivery Network

Power dense and lightweight ZVS Buck and Buck-Boost products are ideally suited to enable delivery UAVs to extend their flight times without taking up valuable payload space and weight. PI33xx ZVS buck and PI37xx ZVS buck-boost products are so dense that designers can include multiple point-of-load converters to save on cabling while powering multiple devices with multiple power buses to create the redundancy needed to ensure safe and reliable delivery operations.



ZVS buck regulators

- Inputs: 12V (8 – 18V), 24V (8 – 42V), 48V (30 – 60V)
- Output: 2.2 – 16V
- Current: Up to 22A
- Peak efficiency: Up to 98%
- As small as 10.0 x 10.0 x 2.56mm

vicorpower.com/zvs-buck

ZVS buck-boost regulators

- Input: 8 – 60V
- Output: 10 – 54V
- Power: Up to 150W continuous
- Efficiency: Over 98%
- 10.5 x 14.5 x 3.05mm

vicorpower.com/zvs-buck-boost

VICOR

Case study: Agricultural UAVs

Enabling greater functionality for reliability and productivity

Customer's challenge

Drones in agriculture are uniquely challenged to carry heavy payloads for longer spraying times while flying in varying conditions. They must cover large areas reliably and safely for an industry that demands high productivity. These drones are equipped with GPS, pumps, radar sensors, vision systems, and fail-safe systems that have different voltage and power levels. The key goals were:

- Significantly reduce power supply weight and maximize space on-board for payload
- Extend flight time for more productivity
- Handle a wide range of input voltages

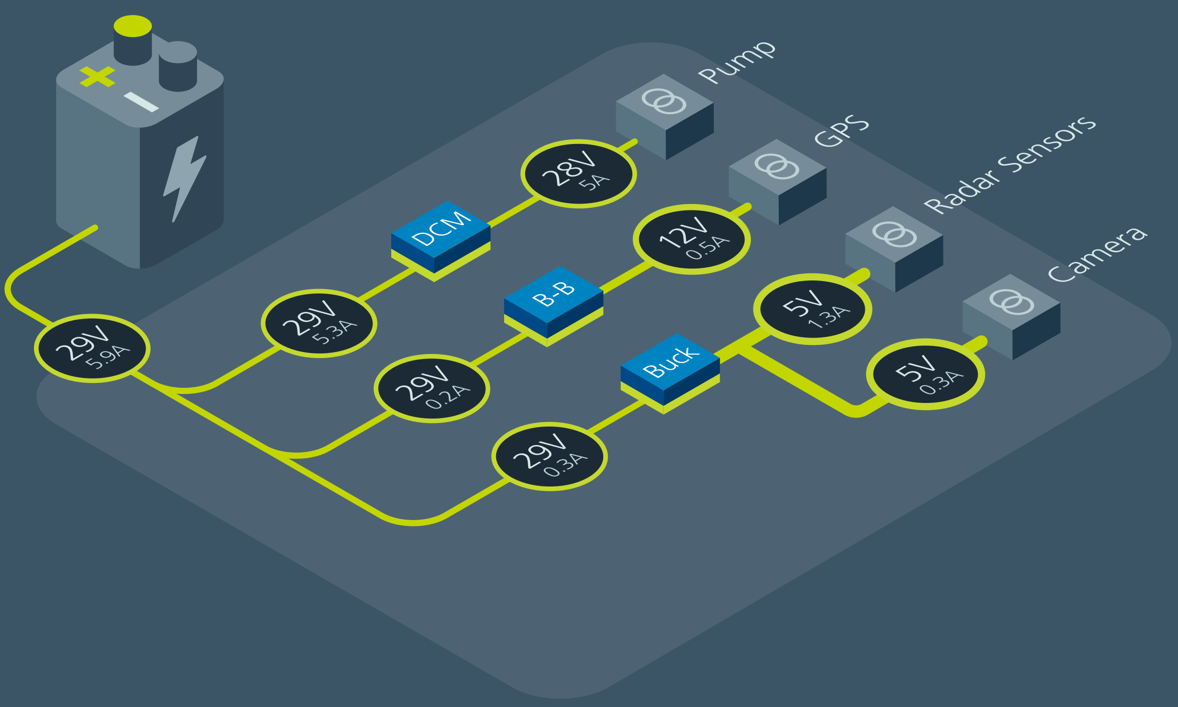
The Vicor solution

Vicor change to high-performance power modules are compact and lightweight, allowing the drone to carry the accessories needed to do its job such as pumps or sensors. At the same time, the high efficiency allows both increased flight time and a simplified thermal management that requires less space on board. Key benefits were:

- Higher efficiency to extend flight times and range of operation
- Power modules support a variety of input voltages for PoL devices
- Advanced packaging and topologies

The Power Delivery Network

The Vicor DCM™ power module is an isolated, highly efficient, regulated DC-DC converter utilizing a high-frequency Zero-Voltage Switching (ZVS) topology, operating from an unregulated, wide range input to generate an isolated output. Modular DCM converters and downstream Vicor ZVS Buck and Buck-Boost products support efficient power distribution, providing superior power system performance and connectivity from a variety of unregulated power sources to the point-of-load.



DCM DC-DC converters

- Input: 9 – 420V
- Output: 3.3, 5, 12, 13.8, 15, 24, 28, 36, 48V
- Power: Up to 1300W
- Efficiency: Up to 96%
- As small as 24.8 x 22.8 x 7.21mm

vicorpower.com/dcm

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vicorpower.com/zvs-buck-boost

VICOR

Case study: Surveillance UAVs

Extend flight times and support high-performance surveillance equipment to ensure safety and security

Customer's challenge

Effective surveillance requires uninterrupted sensing and communication to ensure the safety and security of valued property, equipment, and assets. UAVs are used to surveille wide areas that may be hard to reach or when those spaces are not in a fixed location. The best surveillance UAVs stay in the air for as long as possible and are equipped with high-resolution cameras, thermal imaging sensors and communication links. The key goals were:

- Increase flight time
- Support power-hungry functions without adding size and weight
- High-efficiency and simplified thermals

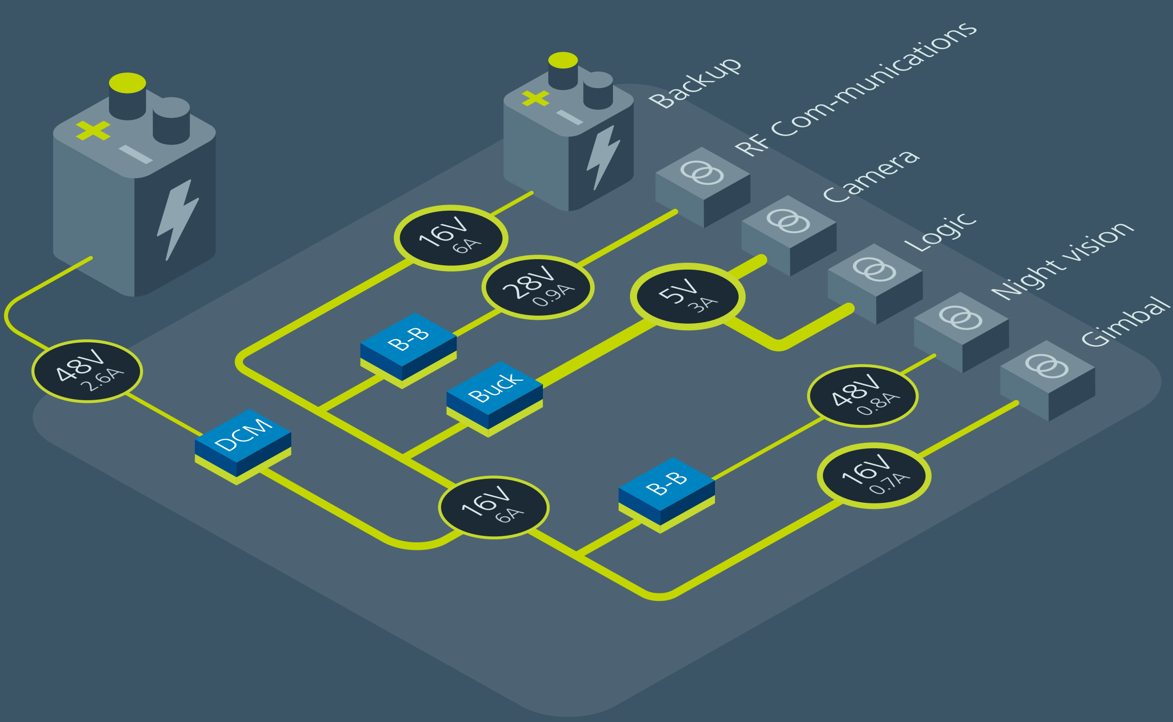
The Vicor solution

A surveillance drone must maximize productivity while also being able to carry high-performance cameras and sensors. Vicor high-density power modules support all these power-hungry functions without adding unnecessary size and weight to the UAV, extending flight time allowing for more functionality. Key benefits were:

- DCM best-in-class power density
- High efficiency extends flight time
- Keeps backup battery charged

The Power Delivery Network

Power dense Vicor DCM™ DC-DC converter modules are ideal for surveillance UAVs. They convert the 48V battery to a manageable voltage that can be matched to the UAV system loads using compact Zero-Voltage Switching (ZVS) Buck and Buck-Boost regulators. The DCM converter modules can also keep the UAV backup battery charged to ensure safety through redundancy.



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vicorpower.com/zvs-buck-boost

Case study: Inspection UAVs

Lightweight power delivery networks enable maneuverable UAVs to inspect remote, wide operations

Customer's challenge

Inspection UAVs ensure that infrastructure is sound, safe, and functional. These UAVs must be able to be easily maneuvered and nimbly access hard-to-reach spaces to inspect vast terrains. To succeed in their mission, they must also operate reliably in harsh environments and withstand electrical interference from power lines and other high-energy sources. The key goals were:

- Extend range and flight time
- Minimize size and weight
- Reliability to minimize chance of failure during flight

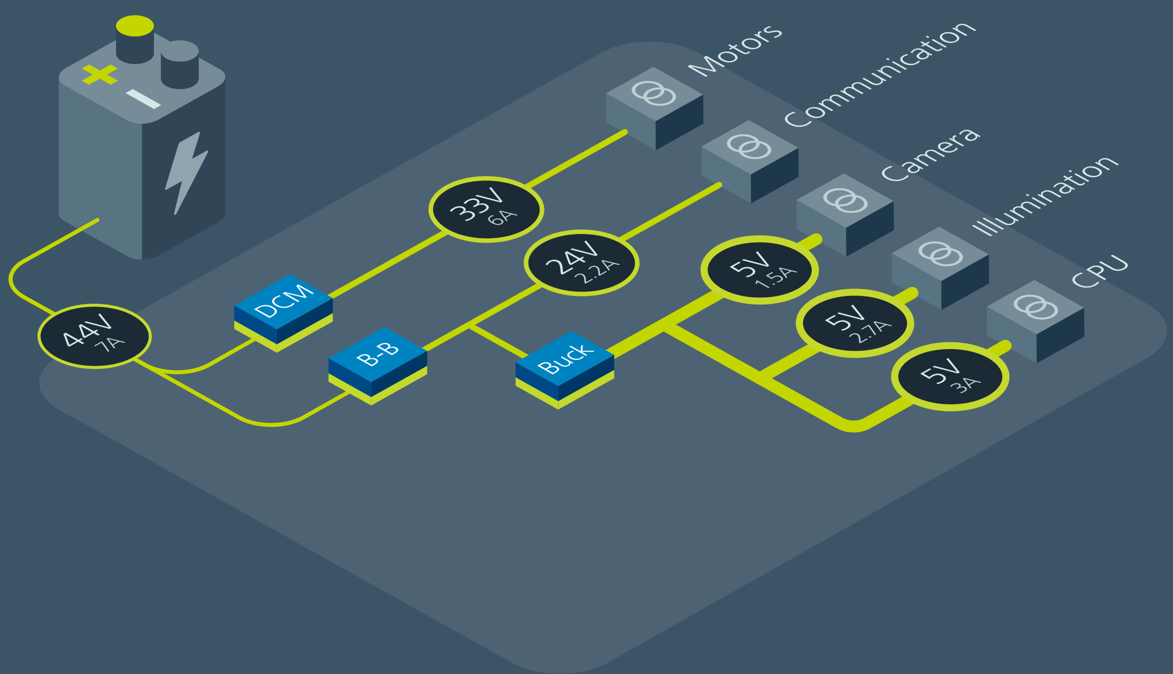
The Vicor solution

Vicor high-efficiency and high-performance power modules enable inspection UAVs to minimize size and weight to maximize the sensor payload required to perform the actual inspection. With enough power and high efficiency, they allow for an agile UAV with increased flight time, even in harsh environments. Key benefits were:

- High-power density to enable smaller form factor and lower weight
- Minimal electromagnetic interference (EMI)
- ZVS topology enables modules with up to 98% efficiency

The Power Delivery Network

Power dense Vicor DCM™ DC-DC converters and ZVS Buck and Buck-Boost regulator modules are ideal for inspection UAVs. The compact DCM delivers enough power to the motors, while the Buck and Buck-Boost regulators operate with a wide input range to allow loads to be powered by the full range of the battery, providing a reserve for safe landing and recovery. The compact modules allow for the use of a smaller magnetic shield, thereby reducing that weight in addition to the weight savings of the Vicor modules.



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vicorpower.com/dcm

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vicorpower.com/zvs-buck-boost

Case study: Fukaden communications tethered drone

Enabling life-saving communications amid natural disasters

Customer's challenge

Responding quickly to natural disasters and restoring uninterrupted wireless communications is important to establish a supply line of essential services and materials such as drinking water, food, electricity, and medical supplies. This enables first responders to support the time-critical needs of victims and helps ensure their safety. The absence of reliable mobile communication frustrates and hinders restoration efforts putting everyone's lives at risk. The key goals for Fukaden were:

- Compact high-density power modules optimize available design space and weight
- Handling higher input voltages to reduce cable weight
- Lower EMI to support clearer communications

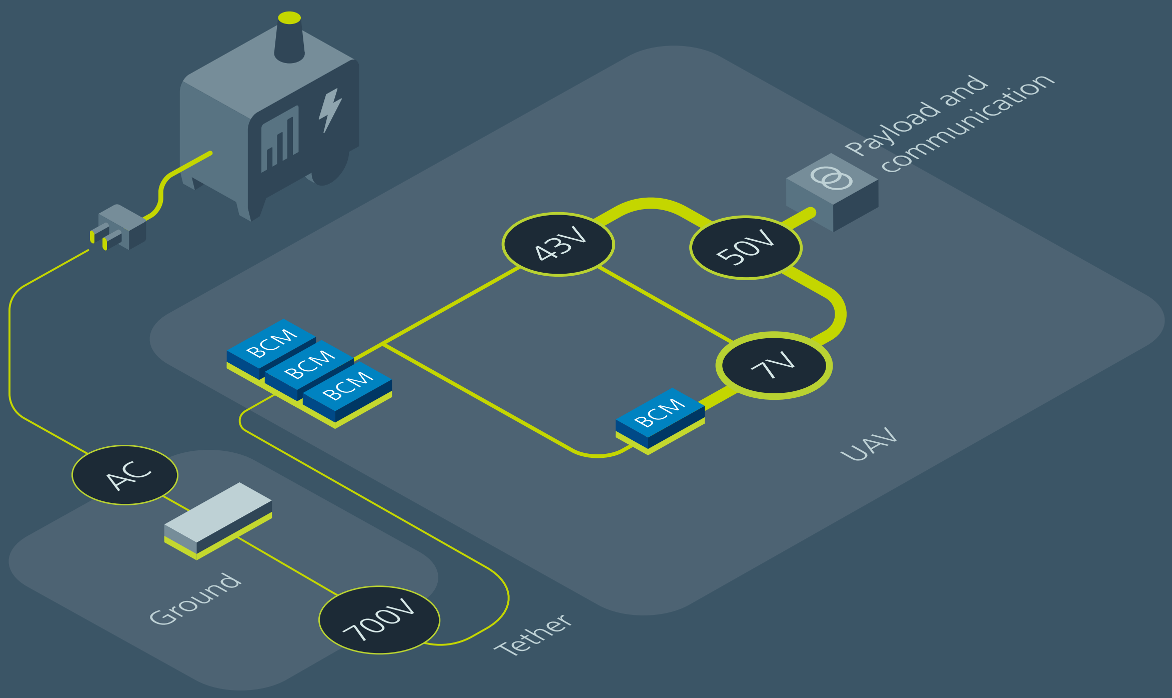
The Vicor solution

Fukaden's drones require power that ranges from 1kW to 5kW. Fukaden was able to minimize the size and weight of the tether cable by using higher voltage power, which reduced current. To support the added weight of the communication base station Fukaden deployed higher voltage (700V), a thinner tether, and used three high voltage Vicor BCM® fixed ratio converters in parallel. This delivered the extra power needed to support, payload, duration, and communication services. Key benefits were:

- High levels of integration and efficiency in the smallest form factor
- Up to 776W/in^3 power density
- Vicor power modules provide integrated EMI filtering

Higher voltage enables lighter and thinner cable

Fukaden's communication station requires up to 9kW. Using higher voltage power (DC 700V), thinner cabling, and an array of three Vicor BCMs® in parallel Fukaden was able to easily scale the power to deliver better performance. In this **power delivery network**, the drone can fly for 92 hours and maintain a communication area diameter of 10km.



BCM bus converter modules

Input: 800 – 48V

Output: 2.4 – 55.0V

Current: Up to 150A

As small as
22.0 x 16.5 x 6.7mm

vicorpower.com/bcm

VICOR

Case study: Doosan hydrogen powered UAV

Lightweight, small converters maximize flight time

Customer's challenge

Extending the operational range of small (<25kG) UAVs has proved challenging using Li-Ion technology as the power-to-weight performance typically limits flight times to below 30 minutes. By miniaturizing hydrogen fuel cell technology Doosan developed a 2.6kW fuel cell solution that is lighter (typically half the weight) and has a higher power density (typically double) compared to conventional battery solutions. The key goals were:

- Flight duration and range quadrupled using the hydrogen fuel cell (>2hrs duration)
- Significantly reduce power supply weight and maximize space on-board for payload
- Reliability to minimize chance of failure over the sea

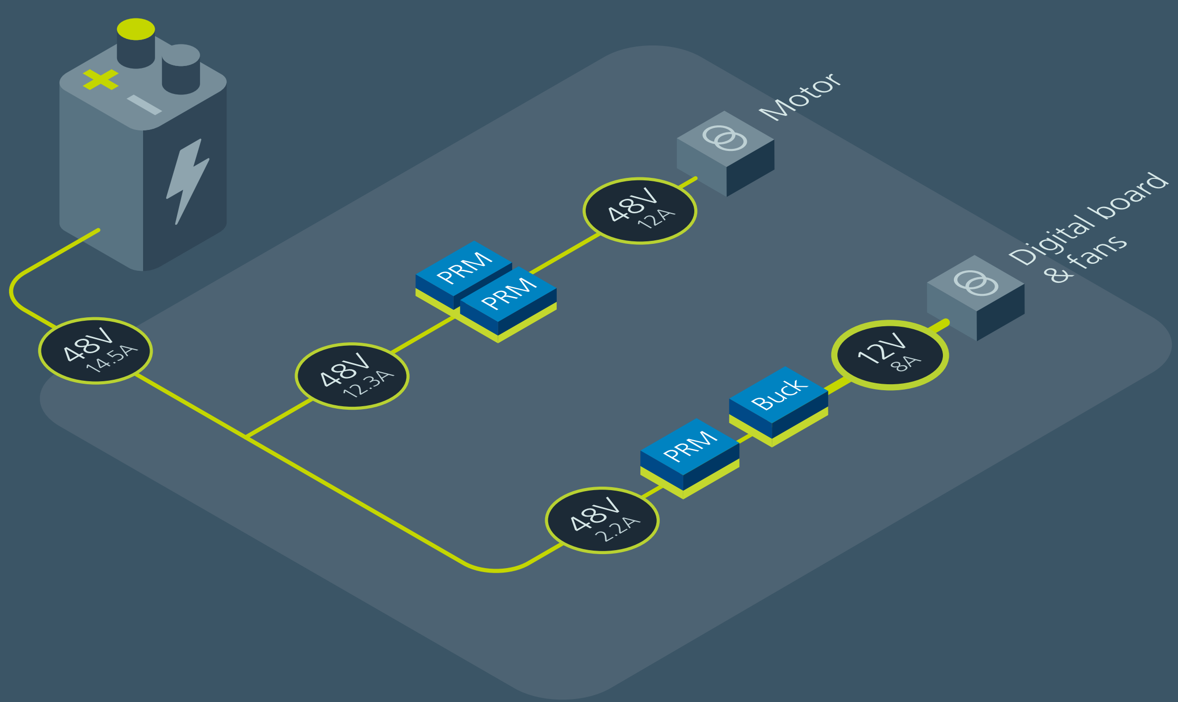
The Vicor solution

To maximize performance the power delivery network for the rotor motors and electronics should save weight for the payload while keeping conversion losses low. Hydrogen fuel cells typically have a widely varying output dependent on their state of charge and load current. In this case the cell voltage varied from 40 to 74V and the stable 48V 580W rail required for the motors was provided by an array of two PRM regulators. Key benefits were:

- Highly power dense components provide 400W in 13.6g
- Zero-Voltage-Switching topology provides 97.4% efficiency
- Highly integrated power components for highest reliability

Low weight, small power components extend flight time

Power delivery network: The widely varying 40 – 74V output from the hydrogen fuel cell was stabilized for the 48V 580W rotor motor supply by an array of two PRM™ regulators. The 12V 100W rail for the on-board electronics was provided by a half-chip PRM that regulated the fuel cell output and was followed by a ZVS Buck regulator that converted the 48V PRM output to 12V. Efficiency of the complete power distribution network was 97% and the weight was only 35g, just 10% of a comparable brick solution. To analyze this power chain go to the **Vicor Whiteboard** online tool.



PRM regulator modules

- Input: 48V (36 – 75V)
- Output: 48V (5 – 55V)
- Power: Up to 600W
- Peak efficiency: Up to 97%
- As small as 22 x 16.5 x 6.73mm

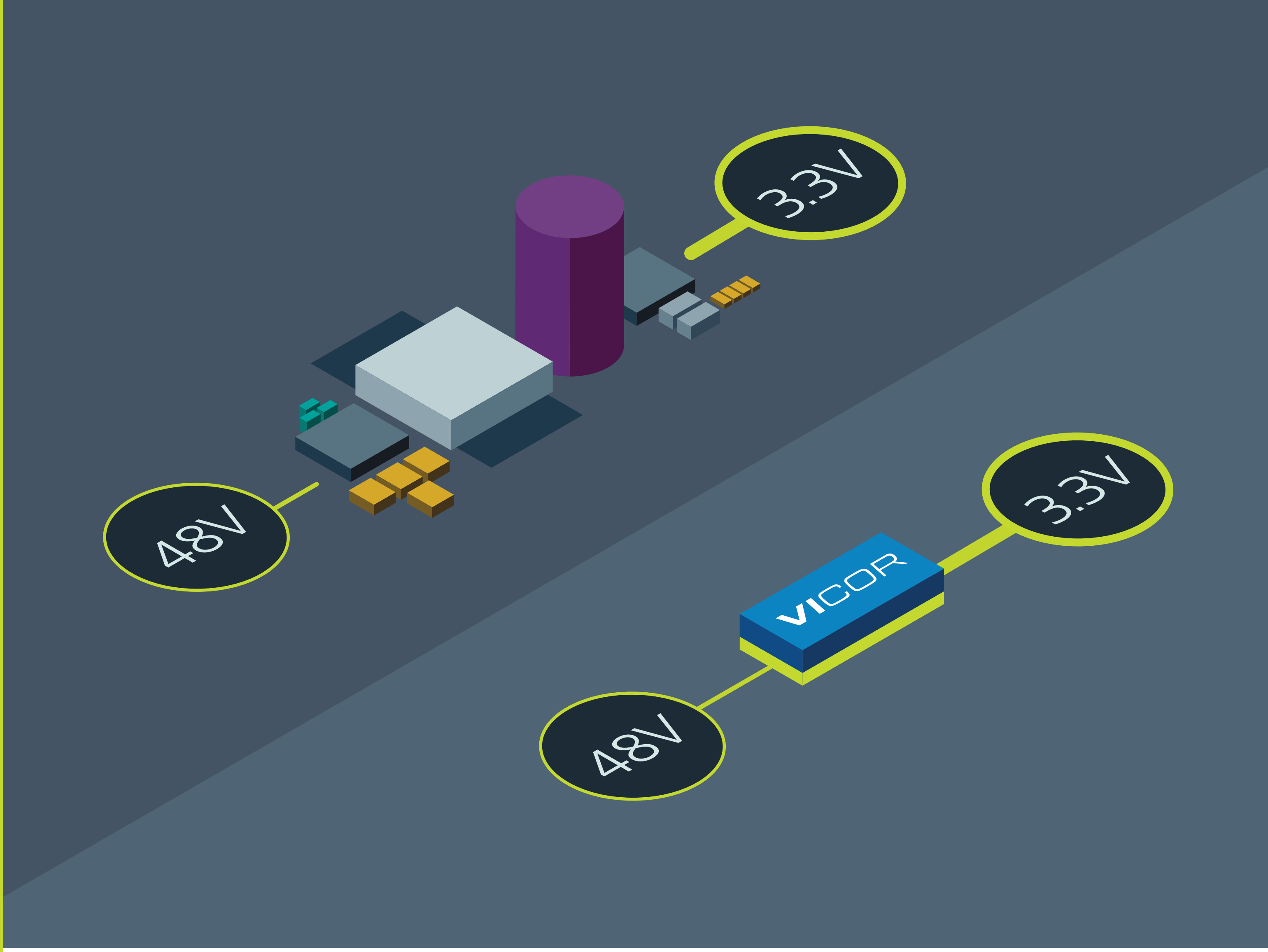
vicorpower.com/prm

ZVS buck regulators

- Inputs: 12V (8 – 18V), 24V (8 – 36V), 48V (30 – 60V)
- Output: 1 – 16V
- Current: Up to 22A
- Peak efficiency: Up to 98%
- As small as 7 x 8 x 0.85mm

vicorpower.com/buck

Technical articles



White Paper

Optimizing high-density power design: modular vs. discrete

Introduction

When evaluating the option to use a power module or a discrete power solution, there are a number of important design variables to consider as well as other ancillary functions that impact the overall power delivery network (PDN) design process.

To start, you need to determine if you have the necessary in-house power design expertise to design, evaluate, test and manufacture a discrete power solution. In most cases, companies do not have the luxury of employing a dedicated team of experienced power design engineers because it is just too costly. In addition to the obvious economic implications, there are many performance and design advantages to using a sourced power module over a home-grown discrete solution.

Taking it one step further, not all power modules are created equal. Innovative and patented Vicor power module technologies incorporate advanced topologies, miniaturization and thermally adept packaging. The combination of these design techniques enables power modules with greatly reduced magnetics and much higher power density and efficiency at higher frequencies as compared to alternative power-modules or discrete-designs. This proven technology has been powering growth markets such as data center, automotive, robotics and more. The following matrix offers a high-level comparison of the differences between Vicor power modules and discrete power solutions.

Vicor power module vs. discrete comparison matrix

Feature	Vicor power module	Discrete solution
In-house power design engineering skill level needed	Minimal	Extensive
Size	Small and compact	Larger BOM and PCB area
Weight	Light	Bigger BOM with larger PCB make it heavier in most cases
Power density	High	Low
Efficiency	High (application dependent)	High (application dependent)
Flexibility	Compact size allows for ease of implementation in any application	Larger footprint makes it difficult to fit into existing application
Scalability	Modular design makes it easy to scale up or down	Fixed circuitry makes it difficult to scale to a new design

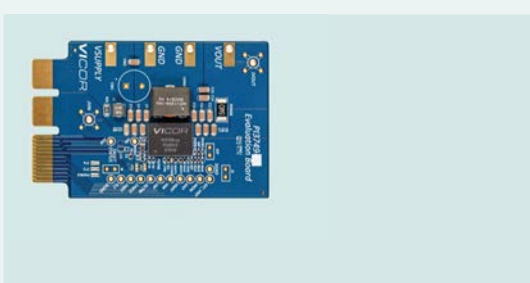
Vicor power module vs. discrete comparison matrix (continued)

Feature	Vicor power module	Discrete solution
Design Cycle / Time-to-Market	Up to 50% shorter compared to discrete solution	Longer
Qualification	Guaranteed from the vendor	Need to be performed in house
Thermal Management	More uniform planar packaging profile and localized source make for a simplified heat management design	Non-uniform and spread out devices make for a more inefficient and complex heat management design
Ease of Assembly	Simple, faster, lower risk of damage	More complicated, slower and higher risk of damage
Procurement / Supply Chain	Simpler with lower risk	More complex with greater risk of supply chain interruption

In power management, size does matter

Discrete power solutions are inherently inefficient to design and manufacture because they require a larger footprint to accommodate the increased bill of materials (BOM) and the circuitry necessary to connect the individual components. In most designs, discrete solutions only utilize one side of the printed circuit board (PCB), which means even a bigger PCB as shown in Figure 1.

Figure 1: Vicor power module designs are smaller than most discrete power solution alternatives.



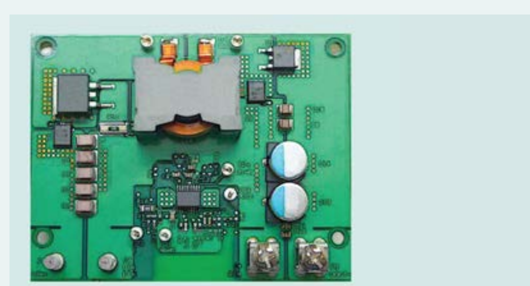
Vicor PI3740

PCB Size: 2.0 x 2.375in

BOM count: 31

Key device: 10 x 14mm DC-DC regulator

Efficiency at 12V: 95%



2 FETs and 2 Diodes

PCB Size: 4.3 x 3.55in

BOM count: 42

Key device: 6.4 x 4.4mm TSSOP20

Efficiency at 12V: 87%

On the other hand, power modules maximize the available design space by using both sides of the integrated PCB resulting in a much smaller footprint and increased power density as illustrated in Figure 2.

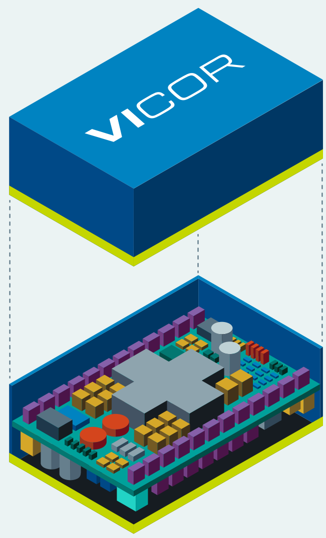


Figure 2: Illustration showing the inside of a power module demonstrating the efficient use of space resulting in a much smaller and power dense solution.

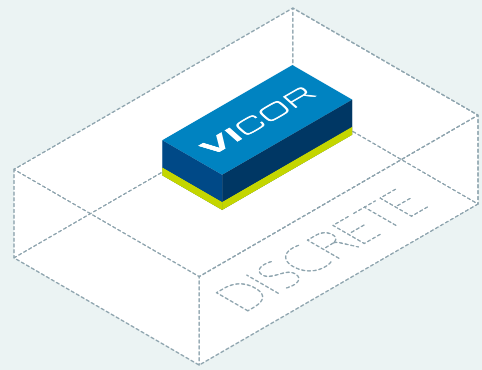


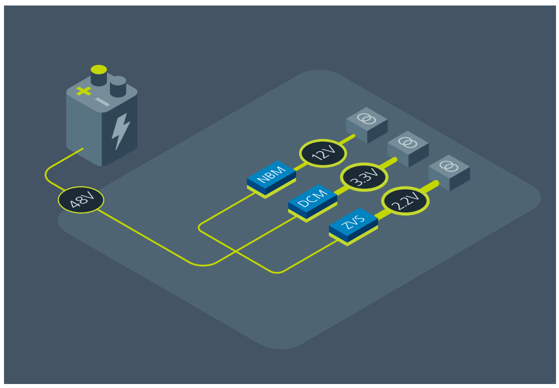
Figure 3: A visual representation demonstrating the size and space advantages of using a Vicor power module.

Just the specs and only the specs

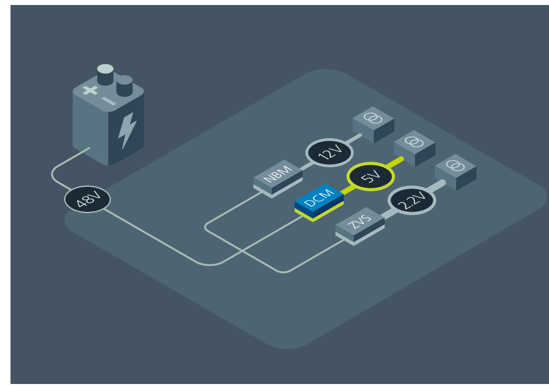
Beyond the obvious physical advantages, modules offer designers a variety of improvements in performance. Because of their compact size and specialized topologies, modules have a higher power density and in most cases are more efficient, meaning you can design a power delivery network that drives more power in less space (Figure 3). This comes in handy when faced with design envelopes that are limited in volume and require a PDN capable of delivering the power needed to support a mission-critical application in challenging environments like space or under the sea. With Vicor power modules you don’t need to sacrifice power because of space limitations or, conversely, add space and weight to accommodate more power. You can still have the power you need (and more) using the existing power footprint. In contrast, discrete solutions need to be significantly resized to account for the additional power requirements.

Room to grow without the growing pains

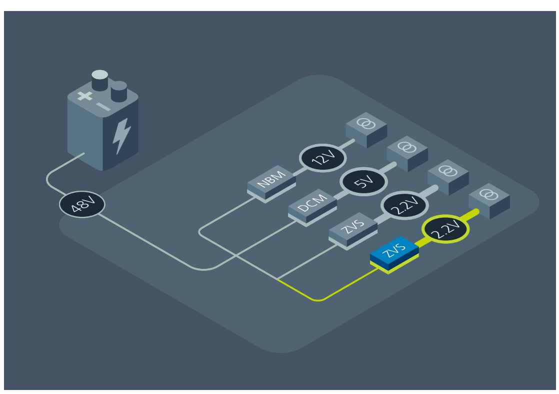
With Vicor power modules, you don't have to live in fear that you may need to redesign the PDN from scratch to accommodate more (or less) power. There's no need for costly and lengthy power redesigns that will set your project back months. Scaling through re-use of prequalified modules eliminates additional testing and recertification, as well as additional work to source the new BOM. Modules provide the flexibility and scalability needed to make design changes quickly and efficiently with minimal design involvement — saving you both time and money, and meaning faster time-to-market.



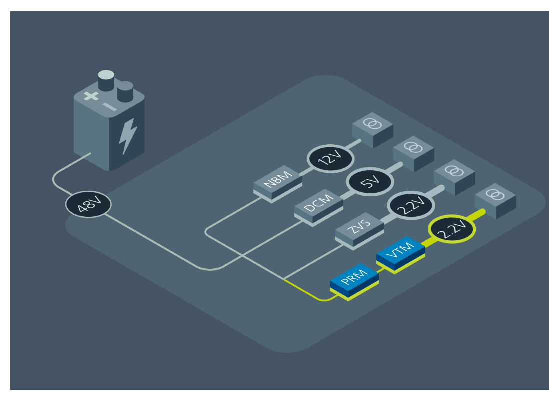
Individual modules perform the needed conversion at each load



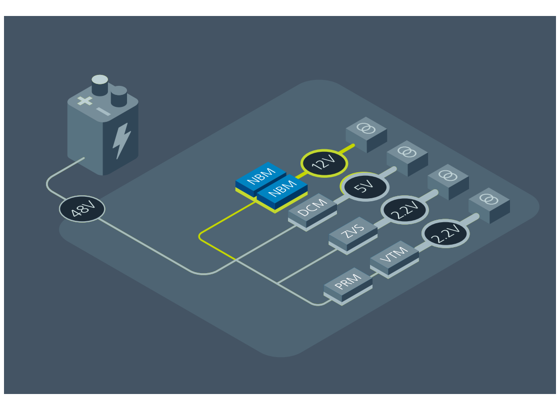
If power needs change, a module is replaced with a suitable power module



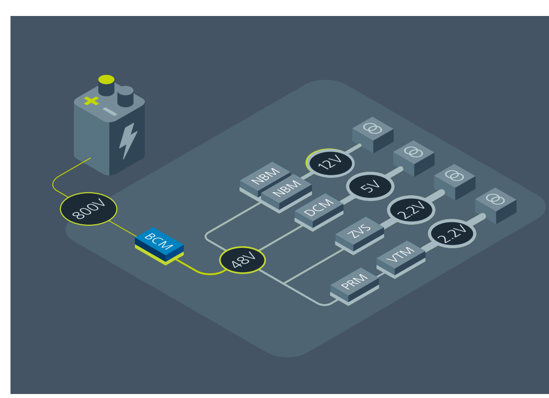
If an additional load is added, another module is added



To reduce losses, one module is used for regulation and one for transformation



To quickly double the power at a load, add a second module



With a high voltage power source, a module is added to create a SELV bus

Staying cool under pressure

The fundamentals of thermodynamics state that the most effective and efficient way to transfer (remove) heat from a heated substrate is to maintain a uniform and consistent flow of fluid (air or liquid) across that surface (laminar flow). To do this you need to have a heat sink profile that minimizes or eliminates any abrupt variations in that surface that could potentially change the flow from laminar to turbulent, thereby reducing thermal transfer efficiency.

This theory can be directly applied to the Vicor-module-versus-discrete comparison. As previously discussed, power modules are very compact and have a higher power density than discretes, which means they could have a higher localized heat signature than a discrete solution. At first you may see this as a win for discretes, but that is not the case. As shown in Figure 4, power modules have a physical profile that supports laminar flow, thus removing heat quickly and efficiently. In a discrete solution, however, heat losses are not isolated to one spot. Rather, they are scattered throughout the design, making it more difficult to cool. Adding to this challenge, the physical form of a discrete solution is chaotic: the profile of a discrete solution looks like a cityscape with many peaks and valleys, and therefore does not support laminar flow. The discrete solution's inherently varied topography promotes turbulent airflow which can lead to excessive localized heating.

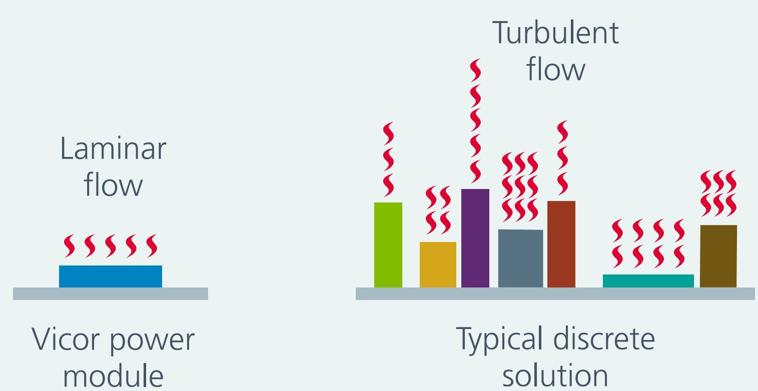


Figure 4: Vicor's packaging profile allows for a uniform and predictable heat dissipation while the discrete solution results in uneven and unpredictable heat dissipation.

To learn more about Vicor innovative high-performance power module packaging, read the white paper by Phil Davies, Senior Vice President at Vicor.

Less is more when it comes to power design

We've all seen videos of pick-and-place machines frantically placing parts on a printed circuit board at high speed. Less visible are the many complex systems that make this advanced manufacturing technique possible. Each of these fine-tuned systems has a narrow margin for operation at peak efficiency. The slightest malfunction in a subsystem could be catastrophic, and at speed, an operator will not notice until it is too late. There are hundreds or even thousands of electrical solder connections on a PCB, depending on the complexity of the finished design as illustrated in Figure 5. Basic statistical analysis theory shows that the odds of a failure increase with every additional connection.

Keeping that in mind, which power design would be less likely to experience a failure due to a manufacturing error? The power module design. There are far fewer connections that need to be made than in a discrete design, making it less prone to quality defects during assembly. With fewer placements, there is also less need for multiple assembly stages. This reduces the number of times the board is handled by operators, thereby reducing the potential for electrostatic discharge (ESD) damage during the assembly process. All of this translates into greater reliability.

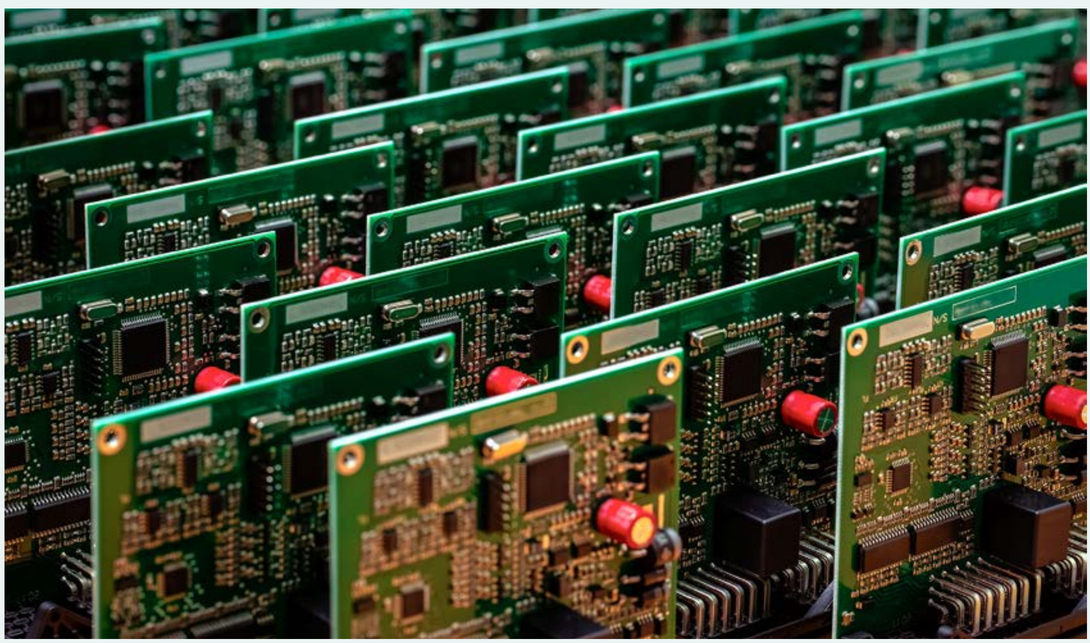


Figure 5: With hundreds of components with multiple connections making up thousands of individual connections your odds increase exponentially for having higher assembly defects in a discrete design.

Easing the product life cycle dilemma

When choosing between a power module and a discrete design you need to take a step back and consider not just the design but the overall life cycle to understand the full benefits of the modular approach. As shown in Figure 6, in the case that you chose to design your own power delivery network using discrete components, your own in-house power design group would shoulder the whole burden of design, test and validation for every power system.

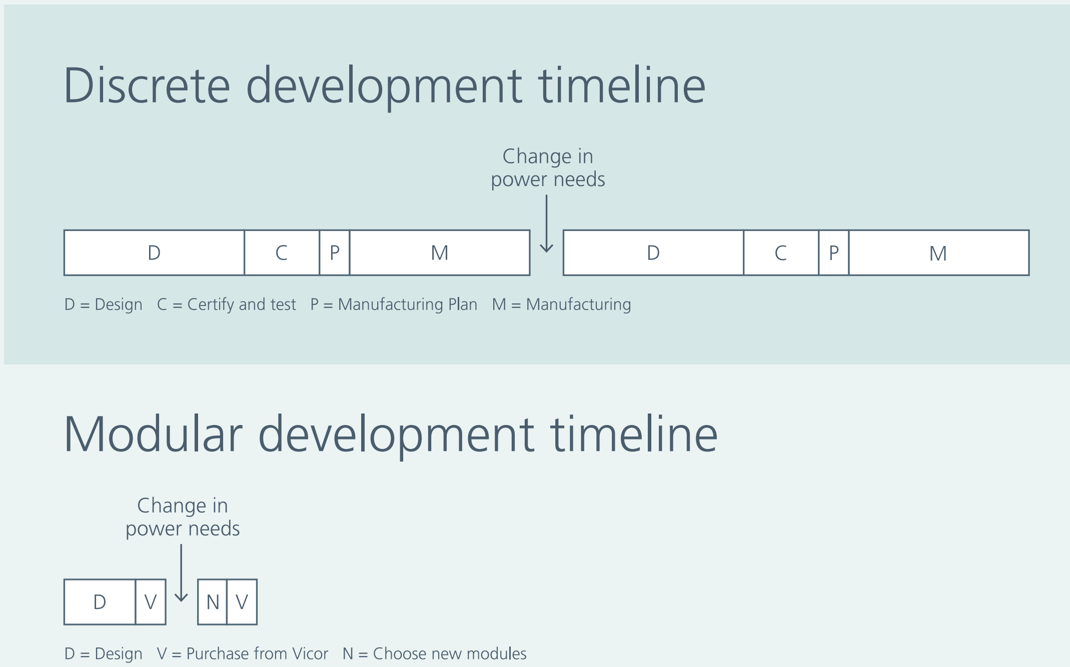
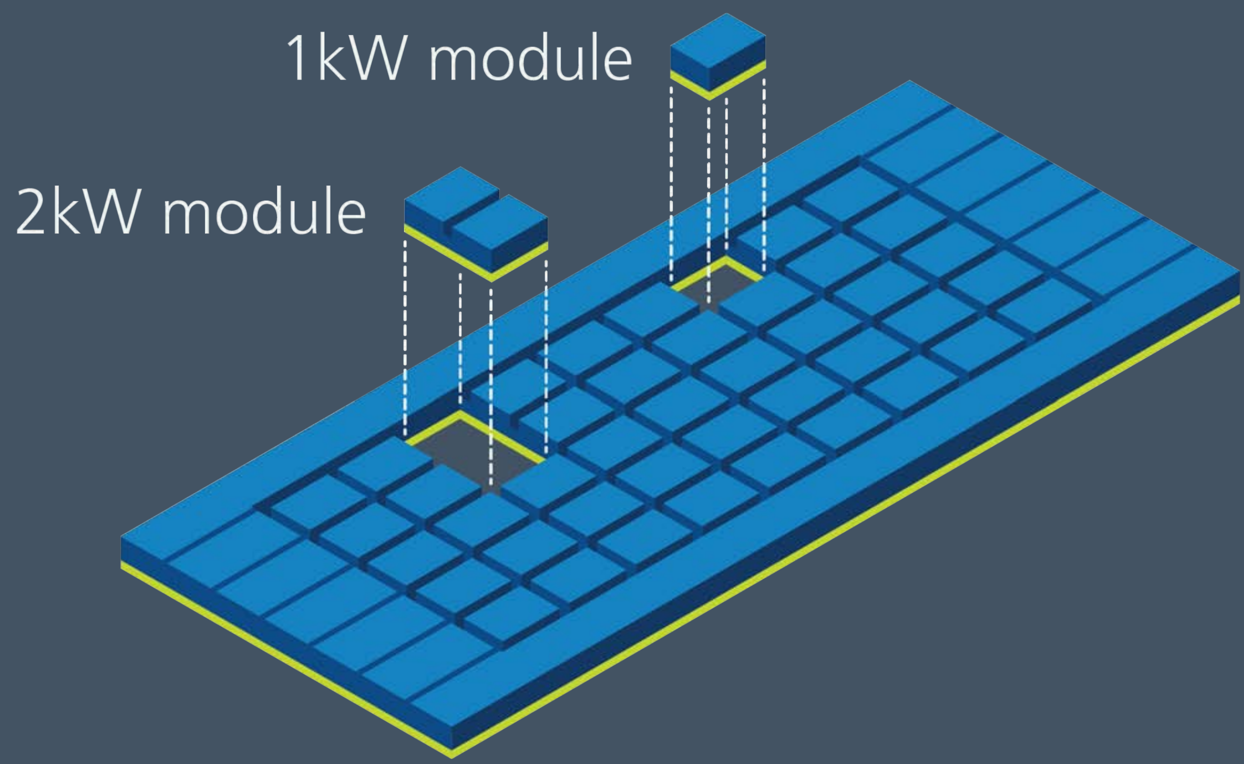


Figure 6: A simplified design lifecycle timeline illustrating the advantages of using a module solution versus a discrete solution.

After the design was validated by your design team you would need to have it tested again in order to be certified by a third-party agency to ensure it meets all required certifications (UL, CE, UR, etc.). Once certified, you would need to work with your own manufacturing group or a contract manufacturer to create a manufacturing plan. Once you are sure the manufacturing process is complete, which includes final test, then you would need to engage with the sourcing department to start the long process of sourcing negotiations and contracts for all of the individual components on the BOM. Many of these components might also require a second source, making procurement that much more difficult. With all these moving parts and dependencies on multiple vendors in your supply chain this introduces the very real potential for mistakes or unplanned interruptions leading to greater risk. Additionally, if the design ever needs to be scaled up, everyone goes back to the drawing board.

On the other hand, if you were to base the design on power modules, you would source pre-qualified power modules from Vicor and use a small number of discrete components to complete the design. This would make the supply chain logistics much easier and less stressful on your organization. You would also be assured that each module you received was thoroughly tested and came with the appropriate QC approval from the vendor. To top it all off, as power requirements increase (they always do!), you would be able to reuse more of the same modules to obtain more power, removing the most painful parts of the re-design process.

For additional information on how Vicor power module products can help you design the optimal PDN solution, go to www.vicorpower.com/innovation. While there explore our technical resources and online design tools available 24/7.



White Paper by Phil Davies, Corporate Vice President

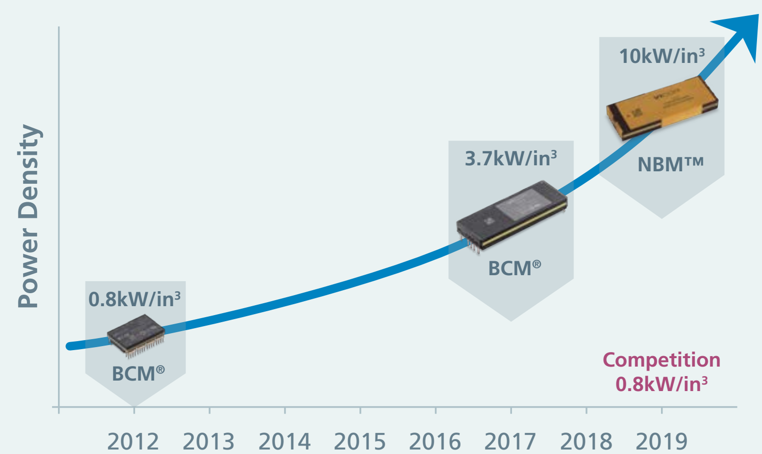
Attributes of high-performance power module packaging

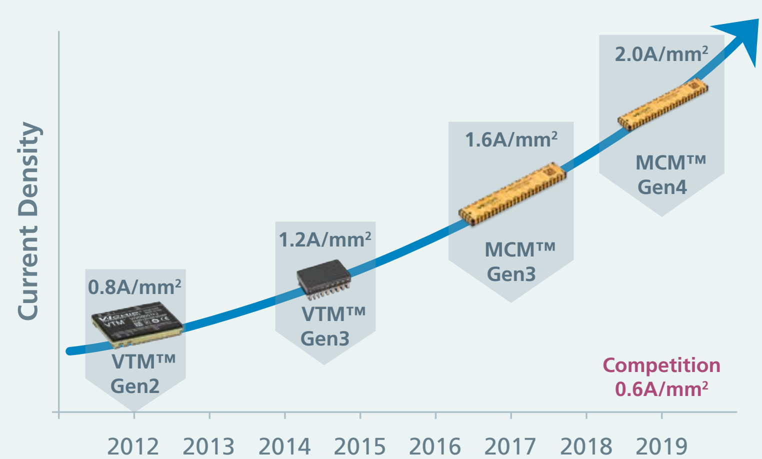
From the first Brick to today's ChiP™ (Converter housed in Package), Vicor has been continually innovating to deliver higher-performance solutions to power-system engineers. These innovations are a result of a steadfast focus on advancing four essential technology pillars: power delivery architectures, control systems, topologies and packaging.

The fourth pillar, power module packaging, has been a unique differentiator for Vicor since its inception. There are several attributes that enable a high-performance power module package, and Vicor consistently leads the industry in advancing each one:

- High power and current density
- Thermal adeptness
- Integrated magnetics
- Compatibility with high-volume PCB assembly techniques
- Automated and scalable high-volume manufacturing

Figure 1: Continual advancements in the four pillars of innovation have reduced power losses by 25% every 2.5 years enabling significant power- and current-density improvements.





High current and power density

Each step of Vicor power module package development leveraged new materials, active and passive components and, most notably, improvements in magnetic structures based on higher switching frequencies. The higher frequencies are enabled by topology and control system improvements incorporated in proprietary Vicor control ASICs. The recent launch of the fourth generation (Gen4) of these ASICs has enabled power density and current density numbers of $10kW/in^3$ and $2A/mm^2$ respectively, enabling a new family of AC and DC high-power front-end converters and point-of-load (PoL) current multipliers. These latest generations of modular power solutions are changing the way power delivery networks (PDNs) are architected and designed in numerous industries.

Thermally-adept packaging

The multi-layer circuit boards within the power module on which components are placed are complex designs. They require special materials for optimal thermal conduction and to manage the flow of high currents and high voltages in tightly-packed spaces, all while minimizing power loss. The circuit boards also play a critical role in the assembly of the planar magnetics, which can be a source of major power loss.

> "Vicor fixed-ratio converters capitalize on the thermally-adept ChiP package by utilizing both chassis-mount and through-hole board-mount package options for up to 50kW arrays of 800V-to-400V bidirectional conversion at up to 98.8% efficiency."

Significant innovation has occurred over the years in the area of power module development. In 2015 Vicor introduced a new ChiP™ package which advanced power density with full double-sided component placement. It delivered heat extraction from both sides of the ChiP to maximize performance and power ratings. Two years later, the introduction of the copper-plated ChiP further advanced ChiP packaging, significantly simplifying thermal management by means of a wrap-around copper jacket.

High-voltage and high-power Vicor fixed ratio converters capitalize on the thermally-adept ChiP package by utilizing both chassis-mount and through-hole board-mount package options for up to 50kW arrays of 800V-to-400V bidirectional conversion at up to 98.8% efficiency.

Integrated magnetics

Materials science plays a big role in advancing power package performance, especially when switching at multiple-MHz levels. Of the several magnetic components in a power module, some are related to the gate-drive circuits for the main power switches and are very small, low-power assemblies. Gate-drive transformers play a major role in minimizing gate-drive losses and have been optimized over many years and cycles of learning.

The main energy storage core for the converter or regulator plays the critical role in overall module performance and can be one of the main sources of power loss. The core, its windings and PCB material compositions are continually optimized for higher switching frequencies, higher power levels and lower output resistances to reduce power losses and increase efficiencies. By integrating the energy storage inductor or transformer into the power module and maximizing its performance, the power-system designer is relieved of the often difficult and time-consuming process of optimizing the power converter magnetics, and they can achieve a reduction in the overall power system footprint. One Vicor power module family that captures all of these critical design elements is the current multiplier, which is now powering some of the most advanced GPUs and AI processors in high-performance computing applications. Vicor VTM™, MCM™ and GCM™ are capable of delivering over 1000 amps, while directly converting 48V to sub-1V levels. The integrated planar magnetics in these devices have been optimized over 20 years and current multipliers now achieve current density levels of 2A/mm^2 with even further advances planned for the near future.

> "The new Vicor SM-ChiP™ is a plated, overmolded package intended for surface-mount attachment to a printed circuit board and is compatible with CM manufacturing techniques and equipment."

Compatibility with high-volume PCB assembly techniques

Surface-mount reflow soldering is used by all of the high-volume contract manufacturers (CMs) around the world. The new Vicor SM-ChiP is a plated, overmolded package intended for surface-mount attachment to a printed circuit board and is compatible with CM manufacturing techniques and equipment. The electrical and thermal connections of the package are formed through soldered connections to plated castellation terminal features along the perimeter of the module and continuous plated surfaces of the main package body. SM-ChiPs are compatible with tin-lead and lead-free solder alloys as well as water-soluble and no-clean flux chemistries; they can also be picked-and-placed onto the PCB. The package has also been designed to withstand multiple reflows for multi-sided PCB assemblies. Detailed SM-ChiP™ Reflow Soldering Recommendations are also provided by Vicor to ensure successful implementation.

High-volume automated power module manufacturing

The original Vicor VI Chip® package was also an overmolded package but was manufactured using individual-cavity construction. In contrast, the new ChiP™ is made and cut from a standard-size panel and make full use of both sides of the module's internal PCB for active and passive components.

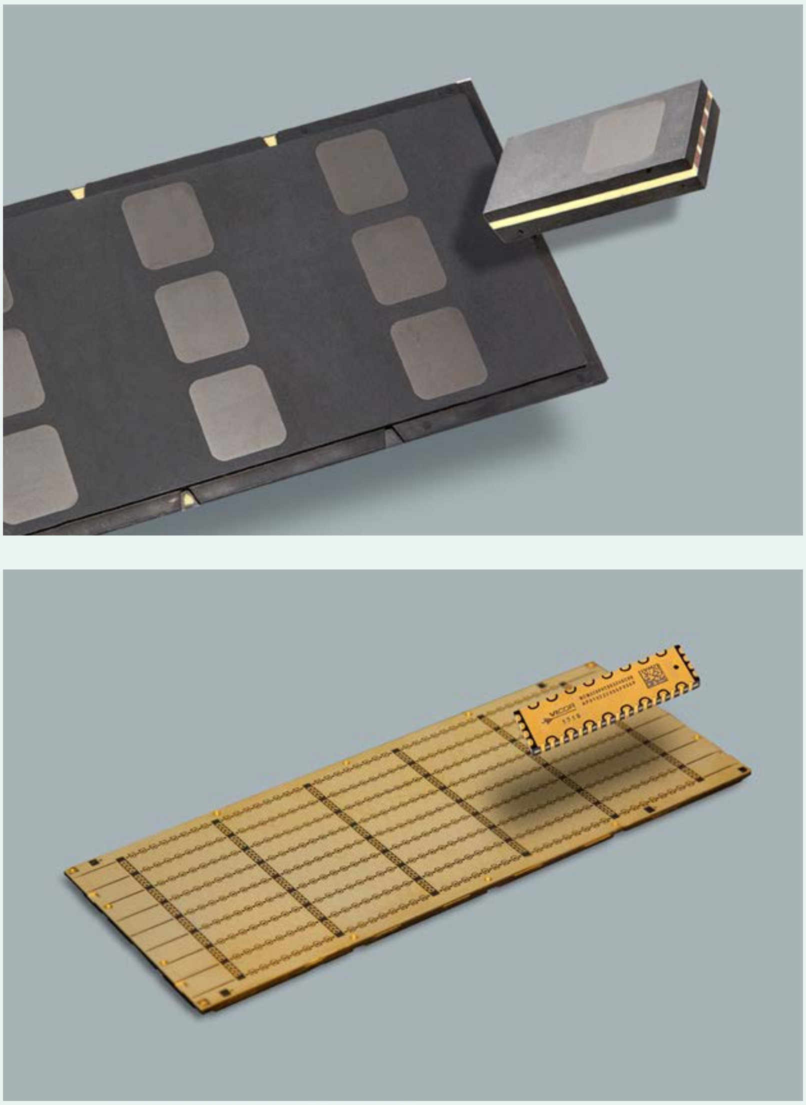


Figure 2: The new panel manufacturing process was another innovation for the power industry. ChiPs are all cut from the same size panel, enabling an automated high-volume manufacturing process.

Thermal management of this package requires double-sided cooling to maximize performance and power density. Making and cutting ChiPs from panels is very similar the way silicon chips are made and cut from wafers, but whatever the power level, current level or voltage level of the module, ChiPs are all cut from the same size panel, enabling a manufacturing operation that is streamlined, high-volume and very scalable.

Conclusion

Vicor will remain on the forefront of delivering modular high-performance power delivery networks (PDNs) by continually advancing its four technology pillars of innovation: power delivery architectures, control systems, topologies and packaging. Each pillar is essential to achieving the performance that customers demand for their advanced systems development in high-performance computing, electrified vehicles, satellite communications and industrial applications. However, the power module package is where all of the elements of innovation come together, and where materials science and a great deal of ingenuity enable the critical performance metrics of density and efficiency.

Article

Overcoming tethered UAV challenges with a high-voltage, compact, module-based power delivery network

Robotic and unmanned vehicle (UV) fleets are reshaping the future of automation and production. Continuous improvements in productivity are being driven by extended range and increased uptime that are reliant on fleet maintenance, particularly the charging process. One of the top costs and inefficiencies today is the need for human intervention in the charging process; therefore, UAV and automated robotics developers are looking for ways to make further improvements in power density and efficiency to lighten loads and extend battery life.

Efficient power delivery with reduced footprint and weight.

Realizing such improvements requires reconsideration of the power delivery network (PDN) and the use of high-density power modules instead of traditional, all-in-one power supplies.

Tethered drones are a growth market for UAVs because of the need for extended uptimes and increased load capabilities for applications such as surveillance and communications. Ispagro addresses this market in an innovative way by retrofitting existing, market-leading small drones from manufacturers such as DJI and Parrot. Retrofitting existing UAVs allows Ispagro to rapidly address evolving market needs in a cost-competitive manner.

However, these battery-operated, small drones have limited payloads and uptimes. So adding a tether extends uptime and provides fail-safe operation for safe landing via onboard battery in case of power failure, tether, damage, etc. The tether, however, does add more challenges for the UAV designer who must accommodate the 50m tether cable and aerial units within a tight 400gm payload limit.

Heavy-gauge tether limits range and performance

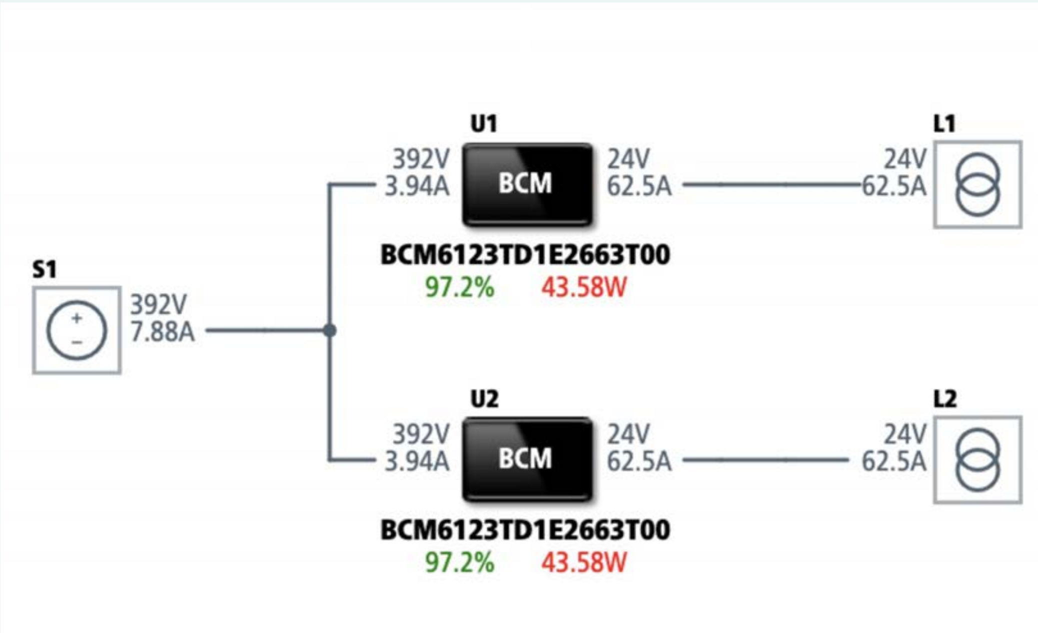
The biggest challenge is to reduce the weight of the tether. A heavier tether will require more power to maintain flight times. More weight will also limit the height and range of the drone. High-power DC-DC conversion would typically require a bulky power supply because they are sending lower voltage power up the tether.

Best power design for tethered drones

The best way to alleviate heavy tethers is to send high-voltage power up the tether and convert down to the load levels at the other end. High-voltage power can travel more efficiently than low-voltage via a thinner-gauge cable, which is lighter and more efficient. To minimize weight of the flying drone, small fixed-ratio bus converter modules are used to efficiently convert high voltage (400 – 800V) to loads (20 – 50V). The Vicor BCMs can achieve 98% peak efficiency and continuous efficiency of 95%.

Vicor BCMs reduce cable weight by 30 – 40%

High-density and lightweight power modules are ideal for this application, enabling lower input currents and thinner and lighter tether cables. The weight saved from the tether cable can be used to maximize payload to improve the functionality and capabilities of the UAV. Newer versions with high-capacity drones also need the power conversion to happen inside drone, and lightweight, high-performance power modules are necessary to fit into the system.



BCM modules can be paralleled with inputs powered from different sources because they are isolated transformers. BCM modules mounted close to each other and cooled equally will also equalize power dissipation.

Vicor high-density, high-efficiency power modules address Ispagro's challenges. The BCM family of fixed-ratio converters offer the highest efficiency and highest power density for use in onboard power conversion. BCMs are available in many combinations of input and output voltages to accommodate a wide range of payload applications, and they can be easily paralleled to simplify development of UAV platforms.

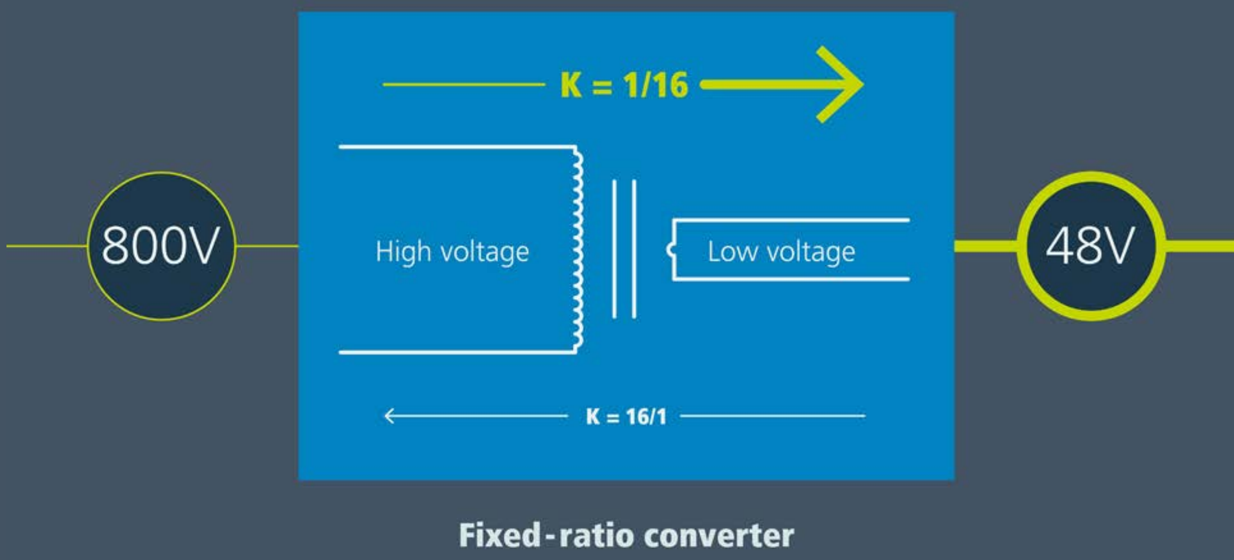
The combination of high efficiency and light weight of Vicor BCMs enables tether cable weight reduction of 30 – 40%. BCM modules can be paralleled with inputs powered from different sources because they are isolated transformers. BCM modules mounted close to each other and cooled equally will also equalize power dissipation. This further reduces amount of space needed, simplifies thermal management, and increases the power available to the drone and its payload.

The Vicor modular solution delivers high efficiency, high power and scalability

BCM® bus converter modules.

The Vicor PDN solution is compact and lightweight due to industry-leading high power density. Ispagro was able to meet higher power requirements with a simple 2-module solution using fixed-ratio BCMs. This solution achieves 98% peak efficiency and continuous efficiency of 95% with high MTBF. As Ispagro increases power requirements, these BCMs can be swapped out for other BCMs or paralleled as needed with minimal additional development.

BCM bus converters are high-density, high-efficiency, fixed-ratio (non-regulating) isolated DC-DC converter modules. BCMs are available in a ChiP™ package or a VIA™ package, which simplifies cooling as well as providing integrated PMBus® control, EMI filtering and transient protection. The family extends from 800V to 48V inputs with various K factors to suit a wide range of applications and markets. Based on the Vicor proprietary Sine Amplitude Converter (SAC™) topology, high-voltage BCM ChiPs are able to reach peak efficiencies of 98% and achieve power densities up to 2,400W/in^3.



White Paper by Phil Davies and Tom Curatolo

Redefining power delivery networks with fixed-ratio converter

Introduction

Power delivery to the various points-of-load within a system is done via a Power Delivery Network, commonly referred to as the PDN. The PDN consists of cables, bus bars, connectors, circuit board copper power planes, power converters and regulators. The performance of a PDN is measured in terms of power loss, size, weight and cost. Governing PDN performance is its overall architecture, such as the use of AC or DC voltage distribution, specific voltage levels and when and how many times the network needs voltage conversion and regulation. This white paper discusses a particular type of DC-DC converter, the fixed-ratio converter (sometimes referred to as a bus converter), and why power system designers should consider it an essential part of the power delivery architecture, particularly for high-power systems.

Power delivery

Power systems 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 high voltage reduces the current ($P = I \bullet V$) and therefore the size, weight and cost (cables, bus bars, connectors, motherboard copper power planes) of the PDN ($PLOSS = I^2R$). Architecting the system to maximize the length of the high-voltage runs before converting down to lower voltages and higher currents is also a big advantage. However, bringing a high-voltage and high-power PDN close to the load requires a DC-DC converter with high efficiency and power density. If safety is a concern as in mobility applications (automobiles), converting down to a SELV (safety extra low voltage) level PDN from a high voltage with high efficiency and power density is critical to overall system performance.

DC-DC converters can be designed with many different architectures and topologies but fundamentally they are either regulated or non-regulated, isolated or non-isolated. DC-DC converters with no regulation are called fixed-ratio converters and they typically have higher efficiency than other converters when operating with a wide input to output voltage ratio. Higher efficiency can result in higher power density and easier thermal management due to lower power losses. However, because they are not regulated, fixed-ratio converters can be more demanding on downstream regulators if their input voltage has a wide operating range. Recent improvements in the efficiency of DC-DC regulators when operating over wider input voltage ranges have made the use of fixed-ratio converters possible. With higher bulk-power DC voltage levels and intermediate bus voltage levels becoming more popular, the use of fixed-ratio or bus converters can offer significant performance and system cost advantages.

What is a fixed-ratio converter?

Product	Input voltage	K factor	Output current	Output power
LV BCM (48V)	48V (36 – 60V)	1/4, 1/6	130 – 150A	1500 – 1950W
HV BCM (380, 270V)	270V (200 – 400V) 384V (260 – 410V)	1/8, 1/16, 1/32	16.9 – 125A	800 – 1750W
MIL-COTS HV BCM (270V)	270V (200 – 400V)	1/8	30A	1000W
UHV BCM (800, 600, 540V)	544V (400 – 700V) 650V (500 – 800V)	1/16	35 – 40A	1600W
NBM	48V (36 –60V) 48V (38 – 60V)	1/3, 1/4, 1/5	60 – 170A	800 – 2400W

A fixed-ratio converter is a DC-DC converter whose output voltage is a fixed fraction of the input voltage. The converter provides no regulation and the input-to-output voltage range is defined by the "turns ratio" of the device. This turns ratio, referred to as the K factor, is expressed as a fraction relative to its voltage step-down capability. K factors can range from K = 1 to as low as K = 1/72 in point-of-load converters.

Typical inputs are low voltage (LV), high voltage (HV) and ultra-high voltage (UHV). K factors are then selected based on the desired PDN voltage and PoL design.

Fixed-ratio converters can be isolated or non-isolated and, as is the case with Vicor converters, capable of bidirectional power flow and voltage conversion. For example, a K 1/12 fixed-ratio converter with bidirectional capability can be operated as a boost converter with a K of 12/1.

Additional design flexibilities offered by fixed-ratio converters include ease of paralleling to meet higher power demands and connecting converter outputs in series to provide higher output voltages, effectively changing the K factor by N • K (N = number of bus converters).

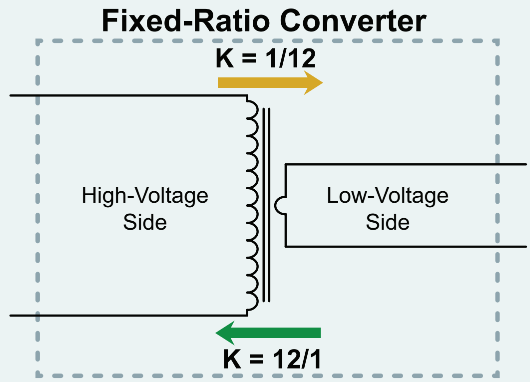


Figure 1: Step-up and step-down factors of a bidirectional fixed-ratio converter.

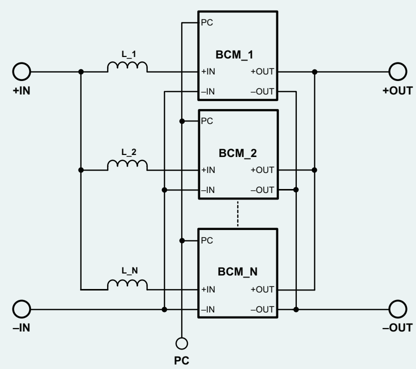


Figure 2: BCM converters in a parallel array.

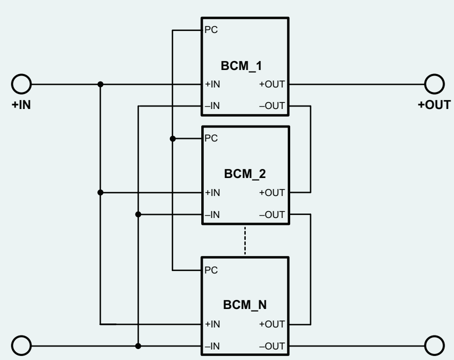


Figure 3: BCMs with outputs connected in series for higher output voltage.

What is a Sine Amplitude Converter (SAC™)?

In a "hard switched" converter the output power is proportional to the converter duty cycle, which can be varied to provide more or less power from the secondary. This category of circuits is called Pulse Width Modulated or PWM converters. The switching frequency is practically limited to several hundred kHz by the high levels of power dissipated by the switching devices. Despite its shortcomings, the PWM converter is superior to linear regulators in applications where the input/output voltage ratio was large; the PWM converter started the movement to the widespread use of DC-DC converters.

The SAC is a transformer-based series resonant topology. Unlike regulated quasi-resonant ZCS / ZVS converters, the Sine Amplitude Converter operates at a fixed frequency equal to the resonant frequency of the primary-side tank circuit.

The switching FETs in the primary are locked to the natural resonant frequency of the primary and are switching at zero crossing points, eliminating power dissipation in the switches (boosting efficiency) and greatly reducing the generation of high-order noise harmonics (requiring less filtering of the output voltage). The current in the primary resonant tank is a pure sinusoid rather than a square wave or a partially sinusoidal waveform as seen in prior generations of converters. This also contributes to reducing harmonic content and provides a much cleaner output noise spectrum.

The leakage inductance of the primary is minimized in a Sine Amplitude Converter since it is not the critical energy storage element.

The SAC can therefore operate at a much higher frequency allowing for a much smaller transformer, and increasing both power density and efficiency. The Vicor BCM operates at a frequency of several MHz; this frequency is fixed regardless of load. In response to an increased load on the secondary, the Sine Amplitude Converter reacts by increasing the amplitude of the sinusoidal current on the primary resonant tank. This in turn increases the amount of energy coupled into the secondary, countering the increased load. When the load current is reduced, the amplitude of the sinusoid decreases approaching zero under "no-load" conditions.

The output impedance of the Vicor bus converter is extremely low, reflecting the low output impedance of the resonating tank circuit on the primary side of the transformer, which ideally presents zero impedance at its resonant frequency. This impedance is essentially flat up to approximately two-thirds of the resonant frequency. This is approximately one half the output impedance of a conventional IBC.

The sinusoidal nature of the current in the primary leads to advantages in the electrical noise profile of the SAC. The output noise spectrum is very narrow with major components at the switching frequency and two times the switching frequency (due to the full wave rectification of the output). Output filtering is easily achieved with small high-frequency ceramic-type capacitance."

Selecting fixed-ratio converters

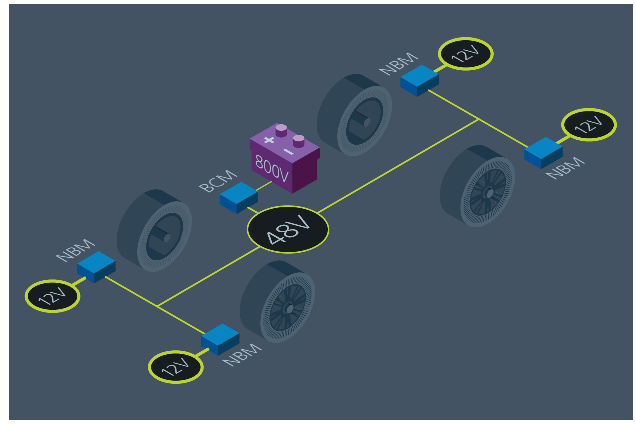
Vicor fixed-ratio converter modules offer a large selection of voltage ranges, K factors, isolation or non-isolation and bidirectional operation. There are four primary families that address different bulk power, intermediate bus and point-of-load conversion needs:

1. BCM® isolated bus converters
2. NBM™ non-isolated bus converters
3. VTM™ isolated and non-isolated current multipliers, used as PoL converters in conjunction with an upstream regulator (PRM™)
4. MCM™ modular current multipliers, used as PoL converters with an upstream regulator and driver (MCD)

The Vicor Sine Amplitude Converter (SAC™) topology is used in all Vicor converter modules, enabling them to outperform competing fixed-ratio converters in virtually every relevant metric, including conversion efficiency, power density, package profile, transient response and bandwidth.

Solving the toughest problems in automobiles and data centers

Power delivery networks are undergoing significant changes due to the soaring power demands within many end-markets and applications. As new features are added and performance levels advance, higher voltages are being used for power delivery as a way to reduce the physical size, weight and cost of the PDN itself.



Two markets undergoing rapid changes to their PDN architectures are automobiles and data centers. The electrification of vehicles to meet new CO_2 emission standards and the move to pure electric vehicles has seen the addition of 800V, 400V and 48V conversion and regulation requirements within vehicles.

The data center market is adding 380V and 48V PDNs to support the addition of artificial intelligence (AI) and high-performance computing. Processor steady-state and peak current demands have been on an almost exponential rise. This dramatic increase is causing a PDN dilemma at the point-of-load, requiring a complete rethinking of architectures, topologies and packaging to solve the problem.

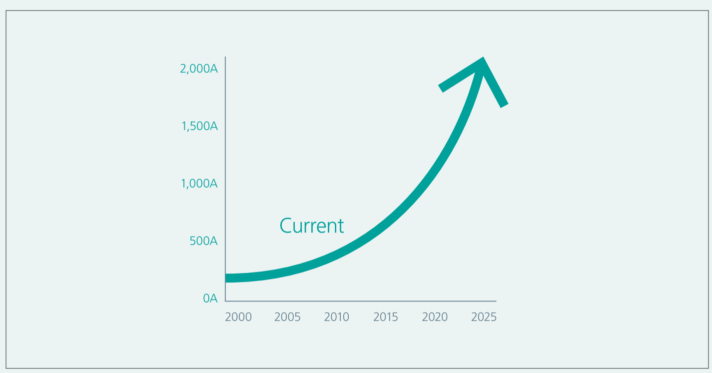


Figure 4: Power requirements are rising at a rapid rate, driven by new higher-powered applications like AI, cloud computing and electric vehicles.

Isolated converters are a great choice for UAVs, EVs and exascale computing

Tethered UAVs and exascale computing racks use high voltages of 800V and 380V, respectively, as a means of reducing the size, weight and cost of their bulk power cables. In the case of a tethered drone, the power cable to the drone can be over 1000 meters in length, which the drone must lift to achieve its flying height.

Exascale computing racks are approaching power levels of 100kW, which eliminates the possibility of using traditional 12V distribution. Redefining the power delivery architecture by utilizing high-power-density Vicor K 1/8 BCMs that can be located in close proximity to each of the server blades enables 380V DC distribution in the rack, significantly reducing the size, weight and cost of the PDN.

The 380V DC is developed from the output of the front-end three-phase AC-DC converter. The bidirectional capability of these devices is also opening up new applications such as delivering power to wireless radio towers equipped with new high-power 5G systems. In these applications the 48V SELV provided by the ground power supply is up-converted to 384V with a K 1/8 fixed-ratio BCM™ used in reverse to give an 8/1 step-up conversion. This significantly reduces the size and cost of the power cable that delivers power to the 5G radio systems at the top of the tower.

In mobility applications such as electric vehicles, high-voltage distribution is not used due to safety issues. However, high-density, low-weight BCMs can provide excellent options for 800V-to-48V or 400V-to-48V conversion. The 48V is SELV and can be distributed around the vehicle to significantly reduce cable size from the traditional 12-volt PDN system.

Three-phase AC-DC front-end power converters can also take advantage of the BCM's high density and efficiency, using them for the DC-DC conversion and isolation functions following the rectification and PFC stages of the converter.

By utilizing new Vicor 800V and 380V fixed-ratio isolated bus converters (BCMs), with power densities up to 2735W/in3 and efficiencies up to 98% peak, power system architects are not only solving their PDN challenges but also achieving very high system performance.

Non-Isolated step-down converters optimize 48V power

Hybrid vehicle and cloud computing server applications that want to take advantage of higher-voltage PDNs but are restricted to SELV environments can utilize the significant density, efficiency and flexibility advantages of a non-isolated fixed-ratio converter like the Vicor NBM. In these applications many designers need to keep their legacy 12V loads, but still require a cost-effective and high-performance 48V-to-12V converter to take full advantage of a 48V PDN.

The Vicor NBM2317 is a 1kW non-isolated fixed-ratio converter in a 23mm by 17mm surface-mount ChiP™ package that provides engineers a flexible, modular, low-noise solution. The NBM is also very scalable and can be paralleled to rapidly provide higher-power solutions with a single qualified component.

Fixed-ratio converters can be used as PoL current multipliers

Fixed-ratio converters can also be used as current multipliers for low-voltage, high-current, point-of-load applications such as data center CPUs, GPUs and AI ASICs. As the input voltage is down-converted by the turns ratio or 1/K factor, the K factor acts as the current multiplication factor as shown in the following simplified equation:

$$V_{IN} \bullet I_{IN} = \left(\frac{1}{K} \bullet V_{OUT}\right)\left(K \bullet I_{OUT}\right)$$

If the converter is fed by a tightly regulated input device, such as a PRM in the Vicor factorized power architecture (FPA™), this provides a very efficient and high-density 48V-to <1V, PoL solution.

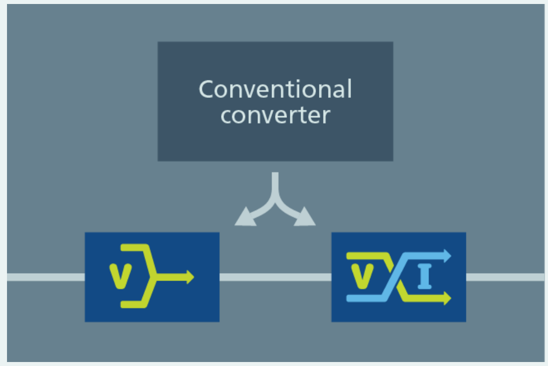


Figure 5: Factorized Power Architecture (FPA) is used when high-current board-mounted power is needed. Today's higher power requirements and lower (<<1V) PoL operating voltages are straining IBA performance. The increased power and dynamic load requirements for CPUs, GPUs and AI processor applications demand that voltage regulators be located closer to the load input power pins.

The high-density current multiplier module (either VTM or MCM) can be placed extremely close to the processor, either laterally alongside the processor or directly beneath, delivering power vertically into the processor power pins above. At 1000 amps of current a PDN resistance of 1µΩ translates to 1W of power loss. Typical PDN resistances with traditional multiphase synch buck VRs have PDN resistances of 200µΩ (200W power loss) which renders system performance unacceptable. Lateral power delivery or vertical power delivery with a Vicor current multiplier lowers the PDN resistance to 50µΩ and 5µΩ respectively.

The unique attributes of Vicor fixed-ratio converters are enabling power systems engineers to redefine their power delivery architectures to meet the high power and performance demands of their advanced systems. High power density, efficiency and ease of paralleling, plus operational capabilities as step-down / step-up converters and as high-density current multipliers at the point-of-load make fixed-ratio converters one of the most flexible and highest performing DC-DC converters. Future-proof your power delivery architecture with Vicor fixed-ratio converters.

Tools

This section outlines Vicor tools that provide novice and experienced engineers a digital workspace where they can design and test power module solutions to best fit their application needs.

Power System Designer

The Power System Designer is a user-friendly software which both novice and experienced system designers can utilize to architect end-to-end power delivery networks. This tool harnesses Vicor's Power Component Design Methodology to produce optimized solutions without time consuming trial and error. The Power System Designer also provides a service which is up to 75% faster than traditional methods and allows users to export the final BOM.

Whiteboard

Whiteboard is an online tool with an easy-to-use workspace where users can analyze and optimize the performance of different power chains. Users are able to find the best solution for their application needs using Vicor's high density, high efficiency power modules. In addition, users can set operating conditions for each component of the power design and get loss analysis for individual components and the system overall.

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