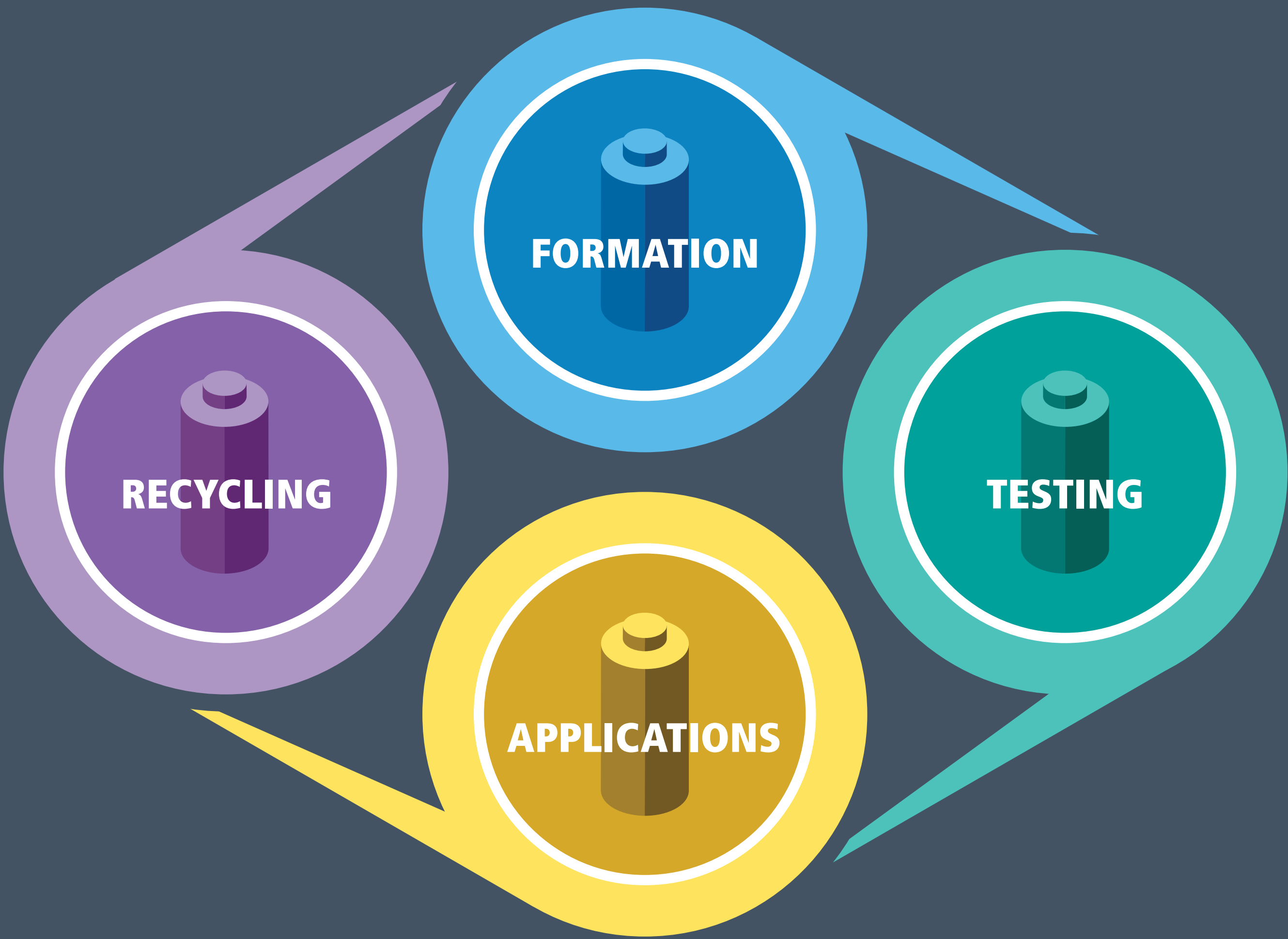
ISSN: 1863-5598

ZKZ 64717
06–24

Bodo´s Power Systems®

Electronics in Motion and Conversion

June 2024



Fixed-ratio Converters unleash Innovation across the Battery Lifecycle

The ongoing adoption of electrification across many industries has been a boon for productivity and the environment, and battery production has been a core technological enabler for this trend. Driven in part by electric vehicles (EVs) and energy storage systems for renewable energy, the battery industry is among the fastest growing in the world.

By David Krakauer, VP of Global Marketing, Vicor

According to the International Energy Agency (IEA), global battery demand has increased tenfold from 43.8GWh/year annually in 2016 to 550.5GWh/year annually in 2022. Given the still-accelerating demand, every stage of the battery lifecycle merits examination. The battery lifecycle consists of four major stages: cell formation, battery testing, application use and battery recycling. A shortcoming in any one of these phases undermines the battery industry and the growth in electrification. Today, the battery lifecycle is constrained by limitations of existing power conversion technologies that threaten this growth. Vicor power-dense fixed-ratio converter technology brings a novel approach to achieving greater sustainability and cost-efficiency across all stages of the battery lifecycle.

Unlocking new possibilities with fixed-ratio converter technology

In high-voltage battery systems, DC-DC power conversion is a fundamental aspect of the power delivery architecture.

DC-DC conversion is commonly achieved with switched-mode power converters like a buck or boost topology or low drop-out regulators (LDOs). While these power converters can be effective , they limit the flexibility and performance of the power delivery network (PDN) with the rigidity of their outputs and their subpar conversion efficiencies. This is particularly true when working with high voltages associated with today's battery systems.

To overcome these shortcomings, Vicor has developed fixed-ratio converters that provide highly efficient, isolated conversion in a small package for high-voltage to low-voltage loads commonly referred to as safety extra-low voltage or SELV.

Analogous to a transformer in an AC-AC solution, a fixed-ratio converter performs DC-DC conversion with the output voltage being a fixed fraction of the DC input voltage (Figure 1). Similar to a transformer's step-down or step-up capabilities that are defined by the coil's turns ratio, a fixed-ratio converter's capabilities are defined by its K factor, which is expressed as a fraction relative to its voltage step-down capability (Figure 2).

Unlike traditional DC-DC converters that regulate the output voltage, a fixed-ratio converter provides no output regulation. These devices are also autonomous, requiring no feedback loop or external control mechanism.

Fixed-ratio converters offer several notable benefits over traditional converters.

Bidirectionality

Given that fixed-ratio converters operate independently of an external host or controller, these devices are inherently bidirectional. This means that, depending on the direction of the current flow, the same fixed ratio converter module will step the voltage either up or down. By achieving voltage boosting and bucking with one module, fixed-ratio converters unlock unprecedented flexibility and simplicity for PDN that rely on the bidirectional flow of current.

Flexibility and scalability

Fixed-ratio converters are exceptionally easy to parallel for higher power demands. Designers can easily add multiple fixed-ratio converter modules in parallel to scale a system to whatever output power demands are required. Similarly, designers can place multiple fixed-ratio converters in series to achieve unique voltage ratios based on their cascading K factors. In these cases, the converters need to be power-matched to ensure safe and reliable operation.

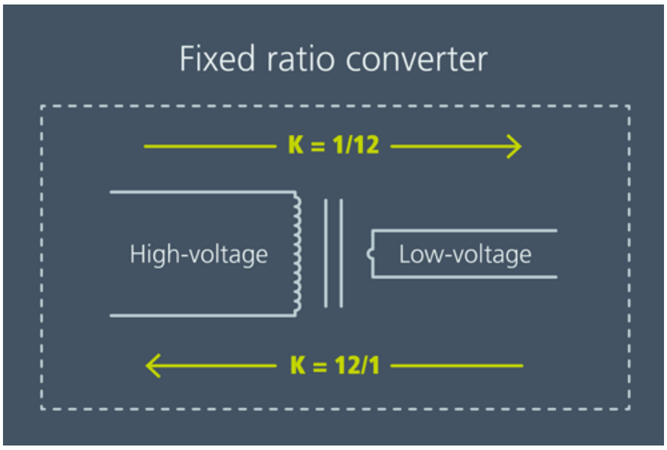


Figure 1: A bidirectional fixed-ratio converter operating as a step-down converter with K = 1/12 can also serve as a boost converter with a K of 12/1. This bidirectionality in a single module unlocks a number of unprecedented use cases for the battery industry.

BCM fixed-ratio converters

Input range	K Factor	Current	Power
36 – 60V	1/4, 1/6	130 to 150A	1,500 to 1,195W
38 – 55V	1/1, 2/3, 1/2, 1/3, 1/4, 1/5, 1/6, 1/8, 1/12, 1/16	6 to 70A	120 to 300W
200 – 330V	1/6	30A	270W
200 – 400V	1/8	30A	1,000W
240 – 330V	1/8	7A	235W
260 – 410V	1/8, 1/16, 1/32	17 to 125A	800 to 1,750W
330 – 365V	1/8, 1/28, 1/32	8 to 28A	300 to 325W
360 – 400V	1/8, 1/32	7 to 27A	300 to 325W
400 – 700V	1/16	40A	1,600W
500 – 800V	1/16	35A	1,600W

Figure 2: With support for a large range of different K-factor and output-power configurations, Vicor BCM fixed-ratio converters can meet the needs of most applications.

High efficiency in a small package

Finally, fixed-ratio converters are unmatched in power efficiency from a very small footprint. Whereas a conventional buck or boost converter achieves maximum power efficiencies in the low 90% range, fixed-ratio converters like the Vicor BCM® line demonstrate conversion efficiencies up to nearly 98%. This leads to more sustainable applications with decreased demand for thermal management overhead.

The importance of the power delivery network in cell formation

The first phase in the battery lifecycle is the cell formation stage.

In this phase, newly manufactured batteries must go through the formation cycling process, which consists of charging and discharging a cell for the first time. During this process, a cell is cycled repeatedly to build up gradually the cell's solid-electrolyte interphase (SEI) layer. The speed of this process is determined by cell chemistry, so cell formation latency is mostly a fixed-rate process.

Formation cycling in the battery requires an underlying power delivery network (PDN) that can support the repetitive charge and discharge cycles.

The standard PDN for such a system takes a three-phase AC input from the grid, rectifies it to high-voltage DC, and then uses multiple phases of DC-DC conversion to reach the nominal voltage required to charge a battery cell (e.g., 4.2V) (Figure 3). This final voltage required for battery charging will vary from plant to plant depending on the specific cell chemistry, but the several intermediary voltage drops from AC to a lower DC bus voltage, such as 12V, is standard across the industry.

Discrete component solutions are extremely difficult to design, require significant in-house power expertise, have a large BOM that presents cost and supply chain challenges, and increase time to market. Discrete solutions limit flexibility as they offer pre-defined output voltages. Where different cell chemistries require different voltages, it is more cost-effective for designers to create a flexible solution that they can modify based on cell chemistry. Discrete solutions don't allow for flexible cell formation systems that can be dynamically modified for compatibility with multiple cell types.

Cell formation demands system high throughput and efficiency

There are two major challenges with the existing PDNs in battery formation: throughput and efficiency.

From a throughput perspective the speed at which manufacturers can form a battery's SEI layer is inherently limited by cell chemistry. Hence, improving the cost-efficiency of the cell-formation process necessitates scalable systems that can form many batteries in parallel. However, with existing PDNs, the lack of a modular intermediary DC-DC phase limits the ability to easily scale a system without major design overhauls.

From an efficiency perspective, the constant charge and discharge of cells is very costly. To optimize efficiency, battery manufacturers reuse the energy spent during cell charging cycles by either storing it locally or sending it back to the grid on discharge cycles. This requires a PDN that supports the bidirectional flow of current and performs high-efficiency power conversion.

In both instances, fixed-ratio converters are an ideal solution. By integrating a fixed-ratio converter into the PDN, designers can redefine the architecture into three distinct phases: AC rectification, transformation to low voltage and constant-current conversion (bus converter).

In the constant-current conversion stage, designers can implement fixed-ratio converters to easily step down the higher DC level to a safer, lower level without the need for discrete solutions or single-module solutions. By simply integrating one or multiple fixed-ratio converters in parallel, designers can create a power delivery network that is modular and easily scales.

In this way, designers can make systems that cycle many batteries concurrently, enabling higher throughput, greater power density and improved efficiency. Additionally, this architecture allows designers to easily change the PDN to accommodate the required DC-DC conversion for a cell's unique nominal voltage. With a more flexible solution that requires no discrete components, designs reach the market faster and are less susceptible to failure.

For power conservation, the inherently bidirectional nature of a fixed-ratio converter is ideal in the cell-formation process. With fixed-ratio converters, cell manufacturers can easily switch between charge and discharge cycles, knowing that the fixed-ratio converter will automatically step up to a predefined higher voltage on discharge and similarly step it down on charging cycles. This unique feature improves process energy efficiency, enabling energy reuse during formation cycling.

Additionally, with a fixed-ratio converter efficiency of 97.9%, there is minimal power loss in the conversion cycle in either direction. Without fixed-ratio converters, such bidirectionality would necessitate multiple components (one for buck and one for boost). This would consume more power due to lower efficiencies and increase component count.

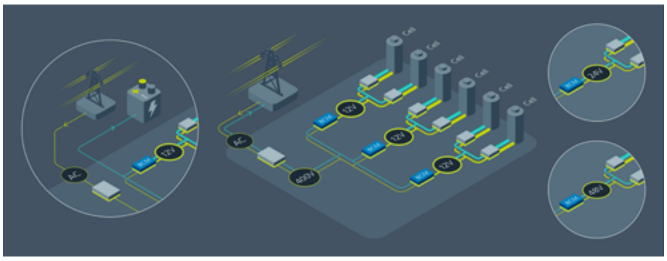


Figure 3: Battery manufacturers can use fixed-ratio converters to integrate bidirectionality and efficiency into cell formation power delivery networks.

Battery testing needs a flexible and scalable PDN

The next stage in the battery lifecycle is battery testing, where manufacturers combine battery cells into larger battery packs. Battery pack production is not constrained by the same chemistry-dependent time requirements related to the charging and discharging of cells, but it still faces similar throughput challenges.

For example, each cell must be properly tested and accurately measured so that multiple cells can be combined to form a larger battery pack. Then the larger battery pack also needs to be rigorously tested. This is not a value-add step, so the faster manufacturers complete this process, the lower the overall cost of the battery pack.

Flexibility and scalability in a PDN are needed to accommodate the wide variety of battery voltage and power levels, and high throughput is needed to test more batteries in the same physical space and in less time. Battery pack testers therefore need power delivery networks that are modular and scalable to the specific needs of their testing requirements and volumes. Like in the cell formation phase, the standard PDN of a battery testing facility entails the conversion of power from AC three-phase down to the cell's nominal voltage (Figure 4).

With fixed-ratio converters in the constant-current conversion stage of the PDN, battery test designers can avoid arduously designing the intermediary conversion stages. Instead, they can trust that their constant-current conversion is managed by the fixed-ratio converter. Designers can now focus on the final stage of the conversion process, where voltages need to match the cell's nominal voltage for testing. This simplified architecture enables the creation of modular and flexible systems that designers can readily modify for varied testing requirements.

Another important benefit of fixed-ratio converters is power density. With extremely high power efficiencies and small form factors, fixed-ratio converters can support kilowatts of power and hundreds of volts in industry-leading form factors. This helps support greater throughput testers by allowing for more testing equipment to fit within the same area constraints, hence creating the opportunity for testing more battery cells concurrently.

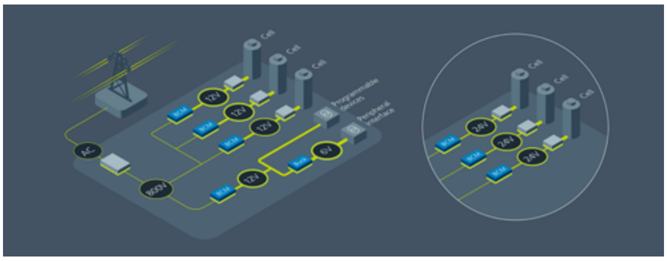


Figure 4: Fixed ratio converters unlock high levels of power density for battery-testing power delivery networks, enabling greater tester throughput by fitting more testing equipment into the same area.

Fixed-ratio converters reduce I^2R losses in battery applications

When the battery finally makes it out of the factory floor and into a real-world application, the challenges with PDN do not end.

In many emerging battery-powered applications, such as tethered robotics or ROVs, energy storage systems for renewables like solar and wind power and electric vehicles, there is a growing demand for extremely high-voltage power delivery (Figure 5). For example, electric vehicles are seeing a shift in architecture from 400V to 800V power delivery for the sake of greater power and efficiency.

For the same power, higher voltage levels allow for power delivery at lower currents. Therefore, one benefit of high-voltage power delivery is greater efficiency, as lower currents incur fewer I^2R losses. This enables more efficient applications that also require less overhead for thermal management.

Additionally, high-voltage power delivery decreases the wire gauge in vehicle wire harnesses. With lower current delivery requirements, designers can use smaller-diameter cables resulting in decreased system weight, material requirement and cost.

Naturally, the successful operation of such high-voltage systems relies on the ability to convert these high-voltages used in delivery to the lower voltages used at the load. At this point in the battery's lifecycle, fixed-ratio converters offer value by providing a simple and efficient means of DC power conversion.

Consider the example of a tethered robot. With a 1/16 K factor fixed-ratio converter, designers can take advantage of the 97.9% efficiency to step down voltages from the high voltage for power distribution (e.g., $800V_{DC}$) down to a lower voltage, like $48V_{DC}$. From the $48V_{DC}$, designers can use a conventional 90% efficient buck converter to reach the final 3.3V used for a microcontroller unit (MCU). Without a fixed-ratio converter, the entire conversion from 800V to 3.3V would occur at 90% efficiency, incurring significantly greater losses than the fixed-ratio converter architecture.

Thermal challenges in battery recycling

Once a battery has served its useful lifespan, the final stage in its lifecycle is recycling.

Battery recycling entails a high-power electrochemical process in which the raw materials and elements from the battery are chemically separated from the cell to be reclaimed and reused in the future. Like other industrial stages of the battery lifecycle, the PDN consists of converting three-phase AC input voltages to high-power DC, and then ultimately down to lower voltages to operate the recycling equipment (Figure 6).

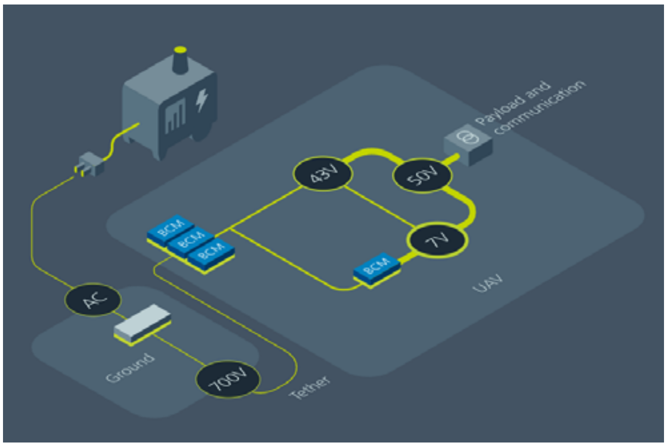


Figure 5: Applications like tethered robotics can use fixed-ratio converters to enable high-voltage power delivery without incurring significant power losses during conversion to lower voltages.

One challenge from the perspective of the PDN is that the battery recycling process creates a significant amount of heat. Therefore, the components within the PDN must be able to operate reliably at elevated temperatures. Similarly, power density becomes increasingly important in the design of the PDN, necessitating small form factors and high-efficiency power conversion.

Fixed-ratio converters offer an extremely power-dense solution to DC-DC conversion, capable of supporting kilowatts of power at hundreds of volts in extremely small form factors.

For example, the Vicor BCM6123 fixed-ratio bus converter boasts a power density of 2352W/in^3 (Figure 7). With this level of power density, designers can easily meet the temperature and performance requirements of battery recycling plants. And, as power requirements and demand continue to grow, the modular power architecture enabled through fixed-ratio converters allows for the system to scale up accordingly with minimal overhead needed.

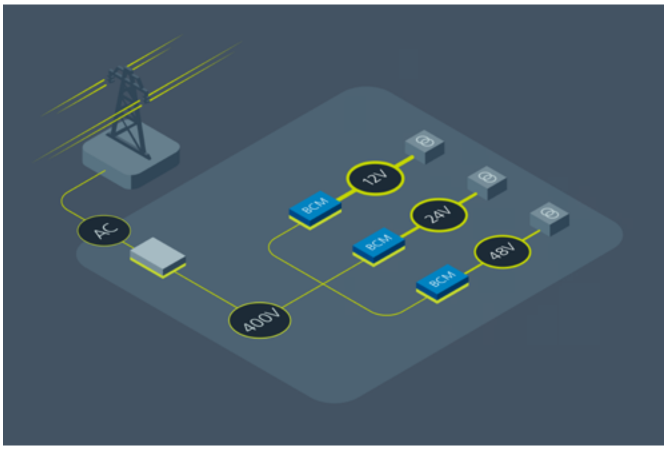


Figure 6: BCM fixed-ratio bus converters allow for reliable high power voltage conversion within the elevated temperature constraints of a battery recycling plant.

Bolstering the battery ecosystem with fixed-ratio converters

At each stage in the battery's lifecycle, there is a growing need for high-voltage power delivery networks that are efficient, power-dense and scalable. Success for the battery lifecycle necessitates success at each individual stage. Whether it's battery cell formation, testing, in-application use or recycling, the entire battery lifecycle benefits from fixed-ratio converters. As compared to traditional power conversion solutions, fixed-ratio voltage converters offer unprecedented levels of efficiency and small form factors, while also presenting unique features like bidirectional operation.

Figure 7: The Vicor BCM6123 fixed-ratio bus converter module offers a 24V output voltage and 62.5A output current while in a 61.0 x 25.14 x 7.26mm ChiP™ package.

Vicor is the only company to offer high-density fixed-ratio converters. The Vicor BCM® products employ a Sine Amplitude Converter™ topology which allows for higher-frequency operation than PWM-based solutions. The BCM family of fixed-ratio converters also comes in a variety of form factors and power ratings to support the needs of a wide variety of high voltage applications. Beyond the BCM family, Vicor offers fixed-ratio converters to meet the needs of many other applications.

The BCM fixed-ratio converter is poised to play a significant role in the growth of battery manufacturing, one of today's fast-growing markets. It supports greater throughput, enhances efficiency and can scale with any application. Regardless of the application or lifecycle phase, fixed-ratio power converters are an exceptional solution for the burgeoning modern battery industry with today is limited by traditional power-conversion approaches.

Vicor and BCM® are registered trademarks of Vicor Corporation; ChiP™ and Sine Amplitude Converter™ are trademarks of Vicor Corporation.

www.vicorpower.com