Automotive eBook

Accelerate vehicle electrification

with the smallest, lightest power modules

VICOR

Contents

Automotive eBook Introduction

The automotive market's approach to tractive power is complex and rapidly-changing. The internal combustion engine (ICE) is still king, but EV sales for both pure battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are accelerating rapidly. The UK, for example, saw over 740,000 EVs registered in December 2021, a 74 percent increase from 2020.

This will continue. Sources estimate EVs will account for 62 percent of total global vehicle production by 2030. This move into dominance is being driven by government legislation, OEM compliance strategies, and above all, consumer demand.

Yet there are other changes afoot. Vehicle electrical subsystem power loads have ballooned in recent years, with upwards of 20x growth. This is triggering more interest in adopting 48V systems to efficiently handle the exponential power demand, while simultaneously supporting 12V legacy systems.

> "Vehicle electrical subsystem power loads have ballooned in recent years, with upwards of 20x growth."

This is creating huge challenges for OEMs. They face pressure to accommodate ever-increasing and more widely-diversified power demands with commercially and technically effective power delivery networks (PDNs) – which must keep pace with fluctuating market demands. They must maintain ICE vehicle production while concurrently developing xEV vehicles.

Powering the next generation of EVs

Very high-power density and efficiency is essential to fulfil today's aggressive power capacity goals. Minimizing power system size and weight while maintaining high-performance power is essential. Flexibility, scalability and reusability are helping OEMs easily adapt to changing requirements in order to get their fleet of vehicles to market as fast as possible.

The best way to meet these objectives is to adopt a modular approach using compact, efficient, lightweight modules with high power density. This eBook looks into the various challenges facing designers of diverse vehicle power delivery networks and how Vicor power modules can be used to overcome them.

Case studies

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Case study:
Optimizing 12V applications in a 48V power delivery network

High-power 48V delivery with 12V legacy load support

Customer's challenge

Recent years' sharp increase in car electrical system loads has made efficient power delivery challenging. Cost-effective 12V legacy systems must be supported alongside 48V power used for heavier loads.

However, doing so without adding size, weight or complexity creates a challenge – one that must be solved with a suitable power delivery network (PDN) that supports all the loads throughout the vehicle. The key goals were:

- Cope with loads that have grown up to 20x over recent years
- Save time and cost by leveraging proven 12V legacy systems' benefits rather than replacing them
- Deliver power throughout the entire vehicle with maximum efficiency

The Vicor solution

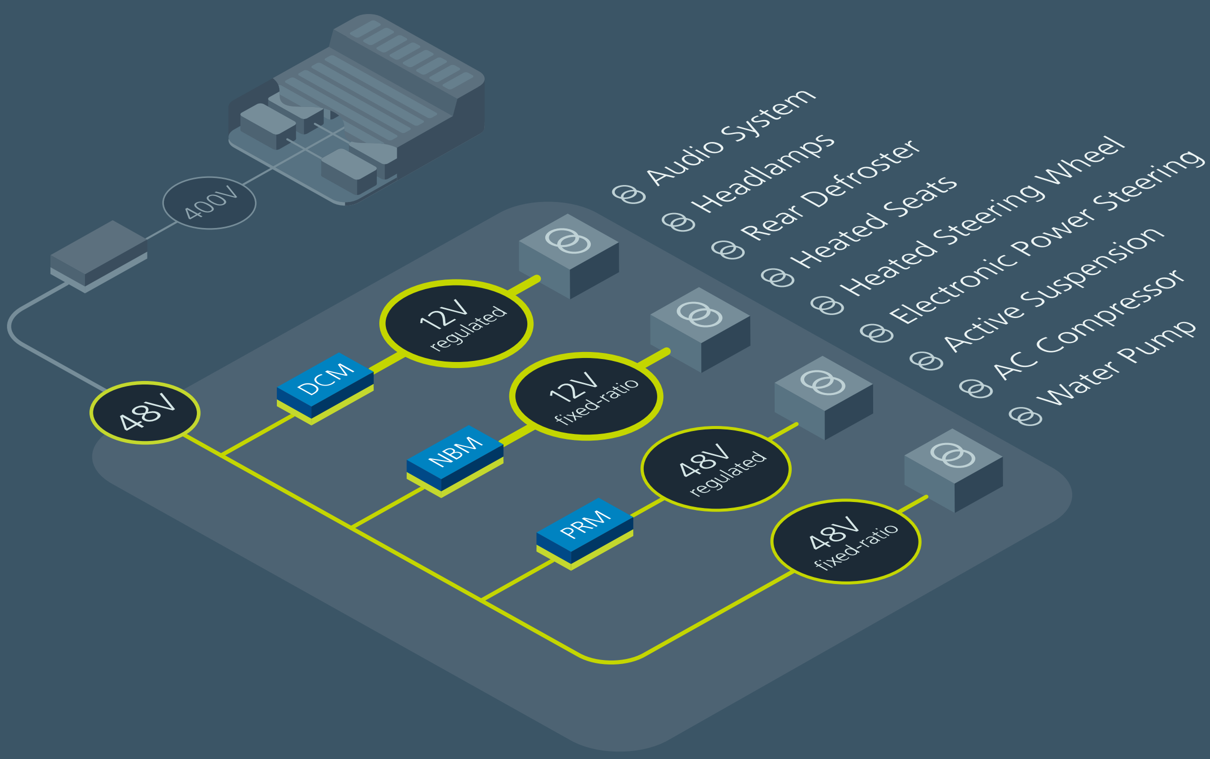
Vicor bidirectional DC-DC converters allow power to be routed through the car at 48V, then converted to 12V at the load.

The modules' extremely high power density allows placement close to loads anywhere within the vehicle, and their small size and weight bring great scalability and flexibility benefits. They can be paralleled for N+1 redundancy or to power new features.The key benefits were:

- Weight saved on cables and harnesses
- Heating and losses in the cables reduced
- Thermal dissipation was further mitigated as conversion heating was delivered around the vehicle

Vicor DCMs and NBMs for greatest flexibility

Vicor products like the DCM™ (DCM3735) non-isolated DC-DC converter or NBM™ (NBM2317) bidirectional non-isolated fixed-ratio converter are far more flexible to work with than hundreds of discrete components. The PRM (PRM3735) can be used to create regulated 48V current where needed. A discrete solution adds development time and risk while also consuming more space and weight than a modular approach.

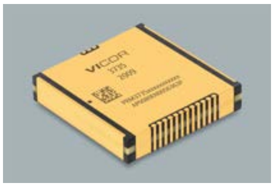


DCM regulator module

Input: 48V (35 – 58V)
Output: 12V (8 – 16V)
Power: 2kW
Peak efficiency: Up to 96.5%
36.6 x 35.4 x 7.4mm

NBM converter module

Input: 48V (40 – 60V)
Output: 12V (10 – 15V)
Power: 1kW
Peak efficiency: Up to 97.9%
23 x 17 x 5.2mm



PRM regulator module

Input: 48V (31 – 58V)
Output: 48V (36 – 54V)
Power: 2.5kW
Peak efficiency: Up to 99%
36.6 x 35.4 x 7.4mm

Case study:
Elimination of low-voltage batteries

How using the right converter can eliminate the 48V battery

Customer's challenge

While extracting 48V power from an EV's 400V or 800V traction battery is an attractive proposition, most DC-DC converters cannot replicate a battery's fast slew rate to provide the transient response critical to loads like active suspension, braking or steering systems.

Discrete designs also lack efficiency: a 48V-to-400V DC-DC converter may be just 94% efficient. The key goals were:

- Save space and weight by eliminating the 48V battery
- Match or improve on battery slew rate to meet load transient response requirements
- Improve power efficiency to reduce losses and dissipation

The Vicor solution

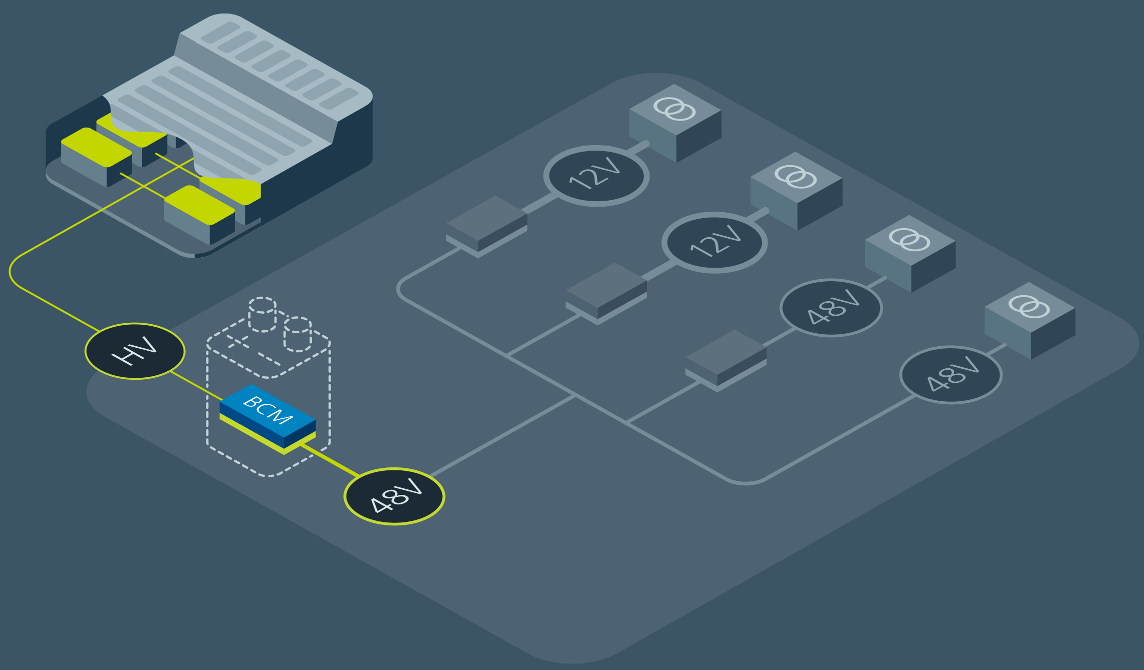
Extensive bench test comparisons show that Vicor modules can respond faster than lead-acid and lithium-ion batteries. A module can switch from zero to full output in 10µs, compared with 30µs for a 12V lead-acid battery.

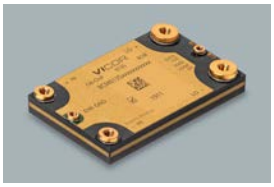
Also, a Vicor BCM® fixed-ratio converter operates at 97% efficiency, a 3% increase over a discrete solution's 94%. This improvement halves energy loss and dissipation.The key benefits were:

- The 48V battery was eliminated, yielding significant space and weight savings
- Vicor modules meet transient response demands for loads like active suspension, braking or steering systems

Vicor modules achieve significant space and weight saving

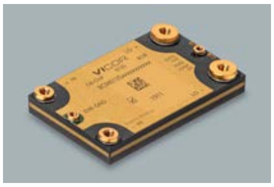
While a Vicor module outperforms the battery that it replaces, it also considerably reduces size and weight. The module eliminates not only the typically 25kg/55lb battery weight, but also the associated cabling. Overall, the Vicor solution in this scenario can eliminate weight and free up vehicle packaging space by 70%.





BCM converter module

Input: 400V (260 – 410V)
Output: 48V (32.5 – 51.3V)
Current: Up to 65A
Peak efficiency: 98.6%
61 x 35 x 7.4mm



BCM converter module

Input: 800V (520 – 920V)
Output: 48V (32.5 – 57.5V)
Current: Up to 80A
Peak efficiency: 98.0%
61 x 35 x 7.4mm

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Case study:
Creating vehicle to charger compatibility

Reduce range anxiety by providing 400V – 800V charging compatibility

Customer's challenge

Range anxiety is inhibiting EV market growth; while more charging networks are appearing, they present compatibility challenges. Drivers frequently encounter chargers incompatible with their 400V or 800V batteries.

Onboard systems that handle both 400V and 800V could resolve this, but such systems could significantly increase size, weight and cooling demands. The key goals were:

- Help OEMs to reduce their customers' range anxiety
- Find a solution to support both 400V and 800V without onerous increases in size, weight and cooling demand
- Support fast chargers with power levels of 50 – 150kW

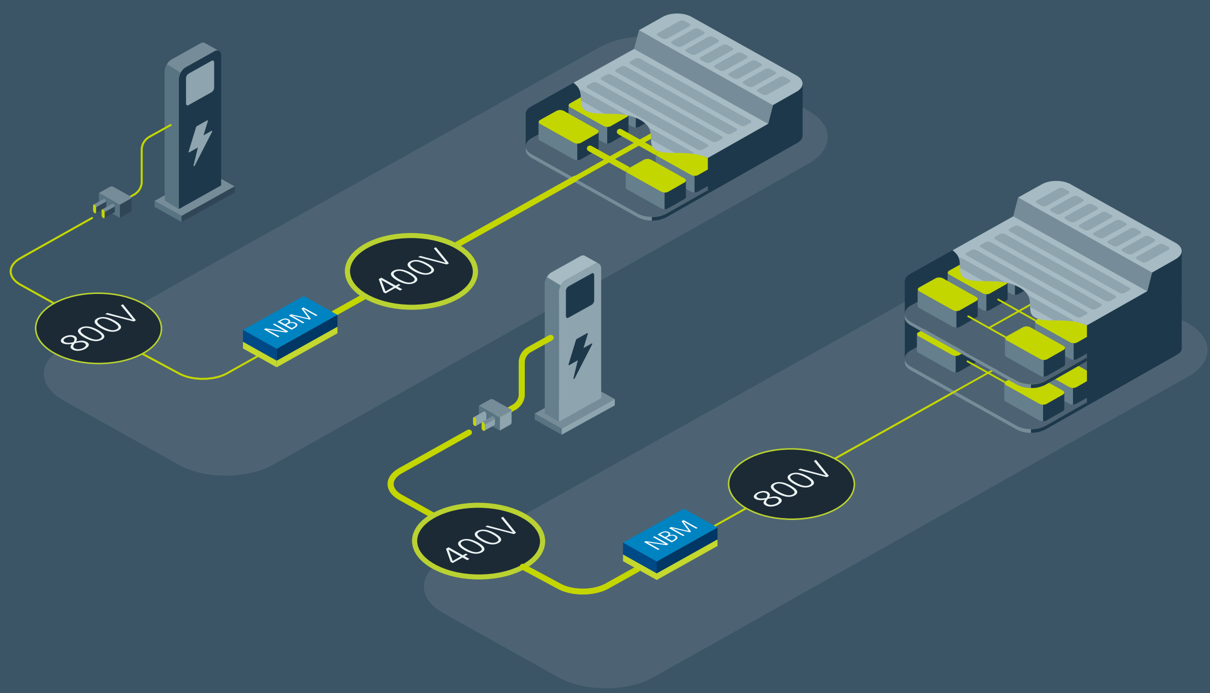
The Vicor solution

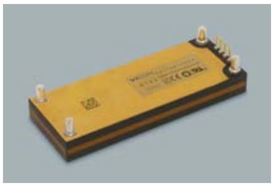
The Vicor NBM™ bidirectional non-isolated fixed-ratio converters provide a universal solution. These compact modules take up less than half the space of most discrete designs while being almost 99% efficient. One module, for example, can handle 30kW; up to four more can easily be added, to create an array of five modules delivering 150kW. The key benefits were:

- These bidirectional modules can be used in both 400V and 800V EVs
- Single part qualification covers both 400V and 800V EVs
- Reduction of consumers' range anxiety without adding considerable weight or taking up valuable space

The Vicor bidirectional NBM modular converter provides flexibility with power

Vicor NBM high-efficiency, high-power-density, low-size and low-weight bidirectional modules convert tens of kilowatts of power reaching 550kW/litre and 130kW/kg in power density, using power converters at least 50% smaller and lighter than discrete solutions. Their proprietary Vicor SAC™ topology reaches 99% efficiency.





NBM converter module

Input: 800V (400 – 920V)

Output: 400V (200 – 460V)

Current: Up to 16A

Peak efficiency: Up to 99.3%

61 x 23 x 7.4mm

Articles

Article by Patrick Wadden, VP of Automotive Business Development

The race to automotive electrification: what it takes to win

VICOR

"If everything seems under control, you're just not going fast enough" —Mario Andretti

For years, automakers have been continuously challenged with the need for more power. In the early days, cars were powered with a six-volt battery right up to the mid 1950s when automotive systems evolved to a 12V power source to meet the perpetual need for more power. Not only did automakers have to anticipate new power delivery demands for windows, steering and seats, but the need for more power was pivotal for the new high-compression engines.

In recent times, CO_2 emission compliance standards have motivated OEMs to reconsider how to power the automobile again. While OEMs are introducing electrified vehicles to meet these standards, there has yet to emerge a harmonized approach for delivering electric power, not only to the motors but to all the subsystems in a vehicle.

This lack of clarity is compounded by the tremendous increase in power requirements. Automobiles with combustion engines typically operate with an electric power level between 600W to 3kW. New electrified EV, HEV, PHEV vehicles (xEV) require power levels of 3kW to over 60kW – more than 5 – 20 times the power.

That 5 – 20x increase puts tremendous strain on vehicles in terms of increased size, weight, and complexity of the power delivery network (PDN). These demands negatively impact energy efficiency, reliability and even comfort and safety as the added size and weight necessitate tradeoffs in vehicle features. There simply isn't enough space to accommodate all the electrical requirements if car manufacturers proceed with traditional methods of power delivery. To meet this challenge they will need to find a solution that is not only lightweight and compact to mitigate the enormous increase in power, but is also flexible and can be reused across the fleet.

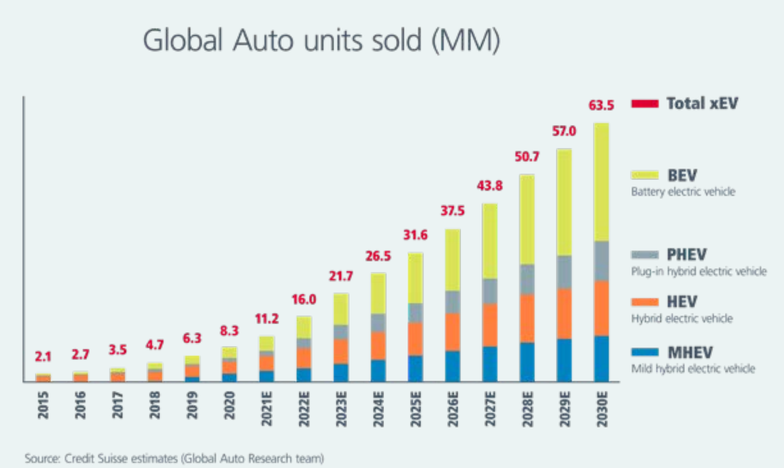


Figure 1: By 2030, Battery Electric Vehicles (BEV) will account for 45% of all xEVs

In addition to the major technical challenges, OEMs are also ratcheting up the pressure and making commitments to fully electrify their fleets over the next decade (Figure 1), even while the specifics of how to achieve the goal remains an open question. There is no clear path to standardizing electrification across the electric vehicle market. So while OEMs will likely all arrive at the same place, the PDNs they design will be different.

Fueling the electrification momentum

For many years, EV production volumes were less than 1% of the overall vehicle production output worldwide. According to the Credit Suisse Global Auto Research team, that will soar from 11% in 2020 to 62% in 2030, topping out at 63 million vehicles worldwide. Of those, nearly half, 29 million are expected to be fully electric.

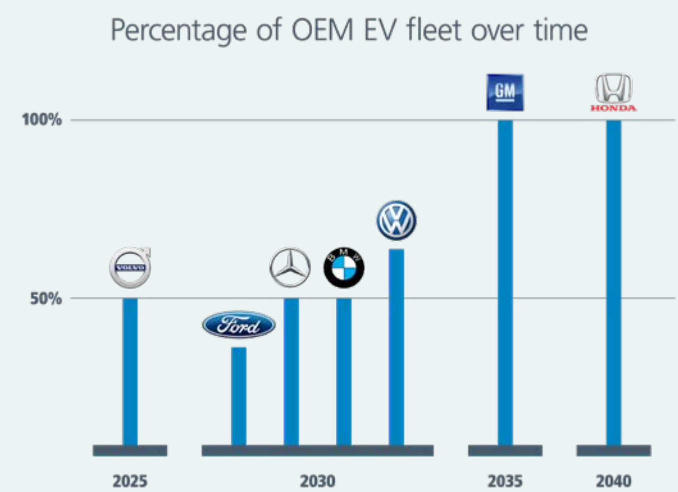


Figure 2: OEMs have set aggressive goals to electrify their fleets. These goals are catalysts for creating a world-class xEV platform.

What is driving the explosive growth in electrified vehicles? While emissions compliance and government incentives started this ball rolling, it is consumer desire that is building the steep demand as OEMs are moving the electric vehicle from niche to mainstream. These OEMs are now making bold commitments (Figure 2).

OEMs are now electrifying some of the most popular and beloved vehicles. GM Hummers, the new Ford Mach E (the electric Mustang) and now the flagship F150 Light-Duty Truck (Lightning) are being electrified. These models are drawing attention from the masses because of impressive performance enhancements and sleek designs.

These new vehicles, with improved fast-charging technology and lower maintenance and repair costs, are the catalysts driving consumer demand and increasing the adoption of electric vehicles. Consumers see value and momentum is therefore growing.

High-stakes, high-performance electrification challenge

The number of vehicle platforms, consumer options, varying powertrain architectures and choice of battery and charging configurations all add to the complexity power system designers have to address as they work to electrify automotive fleets.

To optimize vehicle electrification, OEMs need to enhance power levels, decrease power delivery network size and weight and provide better thermal management and reusability. The traditional way of designing power systems must transition from complex customized discrete-based design to a smaller, more flexible, easier-to-use, higher-density modular solution.

Accelerating electrification

To achieve their aggressive electrification goals, OEMs will need to reconsider their approach to power delivery architectures. In addition to finding a highly efficient solution, to accelerate and optimize electrification three top requirements need to be addressed.

- Power density: Whether designing a fast sports car, a light-duty truck or a family car, OEMs need to pack as much power as possible into a constrained space. Vehicles need compact and efficient power solutions.
- Flexibility / Scalability: Fleets have many vehicles using the same platform, so easy power scaling is essential when modifying the power between sedans, minivans, SUVs, etc. that share the same platform.
- Reusability: To achieve full fleet electrification, OEMs need to be able to reuse power designs across different models to speed time-to-market.

Power Density

The size and weight of power electronics used in various xEV platforms have a direct bearing on vehicle performance, energy efficiency and battery range. OEMs are aggressively reducing the size and weight of their power electronics in an effort to go further and faster and R&D teams are incentivized to reduce vehicle weight.

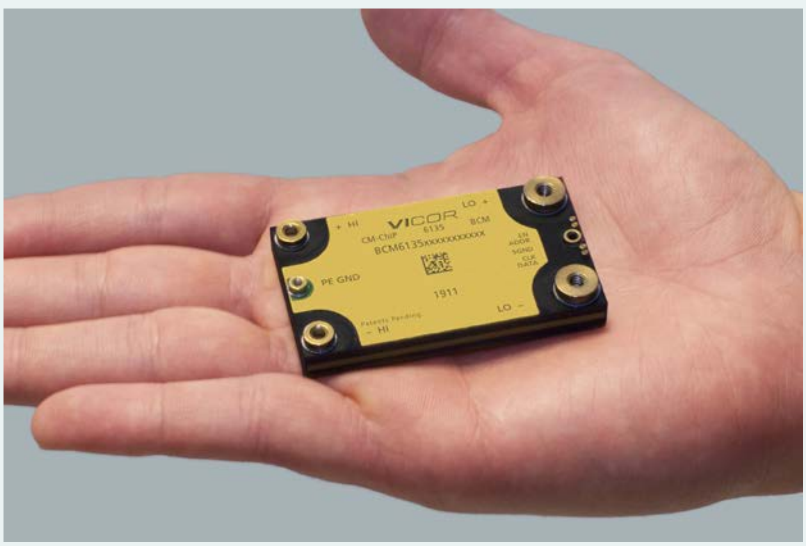


Figure 3: Reduced size and weight of the power delivery network are essential factors for the next generation of xEV platform. For example, 2.5kW of power from the Vicor BCM6135 can be held in the palm of your hand.

A small, 98% efficient bus converter module weighing only 68g from Vicor (BCM6135) can be bundled easily with EMI filtering, a reduced cooling structure and an enclosure to replace the 25kg 48V battery. This frees up considerable space and weight and can yield €125 – €250 in R&D weight reduction incentives. The high-density power module converts the main 400 – 800V battery to 48V in a small 61 x 35 x 7mm package capable of delivering over 2kW of power with a power density of >4.3kW/in.3 (Figure 3).

Flexibility/Scalability

OEM designers try to standardize the subsystems integrated within a vehicle as much as possible to save time, money and resources. However, each varies slightly with vehicle trim levels requiring multiple designs. Because of vehicle electrification advancements, power system design teams are challenged with changing power delivery requirements. The flexible and scalable modular power system design approach offered by Vicor allows designers to implement standardized solutions across a wide variety of powertrains such as SUV, minivan or light-duty trucks.

For example, a minivan's power requirements may be 5kW, but powering a light-duty truck with lightbars, tow and plow packages and AC power stations may require 10kW. Using the same platform and a little extra space, engineers can quickly add or remove prequalified parts to the array to scale power up or down.

Modularity also offers additional levels of flexibility by enabling distributed power architectures from a 48V bus. Power modules can be placed in convenient locations for localized 48V/12V conversion – behind the glove compartment, near the trunk or by each wheel. Deploying a modular solution delivers not only design flexibility, but a better way to streamline power changes and the manufacturing process.

Figure 4: The impact of modularity is best illustrated by the fact that four power-dense modules can be combined in over 300 different ways to support varying power needs and a many different kinds of loads.

Reusability

One of the most common delays in vehicle development is the qualification and approval of electronic components used in the vehicle. Sometimes the process can take up to two to three years to qualify and PPAP a single component. R&D teams look for ways to reuse what they have to save development and qualification time, conserving valuable resources.

For example, a traditional PDN based on a discrete DC-DC converter design can consist of over 200 bulky components, whereas Vicor advanced technology provides a single high-density power module. The time savings for an engineering design team is significant when qualification is required for one module versus 200+ individual components for the same function.

Additionally, the Vicor modular approach allows engineers to achieve approximately 300 combinations of power delivery by using just three to four scalable building-block modules of various types (Figure 4). This design approach amounts to hundreds of hours of time and resource savings, allowing OEMs get out in front in the electrification race.

The final lap

OEMs are facing daunting challenges not just to cross the electrification finish line, but also to finish with an xEV fleet that will deliver long-term results. Utilizing a modular power system design approach can provide a competitive advantage in this critical market-share race. Innovation is needed now in the form of new architectures and topologies that deliver the highest performance today and also can be re-used and reconfigured for the future.

Conventional power designs cannot meet this level of flexibility and ease-of-use. The best way for OEMs to meet their aggressive electrification goals is to adopt a modular approach that delivers the highest performance on a number of critical levels, and enables them to meet the most complex xEV power demands.

About the Author

Patrick Wadden is the Global Vice President of Automotive Business Development for Vicor Corp. Vicor Corporation, the leader in high-performance power modules, solves the toughest power challenges for our customers, enabling them to innovate F re-useablilityand maximize system performance. Our easy-to-deploy power modules provide the highest density and efficiency enabling advanced power delivery networks from the power source to the point-of-load. Headquartered in Andover, Massachusetts, Vicor serves customers worldwide with unequaled power conversion and power delivery technologies.

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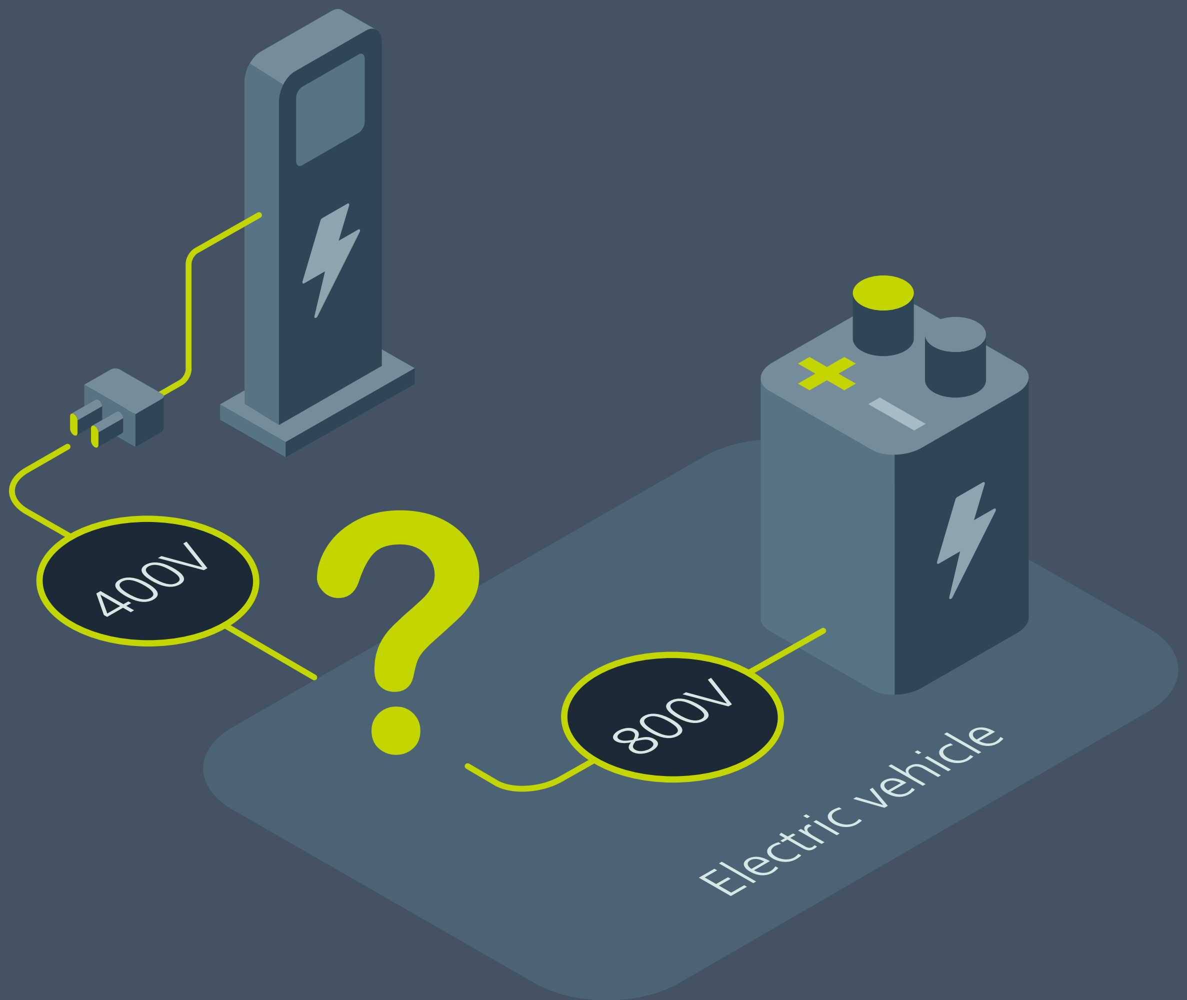

Article by Haris Muhedinovic,
Senior Field Application Engineer

Preparing the way ahead for a compatible EV infrastructure

VICOR

Charge anxiety is on the rise as today's EVs are increasing the primary battery voltage from 400 to 800V, even though public infrastructure is not adequate to support 800VDC fast charging. Upgrading the charging station infrastructure is not a tenable short-term solution. A faster, more holistic approach is an onboard conversion solution which enables 400 or 800V compatibility. This approach can be adopted without significant capital investment and is a far easier execution.

DC fast-charging incompatibility

The incompatibility problem is focused on DC charging, which is commonly used for long-range driving where time and access are limited. AC charging for everyday charging is not an issue because the existing grid infrastructure AC charging is fairly convenient. This type of charging is readily accessible to people who own EVs and can charge at home (overnight) or work (daytime) where charging speed is not critical. AC charging is ideal for daily use and short-range driving, and it is the cheapest and most practical solution for daily trips up to 300km.

When people are traveling long distances, however, they need to charge quickly and in public places, such as at a highway rest stop. In those cases, they can use DC fast charging stations. These stations require more than 50kW of power, reaching 150kW or 350kW at peak. While DC charging may be used less frequently than AC charging, it is very important to have a solid network of this type to reduce range anxiety. In 2020, the DC charging network totaled around 400,000 publicly-accessible fast chargers, with few of these supporting 800V vehicles. For example, in Europe, only 400 of 40,000 total charging stations support 800V vehicles.

This imbalance between 400V and 800V charging stations presents a significant problem as OEMs begin rolling out new 800V vehicles: the public infrastructure to charge them is inadequate.

Exploring the DC fast-charging solutions

Broadly speaking, there are two approaches to solving DC fast-charging problem: one focuses on making changes to the charging stations, the other on making changes to the vehicle.

Expanding the DC fast-charging network of charging stations can alleviate this problem, but it may not be the most expeditious nor cost-effective. There are two ways to expand the DC fast-charging network:

- Adding 800V stations: installing new DC fast-charging stations with wide-voltage capability (from 250 to 920V) is one solution, but it requires considerable investment in time and money. Today there are approximately 1,000 charging stations in Europe and USA that offer 800V charging, which accounts for only about 2% of all available DC charging stations. To address the growth of 800V EVs, that network would need to expand to hundreds more stations. Installing that many new stations will take years and be cost-prohibitive.
- Utilizing 400V stations: another approach is to leverage the 400V stations and upgrade them to also support 800V, but this presents its own set of challenges. Charging at ultra-high-power rates (>150kW) is not always available and not always possible (temperature, battery degradation, etc.). Also, charging times would be slower than desired for 800V.

Onboard charging with a modular DC-DC virtual battery offers flexibility and 99% efficiency. In contrast to expanding the charging network, onboard conversion solutions are a more holistic approach to enable 400 or 800V compatibility. This approach can be adopted much more quickly and with no capital investment in charging infrastructure.

The incompatibility between 800V batteries and 400V chargers can be solved through "battery virtualization." With battery virtualization, the charger "sees" a 400V battery on one side of the onboard charger even while the 800V battery is connected to the other side. This approach starts from the battery voltage and adapts it to the voltage range acceptable by charging station (Figure 1).

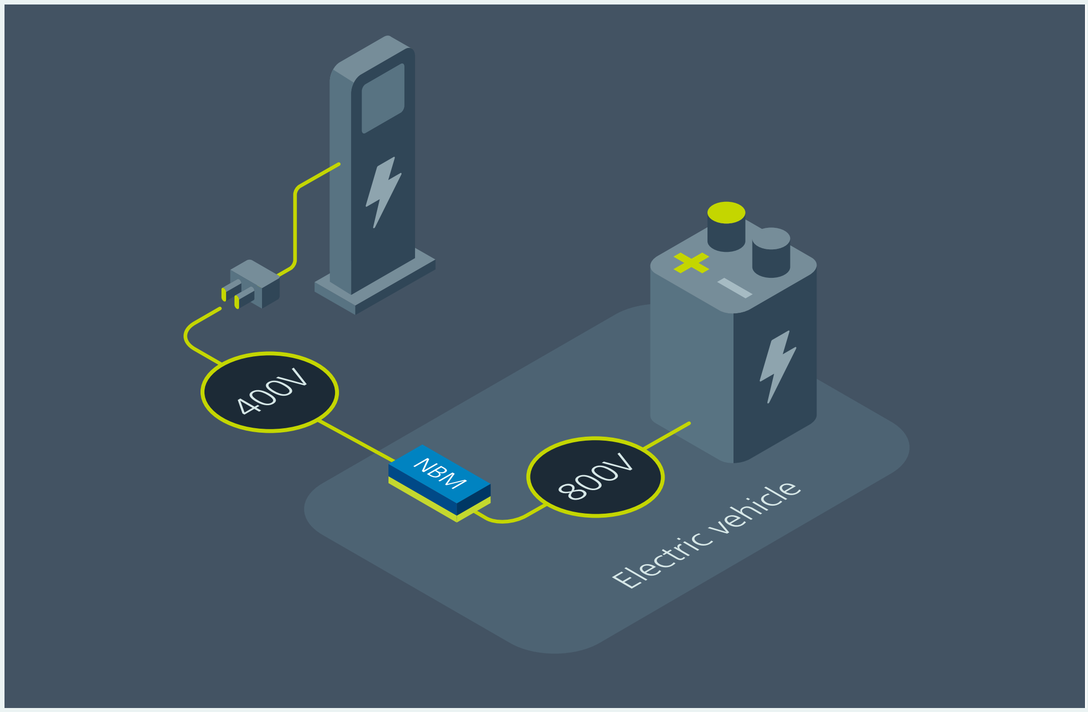

Figure 1: The incompatibility between 800V batteries and 400V chargers can be solved through "battery virtualization." With battery virtualization, the charger "sees" a 400V battery on one side of the onboard charger even while the 800V battery is connected to the other side.

This approach starts from the battery voltage and adapts it to the voltage range acceptable by charging station.

Vicor high-density, high-power modules can be used to implement a DC-DC converter onboard charging solution for battery virtualization without adding size, weight and design complexity.

Vicor NBM™ bidirectional modules convert tens of kW of power reaching 550kW/liter and 130kW/kg in power density, using power converters at least 50% smaller and lighter than discrete solutions. The Vicor proprietary SAC™ (Sine Amplitude Converter) topology ensures soft switching on primary and secondary sides, reaching 99% efficiency. This behavior implies simple EMC design and offers flexible cooling management (Figure 2).

Figure 2: Vicor NBM bidirectional modules convert tens of kW of power reaching 550kW/litre and 130kW/kg in power density, using power converters at least 50% smaller and lighter than discrete solutions.

Connecting a battery to one side of an NBM module will immediately virtualize a battery on the other side, dividing or multiplying the voltage or current by constant factor. Ultimately, NBM modules extend the voltage range of charging stations (250 to 460V to 500 to 920V), thus increasing the number of overall available charging points and making an EV compatible with any DC charging station.

Flawless powertrain design and a high-bandwidth controller enable this battery virtualization. Vicor packaging technology not only simplifies assembly and manufacturing but also offers flexibility and scalability of power. OEMs can configure scalable packages of charging power from 50 to 150kW using the same module without need for additional qualification and certifications.

Another reason to use power modules

Not only does the NBM have the capacity to offer battery virtualization for charging, it can also integrate with the traction battery to deliver higher efficiency for low-RPM driving. For example, city driving requires lower RPMs and the 800V traction inverter efficiency falls drastically by more than 15%. The NBM can be used in this ancillary manner to supply the inverter with half of the battery voltage, cutting switching losses in half and extending driving range. This is another advantage of how an integrated, modular approach to power can optimize the power delivery network, enabling partial utilization of the DC-DC converter to maintain peak efficiency.

Eliminate range anxiety before starting up by using onboard boost conversion

While charging station infrastructure will certainly expand to support the growth of EVs, expansion alone will not resolve the 400V/800V compatibility problem. The most impactful solution to reduce range anxiety is to design onboard chargers that are compatible with any DC fast charger.

The Vicor onboard solution using high performance power modules enables full compatibility between 800V/400V vehicles and DC charging networks with minimal investment and maximum benefit. On average, the Vicor solution is half the size and weight of most discrete solutions and delivers very high efficiency and scalability. It can convert tens of kW of power reaching 550kW/liter and 130kW/kg in power density. The combination of high power density, flexibility and high efficiency make Vicor power modules an ideal onboard solution to solve 400V/800V EV charging compatibility problem.

About the Author

Haris Muhedinovic works with OEMs and TIERs to design and develop highest performance power solutions for most demanding automotive applications. With his interest in power electronics and electronics systems, Haris is aware of new technologies and trends in industry, which allows him to implement power solutions to meet the most demanding specifications. Haris received his MSc from the University of Sarajevo and has 7 years of experience in power electronics in design and application engineering.

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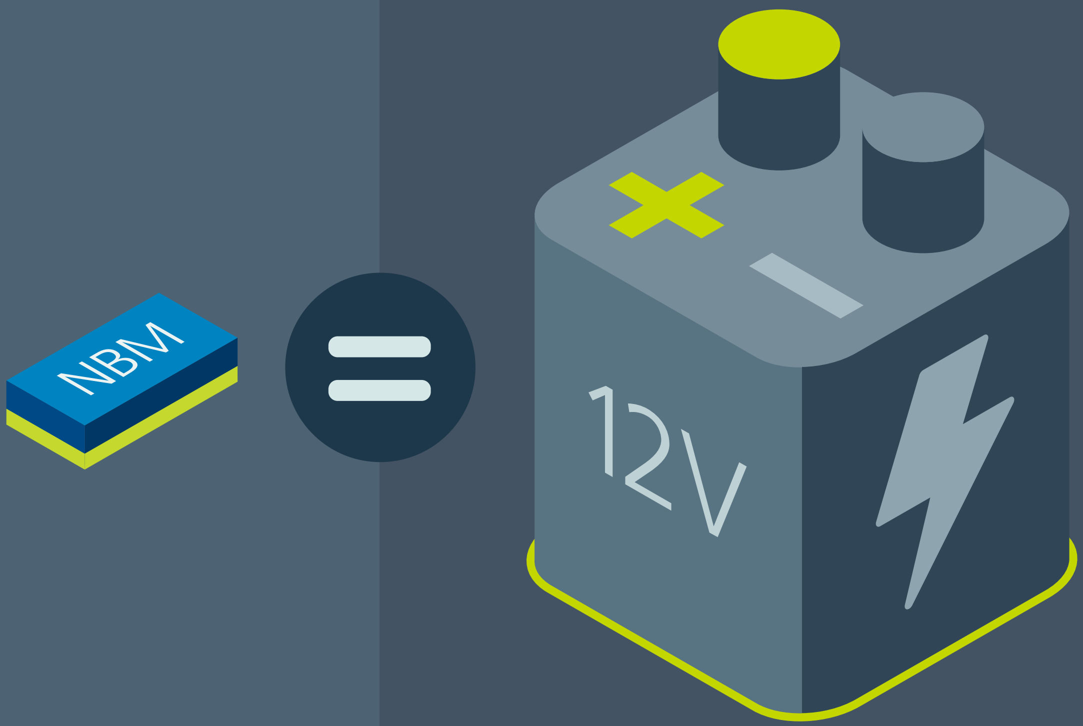

Article by Pat Kowalyk,
North American Automotive Principal Field Applications Engineer

Eliminate the 12V battery and increase EV performance

VICOR

A modular power approach allows one to far exceed the slew rate—the transient response—of a 12V lead-acid battery by 3x.

Power module transient response is 3x faster than 12V battery

With EV power demands on the rise (going from 3kW to over 50kW) it is time to take a fresh look at how to best deliver the power needed rather than trying to retrofit the internal combustion engine (ICE) power delivery architecture. Today's BEVs are already have a primary battery (800V or 400V), so why a 12V battery needed? It's not, provided you can replace its functionality as a power reservoir by achieving transient response speeds equal to or better than 250A/m. Vicor power modules deliver 3X faster transient response than a 12V battery.

The simple answer is that many automotive systems, especially safety systems, must respond quickly to sudden changes in power, and batteries historically have much better response times than DC-DC power converters. Until recently, power systems engineers have not had options for safely and reliably converting 800V or 400V down to 48V or even 12V with a fast transient response and without adding unwanted volume or weight.

Additionally new EV's consume up to 20x more power (going from 3kW to over 50kW) than combustion engines which puts significant strain on the power delivery network, when using hard switching DC-DC converter topologies, resulting in a hefty increase in conventional power electronics that consume space, increase weight and limit range.

Because of EV power requirements, it is time to take a fresh look at how to best deliver the power needed rather than trying to retrofit the internal combustion engine (ICE) power delivery architecture. Using traditional DC-DC power converters EVs cannot handle the associated ~20x increase in power without making performance and functionality compromises which diminish their appeal. This fresh look is not a light remodeling exercise. It is a knock-down and rebuild project that needs to be explored through the lens of innovation, not convention.

The conventional progress achieved toward electrification has been driven by adding more and higher-powered batteries to cars. These batteries are heavy and large. The latest models are touting 800V batteries, but the same vehicle is also hauling a 12V and maybe even a 48V battery. With package space and weight at a premium, three batteries is inefficient and unnecessary.

Where conventional approaches add batteries, a fresh, innovative approach removes a battery, frees package space and reduces weight, all while increasing much need power transient response.

The end of the road for 12V batteries?

High-performance power conversion is essential to removing a battery. More specifically, faster transient response from a converter is the most important variable. If a high-performance power converter can deliver the rapid response equal to or better than a 12V battery (250A/ms), then removing the 12V battery and its associated weight and packing space becomes plausible.

The most essential role of the 12V battery has been to provide a reservoir of power for loads that require a lot of power. The typical load in a vehicle will have two types of current draw—one for start-and one for steady-state operation. When power is initially applied to a particular load, either raw power is applied or the power is already present and only an enable signal is needed.

The loads that use raw power will draw a large amount of current either to charge a capacitor or to turn an armature. Then, after the load is energized (start-up), the current drops down and the load operates continuously (steady state). This initial current draw is what makes the battery a good option for a legacy ICE vehicle, but not for an EV where weight dramatically impacts range and performance. So it makes sense to eliminate the heavy lead-acid or lithium 12V battery and replace it with a lighter, compact and high-performance DC-DC converter that delivers very fast transient response.

12V battery vs. high-performance power modules

Replacing the 12V battery in a vehicle with a traditional converter may cause the load voltage to drop low enough that the load turns off, thus causing a reboot in a vehicle. A key parameter to look at is the load voltage deviation during a change in current relative to time. This is referred to as the transient response; the lower the voltage deviation, the higher the performance of the system.

When designing a new electric vehicle, one needs to consider a great number of new high-tech solutions. A modular power approach combined with topologies like the proprietary Vicor Sine Amplitude Converter (SAC™) allows one to far exceed the slew rate—the transient response—of a 12V lead-acid battery. A modular approach leveraging SAC can process thousands of amperes from the high voltage battery to the load eliminating any dips or loads falling out of regulation. Bench testing shows that modular power can deliver a response three times faster than a typical 12V battery (Figure 1) .

Automobile manufacturers typically require 250A/ms for their fastest loads, which 12V batteries can achieve(75A/30µs). The Vicor modular approach can provide faster transient response (75A/10µs), creating a "virtual battery" that responds three times faster than 12V.

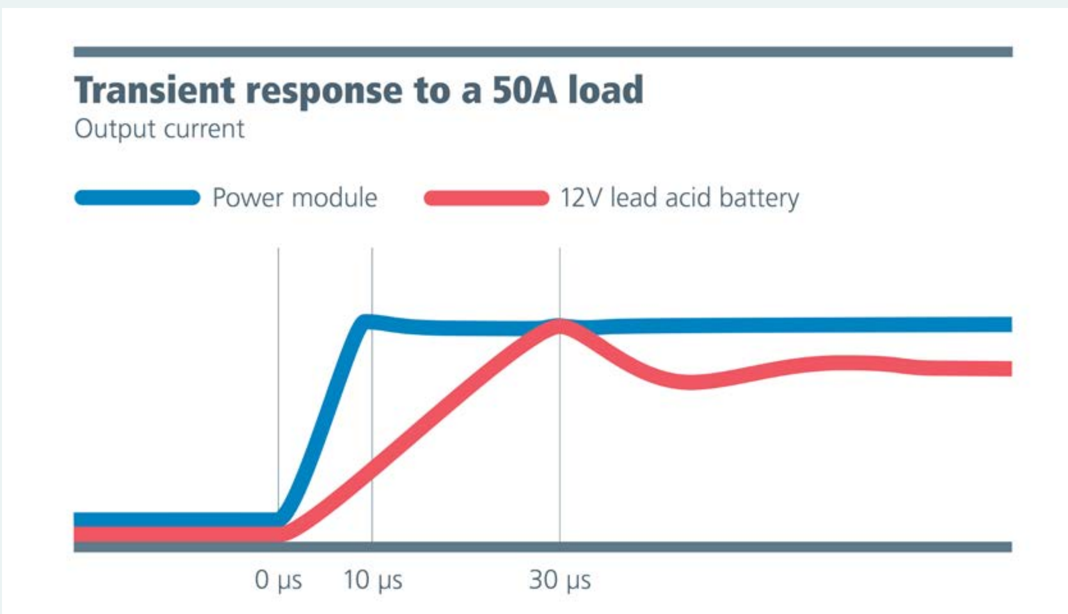

Figure 1: Transient test comparison: 48V-to-12V at 75A compared to a 12V battery. The NBM2317 power module response to a 50A load is three times faster than a standard 12V battery.

Replacing 12V battery with a faster, lighter and smaller high-performance power converter

Modular power combined with SAC is part of what makes this solution optimal for automotive power. The SAC has a turns ratio, called the K-factor that is a ratio of the primary to secondary turns. A key advantage of this topology is that any primary-side capacitance is multiplied by the K-factor squared. For a 12V-to-48V conversion, the K-factor is ¼, which means the effective secondary capacitance is four squared, or 16 times the primary capacitance.

The Vicor NBM is an ideal converter to transfer the energy load from a mechanical source, which is on all the time, to an electrical source of energy that cycles on and off, allowing better control and better efficiency. The NBM in conjunction with the SAC allows an engineer to create a virtual battery that replicates the essential properties of a physical battery, complete with all the benefits of a battery but without the weight, size or temperature limitations of a battery (Figure 2).

Power source	di/dt
660CCA, 12V car battery	75A/30µs
48V to 12V SAC at 80A	75A/10µs

Figure 2: Bench testing shows that modular power can deliver a response three times faster than a typical 12V battery.

Using a modular approach allows the designer to split the power source into different zones. Instead of having one centralized power architecture, the designer can place an NBM in the dashboard, in the trunk and or by all four wheels. Having the power source closer to the load reduces parasitic inductances and series resistances for a high-performing power system. The same approach also applies to HV-to-48V conversion which would show similar performance, creating a 48V virtual battery (Figure 3).

Figure 3: Vicor power modules bundled with EMI filtering, minimal components and an enclosure could replace a 12V lead-acid or lithium-ion battery eliminating 15 – 40lbs of weight.

It makes sense to use the traction motor battery which is the largest energy source in the vehicle to down-convert to different safe voltages. Typically, the traction motor battery in an electric vehicle is either 400V or 800V and will be quickly replaced with 1,200V_{DC} or 1,400V_{DC}.

A modular approach eliminates any internal series inductance on the input or output and can process easily 700,000 amperes per second or 700 amperes per millisecond. It can be easily be paralleled in an array to create a large power-processing system and has isolation from any primary bus voltages which are 60V or higher.

The NBM™ in theory is only thermally limited in terms of its power capability and if properly cooled it can process very high amount of power. It provides the added benefit of bidirectional operation and can start up in either direction.

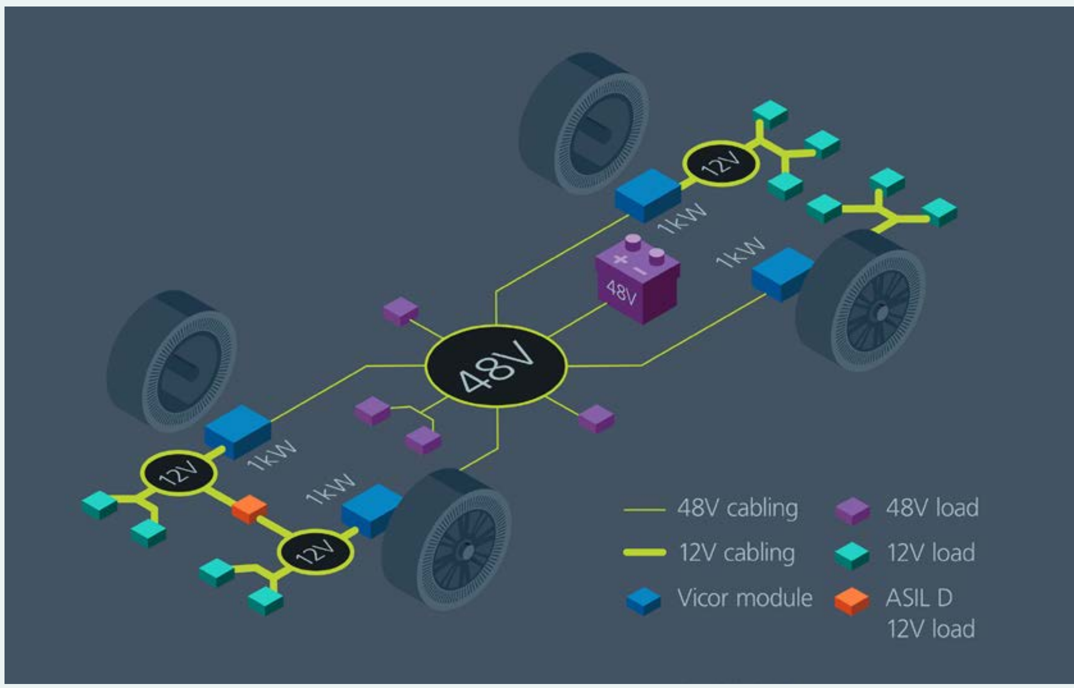

Figure 4: A Decentralized architecture offers more design flexibility and can reduce the cable and harnessing weight in the vehicle, freeing space and extending range.

Revolutionize your electrification with modular power

In this new age of electrification, OEMs will benefit from taking a fresh look at how cars are electrified. By designing the power delivery network from the ground up and considering all of the vehicles' electrical needs, you can derive far more benefits and deliver far greater performance.

In short, by switching to modular power you can eliminate the 12V battery and achieve enhanced transient response, decreased weight and additional package space—all of which contribute to extended range and better overall performance.

About the Author

Patrick Kowalyk has been solving power delivery issues for over 20 years with Vicor's innovative, high power, high density and high efficiency solutions. Patrick is the lead Automotive Principal Field Applications Engineer for Vicor in North America, helping power engineers architect new Automotive power delivery systems. He has a BS in Electrical Engineering from Illinois Institute of Technology.

Article by Nicolas Richard,
Director Automotive Business Development, Vicor Europe

Is the 12V lead-acid battery dead?

VICOR

Yes, the 12V lead-acid car battery is dead. Europe has decreed that no new cars will have lead-acid batteries after 2030, creating a considerable challenge for OEMs to find alternative solutions. While this may seem like a daunting task, it also presents a tremendous opportunity to eliminate the environmentally toxic battery while also reducing weight in a vehicle and improving overall efficiency.

The 12V battery and power delivery network (PDN) are standard across the globe, supporting hundreds of loads, including some critically related to safety, so the solution will need to be both innovative and robust. High-density, high-power and efficient power modules used to interconnect high-voltage, 48V and 12V PDNs offer the most flexible and scalable solution to this impending challenge.

When considering potential solutions, OEMs must take into account a number of key factors: adding more power to support new features with better performance, increasing efficiency for longer range and better thermal management, reducing CO2, optimizing cable routing, reducing harness weight and meeting EMI requirements are some of the variables within this complex equation.

There are two primary options for solving this equation. Replacing the 12V lead-acid battery with a 12V Li-ion battery is one option. While it does slightly reduce weight, it retains the decades-old legacy of the 12V PDN, which yields no additional benefits. The other option is to support a 12V PDN powered from the primary 400V or 800V battery in EV and HEV/PHEV. There are many benefits to the latter option, but both merit further exploration.

Switch to 12V Li-Ion battery

Simply replacing the 12V lead-acid battery with a 12V Li-ion battery saves ~55% weight; however, it has a high cost impact. The 12V Li-ion battery needs a Battery Management System (BMS) to control the charging and maintain the full battery operation over the vehicle life. It is the direction taken for instance by Tesla and Hyundai .

Furthermore, adding a bulky DC-DC converter from HV to 12V (with voltage and current regulation feature) is needed to recharge the 12V Li-Ion battery and supply the electrical loads. But this adds no benefits. What it does add is weight, vehicle packaging complexity, and system cost; it also reduces overall vehicle reliability. By contrast, eliminating the 12V battery altogether removes 13kg from the vehicle and can improve the cargo space by 2.4%.

Legacy 12V PDNs are inefficient

Maintaining a physical 12V battery means maintaining an inefficient PDN with unnecessary redundancy. In a typical automotive 12V PDN, all the 12V loads connected to the 12V bus have internal pre-regulators able to convert wide input voltage range typically from 6 to 16V to regulated rails of 5V, 3.3V or lower. From a global system view for an EV, HEV or PHEV, there is redundancy of series regulator stages. A high-voltage-to-12V DC-DC converter regulates the 12V bus (with efficiency hit) and the pre-regulator provides the suitable internal rail voltage for each load (Figure 1).

This legacy architecture originated when vehicles had an alternator, a sensitive 12V PDN that needed regulation to charge the battery, keep the radio operating during cranking event or maintain incandescent headlights at the right intensity. OEMs were very creative to bypass the 12V power limitation and complex electrical architectures have been designed in recent years with two 12V batteries, one 24V battery for power steering and several DC-DC converters between them.

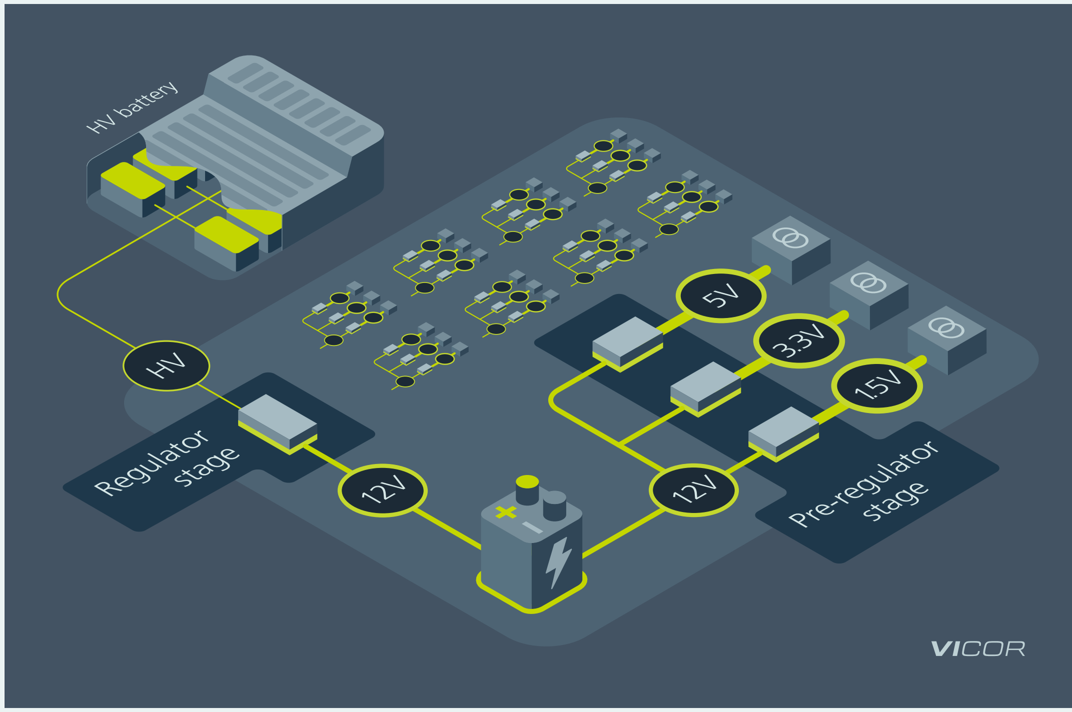

Figure 1: Typical E/E used in xEVs with 12V battery using redundant voltage regulator stages. The HV-to-12V DC-DC regulates the 12V output to charge the 12V battery. Every 12V load in the vehicles has a pre-regulator stage to supply the proper rail voltage needed for the load to operate.

Replacing the 12V with a virtual battery

A better approach to solving this problem is to completely rethink the PDN in a vehicle: eliminate the physical 12V battery and replace it with a 12V "virtual" battery from the primary EV battery (Figure 2). Every EV carries a main battery, so it does not make sense to transport additional energy storage devices. The ideal vehicle architecture would be one high-voltage (HV) battery used to power the powertrain and all the auxiliary loads. Vicor high-density bus converter module technology enables this approach by virtualizing a low-voltage battery (48 or 12V) directly from the HV battery (400 or 800V).

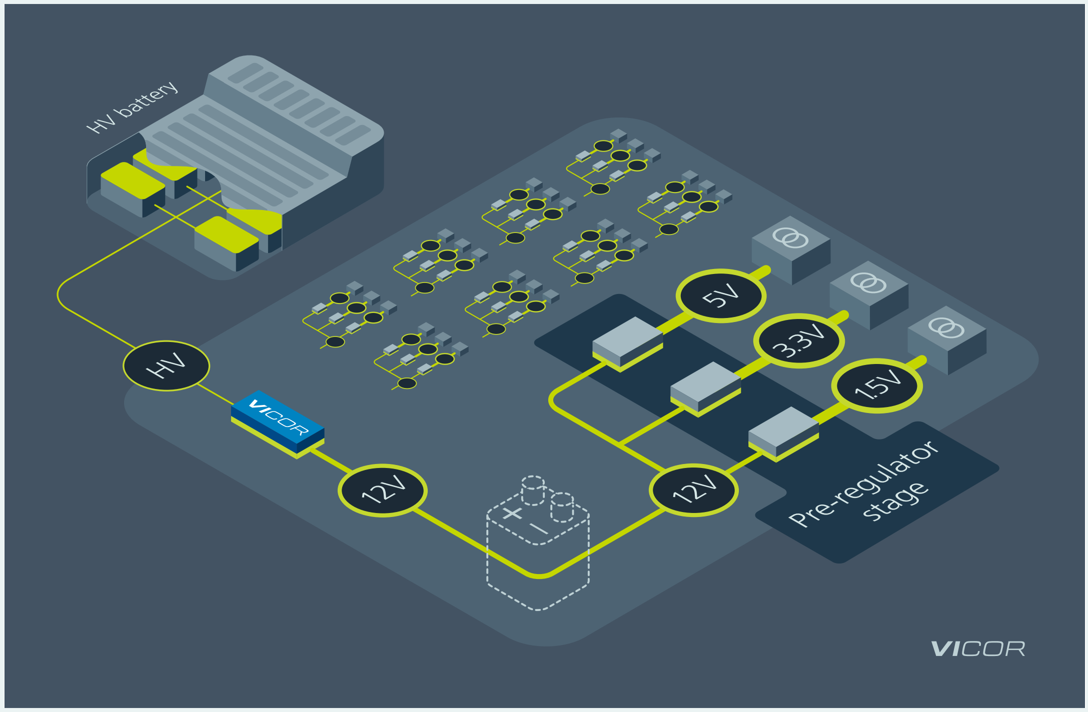

Figure 2: Optimized E/E architecture eliminates the physical 12V battery. A virtual 12V battery is created by transforming the high-voltage battery with Vicor BCM Bus Converter technology.

Utilizing zero-voltage, zero-current switching (ZVS/ZCS), Vicor BCM® Bus Converters operate at higher frequencies than conventional converters making them more responsive than a physical battery. For example, the BCM6135 operates at 1.2MHz and, unlike a conventional ZVS/ZCS resonant converter, the BCM operates within a narrow band frequency (Figure 3). The BCM's high-frequency operation provides a fast response to changes in load currents and a low-impedance path from input to output. Fixed-ratio conversion, bidirectional operation, fast transient response (higher than 8megaamps per second), and a low-impedance path collectively enable the BCM to make HV battery appear like a 48V battery, which we term "transformation." This ability to transform a power source is both the key benefit and key differentiator when compared to conventional converters.

The Vicor BCM operates as a fixed-ratio converter where the output voltage is a fixed fraction of the input voltage. The Vicor BCM6135 converter is isolated and provides 2.5kW of power in a 61 x 35 x 7mm package with over 97% peak efficiency. It can be paralleled easily in an array to deliver even more power.

The fixed-ratio nature of the BCM ensures that the virtual battery will stay within its appropriate operating range. For example, the HV battery is guaranteed to stay between 520 and 920V on an 800V battery-powered electric vehicle. A BCM6135 with 1/16 ratio virtualizes a 48V battery with a voltage range guaranteed to stay between 32.5 and 57.5V. A BCM6135 1/8 ratio could be used for 400V EVs (Figure 3).

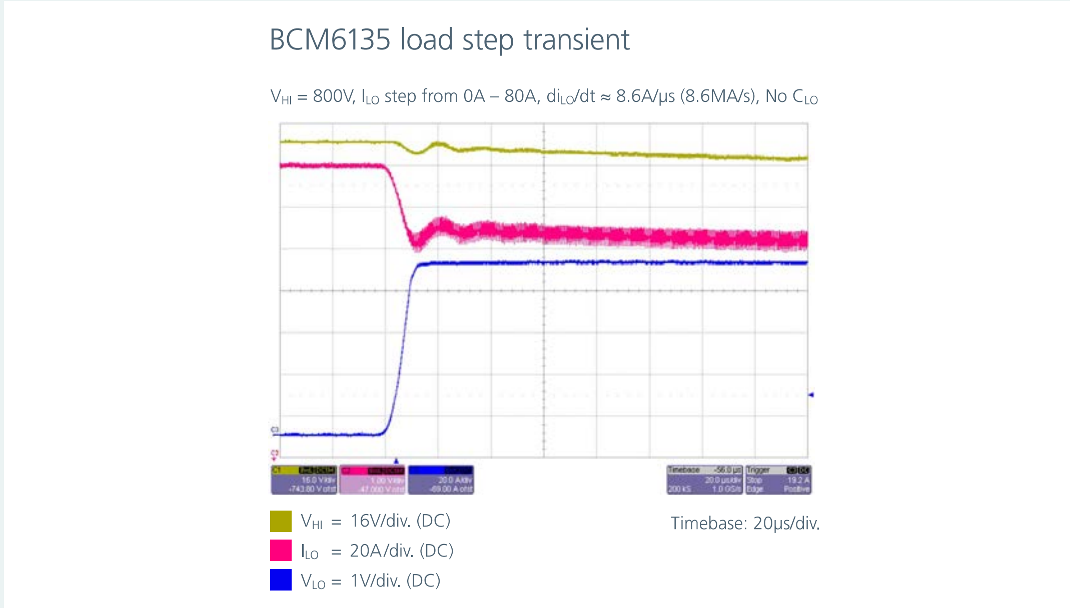

Figure 3: The fast load transient response of BCM6135 is the key to supporting the 12V loads. The transient response is 8 MA/s or 8 million Amperes per second. Yellow : input voltage (800VDC), Red: output voltage (48V), Blue: output current.

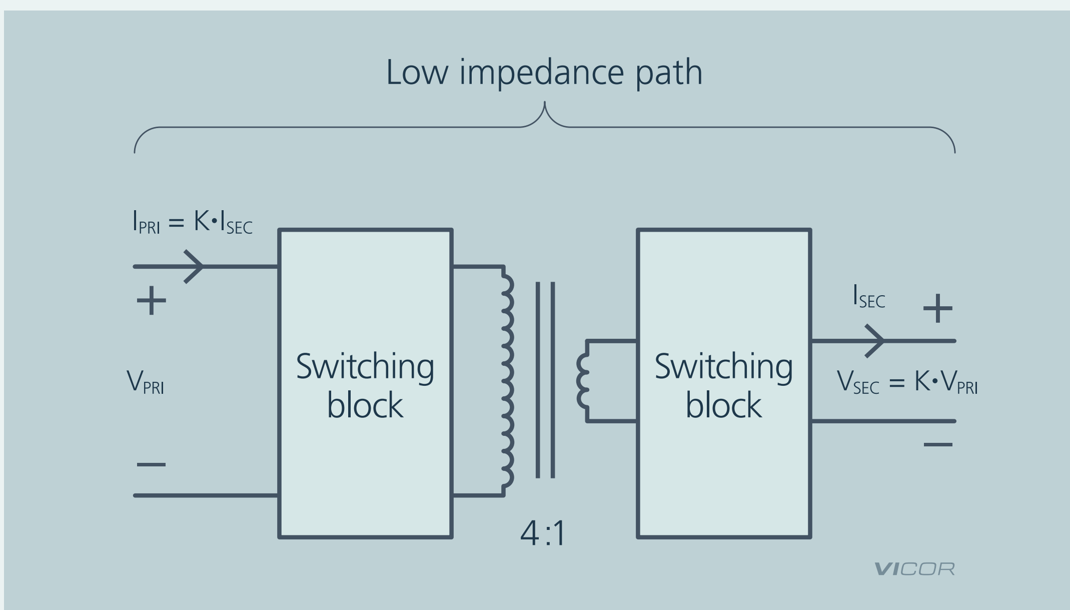

Figure 4: Functional block diagram of BCM Bus Converter. Even though it converts DC to DC, the BCM uses a transformer to convert AC to AC at high efficiency, scaling the magnitude by the K factor and using the switching blocks to convert between AC and DC. The switching is done at a high frequency, and, due to the transformer-like energy transfer the conversion, has a fast response to transient load changes and presents a low-impedance path between input and output.

	800V Battery	48V Bus Range	12V Bus Range
Min Bus Voltage	520V	32.5V	8.125V
Max Bus Voltage	920V	57.5V	14.375V

	400V Battery	48V Bus Range	12V Bus Range
Min Bus Voltage	260V	32.5V	8.125V
Max Bus Voltage	460V	57.5V	14.375V

Table 1: Minimum and maximum voltages on the 48V bus and 12V bus with Vicor BCM/NBM bus converter technology. Both 48V and 12V voltage ranges are VDA 320 and LV 124 compliant.

The battery virtualization can also be extended to the 12V bus with a fixed-ratio converter of 1/4. In that case, galvanic isolation is not required and a Vicor NBM™ Bus Converter could be used. Identical in all other features to a BCM, the NBM non-isolated bus converter has all the same benefits previously described: fast transient response, low impedance, and bidirectional operation. The voltage range on the 12V stays between 8.125 and 14.375V with a fixed ratio to the HV battery voltage. BCM and NBM technology are ideal transformers connecting each of the vehicle power networks.

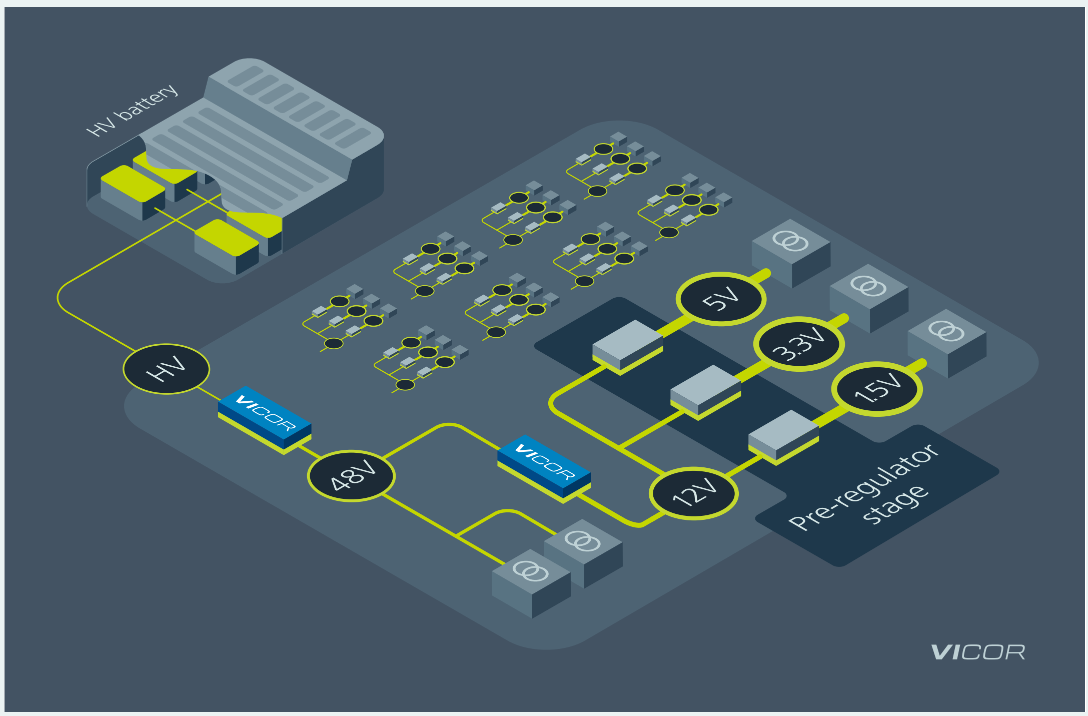

Figure 5: E/E architecture with 12V and 48V battery virtualization based on BCM6135 and NBM2317 modules. The 48V bus also serves as a more efficient source for powering higher loads in a vehicle such as the A/C condenser, water pump and active chassis stabilization systems.

Ensuring redundancy of power delivery for functional safety loads is essential. Because Vicor power modules are fully scalable in power and delivery, they can be designed to act as redundant PDNs enabling functionally safety-critical loads to be supplied with two dedicated power conversion paths. Ultimately, OEMs could implement localized energy storage to ensure functionally safe operating of critical systems such as ADAS, steering and braking.

EV power delivery network at a crossroads

The 12-volt lead-acid battery will soon meet its demise in Europe. And the timing is perfect given all the innovation that is driving the redesign of the EV power delivery network.

The automotive electrical PDN is at a crossroads with 12V power delivery. More and more demanding power loads are being implemented in vehicles while trying to keep architectural changes to a minimum. "What are we still doing at twelve volts? Twelve volts is very much a vestigial voltage, it's certainly low," said Elon Musk, Tesla CEO.

OEMs are scrambling to design better PDNs to deliver more EV range and performance. Eliminating the 12V battery altogether is the obvious long-term solution that reduces weight and space and delivers better transient response and system performance. Vicor technology not only enables these benefits but also offers an unequaled combination of flexibility, scalability and power density. The Vicor module approach to PDNs offers the ideal building blocks to address the near-term challenge of 12V power delivery network for next generation of xEVs.

About the Author

Prior joining Vicor, Nicolas worked at IDT (Renesas) as the North America Automotive Segment leader focused on technical sales in powertrain, infotainment and ADAS based systems. Prior to IDT, he spent four years at ON Semiconductor in the role of Field Application Engineer leading an internal design and applications team as a "Concept to Product Champion" heading up the company's new product growth strategy for automotive sales in Detroit, MI. His background also includes nine years of engineering and development at Continental Automotive where he held various engineering roles in their hybrid and electric vehicle divisions designing DC-DC converters and traction inverters.

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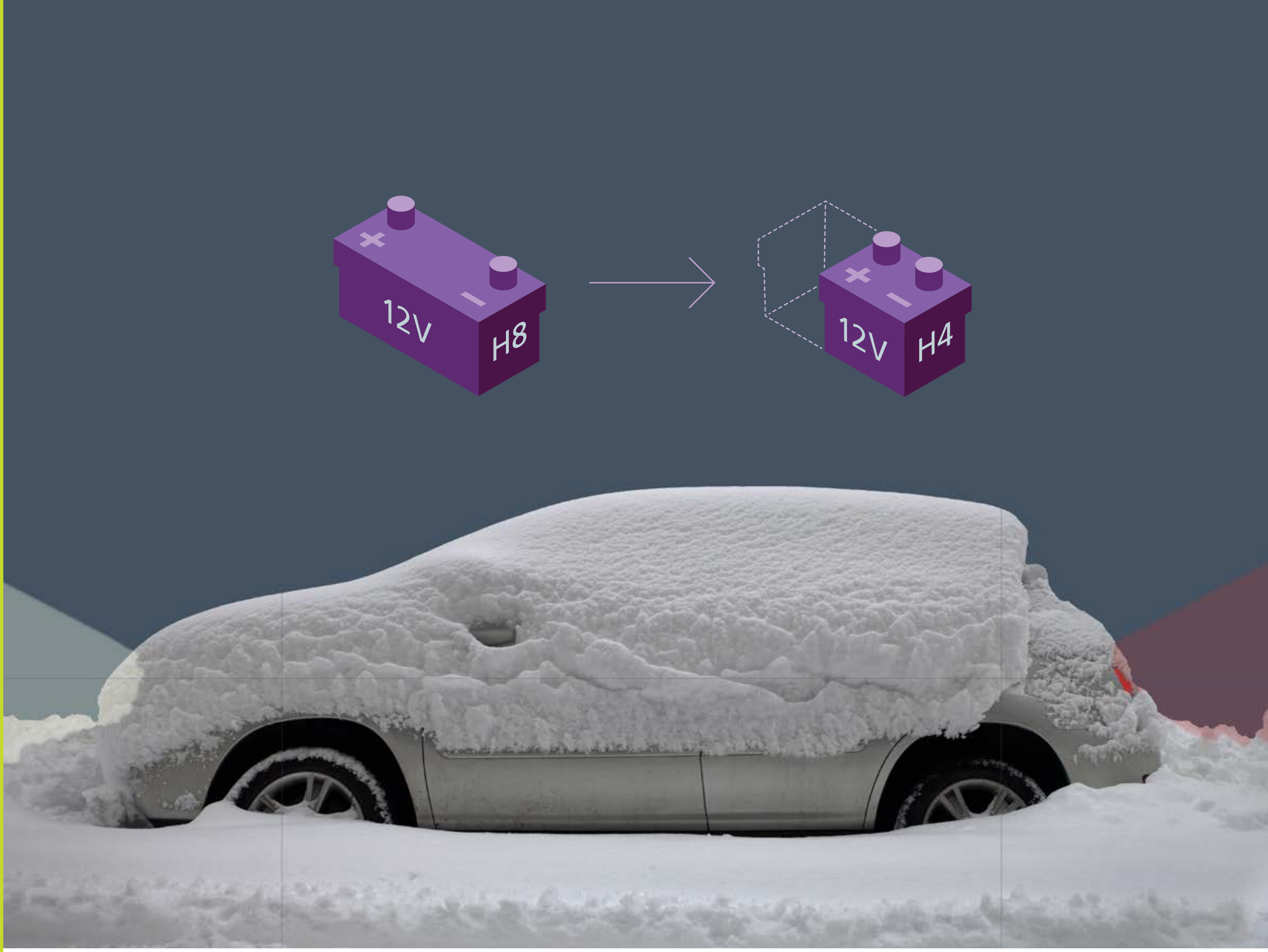

Article

Shrink the 12V battery by half and maintain cold crank?

VICOR

Advances in safety features, comfort and infotainment systems in automobiles are escalating power requirements, challenging power systems engineers to meet the growing power demands with restrictions in weight and space. Over the last decade, the typical 12V power requirements have increased from 1.2kW to 4kW continuous load, which has a compounded effect on the 12V lead-acid battery, which must be sized for double the required power because of their 50% depth of discharge (DoD) restriction.

Why use a 12V lead-acid battery at all? Well, PHEVs and MHEVs cannot completely eliminate the 12V battery as it remains the only choice for cold-crank starting. However, sizing the 12V battery correctly to meet all the quiescent current (always-on) use cases as well as cold crank is a complex calculation.

Optimizing the 12V battery for new power demands

Most OEMs are redesigning their power delivery architectures for both BEV and ICE vehicles to support the demands on mild-hybrid (MHEV) and plug-in hybrid (PHEV) categories. They are working feverishly to contribute to the adoption of electric vehicles for consumers who are reticent about limited BEV range and charging network availability and compatibility issues. Today, the PHEV is a practical option delivering the benefits of electrified traction without the range anxiety.

Power system designers have to consider worst-case scenarios and all corner cases, which include –40 to +50°C environments. Starting the engine at –40°C is one of the most difficult use cases and is referred to as cold cranking.

Batteries are specified with their cold current supply in amperes at –40°C with a term known as ‘cold current amperage’ or CCA. Batteries, due to their chemistry, inherently resist charging and discharging at low temperature and the CCA rating helps system engineers decide whether the chosen battery will meet the system demand or not. At these low temperatures, the typical traction lithium-ion batteries perform poorly due to their chemistry. They cannot provide this rapid peak current (75A/30µs) via the DC-DC converter to support the engine cranking requirements. The lithium-ion cathode chemistries are optimized for packaging efficiency and maximizing BEV range, not cold cranking.

An added advantage of the 12V battery is that it provides the required capacitance for absorbing any transients from the low voltage bus. These transients are typically generated from the electrical starter generator motor.

Packaging challenges for the 12V battery

Typically, the starter batteries are packaged under the front passenger seat as the engine bay temperatures are not suitable for the batteries to be packaged. However, finding package space for the PHEV battery often takes priority to maximize the EV range. Furthermore, the growing power requirements for the 12V battery make packaging even more difficult. An automobile typically requiring an H6-sized battery now requires an H8 AGM battery (Table 1), requiring relocation to the rear passenger compartment. The packaging, coupled with the added distance of routing 50mm2 cables (up to three times further) increases the total system cost and adds weight.

Power delivery architectures and component packaging on vehicle platforms are typically designed to reduce system complexity across all powertrains (ICE, MHEV, PHEV) and therefore the increased system costs carry over from PHEVs to ICE models as well.

Naming convention	Capacity	Dimensions
H4 AGM	50Ah (24 useable) 650CCA	Length: 207mm Width: 175mm Height: 190mm Weight: 9.7kg
H6 AGM	70Ah (38 useable) 750CCA	Length: 278mm Width: 175mm Height: 190mm Weight: 20.3kg
H7 AGM	80Ah (40 useable) 800CCA	Length: 315mm Width: 175mm Height: 190mm Weight: 22.8kg
H8 AGM	90Ah (43 useable) 850CCA	Length: 353mm Width: 175mm Height: 190mm Weight: 26.1kg

Table 1: This represents the sizing, dimensions and typical naming conventions for 12V starter batteries. As more OEMs increase 12V battery capacity (from H4 to H8), the added size and weight serve to limit vehicle range. With Vicor modules, 12V battery sizes can be reduced by 2/3rd by weight and almost 1/2 by volume. (Data sourced from Automotive DIN standards).

Minimizing the 12V battery to maximize the power delivery network

The typical loads for a 12V battery have two primary purposes – one is to start the engine and the other is for standby operation or 'quiescent current.' With the growing number of electric customer comfort features, and the number of 'always-on' features, the demand of the standby current and the number of features that need to be always-on has been increasing exponentially. In the typical use case, most car OEMs design the standby time for 50 days. This usually amounts to 14 – 16mA current drain which over 50 days is equivalent to 16A·h of total capacity of the battery pack.

The infotainment, telematics and vehicle approach unlocking features, further add up to 6A·h of battery capacity (as they are not always on). The always-on loads have always increased the cycling on the lead-acid batteries which have led to high warranty spends arising out of flat (depleted below 50% DoD) lead-acid batteries.

Alternatively, the always-on energy can be supplied from the traction Li-ion battery using Vicor fixed-ratio bus converter modules to transfer the energy efficiently to a load that is always on or cycles on and off, allowing better control and better efficiency. Further, the Vicor Sine Amplitude Converter (SAC™) topology used in bus converters enables even faster transient responses than a 12V lead-acid battery (Table 2).

Power source	di/dt
660CCA, 12V car battery	75A/30µs
48V to 12V SAC at 80A	75A/10µs

Table 2: Vicor modules have transient performance much faster than 12V batteries and can easily process 700 amperes per millisecond.

The SAC topology can process thousands of amperes from a high-voltage battery to the load without any dips and bench testing shows response times three times faster than a typical 12V battery (Table 2).

$$K = \frac{V_{LO}}{V_{HI}}$$

A key advantage of fixed-ratio converters, like SAC, is the ratio or K factor, which is the ratio of primary to secondary turns, that has a squaring effect on its effective output capacitance.

$$I_{LO}(t) = \frac{C}{K^2} \bullet \frac{dV_{LO}}{dt}$$

The SAC topology has a squaring effect on its effective output capacitance.

For example, for a 48-to-12V converter the K factor is 1/4 which means the effective secondary capacitance is four squared, or 16 times, the primary capacitance.

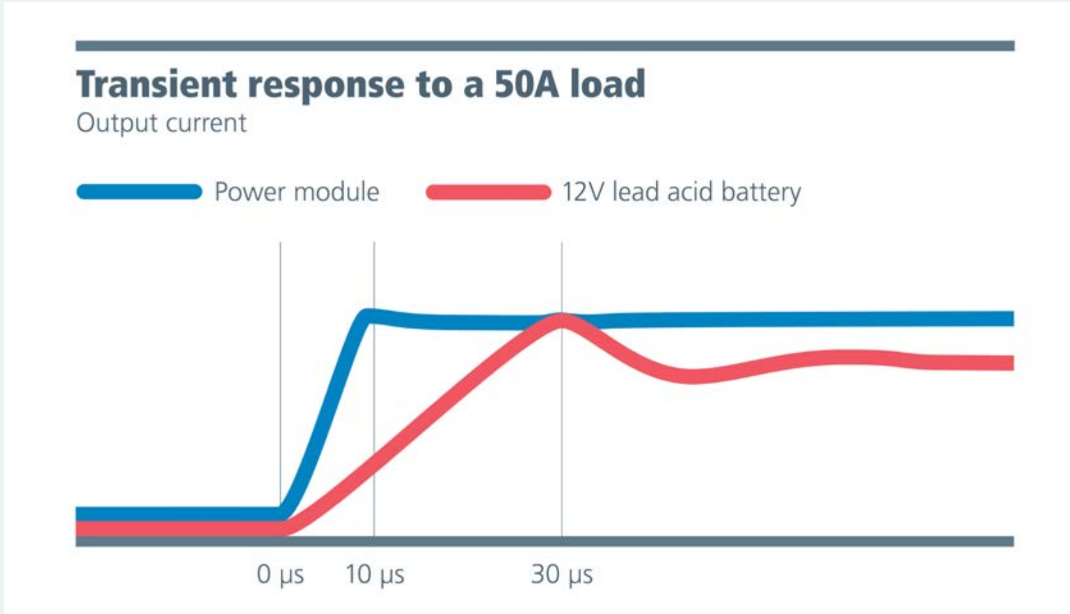

Figure 1: Vicor modules have excellent transient response and can be treated as a ‘virtual battery’.

A lighter, smaller virtual battery for standby power and routine starting functions

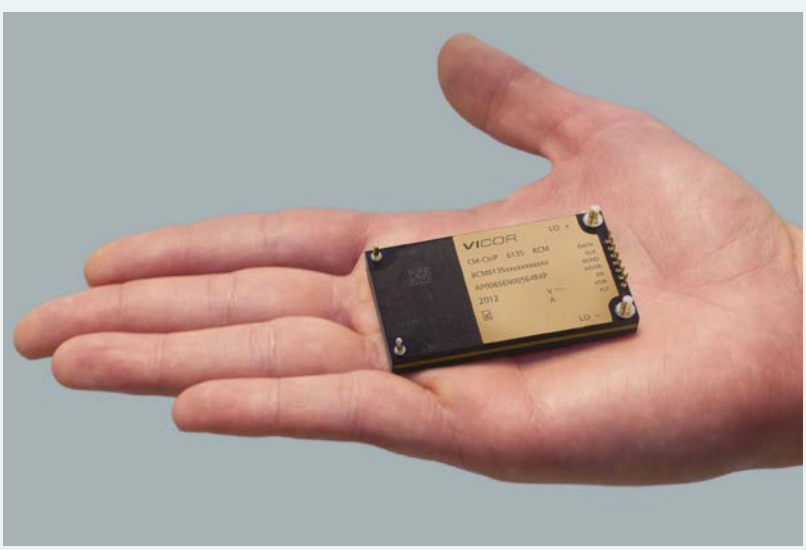

Figure 2: Vicor modules are the smallest and lightest power modules. The image shows a K 1/16 BCM that packages 2kW of power in the palm of your hand.

A Vicor high-voltage isolated (BCM®) (Figure 2) and low-voltage non-isolated (NBM™) bus converter modules, provide optimal solutions for a “virtual battery” that replicates the essential properties of the battery while reducing size, weight and temperature limitations.

If the standby loads are powered by the Vicor BCMs or NBMs along with the majority of starting conditions, the sizing of the 12V lead-acid battery can be significantly reduced down to H4 or even lower sizes for only cold crank, further improving the system weight. This further improves the packaging options to under the front passenger seats, reducing associated harnessing (Figure 3).

Being closer to the load reduces parasitic inductances and series resistances that come with a high-amperage power system. Vicor offers packaging advantages which allow it to be closer to the load. This eliminates any internal series inductance at the input or output and can easily process 700,000 amperes per second or 700 amperes per milliseconds as they show excellent transient response (Figure 1).

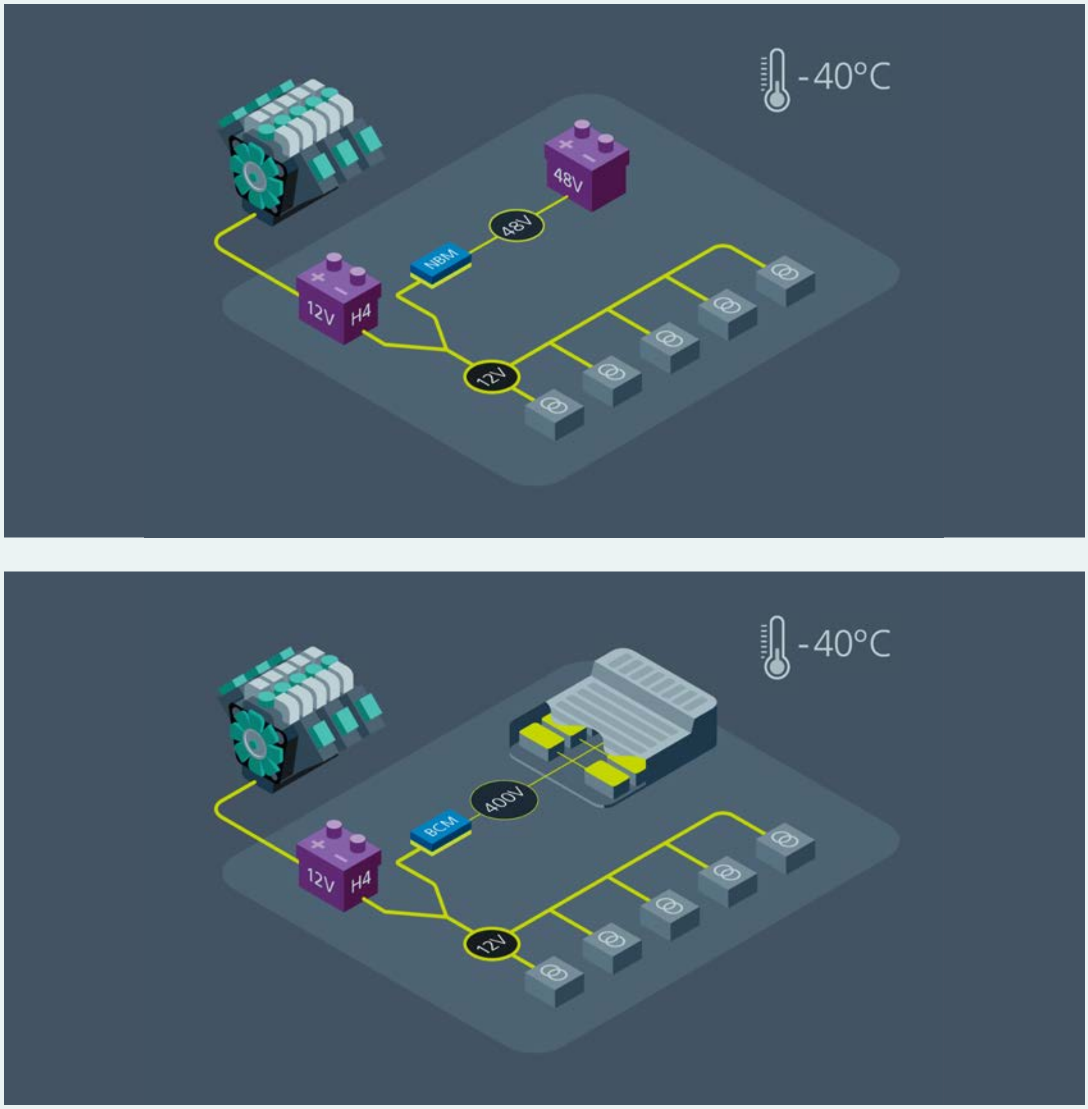

Figure 3: Vicor modules coupled with 12V starter battery helps to shrink the 12V battery size significantly without losing the critical –40°C cold-cranking capability. It also allows the batteries to be packaged in favorable locations, while achieving a simpler and common electrical architecture across MHEVs & PHEV. Lastly, it helps to achieve ASIL D power system ready for Level 3 ADAS features.

Optimizing the PHEV power delivery network

Comparing today's standard 12V solution vs a power module solution

Parameter	H8 12V lead-acid battery	Vicor solution for PHEV (lead-acid + BCM6135)
System weight (incl. wiring)	30kg	14kg
Size	3x	1x
System efficiency	70%	85% total system (Vicor efficiency = 98%)
Total material cost	€176	€168
CO_2 Delta	1.12g/km	0.55g/km
CO_2 Delta EU fines equivalent (E95/g)	€104	€51
Warranty average car cost	€20	€0
Total enterprise cost	€313	€219

Table 3: Vicor modules not only help to improve the material cost but also overall system costs while simplifying the electrical architecture, vehicle efficiency and improved performance all without losing any functionalities.

Vicor power modules enable new ways to optimize EV power systems

With the ever-increasing complexity of the growing comfort and connected features in combination with multiple powertrains on a single platform, OEMs will benefit from the simplification of the power distribution architecture while improving the reliability.

As automotive PDNs strive for greater power design efficiency, Vicor power modules offer innovative opportunities for engineers to achieve their goals. There is a variety of benefits for PHEVs to adopt a power module PDN (Table 3). Leveraging power modules and reducing the 12V battery, enables a reduction in power system design size by 66%, reduces weight by more than 50% and increase efficiency over 15%. Effectively car companies can realize savings up to €95 per vehicle.

With modular power, engineers can minimize the 12V battery, achieve a common power architecture across ICE, MHEV & PHEVs and meet additional feature requirements. Designing with power modules reduces complexity and weight, increase reliability and improves system efficiency – all of which contributes to improved system costs and increased EV range.

This article was originally published by Power Systems Design.

Partnering to create tailored power conversion solutions

Vicor is your partner to develop power delivery networks that accelerate your time to market to meet your aggressive electrification goals. We are working with leading OEMs and Tier 1 suppliers not only to adapt our proven DC-DC converter products for use in xEVs, but we are also developing customized solutions tailored to their needs. Our team of engineers is collaborating with customers to architect new, efficient modular power delivery networks that enable automotive designers to take advantage of the reduced size and weight of Vicor solutions.

The ability to scale our miniaturized power modules provides benefits for the ongoing development of automotive power solutions with lower development costs. Just a few Vicor modules can support hundreds of unique power network designs, saving development and certification time and cost. The benefits of this scalability, flexibility, and re-usability in system design from Vicor power modules enable the system designer to achieve the best mix of power, weight and package space.

To learn more about Vicor in automotive, please visit our website at www.vicorpower.com/automotive or reach out to us personally. We look forward to working with you and exploring ways we can help you solve your electrification challenges.

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