Is the 12V Lead-Acid Battery Dead?

Yes, the 12 V 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.

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The 12 V 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, 48 V and 12 V 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 CO_2, 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 12 V lead-acid battery with a 12 V Li-ion battery is one option. While it does slightly reduce weight, it retains the decades-old legacy of the 12 V PDN, which yields no additional benefits. The other option is to support a 12 V PDN powered from the primary 400 V or 800 V 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 12 V lead-acid battery with a 12 V Li-ion battery saves ~55 % weight; however, it has a high cost impact. The 12 V 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 [1] and Hyundai [2].

Furthermore, adding a bulky DC/DC converter from HV to 12 V (with voltage and current regulation feature) is needed to recharge the 12 V 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 12 V battery altogether removes 13 kg from the vehicle and can improve the cargo space by 2.4 % [3].

Legacy 12 V PDNs are inefficient

Maintaining a physical 12 V battery means maintaining an inefficient PDN with unnecessary redundancy. In a typical automotive 12 V PDN, all the 12 V loads connected to the 12 V bus have internal pre-regulators able to convert wide input voltage range typically from 6 to 16 V to regulated rails of 5 V, 3.3 V or lower. From a global system view for an EV, HEV or PHEV, there is redundancy of series regulator stages. A high-voltage-to-12 V DC/DC converter regulates the 12 V 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 12 V 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 12 V power limitation and complex electrical architectures have been designed in recent years with two 12 V batteries, one 24 V battery for power steering and several DC/DC converters between them.

Replacing the 12 V with a virtual battery

A better approach to solving this problem is to completely rethink the PDN in a vehicle: eliminate the physical 12 V battery and replace it with a 12 V "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

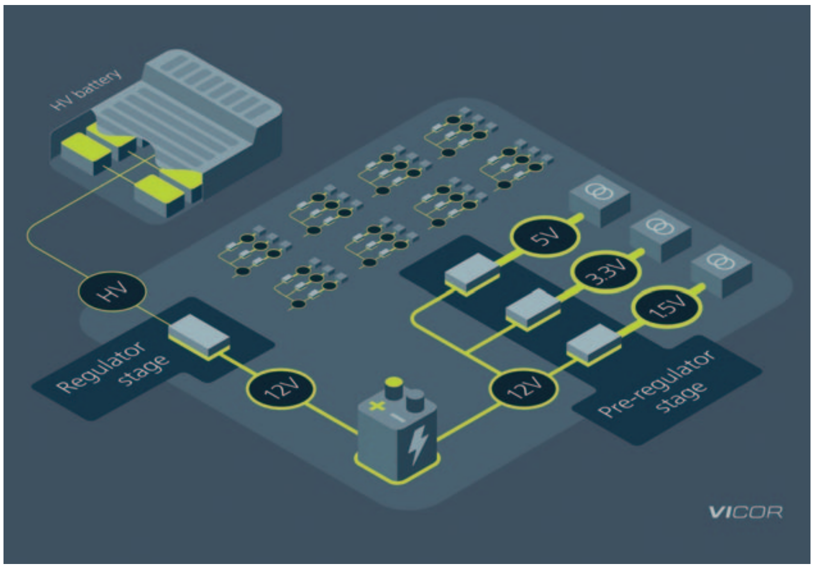


Figure 1: Typical E/E used in xEVs with 12V battery using redundant voltage regulator stages. The HV-to-12 V DC/DC regulates the 12 V output to charge the 12 V battery. Every 12 V load in the vehicles has a pre-regulator stage to supply the proper rail voltage needed for the load to operate.

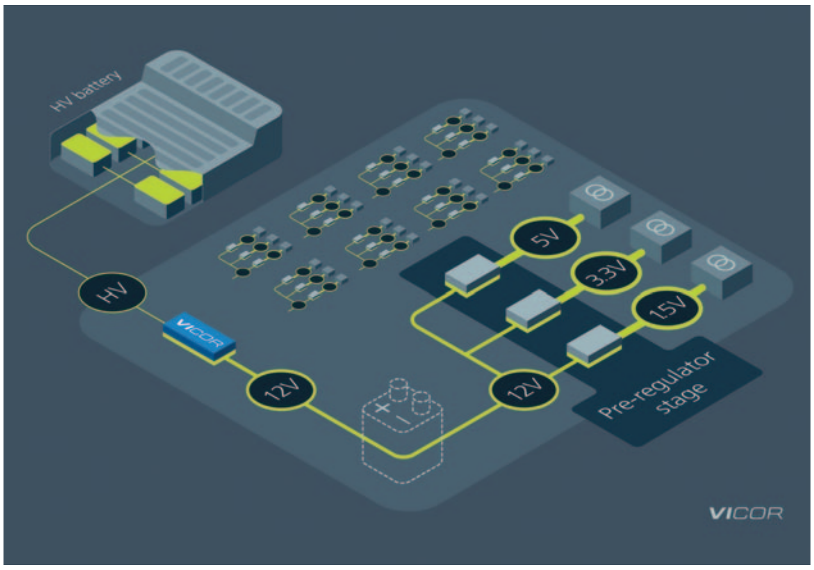


Figure 2: Optimized E/E architecture eliminates the physical 12 V battery. A virtual 12 V battery is created by transforming the high-voltage battery with Vicor BCM® Bus Converter technology

the powertrain and all the auxiliary loads. Vicor high-density bus converter module technology enables this approach by virtualizing a low-voltage battery (48 V or 12 V) directly from the HV battery (400 or 800 V).

Utilizing zero-voltage, zero-current switching (ZVS/ZCS), CM® Bus Converters operate at higher frequencies than conventional converters making them more responsive than a physical battery. For example, the BCM6135 operates at 1.2 MHz 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 8 MA/s), and a low-impedance path collectively enable the BCM to make HV battery appear like a 48 V 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 BCM operates as a fixed-ratio converter where the output voltage is a fixed fraction of the input voltage. The BCM6135 converter is isolated and provides 2.5 kW of power in a 61 x 35 x 7 mm 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 V and 920 V on an 800 V battery-powered electric vehicle. A BCM6135 with 1/16 ratio virtualizes a 48 V battery with a voltage range guaranteed to stay between 32.5 and 57.5 V. A BCM6135 1/8 ratio could be used for 400 V EVs (Figure 3, 4).

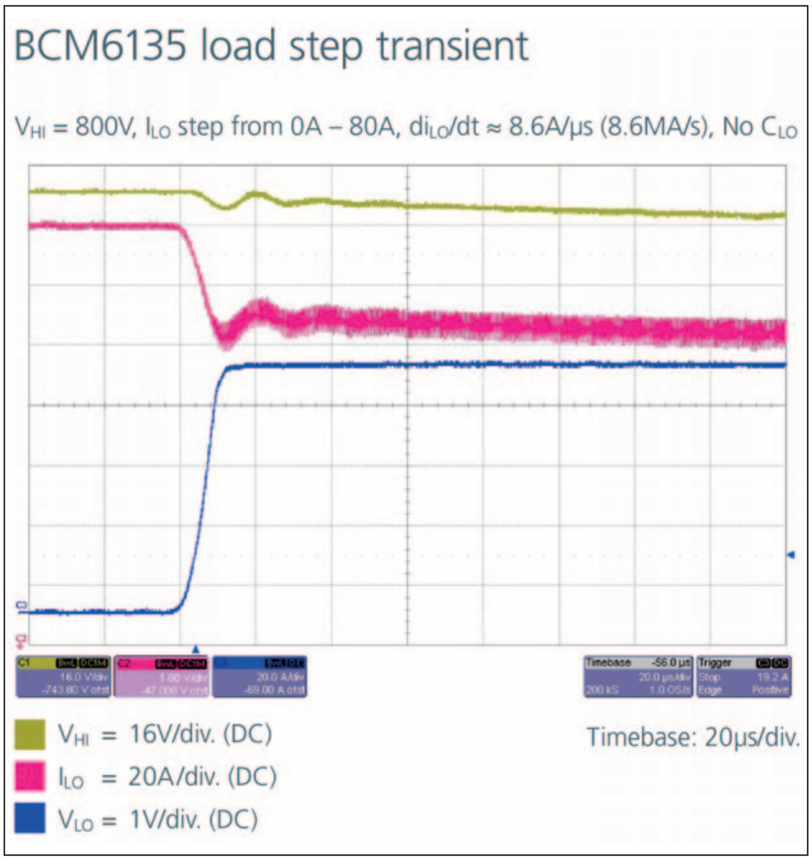
The battery virtualization can also be extended to the 12 V bus with a fixed-ratio converter of 1/4. In that case, galvanic isolation is not required and a NBM™ Bus Converter could be used. Identical in all other features to a BCM, the NBM non-isolated bus converter has all the same benefits previously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

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 12 V power delivery. More and more demanding power loads are



LEFT Figure 3: The fast load transient response of BCM6135 is the key to supporting the 12 V loads (yellow : input voltage (800 V DC), red: output voltage (48 V), blue: output current)

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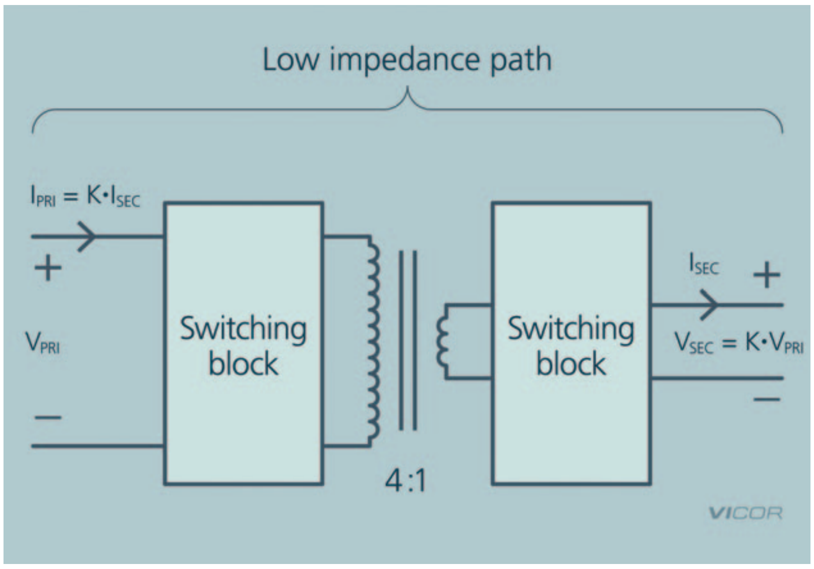

Figure 4: Functional block diagram of BCM Bus Converter. Even though it converts DC to DC, the BCM uses a transformer to convert AC to AC at high efficiency, scaling the magnitude by the K factor and using the switching blocks to convert between AC and DC. The switching is done at a high frequency, and, 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

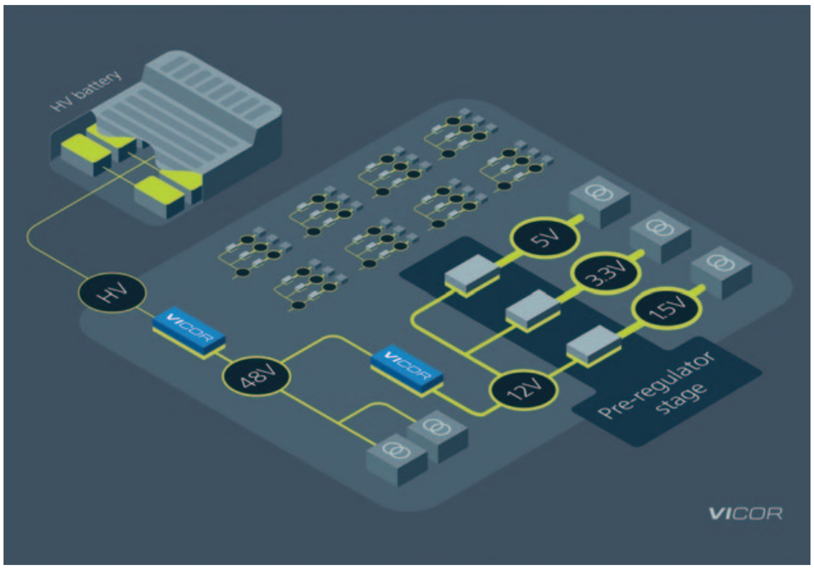

Figure 5: E/E architecture with 12 V and 48 V battery virtualization based on BCM6135 and NBM2317 modules

being implemented in vehicles while trying to keep architectural changes to a minimum. "What are we still doing at 12 volts? Twelve volts is very much a vestigial voltage, it's certainly low," said Elon Musk, Tesla CEO [4].

OEMs are scrambling to design better PDNs to deliver more EV range and performance. Eliminating the 12 V 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 a combination of flexibility, scalability and power density. The Vicor module approach to PDNs offers building blocks to address the near-term challenge of 12 V power delivery network for next generation of xEVs.

Literature

[1] Charles Morris, "Refreshed Tesla Models S and X to ditch lead-acid for Li-ion 12 V battery"; Electric Vehicles Magazine, (Feb. 9, 2021) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/

[2] Bengt Halvorson, "All 2020 Hyundai hybrids have a clever 12-volt lithium-ion accessory battery", www.greencarreports.com (Apr 28, 2020) https://www.greencarreports.com/news/1127972_all-2020-hyundai-hybrids-have-a-clever-12-volt-lithium-ion-accessory-battery

[3] Jeffrey Jenkins, A closer look at DC-DC converters; Electric Vehicles Magazine (Aug. 6 2018) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/

[4] Charles Morris, "Refreshed Tesla Models S and X to ditch lead-acid for Li-ion 12 V battery"; Electric Vehicles Magazine (Feb. 9, 2021) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/