Mild Hybrid Vehicles
High Power Converters for 48 V / 12 V Automotive Electrical Systems

The challenges in 48 V mild hybrid vehicles are increasing, and 48 V / 12 V converters need the flexibility to satisfy future requirements. Power levels of at least 1.2 kW to 3.5 kW are needed, depending on the vehicle's options. In addition to this broad power range, the priority is to offer scalable concepts optimized for cost, as not every vehicle can be sold with the same options.

Voltage Converters for Regulating Automotive Electrical Systems
In recent years, a large number of applications in the areas of active safety, consumption reduction, and emissions optimization have been incorporated into new vehicles. These applications include start-stop systems (micro hybrid), electric water pumps, air-conditioning compressors, turbochargers, steering, roll stabilization, parking brakes, automatic transmissions, and power brakes without vacuums. Added to this are ADAS (radar, lidar, camera with ultrafast processors) and SCR systems (AdBlue, etc.). As a result, voltage converters for regulating a vehicle's electrical system up to 1 kW and bidirectional 48 V / 12 V voltage converters for up to 3.5 kW are necessary.

The question for developers is: how should a 48 V / 12 V converter be built and does it make sense to provide the maximum power of up to 3.5 kW continuously for all vehicle models? That is to say, power from 1.2 kW to 3.5 kW is required, depending on the vehicle's options. There are 48 V starter-generators already available and automobile manufacturers are offering more and more diesel vehicles with 48 V belt-driven starter-generators.

42 V Electrical Systems
The first tests using 42 V automotive electrical systems in 2000 failed for several reasons. So starting in 2003, they were replaced with 12 V micro hybrid vehicles. Consumption optimization of about 5 % was achieved with this temporary solution (start-stop). This technology is used today in more than 60 % of all vehicles. The 12 V vehicle electrical system is regulated to a voltage with a maximum fluctuation of 3 V (11 V to 14 V). This protects other electrical devices against load fluctuations and avoids critical states in the vehicle's electrical system.

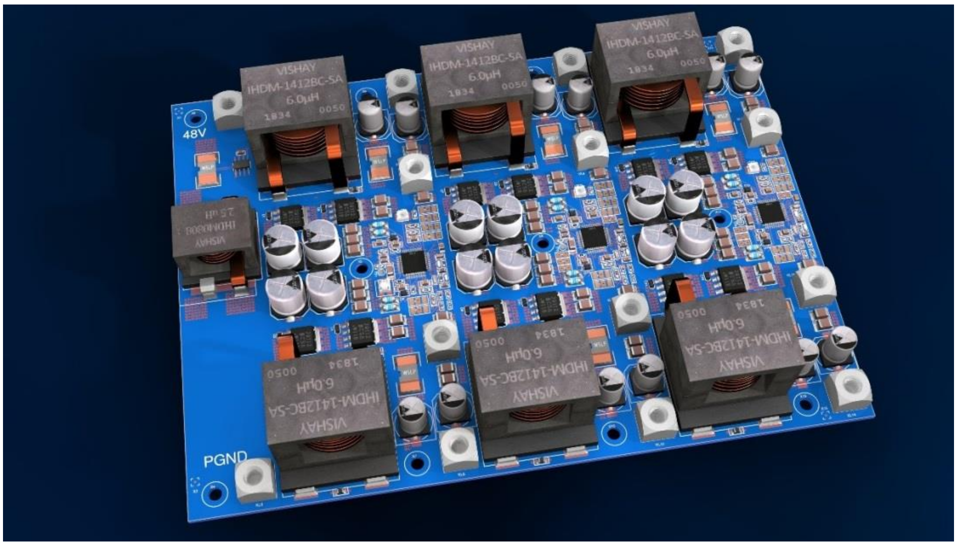

Figure 1 DC/DC converter 3.5 kW with 6 phases and IHDM inductors (© Vishay)

If the voltage drops below the regulated minimum level of 11 V, the power to the high current systems is reduced, depending on the situation. In the range below 9 V, additional control units are slowed or switched off, depending on their functionality and energy requirements. A voltage drop to below 6 V can lead to a total failure of the vehicle's electrical system. For this reason, all micro hybrid vehicles need a DC/DC voltage converter (Fig. 1) in the power range from 400 W to 1.5 kW to assure the start-stop function is operational, while not having a negative impact on other devices in the vehicle.

DC/DC Converters for Regulating the Electrical System
DC/DC converters are used to regulate the electrical systems in 12 V micro hybrid vehicles to prevent a voltage drop in the electrical system when restarting. The infotainment, audio, and lighting systems continue to run without interruption. Smart battery sensors with shunt resistors make it possible to continuously measure both the power level of the battery and the current consumption. Energy transfer via the 12 V system is limited. Even with maximum power generators, no additional dynamic high current systems can be supplied.

For this reason, a higher operating voltage was introduced into the electrical system, resulting in new alternators being developed. This provides automobile manufacturers with the freedom to integrate additional high power electrical devices to further increase the efficiency of the overall vehicle. These vehicles are usually known as mild hybrid electrical vehicles (MHEV).

The 48 V Electrical System Isn't Regulated
Compared to a 12 V vehicle electrical system, the 48 V system operates over a wide range of 16 V (52 V to 36 V) and is also intentionally not regulated. All 48 V control units must reliably operate over this 16 V voltage swing. Many setups and application tests have shown that, with 48 V systems, the upper dynamic voltage of > 48 V lasts a maximum of 3 s, while the lower dynamic voltage lasts up to 100 s. Although galvanic separation is not necessary for the 48 V MHEV, it is absolutely mandatory in the other case to maintain 60 V as the maximum voltage limit, because of the necessary protection against electric shock. The test specification for this is VDA 320. Components developed in accordance with VDA 320 can operate reliably within the defined voltage range.

The starter-generator designed for 48 V systems (low voltage systems of < 60 VDC) provides a considerably higher peak electrical power from 15 kW to 20 kW and continuous power from 5 kW to 10 kW. This option will make it possible to gradually operate all high current applications, such as the air-conditioning compressor, windshield defroster, electric compressor (turbocharger), and a PTC heater booster directly with 48 V. However, many 12 V applications below about 600 W in the vehicle cannot yet be converted to 48 V for cost reasons.

Bidirectional Voltage Converters
In the MHEV, 48 V and 12 V batteries are both needed (Fig. 2). For this reason, it will be necessary to install bidirectional 48 V / 12 V voltage converters in these 48 V mild hybrid vehicles in the coming five to ten years. These converters will replace 12 V alternators. Electrical systems requiring power exceeding 600 W will be incrementally converted to 48 V subsystems. In the case of dynamic systems such as electric assisted power steering and when starting the engine, it is necessary to use a 12 V battery as a buffer.

Start-stop systems remain the answer to reducing CO_2 emissions. For hybrid vehicles, a second voltage is necessary. A 48 V vehicle (MHEV) reduces the CO_2 values by up to 16 %, while also increasing engine power by up to 23 %. Now comes the big question. How should a 48 V / 12 V converter be built and does it make sense to provide the maximum power of up to 3.5 kW permanently for all vehicle models? That is to say, power from 1.2 kW to 3.5 kW is required, depending on the vehicle options.

Demo 9 DC/DC Converter 1.5kW Image
Buck-Boost Operation
The requirements for this type of converter are very high. Starting with the 48 V input (terminal 40), whose voltage can vary from 24 V to a maximum of 54 V, the output side (terminal 30) also faces a stiff challenge with an operating range of 6 V to 16 V. The very high input currents (boost) and the

output currents (buck), which are just as high, resulting from this are not difficult to determine. Buck-boost currents increase inversely proportional to low voltage levels of both vehicle electrical systems. The currents may briefly become very high in buck-boost operation at 3.5 kW, particularly if assuming minimum input voltages.

In addition to the challenge of achieving high efficiency (> 96 %), scalability and cost optimization present additional difficulties. As it is projected that many vehicles — primarily diesel vehicles — in the future will undergo conversion to 48 V mild hybrid operation, scalable voltage converter strategies should be the goal. It is necessary to optimize the new semiconductors for 80 V and 100 V, as well as the high current inductors for memory and filter applications, for these power ratings.

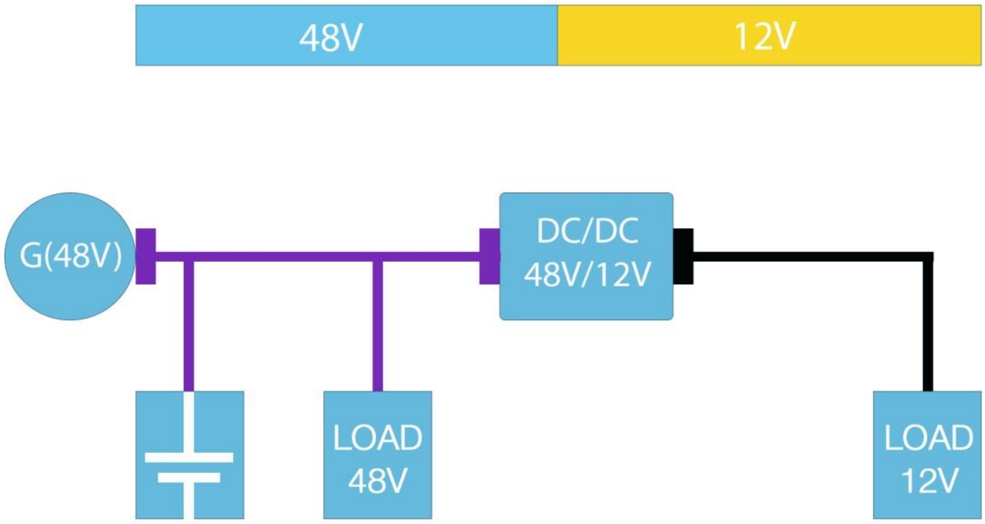

Figure 2 Simplified diagram of a 48 V MHEV (© Vishay)

The range of products offered by Vishay contains virtually every topology (synchronous converters with 3, 4, 6, or 8 phases), high current inductors of the IHDM Series (Fig. 3), and the IHLP Series of symmetrically coupled and asymmetrically coupled inductors. The portfolio also includes the semiconductors that dictate efficiency, such as power MOSFETs, high precision shunt resistors up to 15 W, and suppressor (TVS) diodes. In addition to the high current iron-core coil filters from the IHDM Series, the new IHSR SMD inductor is one of the output filters among the key components for terminal 40 (48 V).

Figure 3 Customized buck-boost IHDM storage coil (© Vishay)

For a power level of 3.2 kW, a current of about 74 A must flow from terminal 40, and for the 12 V supply (terminal 30) the converter provides 12 V at 292 A (Fig. 4). With a supply current of about 300 A at terminal 30, multiphase converter systems are selected because they make the most sense for reasons of cost and the efficiency / volume ratio.
DC/DC Converter 3.5kW Image

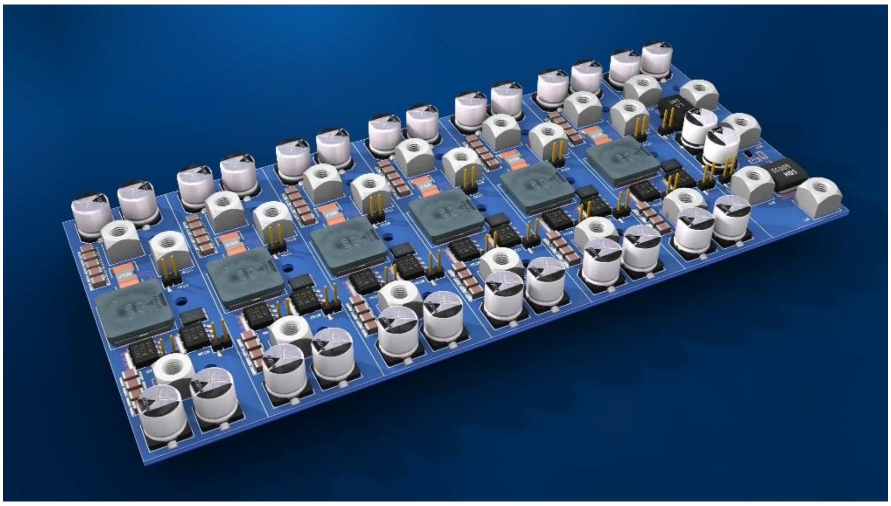

Figure 4 DC/DC converter, 6 phases, 1.5 kW using IHLP6767GZ standard inductors (© Vishay)

Summary
To offer cost-effective systems at a 12 V level for various power levels (1 kW to 3.5 kW), a digital regulator is preferred to an analog regulated bidirectional voltage converter. The reasons for this are the following:
Flexibility:
- Variable power profiles by being partially populated
- Soft-start or digitized current regulation
- Fault recognition (communication via the bus system) and variable phase shift
- Possible spread spectrum to reduce EMI
Efficiency:
- Shutdown of individual phases in the part load range
- Efficiency optimization using variable frequency selection; theoretically: automatic efficiency optimization such as the maximum power point tracking (MPPT) method
- Single-phase efficiency analysis — optimized part load strategy

Temperature:
- Cyclic full-load use of a single phase in the part load range
- Temperature monitor
- On-demand fan control
- Temperature-dependent distribution of the load to the individual phases

To reliably switch these power levels, voltages of up to 60 V (terminal 40), and maximum peak voltages of 70 V, MOSFETs of at least 80 V must be used for the 48 V level.

Finally, the big challenge is to offer scalable concepts optimized for cost for the dual electrical system, because not every vehicle can be sold with the same options. The forecast for the 48 V mild hybrid is very positive, and by 2025 this equipment option could affect up to 25 % of all vehicles.

Author
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