PASSenger Car Drives

48-V High-power Full Hybrid System
Electric driving is already possible with 48-V hybridization. Vitesco Technologies is developing a system that is suitable as a drivetrain in a 48-V full hybrid. The high-power technology offers low-cost hybridization to achieve up to 20 % lower CO₂ emissions in the WLTP. In addition to the drive, the system includes the combined 12- and 48-V lithium-ion battery Advanced Energy Storage and the electrically heated catalyst Emicat.
The further time progresses, the more pressing the task of further reducing the CO₂ emissions of new cars becomes in order to meet the goals required by the EU to reduce the new-vehicle fleet average by 15 (2025) and 37.5 % (2030) compared to 2021. This requires a greater spread of electrified powertrains. In addition to purely electric vehicles and Plug-in Hybrid Electric Vehicles (PHEV), Full Hybrid Electric Vehicles (FHEV), which do not feature external charging but nonetheless enable purely electric driving, also fit the bill in this context, particularly in urban areas.

An analysis of the publicly available figures on the German hybrid market reveals the following picture: Mild Hybrid Electric Vehicles (MHEV) cover a wide range of vehicle types and price ranges, Figure 1. Compared with the other systems, MHEVs enable only small CO₂ savings. FHEVs are comparatively rare, but are predominantly used in the high-volume segment and enable significantly lower CO₂ emissions compared to MHEVs. PHEVs achieve very low CO₂ type-approval values, but at the disadvantage of a significant price premium compared with MHEVs and FHEVs, which means that they can only be found above the A and B segments, in the higher price classes. The next task can be readily derived from this market.

**FIGURE 1** Overview of the German hybrid market (market study of Vitesco Technologies without claim to completeness; CO₂ emissions weighted in accordance with EU 2017/1151; prices incl. 19 % VAT) (© Vitesco Technologies)
In order to achieve the required CO₂ reduction for new cars in the fleet, it will be necessary to further reduce fuel consumption in the cost-sensitive high-volume segment.

**DATA-DRIVEN DESIGN OF THE 48-V FULL-HYBRID DRIVE**

To answer the question of how much power an electric drive requires to be applied in a FHEV, it was necessary to employ data-driven analyses of driveability in real-life traffic, as well as simulations to determine efficiency. Such investigations are possible because Vitesco Technologies equips its test and benchmark vehicles with an IoT client and continuously stores the operating data captured in the vehicle, combined with map information, in the cloud. This means that it is always possible to examine and respond to new issues that arise.

**FIGURE 2** shows such an examination. The distribution of traction and recuperation power in the drivetrain is shown on different route profiles (city, country, highway). An electric vehicle from the C-segment that had been used by several drivers in different regions served as the medium for data acquisition here, in order to exclude influences through gear shifts or the turbocharger dynamics. The drives stretched over a total distance of 4887 km. Under traction conditions, it was found that a power output of between 20 and 30 kW, or more precisely, a power output averaged over 20 s, is sufficient to cover most driving situations in inner-city operation. Even during driving on country roads, a significant part of the load requirements can easily be covered. Only on highways the bulk of the power requested by the driver is significantly higher. With regard to recuperation, the power class up to 30 kW proves even more relevant: almost all regenerative deceleration processes, regardless of the type of road, are covered. To sum up, it can be said that an electric drive power output of between 20 and 30 kW is suitable in the C-segment to constitute a FHEV that can drive purely electrically in the city and which has good efficiency in real traffic thanks to a high level of recuperation.

**THE 48-V HIGH-POWER DRIVE**

To cover the described requirements for an electric FHEV drive as cost-effectively as possible with 48-V technology, Vitesco Technologies has drawn on its many years of experience in this field to enhance the potential of this technology. The result is an electric 48-V high-power drive system that can temporarily cover...
deliver twice the power of a conventional 48-V machine. In this way, the key features of conventional high-voltage full hybridization can be met – at a market price for the system that is around 25 % lower [1].

The 48-V high-power drive, now in advanced development, will presumably be available for use in production vehicles from 2024, achieving up to 30 kW mechanical peak power in motor mode for up to 5 s and 70 Nm of electric torque, **FIGURE 3**. The new machine can deliver at least 20 kW for up to 20 s, and 12 kW of power virtually permanently. Nevertheless, at a length of 235 mm, the machine measures only 175 mm in diameter – an essential requirement for installation in a transversal geometry. Fundamentally, all forms of the integration in hybrids are feasible, that is as P0, P2, P3 and P4. The Permanently excited Synchronous Machine (PSM) is liquid-cooled and reaches a speed of up to 20,000 rpm. An I-pin winding was selected for the stator of this PSM. Permanent magnets are positioned on the rotor side in such a way that the magnetic reluctance effect also contributes significantly to the torque. The six-phase inverter integrated in the unit is based on liquid-cooled power electronics with power semiconductors integrated into the printed circuit board (embedded technology), thus enabling the high power density. The efficiency is up to 90 % in the initial samples and can be further increased with regard to production design.

**DEMO VEHICLE**

In order to practically test the full potential of its 48-V technology and to demonstrate the resulting synergies, Vitesco Technologies integrated the 48-V high-power drive, the Advanced Energy Storage (AES) module and the 48-V electrically heated catalyst Emicat with 4 kW power in a demo vehicle, **FIGURE 4**. **FIGURE 5** CO₂ savings with the 48-V high-power FHEV in the WLTP; measured values with further saving potentials (right) in comparison to simulation results (left) (© Vitesco Technologies)
basis, the P2 hybrid architecture developed previously with partners for a 48-V MHEV was used [2]. The previous 48-V e-motor was replaced with the new high-power drive system. There are two solutions available as energy storage: either the 48-V AES can be used for realizing a FHEV, or a larger 48-V battery is used to investigate the potential of a 48-V PHEV. The electric machine is integrated with a belt drive system on the side between the combustion engine and a six-speed manual gearbox with two automated clutches, K0 and K1. Two electric water pumps cool the combustion engine and the electric drive on demand, for maximum efficiency. The combustion engine in the test vehicle is the turbocharged 1.0-l three-cylinder EcoBoost gasoline engine by Ford (model year 2015).

FUEL EFFICIENCY AND DRIVABILITY

The CO₂ savings potential in WLTP with the 48-V high-power FHEV is 19 % on the basis of simulations compared to the non-electrified reference vehicle, FIGURE 5. Measurements with the demo vehicle confirm this value if the following factors are taken into account: On one hand, the recuperation potential can be increased. The brake system of the prototype car allows only limited brake blending and the manual transmission requires the opening of the driveline during recuperation to shift the gears. On the other hand, the first samples of the 48-V high-power drive are not yet showing the full potential of production parts, which suggest an efficiency well above 90 %. Finally, a further downsizing by using the torque of the electric motor brings an additional saving potential of 1 %.

The high energy efficiency of the 48-V high-power FHEV is not only relevant in WLTP but also in real-life traffic. On a city cycle in Regensburg (Germany), a fuel consumption of only 4.7 l/100 km was measured as average over various drivers and drivers.

In addition to its excellent efficiency, the instantaneous availability of the electric motor’s torque is a major advantage for the 48-V high-power system. FIGURE 6 shows the dynamics of the demo vehicle in the maneuver when accelerating from 20 to 60 km/h in third gear compared to acceleration using the combustion engine only. Electric boosting reduces time-to-torque to 200 ms and the final speed is reached almost twice as fast by fully compensating for the turbo lag and, once the combustion engine has built up its full torque, the electric machine further increases the driving torque.

AES AND VEHICLE ELECTRICAL SYSTEM

The complexity of a hybrid on-board vehicle electrical system with a 12- and 48-V side can be made much easier by using a common energy accumulator for both systems. For this purpose, Vitesco Technologies has developed a combined lithium-ion storage module with 12- and 48-V output and integrated it in the 48-V high-power FHEV. Inside the AES module, a 12- and a 36-V cell stack are interconnected in such a way that they can generate and release 12 and 48 V, FIGURE 7. Additionally, a bidirectional 3-kW DC/DC converter is integrated as well as a battery management system for both voltage levels. The prototype tested has a nominal capacity of 1.45 kWh and can supply up to 40 kW of electric power. This gives it the right dimensions for the 48-V high-power drive with 30 kW of mechanical power. The AES is cooled by a series of integrated fans. Liquid cooling is optional as is an adaptation of the energy storage to 48-V P0 systems, for example.

Different lithium-ion cells are used for the two cell stacks in the AES. The two cell stacks, connected in parallel with a total of 40 Ah for the 12-V system, are...
based on Lithium Iron Phosphate (LFP) and due to their low level of variation of the open circuit voltage across the State of Charge range (SoC) of the battery, they are ideally suited to feed the 12-V system with its narrow voltage limits. For the 36-V cell stack, on the other hand, lithium Nickel Manganese Cobalt (NMC) oxide cells with a total of 28 Ah are used because they offer a particularly high power density.

When switching to the AES, the heavy 12-V lead acid battery can be omitted. In addition to the significant weight savings and reduced installation space (390 × 300 × 180 mm in the prototype described here) compared to a dual-battery design with a lead acid component and an external DC/DC converter, the AES offers further advantages. On the one hand, the lithium-ion technology also enables extensive use of the installed capacity on the 12-V system through cyclic discharging and charging. On the other hand, the DC/DC converter can be used to flexibly shift the stored energy between the two cell stacks (cell balancing). So, the AES can supply a parked vehicle with electrical energy on the 12-V system through cyclic discharging and charging.

The ability to drive electrically with the 48-V high-power drive begged the question early on whether such a vehicle with a larger traction battery would also be suitable as a PHEV to save even more fuel. This was investigated on the basis of simulations. The external charging option opens up the opportunity to cover long distances with the vehicle pure electric mode (charge depleting mode), whereby, for example, the WLTP is not driven purely electrically, but in which the combustion engine and the electric machine are combined in an efficient manner. The simulation results indicate that a C-segment vehicle with this drive can achieve CO2 emissions of below 50 g/km, weighted according to EU 2017/1151, and is therefore eligible as a low-emissions vehicle in many countries, which in Germany means a subsidy of 4500 euros (as of 2020).

It is a much-discussed fact that the actual fuel consumption values of a PHEV – regardless of the homologation values – depend very much on the behavior of the driver, especially vis-à-vis the frequency of charging. With the suggested representation of a 48-V high-power PHEV, the focus is on the lowest possible real consumption values such as those of diesel vehicles today. In WLTP for example, where a large part of a route is driven purely electrically as long as sufficient energy is available in the battery (assumed here with a capacity of 8.6 kWh), an average consumption of only 1.6 l/100 km results for a distance of around 50 km – corresponding to two WLTC cycles in succession, FIGURE 9.

CONCLUSION AND OUTLOOK

The electric 48-V high-power drive provides a solution for introducing electrification in cost-sensitive volume segments. This applies in particular in combination with the AES as a compact, light and powerful energy supply unit for the electrical 12- and 48-V system and with the electrically heated catalyst Emicat in order to guarantee a clean use of the combustion engine even at low temperatures.

As a 48-V high-power full hybrid system, it offers driving functions that were previously reserved for high-voltage FHEVs with a much higher system price. A 48-V FHEV, for example, is expected to reduce the market price by around 25 % compared to a high-voltage system. Based on current estimates, a 48-V high-power PHEV with a correspondingly larger battery is likely to have a 10 % price advantage over high-voltage technology [1]. The 48-V high-power FHEV can be used to implement concepts that support pure electric driving, particularly in urban areas, or support the combustion engine through electric boosting in such a way that drivability becomes much more attractive.
With regard to the volume segment, it is crucial that this new drive in the 30-kW power class is implemented with today’s large-scale production technology and is therefore economically viable. Its dimensions have been deliberately optimized for platform suitability. With CO₂ savings in the WLTP of almost 20 % and the option of particularly high fuel savings in the 48-V PHEV design, the performance of the electric machine can make a substantial contribution to further CO₂ reduction. For future purely electric inner-city vehicle concepts (sub-A segment), 48-V high-power technology is suitable as the sole drive solution with significant advantages in terms of costs and packaging.

REFERENCES
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