Power Guaranteed

Rapid control prototyping of fuel-saving functions in a 48 V system

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When 48 V systems are used in vehicles, new high-performance functions and technologies can be introduced that significantly reduce fuel consumption. Within this context, Bosch Engineering China has developed a 48 V belt-driven starter generator. MicroAutoBox II, used as a prototyping controller here, has considerably accelerated the development process.

The evolution of vehicle power systems in voltage level and power demand has increased significantly during the past few decades. With the development of vehicle technology, the increasing use of electrical components in vehicle systems has led to better vehicle performance and reliability. However, the trend also leads to an exponential increase in the power demand and creates new challenges for the power net.

Why 48 V?

To meet the increasing power needs in the future, the current 12 V system is in transition to a higher voltage level system [1]. In addition, the higher voltage level also reduces the energy loss during the power distribution in the vehicle system. The 36 V and 42 V systems have been well discussed and analyzed in the past few years. However, they were not widely used in vehicle applications, because only a few SAE standards (SAE = Society of Automotive Engineers) were established for them. The 48 V system is a hot topic in Europe. Major OEMs, such as Audi, BMW, Daimler, Porsche and VW, have proposed the standard LV148 [2], which defines the concept of an operating voltage in a range from 25 V to 60 V. According to LV148, the unrestricted functional operation range lies between 36 V to 52 V (with an average of 48 V), which is below the 60 V threshold, so no special, expensive protection is needed to prevent electrical hazards (figure 1). This also leads to lower system costs in comparison with hybrid vehicles which operate at voltages higher than 60 V and require

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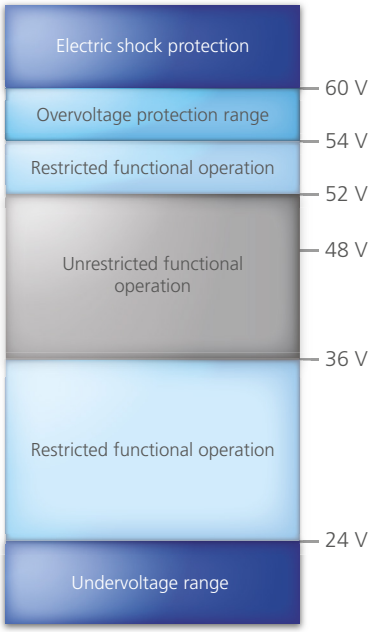


Figure 1: Safety voltage definition.

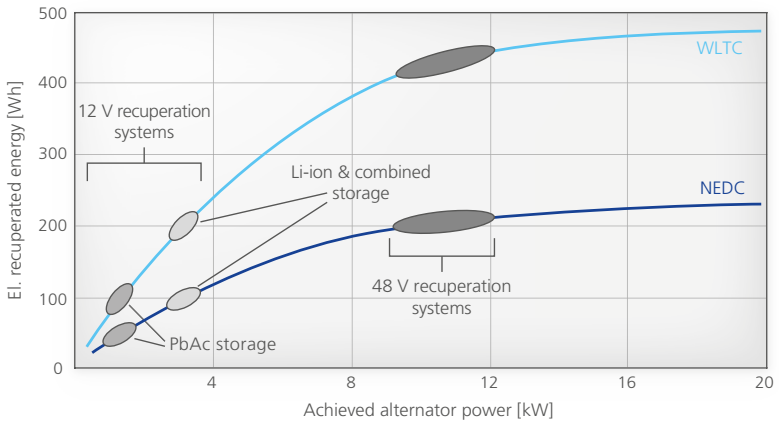
these safety mechanisms. In addition, significant fuel savings can be achieved by using a 48 V system instead of a traditional 12 V system, because the recuperation function (brake energy recuperation) in a 48 V system is capable of recuperating more energy than a 12 V system under the New European Driving Cycle (NEDC) and Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC). Figure 2 shows the qualitative advantages of a 48 V recuperation system. The most important points that speak for the widespread use of a 48 V system are:

- It enables the operation of high-power accessories, such as the air compressor, turbo, PTC auxiliary heater (PTC = positive temperature coefficient).
- Fuel-saving hybrid driving functions in terms of recuperation, boost, and start/stop can be easily implemented.
- The driving experience can be enhanced by adding more functionalities, such as comfortable start/stop, change-of-mind start (restart during power-down), and start/stop coasting.
- With the increase of system voltage, the cable current will be reduced, thereby decreasing cable power loss and improving power efficiency.

48 V System Overview

The Bosch boost recuperation system (BRS) is a 48 V belt-driven starter generator composed of three key components (figure 3): an air-cooled boost recuperation machine (BRM), a DC/DC converter (also called a power control unit, PCU), and a 48 V Li-ion battery. In the BRS, two power nets (48 V/12 V) co-exist and are connected via the PCU.

Figure 2: Recuperation under the driving cycles New European Driving Cycle (NEDC) and Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC).



In the 48 V system, the BRM, PCU, and 48 V Li-ion battery are connected electrically. The BRM can operate either as a generator or as a motor. As a generator, it charges the Li-ion battery according to the driving status. As a motor, it assists the engine with additional torque, which either enhances drivability or saves fuel. The 48 V Li-ion battery is used to absorb the recuperated braking energy and provide the power to the BRM during the comfortable engine cranking phase and the boosting phase. The 48 V Li-ion battery system contains the battery stack, relay box, and battery management system (BMS). The BMS has CAN interfaces that can send out the battery status and also receive the commands to control the main relay or coordinate the external charging function. The PCU has a nominal power of 2.5 kW, which completely fulfils the power requirement of a normal vehicle power net. The 48 V system provides the possibility to use higher electrical loads for the PTC auxiliary heater, an e-compressor for air conditioning, electric power steering (EPS), cooling fan motors, and window heating, for example.

Boost Recuperation Machine: Efficient Prototyping with dSPACE MicroAutoBox II

Several demo vehicles with a 48 V BRS have been developed by Bosch Engineering China. Figure 4 gives an overview of a prototype 48 V BRS from one of the demo vehicles. The 48 V BRS can achieve a convenient engine start/stop function (including start/stop coasting) which uses the belt-driven boost recuperation machine to recuperate the braking energy and store it in the 48 V Li-ion battery. It also provides an additional torque on the engine crankshaft to boost the vehicle, or it can move the vehicle purely electrically with limited speed and constrained functions (called E-creep). In short, with the described 48 V system, the start/stop, coasting, recuperation, boost, and E-creep functions can be

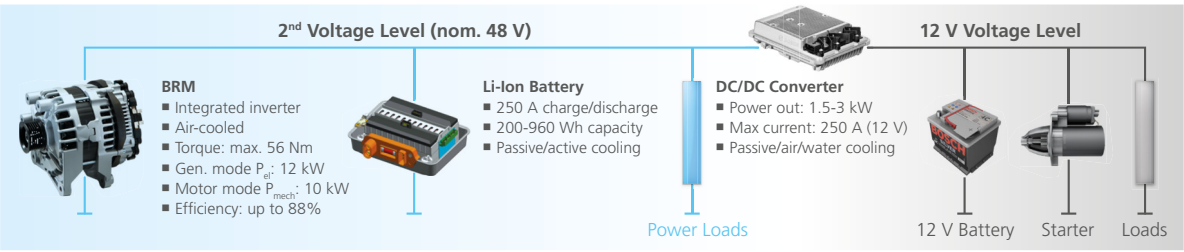


Figure 3: Layout of a Bosch 48 V belt-driven starter generator.

> "During the prototyping process, the control algorithms of the 48 V boost recuperation machine were run on a dSPACE MicroAutoBox II. This let us evaluate the influences on the entire vehicle at an early stage and significantly accelerate the development process."
>
> *Zhu Xiaofeng, Bosch Engineering China*

performed. The BRM is usually installed in the engine compartment, and the PCU and 48 V Li-ion battery are installed in the space of the rear trunk (figure 6). The BRS control algorithm runs on the MicroAutoBox II (1401/1511), which has 4 channels for CAN communication and enough resources for processing the digital/analog signals and can fully meet the control requirements at the hardware and software levels. In addition, the Gateway function in the RTI CAN Blockset provides the means to modify the original vehicle CAN network to implement the BRS functions. MicroAutoBox II is a compact module that can be installed in the vehicle and powered by the 12 V battery. The control software on the MicroAutoBox II has several layers and modules. In the application layer, there are two main modules: EEM coordination (EEM = electrical energy management) and powertrain coordination.

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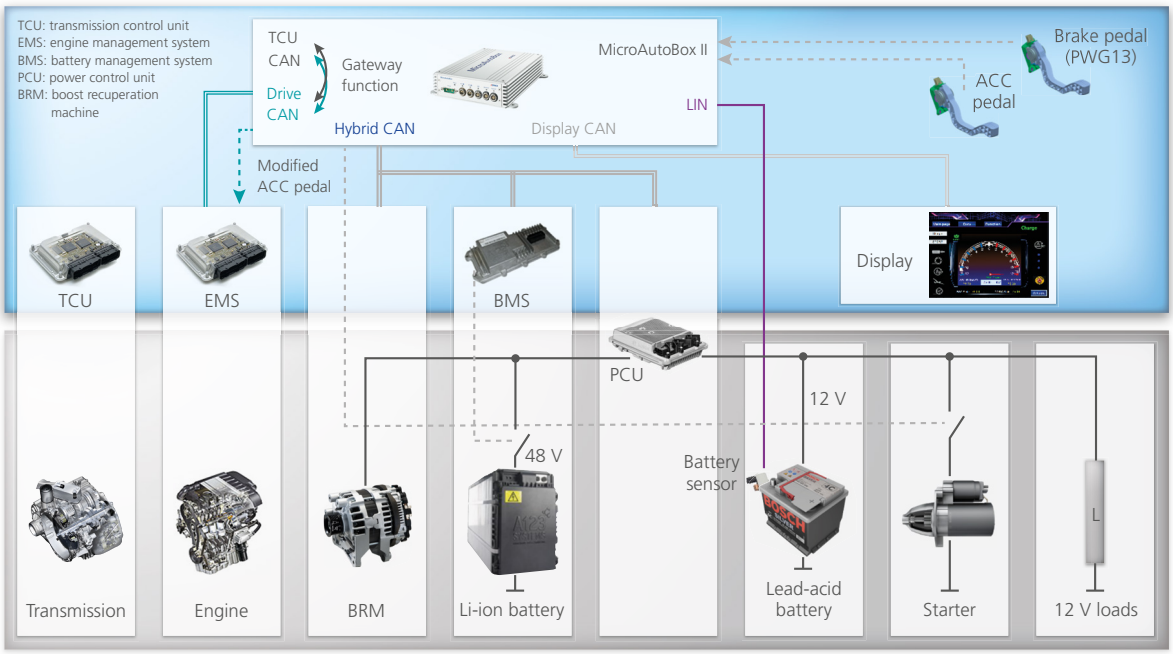
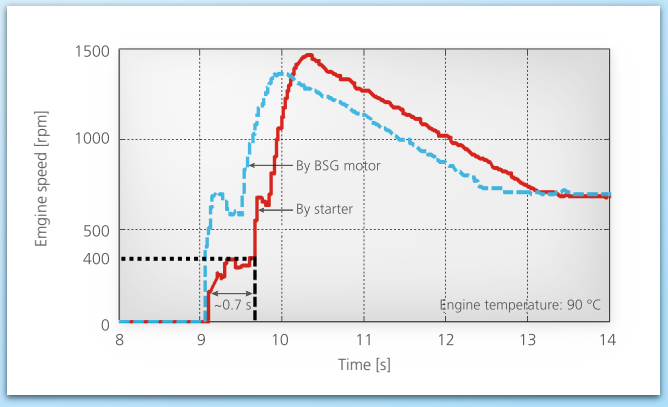
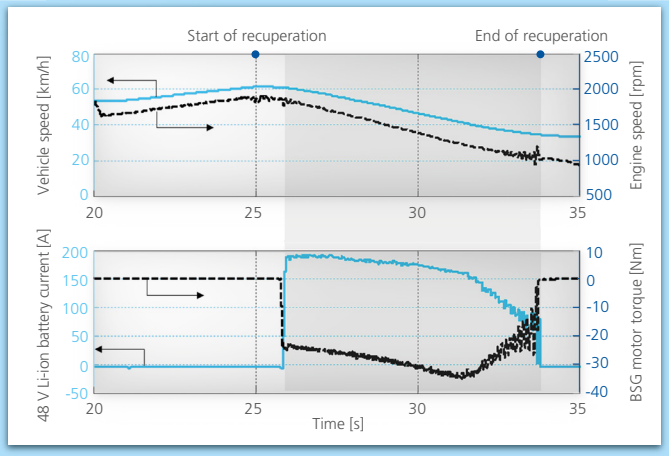
Figure 4: Prototyping a 48 V system with dSPACE MicroAutoBox II.





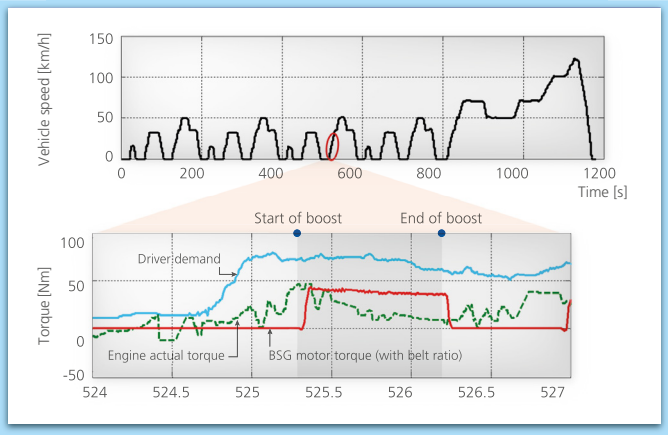
Engine Cranking

In direct comparison between a normal starter and the 48 V BSG motor, the cranking ability of the 48 V BSG motor reaches 400 rpm approximately 0.7 s faster. In addition, the BSG motor is connected with the engine crankshaft via a belt, resulting in less vibration during the engine cranking phase.



Recuperation

In this example of a typical braking process (around 8 s), the BSG motor works as a normal generator and recuperates the kinetic energy during the braking and stores it as electrical energy. The BSG torque is negative due to the recuperation command. During recuperation, the 48 V battery absorbs the energy with a current of up to 200 A. This free recuperated energy reduces fuel consumption.



Boosting During Engine Cranking

This graph shows the boosting process in the NEDC driving cycle. The 48 V BSG motor provides the torque (positive value, red solid line) to compensate the driver's demand torque (blue solid line).

Figure 5: Selected test data of the main functions in the 48 V system.

Figure 6: MicroAutoBox II installation (on the left) in a demo car.

Within the EEM coordination, the Power on/off management, EEM strategy, and basic diagnostics are included. The powertrain coordination has the start/stop function and the BSG motor (BSG = belt-driven starter generator) operation mode control strategies. The two main application modules transfer and receive the signal from the Real-Time Interface (RTI)-supported drivers in the lower layer, like CAN, LIN, and digital I/O.

Summary

With dSPACE MicroAutoBox II as a prototyping controller, the efforts on coding, such as the fixed-point adaption of the controller model and management of run-time resources (like RAM and flash space), are reduced significantly. Furthermore, the control algorithm can be focused on at the very beginning of the system development phase. With the rapid control prototyping approach, the development time for the demo vehicles and first prototypes is reduced remarkably, because functions can be realized more efficiently and real measurement data for future decisions is available in the early phase of mass production. There are even more benefits for the OEM. For example, the fuel-saving functions can be investigated with the 48 V technology on the target vehicle and the interactive system influences can be further studied for the complete vehicle design. In addition, the prototyping controller (i.e., MicroAutoBox II) can be integrated into the vehicle easily due to its compact size. ■

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References:
[1] Da Silva, W.; de Paula, P., 12V/14V to 36V/42V Automotive System Supply Voltage Change and the New Technologies [J], SAE Paper 2002-01-3557
[2] Kuypers, M., Application of 48 Volt for Mild Hybrid Vehicles and High Power Loads [J], SAE Paper 2014-01-1790

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