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Micro-hybrid electric vehicle application of valve-regulated lead–acid batteries in absorbent glass mat technology: Testing a partial-state-of-charge operation strategy

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ABSTRACT

The BMW Group has launched two micro-hybrid functions in high volume models in order to contribute to reduction of fuel consumption in modern passenger cars. Both the brake energy regeneration (BER) and the auto-start-stop function (ASSF) are based on the conventional 14 V vehicle electrical system and current series components with only little modifications. An intelligent control algorithm of the alternator enables recuperative charging in braking and coasting phases, known as BER. By switching off the internal combustion engine at a vehicle standstill the idling fuel consumption is effectively reduced by ASSF. By reason of economy and package a lead–acid battery is used as electrochemical energy storage device.

The BMW Group assembles valve-regulated lead–acid (VRLA) batteries in absorbent glass mat (AGM) technology in the micro-hybrid electrical power system since special challenges arise for the batteries. By field data analysis a lower average state-of-charge (SOC) due to partial state-of-charge (PSOC) operation and a higher cycling rate due to BER and ASSF are confirmed in this article.

Similar to a design of experiment (DOE) like method we present a long-term lab investigation. Two types of 90 Ah VRLA AGM batteries are operated with a test bench profile that simulates the micro-hybrid vehicle electrical system under varying conditions. The main attention of this lab testing is focused on capacity loss and charge acceptance over cycle life. These effects are put into context with periodically refresh charging the batteries in order to prevent accelerated battery aging due to hard sulfation. We demonstrate the positive effect of refresh chargings concerning preservation of battery charge acceptance. Furthermore, we observe moderate capacity loss over 90 full cycles both at 25 °C and at 3 °C battery temperature.

1. Introduction: BMW EfficientDynamics

Within the BMW EfficientDynamics initiative several activities are focused on the reduction of fuel consumption and CO_2 emissions of modern passenger cars. Those developments are based on increased efficiency of the internal combustion engines (ICE), a consequent lightweight construction strategy and sophisticated aerodynamic features of the car body. By an intelligent energy management the vehicle electrical power system also contributes to the EfficientDynamics program resulting in an upgrade of the conventional power supply to the micro-hybrid electrical power system. The BMW short-term strategic approach is to implement micro-hybrid functionality in almost the whole product portfolio in order to reduce the average CO_2 emissions of the BMW vehicle fleet according to the ACEA (European Automobile Manufacturers' Association) voluntary agreement in 1998. In a further mid-term oriented step higher levels of powertrain hybridization are developed and implemented in mild and full-hybrid vehicles.

2. Micro-hybrid electrical power system

As first Original Equipment Manufacturer (OEM) the BMW Group has introduced micro-hybrid functions in high volume series vehicles in March 2007 (see Fig. 1). As described in detail in Sections 2.2 and 2.3 the micro-hybrid functions are based on the 14 V power system with only slightly modified current series components and a 12 V valve-regulated lead–acid (VRLA) battery in absorbent glass mat (AGM) technology.

Diegelmann et al. [1] describe the micro-hybrid electric vehicle (Micro-HEV) as an intermediate stage towards the development of BMW mild-hybrid electric vehicles (Mild-HEV) and full-hybrid electric vehicles (Full-HEV). The lowest level of hybridization, the Micro-HEV, combines brake energy regeneration (BER) with an auto-start-stop function (ASSF) of the internal combustion engine,

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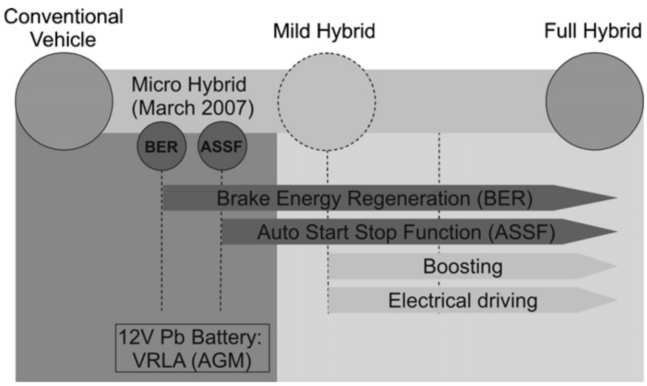

Fig. 1. According to [1]. Powertrain micro-hybridization is described as intermediate stage towards BMW mild-hybrid and full-hybrid electric vehicles.

which is conceptually part of higher level HEVs as well. Advanced functionalities like boosting and electrical driving require higher voltage systems and therefore nickel/metal-hydride (NiMH) and high-power lithium-ion (Li-ion) batteries, respectively. More specific vehicle attributes of Mild-HEVs and Full-HEVs, especially energy management aspects and energy storage requirements are discussed by Karden et al. [2].

2.1. Topology of the Micro-HEV power system

In Fig. 2 the topology of the micro-hybrid electrical power system is schematically depicted. The intelligent battery sensor (IBS) acts as a main component in conjunction with a bit-serial data (BSD) interface, which is an advanced interface to the slightly modified alternator. The IBS is directly connected to the negative terminal post of the VRLA battery. By continuously measuring battery voltage, current and temperature also in the sleep mode, the intelligent battery sensor acquires critical data for the algorithms of brake energy regeneration and automatic engine start/stop. These algorithms are implemented in the power management software module as part of the vehicle electrical energy management on the engine control unit (ECU). The ECU and the electric consumers within the vehicle electrical system are cross-linked via bi-directional communication in a conventional controller area network (CAN) bus.

2.2. Functionality of automatic engine start/stop

The auto-start-stop function, ASSF, switches off the internal combustion engine automatically if a standing phase is recognized—like stopping at a traffic light, in a traffic jam or at a railroad crossing. ASSF restarts the engine automatically on demand of the driver. For the driver the operation of ASSF is implemented as intuitional as possible. Fig. 3 illustrates the procedure of ASSF in combination with a manual gear shift. The ASSF is only triggered if the driver stops the car, engages the neutral gear and releases the clutch. If several technical on-board requirements are fulfilled, ASSF will switch off the engine automatically and display the current state of the machine in the instrument panel.

Approximately the amount of fuel which is usually consumed by the engine idle during the red traffic light phase is not used and the according CO_2 emissions are not produced. If the driver operates the clutch and therefore sets the requirement for continuation of the ride, the engine will be restarted automatically. The high number of starts has to be accomplished reliably, accompanied by as few vibrations and noise as possible. Furthermore, the traction power has to be provided immediately after an engine switch-on. Therefore, the starter system is enforced compared to previous series systems.

During the vehicle standstill all electrical consumers are provided with electrical energy from the battery acting as additional load for the battery. The engine restart after each automatic stop also results in a significantly increased number of high-rate load phases during battery cycle life. These aspects will be faced in Section 3.

The automatic restart opposes the fuel saving potential during standstill by temporarily increased consumption. This effect is compensated by a minimum engine-off time period of 5 s according to Wolff et al. [3]. They report about a maximum potential for fuel savings of 3.5% in the New European Driving Cycle (NEDC). In the first launch, ASSF is integrated in 4-cylinder vehicles with manual gear shift and always combined with BER. Since BER is available in vehicles with automatic transmission and/or bigger engines without ASSF, the number of affected cars is higher.

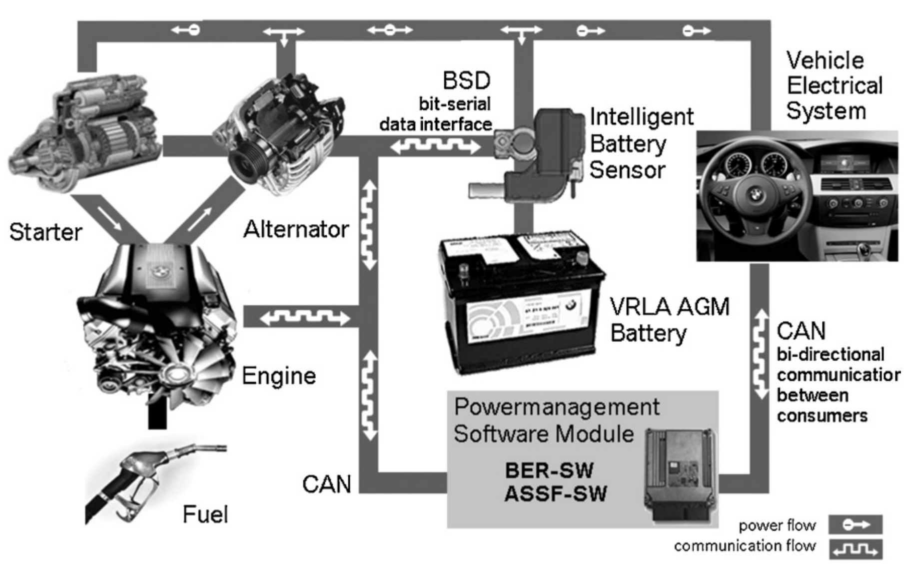

Fig. 2. Schematic topology of the micro-hybrid electrical power system. Main components are the power management software (SW) module integrated in the engine control unit, the VRLA AGM battery and the intelligent battery sensor.