Microcontrollers for the drive train in hybrid and electric vehicles

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The electric drive train is superior in many respects to the conventional drive train with combustion engines. The electric motor has higher efficiency, as well as better torque and performance.

An electric drive train provides a much simpler mechanical design while eliminating undesirable noise and pollution emissions. Although today's electrical energy storage systems limit the vehicle range employing intelligent battery management and the hybrid concept (i.e., the combination of electric motor and combustion engine), helps to compensate for this.

In addition, certain system faults can be dangerous to passengers and damage the electrical components of the vehicle, so automotive safety requirements, under the ISO 26262 standard, must be taken into account. This article describes the types of e-machines used, the electronic controller for e-motor control, and the resulting specific demands on the microcontroller.

The various development stages of electric vehicles range from simple start/stop systems, to mild hybrids, in which an electric motor provides the combustion engine with torque support, to full electric vehicles. In full electric vehicles, a distinction is made between parallel and serial architectures. In parallel architectures, either combustion engines or electric motors directly power the vehicle. Serial architectures, also known as "range extenders," can drive solely on electric power. A small combustion engine is switched on when the batteries need recharging.

Switched reluctance machines and three-phase asynchronous machines are sometimes used for electric motors, but permanent magnet synchronous motors (PMSM) are most widely used because of their high efficiency, high-power density and high torque, even at low speeds. The synchronous machine runs with a synchronous rotor and stator frequency speed.

Depending on the type of vehicle, it can be powered by a single electric motor, one electric motor per axle or one per wheel, as in wheel-hub motors. All of these systems have been realised in electric vehicles or prototypes today. When braking in recuperation mode, the kinetic energy is converted into electrical energy and stored in the battery (regenerative braking). During this mode the electric motors of the drive are used as generators.

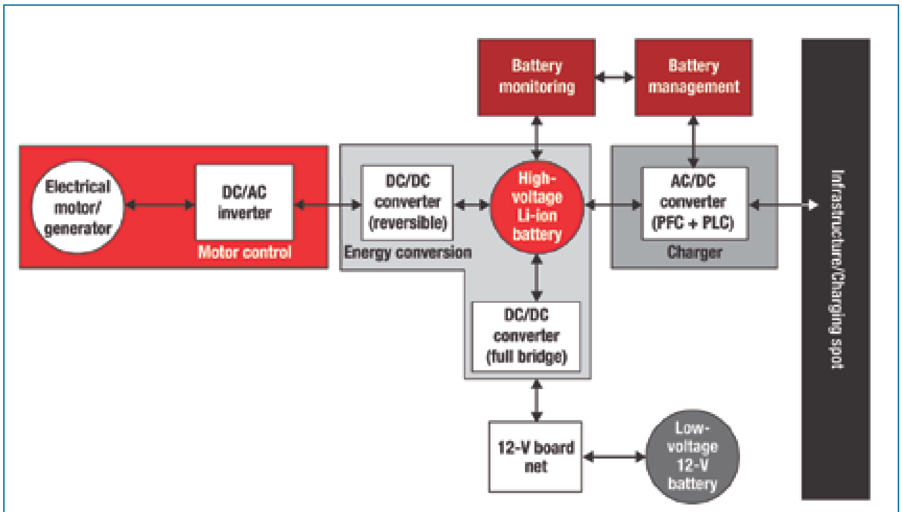

Fig. 1: System architecture of an electric vehicle.

Power inverter and electric control unit

The high-voltage battery in mild hybrids has a range of about 40 – 150 V; in full hybrids the voltage range is several hundred volts. The pulse inverters used (DC/AC inverters) typically have a B6 bridge configuration with MOSFETs as electronic circuit breakers for voltage ranges up to approximately 120 V. At higher voltages, insulated gate bipolar transistors (IGBTs) with the lowest possible on-state resistance and low-switching losses are used. The motor controller consists mainly of the digital microcontroller, components for regulating and monitoring the motor and power electronics and modules for processing sensor signals, communication and power supply.

Measuring the phase currents

To regulate the torque of the motor, the microcontroller requires instantaneous information on the phase currents of the motor in every control cycle. Phase currents of several hundred amps can occur at high torques. For this reason, current transformers with galvanic isolation are used between the primary (heavy current circuit) and secondary circuit (electronic circuit). These converters are based on the Hall Effect and typically deliver an output voltage on the secondary side that is proportionate to the current to be measured. The advantage of Hall Effect current converters is that they can be placed outside the signal cable therefore they do not interfere with the signal (contact-free). Using an alternative of serial measuring shunt resistors, resistive losses and overheating would occur which is problematic for measuring high currents, but these Hall Effect current converters do not exhibit these effects and even resist very high currents in the primary cable.

Isolation

Since currents and voltages in the inverter are much higher than in the control unit of the microcontroller, isolation is required at all interfaces between these components in order to protect the control unit from failure and malfunction. Texas Instruments offers automotive-qualified digital isolators with the ISO72xx family featuring low-power consumption and clock speeds of up to 250 Mbps. These modules use capacitive galvanic isolation, which compared to optical or magnetic isolation, exhibits very good characteristics with regard to clock speed, reliability, ESD protection and EMC behaviour.

The microcontroller

The Hercules TMS570LS safety microcontrollers are used in the automotive sector in complex and safety-critical systems. These microcontrollers aid in the development of safety-critical applications since they were specifically designed to meet and have been deemed suitable for use in safety integrity level 3 (SIL3) under the IEC 61508 standard. These safety microcontrollers will be highlighted in greater detail below with respect to function and safety characteristics for use in drive controls for electric vehicles.

The field-oriented principle for controlling rotating field e-machines is state-of-the-art. Communication networks, online safety and diagnostic functions, standardised software architectures (i.e., AUTOSAR), and the field-oriented control routines can lead to high demands on the microcontroller's processing power and memory requirements. Faster microcontrollers generally permit a higher function density and especially for e-motor drives, better dynamics and control efficiency because shorter control loop times can be achieved.

To tackle the increased processing load, the Hercules TMS570LS safety microcontroller series offers the 32-bit ARM Cortex-R4F CPU which can be clocked at up to 180 MHz (>280 DMIPS) and includes a double-precision floating-point unit (FPU) for fast 32-bit and 64-bit floating-point operations (IEEE 754). The floating-point and integer operations can run in parallel to achieve higher processing power. The FPU facilitates software development since control and regulating algorithms are increasingly being developed with model-based code generators, whose results are then integrated into the entire project as floating-point subprograms.

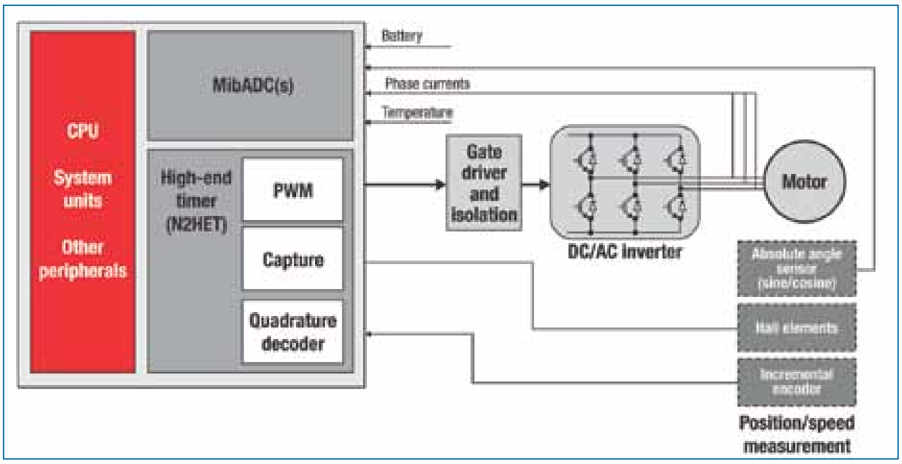

Fig. 2: Microcontrollers and power electronics for controlling the electric motor.

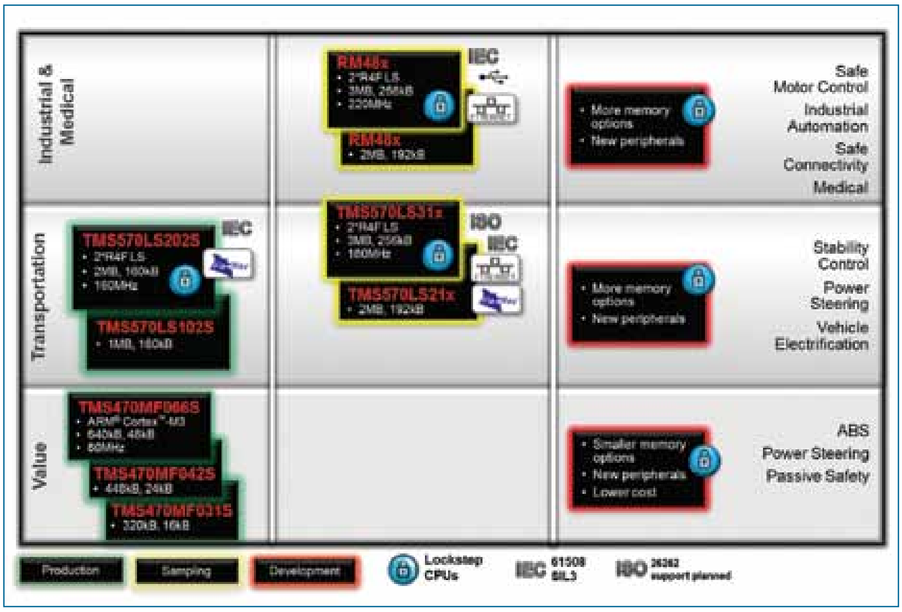

Fig. 3: Hercules safety microcontroller roadmap.

The ARM Cortex-R4F core can process 16- or 32-bit commands, depending on the requirements of the program code because of the Thumb-2 instruction set, resulting in an optimal compromise between processing speed and code size. The Hercules TMS570LS safety microcontroller series is currently available with large amounts of integrated Flash memory from 1 to 3 MB and data memory from 128 kB to 256 kB.

High-end timer coprocessor

The high-end timer (N2HET) module of the safety microcontroller series is a flexible, user programmable, timing generator and capture engine. A single program can control up to 32 pins that can be freely configured as input or output. The N2HET program is copied into its local RAM during system initialisation. During operation, the core can update key values in the N2HET RAM in order to create pulse width modulations (PWM) or read out values captured by input pins. In order to further reduce the CPU's load, transactions between the N2HET RAM and the CPU memory can also be carried out by system direct memory access (DMA) or the high-end transfer unit (HTU), a DMA controller specific to N2HET. Due to its high degree of flexibility, the N2HET is capable of generating simple, as well as very specialised timer requirements, such as the PWM control of an electric motor or the reading in sensor signals. The N2HET also has the ability to implement state machines without CPU load because it can process input signals and create appropriate output responses or status information on its own.

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