Technical training.
Product information.

F04 Complete Vehicle

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Technical Training
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BMW Service

General information

Symbols used

The following symbol / sign is used in this document to facilitate better comprehension and to draw attention to particularly important information:

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contains important safety guidance and information that is necessary for proper system functioning and which it is imperative to follow.

Information status and national-market versions

The BMW Group produces vehicles to meet the very highest standards of safety and quality. Changes in terms of environmental protection, customer benefits and design make it necessary to develop systems and components on a continuous basis. Consequently, this may result in differences between the content of this document and the vehicles available in the training course.

As a general principle, this document describes left-hand drive vehicles in the European version. Some controls or components are arranged differently in right-hand drive vehicles than those shown on the graphics in this document. Further discrepancies may arise from market-specific or country-specific equipment specifications.

Additional sources of information

Further information on the individual topics can be found in the following:

- in the Owner's Handbook
- in the integrated service technical application

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The information in the document is part of the BMW Group technical training course and is intended for its trainers and participants. Refer to the latest relevant BMW Group information systems for any changes/supplements to the technical data.

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1. Introduction

As part of BMW EfficientDynamics, the BMW Group began early on to develop a wide variety of measures for promoting efficiency. These measures have since been implemented across the entire model line and are included as standard equipment.

BMW ActiveHybrid is an important module within the development strategy of BMW EfficientDynamics and is based on the modular principle "Best of Hybrid". It enables integration of the optimum components for each of the different vehicle classes. The primary development objectives are, on the one hand, a considerable increase in efficiency, i.e. a reduction in fuel consumption of up to 20 percent in the legally mandated consumption test cycle with lower CO_2 emissions compared to BMW models with a conventional engine. On the other hand, the BMW Group wants to offer the most dynamic hybrid vehicle in the competitive environment.

ActiveHybrid 7

On the heels of the ActiveHybrid X6, in spring 2010 BMW launched its second series-production vehicle with hybrid technology, the BMW ActiveHybrid 7 (F04). Unlike all the other hybrid vehicles currently available on the market, the ActiveHybrid 7 is characterized by the fact that, in addition to high efficiency, it delivers equally great performance and agility – thereby providing the ultimate benchmark when it comes to vehicle dynamics amidst the competition.

The powertrain of the BMW ActiveHybrid 7 includes an especially tuned (gasoline powered V8) N63 engine with 450 hp/330 kW (5500 - 6000 rpm) supplemented by an electric motor with 20 hp/15 kW (900 - 4500 rpm) located inside the transmission bellhousing. The maximum power output is 455 hp/342 kW (5500 - 6000 rpm) with a maximum torque of 515 lb-ft (700 Nm). The electric motor increases overall power and reduces fuel consumption as it functions as a generator (during vehicle regenerative braking) to provide current back to the lithium-ion battery pack located in the trunk. The same electric motor is also used to start the gasoline engine, eliminating the need for a traditional starter.

Although the motor relieves the load on the combustion engine and provides a supplemental power boost during certain acceleration situations, it cannot propel the vehicle by itself. This classifies the powertrain as a “mild hybrid”. Delivering 12-cylinder performance with 6-cylinder fuel consumption, the BMW ActiveHybrid 7 offers noticeably better performance (when accelerating from a standstill) and also has better low-end torque than the BMW 750i. The hybrid system has an excess weight of only about 165 lb (75 kg) compared with the conventional powertrain. The 8-speed automatic transmission has the same design as that of the BMW 760i/Li. The vehicle also incorporates a “stop/start” function, known as Auto Start/Stop. This system increases fuel efficiency by stopping the engine when the vehicle comes to a stop, without any driver interaction and restarting it when the driver continues.

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The F04 (short wheel base) accelerates from 0 to 60 mph in 4.7 seconds and the long wheel base version in 4.8 seconds. The overall combined fuel economy is a “preliminary” 20 mpg. The vehicle's CO_2 emissions equate to a value of 219 grams per kilometer. It also complies with the American LEV-II exhaust emission standards.

1.1. Identifying features

1.1.1. Exterior

BMW ActiveHybrid vehicles differ externally from other BMW vehicles through various features. These include, the exclusive exterior color "Bluewater metallic", which signifies the innovative BMW ActiveHybrid technology. This primary exterior color (within the Series) is reserved exclusively for ActiveHybrid vehicles. However customers can also choose other colors for their ActiveHybrid vehicles and order their ActiveHybrid 7 as a short or long wheelbase (ActiveHybrid 7 / ActiveHybrid 7L).

Exterior identifying features

Index	Explanation
1	"Bluewater metallic" paint color
2	"ActiveHybrid 7" badge on the trunk lid
3	"ActiveHybrid 7" badge on both C-pillars
4	Door sill strips with "ActiveHybrid 7" wording featuring 4 times in the long version and only at the front in the normal version
5	Aero wheel (Streamline 357)

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The rims of the BMW ActiveHybrid 7 have their own original look. Not only does the directional turbine blade shape look good, it also improves the car's aerodynamics (2 g/km fewer CO_2 emissions).

The "ActiveHybrid 7" badge appears on the trunk lid. This wording is also featured on both C-pillars. The door sill strips featuring the "ActiveHybrid 7" wording enhance the appearance of the door entry area. In the luggage compartment the wording "ActiveHybrid Power Unit" is featured on the casing of the high-voltage battery.

1.1.2. Interior

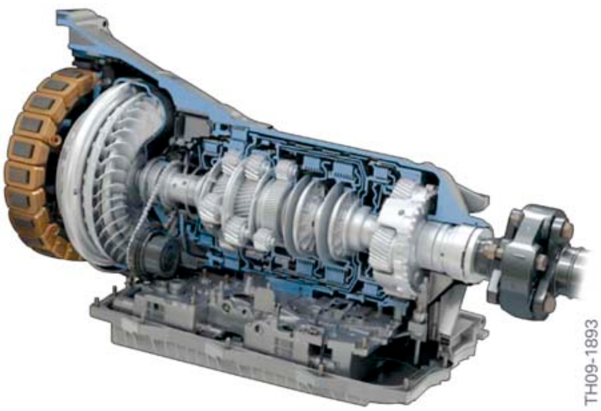
The luxurious "Oyster" color in the BMW ActiveHybrid 7 in nappa leather lends the interior an appearance of high quality and sophistication.

Interior identifying features

Index	Explanation
1	Hybrid-specific displays in the instrument cluster
2	Hybrid-specific displays in the CID

If they so wish, the customer can display in the CID the hybrid-specific power/energy flows or the electrical energy consumption from the last 15 minutes.

1.2. Electric motor



Electric motor and 8-speed automatic transmission in the F04

The electric motor connected to the crankshaft and located between the combustion engine and the transmission develops 20 hp/15 kW and supports the 8-cylinder engine in driving off and accelerating with a torque of up to 155 lb-ft (210 Nm). The electric motor also permits a reduction in fuel consumption by lowering the engine revs up to 600 rpm. It acts as a starter or generator, depending on the driving situation. This is useful above all in heavy urban traffic, because it provides for a barely perceptible automatic engine start-stop function. In generator mode the electric motor generates electrical energy through coasting and brake energy regeneration, which is stored in the lithium-ion battery. The power output of the electric motor can increase up to 25.5 hp (19 kW) in this mode.

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1.3. Lithium-ion battery

Lithium-ion battery in the F04

The technical highlight of the progressive mild hybrid drive is the highly efficient lithium-ion battery. Relatively new to the automotive industry, it has the highest energy density of all battery types. It is only slightly larger than a conventional 12 V battery and weighs only about 62 lb (28 kg). Because of its compact volume it has been incorporated in the installation space of the (optional) rear air conditioner and integrated in the vehicle. The lithium-ion battery has a capacity of 0.9 kWh and is ideally suitable for use in mild hybrid vehicles, which because of their design do not need a more powerful battery. The BMW ActiveHybrid 7 and the Mercedes-Benz S 400 Hybrid are the world's first hybrid vehicles to feature this particularly powerful battery technology.

1.4. Driving situations

1.4.1. Automatic engine start-stop function

ActiveHybrid 7

As the BMW ActiveHybrid X6 the BMW ActiveHybrid 7 is also equipped with an automatic engine start-stop function in conjunction with an automatic transmission. The automatic engine start-stop function switches off the combustion engine when at idle, for example, at a red light or in a traffic jam. This means that the engine is not emitting CO_2 and fuel consumption is reduced. While the vehicle is at a standstill the high-voltage battery supplies power for climate control, vehicle lights, etc. If the state of charge of the high-voltage battery is not sufficient to cover these loads, the combustion engine is started to charge the high-voltage battery using the electric motor and provide enough electrical energy to power the various consumers.

For the first time the climate control system can continue to run even when the combustion engine is switched off, because the climate control is supplied with power directly via the high-voltage electrical system from the lithium-ion battery. This energy management concept facilitates the operation of the independent (parked-car) air conditioning, which when required, can be set up to cool the interior of the BMW ActiveHybrid 7 to a significantly lower temperature before the customer enters the vehicle.

1.4.2. Driving off

When the driver's foot comes off the brake pedal, the combustion engine is quickly started and with minimal vibration. When the Automatic Hold function is activated the combustion engine is started only when the accelerator pedal is pressed.

Power development begins just above idle speed. The resulting dynamic response is further reinforced by the additional drive torque developed by the electric motor. The response to the accelerator pedal of the BMW ActiveHybrid 7 (especially when driving off from a standstill) produces an acceleration performance thus far unmatched neither by other combustion engine vehicles nor by any competitor hybrid model. Accelerating from 0 to 100 km/h (62mph) in 4.9 s places the F04 among the performance of the top-class sports cars.

A newly developed hydraulic pressure accumulator ensures an accelerated build-up of transmission fluid pressure in the 8-speed automatic transmission that enables the vehicle to drive off very quickly just after starting the engine.

1.4.3. Steady driving

While the vehicle is driving on the combustion engine the electric motor can (depending on the driving speed and the state of charge of the battery) be operated in different modes. Combustion engines do not operate at maximum efficiency when required to propel the vehicle at low to medium speeds. The electric motor, in contrast, is capable of delivering full torque at very low rpm. When the high-voltage battery is sufficiently charged, the electrical energy can be drawn from the battery in order to place the combustion engine in a more favorable load range and thereby optimize its efficiency. A combustion engine can operate at maximum efficiency when the vehicle is being driven at a steady, relatively high speed. At this end of the performance band the electric motor would have to draw too much energy from the high-voltage battery, therefore, the combustion engine is the primary driving source under these conditions. If the high-voltage battery is in a low state of charge, part of the power developed by the combustion engine is used to recharge the battery through the electric motor.

1.4.4. Acceleration

The particular advantage of the electric motor lies in its spontaneous and strong performance when driving off. The driver gets a impressive sense of this when accelerating or overtaking another vehicle. When sharp acceleration is needed from a complete stop, to overcome a steep gradient or to pass slower traffic, if the high-voltage battery is sufficiently charged, its power can be tapped and the additional force made available as kinetic energy through the electric motor. This is known as the boost function. The combination of the power outputs of the combustion engine and the electric motor achieves levels of driving dynamics and powerful acceleration normally encountered in vehicles with larger more powerful engines. The electric motor acts here like a kind of "electric turbocharger", which also supports the combustion engine when accelerating and does so without additional fuel consumption.

1.4.5. Brake energy regeneration

When the driver's foot comes off the accelerator pedal, the electric motor acts as a generator to generate electric power without consuming fuel. Like a bicycle dynamo, it converts the kinetic energy of the rolling vehicle into electrical energy. The high storage capacity of the high-voltage battery makes it possible to take advantage of the energy recovery potential.

The ability to utilize the kinetic energy that would otherwise be shed on descents or wasted when the car is decelerating is one of the main advantages of a hybrid drive. Instead of the energy only being converted into heat at the brakes, it is converted by the electric motor (which functions as a generator) into electrical energy and stored in the high-voltage battery. This energy, which can be reused later, does not have to be generated by the combustion engine. If the driver brakes lightly, the electric motor generates even more power and acts like an engine brake. This is known as recuperation or regenerative braking. The mechanical/hydraulic brakes do not need to work until stronger braking is required.

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1.5. Cooperation

In order to bring various concepts with innovative solutions to market faster, the BMW Group worked in cooperation with two other manufacturers. From this union arised components for different hybrid concepts that allowed the use of a modular system for developing drive concepts tailored to the respective vehicle types and that have a high savings potential.

For the full hybrid vehicle, the ActiveHybrid X6, Chrysler, Daimler and General Motors participated within the "Global Hybrid Cooperation".

The hybrid components used in the BMW ActiveHybrid 7 come from the cooperation between BMW and Daimler. The purpose of this cooperation is to develop and test components which are used as hybrid drives for luxury performance vehicles. Apart from the electric motor and the lithium-ion battery, the power electronics for the high-voltage electrical system of the BMW ActiveHybrid 7 also emerged from this cooperation. The manufacturers integrate the hybrid components into the respective vehicles in accordance with individual, brand-specific requirements. This original characteristic is exemplified in the BMW ActiveHybrid 7 by its combination of an 8-cylinder engine with an electric motor. BMW ActiveHybrid is based on a modular principle which, following the "Best of Hybrid" strategy, ensures perfect integration of the optimum components in various vehicle concepts. Thus the mild hybrid concept of the BMW ActiveHybrid 7 is just as ideally tailored to the model-specific requirements as the full hybrid concept for the BMW ActiveHybrid X6.

Through consistent use of common components, production plants and suppliers, the cooperation enables significant cost advantages, from which the customer also benefits.

1.6. Technical data

The ActiveHybrid 7 will only be available in a left-hand drive version. Its introduction will therefore not be worldwide, but instead limited to selected markets.

		BMW ActiveHybrid 7	**BMW 750i**	**Mercedes S 400 Hybrid**	**Lexus LS 600h**
Engine and transmission					
Design/no. of cylinders/valves per cylinder		V8/4	V8/4	V6/4	V8/4
Displacement	cm^3	4395	4395	3498	4969
Transmission		8-speed automatic	6-speed automatic	7-speed automatic	Infinitely variable automatic
Drivetrain		Rear-wheel	Rear-wheel	Rear-wheel	Four-wheel
Maximum combustion engine power	hp (kW) rpm	440 (330) 5500–6000	400 (300) 5500–6400	205 (279) 6000	290 (394) 6400
Combustion engine torque	lb-ft (Nm) rpm	480 (650) 2000–4500	450 (600) 1750–4500	(350) 2400–5000	(520) 4000

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		BMW Active-Hybrid 7	BMW 750i	Mercedes S 400 Hy-brid	Lexus LS 600h
Complete sys-tem power	hp (kW) rpm	455 (342) 5500–6000	400 (300) 5500–6400	200 (220)	445 (327)
Overall torque	lb-ft (Nm) rpm	515 (700) 2000–3000	450 (600) 1750–4500	(385)	No data
Battery type		Lithium-ion	-	Lithium-ion	Nickel metal hy-dride
Vehicle perfor-mance					
Acceleration 0-100 km/h/62mph	s	4.9	5.2	7.2	6.3
Maximum speed (limited)	mph (km/h)	155 (250)	155 (250)	155 (250)	155 (250)
Fuel economy and emissions					
City	mpg	17	15	19	20
Highway	mpg	26	22	26	22
Combined	mpg	20	17	22	20
CO_2 emissions	g/km	219	266	186	219
Dimensions and weights					
Length/width/height	mm	5072/1902/1485	5072/1902/1479	5096/1871/1485	5030/1875/1465
Wheelbase/turn-ing circle	mm / m	3070 / 12.5	3070 / 12.2	3035 / no data	2970 / no data
Track width front/rear	mm	1621 / 1632	1611 / 1650	1600 / 1606	1630 / 1635
Vehicle curb weight	kg	2120	2020	1955	2345

1. Introduction

		BMW ActiveHybrid 7	BMW 750i	Mercedes S 400 Hybrid	Lexus LS 600h
Payload in accordance with DIN	kg	590	630	595	385
Fuel tank capacity	l	80	82	84	80
Luggage compartment capacity	l	460	500	560	390

The F04 and F01/F02 differ not only in the technical data but also in the range of optional equipment offered.

The most important optional equipment which is not offered in the F04 is briefly summarized below:

- xDrive four-wheel drive system (installation location of the front differential is taken up by the power electronics)
- Integral Active Steering
- Dynamic Drive
- Active Cruise Control with Stop & Go function
- Extended rear air conditioning (rear air conditioner, installation location is taken up by the lithium-ion battery)

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2. Powertrain

2.1. Modified N63 engine

2.1.1. Overview

The N63B44O0 engine from the F01/F02 is used in the F04.

The engine has however been modified in the following areas:

- Engine management
- Technical data
- Auxiliary components
- Belt drive
- Cooling system

The engine management DME (Digital Engine Electronics) in terms of its hardware is essentially the same as that in the F01/F02 (MSD 85), but has an additional CAN connection. As well as the PT-CAN and the PT-CAN2 the DME in the F04 also communicates via the Hybrid-CAN (H-CAN) with the electric motor electronics. The DME software has been adapted to this new communication interface: The DME coordinates the two drives, i.e. the drive torque requested by the driver is (depending on the driving situation) distributed to the combustion engine and the electric motor.

The maximum power output and the maximum torque of the engine have been increased exclusively through adaptation of the software. The table below shows the difference in these data between the F01/F02 and the F04.

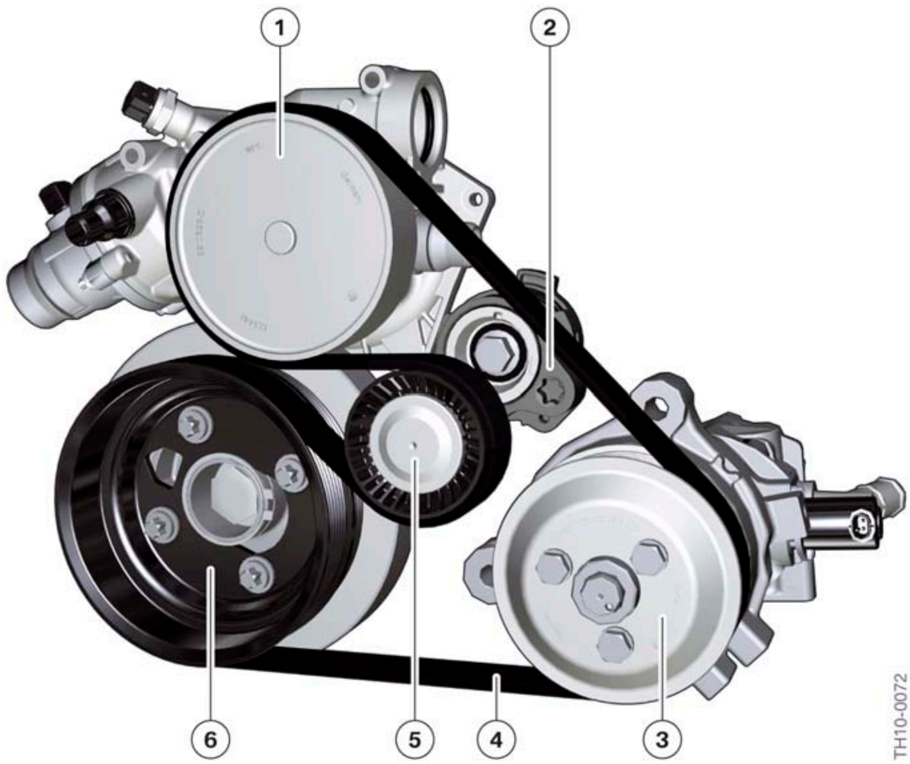
Data	Unit	N63B44O0 in F01/F02	N63B44O0 in F04
Maximum power at engine speed	hp [kW] [rpm]	400 [300] 5500–6400	440 [330] 5500–6000
Maximum torque at engine speed	lb-ft[Nm] [rpm]	450 [600] 1750–4500	480 [650] 2000–4500

The following auxiliary components on the N63 engine are not featured in the F04:

- Starter (combustion engine is started by the electric motor of the hybrid drive)
- 14 V alternator (14 V electrical system is supplied with power by the high-voltage electrical system)
- Mechanically driven A/C compressor (replaced by an electrically driven A/C compressor).

2.1.2. Belt drive

The omitted auxiliary components mean that the F04 N63 engine features a simplified belt drive (pictured below).



Belt drive for N63 engine in the F04

Index	Explanation
1	Belt pulley of mechanical coolant pump
2	Belt tensioning device
3	Belt pulley of power steering pump
4	Poly-V belt
5	Belt tensioning pulley
6	Belt pulley on torsional vibration damper

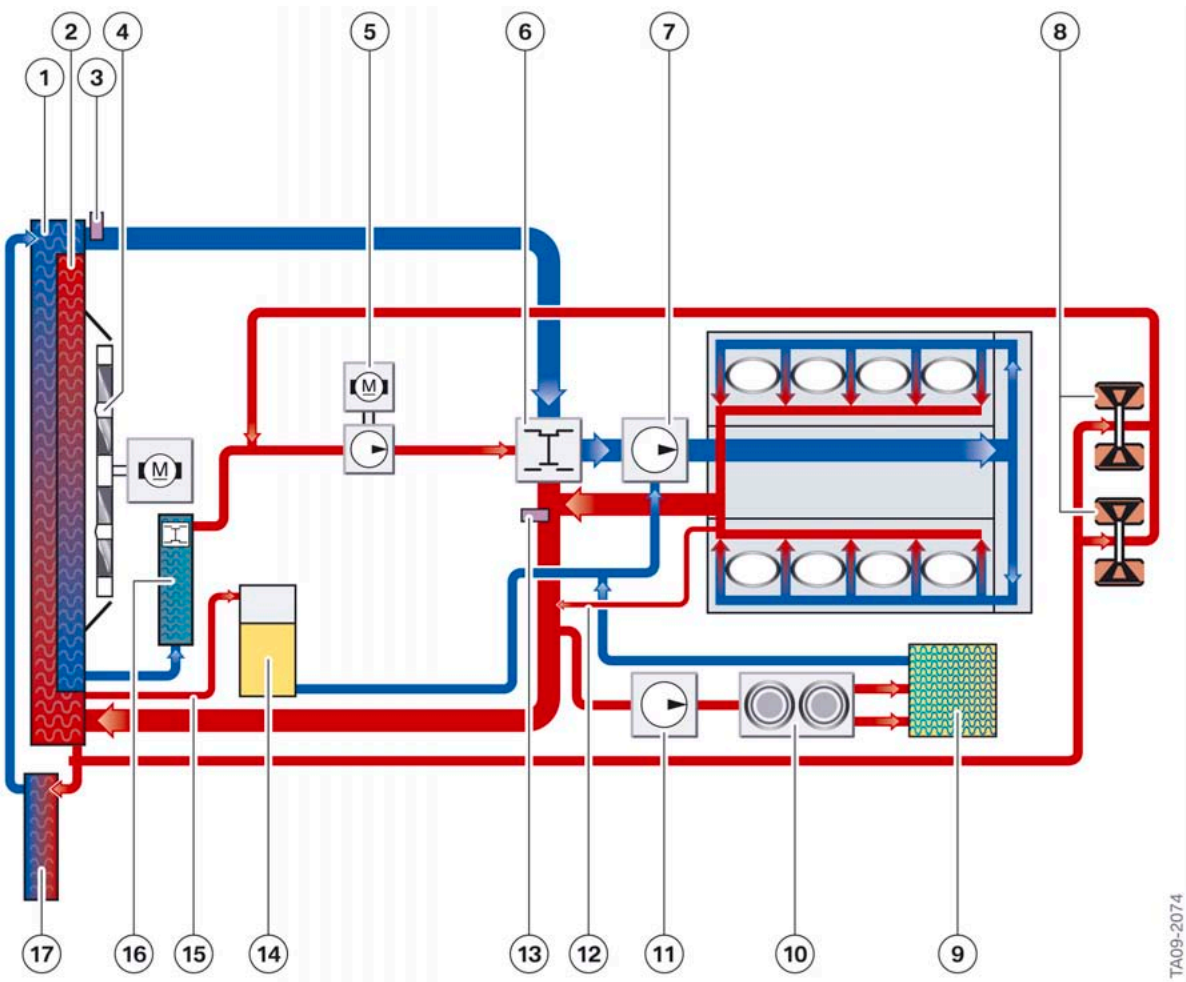
The combustion engine therefore only drives the mechanical coolant pump and the power steering pump with the aid of the belt. A poly-V belt is used instead of an elasto-belt as on the F01/F02. Therefore it cannot be tensioned either via the "revolver tensioning system", which is visible on the belt pulley on the torsional vibration damper. Instead the separate tensioning pulley must be used to tension the belt. The torsional vibration damper has been altered when compared with the N63 engine in the F01/F02. The reason for this is the greatly modified drivetrain in the F04, in which the electric motor has been integrated and because of which the vibrational behavior at the crankshaft has changed.

2.1.3. Cooling system

The F04 N63 engine has two separate cooling circuits (as F01/F02). One serves to cool the engine, while the other is a low-temperature cooling circuit which serves to cool the charge air (intercoolers), the engine management and the power electronics for the electric drive.

2.1.4. Engine cooling

The main cooling circuit for engine also supplies the bearings of the turbocharger with coolant. A 20 W auxiliary coolant pump supports the mechanical main coolant pump and circulates coolant through the turbocharger even after the engine has been stopped.



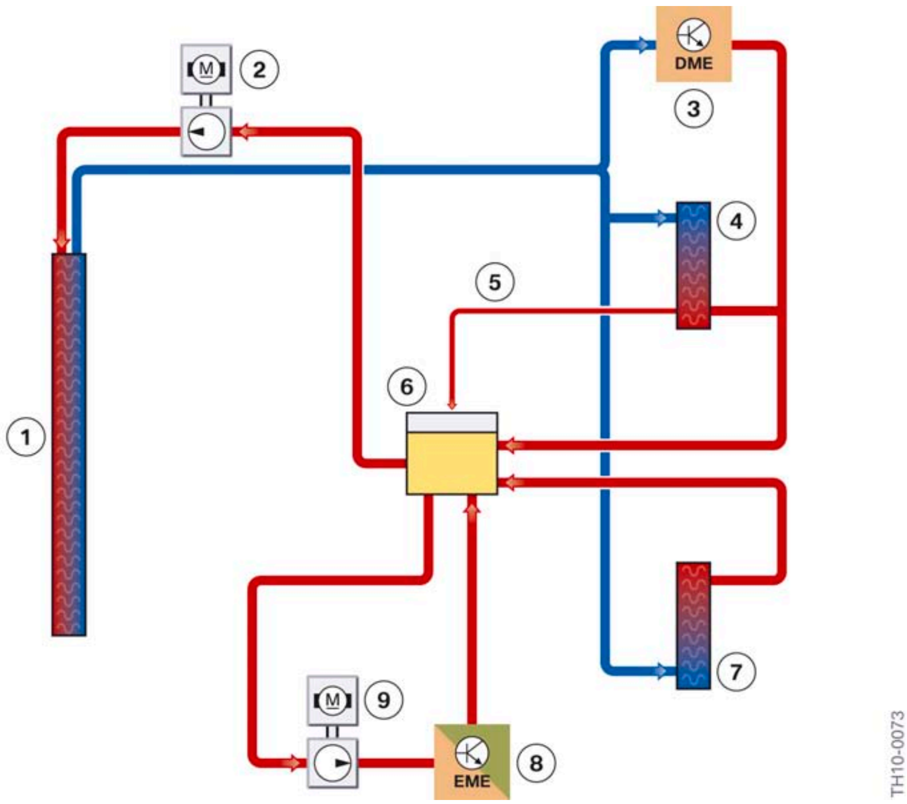
Index	Explanation
1	Radiator
2	Transmission cooler
3	Coolant temperature sensor at radiator outlet
4	Electric fan
5	Electric auxiliary coolant pump for turbocharger cooling
6	Map thermostat
7	Coolant pump
8	Turbochargers
9	Heater matrix

Index	Explanation
10	Duo heater valve
11	Electric auxiliary coolant pump for vehicle heating
12	Ventilation line of the cylinder heads
13	Coolant temperature sensor at engine outlet
14	Coolant expansion tank
15	Ventilation line of the radiator
16	Transmission fluid-to-coolant heat exchanger
17	Separate auxiliary coolant radiator

Compared with the F01/F02 the engine cooling circuit of the F04 has been modified and instead is the same as that in the E72. Coolant is circulated through the bearings of the turbochargers and the transmission fluid-to-coolant heat exchanger via the suction side of the auxiliary coolant pump (this has improved transmission fluid cooling). As in the other models featuring the N63 engine this pump can run on even after the combustion engine has been switched off in order to dissipate the residual heat from the turbochargers. Depending on the situation, the pump may run for 15 to 20 minutes after the engine is tuned off.

2.1.5. Low-temperature cooling circuit

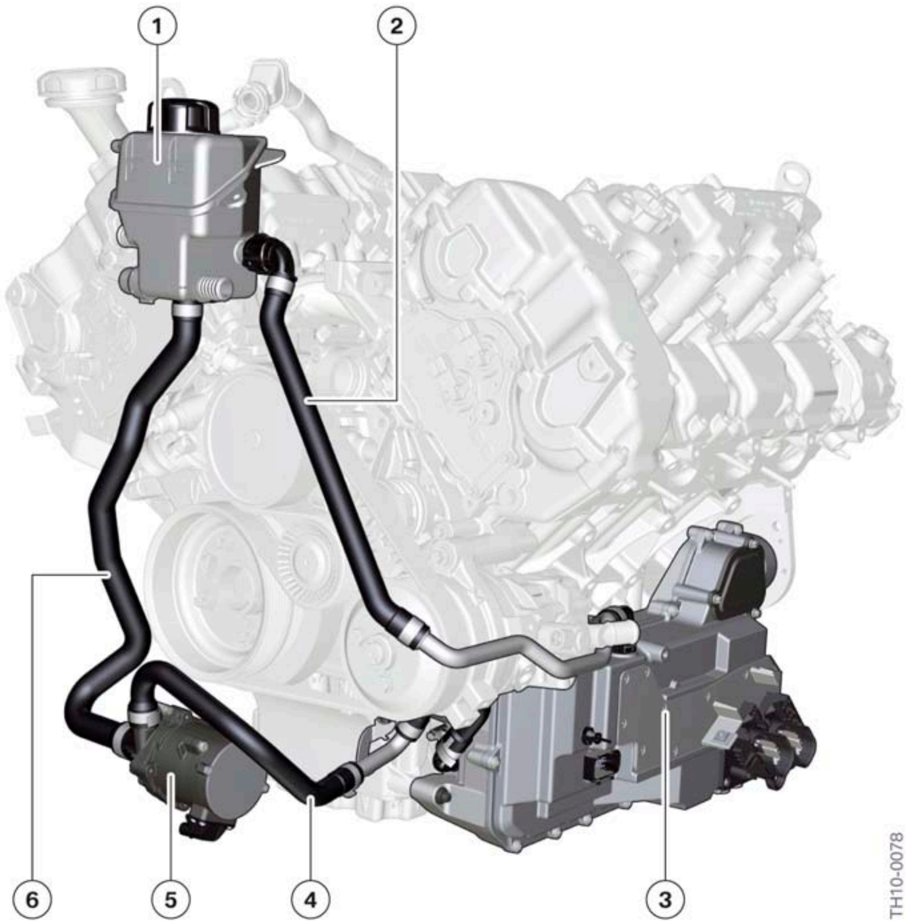
The low-temperature cooling circuit of the F04 is based on that of the F01/F02 with N63 engine. In the F04 It is also used for cooling the charge air and the DME but has the additional task of cooling the power electronics for the electric drive, referred to as "electric motor electronics (EME)". The low-temperature circuit of the F01/F02 has therefore been extended for the F04 to include this additional circuit.



Low-temperature cooling circuit of the F04

Index	Explanation
1	Radiator
2	50 W electric coolant pump in the circuit for charge air and DME cooling
3	Digital Engine Electronics (DME)
4	Charge air cooler (Intercooler)
5	Vent line
6	Coolant expansion tank
7	Charge air cooler (Intercooler)
8	Electric motor electronics (EME)
9	50 W electric coolant pump in the EME cooling circuit

The additional circuit for the electric motor electronics consists of the modified expansion tank, an additional electric coolant pump and the lines to the electric motor electronics. The electric coolant pump in the EME circuit has a maximum power output of 50 W and is activated by the EME as a function of its cooling demand.



Cooling circuit, electric motor electronics

Index	Explanation
1	Coolant expansion tank
2	Return line, electric motor electronics → coolant expansion tank
3	Electric motor electronics (EME)
4	Feed line, electric coolant pump → electric motor electronics
5	50 W electric coolant pump
6	Feed line, coolant expansion tank → electric coolant pump

The EME circuit is not directly connected to the coolant-to-air heat exchanger. Instead the expansion tank serves here as a mixer, i.e. the coolant from the EME cooling circuit dissipates thermal energy to the coolant in the expansion tank. Cooling of the EME can thus be controlled to a large extent independently of the charge air cooling circuit. Cooling of the charge air and the Digital Engine Electronics is not negatively affected by this. The coolant is first cooled in the coolant-to-air heat exchanger before flowing to the charge air coolers and the Digital Engine Electronics.

2.2. Electric motor

2.2.1. Overview

The electric motor is manufactured by ZF Sachs AG, the drive and chassis components division of the ZF Group.

The electric motor is used in the F04 for the following functions:

- Automatic engine start-stop function
- Support of the combustion engine (boost function)
- Brake energy regeneration

The combustion engine of the F04 is started by the electric motor, this eliminates the need to use a conventional starter.

The F04 does not have a conventional 14 V alternator either, as the electric motor assumes this function in conjunction with a DC/DC converter.

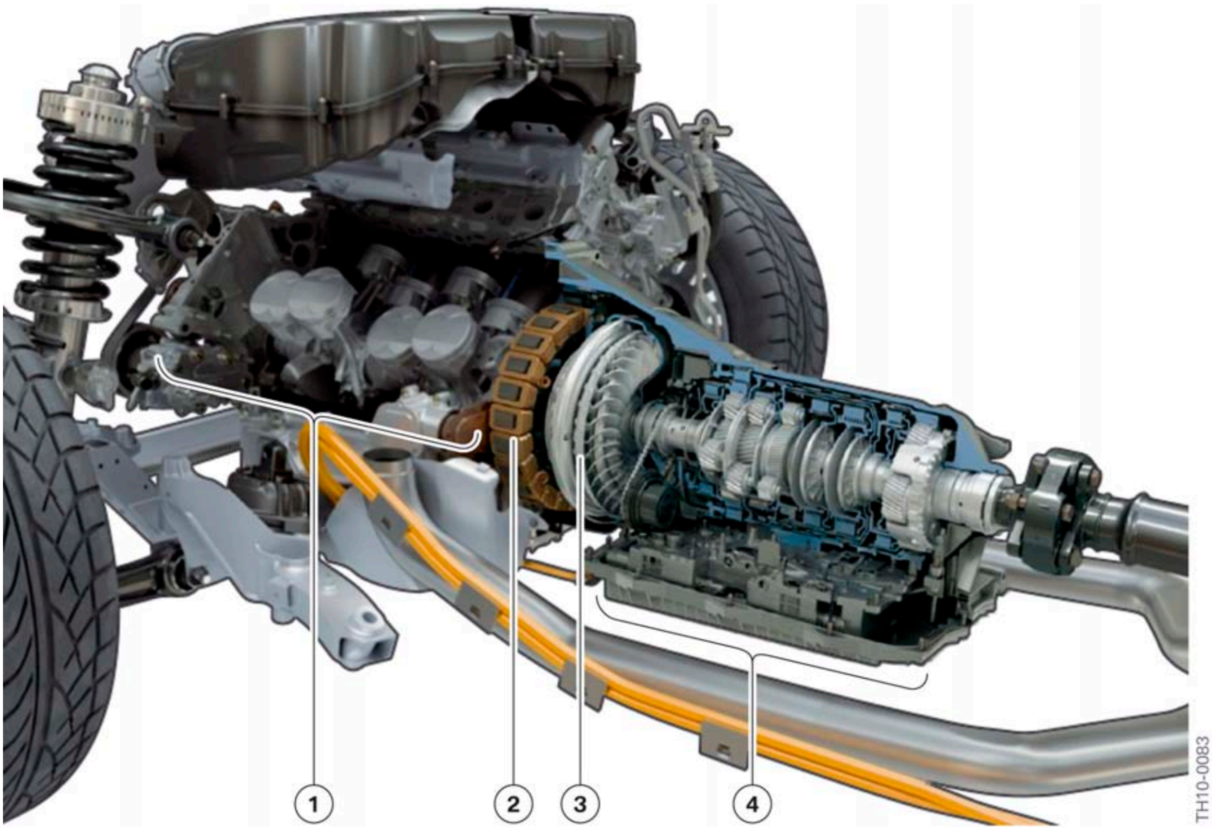
The technical data of the electric motor are summarized in the table below.

Data	Electric motor in the F04
Weight	50.7 lb (23 kg)
Nominal voltage during drive operation	105 V
Maximum power output during drive operation	20 hp (15 kW)
Maximum torque for starting the combustion engine	155 lb ft (210 Nm) at 0 – 400 rpm
Maximum torque during drive operation	118 lb ft (160 Nm) at 1000 rpm
Nominal voltage during generator operation	135 V
Maximum power output during generator operation	25.5 hp (19 kW)

The electric motor is a high-voltage component. The voltage is generated by the electric motor electronics and reaches values in excess of 100 VAC depending on the operating status. The electric motor electronics also assumes the task of regulating the electric motor during drive and generator operation.

2.2.2. Installation location

The rotor of the electric motor is connected to the crankshaft of the combustion engine and to the torque converter of the automatic transmission. The arrangement of the drivetrain components is the same as that of a parallel hybrid. The torques of both drives, i.e. from the combustion engine and the electric motor, can act simultaneously on the transmission input shaft.



Installation location of electric motor in the F04

Index	Explanation
1	Combustion engine (N63 engine)
2	Electric motor
3	Torque converter, automatic transmission
4	Automatic transmission (GA8HP70Z)

Because the F04 is a mild hybrid, 100% electric driving is not possible. Therefore, a clutch is required between the electric motor and the combustion engine. The rotational speeds of the crankshaft, the electric motor and the transmission input shaft are thus identical in all driving states. Consequently, the electric motor on the F04 always rotates in one direction. Unlike the electric motors (E machines) in the active transmission of the E72, the electric motor in the F04 cannot reverse direction.

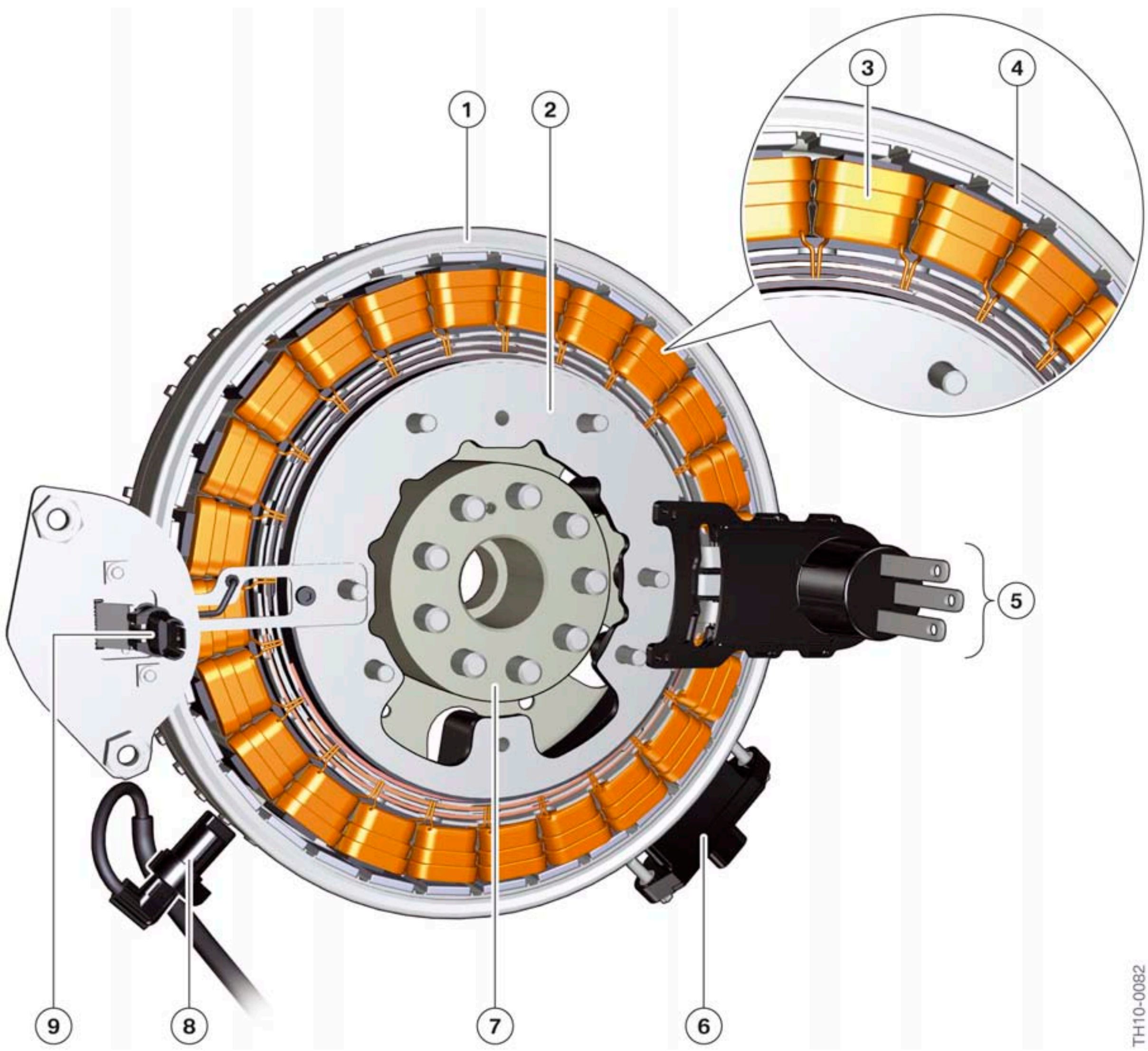
2.2.3. Design

The most important components of the electric motor are:

- Rotor and stator
- High-voltage connection
- Temperature sensor
- Rotor position sensor
- Crankshaft sensor

Rotor and stator

A permanent-field synchronous machine which is designed as an outer rotor is used for the electric drive. "Outer rotor" means that the **rotor** is arranged with the permanent magnets arranged in a ring shape on the **outside.** The windings for generating the rotating field are located on the inside and form the stator.



Design of electric motor

Index	Explanation
1	Rotor
2	Stator
3	Windings in the stator
4	Permanent magnets in the rotor
5	High-voltage connection
6	Rotor position sensor
7	Rotor (inner part connected to the crankshaft)
8	Crankshaft sensor
9	Temperature sensor

Temperature sensor

The windings of the electric motor must not exceed a temperature of about 392 °F (200 °C) during operation. The temperature is therefore representatively measured in one of the windings with the aid of a temperature sensor. A thermistor with negative temperature coefficient (NTC) is used for this purpose.

The electric motor electronics uses voltage and current measurements to determine the resistance and calculates the temperature from these measurements. If the temperature of the windings approaches the maximum permissible temperature (about 356 °F [180 °C]), the power output of the electric motor is reduced. This is a degradation for protecting the components and is controlled by the electric motor electronics. An appropriate Check Control message is displayed starting from a level of power reduction to alert the driver of this condition (see the chapter entitled "Displays and Controls" for more information).

Sensors on the electric motor

Index	Explanation
1	High-voltage connection
2	Connection for temperature sensor
3	Crankshaft sensor
4	Tooth profile as sensor for the crankshaft sensor
5	Sinusoidal (sine wave shaped) structure as sensor for the rotor position sensor
6	Rotor position sensor

Rotor position sensor

The rotor position sensor senses exactly the position of the electric motor's rotor. In contrast to the crankshaft sensor, the rotor position sensor is also suitable for clearly determining the position within a quadrant. This is necessary for exact regulation of the electric motor, because the voltages must be generated at the stator windings to match the position of the rotor. This precise, high accuracy measurement would not have been possible with the crankshaft sensor. Instead, this is configured for higher rotational speeds and exact driving speed measurement.

The principle of the rotor position sensor is based on the change in the magnetic properties of the rotor. The outer surface of the rotor therefore features a sinusoidal (sine wave shaped) structure. The sensor element consists of two coils which are operated with AC voltage. When the rotor moves, the magnetic properties change. This gives rise to changing induction voltages and currents in the coils. The position of the rotor can be determined from these variations.

The analogsensor signal is read in and processed by the electric motor electronics.

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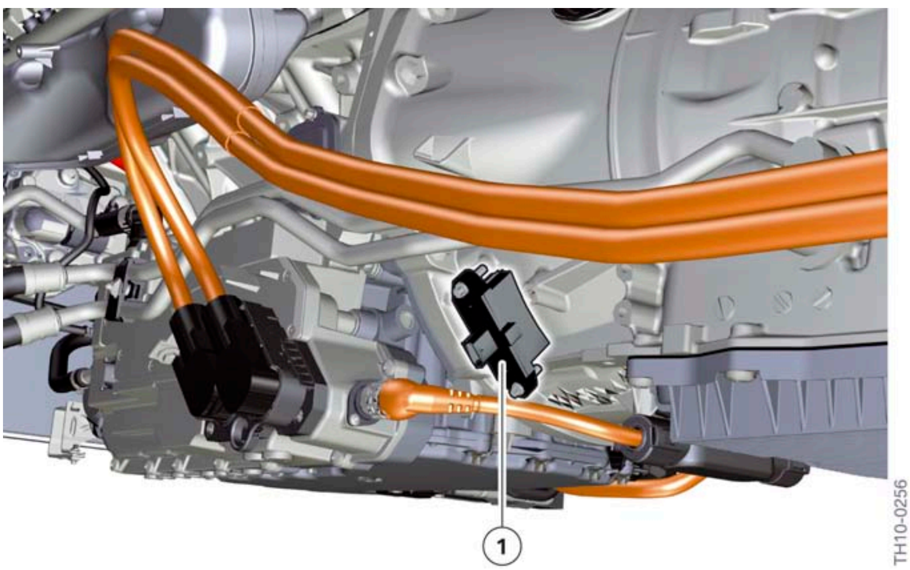
Note: The rotor position sensor can be replaced separately in a Service when prompted to do so by the ISTA diagnosis system test plan.



Installation location, rotor position sensor

Index	Explanation
1	Rotor position sensor

The rotor position sensor is mounted on the outside of the transmission housing.

⚠

Note: The rotor position sensor must always be removed before the automatic transmission is removed or even separated from the combustion engine. Otherwise the rotor position sensor will be damaged!

To ensure that the rotor position sensor functions flawlessly, it is necessary to adjust it using the ISTA diagnosis system. In the course of the adjustment, mechanical tolerances are recorded so that the exact position of the rotor can be determined during subsequent operation. The electric motor electronics records and stores the data from the adjustment process.

⚠

The rotor position sensor must be adjusted when:

- the rotor position sensor has been replaced,
- the electric motor has been replaced,
- the electric motor electronics has been replaced, or
- if the bolts of the transmission housing, the electric motor or the rotor position sensor itself have been loosen.

The adjustment is performed using the Service Function "Rotor position sensor adjustment" in the ISTA diagnosis system.

The individual operations involved are:

1. Start the Service Function "Rotor position sensor adjustment"
2. Start the combustion engine and run at idle, engage the parking lock
3. Start adjustment and wait until the Service Function confirms that the adjustment has been successful
4. Close the Service Function and allow the car to return to sleep mode

The test plan for the Service Function specifies the operations mentioned here. The instructions in the test plan must be followed to the letter.

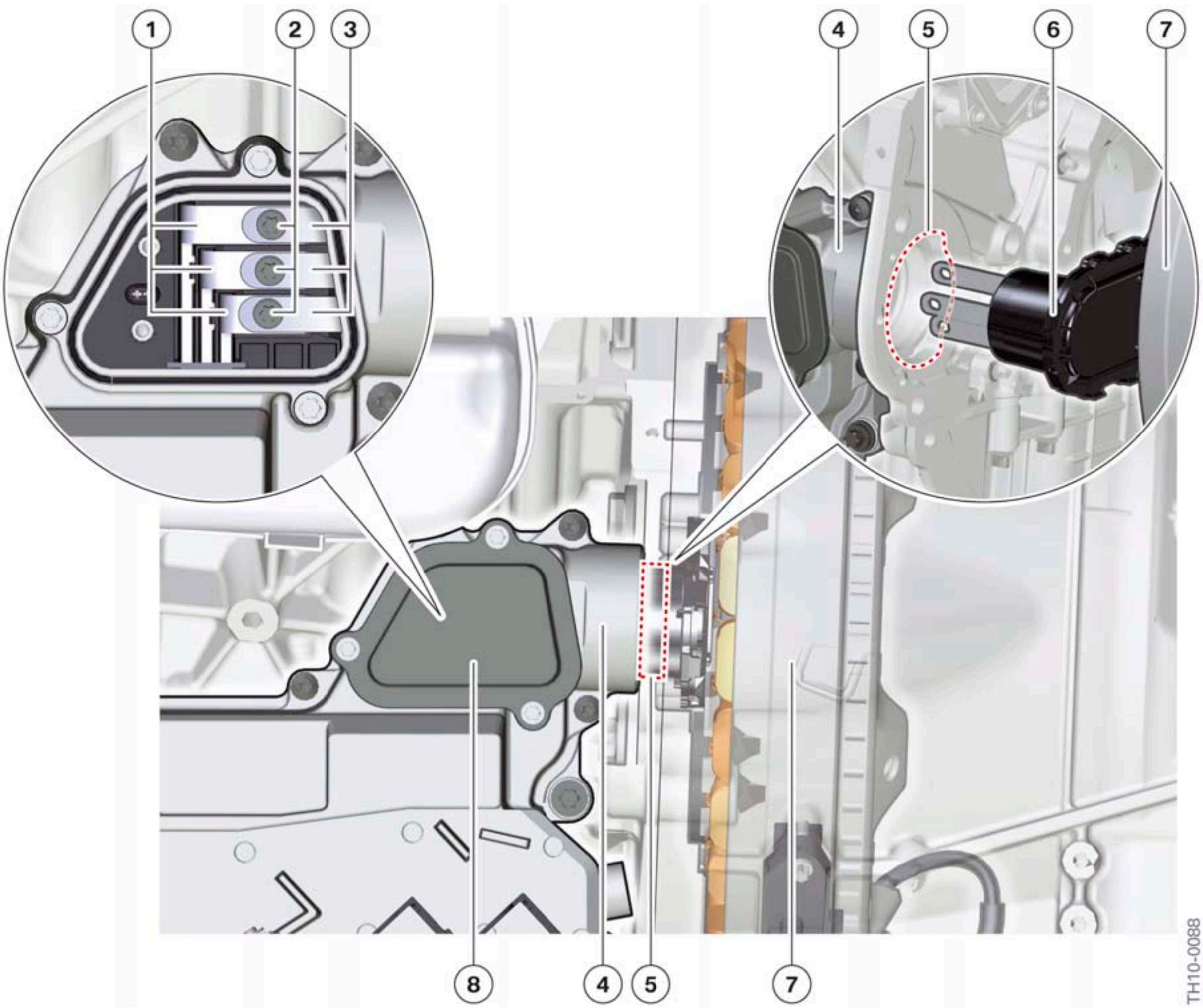
High-voltage connection

The three voltages and currents for the electric motor windings are supplied via the high-voltage connection. The high-voltage connection connects the electric motor to the electric motor electronics. This is not a flexible line connection, but instead three rigid busbars which come out of the left side of the motor. Sheathed in plastic, the three busbars of the electric motor are brought through the starter flange of the engine block and are directly bolted to the three connections of the electric motor electronics.

⚠

When connecting the busbars, it is essential to observe the correct tightening torque.

Faults may result either by applying too much torque or too little torque to the busbar connections. If an excessively low tightening torque is applied, this may result in faults (unreliable electrical connection). If excessively high tightening torque is applied (unacceptable deformation of the busbars) may be displayed.



High-voltage connection, electric motor/electric motor electronics

Index	Explanation
1	Busbars of electric motor electronics
2	Busbar connecting screws
3	Busbars of electric motor
4	Opening of electric motor electronics to accommodate high-voltage connection for electric motor
5	Flange in crankcase (The F01/F02 starter mounting flange in the F04 is used to establish the high-voltage connection)
6	High-voltage connection of electric motor
7	Electric motor (rotor)
8	Cover of high-voltage connection on electric motor electronics

2.2.4. Service instructions

Although the rotor position sensor can be replaced separately, the electric motor can only be replaced as a complete unit.

It is essential to follow the repair instructions to the letter when ever removing and installing any high voltage components.

The following operations are particularly important.

High-voltage component warning sticker

The electric motor is a high-voltage component. Before working on the electric motor, it is essential to observe the electrical safety rules:

- Disconnect the vehicle from the high voltage supply
- Safeguard to prevent unintentional starting
- Verify safe isolation from the high voltage supply.

Removal: Install centring bolts before loosening the mounting bolts on the stator and rotor. Secure the stator and rotor at a fixed distance to each other. This will prevent the stator and rotor from banging against each other and being damaged when the mounting bolts are removed.

Installation: Do not remove the centring bolts until the rotor and stator have been secured with the mounting bolts. Otherwise the rotor and stator could bang against each other during installation and be damaged.

Analysis of defective parts: Removed high-voltage components such as the electric motor may have to be returned to the manufacturer for analysis. To enable the manufacturer to determine the exact cause of the failure, it is essential to handle the removed high-voltage components with care. Damage during removal and shipping must be avoided at all costs.

High-voltage connection

Secure the screws of the busbar contacts to the prescribed tightening torque. Both excessively high and excessively low tightening torque can produce a faulty contact and damage to components.

Note: The high-voltage connection must not be used to hold or carry the electric motor. It is not structurally designed to withstand the weight of the electric motor.

2.3. Modified GA8HP70Z automatic transmission

The GA8HP70Z automatic transmission (introduced in the F07 with the N63 engine) is used in the F04 with a few modifications.

These modifications are summarized here and are described in the following chapters:

- Transmission housing
- Torque converter
- Hydraulic pressure accumulator
- Adaptive transmission control

2.3.1. General hardware requirements

Compared with the GA8HP70Z automatic transmission which is used in vehicles with conventional drives, the transmission housing has been adapted for use in a hybrid powertrain. The front of the transmission housing has been lengthened to accommodate the electric motor. The greater length 1.8 in (+47 mm) has also necessitated the use of additional reinforcements in the transmission housing. Hydraulic lines have been supplemented and modified inside the transmission housing in order to integrate the hydraulic pressure accumulator into the hydraulics. These design modifications increased the weight of the F04 transmission by about 9 lb (4 kg) more than the GA8HP70Z transmission used in conventional vehicles.

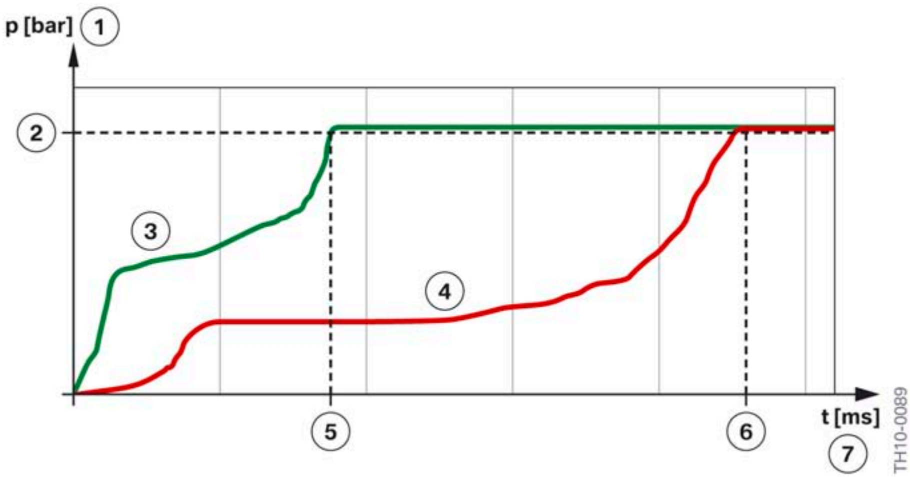
The hybrid drive of the F04 develops a maximum torque of 515 lb ft (700 Nm). Due to the significantly greater torque (compared to the conventional N63 engine torque of 450 lb ft/600 Nm) the torque converter and the planetary gear sets had to be reinforced. The other transmission components are already designed to accommodate this maximum torque and therefore have not been modified (when compared with the version used in the F07).

2.3.2. Hydraulic pressure accumulator

Overview

The F04 uses an automatic engine start-stop function which switches off the combustion engine when the vehicle is at a standstill. In the engine stop phases the transmission fluid pump is not driven, thus the fluid pressure supply ceases, the gearshift elements open, and there is no longer a transfer of power in the transmission. The drive off processes should always be dynamic and without a noticeable delay (especially in BMW vehicles). The combustion engine must start quickly (this is guaranteed by the F04 electric motor), at the same time, in the automatic transmission the gearshift elements for driving off must still be engaged, while the engine is starting. This requires transmission fluid pressure, which cannot be built up quickly enough by the conventional mechanically driven transmission fluid pump while the engine is starting.

Therefore a hydraulic pressure accumulator is used in the automatic transmission of the F04. The gearshift elements needed for driving off are supplied with the stored transmission fluid volume from the accumulator before the transmission fluid pump has built up sufficient pressure.

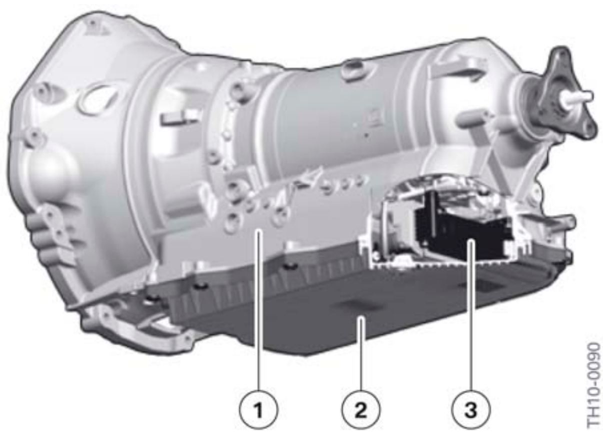


Time characteristic of transmission fluid pressure during combustion engine starting

Index	Explanation
1	Transmission fluid pressure
2	Nominal value of the transmission fluid pressure which is required to hydraulically actuate the gearshift elements
3	Characteristic of the transmission fluid pressure **with** hydraulic pressure accumulator
4	Characteristic of the transmission fluid pressure **without** hydraulic pressure accumulator
5	Point at which the automatic transmission **with** hydraulic pressure accumulator is ready for driving off
6	Point at which the automatic transmission **without** hydraulic pressure accumulator is ready for driving off
7	Time

Installation location

The hydraulic pressure accumulator is integrated near the tail of the automatic transmission. It is installed in the transmission fluid sump behind the mechatronics module and can be replaced as a separate component.

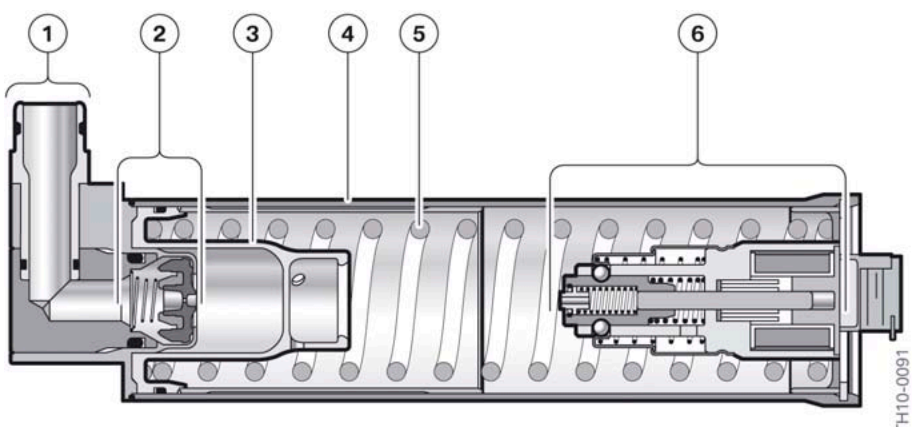


Installation location of hydraulic pressure accumulator

Index	Explanation
1	Automatic transmission housing
2	Transmission fluid sump
3	Hydraulic pressure accumulator

Note: The hydraulic pressure accumulator can be replaced as a separate component.

Design



Design of hydraulic pressure accumulator

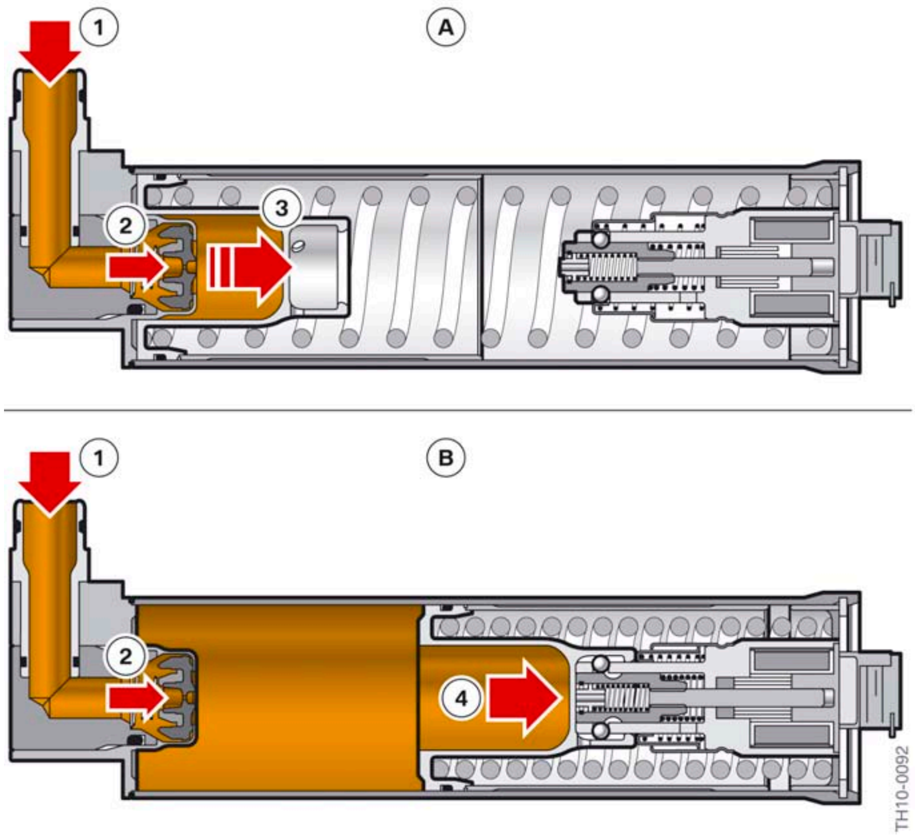
Index	Explanation
1	Port to hydraulic system of automatic transmission
2	Throttle and non-return valve
3	Hydraulic piston
4	Hydraulic cylinder
5	Coil spring
6	Electromechanical lock

The hydraulic pressure accumulator consists of a hydraulic cylinder. The cylinder contains a piston which is moved against the force of a spring. The piston can be electromechanically locked in the tensioned position. The electromechanical lock incorporates locking balls, a tension spring, a release spring, and a solenoid. The solenoid is activated and deactivated by the electronic transmission control. The wiring harness for the hydraulic pressure accumulator is laid inside the transmission housing.

The cylinder of the hydraulic pressure accumulator is connected to the transmission's hydraulic system without valves connected in between. The hydraulic pressure accumulator simply contains an element which functions as a throttle and non-return valve. The throttle limits the volumetric flow while the hydraulic pressure accumulator is being filled. The non-return valve allows the transmission fluid to flow through the throttle into the hydraulic pressure accumulator during the charging process. During the discharging process the transmission fluid flows not through the throttle, but instead unrestricted through the now opening non-return valve back into the transmission hydraulic system. The non-return valve therefore does not serve, as one would assume, to maintain the pressure in the charged state. Instead, in the charged state, the transmission fluid in the hydraulic pressure accumulator is at zero pressure. The stored energy on the other hand is accumulated in the tensioned spring.

Charging

The hydraulic pressure accumulator is always subject to charging when the combustion engine is running and the transmission fluid pump is working. During charging, transmission fluid flows through the throttle into the hydraulic cylinder. The throttle allows only a small volume of fluid to be drawn from the transmission hydraulic system so that the pressure level does not unintentionally drop. The transmission fluid pushes on the piston which acts against the spring force increasing the tension on the spring.



Charging of the hydraulic pressure accumulator

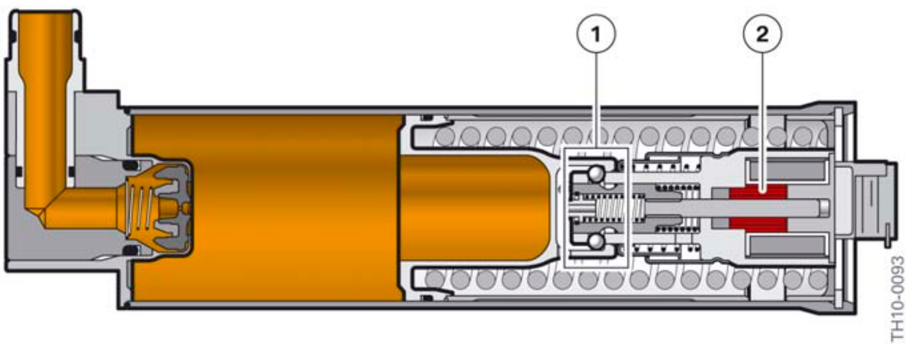
Index	Explanation
A	Start of charging, "discharged" state
B	End of charging, "charged" state
1	Transmission fluid flows from the hydraulic system of the automatic transmission into the hydraulic pressure accumulator
2	Volumetric flow of the transmission fluid is limited by the throttle
3	Transmission fluid exerts a force on the piston which moves and tensions the coil spring
4	Transmission fluid exerts a force on the piston so that it is held in the "charged" end position

At the end of the charging process the piston slides over the locking balls up to the stop. The applied transmission fluid pressure now holds the piston against spring force in the end position. Therefore locking is not yet in operation here. The hydraulic pressure accumulator is fully charged in this end position.

Locking

When the combustion engine is switched off (while the hydraulic pressure accumulator is charged) the transmission fluid pressure drops causing the spring to be released slightly. This allows the piston to slide into the locked position. Here, the locking balls engage and the piston is mechanically held in place.

The now activated solenoid in turn holds the inner slide in place so that the balls cannot enter the channels designated for releasing the lock. The electric power required for this is low (< 10 W). Furthermore it is only required while the combustion engine is switched off. Therefore the additional energy consumption of the hydraulic pressure accumulator viewed over an entire driving cycle is very low.



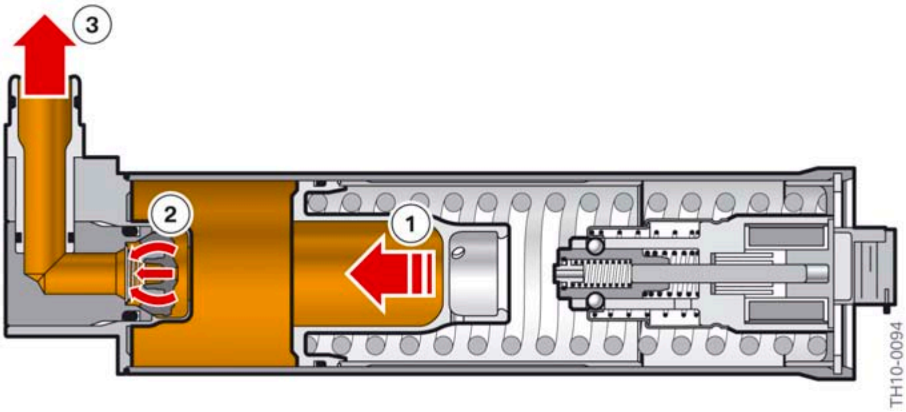
Charged and locked state of the hydraulic pressure accumulator

Index	Explanation
1	Mechanical lock
2	Solenoid activated

Discharging

When the combustion engine is started, as the driver wishes to drive off, the gearshift elements in the automatic transmission for driving off must be engaged. The hydraulic pressure accumulator supplies the transmission fluid pressure required for this during the discharging process.

As the solenoid is deactivated, the inner slide (driven by the smaller spring) moves in the direction of the locking balls. This allows the balls to enter in the channels designated for releasing the lock, which in turn releases the piston. The spring (compressed during the charging process) exerts a force on the piston which pressurizes the transmission fluid inside the cylinder.



Discharging of the hydraulic pressure accumulator

Index	Explanation
1	The large spring pushes on the piston, which in turn, forces the transmission fluid out of the hydraulic cylinder
2	Transmission fluid can now flow through the throttle **and** the opened non-return valve
3	Transmission fluid flows from the hydraulic pressure accumulator back into the hydraulic system of the automatic transmission

The piston moves (in the graphic to the left) and thereby pushes the transmission fluid back into the transmission hydraulic system. The transmission fluid exits the cylinder through the now opened non-return valve and throttle.

The oil volume forced back into the hydraulic system of the transmission is sufficient to engage the gearshift elements needed for the driving off process. This system is designed to provide the initial fluid pressure needed for the transmission to go into “Gear” at the moment just before the engine is started. As soon as the engine is started, the transmission fluid pressure is then again generated by the transmission fluid pump and the process is restarted.

2.3.3. Modified functions

The essential functionality of the adaptive transmission control, as used in all current BMW automatic transmissions, also applies to the GA8HP70Z automatic transmission in the F04. Some program parts and parameters have however been modified to cater for the special characteristics of the hybrid drive. These modifications are described below.

Gear selection when decelerating

When the driver takes his/her foot off the accelerator pedal, fuel injection into the combustion engine is cut off (overrun fuel cutoff). This creates a negative torque which, depending on the gradient being negotiated, results in a deceleration of the vehicle. It is also known as "engine drag torque". This engine drag torque is dependent on the revs of the combustion engine and it is greater at high revs than at low revs. Therefore the brake force acting on the vehicle is greater at high revs.

Because of the gear ratios used, the brake force is also greater in low gears than in high gears.

In vehicles with conventional drives, the service brake is complemented by a powerful "engine braking effect". Therefore the adaptive transmission control in these vehicles shifts one or more gears down when longer-lasting brake activation or downhill driving is detected.

However, in vehicles with hybrid drives the braking effect of the combustion engine is not required to the same extent. Instead, in hybrid vehicles the aim is to use the electric motor to decelerate the vehicle whenever possible. Therefore, when the brakes are activated or longer downhill driving is detected, the adaptive transmission control in the F04 does not perform **any downshifts**; instead it holds the high gear for as long as possible. In this way the engine drag torque is kept at a low level. To complement and aid the service brakes, the electric motor is operated as a generator and an electrical "engine braking effect" is thereby achieved. The kinetic energy recovered from the motion of the vehicle is stored in the high-voltage battery as electrical energy and used for propulsion later.

Upshift curves

The upshift curves of the automatic transmission are modified for the F04 and help to reduce fuel consumption. When accelerating at low load (< 30 %) the adaptive transmission control shifts into the next gear up earlier than in vehicles with conventional drives. A coupling rotational speed of about 900 to 950 rpm is thus achieved. This applies to drive position D, the upshift curves of drive position S have not been modified.

This results in a very low engine revs, even when driving at a constant speed, which helps to reduce fuel consumption. As is customary with BMW vehicles, this increase in efficiency is not obtained at the expense of dynamics. When the driver requests powerful acceleration through the accelerator pedal, the electric motor supports the combustion engine (whenever necessary). It works as a motor and thereby increases the total drive torque significantly. As a result the driver of an F04 experiences a surge of spontaneous power which is comparable to that of a vehicles with conventional powertrains while at lower engine revs and with lower fuel consumption.

2.4. Shafts and rear differential

Due to the lengthened transmission housing of the F04, a shorter drive shaft is installed.

As shown in the table below, the F04 does not have the same rear differential as the F01 750i or the F02 750Li. The F04 uses the 235L rear differential, which is known from the F01 760i or the F02 760Li.

The longer gear ratio together with the modified upshift curves contribute to a low engine revs and thus enhanced fuel efficiency.

	F01 750i or F02 750Li	**F04 ActiveHybrid7**
Rear differential	225AL	235L
Gear ratio	3.462	2.813
Output shafts	VL3300I	VL4400I

The output shafts in the F04 are different from those in the F01 750i or F02 750Li, because they are adapted to the 235L rear differential.

2.5. New automatic engine start-stop function

2.5.1. Overview

With the introduction of the F04 the automatic start-stop function is being used for the first time in a hybrid vehicle with automatic transmission. Prior to this the system, automatic engine start-stop was only used in manual gearbox 4 cylinder model BMW vehicles (not available in the US). With that version, when the vehicle is stopped, the driver engages neutral and releases the clutch pedal, the automatic start-stop function switches the combustion engine off. This means that the vehicle does not use any fuel when it is at a standstill. During this period the electrical consumers are supplied with power from the 12 V battery. When the driver depresses the clutch pedal again, the combustion engine is automatically restarted and the driver can continue driving. In contrast to this, in the F04 system, the electrical consumers are supplied with power directly from the high-voltage electrical system while the vehicle is stopped.

Note: Only those modifications and special characteristics of the automatic start-stop function which are specifically applicable to the F04 are described in this document.

2.5.2. Function from the customer's point of view

Stopping

While the vehicle is moving, the customer does not notice the automatic start-stop function.

Index	Explanation
1	Vehicle moving
2	Gear selector in the "D" position, driver depresses the accelerator pedal
3	Combustion engine running, tachometer and fuel consumption indicator reflect the driving situation

The purpose of the automatic start-stop function is to switch off the combustion engine when the vehicle is stopped.

From the customer's point of view the stopping process with subsequent engine stop in the F04 is as follows:

Index	Explanation
1	Vehicle slows to a stop, e.g. at a red light
2	Gear selector remains in the "D" position, driver depresses the brake pedal to decelerate and hold the vehicle at a standstill
3	Combustion engine is switched off, tachometer shows 0, the "Ready to drive" terminal status is indicated by a pulsating "Ready" display

In the situation depicted above the driver holds the car at a standstill by depressing the brake pedal. If the driver has activated the "Automatic Hold" function, he/she can also release the brake pedal after the car has come to a stop. The car is then held at a standstill by the DSC hydraulics. The automatic start-stop function also switches off the combustion engine in this case as long as the car is stopped and the driver does not depress the accelerator pedal.

Driving off

In vehicles with automatic transmissions the driver signals his/her wish to drive off by releasing the brake pedal and then depressing the accelerator pedal.

Index	Explanation
1	Driver wishes to continue driving (green light)
2	Gear selector remains in the "D" position, driver releases the brake pedal and then depresses the accelerator pedal
3	Combustion engine is started, tachometer and fuel consumption indicator display normally again to suit the driving situation

If the driver held the vehicle at a standstill by depressing the brake pedal, the combustion engine is started as soon as the driver releases the brake pedal. If the vehicle was held at a standstill by the "Automatic Hold" function, the combustion engine is started only when the driver depresses the accelerator pedal.

2.5.3. Distributed function

The Digital Engine Electronics is the master control unit for the automatic start-stop function. It reads in all the input signals and the switch-off inhibitors and switch-on prompts communicated by other systems. Based on this information, the DME decides when the combustion engine is to be switched off and restarted.

Basically the combustion engine is switched off when in drive (position "D") the vehicle speed reaches 0 mph and the car is held at a standstill. The vehicle speed is determined with the aid of the wheel speed sensors, the Dynamic Stability Control and the Integrated Chassis Management. Holding at a standstill is detected by reference to the brake light switch signal or to the status of the Automatic Hold function. Starting of the combustion engine always occurs automatically when the driver outputs the "not actuated" brake light switch signal or the accelerator pedal angle is greater than 0° (especially if the Automatic Hold function was previously activated).

In addition to these generally applicable conditions there are several other situations which limit the automatic start-stop function. These conditions are listed in the following chapters.

Several logically related conditions are summarized into groups in the following table. In the event of a customer complaint, an exact analysis of the system can be done using the ISTA diagnostic system.

Switch-off inhibitors

"Switch-off inhibitors" are conditions or states which prevent the combustion engine from being switched off, although the vehicle is stopped and is being held at a standstill.

Source	Condition
Power management (electric motor electronics)	High load in the high-voltage electrical system (e.g. due to high power request by the electric A/C compressor), low state of charge of the high-voltage battery
Integrated automatic heating / air conditioning	Heating request
Engine management (Digital Engine Electronics)	Special combustion engine states such as e.g. idle speed not reached, coolant temperature too high or too low, engine oil temperature too high, catalytic converter temperature too low, engine adaptation active, purging of charcoal canister active
Automatic transmission (electronic transmission control)	Transmission adaptation active, drive position "S", "M", "N", "R"
Start-Stop logic (Digital Engine Electronics)	Minimum speed since the last stop phase not yet reached, steering movement, large steering angle or maneuver detected

Apart from in drive position "D" the combustion engine is only switched off in drive position "P". All the other gear positions are considered switch-off inhibitors.

In addition to the switch-off inhibitors listed in the table one or more satisfied deactivation conditions of the automatic start-stop function result in the combustion engine not being switched off when the vehicle is stopped.

Switch-on prompts

If a "switch-on prompt" is present, this results in an advanced starting of the combustion engine, even though no signal has yet been displayed that would indicate that the driver wishes to drive off.

Source	Condition
Power management (electric motor electronics)	High load in the high-voltage electrical system (e.g. due to high power request by the electric A/C compressor), low state of charge of the high-voltage battery
Integrated automatic heating / air conditioning	Heating request
Automatic transmission (electronic transmission control)	Change of drive position (after "S", "M", "N", "R")
Start-Stop logic (Digital Engine Electronics)	Steering movement detected, car begins to move

Deactivation conditions

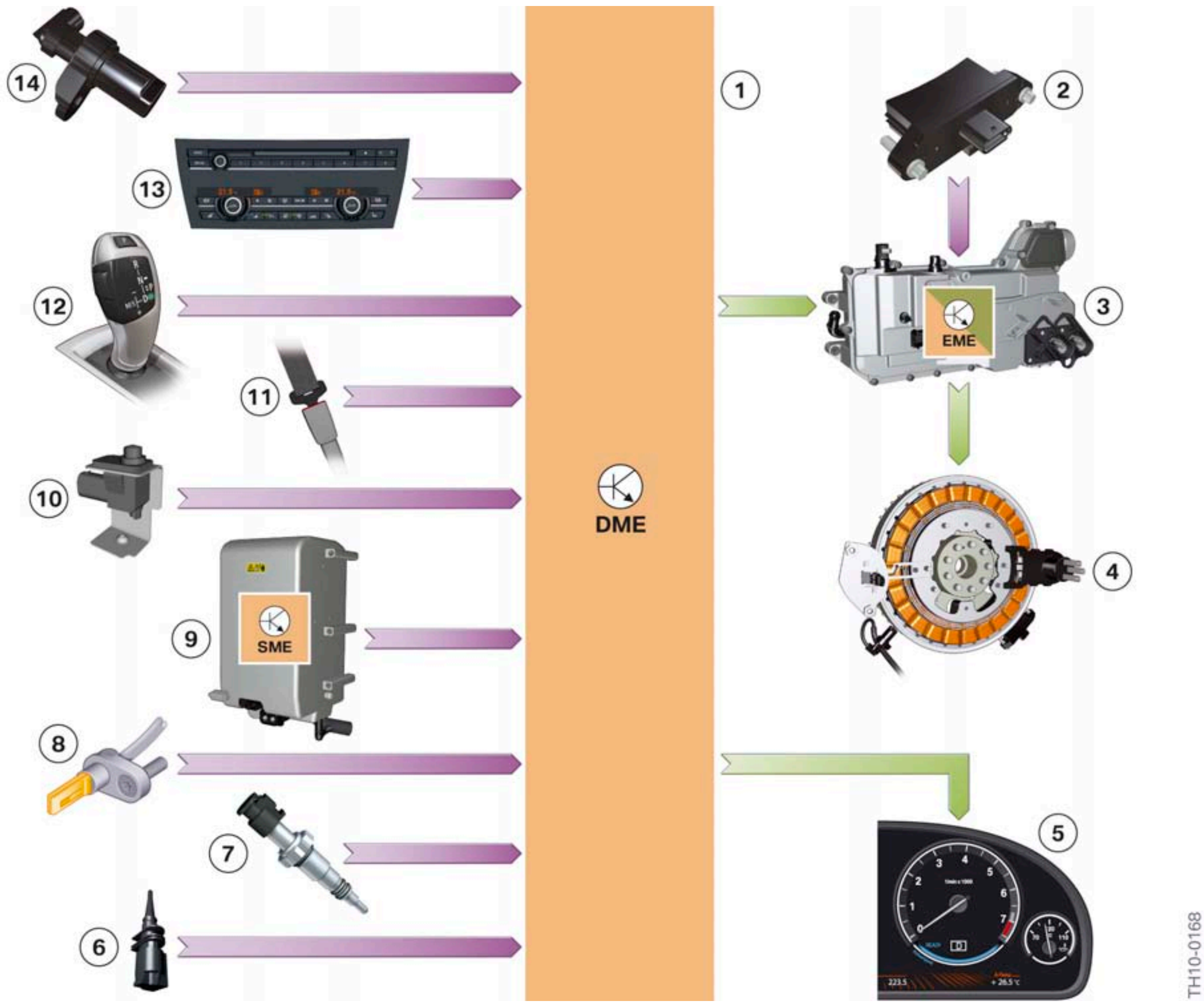
If a deactivation condition is present, the automatic start-stop function will neither automatically switch off nor start the combustion engine. The automatic start-stop function is therefore passive in this case. If the engine was switched off automatically before the onset of a deactivation condition, the driver must start it manually by depressing the brake pedal and pressing the Start/Stop button. In this case a Check Control message alerts the driver of the condition.

Source	Condition
Engine management (Digital Engine Electronics)	Fault status (combustion engine, engine management, bus communication), engine stalls
Automatic transmission (electronic transmission control)	Fault status
Operating mode of vehicle	Vehicle in transport mode
Start-Stop logic (Digital Engine Electronics)	Automatic start-stop function temporarily deactivated by Service Function, driver absence detected, no valid ID transmitter detected, hood is detected opened

Input/output

The following graphic provides an overview of the inputs and outputs of the automatic start-stop function in the vehicle.

F04 Complete Vehicle
2. Powertrain



Input/output, automatic start-stop function in the F04

Index	Explanation
1	Digital Engine Electronics (DME)
2	Rotor position sensor of electric motor
3	Electric motor electronics (EME)
4	Electric motor
5	Instrument cluster
6	Outside temperature sensor
7	Coolant temperature sensor
8	Wheel speed sensor
9	Battery management electronics (SME)
10	Hood contact switch

Index	Explanation
11	Seat belt buckle switch
12	Gear selector
13	Integrated automatic heating / air conditioning
14	Crankshaft sensor

F04 Complete Vehicle

3. Hybrid Braking System

3.1. System overview

The main function of the braking system of the F04 is to decelerate the vehicle safely under stable conditions. It has the additional function of converting the vehicle's brake energy, that would otherwise be wasted as heat, into electrical energy with the use of the electric motor.

Because the F04 is mild hybrid, the maximum power output and torque of the electric motor is lower than that as full hybrid vehicle such as, the E72. Accordingly the maximum braking deceleration, which can be regeneratively generated, is also lower. For this reason, the F04 and the E72 have very different hybrid braking systems. The following table provides an overview of these differences.

	F04	E72
Connection between brake pedal and brake system	Mechanical	Electrical (except in event of a fault: mechanical)
Maximum regeneratively attainable deceleration	about 0.06 g (0.6 m/s²)	0.3 g (3 m/s²)
Distribution of brake request (regenerative/hydraulic)	Permanently specified	Flexibly controllable

The properties of the F04 hybrid braking system described in the table were achieved by modifying the braking system of the F01. Primarily because the braking system of the F04 does not feature mechanical decoupling of the brake pedal and brake servo (as on E72), it has been possible to adopt to a great extent the components of the F01 service brake.

The following components are new or modified:

- Brake master cylinder (plunger brake master cylinder)
- Brake pedal travel sensor (on the brake master cylinder)
- Brake servo (connection to the brake master cylinder)
- Dynamic Stability Control (reading in of the signal from the brake pedal travel sensor)

To implement regenerative braking, the following components (needed anyway for the hybrid drive) are required:

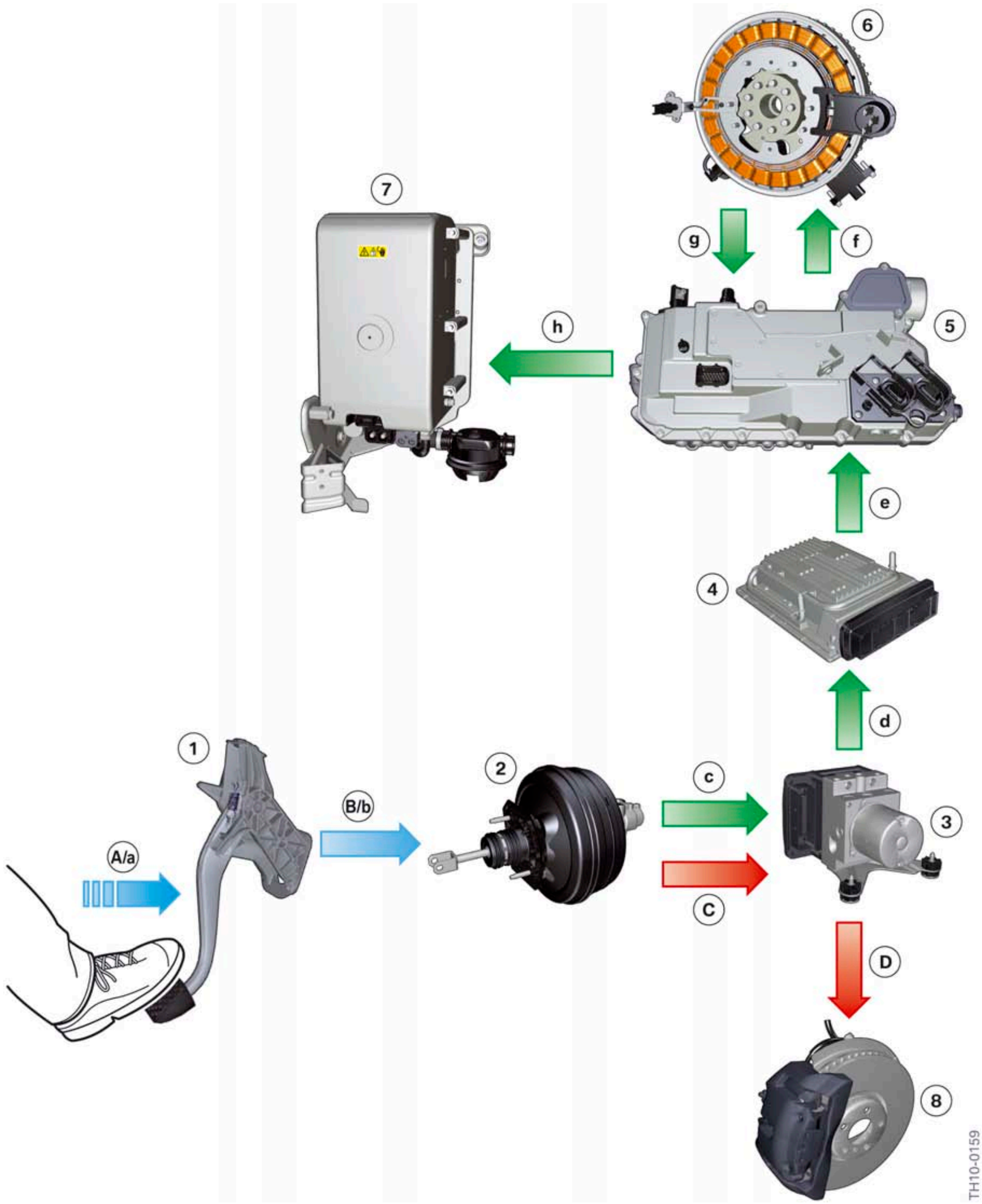
- Dynamic Stability Control (reading in of the brake pedal travel signal and calculation of the regenerative set-point braking torque which is to be implemented by the drivetrain)
- Digital Engine Electronics (forwarding of the regenerative set-point braking torque to the electric motor electronics, if the status of drivetrain permits this)
- Electric motor electronics (implementation of the set-point braking torque through activation of the electric motor as a generator, voltage transformation of the generated electrical energy)
- Battery management electronics (provision of data for the energy absorption capacity of the high-voltage battery)
- High-voltage battery (storage of the generated electrical energy)

3.2. Functions

3.2.1. Hydraulic and regenerative braking

In the F04 the components for hydraulic braking mode and those for regenerative braking mode operate virtually independently of each other. Basically, each time the brake pedal is depressed, there is a hydraulic portion and a regenerative portion. The hydraulic portion and its dependence on the brake pedal travel are determined by the design of the components. The regenerative portion is electronically controlled as a function of the brake pedal travel amongst other marginal conditions.

3. Hybrid Braking System



Implementation of the brake request by the hybrid brake system

Index	Explanation
1	Brake pedal
2	Brake servo with brake master cylinder and brake pedal travel sensor
3	Dynamic Stability Control
4	Digital Engine Electronics
5	Electric motor electronics
6	Electric motor
7	High-voltage battery unit
8	Four wheel brakes
a	Pressing of the brake pedal
b	Mechanical connection from the brake pedal to the brake servo
c	Electrical signal "brake pedal travel" from the brake pedal travel sensor at the brake master cylinder to the Dynamic Stability Control
d	Bus signal "regenerative setpoint braking torque" from the Dynamic Stability Control to the Digital Engine Electronics
e	Bus signal "regenerative setpoint braking torque" from the Digital Engine Electronics to the electric motor electronics
f	Phase voltages for activating the electric motor
g	Electrical energy generated by the electric motor (AC voltage)
h	Electrical energy to be stored in the high-voltage battery (DC voltage)
A	Pressing of the brake pedal
B	Mechanical connection from the brake pedal to the brake servo
C	Hydraulic pressure in the two brake circuits from the brake master cylinder to the Dynamic Stability Control
D	Hydraulic pressure in the four brake lines from the Dynamic Stability Control to the wheel brakes

Hydraulic braking

When the driver depresses the brake pedal, a direct mechanical connection is established to the brake servo and thus to the hydraulic brake system.

Activation is therefore carried out as in a conventional vehicle:

- Brake pedal – mechanical connection – brake servo
- Brake servo – pneumatic boosting – brake master cylinder
- Brake master cylinder – hydraulic boosting and distribution into two brake circuits – Dynamic Stability Control
- Dynamic Stability Control – driving dynamics control and electronic brake force distribution – wheel brakes

Regenerative braking

The accelerator pedal angle and the brake pedal travel are the decisive input variables for regenerative braking. The electric motor is operated as a generator when the brake pedal is not depressed but the accelerator pedal is already at an angle of zero degrees. The electric motor electronics activates the electric motor in such a way that a braking force is obtained which corresponds to a conventional vehicle in overrun mode (engine braking). The extent of energy regeneration at this point is still at a low level.

If the brake pedal is depressed at this time, initially (as in every conventional braking system) a “free play” travel must be overcome during which no hydraulic braking occurs. However, here this brake pedal travel is evaluated and a greater brake force (than that of overrun mode) is generated with the aid of the electric motor in response.

If the brake pedal is depressed beyond the “response” travel, both brake modes are simultaneously active, because now hydraulic braking is added to regenerative braking. The brake force generated by the electric motor is increased even further as the brake pedal travel increases until it reaches the maximum. The maximum brake force which is possible through regenerative braking corresponds on a level road to a deceleration of 0.6 m/s^2.

Regenerative braking acts only on the rear axle of the F04 through the electric motor, automatic transmission and the rear differential. The brake force on the rear axle must not exceed a specific value in proportion to that on the front axle. This would otherwise compromise driving stability. For this reason, the maximum deceleration which can be achieved through regenerative braking is limited to 0.6 m/s^2.

Several components are involved in realizing regenerative braking. The following list summarizes the components involved and their functions:

Component	Input variable(s)	Function	Output variable(s)
Brake master cylinder	Pressing of the brake pedal	Measurement of the brake pedal travel with the integrated brake pedal travel sensor	Amount of brake pedal travel
Dynamic Stability Control	Extent of the brake pedal travel	Determination of the mode of the braking torque for service brake and drivetrain; calculation and provision of the information on the stability of the driving situation as bus signal	Setpoint value of the braking torque which is to be regeneratively generated by the drivetrain; information on driving stability
DME Digital Engine Electronics	Extent of the braking torque to be regeneratively generated; information on driving stability	Coordination of the functions of combustion engine, automatic transmission and electric motor	Setpoint value braking torque for electric motor

Component	Input variable(s)	Function	Output variable(s)
Electric motor electronics (EME)	Setpoint value braking torque for electric motor; State variable of the high-voltage battery	Calculation of the phase voltages for the electric motor for generating the braking torque	Phase voltages for electric motor; actual value braking torque of the electric motor; extent of the electrical power output
Electric motor	Phase voltages for generator mode	Conversion of mechanical energy into electrical energy	Braking torque in the drivetrain Electrical energy
High-voltage battery	Electrical energy generated by the electric motor	Storage of the electrical energy	-
Battery management electronics (SME)	Measurement signals of internal sensors	Control of the energy flow to the high-voltage battery; monitoring and calculation of state variables of the high-voltage battery	State of charge of the high-voltage battery; maximum permissible current in/out of the high-voltage battery; voltage of the high-voltage battery

Distribution of hydraulically and regeneratively generated brake force

When the electric motor is operated as a motor, it generates a torque in the drivetrain (in addition to that of the combustion engine). In generator mode the electric motor generates a braking torque in the drivetrain. This braking torque exerts a drag on the rear wheels which results in a brake force.

The following diagram summarizes how the entire brake force is distributed into the hydraulic and regenerative portions. In the diagram it is presupposed that there is no unstable driving state and the high-voltage battery is able to store electrical energy.

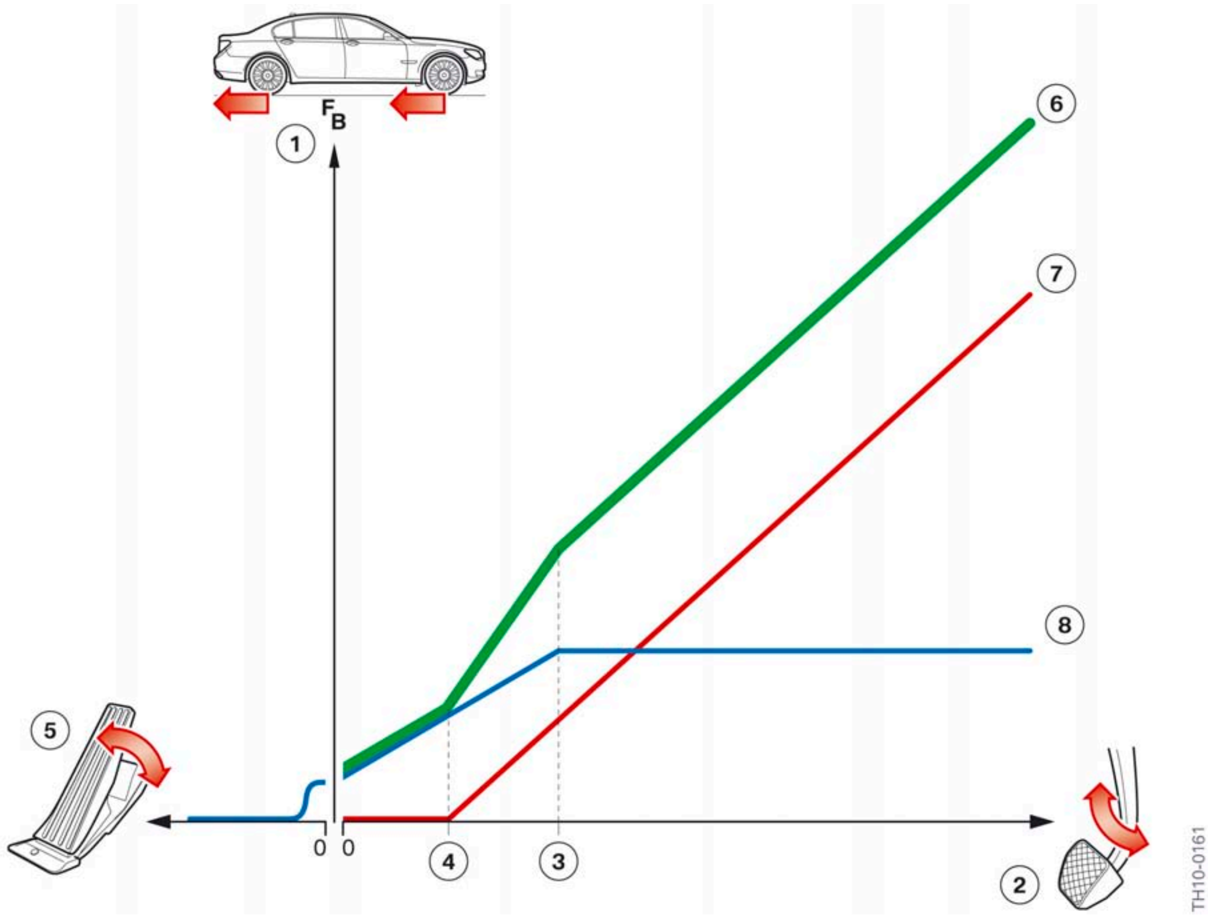


Diagram for distributing the brake force

Index	Explanation
1	Brake force on the wheels
2	Brake pedal travel
3	Brake pedal travel at which the maximum possible regenerative generated brake force acts
4	Brake pedal travel at which the hydraulic brake force begins (end of response travel)
5	Accelerator pedal angle
6	Total brake force
7	Hydraulically generated brake force
8	Regenerative generated brake force

3.2.2. Special states

Regenerative braking with the aid of the drivetrain generates a longitudinal force on the rear wheels. Together with a straight-acting lateral force the resulting force must not be greater than the maximum transmittable force. Otherwise traction would be lost and handling would become unstable. Therefore the Dynamic Stability Control permanently monitors the slip at the rear wheels and from it calculates (among other things) information on the stability of the vehicle in the relevant driving situation. Braking with the aid of the drivetrain is only permitted as long as the driving situation is stable. The Dynamic Stability Control takes into account this information when calculating the set-point value of the braking torque which is to be generated with the aid of the drivetrain.

If the high-voltage battery is fully charged, it cannot store any more electrical energy. This special state (which arises rarely) may be a reason why regenerative braking cannot be possible. A sufficiently large reserve in the state of charge of the high-voltage battery is maintained during normal driving by the operational strategy. In other words, energy is constantly drawn from the high-voltage battery intentionally and thereby the state of charge is maintained in a range which makes available (even during longer instances of downhill driving) the capacity for the electrical energy to be generated during regenerative braking.

Due to the principles involved, the electric motor cannot operate as a generator at very low engine revs. Shortly before standstill is reached the converter lockup clutch in the automatic transmission is also opened. These two factors are the reasons why regenerative braking is not possible shortly before standstill is reached.

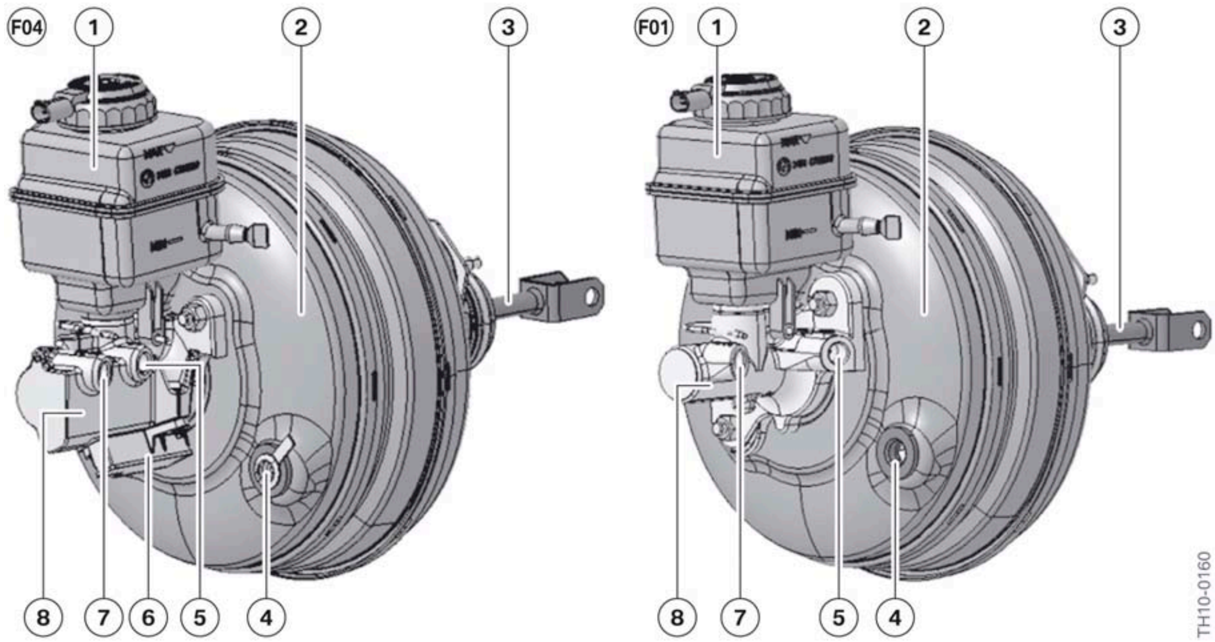
The following table summarizes the special states in which regenerative braking is possible only under limited conditions or is not possible at all:

Criteria	Reason
Excessive slip at the rear wheels or traction control system intervention active (ABS/ASC/DSC)	Driving stability
High lateral acceleration	Driving stability
Large steering angle	Driving stability
State of charge of the high-voltage battery greater than 80%	Capacity and service life of the high-voltage battery
Driving speed lower than a threshold value	No power transmission, no generator operation possible

3.3. System Components

3.3.1. Plunger brake master cylinder

Tandem brake master cylinders are used in BMW vehicles. A special design, referred tp as a plunger brake master cylinder, is used in the F04. It offers the advantage of having a compact design and was chosen for the F04 because the sensor system for the brake pedal travel can be easily integrated.



Comparison of the brake master cylinders of F04 and F01

Index	Explanation
1	Brake fluid reservoir
2	Brake servo housing
3	Connecting rod to brake pedal
4	Connection for vacuum supply
5	Brake line connection for brake circuit 1 (pressure chamber of pushrod piston)
6	Brake pedal travel sensor
7	Brake line connection for brake circuit 2 (pressure chamber of secondary piston)
8	Brake master cylinder housing

On the F04 brake master cylinder the connection for the brake circuit (which leads into the pressure chamber of the pushrod piston) is in a slightly different position from that in the F01. For this reason the corresponding brake line in the F04 differs in length and shape from that in the F01.

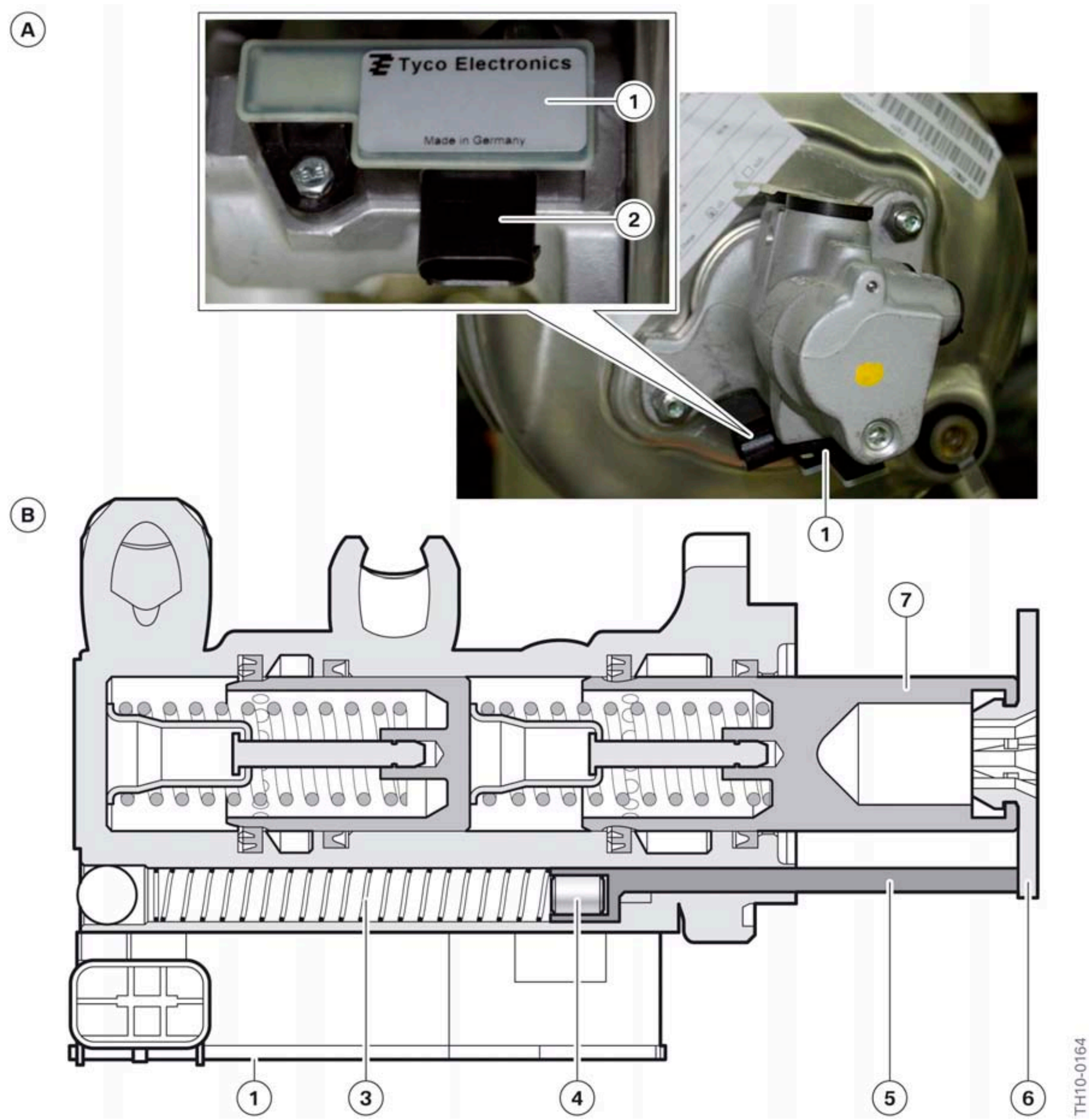
Because the brake master cylinders of the F04 and F01 also have different internal designs, the connection to the brake servo via the pushrod is different. For this reason the brake servo is also specific to the F04.

⚠

Note: The brake servo and the brake master cylinder are specific F04 components and therefore have their own part numbers. They must not be mixed up with F01/F02 components.

3. Hybrid Braking System

The brake master cylinder incorporates a permanent magnet to record the brake pedal travel. Depressing the brake pedal moves not only the piston in the brake master cylinder, but also the permanent magnet via a drive plate and a pushrod. When the driver's foot comes off the brake pedal, a coil spring presses the permanent magnet back into its initial position.



Brake master cylinder and brake pedal travel sensor in the F04

Index	Explanation
A	Installation location
B	Sectional drawing
1	Brake pedal travel sensor
2	Electrical connection of brake pedal travel sensor
3	Coil spring
4	Permanent magnet
5	Pushrod
6	Drive plate
7	Piston

The position of the permanent magnet is detected by an externally mounted sensor element. The sensor measures in accordance with the PLCD (Permanent magnetic Linear Contactless Displacement) principle. The position of the permanent magnet is determined with the aid of two coils and an electronic circuit which is integrated in the sensor housing. The same sensor principle is also used for example in the Sequential Manual Gearbox and in vehicles with manual gearboxes and the automatic engine start-stop function.

The brake pedal travel sensor can be replaced as a separate component. There is a repair kit which also contains the mounting screws.

⚠

The tightening torque for the mounting bolts must be exactly as specified in the repair instructions and must not be exceeded!

When replacing the brake pedal travel sensor, it is also necessary to observe the ESD safety rules and to protect the sensor against dirt contamination.

3.3.2. Dynamic Stability Control

The Dynamic Stability Control in the F04 is essentially the same as that in the F01/F02. Modifications have been made to the hardware of the DSC control unit and also to its software to comply with the hybrid brake system:

- Brake pedal travel sensor:
  Provision of the supply voltage for the sensor and reading in of the sensor signal (modified control unit connector and expansion of the software)
- Evaluation of parameters for driving stability to be taken into account in the calculation and distribution of the brake force:
  Wheel slip, ABS/ASC/DSC interventions, lateral acceleration and steering angle.
- Calculation of the regenerative mode of the brake force which is to be generated by the drivetrain and communication of this value to the Digital Engine Electronics.

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4. Bus Systems

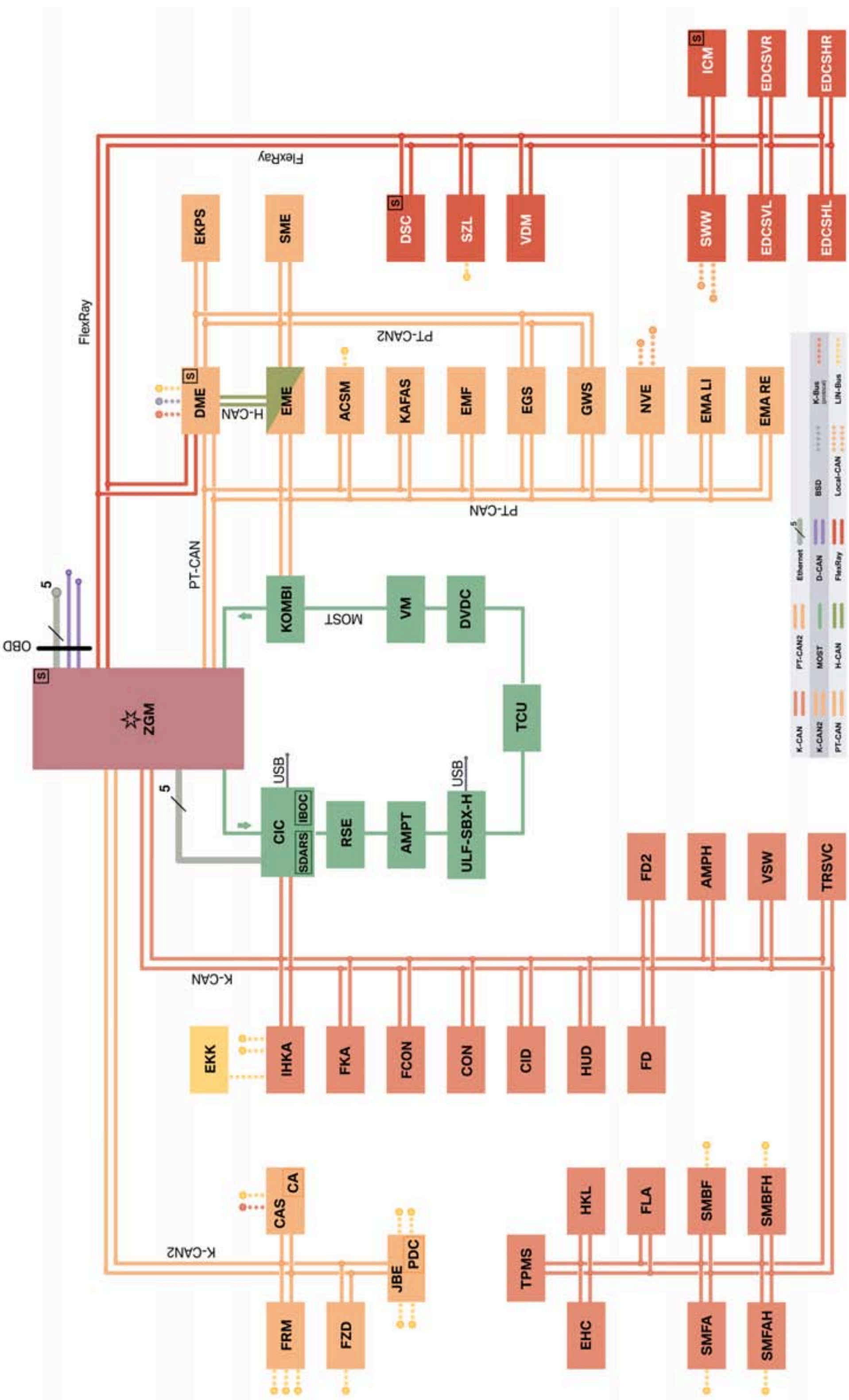
Due to the introduction of hybrid technology the bus system of the F04 differ from the previous bus systems of BMW vehicles (F01/F02). All the main and sub-bus systems of the F01/F02 are also used in the F04. A new bus system has been added referred to as Hybrid-CAN (H-CAN). Compared with the bus systems of the F01/F02 some new control units have been added, some have had to be adapted and some are not installed in the F04 at all.

The resulting bus structure of the F04 is as follows.

F04 Complete Vehicle

4. Bus Systems

4.1. Bus Chart Overview



F04 bus overview

Index	Explanation
ACSM	Crash Safety Module
AHM	Trailer module
AMPH	Amplifier High (high fidelity amplifier)
AMPT	Amplifier Top (top high fidelity amplifier)
CA	Comfort Access
CAS	Car Access System
CIC	Car Information Computer
CID	Central information display
CON	Controller
DME	Digital Engine Electronics
DSC	Dynamic Stability Control
DVDC	DVD changer
EDC SHL	Electronic Damper Control satellite, rear left
EDC SHR	Electronic Damper Control satellite, rear right
EDC SVL	Electronic Damper Control satellite, front left
EDC SVR	Electronic Damper Control satellite, front right
EGS	Electronic transmission control
EHC	Electronic ride height control
EKK	Electric A/C compressor
EKPS	Electronic fuel pump control
EMF	Electromechanical parking brake
EME	Electric motor electronics
FCON	Rear compartment controller
FD	Rear compartment display
FD2	Rear compartment display 2
FKA	Rear climate control
FLA	High-beam assistant
FRM	Footwell module
FZD	Roof function center
GWS	Gear selector
HKL	Automatic luggage compartment lid actuation
HUD	Head-Up Display
ICM	Integrated Chassis Management
IHKA	Integrated automatic heating / air conditioning
JBE	Junction box electronics

Index	Explanation
KAFAS	Camera-based driver support systems
KOMBI	Instrument cluster
NVE	Night Vision Electronics
PDC	Park Distance Control
OBD	Diagnostic socket
RSE	Rear Seat Entertainment
SDARS	Satellite tuner (US)
SMBF	Seat module, passenger
SMBFH	Seat module, passenger, rear
SMFA	Seat module, driver
SMFAH	Seat module, driver, rear
SME	Battery management electronics
SWW	Blind Spot Detection
SZL	Steering column switch cluster
TCU	Telematic Control Unit
TPMS	Tire Pressure Monitoring System
TRSVC	Control unit for reversing camera and Side View
ULF-SBX High	Interface box high
VDM	Vertical Dynamics Management
VM	Video Module
VSW	Video switch
ZGM	Central gateway module

4.2. New control units and bus systems

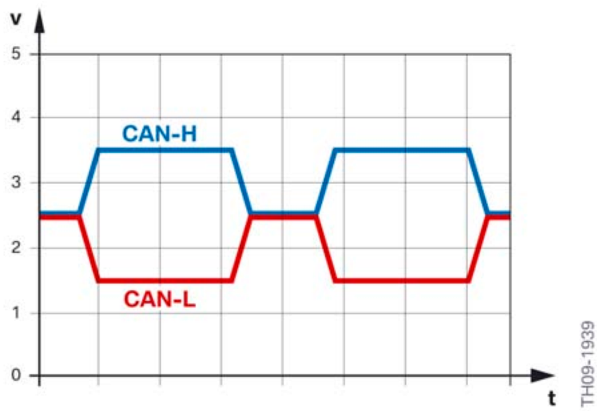
4.2.1. Electric motor electronics (EME)

Electric motor electronics

The function of the electric motor electronics (EME) is to activate and regulate the permanent-field electric motor in the high-voltage electrical system. This necessitates the use of a bidirectional inverter which converts the high DC voltage of the high-voltage battery into a three-phase alternating current for the electric motor. When the electric motor is running in generator mode the high-voltage battery is recharged via the inverter.

The EME also incorporates the DC/DC converter which is responsible for the power supply to the low-voltage electrical system. The EME is connected to the PT-CAN and PT-CAN2. The EME exchanges information with the DME via the H-CAN.

4.2.2. Hybrid CAN (H-CAN)



Signal level on H-CAN

A CAN bus is used in the F04 as an additional bus system for networking the control units which communicate high levels of information (DME and EME).

The data transfer rate on the hybrid CAN is 500 kbit/s. As with previously established CAN bus systems the H-CAN is also designed as a twisted pair cable. The use of twisted pair cables helps to improve the electromagnetic compatibility of the bus systems. The signal levels on the H-CAN for a logical "1" are:

- CAN-H: 3.5 V
- CAN-L: 1.5 V

In the non-active bus the bus level of low and high is 2.5 V (logical zero). A logical 1 is transmitted with a voltage difference of 2 V. The H-CAN has emergency running properties, i.e. if one of the two bus cables has been interrupted, the data continues to be transferred along the cable that is still intact.

4.2.3. Battery management electronics (SME)

High-voltage battery in the F04

The SME control unit is integrated in the high-voltage battery and executes (among others) the following functions:

- Monitoring of the state of the lithium-ion battery
- Control of the shut-off valve in the refrigerant circuit of the air conditioning for cooling the high-voltage battery
- Monitoring of the high-voltage electrical system for insulation faults
- Control of the switch contactors for activating the high-voltage system

The SME control unit is connected to the PT-CAN2.

4.2.4. Electric A/C compressor

An electrically operated A/C compressor is used. To be able to deliver the necessary power, the electric A/C compressor is operated with high voltage; it is a new BMW development. The electric A/C compressor enables the refrigerant of the hybrid car's air conditioning to circulate in all driving situations. In addition to cooling the passenger compartment, the refrigerant circuit also cools the high-voltage battery. The electric A/C compressor control unit is mounted on the A/C compressor housing and is connected via the LIN bus to the integrated automatic heating / air conditioning (IHKA).

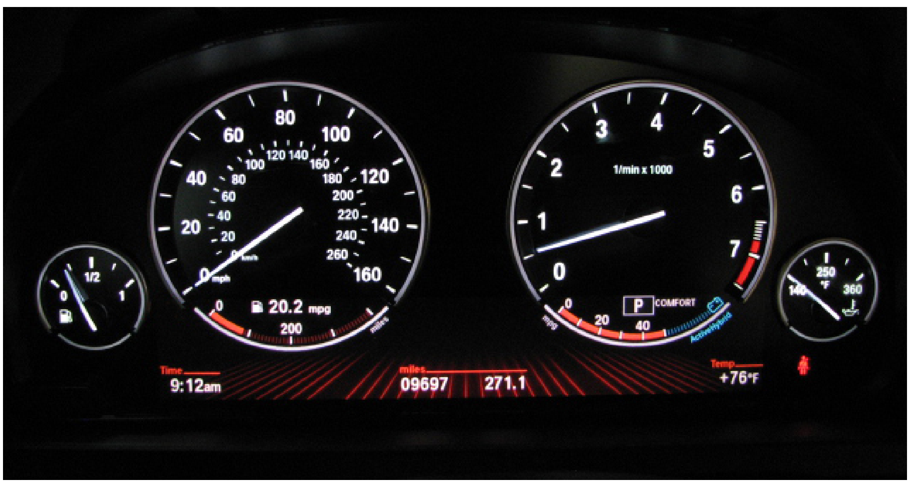
F04 Complete Vehicle
4. Bus Systems

4.3. Adapted control units

4.3.1. IHKA

The software for the IHKA control unit has been adapted due to the use of the electrically operated compressor. For this purpose, the message cataloghas been expanded to include new messages. The IHKA control unit is also the LIN master for the electric A/C compressor.

4.3.2. Instrument cluster



F04 instrument cluster

The hybrid-specific displays appear in the instrument cluster. For this purpose, the software of the instrument cluster has had to be adapted. The display of the current (instantaneous) fuel consumption indicator is supplemented by hybrid displays. In addition, hybrid-specific Check Control messages are displayed.

4.3.3. CIC

The Car Information Computer (CIC) has been modified so that hybrid-specific displays can be indicated in the Central Information Display (CID). By selecting "Hybrid" in the "Vehicle Info" menu it is possible to display the energy and power flows for each driving situation and the state of charge of the high-voltage battery.

4.3.4. DME

The software of the Digital Engine Electronics (DME) has been adapted to effectively handle the torque coordination of electric motor and the combustion engine. The DME also has another H-CAN connection for connecting to the EME.

4.3.5. DSC

The DSC software has also been adapted for regenerative braking. This includes the reading in of the brake pedal travel sensor as a hardware interface.

4.3.6. ACSM

Rollover detection is required for the hybrid vehicles (worldwide) so that in the event the vehicle rolls over, the high-voltage system is deactivated. Rollover detection is achieved with the aid of the central sensor with rollover detection. The central sensor with rollover detection was implemented in the F01/ F02 for the first time and is now fitted in all F04 vehicles. The ACSM was adapted with regard to the evaluation of the central sensor with rollover detection.

4.4. Omitted control units

The F04 does not have Active Steering, as the space for the Active Steering is needed in part by the EME. Because Integral Active Steering is only offered in combination with Active Steering, the control unit for rear axle slip angle control (HSR) is also omitted.

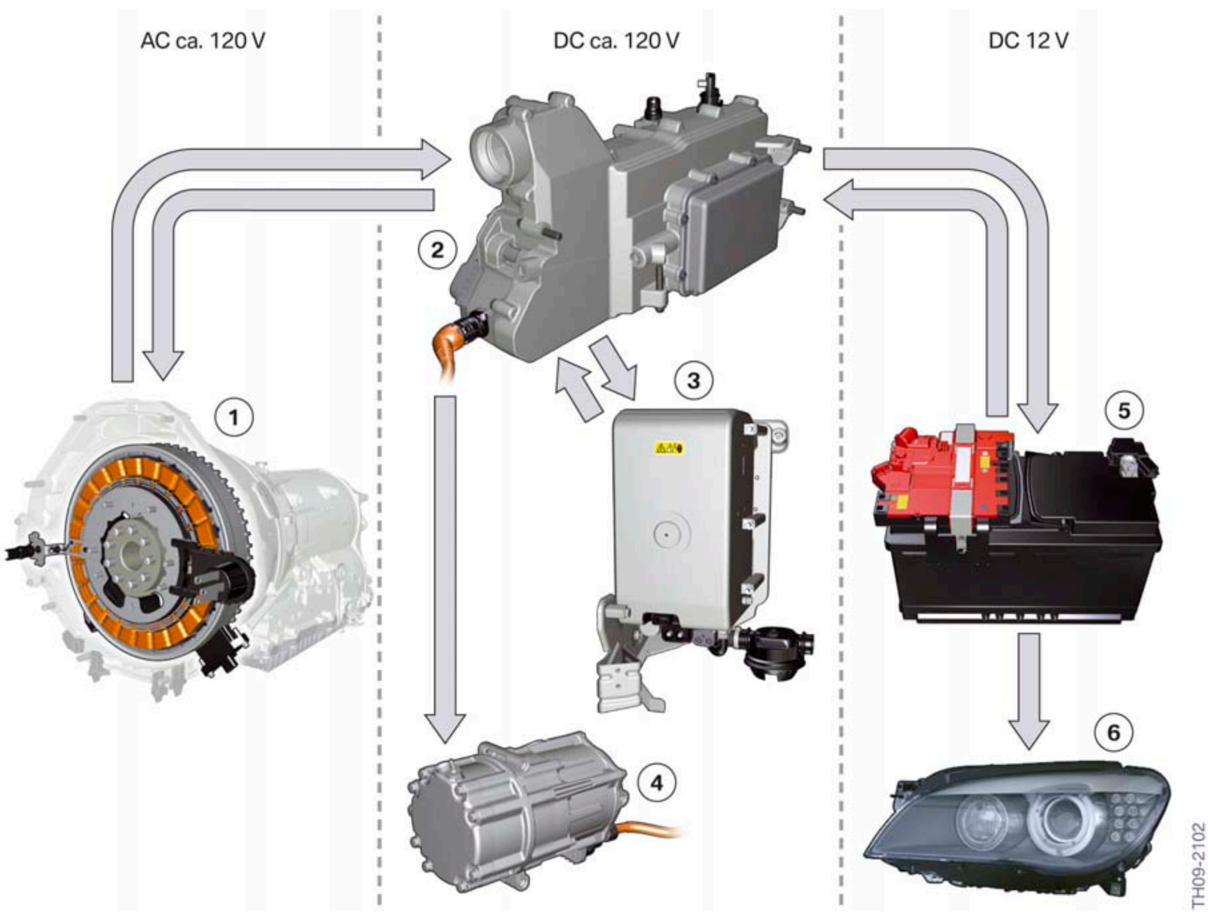
The rear air conditioner (HKA) is not offered in the F04, as the space for it is needed for the high-voltage battery.

Because of the complex control and the low production numbers involved, ACC is not an available feature in the F04 either.

5. Power Supply

The electrical system of the F04 can be divided into three areas:

- Drive with electric motor (high voltage with AC voltage)
- High-voltage electrical system with DC voltage
- 14 V vehicle electrical system.



Electrical systems in the F04

Index	Explanation
1	Electric motor
2	Electric motor electronics (EME)
3	High-voltage battery
4	Electric A/C compressor
5	12 V battery
6	Electrical consumer in the 14 V electrical system

F04 Complete Vehicle
5. Power Supply

A bidirectional DC/AC inverter in the EME serves as the coupling element between the high-voltage electrical system with AC voltage (for the electric motor) and the high-voltage electrical system with DC voltage (high-voltage battery). The 14 V electrical system of the F04 is essentially the same as the electrical system of the F01/F02. The main difference is that the power is no longer supplied by the 14 V alternator, but by the DC/DC converter in the EME. The electric voltage supply of the 14 V vehicle electrical system is thus no longer dependent on the speed of the combustion engine when driving. Another difference is that the combustion engine is started by the electric motor and the high-voltage battery instead of a conventional starter and 12 V battery.

The new control units are supplied with voltage via the following terminals:

Control unit	Terminal
EME	Terminal 30B
SME	Terminal 30F
EKK	Terminal 30B

5.1. Energy management

The energy management of the F04 is regulated and coordinated by the high-voltage power management. The high-voltage power management regulates the energy flow on the high-voltage electrical system (AC and DC) as well as between the high-voltage and low-voltage electrical systems. The power management for the low-voltage electrical system is based on the Advanced Power Management (APM) familiar from the F01/F02. Functions such as consumer reduction, consumer cutoff, electrical system diagnosis and 12 V battery diagnosis are still integral to the APM. The APM is still integrated in the DME. The APM is subordinate to the high-voltage power management. The high-voltage power management is integrated in the EME.

5.1.1. Vehicle starting capability

The combustion engine in the F04 is not started with the assistance of the 12 V battery, but instead with the high-voltage battery. The purpose of the 12 V battery is only to ensure the powering up of the high-voltage system. The 12 V battery is required to store a minimum SoC to protect the 12 V battery against freezing at temperatures below 32 °F (0 °C) and to power up the high-voltage system.

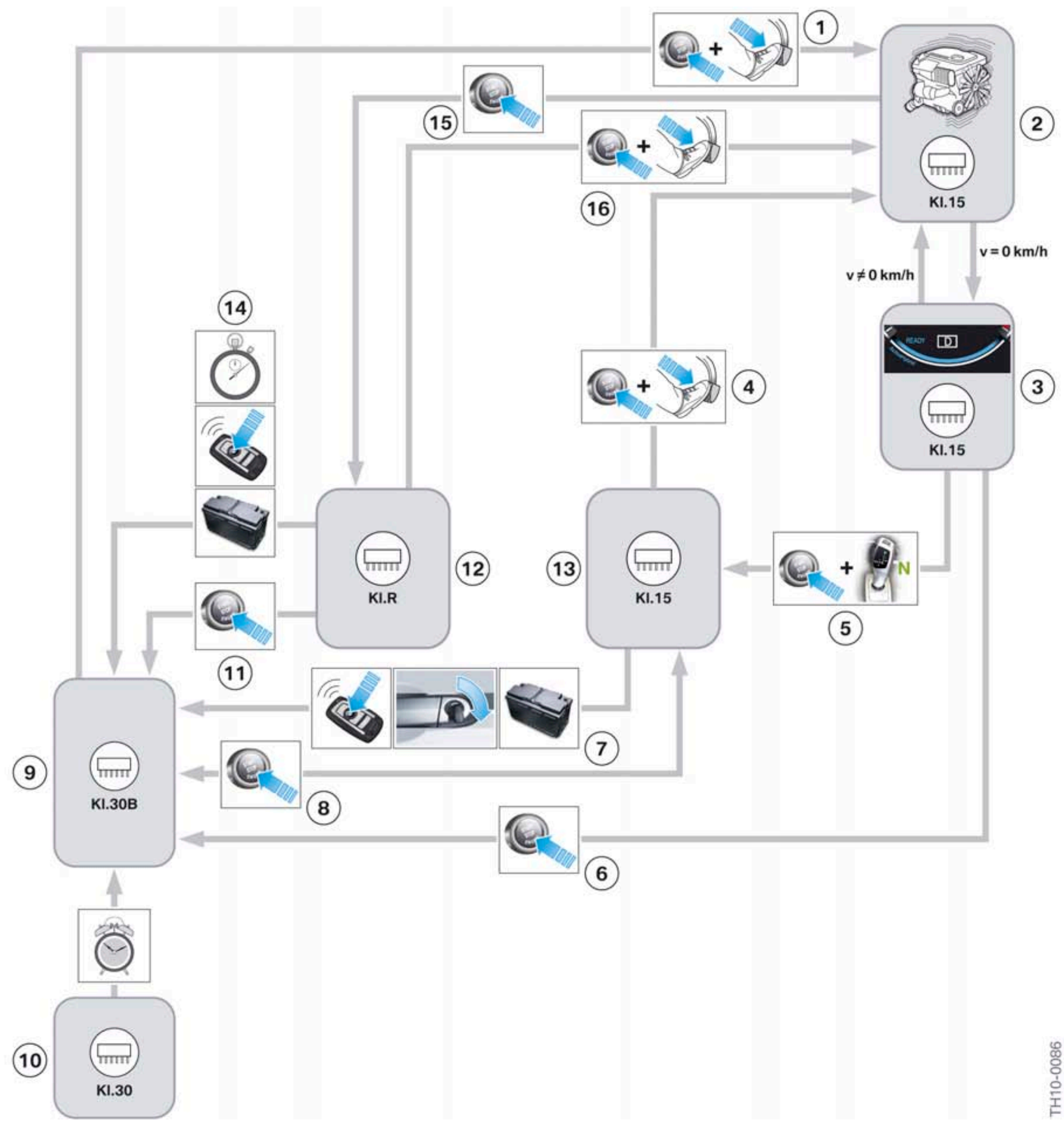
The ability to start the combustion engine is now ensured by the high-voltage operational strategy. When the vehicle has been parked or stored for an extended period, the SoC of the high-voltage battery must be sufficiently high to restart the combustion engine, even after an immobilization period of six weeks. If the combustion engine cannot be started (after storing the vehicle for an extended period) due to a low SoC of the high-voltage battery, the high-voltage battery must be charged by an external 14 V charger and the DC/DC converter within the EME. Charging the high-voltage battery in this manner takes about 20 minutes. A sufficient state of charge (for starting the combustion engine) is accompanied by the display of a yellow Check Control symbol and the corresponding text message in the CID.

5.1.2. Starting aid

The "starting aid" function ensures that the combustion engine can be started even if the SoC of the high-voltage battery is low. This involves energy being transferred from the 14 V electrical system to the high-voltage electrical system so that the SoC of the high-voltage battery is increased in order to start the combustion engine. In order to protect the battery of the 14 V vehicle electrical system against total discharge, this energy must be supplied by an external voltage supply (charger or via starting aid).

The voltage of the external voltage supply must correspond to the voltage level of the 14 V electrical system. The external voltage supply must remain connected for a period of time in order to charge the high-voltage battery, i.e. a direct engine start is not possible after the external voltage supply has been applied.

5.2. Terminal control



Terminal control from the customer's point of view

Index	Explanation
1	The combustion engine is started by simultaneously pressing the START-STOP button and the brake pedal
2	Driving with assistance of the combustion engine
3	"Ready to drive" with terminal 15
4	The combustion engine is started by simultaneously pressing the START-STOP button and the brake pedal
5	When the selector lever is at "N" and engine operation is ended with the START-STOP button, terminal 15 remains switched on for 15 minutes (car wash function)
6	When the START-STOP button is pressed the terminal status changes from ready to drive to terminal 30B
7	Terminal 15 OFF when the car is locked or the state of charge of the 12 V battery is too low
8	When the START-STOP button is pressed the terminal status changes between terminal 15 and terminal 30B
9	Terminal 30B
10	Terminal 30
11	When the START-STOP button is pressed the terminal status changes from terminal R to terminal 30R
12	Terminal R
13	Terminal 15
14	Change from terminal R to terminal 30B if more than eight minutes have passed or the car has been locked or a critical SoC of the 12 V battery has been reached
15	When the START-STOP button is pressed the terminal status changes from engine running (terminal 15) to terminal R
16	The combustion engine starts when the START-STOP button and the brake pedal are simultaneously pressed

5.2.1. "Ready to drive" mode

Displays for "Ready to drive" mode in the instrument cluster and CID

Index	Explanation
1	READY display in the instrument cluster
2	READY display in the CID

"Ready to drive" is a status of the vehicle while it is stopped, e.g. in a traffic jam or at traffic lights, in which the combustion engine is switched off, but the ignition remains switched on. The combustion engine starts automatically as soon as the brake pedal is released or when the Automatic Hold function is activated the accelerator pedal is depressed. Another way of starting the combustion engine directly from stopped is to turn the steering wheel to the left or right. "Ready to drive" is practically the status of the vehicle between terminal 15 and the combustion engine running. The prerequisites for activating the "Ready to drive" mode in the F04 is for the combustion engine to be at operating temperature and the state of charge of the high-voltage battery to be sufficient to supply the auxiliary consumers with power while the vehicle is stopped.

Unlike conventional vehicles the "Ready to drive" status in a hybrid vehicle cannot be recognized by the combustion engine running.

5.3. Reverse polarity protection

Reverse polarity protection serves to avoid consequential damage to the vehicle electrical system and electronic components connected to it in the event of the polarity being reversed by the customer during an external start. The diodes in the alternator are generally used for this task. Because the conventional alternator is omitted from the F04, this task is performed by the DC/DC converter in the EME. In other words, the F04 does not have a separate reverse polarity protection module.

F04 Complete Vehicle

6. High-voltage Battery Unit

6.1. Overview

The high-voltage battery unit is a complete system that contains not only the high-voltage battery itself, but also the following additional components:

- Electronic control unit, battery management electronics (SME)
- Electromechanical switch contactors
- Connections for high-voltage cables
- Connections for low-voltage cables
- Connections for refrigerant line and condensation drain line
- Gas vent pipe

The primary task of the high-voltage battery unit is to draw electrical energy from the high-voltage electrical system, store it and make it available again later as necessary. In addition, it assumes important tasks that contribute to the safety of the high-voltage system, such as the high-voltage interlock loop. The high-voltage safety connector (also called the "Service Disconnect") is not an integral part of the high-voltage battery unit in the F04. Instead it is located in the luggage compartment well near the 12 V battery.

The system supplier of the high-voltage battery unit for the F04 is the company TEMIC Automotive Electric Motors GmbH. It was developed in a cooperation between BMW AG and Daimler AG.

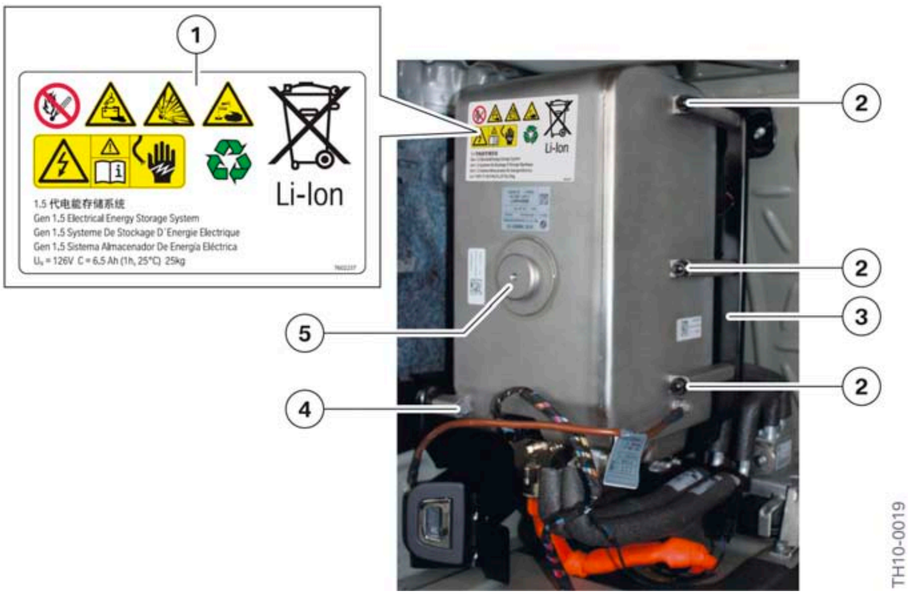
The following is a summary of the important characteristics of the high-voltage battery unit:

Nominal voltage	126 V
Battery cells	35 at 3.6 V each
Storable amount of energy	800 Wh
Used amount of energy	400 Wh
Maximum power	19 kW
Storage technology	Lithium-ion
Dimensions	14.4 in x 8.7 in x 9.2 in (370 mm x 222 mm x 234 mm)
Weight	about 62 lb (28 kg)
Cooling system	Cooling via refrigerant circuit

6.1.1. Installation location and external characteristics

The installation location of the high-voltage battery unit in the F04 is identical to the installation location of the rear air conditioner of an F02 with the optional equipment "Extended rear air conditioning". Although the F02 is not currently available in the US market with the optional equipment "Extended rear air conditioning" it is similar to the system used on the E66. The high-voltage battery unit is covered by a panel and is therefore not directly visible. When this panel is removed the features and connections shown in the following graphic can be identified.

F04 Complete Vehicle
6. High-voltage Battery Unit

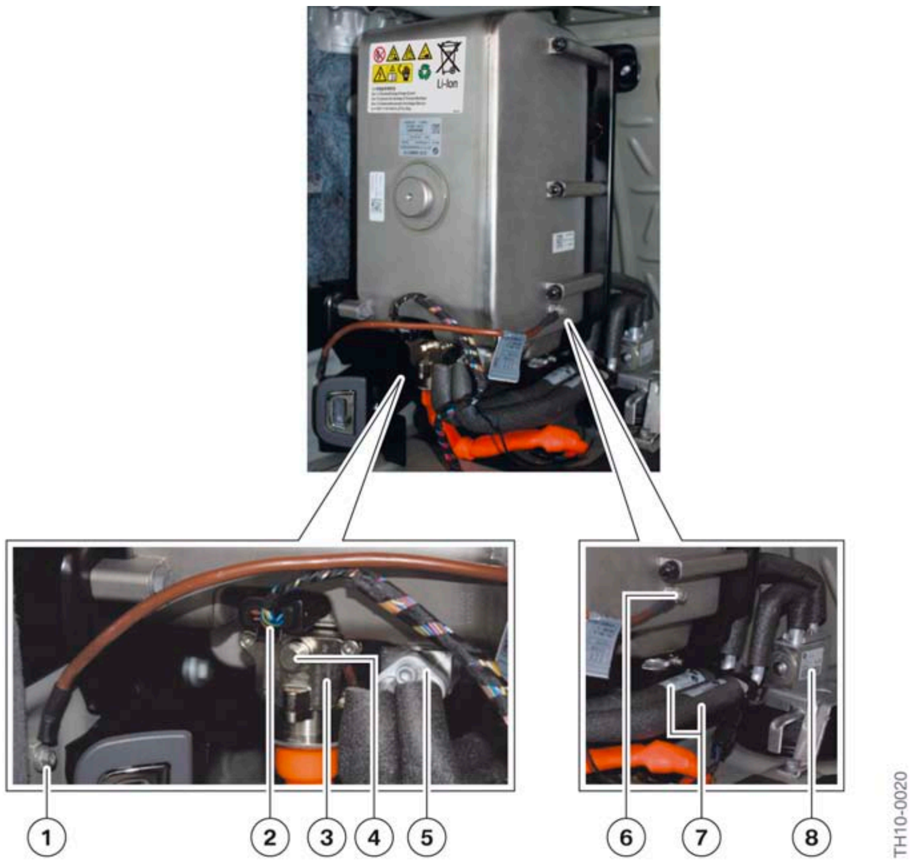


Installation location, high-voltage battery unit in the F04

Index	Explanation
1	Warning sticker for high-voltage battery
2	Mounting hardware for the high-voltage battery unit to the bracket
3	Support
4	Mounting hardware for the high-voltage battery unit to the bracket
5	Mounting for special tool – (not used by BMW)

The high-voltage battery unit is connected with a bracket to the left side of the vehicle body and to the rear seat backrest.

There is a special tool available to facilitate removal and installation of the high-voltage battery unit (Part # was not available at the time of this material). However, this special tool does not use the knob shown in the graphic (5) – the knob is instead used during the manufacturing process of the high-voltage battery unit.



Connections and components on the high-voltage battery unit of the F04

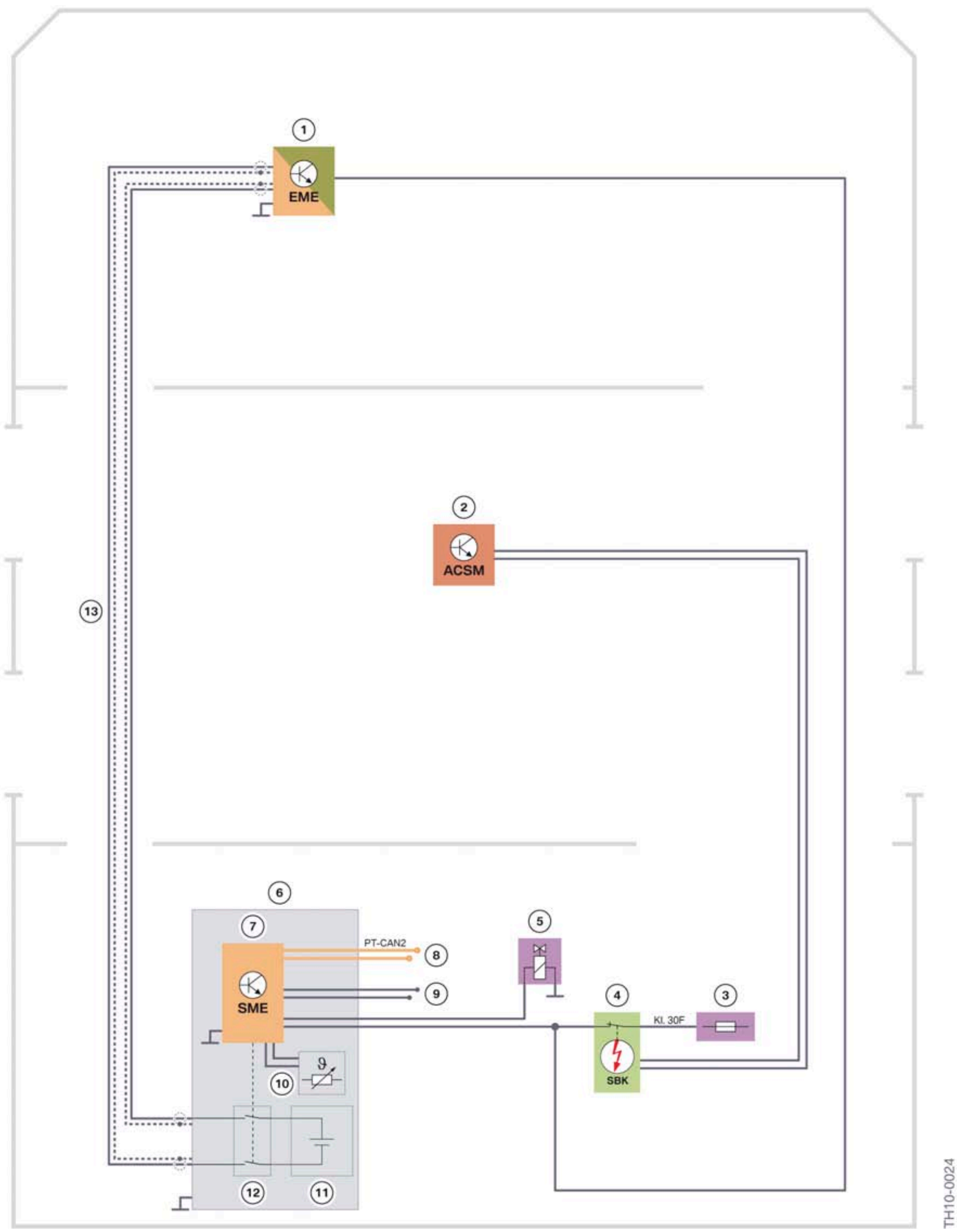
Index	Explanation
1	Connection of grounding cable to vehicle body
2	Low-voltage connection (for battery management electronics control unit)
3	High-voltage connection
4	Retaining screw for high-voltage connection
5	Connection, refrigerant lines
6	Connection of grounding cable to high-voltage battery unit housing
7	Refrigerant lines
8	Combined shut-off and expansion valve for cooling the high-voltage battery

The required electrically connection between the high-voltage battery unit housing and vehicle ground is provided (as shown in the graphic) by a separate electrical cable.

F04 Complete Vehicle

6. High-voltage Battery Unit

6.1.2. System wiring diagram



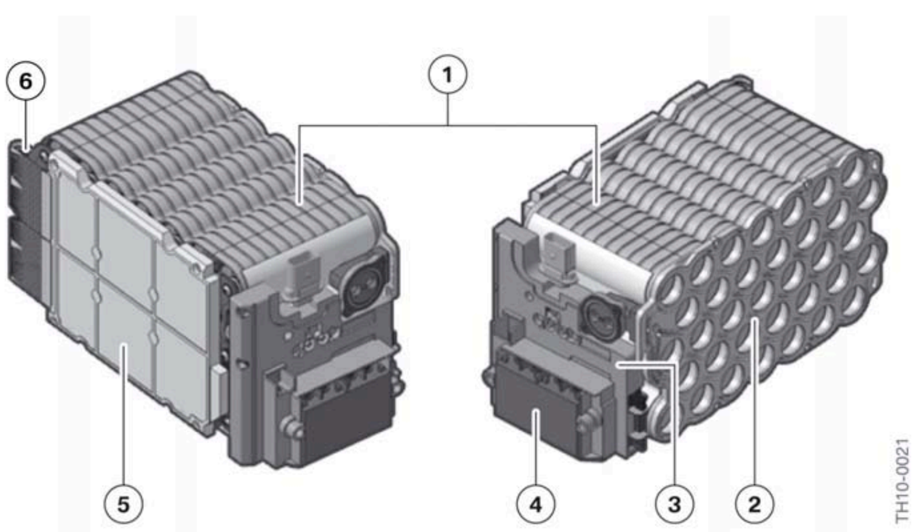
System wiring diagram of high-voltage battery unit

Index	Explanation
1	Electric motor electronics (EME)
2	Crash Safety Module (ACSM)
3	Fuse for battery management electronics in luggage compartment fuse holder
4	Battery safety terminal
5	Combined shut-off and expansion valve
6	High-voltage battery unit
7	Battery management electronics (SME)
8	PT-CAN2 cables
9	Wiring of the high-voltage interlock loop
10	Temperature sensor for measuring cell temperatures
11	High-voltage battery
12	Contacts of electromechanical switch contactors
13	High-voltage cables with shielding

6.1.3. High-voltage battery

The term "high-voltage battery" refers to the actual energy accumulator for the high-voltage system. The nominal voltage of 126 V is achieved by connecting 35 battery cells in series with a nominal voltage of 3.6 V each.

Each individual cell is cylindrical in shape and has access points for measuring the cell voltage. Situated in the spaces between the cells are elements which absorb impacts and vibrations and thereby protect the cells against mechanical damage. The cells are designed in accordance with lithium-ion technology. This technology is characterized by the highest available energy and power density currently on the market.

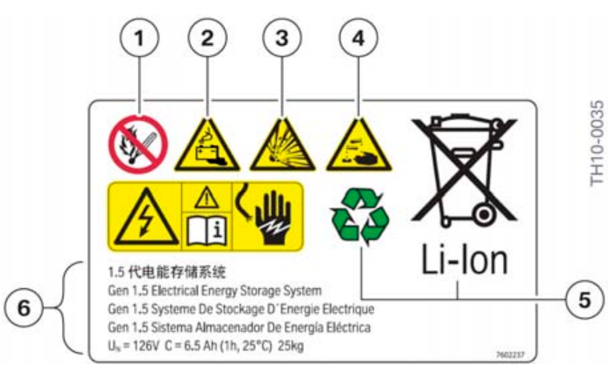


Design of the high-voltage battery

Index	Explanation
1	Protective plate for the cells
2	Heat sink
3	Battery management electronics (SME)
4	Electromechanical switch contactors
5	Electronic circuits for cell monitoring
6	150A fuse (Non-replaceable)

Lithium-ion technology cells are sensitive to overloading, overvoltage, overcurrent and excess temperature. The cells are therefore monitored individually and in blocks. Electronic circuits located on one side of the cell block perform this monitoring task and permanently measure the voltage of each individual cell and the temperature at four different positions. A heat sink which projects between the cells also serves to cool the cells. The cells are sealed with this heat sink during the manufacture process. The refrigerant is routed along the cells through channels in the heat sink. If an unacceptably high temperature or an unacceptably high pressure occurs in a cell, the housing of each cell has a predetermined breaking point. Above this point the excess gas pressure in the cell can be decreased. The gases released in the process are discharged from the vehicle through the gas vent pipe.

The high-voltage battery can be connected to or isolated from the high-voltage electrical system using the contacts of electromechanical switch contactors inside the high-voltage battery unit. These contacts are located on the positive terminal and the negative terminal, before the terminals are routed out of the high-voltage battery. The electromechanical switch contactors are activated by the battery management electronics (SME). The supply voltage for the switch contactors is supplied through the battery safety terminal.



Warning sticker on the high-voltage battery

Index	Explanation
1	Prohibited symbol: No open flames, sparks or smoking
2	Warning symbol: Warning against dangers of batteries
3	Warning symbol: Warning against explosive substances / materials
4	Warning symbol: Warning against caustic substances / materials
5	Reference to disposal of high-voltage battery unit: Recycling by specialist personnel possible, not to be disposed of in domestic waste
6	Multilingual text: "Gen 1.5 Electrical Energy Storage System U_N = 126 V, C = 6.5 Ah (1 h, 25 °C), 25 kg"

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Observe the safety data sheet for the high-voltage battery for all repair work on these components. Use the personal safety equipment prescribed there. If there is any uncertainty regarding a possible hazard, contact the technical support (PUMA) of the BMW Group.

6.1.4. Battery management electronics

High demands are placed on the high-voltage battery lasting the service life of the vehicle. To maximize the service life of the high-voltage battery it is operated in a precisely defined range.

This includes the following measures:

- Protecting the cells against overheating (by cooling and/or limiting the current)
- Adjusting the state of charge of the individual cells where necessary to one another
- Not fully depleting the battery's amount of storable energy

For this reason the high-voltage battery of the F04 also has its own control unit, which monitors these conditions and intervenes where necessary. This control unit is called the "battery management electronics (SME)" and is located inside the high-voltage battery unit, which is why it is not accessible from the outside.

The SME control unit must perform the following tasks:

- Controlling cooling
- Determining the state of charge (SoC) and the state of health (SoH) of the high-voltage battery
- Determining the available power of the high-voltage battery and where necessary requesting a limitation from the electric motor electronics
- Controlling the starting and shutting down of the high-voltage system at the request of the electric motor electronics
- Safety functions (e.g. high-voltage interlock loop, insulation monitoring)
- Monitoring the voltage and temperature of the battery cells and the current
- Communicating fault states to the electric motor electronics.

The SME control unit has its own fault memory which can be read out using the ISTA BMW diagnosis system.

The electrical interfaces of the SME control unit are:

- 12 V supply voltage (terminal 30 from the battery safety terminal to supply the switch contactors and the SME control unit itself, terminal 31)
- PT-CAN2
- Wake-up line
- Forward and return lines for high-voltage interlock loop
- Line for activating the combined shut-off and expansion valve

6.1.5. High-voltage connection

The connection of the high-voltage battery unit to the high-voltage electrical system is designed as a plug connection, but it is protected by a retaining bolt against being unintentionally released. The connector on the high-voltage battery unit contains contacts for:

- Positive battery terminal and negative battery terminal
- High voltage interlock loop

The connector of the high-voltage cable features the contacts for the high-voltage positive lead and negative lead, as well as a bridge for the high-voltage interlock loop. The plug connection is designed in such a way that when the high-voltage cable is disconnected from the high-voltage battery, the bridge of the high-voltage interlock loop is pulled first. Only then are the high-voltage connections disconnected from the power supply. When the high-voltage connector is released, the high-voltage system is automatically shut off by the opening of the electromechanical switch contactors. This process is an additional safety precaution to eliminate dangers posed by the high-voltage system to Service Personnel. Service Personnel must nevertheless still observe the electrical safety rules before carrying out any work on high-voltage components.

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Before working on the high-voltage connection of the high-voltage battery unit or any other high voltage component, it is essential to disconnect the high-voltage system from the power supply, to safeguard the system against unintentional starting and to verify its safe isolation from the high voltage power supply.

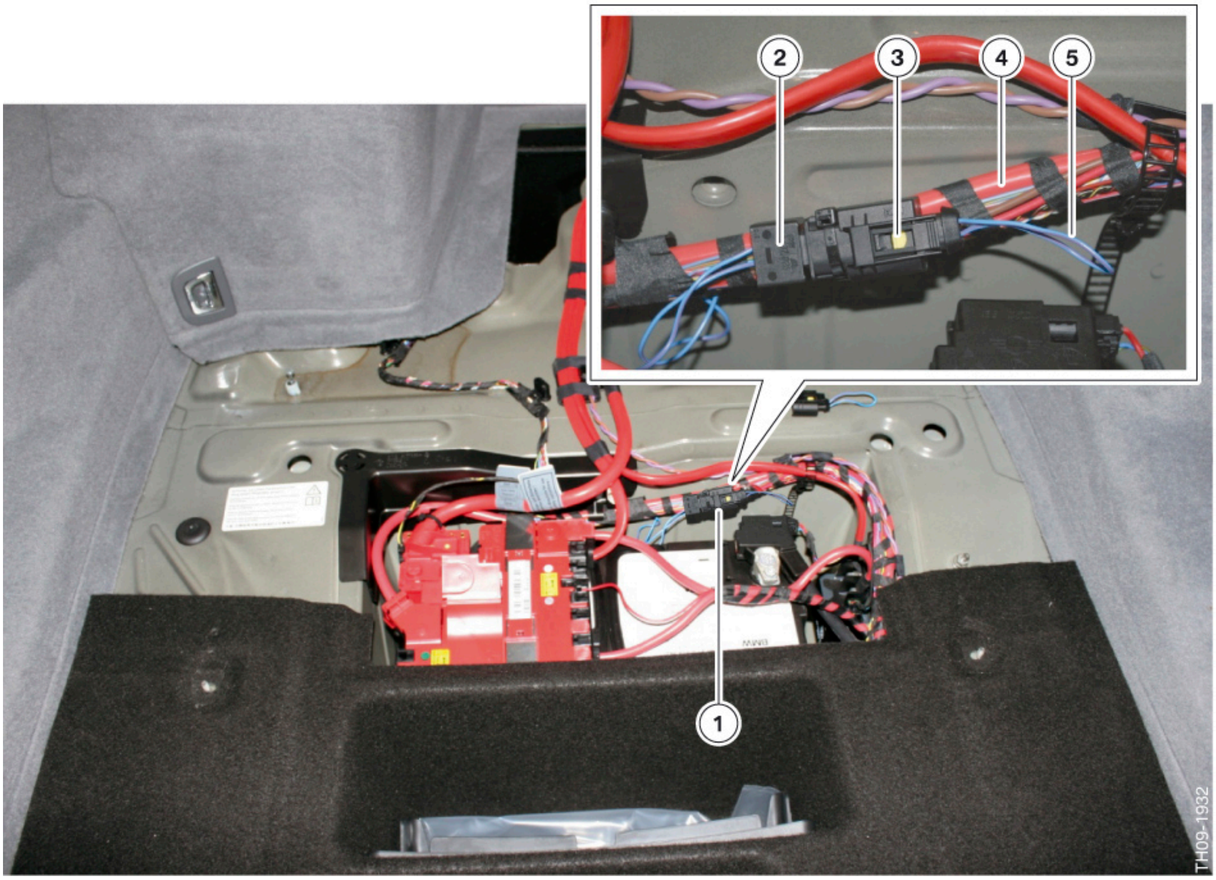
High-voltage connection on the high-voltage battery unit

Index	Explanation
1	Connector, battery management electronics (SME)
2	High-voltage connector
3	High-voltage connections
4	Connections for high-voltage interlock loop
5	Threaded support sleeve for retaining bolt

6.1.6. High-voltage safety connector (Service Disconnect)

The high-voltage safety connector ("Service Disconnect") in the F04 is located in the luggage compartment well near the 12 V battery.

6. High-voltage Battery Unit



F04 high-voltage safety connector

Index	Explanation
1	High-voltage safety connector ("Service Disconnect")
2	Socket with wires of high-voltage interlock loop circuit
3	Removable high-voltage safety connector
4	Remaining wiring harness in which the high-voltage safety connector is mechanically incorporated
5	Bridge

The high-voltage safety connector is responsible for the following tasks:

- Disconnecting the high-voltage system from the power supply
- Providing a safeguard to prevent unintentional restarting

The operating principle of the high-voltage safety connector in the F04 is based on the fact that the circuit of the high-voltage interlock loop is designed to be interrupted. The high-voltage system monitors this circuit permanently and powers down the high voltage automatically when an open circuit is detected.

6.1.7. Overcurrent protection

The F04 features several devices for protecting against overcurrent in the high-voltage circuit which are integrated in the high-voltage battery unit:

- Measurement of the current with a precision resistor and shut-off of the high-voltage system when a threshold value is exceeded.
  — This is controlled through software by the battery management electronics (SME), which opens the contacts of the electromechanical switch contactors.
- Measurement of the current and shut-off of the high-voltage system when a threshold value is exceeded.
  – This is triggered by the shut-off electronics and is specially intended for this purpose (a redundant hardware solution in contrast to the above-mentioned software solution).
- A safety fuse, connected in series with the cells, interrupts the circuit automatically in the event of a short circuit.

The current is determined with a precision resistor which is connected in series with the cells. The current is evaluated by the battery management electronics and by the shut-off electronics. If the battery management electronics detects an excessively high current, the shut-off of the current is first communicated via bus signals to the electric motor electronics. In the optimum case, the current in the high-voltage circuit is thereby reduced to zero and only then are the contacts of the electromechanical switch contactors opened. In this way these contacts are subject to a very low load.

Another type of shut-off is possible by way of special shut-off electronics – in this case, however, the contacts of the electromechanical switch contactors are opened directly. These electronic overcurrent protective devices are designed in such a way that they intervene before the safety fuse trips.

The safety fuse has a nominal current of 150 A and will only trigger if the electronic protective measures do not respond or do not respond quickly enough. When the safety fuse triggers, the high-voltage system will no longer go into operation. Because it is integrated in the high-voltage battery unit, the fuse cannot be replaced separately.

6.1.8. Cooling system

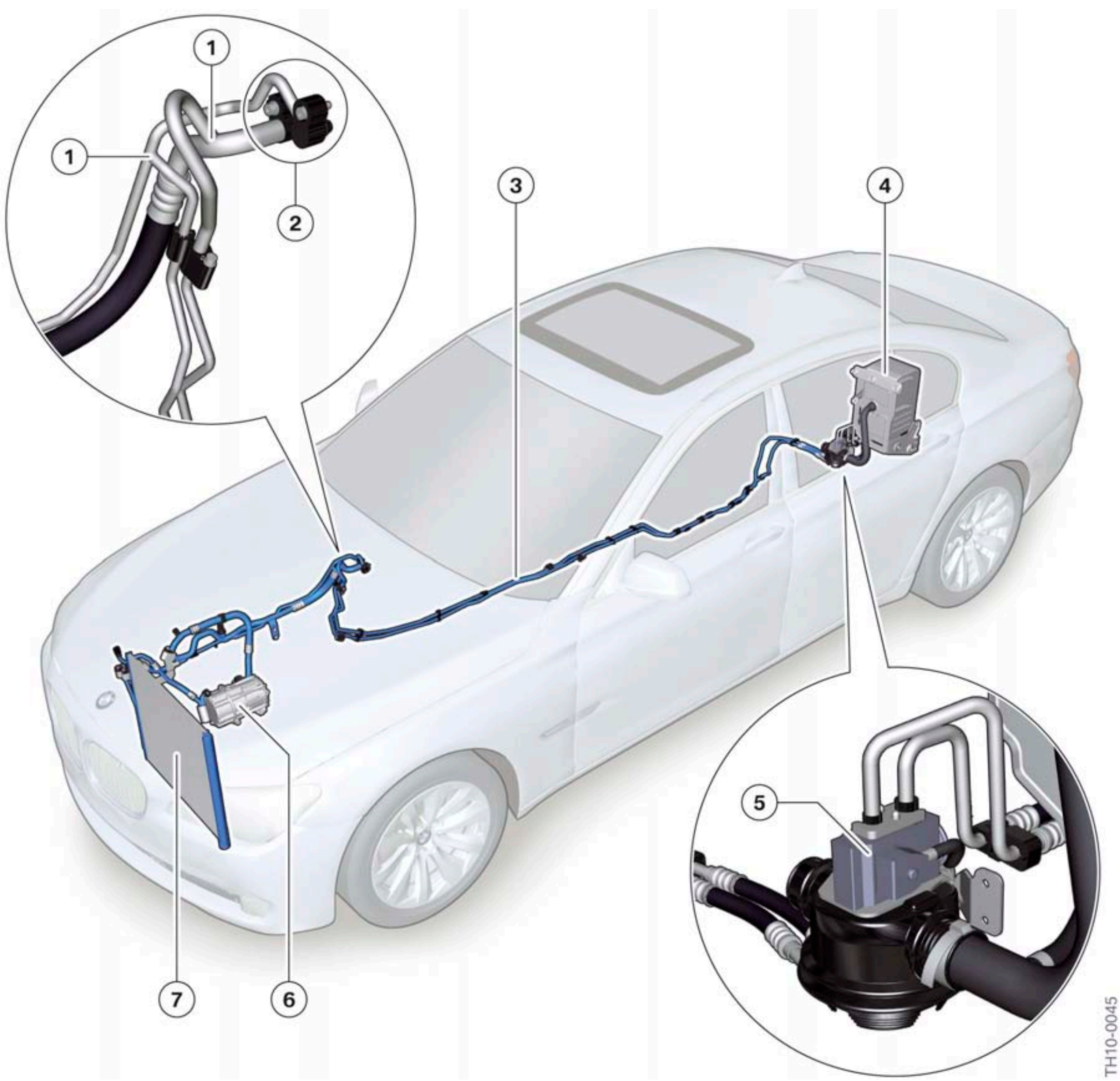
To maximize the service life of the high-voltage battery and obtain the greatest possible power, it is operated in a defined temperature range. The high-voltage battery is essentially operational in the range of -13 °F to 131 °F (-25 °C to +55 °C). However, these temperature limits relate to the actual temperature of the cell, not the outside temperature. In terms of temperature behavior the high-voltage battery is a slow-action system, thus it can take several hours for the cells to reach ambient temperature. Therefore having the battery spend a short period of time in an extremely hot or cold environment does not mean that the cells will have assumed this temperature.

The high-voltage battery has been developed in such a way that it provides sufficient power to start the combustion engine within a large cell temperature range. Trials have demonstrated that starting the combustion engine is possible even at cell temperatures of -13 °F (-25 °C) and below. It is important to bear in mind that the cells assume the ambient temperature only when the vehicle has been exposed to this ambient temperature for several days. It is highly unlikely for the combustion engine of an F04 not to be able to be started due to low ambient temperatures. However, should this extreme case occur, the vehicle must be introduced into a warmer environment.

F04 Complete Vehicle

6. High-voltage Battery Unit

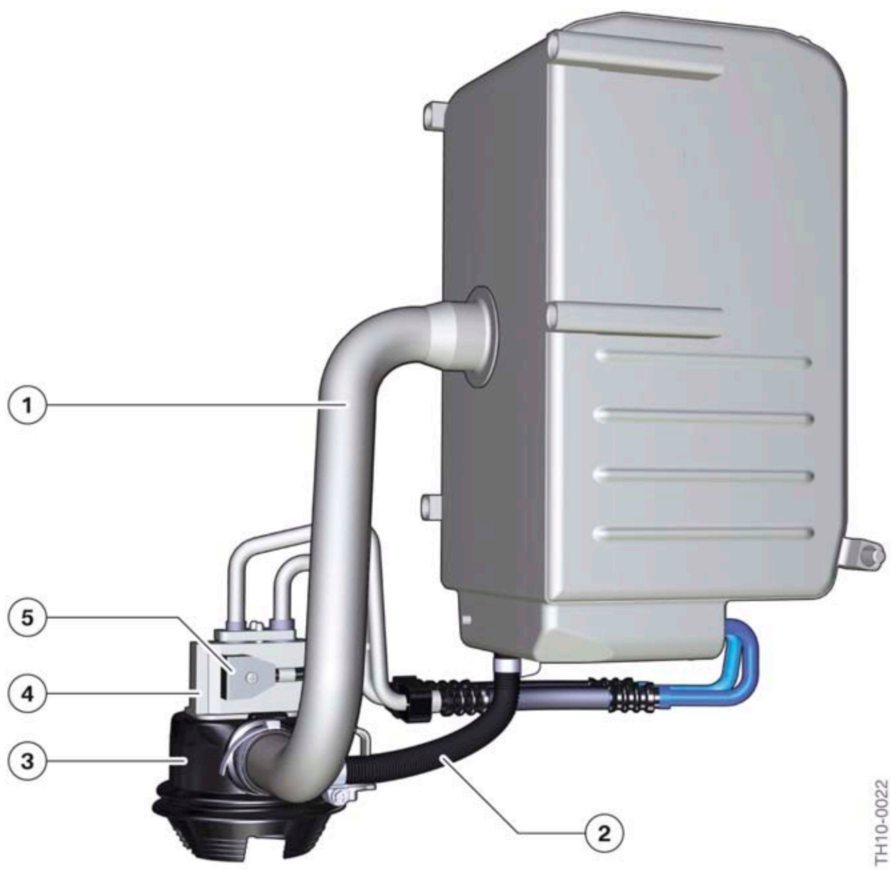
The upper temperature limit does not pose any restriction with regard to starting capability, since temperatures higher than 131 °F (55 °C) at the installation location of the high-voltage battery cannot be reached. This has been demonstrated by trials in "hot climates". In order to protect the battery against damage at such high cell temperatures, the high-voltage battery current (in and out) is limited by software. Cooling the high-voltage battery maintains the cell temperature at a lower level and increases the service life of the high-voltage battery. Therefore, the hybrid functions are available even when the electric drive is subject to intensive use and at high outside temperatures.



Refrigerant circuit in the F04

Index	Explanation
1	Branching of refrigerant lines to high-voltage battery unit
2	Connection to expansion valve for passenger compartment
3	Refrigerant lines to high-voltage battery
4	High-voltage battery
5	Combined shut-off and expansion valve for high-voltage battery
6	Electric A/C compressor
7	Condenser

The high-voltage battery in the F04 is cooled by refrigerant. The air conditioning refrigerant circuit has therefore been extended in order to cool the high-voltage battery unit. The expansion valves for climate control of the passenger compartment and for the high-voltage battery are connected in parallel. The battery management electronics can activate and open the combined shut-off and expansion valve for the high-voltage battery unit via a pulse-width modulated signal.



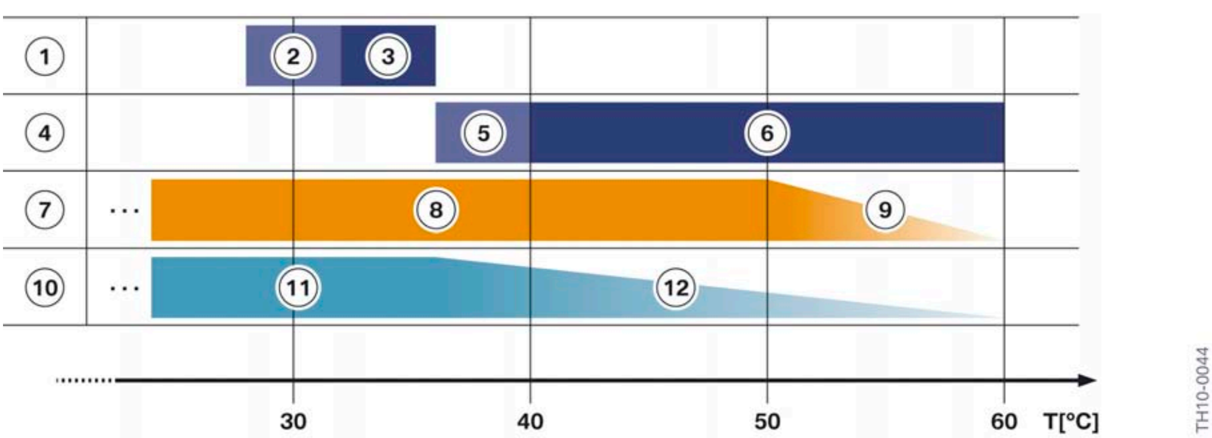
Components for cooling the high-voltage battery

Index	Explanation
1	Gas vent pipe
2	Drain hose for condensation water
3	Grommet
4	Combined shut-off and expansion valve
5	Electrical connection for shut-off valve

Due to the cooling of the high-voltage battery with refrigerant and the resulting large temperature differences, water vapor can condense inside the high-voltage battery. This condensation is discharged via a drain hose which is connected to the housing base. This drain hose and a gas vent pipe are brought together outside the high-voltage battery and led through a grommet out of the passenger compartment. The gas vent pipe serves to compensate large pressure differences between the interior and the exterior of the high-voltage battery. Pressure differences of this nature can only arise if a cell is damaged. In this case (as a safety measure) the housing of the damaged cell opens in order to reduce the pressure. The escaping gases are then directed out of the vehicle through the gas vent pipe.

The cooling strategy for the high voltage battery is explained below:

When in the “Low-priority cooling” mode, the battery temperature (in range 1) is not that high, but cooling the battery there is also beneficial. When coming from a lower temperature, cooling will start at range (3). But once cooling has started, it will continue until the lower end of the range (left margin of “2”) is reached, this is referred to as the “Extended cooling range”. This works the same way for the “high–priority cooling” (range 4), once cooling has started, it will continue until the lower end of the range (left margin of “5”) is reached. The only difference is that cooling of the battery in this range is absolutely vital! The “Extended cooling range” is implemented in both cases order to reduce the number of switch on – switch off cycles of the cooling function and thus extend the life of the related components.



Cooling and functions of the high-voltage battery dependent on the cell temperature

Index	Explanation
1	Low-priority cooling
2	Extended cooling range: Here the low-priority cooling, which has already started in (3), is continued until the lower temperature limit of (2) is reached
3	Switch-on range: low-priority cooling starts in this temperature range
4	High-priority cooling
5	Extended cooling range: Here the high-priority cooling, which has already started in (6), is continued until the lower temperature limit of (5) is reached
6	Switch-on range: high-priority cooling starts in this temperature range
7	Available electrical power of the high-voltage battery
8	Full power of the high-voltage battery available
9	Restriction of the supplied and consumed power of the high-voltage battery in order to prevent further heating
10	Availability of hybrid functions (e.g. boost function)
11	All hybrid functions are fully available
12	Hybrid functions are continuously reduced or switched off in order to counteract further heating

Note: In the “Extended cooling ranges” cooling continues beyond the typical cut off point in order to reduce the number of switch on – switch off cycles of the cooling function. This results in longer but less frequent cooling cycles which extend the life of the related components.

In the temperature range in which the high-voltage battery does not need to be cooled, the expansion valve for the high-voltage battery remains closed.

When the temperature rises and "low-priority cooling" is required, the SME control unit sends a cooling demand for the high-voltage battery to the IHKA control unit via bus signals. The IHKA control unit reports back to the SME control unit whether cooling output is available for the high-voltage battery. If cooling output is available, the SME control unit opens the shut-off and expansion valve for the high-voltage battery. If no cooling output is available, the valve remains closed and no refrigerant is allowed to flow through the high voltage battery (priority remains with the cooling of the passenger compartment).

If the temperature of the cells continues to rise, it is absolutely necessary to cool the high-voltage battery. The SME control unit signals again the now urgent cooling demand "high-priority cooling" to the IHKA control unit. The shut-off and expansion valve for the high-voltage battery is opened in this case to protect the high-voltage battery against damage. If the electric A/C compressor was not switched on previously, it is now activated by the IHKA control unit in response to this request by the battery management electronics. This also occurs if the driver has switched off the air conditioning function for the passenger compartment.

Although the cooling output is generally adequate, the situation may arise under extreme conditions where the temperature in the high-voltage battery continues to rise. In such an extreme case, the hybrid functions are reduced in stages or no longer made available (e.g. the boost function). Here the focus is on protecting the high-voltage components. If the temperature increases further, the system is protected by electronically limiting the high-voltage battery input and output current.

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Note: Because the high-voltage battery is connected to the refrigerant circuit, preliminary work similar to that conducted on the air conditioning of conventional vehicles (e.g. evacuation and recycling of the refrigerant) will be required prior to removal and installation of some components. Always follow repair instructions.

6.2. Functions

6.2.1. Starting the high-voltage system

Starting the high-voltage system occurs in the interaction between the electric motor electronics (EME) and battery management electronics (SME) control units. The EME control unit performs the role of the primary (master) and the SME control unit that of the secondary. The associated commands are transferred as bus signals via the PT-CAN2.

The EME control unit requests starting of the high-voltage system when either terminal 15 is switched on or a request for independent air conditioning is present. The start takes place in multiple steps, each of which takes place only if the previous step has been completed successfully.

1 Testing the high-voltage electrical system
2 Raising the voltage
3 Closing the contacts of the switch contactors.

The first step, testing the high-voltage system, involves checking whether the high-voltage battery and the entire high-voltage electrical system are operational. This includes the requirement that the circuit of the high-voltage interlock loop be closed in order to start the high-voltage system.

Even after the tests have been completed successfully, the contacts of the switch contactors still cannot be closed. Because of the capacities in the high-voltage circuit (link capacitors) a very high switch-on current would flow which would permanently damage both the link capacitors and the switch contactors. Therefore, the voltage is raised slowly beforehand. To do so, the negative lead of the switch contactor contact is initially closed. A constant current of about 2 A is set in the positive lead via an electronic circuit to charge the link capacitors. In this way the voltage in the high-voltage electrical system increases within a few hundred milliseconds to a value which is slightly below the voltage of the high-voltage battery. Then the positive lead of the switch contactor contact is closed.

The SME control unit communicates successful starting via the PT-CAN2 to the EME control unit. In the same way, faults are signalled if the start was not successful.

Note: Although the starting of the high-voltage system contains the above-mentioned steps, there is no noticeable delay when starting the car as far as the customer is concerned. An F04 starts practically as quickly as an F01/F02.

6.2.2. Shutting off the high-voltage system

When it comes to shutting off the high-voltage system a distinction is made between regular shut-off and fast shut-off. In the case of regular shut-off the emphasis is on protecting the electrical components and checking the high-voltage system. For example, the contacts of the electromechanical switch contactors are to be opened only when the current has dropped to a value close to 0 A, as they are otherwise subjected to heavy load.

The conditions which trigger a regular shut-off are:

- Deactivation of terminal 15
- End of independent air conditioning and programming procedure of a high-voltage control unit
- Interruption of the circuit of the high-voltage interlock loop

The basic sequence of regular shut-off is then (regardless of the triggering condition) the same:

1. Regulating currents in the high-voltage electrical system down to zero (EME)
2. Opening the switch contactors in the high-voltage battery unit (SME)
3. Discharging the high-voltage circuit, i.e. active discharging of the link capacitors and short-circuiting of the windings in the electric motor (EME)
4. Checking the high-voltage system, e.g. as to whether the contacts of the electromechanical switch contactors were correctly opened.

The regular shut-off is interrupted if in the meantime starting is initiated again (e.g. because the driver switches on terminal 15 again). The regular shut-off is also interrupted if a situation arises that requires a fast shut-off of the high-voltage system.

6.2.3. Fast shut-off of the high-voltage system

The fast shut-off of the high-voltage system is carried out whenever, for safety reasons, the voltage in the high-voltage system must be reduced to a safe value as quickly as possible.

The following list describes these situations and the signals with which fast shut-off of the high-voltage system is triggered:

- Accident:
  Crash Safety Module detects an impact of appropriate severity → communication via bus signals and disconnection of the battery safety terminal from the positive terminal of the 12 V battery.
- Short circuit monitoring:
  Current sensor in the high-voltage battery detects an excessively high current in the high-voltage cables or the overcurrent cut-out in the high-voltage battery is activated.
- Cell monitoring detects a critical state, e.g. undervoltage, overvoltage or excess temperature
- Failure of the 12 V voltage supply of the high-voltage battery unit → SME control unit stops working

In all these cases the contacts of the electromechanical switch contactors are opened and the high-voltage circuit is discharged immediately. This ensures the fastest possible shut-off, as is appropriate for these safety-relevant condition.

6.2.4. Charging and operational strategy

The charging strategy for the high-voltage battery has two primary objectives, to maximize the service life of the high-voltage battery and to maintain reserves with regard to both energy consumption and energy draw. In order to achieve the first objective, the strategy involves not only the already mentioned regulation of the cell temperature but also the regulation of the useful energy content. Instead of using the full state of charge range from zero to 100 %, only a range between approximately 30 and 80 % is used. Depending on the cell temperature and the calculated state of health of the high-voltage battery, this useful range can be limited further. However, a sufficiently large useful energy content remains available over the full service life in order to implement the hybrid-specific functions and advantages. The state of charge of the high-voltage battery is indicated in the Central Information Display in the form of bars. The value displayed there of zero bars to five bars corresponds to the value used by the charging strategy of roughly 30 to 80 %. Therefore, there are still power reserves below the minimum displayed value and above the maximum displayed value.

Indication in Central Information Display	Displayed state of charge	Actual state of charge
	0 %	about 30 %
	100 %	about 80 %

During brake energy regeneration or load point increase of the combustion engine excess energy is converted by the electric motor into electrical energy. The high-voltage battery stores this electrical energy and makes it available again as required for the following purposes:

- To supply the 14 V electrical system while the combustion engine is switched off
- To relieve and support the combustion engine (increase efficiency)
- For the boost function (increase dynamics)
- For independent air conditioning

6.2.5. Monitoring functions

There is a large number of monitoring functions in which the high-voltage battery unit and the battery management electronics play a substantial role.

They include:

- Monitoring functions to ensure the safety of the high-voltage system
- Monitoring functions to ensure optimal operating conditions of the high-voltage battery

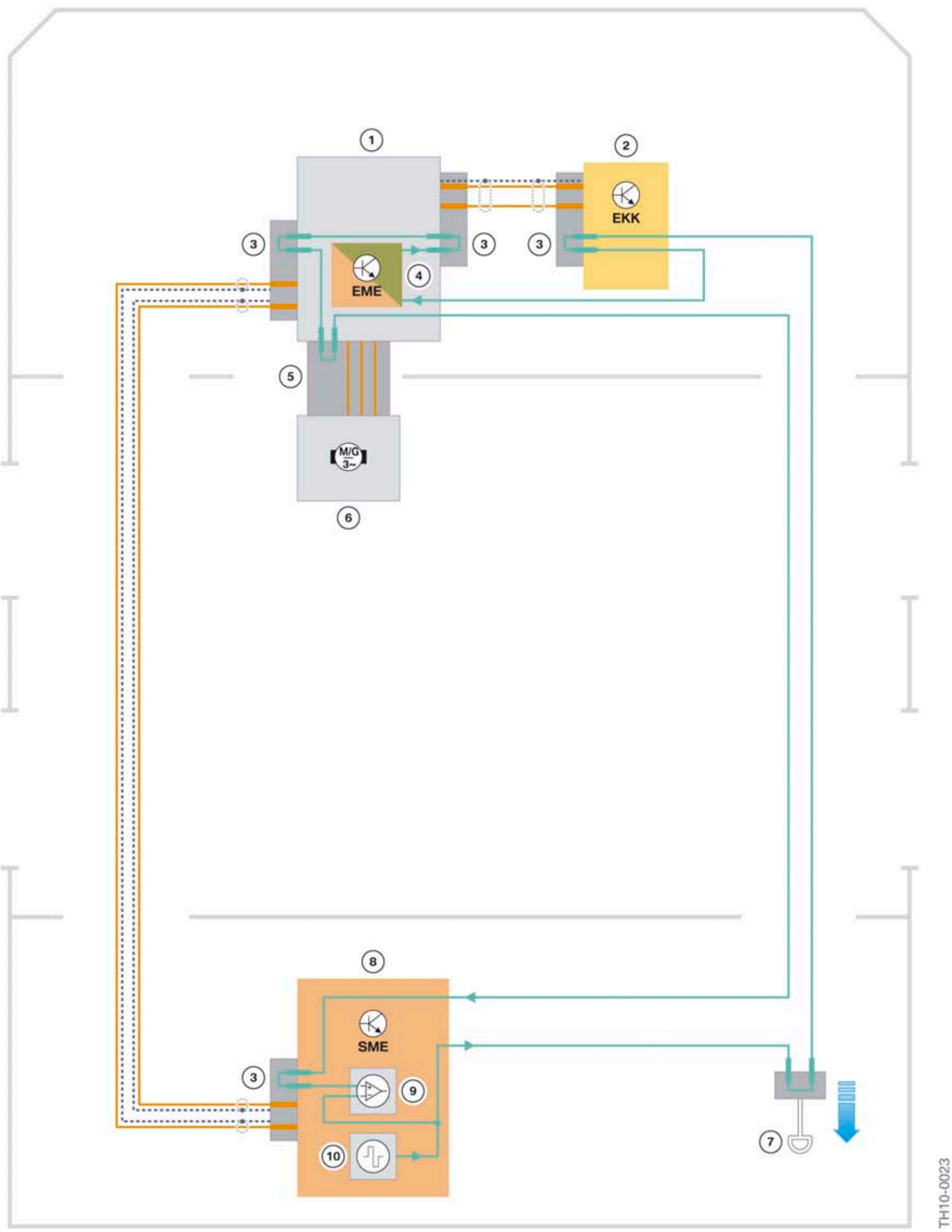
6. High-voltage Battery Unit

For the safety-related monitoring functions, we will specifically discuss the role of the high-voltage battery unit in the high-voltage interlock loop and the insulation monitoring.

The principle of the **high-voltage interlock loop** is described in detail in the "Principles of hybrid technology" training material available on TIS and ICP.

In the F04 the high-voltage interlock loop is made up of the high-voltage components in the graphic below.

6. High-voltage Battery Unit



System wiring diagram of high-voltage interlock loop

Index	Explanation
1	Electric motor electronics (structural unit which incorporates the power electronics and control unit)
2	Electric A/C compressor
3	High-voltage connection with bridge for high-voltage interlock loop
4	EME control unit
5	Busbar between electric motor and electric motor electronics, accessibility of which is guaranteed by a flap with a bridge of the high-voltage interlock loop
6	Electric motor
7	High-voltage safety connector (Service Disconnect)
8	Battery management electronics (inside the high-voltage battery unit)
9	Evaluation circuit for interlock signal
10	Generator for interlock signal

The electronics for controlling and generating the test signal for the high-voltage interlock loop is integrated in the battery management electronics. Generating the test signal starts when the high-voltage system is to be started and ends when the high-voltage system has been shut down. A square wave AC signal is generated as the test signal by the battery management electronics and supplied to the test lead. The test lead has a ring topology (similar to that of the MOST bus). The signal of the test lead is evaluated at two points in the ring: in the electric motor electronics and finally right at the end of the ring, in the battery management electronics. If the signal is outside a permanently defined range, an interruption of the circuit or a short circuit in the test lead is detected. As already described in the section "Fast shut-off of the high-voltage system", the high-voltage system is then shut off immediately.

The **insulation monitoring** determines whether the insulation resistance between active high-voltage components (e.g. high-voltage cables) and ground is above or below a required minimum value. If the insulation resistance falls below the minimum value, the danger exists that the vehicle parts will be energized with hazardous voltage. If a person were to touch a second active high-voltage component, he or she would be at risk of electric shock. There is therefore fully automatic insulation monitoring for the F04 high-voltage system. It is performed by the battery management electronics at regular intervals while the high-voltage system is active. Ground serves as the reference potential. Without additional measures only local insulation faults in the high-voltage battery unit could be determined in this way. However, it is equally important to identify insulation faults from the high-voltage cables in the vehicle to ground. For this reason, all the electrically conductive housings of high-voltage components are directly connected to ground. This enables insulation faults in the entire high-voltage electrical system to be identified, from a central point (the high-voltage battery).

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The proper electrical connection of all high-voltage component housings to ground is an important prerequisite for proper function of the insulation monitoring function. Therefore, this electrical connection must be restored carefully if it has been interrupted during repair work.

The insulation monitoring responds in two stages. When the insulation resistance drops below a first threshold value, there is still no direct danger to people. The high-voltage system therefore remains active; no Check Control message is displayed, but the fault status is naturally stored in the fault memory. In this way the Service technician is alerted the next time the car is in the workshop and can then check the high-voltage system. When the insulation resistance drops below a second, lower threshold value, this is accompanied not only by the storage of the fault in the fault memory, but also by the display of a Check Control message prompting the driver to visit a BMW Service Center.

However, the service technician does not have to perform a fundamental measurement of the insulation resistance him-/herself – this task is performed by the high-voltage system through the insulation monitoring. When an insulation fault is detected, the service technician must run through a test plan in the ISTA diagnosis system to find the actual location of the insulation fault.

6.3. Service Instructions

6.3.1. Installation and removal

The high-voltage battery unit can only be replaced as a complete unit and only when indicated by the test plan on ISTA BMW diagnostic system.

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Note: Because the high-voltage battery unit is a high-voltage component, it is essential during removal and installation to observe the electrical safety rules before starting work.

In the event that the refrigerant lines have to be removed or any service is being done on the cooling system of the high voltage battery that requires the opening of the circuit, the refrigerant must be recycled following approved BMW procedures prior to removal and after installation re-introduced.

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A precise description of the work sequence for removal and installation of all the hybrid components can be found in the repair instructions. Always follow the proper repair instructions when working on BMW vehicles.

Note: The special tool has been developed to help in lifting the high-voltage battery unit out of and back into the vehicle, this tool must be used whenever service is required (A part no. was not yet available at the time of this material.)

6.3.2. Charging and starting aid

This section discusses the charging process and the starting aid when the high-voltage battery is discharged. If the 12 V battery of an F04 is flat, it can be charged as in conventional vehicles.

The operational strategy controls the state of charge of the high-voltage battery such that the vehicle can be restarted, even after a long immobilization (storage) period. If, despite this, the high-voltage battery is discharged deeply enough that it can no longer be started, a corresponding Check Control message is displayed.

In this case, the high-voltage battery can be charged via the 14 V electrical system. However, when you connect an approved battery charger to the positive battery connection point and to ground, initially only the 14 V vehicle electrical system will be supplied with power and the 12 V battery is charged.

The following prerequisites must be satisfied before the high-voltage battery can be charged:

- High-voltage battery discharged to the extent that engine starting is no longer possible
- Two unsuccessful attempts to start the engine or Service function "Charge high-voltage battery" started
- Terminal 15 switched on
- Charger with a minimum voltage of 13.5 V connected. We recommend that you use a charger with a maximum current of 70 A (or higher) so that not only the 14 V electrical system is supplied, but also a significant current is still available to charge the high-voltage battery

The DC/DC converter in the electric motor electronics now functions as an up converter. Electrical energy then flows from the 14 V vehicle electrical system to the high-voltage electrical system and the high-voltage battery is charged.

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During this process, all electrical consumers in the vehicle that are not needed must be switched off. The charging process can take several minutes, depending on the battery charger used. The process of charging the high-voltage battery should only be ended when a Check Control message issues a prompt to that effect.

Check Control symbol for high-voltage battery

The same Check Control symbol is used for all Check Control messages displayed in the instrument cluster regarding the state of charge of the high-voltage battery. The Check Control messages are explained by the notes displayed in the central information display.

If start assistance (emergency jump) has to be given to an F04 with a flat high-voltage battery, proceed as previously described to charge the high-voltage battery with a battery charger. It must be noted here that after the energy-dispensing vehicle has been connected to the F04 the "Ready to drive" status cannot be established immediately. Instead you must wait until the Check Control message in the F04 indicates that the high-voltage battery is sufficiently charged. Only then may they energy-dispensing vehicle be disconnected from the F04.

6.3.3. Safe working practices for working on a high-voltage system

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Before working on high-voltage components of the F04, it is essential to observe and implement the electrical safety rules:

1 The high-voltage system must be disconnected from the power supply

2 The high-voltage system must be provided with a safeguard to prevent unintentional restarting

3 The safe isolation of the high-voltage system must be verified

The following chapters provide brief descriptions on how to implement the electrical safety rules in the F04.

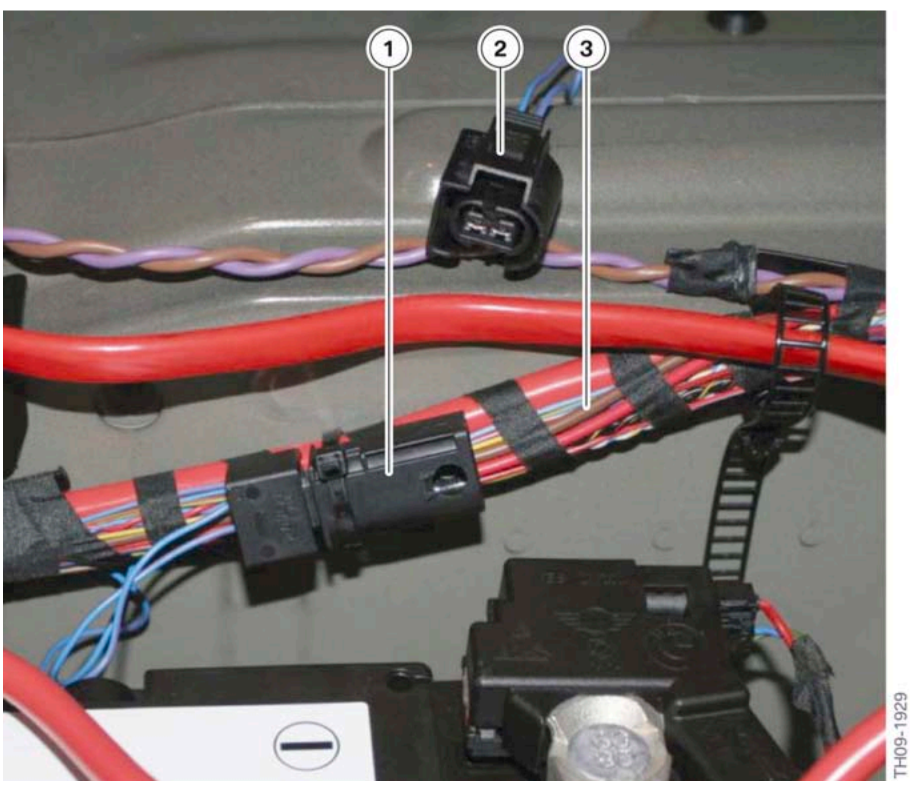
Preparations

Prior to beginning any work the following steps must be taken:

1. The vehicle must be secured against rolling (engage the parking lock of the automatic transmission and activate the parking brake).
2. Terminal 15 and terminal R must be switched off.
3. If a charger is connected, it must be switched off and disconnected.

Disconnecting the high-voltage system from the supply

The high-voltage system in the F04 is disconnected from the power supply with the high-voltage safety connector. To disconnect from the power supply, the high-voltage safety connector must be pulled from its socket. This interrupts the circuit of the high-voltage interlock loop.



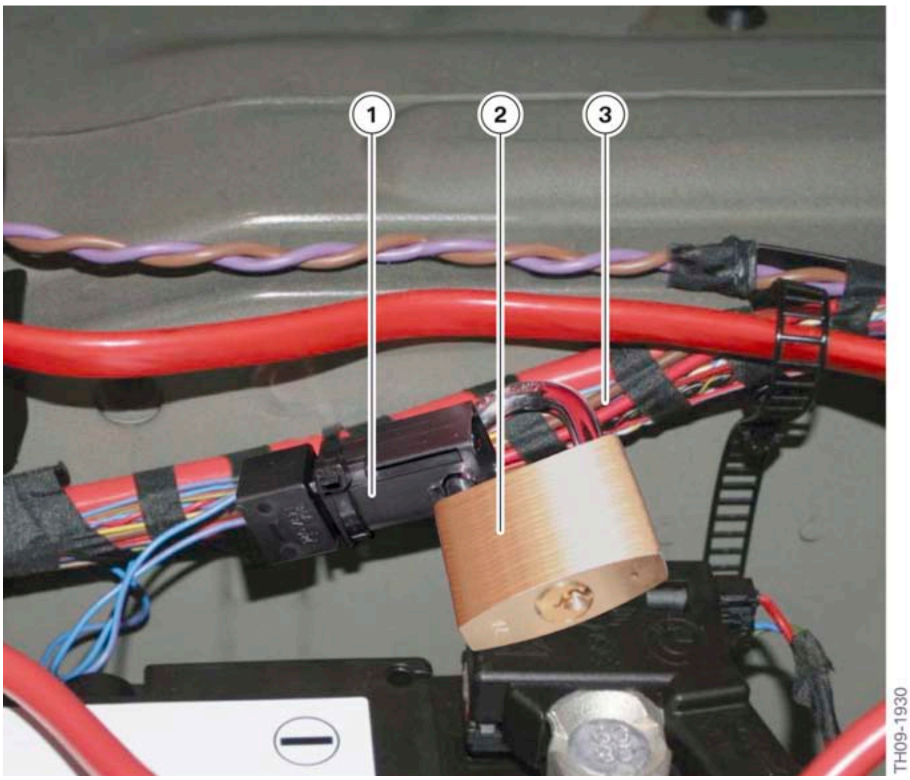
High-voltage safety connector after disconnection from the power supply

Index	Explanation
1	Socket with wires from circuit of high-voltage interlock loop
2	Removed high-voltage safety connector
3	Remaining wiring harness in which the high-voltage safety connector is mechanically incorporated

6. High-voltage Battery Unit

Safeguarding the high-voltage system against unintentional restarting

The safeguarding of the high-voltage system against unintentional restarting is performed on the socket side of the high-voltage safety connector. A commercially available padlock (for example, ABUS 45/40) is required for this purpose.



High-voltage safety connector with padlock

Index	Explanation
1	Socket with wires from circuit of high-voltage interlock loop
2	Padlock
3	Remaining wiring harness in which the high-voltage safety connector is mechanically incorporated

The high-voltage safety connector cannot be connected when the padlock is inserted in the socket and locked. This is an effective way of ensuring that the high-voltage system is not switched on again without the knowledge and consent of the service technician working on the vehicle.

Verifying safe isolation from the supply

The de-energized state is not verified using a measuring device or via the ISTA diagnostic system. Instead, the high-voltage components measure the voltage themselves and transmit the measuring result via bus signal to the instrument cluster. The instrument cluster does not generate the Check Control message to display the de-energized state unless all involved high-voltage components consistently signal the de-energized state.

Display of isolation from the supply in the instrument cluster

Index	Explanation
1	Check Control symbol for isolation from the power supply
2	Check Control message "Hybrid system deactivated"

In order to verify the de-energized state, you must switch on terminal 15 and wait until you see the Check Control message with the symbol shown above on the instrument cluster. Then, and only then, you have ensured that the high-voltage system is de-energized. After the de-energized state has been verified, terminal 15 and terminal R must be switched off again before you can start the actual work on the vehicle.

⚠

If the Check Control message is not displayed, you must not carry out any work on high-voltage components!

You must STOP work and enter a PUMA case for instructions as to how to proceed with the repair.

6.3.4. Procedure after an accident

The safety concept of the high-voltage system ensures that, even during or after an accident, there is no danger to the customer or the Service personal. The high-voltage system is automatically deactivated in the event of an accident in such a way that no dangerous voltages are applied at those points on the high-voltage components which are accessible from the outside.

Deactivation of the high-voltage system is carried as follows:

In normal operation the battery management electronics is supplied via terminal 30F. The coils of the electromechanical switch contactors are also supplied. Deactivation in the event of an accident is done by an extended battery safety terminal. It contains an additional normally closed contact. This switch contact opens when the battery safety terminal is triggered at the same time as the positive battery cable is severed. This interrupts the voltage supply to the battery management electronics and to the switch contactors. The contacts of the switch contactors open so that dangerous voltage can no longer be fed by the high-voltage battery into the high-voltage electrical system. A lead to the electric motor electronics is also branched from the supply lead of the battery management electronics. The electric motor electronics evaluates this lead. In the event of an accident the voltage on this lead drops to 0 V, and the electric motor electronics discharges the link capacitors and closes the windings on the electric motor briefly.

After an accident the safety battery terminal remains in the above-described state such that the battery management electronics is not operational. Thus the high-voltage system remains inactive even if terminal 15 is switched on again.

This is useful for safety reasons, but has two effects, which the Service Technician must be aware of:

1. The instrument cluster will not display the isolation from the power supply, because the corresponding bus signal from the battery management electronics fails to appear. The Service Technician therefore must not work on the high-voltage components.
2. The diagnosis system cannot address the battery management electronics and read out the fault memory. Thus diagnosis of the high-voltage battery unit is not possible either.

Note: If the F04 battery safety terminal has triggered in the event of an accident a special handling procedure is needed. Refer to the repair instructions available in ISTA for more information.

⚠

Before working on the high-voltage components or on the battery safety terminal of an F04 which has been involved in an accident with a triggered battery safety terminal, contact the Technical Support (PUMA) of the BMW Group.

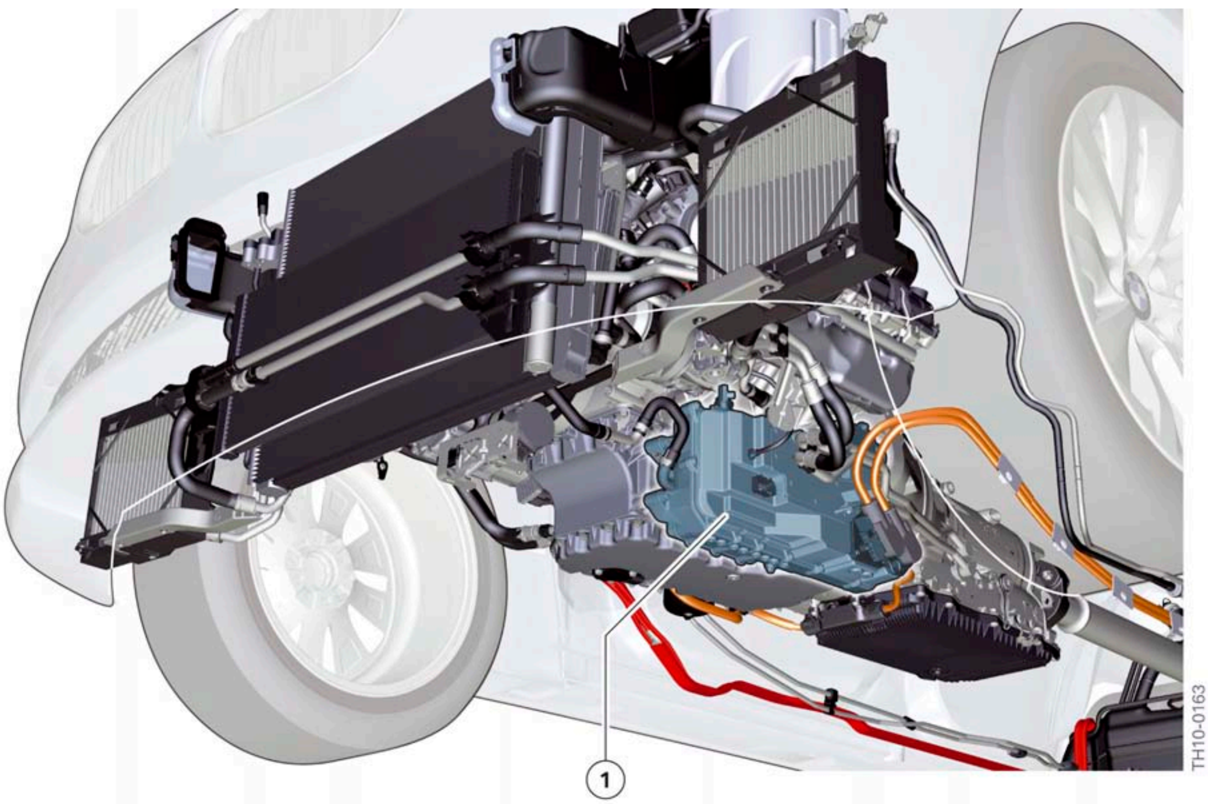
F04 Complete Vehicle

7. Power Electronics

7.1. Installation location and connections

The power electronics of the F04 serves as the control electronics for the permanent-field electrical synchronous machine in the powertrain. A bidirectional inverter is used for converting the DC voltage (120 V DC) from the high-voltage battery into a three-phase AC voltage (120 V AC) to activate the three-phase machine and vice versa in generator mode. A DC/DC converter ensures the voltage supply to the 14 V electrical system. The entire power electronics of the F04 is located within the aluminum housing of the electric motor electronics (EME). This housing contains the control unit, the DC/DC converter and the (DC/AC, AC/DC) bidirectional inverter. The EME can only be replaced as a complete unit, as its components are not available separately.

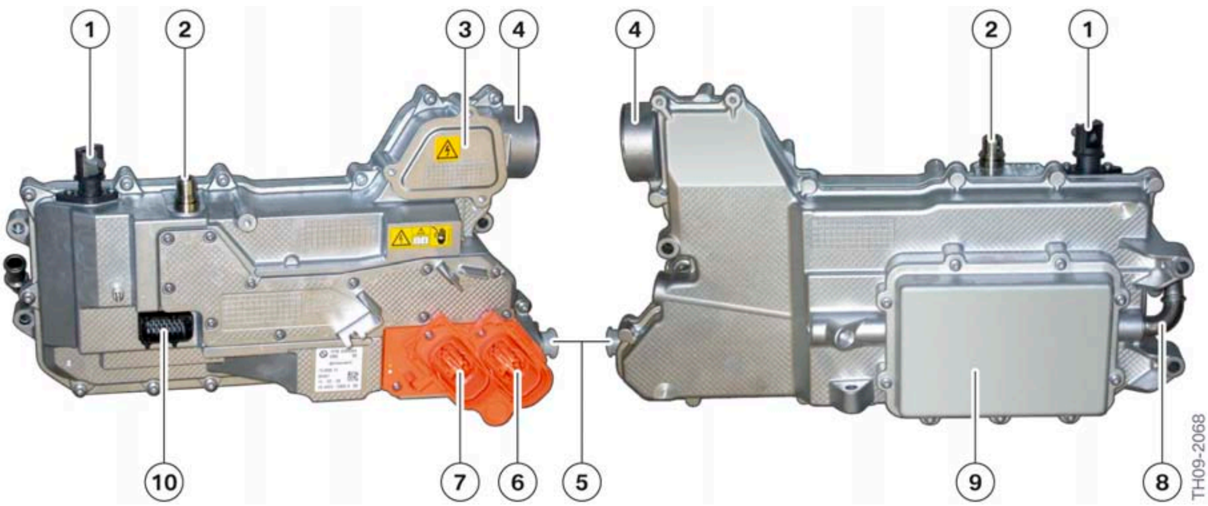
Note: The system supplier of the EME for the F04 is the company Continental AG. It was developed in a cooperation between BMW AG and Daimler AG.



Installation location of EME

Index	Explanation
1	Electric motor electronics (EME)

The electric motor electronics (EME) weighs about 26.5 lb (12 kg) and is located on the left side of the engine, it is mounted with four bolts at the height of the oil sump.



Electric motor electronics, front and rear views

Index	Explanation
1	Connection for 14 V electrical system (positive lead)
2	Connection for coolant return
3	Cover for busbars (mounting cover)
4	Connection fitting for electric motor
5	Connection for electric A/C compressor
6	Connection for high-voltage battery (HV +)
7	Connection for high-voltage battery (HV –)
8	Connection for coolant return
9	Cover for link capacitor
10	Signal connector (low-voltage connector)

CAUTION! The electric motor electronics is a high-voltage component!

High-voltage component warning sticker

Each high-voltage component is clearly labeled, on its housing or casing, to enable Service Personnel and vehicle users to identify the possible hazards associated with high voltages and the precautions that must be taken when handling them.

⚠

Only high voltage certified Service Technicians are permitted to work on high-voltage components. Always comply with the safety rules and procedures and follow the repair instructions to the letter.

Because the EME is installed in the lower area of the vehicle, a vent line is required to prevent water (resulting from temperature changes and possible condensation of air moisture) from collecting inside the EME. The vent line is situated at the highest possible location, on top of the EME housing.

The insulation monitoring determines whether the insulation resistance between active high-voltage components (e.g. high-voltage cables) and ground is above or below a required minimum value. If the insulation resistance falls below the minimum value, there is a risk that the vehicle parts will be energized with hazardous voltage. If a person were to touch a second active high-voltage component, he or she would be in danger of electric shock.

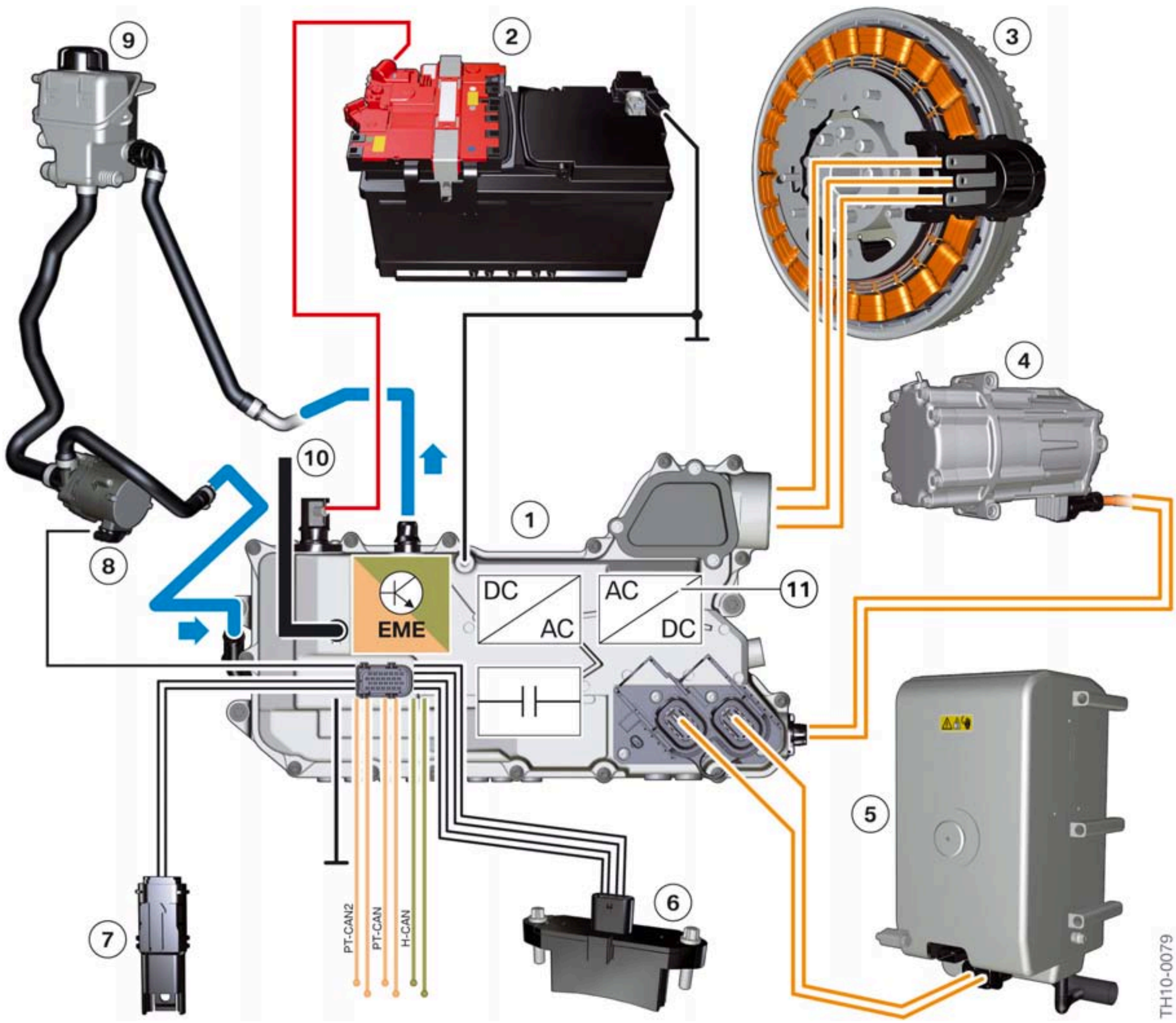
There is therefore fully automatic insulation monitoring for the F04 high-voltage system. It is performed by the battery management electronics (SME) at regular intervals while the high-voltage system is active. Ground serves as the reference potential. Without additional measures only local insulation faults in the high-voltage battery unit could be determined in this way. However, it is equally important to identify insulation faults from the high-voltage cables in the vehicle to ground. For this reason, all the electrically conductive housings of high-voltage components are connected to ground. In this way insulation faults in the entire high-voltage electrical system can be identified from a central point by the insulation monitoring.

⚠

The proper electrical connection of all high-voltage component housings to ground is an important prerequisite for proper function of the insulation monitoring. Accordingly, this electrical connection must be restored carefully if it has been interrupted during repair work to the vehicle.

The points of contact must be kept clean, e.g. free from oil and grease!

7.2. System Overview



EME system overview

Index	Explanation
1	Electric motor electronics (EME)
2	12 V battery
3	Electric motor
4	Electric A/C compressor
5	High-voltage battery
6	Rotor position sensor
7	Temperature sensor (electric motor windings)

Index	Explanation
8	Electric coolant pump 50 W
9	Coolant expansion tank
10	Vent line
11	AC/DC bi-directional inverter

7.3. Functions

The EME internally comprises three logic units: The bidirectional inverter, the DC/DC converter for supplying the 14 V electrical system, and the control electronics with the hybrid master functionality. The inverter and the DC/DC converter are both activated by the control electronics.

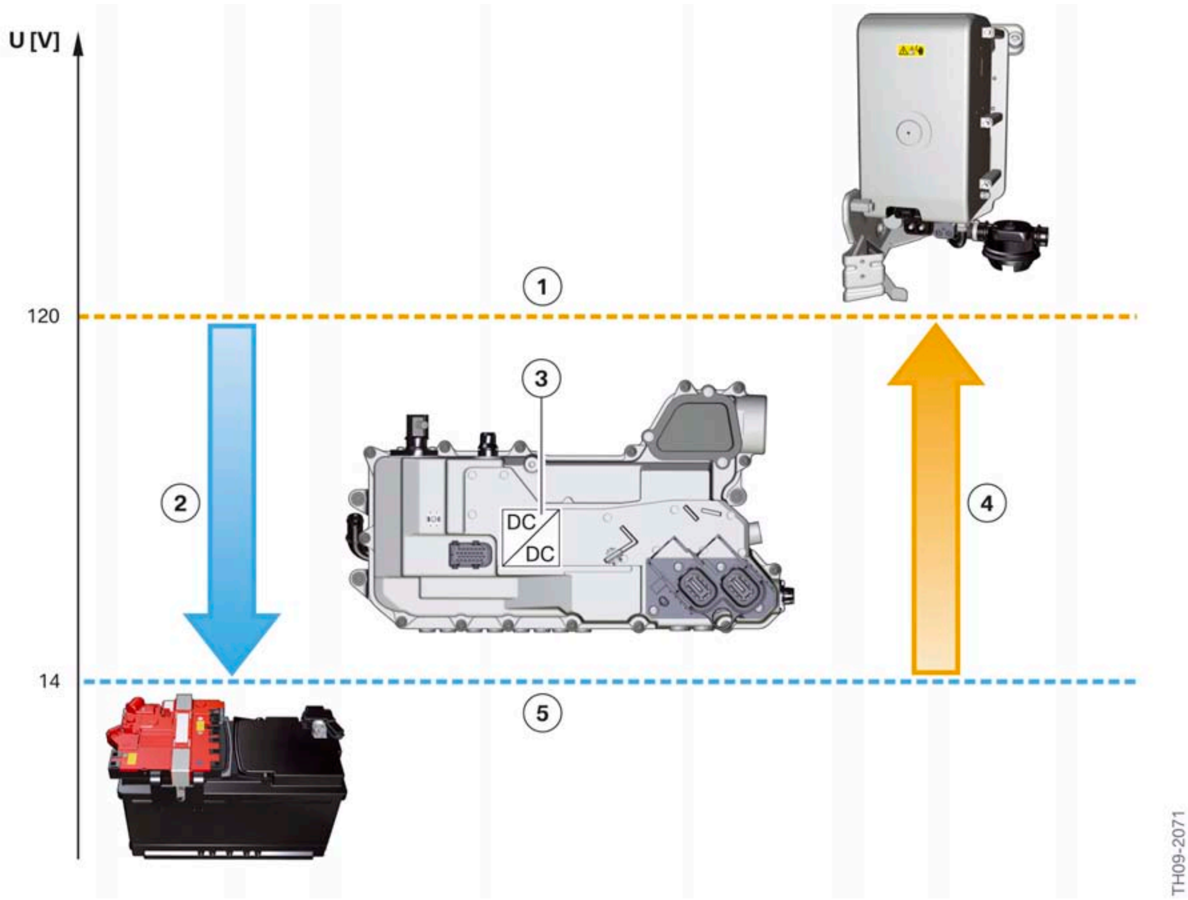
The EME performs the following functions:

- Supply of the 14 V electrical system via the DC/DC converter
- Charging of the high-voltage battery from the 14 V electrical system for external starting
- Support of the high-voltage battery during cold starting
- Regulation of the electric motor (rotational speed, torque or voltage)
- Connecting to the electric motor via busbars
- Cooling of the EME
- High-voltage connection for the electric A/C compressor
- Connection of the high-voltage battery
- Communication with other control units
- Active and passive discharging of the link capacitor to voltages less then 60 V
- Reverse polarity protection
- Active evaluation of a signal for the high-voltage interlock loop (interlock)
- Self-test and diagnostic function

7.3.1. DC/DC converter

The DC/DC converter transfers electrical power from the high-voltage electrical system to the 14 V electrical system and vice versa. There are two operating modes, depending on the direction in which the DC/DC converter converts the voltage:

- Down conversion
- Up conversion



Operating modes of the DC/DC converter

Index	Explanation
1	Voltage level with 120 V
2	Down conversion
3	DC/DC converter in the EME
4	Up conversion
5	Voltage level with 14 V

Down conversion

Down conversion (also known as buck mode) refers to the voltage conversion from the high-voltage level to the 14 V level. In this operating mode the DC/DC converter has a maximum power output of 2.1 kW or 150 A.

The nominal voltage can be specified by the EME in a range from 11.0 V to 15.5 V. The DC/DC converter is operated with a set-point input of 14 V. This operating mode is selected whenever the vehicle is being driven. The 14 V electrical system is supplied in vehicle mode via the DC/DC converter with electrical energy. Thus it replaces the alternator previously used for this purpose.

Up conversion

Up conversion (also known as boost mode) refers to the voltage conversion from the 14 V level to the high-voltage level. In this operating mode the DC/DC converter can transfer a power output of 0.5 kW and is capable of charging a heavily discharged high-voltage battery.

The charging process is automatically started by the EME under the following conditions:

- If the voltage of the high-voltage battery has dropped below a predetermined threshold value
- If a charger has been detected (vehicle voltage greater than 13.5 V in the 14 V electrical system)
- If two engine starts have failed consecutively
- Terminal 15 must be switched on

If the voltage of the high-voltage battery is too low and an engine start has failed, the following Check Control message is displayed: "Vehicle not ready to drive".

If a second engine start has failed, the following Check Control message is displayed: "Switch on ignition to charge".

Alternatively the charging process can be started with the following Service function: "Charge high-voltage battery".

While the voltage is being converted from the 14 V electrical system to the high-voltage electrical system (high-voltage battery is being charged), the following Check Control message is displayed: "High-voltage battery charging".

The process is cancelled in the following situations:

- The charge current of the high-voltage battery has dropped below the threshold value of 1 A
- The charger has been disconnected from the 14 V electrical system
- A fault has occurred or the ignition has been switched off. Then the following Check Control message is displayed: "Charging finished".

⚠

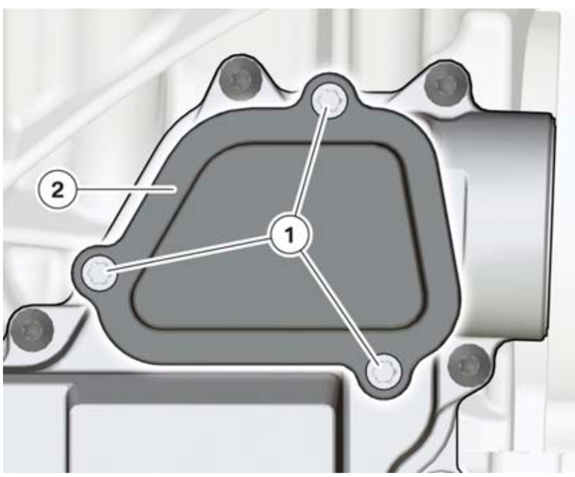
To supply the 14 V electrical system and at the same time charge the high-voltage battery, use a sufficiently powerful charger (maximum charge current of at least 70 A). Switch off unnecessary power consumers in the vehicle (e.g. exterior lights or air conditioning).

Note: The BMW recommended Multicharger 1500, 100A battery charger (PN 81 39 2 161 589), is available for use with ActiveHybrid vehicles.

7.3.2. Connection to the electric motor

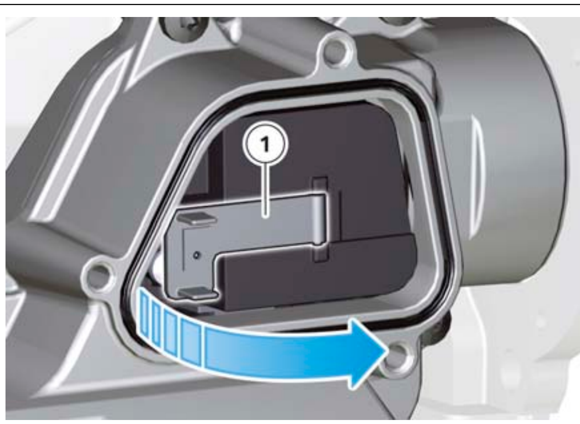
The power electronics in the EME is connected to the electric motor via three busbars. The contacts can be released in the following manner:

Apply three safety rules	1 Disconnect the high-voltage system from the supply 2 Safeguard the high-voltage system against unintentional restarting 3 Verify the safe isolation of the high-voltage system from the supply



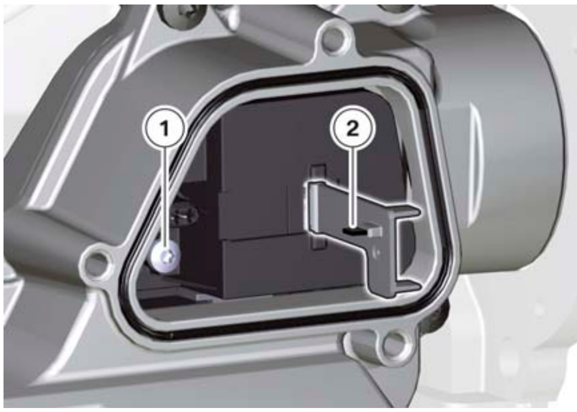
TH10-0162

First release the three bolts (1) and remove the cover (2).



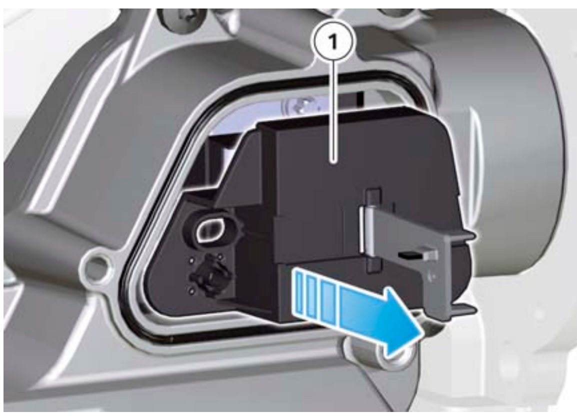
TH10-0169

Swing open the lever (1) in the direction of the arrow.
This interrupts the circuit of the high-voltage interlock loop.



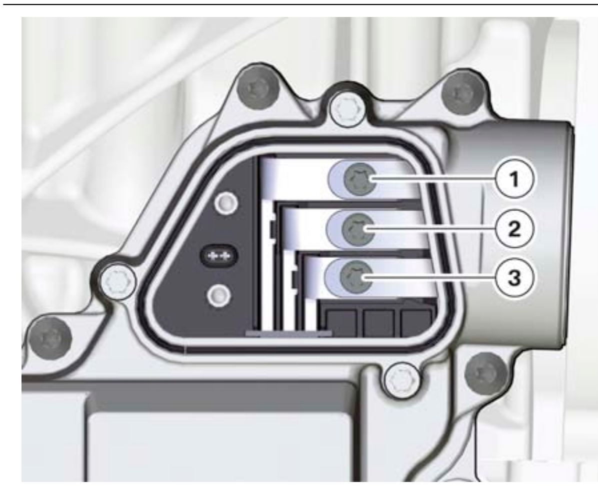
TH10-0170

Release the screw (1).
When the lever is swung open the bridge of the high-voltage interlock loop is visible.



TH10-0171

The cover (1) can now be removed.
The busbars (U, V, W) and the screws are visible.



TH10-0172

Release the screws (1, 2, 3).

⚠

Adhere exactly to the prescribed tightening torques for the screws and if necessary degrease the busbars.

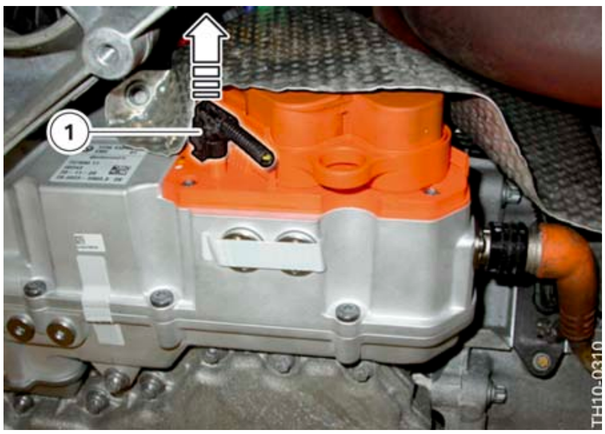
When replacing the complete assembly, replace the seal to the electric motor. When fitting, make sure that none of the seals (in the line connection to the electric motor and in the mounting cover) are damaged.

7.3.3. Connection for high-voltage battery

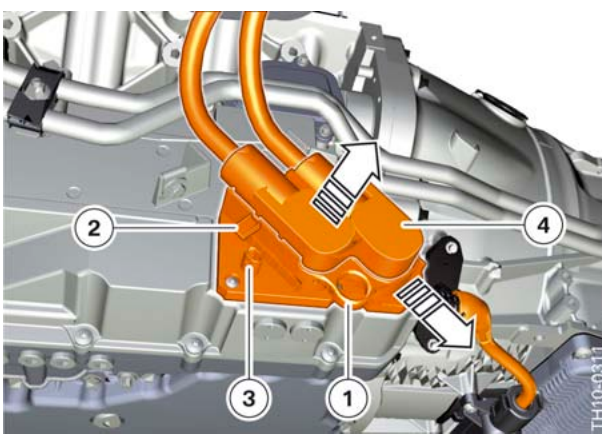
The connection for the high-voltage battery is located in the lower area of the EME and is designed as a plug connection.

The connector for the high-voltage battery contains contacts for:

- Positive battery terminal
- Negative battery terminal
- High voltage interlock loop



The plug connection is designed in such a way that before the high-voltage cable is disconnected, the bridge (1) of the high-voltage interlock loop must be unlocked and pulled.



Then the slide (1) is pulled downwards into the first locking position. Here the plug (3) for the high-voltage interlock loop is partially concealed by the plastic cover (2). The connector of the high-voltage cable (4) can now be pulled out to the first locking position. The slide (1) can now be pulled into the second locking position and the connector of the high-voltage cable (4) pulled off entirely. Here the plug (3) of the high-voltage interlock loop is fully concealed by the plastic cover (2).

7.3.4. EME low-voltage connector

All the signal lines are connected via a 28-pin EME low-voltage connector to the wiring harness.

Voltage supply

Voltage is supplied to the electronics (12 V) in the EME via terminal 30B. The connection of terminal 31 in the signal connector is not designed as a supply pin. The actual reference potential of the power electronics is provided on series via the housing. The EME housing is secured with four bolts to the oil sump, thereby creating the ground connection.

CAN connections

The EME communicates with other control units via the PT-CAN/PT-CAN2 and with the DME via the H-CAN. The EME contains two terminal resistors connected in series for the H-CAN. Each resistor has a value of 60 ohms (60 ohms + 60 ohms = 120 ohms). The PT-CAN connections of the EME have no terminal resistors.

Temperature sensor

The windings of the electric motor must not exceed a temperature of 392 °F (200 °C) during operation. The temperature is measured in one of the windings with the aid of a temperature sensor. A thermistor with negative temperature coefficient (NTC) is used for this purpose. The electric motor electronics uses voltage and current measurements to determine the resistance and calculates the temperature from these measurements. If the windings approach the maximum allowable temperature (356 °F), the power output of the electric motor is reduced. This function is controlled by the electric motor electronics.

Rotor position sensor

The rotor position sensor senses the exact position of the electric motor's rotor. This is necessary for precise regulation of the electric motor, because the voltages must be generated at the stator windings to match the position of the rotor. The rotor position sensor outputs an analogsignal, which is read and processed by the electric motor electronics.

High voltage interlock loop (interlock)

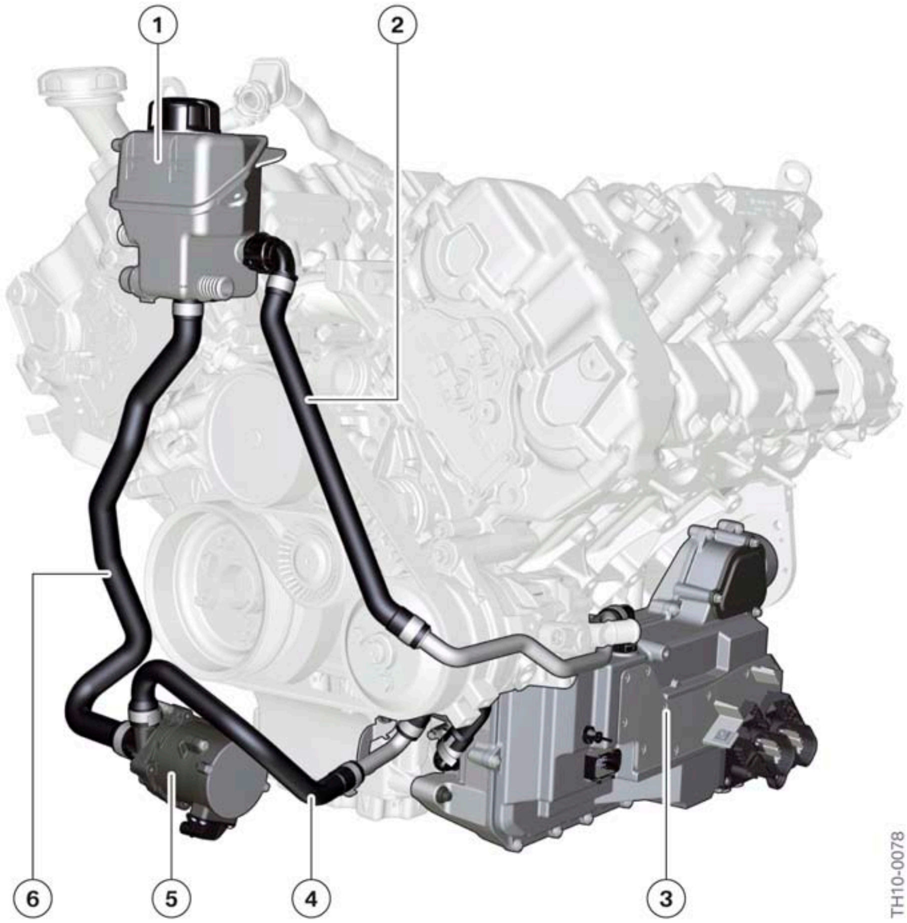
The electronics for controlling and generating the test signal (88 Hz square wave signal) for the high-voltage interlock loop is integrated in the F04 in the battery management electronics. The signal of the test lead is evaluated at two points in the ring: in the electric motor electronics (EME) and finally (right at the end of the ring) in the battery management electronics (SME). The high-voltage system is shut off immediately, if the signal is outside a permanently defined range, an interruption of the circuit or a short circuit in the test lead is detected.

When the high-voltage system is shut off, the link capacitors must be discharged in a specified time to a determined voltage. In the case of active discharging the voltage at the link capacitors drops below 60 V within 5 seconds. In the case of a passive discharge circuit the voltage drops below 60 V DC after 120 seconds.

Crash signal

If the Crash Safety Module detects an impact of appropriate severity → this is communicated via the Bus line and to the battery safety terminal via a hardwire line, to disconnect the positive terminal of the 12 V battery → the SME and the EME are also signaled via a hardwire line.

7.3.5. Cooling of the EME



Cooling circuit, electric motor electronics

Index	Explanation
1	Coolant expansion tank
2	Return line, electric motor electronics → coolant expansion tank
3	Electric motor electronics
4	Feed line, electric coolant pump → electric motor electronics
5	Electric coolant pump 50 W
6	Feed line, coolant expansion tank → electric coolant pump

The semiconductors of the power electronics must be protected against excess temperature. Therefore, the EME unit is cooled by the cooling circuit. The EME circuit is not directly connected to the coolant-to-air heat exchanger. Instead the expansion tank serves here as a mixer, i.e. the coolant from the EME cooling circuit dissipates thermal energy to the coolant in the expansion tank. Cooling of the EME can thus be controlled independently of the charge air cooling circuit. Thus the cooling of the charge air and the Digital Engine Electronics is not affected by this. The coolant is first cooled in the coolant-to-air heat (low temperature system) exchanger before flowing to the charge air coolers (intercoolers) and the Digital Engine Electronics. Standard coolant (50% water and 50% glycol) is used as the cooling medium. This circuit includes an electric coolant pump (50 W) which is speed-controlled (with a pulse-width modulated signal) and diagnosed by the EME . The flow rate is dependent on the power and amounts on average to 6.3 quarts (6 liters) per minute.

7.3.6. Reverse polarity protection

Reverse polarity protection serves to avoid consequential damage to the vehicle electrical system and electronic components connected to it in the event of the polarity being reversed by the customer during an emergency jump start. The diodes in the alternator are generally used to for this purpose but because the conventional alternator is not used in the F04 (electric motor in the transmission), this is done by the DC/DC converter in the EME. In other words, the F04 does not have a separate reverse polarity protection module as in E72.

7.4. Service Instructions

The most important service instructions for handling the EME are explained in the following chapter.

⚠

Only high voltage Certified Service Technicians are permitted to work on hybrid high-voltage components. Always comply with the safety rules and procedures and follow proper repair instructions.

⚠

Make sure that the EME housing and ground cable have a good ground connection. Use the correct screws/bolts and observe the correct tightening torque and sequence.

The points of contact must be kept clean (free from oil and grease). The assembly sequence and the repair concept must be observed. Assembly and disassembly of the high-voltage plug connection must be observed.

Insulation monitoring can function only if all electrically conductive housings of the high-voltage components are galvanically (electrically) connected to ground, in other words to the body of the vehicle. This galvanic connection has to be present in order, for example, for the monitor implemented in the power electronics to reliably detect a short circuit in a high-voltage cable to the housing. In the absence of this galvanic connection between housing and ground the fault would remain undetected and would therefore constitute a potential hazard.

⚠

Note: The EME itself does not require maintenance. However the fluid level of the coolant circuit does have to be checked as regular maintenance.

⚠

For reasons of high-voltage safety the EME must not be opened or otherwise dismantled. It is not permitted to remove the mounting cover and release the contacts of the three busbars (U, V, W).

In the event of a failure of the component, always replace the EME as a complete unit.

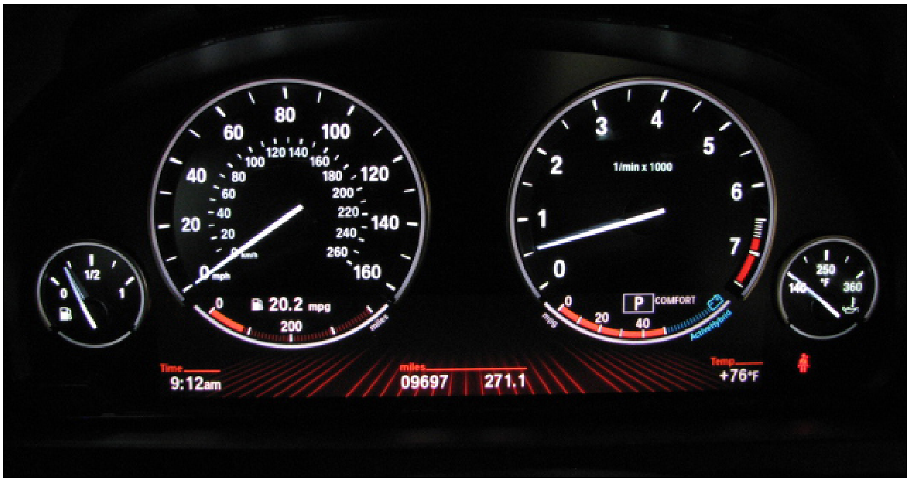
7. Power Electronics

The EME must also be replaced if damaged (e.g. break in the housing, damage to the connector).

The EME is diagnosed and programmed as the rest of the control units in the vehicle.

F04 Complete Vehicle

8. Displays and Controls



Instrument cluster in the F04

The hybrid-specific operating modes are displayed in the instrument cluster and if desired, in the Central Information Display.

The following hybrid-specific operating modes are displayed in the instrument cluster:

- "Ready to drive" display
- Boost function display
- Energy recovery display

They are permanently displayed in the lower part of the tachometer (in the info display). Both the display in the CID and in the instrument cluster are activated when terminal 15 is switched on.

The energy/power flows and the state of charge of the high-voltage battery can be shown in the CID in all the vehicle's operating modes. This provides the driver with a “real time” overview of the operation of the hybrid system in the different driving states. The hybrid-specific displays are called up in the CID via the "Vehicle Info > Hybrid" menu.

8.1. "Ready to drive" displays

"Ready to drive" displays in the instrument cluster and CID

Index	Explanation
1	READY display in the instrument cluster
2	READY display in the CID

The "Ready to drive" status is signalled to the driver when the tachometer needle points to zero and at the same time in the lower part the blue arc flashes with "READY". Here the vehicle is stationary and the combustion engine is not running. When the driver's foot comes off the brake pedal, the accelerator pedal is depressed or the steering wheel is moved, the combustion engine will start and the vehicle can start moving.

The combustion engine is switched off when the vehicle is in the "Ready to drive" status. The tachometer needle points to 0 rpm. In the CID the current state of charge of the high-voltage battery is indicated by the blue color of the five segments. When the driver's foot comes off the brake pedal, the combustion engine is started quickly and with minimal vibration. When the Automatic Hold function is activated the combustion engine is started only when the accelerator pedal is pressed. Another way of starting the combustion engine from stopped is to turn the steering wheel to the left or right. The combustion engine is started to give the driver adequate steering support.

8.2. Displays while driving

Hybrid-specific displays while driving

Index	Explanation
1	Drive arrow for the combustion engine
2	Automatic transmission with electric motor
3	Power flow on the rear axle
4	Text message for current driving situation "DRIVE"
5	State of charge of the high-voltage battery

When the vehicle is driving at a constant speed there are no changes in the instrument cluster when compared with the F01/F02. Only the battery symbol and the wording "ActiveHybrid" are displayed.

The display of the energy/power flows in the CID functions according to the following principle:

- Blue: Electrical energy
- Red: Energy of the combustion engine
- Arrow: Direction of the energy/power flow

A combustion engine can operate at maximum efficiency when the vehicle is being driven at a steady, relatively high speed. Consequently, the combustion engine is the primary source of propulsion for driving under these conditions. This is indicated in the CID by the red drive arrow.

If the high-voltage battery is in a low state of charge, part of the power developed by the combustion engine is used to recharge the battery through the electric motor. This is indicated to the customer by an active automatic transmission (blue) and the blue arrows flowing in the direction of the battery symbol.

When the high-voltage battery has a sufficient state of charge the electrical energy can be drawn from the high-voltage battery for the electric motor to support the vehicle's drive. The combustion engine can thereby be operated at low (favorable) revs. In this case the arrows flow from the battery symbol to the symbol for automatic transmission.

8.3. Displays when accelerating

Displays for the boost function

Index	Explanation
1	Display for boost function
2	Drive arrow for combustion engine (red) and drive arrow for electric motor (blue)
3	Automatic transmission with electric motor
4	Power flow to rear axle
5	Text message for current driving situation "eBOOST"

In the case of powerful acceleration (boost function) both the power of the combustion engine and the power of the electric motor are called up simultaneously to drive the vehicle. In the instrument cluster, an arrow appears to the left of the battery symbol as well as the word "BOOST" to indicate the electrical energy output. The tachometer needle indicates the current revs of the combustion engine and the red display indicates its fuel economy.

In the CID the boost function is represented by a red arrow (combustion engine contribution) and a slightly smaller blue arrow (electric motor contribution). The combustion engine is shown in red here. The activity of the electric motor in the automatic transmission is indicated by the blue color of the transmission.

The five segments symbolize the state of charge of the high-voltage battery. Each segment equals 20% of the state of charge. The last segment (which displays the current state of charge of the HV battery) is shown in different shades of blue. This enables the intermediate stages in the range of 0% to 20% to be visualized. In the example above four segments are filled, this equates to a usable state of charge of 80%. The power flow is depicted with two colors to show that the power flow to the rear wheels comes from both drive sources. Red indicates the contribution by the combustion engine and blue the contribution by the electric motor.

8.4. Displays when braking

Hybrid displays in the instrument cluster and CID in overrun mode or when braking

Index	Explanation
1	Display for brake energy regeneration
2	Combustion engine running (shown in red)
3	Arrow for brake energy regeneration
4	Power flow to rear axle
5	Text message for current driving situation "CHARGE"

The display for brake energy regeneration in the instrument cluster takes the form of a blue arrow pointing in the direction of the battery symbol. The blue arrow varies in length, depending on the deceleration or on the intensity of the brake pedal actuation. Because the combustion engine is no longer delivering drive torque, the red drive arrow disappears from the display.

The transmission is shown in blue because the electric motor is now functioning as a generator and generating a braking torque. Here electrical energy flows into the high-voltage battery. This is indicated by two thin blue lines and the large blue arrow pointing to the high-voltage battery. The power flow from the rear wheels to the output shaft is depicted by animated blue arrows.

8.5. Differences between the European and US versions

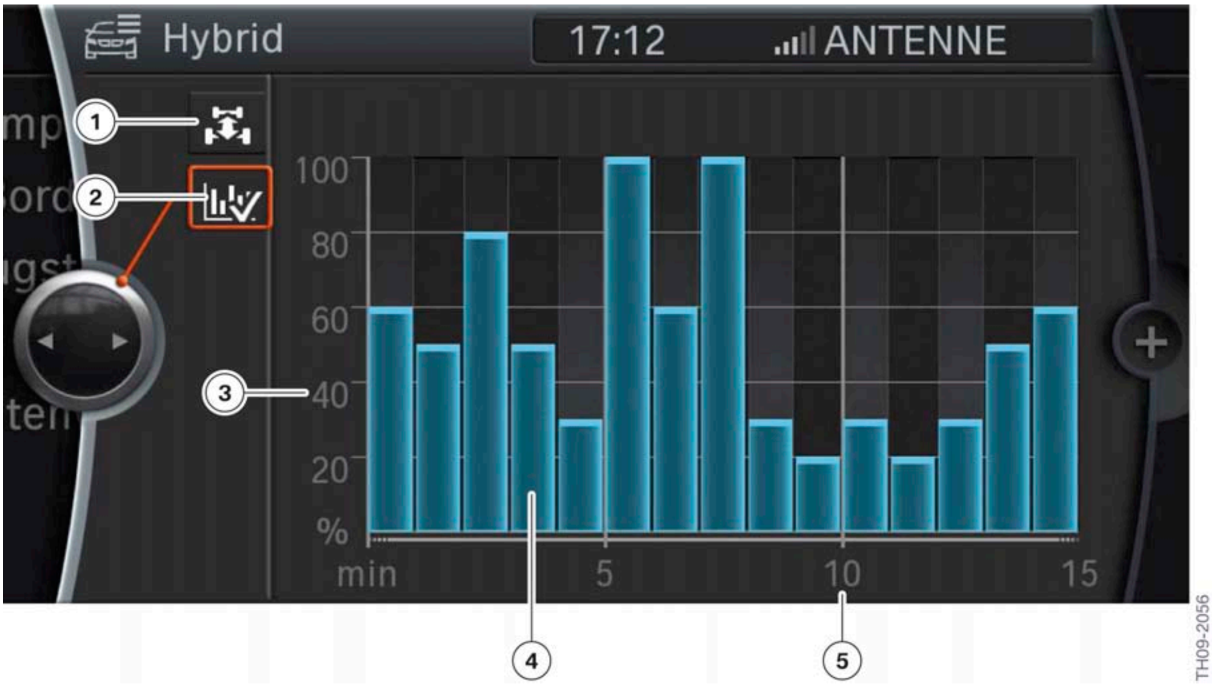
Left: Instrument cluster, European version, Right: Instrument cluster, US version

Index	Explanation
1	Display for boost function (European version)
2	Display for boost function (US version)

The hybrid-specific displays for the boost function are inverted in the European compared to the US versions. The reason for this is that in Europe the fuel consumption is given in the consumption indicator in liters per 100 kilometers, while in the US the fuel economy it is given in miles per gallon. In other words, the fuel consumption indicator in European cars indicates how much fuel (in liters) is consumed over a predefined distance travelled (100 km). In US vehicles the situation is reversed in that the indicator shows how far (in miles) one can drive on a predefined amount of fuel (gallons).

Brake energy regeneration generates energy which can be used later to start the combustion engine or for the boost function. This function enhances fuel efficiency and in order to indicate this to the driver, the hybrid-specific display (in US vehicles) are located to the right of the fuel economy indicator (in the direction of more miles), in order to indicate to the driver that he/she can drive a greater distance thanks to the regenerated energy. In European vehicles, the hybrid-specific displays are located directly to the left of the fuel consumption indicator, i.e. in the direction of the smaller display for current (instantaneous) fuel consumption.

8.6. Additional displays in the CID



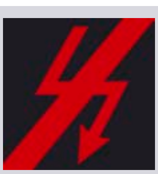
Display for utilization of the hybrid system

Index	Explanation
1	Selection of display for energy / power flows
2	Selection of display for electrical energy consumption
3	% scale
4	Bar representing minutes
5	Time axis

The utilization of the hybrid system in the last 15 minutes of driving can be shown in the CID. Each blue bar stands for a period of one minute. The higher the bar, the greater was the utilization of the hybrid system and thus the fuel economy. Each bar indicates the percentage of the driving time in which the hybrid system supported vehicle propulsion or in which brake energy was regenerated.

8.7. Hybrid-specific Check Control messages

If faults occur in the F04, the driver is informed about them by the Check Control messages. The following table summarizes the hybrid-specific Check Control messages.

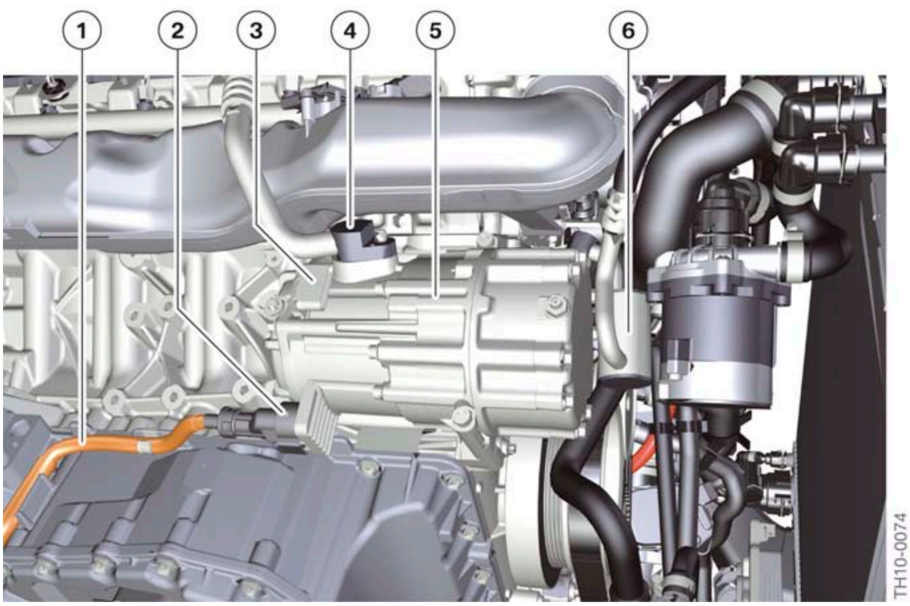
Check control message	Meaning	Cause
	Vehicle not ready to drive; To charge: switch on ignition; — High-voltage battery charging; Charging finished; Charging cancelled; Power high-voltage battery! Regeneration high-voltage battery! — Service life high-voltage battery	Flat high-voltage battery; Charging source connected, driver must switch on ignition; Charging in progress… Charging ended, battery charged; Charging cancelled; Power of high-voltage battery too low Operating period without regeneration too long State of health of high-voltage battery reaches 95% of service life
	No brake energy regeneration	No brake energy regeneration! Continued driving possible. Have vehicle checked by your authorized BMW Service Center.
	Engine malfunctioning!	Engine malfunctioning! Engine does not automatically switch on or off. If necessary start engine via Start/Stop button. Limited drive functions. Have vehicle checked by your authorized BMW Service Center.
	Engine! Only creeping possible; Engine! Greatly limited range;	Engine malfunctioning! Only forward and reverse creeping possible. Greatly limited range. Have vehicle checked by your nearest authorized BMW Service Center.
	Engine! Stop with care.	Engine! Stop with care and switch off engine. Call BMW Roadside Assistance.
	Hybrid system malfunctioning!	Insulation fault
	Hybrid system shut down.	High-voltage system shut down

9. Climate Control

An electrically driven A/C compressor is used in the F04 as in the E72. Because the A/C compressor has an electric motor, it is possible to operate the air conditioning independently of the combustion engine. Thus the customer can enjoy the cooling effect of the air conditioning even while driving in electric mode (E72) and while the vehicle is stopped. Due to special silencing of the compressor, the air conditioning can barely be heard even when the vehicle is stationary and the combustion engine is off.

The independent (parked-car) air conditioning function is offered for the first time in a BMW production vehicle. When the vehicle is parked, for example in the blazing sun, the interior temperature can be reduced by virtually half in about two minutes. The customer can activate the independent air conditioning via the remote control button. The car cools down noticeably while the customer, for example, loads his/her shopping. When the vehicle is started the full cooling output is then available immediately without the (otherwise typical) initial burst of hot air coming out of the air vents.

9.1. Electric A/C compressor



Electric A/C compressor in the F04

Index	Explanation
1	High-voltage cable for compressor
2	High-voltage connector for compressor
3	Signal connector
4	Connection for gaseous refrigerant with low temperature and low pressure (input)
5	Electric A/C compressor
6	Connection for gaseous refrigerant with high temperature and high pressure (output) with silencer

The electric A/C compressor is a high-voltage component!

High-voltage component warning sticker

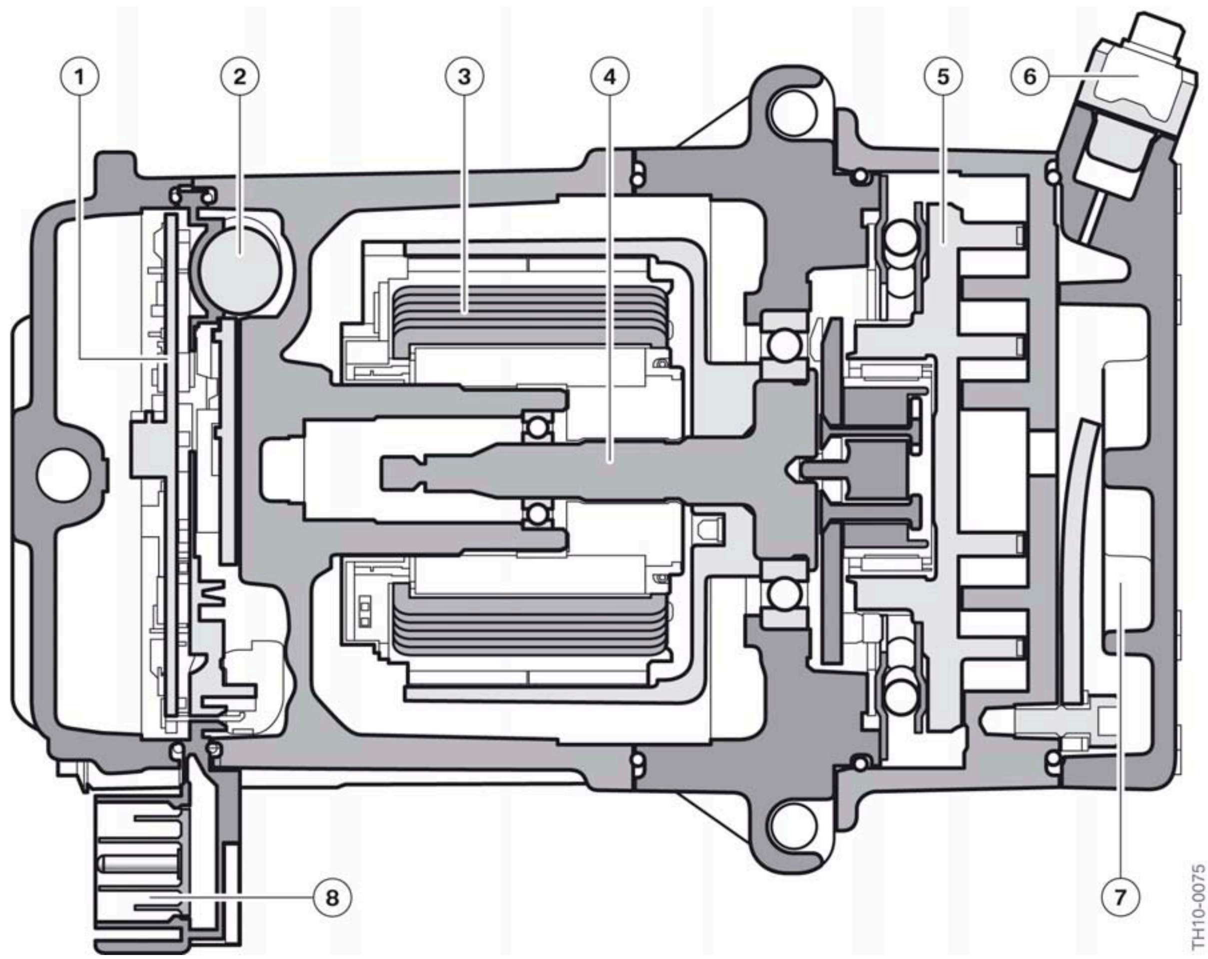
Each high-voltage component is clearly tabled, on its housing or casing, to enable Service Personnel and vehicle users to identify the possible hazards associated with high voltages and the precautions that must be taken when handling them.

Only high voltage Certified Service Technicians are permitted to work on hybrid high-voltage components. Always comply with the safety rules and procedures and follow proper the repair instructions.

Before working on a high-voltage component, you must apply the safety rules to shut down the high-voltage system. Once this has been accomplished according to procedure and all high-voltage components are no longer live, work can proceed in safety. There is, of course, a remote possibility that the correct shutdown procedure might be omitted, so an extra safety precaution is implemented as a means of imposing an automatic shutdown of the high-voltage system. Bridges of the high-voltage interlock loop (HVIL) are located both in the signal connector and in the high-voltage connector of the compressor.

The electric A/C compressor in the F04 is installed in the same location as the belt-driven A/C compressor in the F01/F02. Because the electric A/C compressor in the F04 is not driven via the ribbed V-belt, it could theoretically have been installed anywhere in the vehicle, but for reasons of space and to utilize the existing connections to the condenser the installation location has not been changed.

9.1.1. Structure of the electric A/C compressor

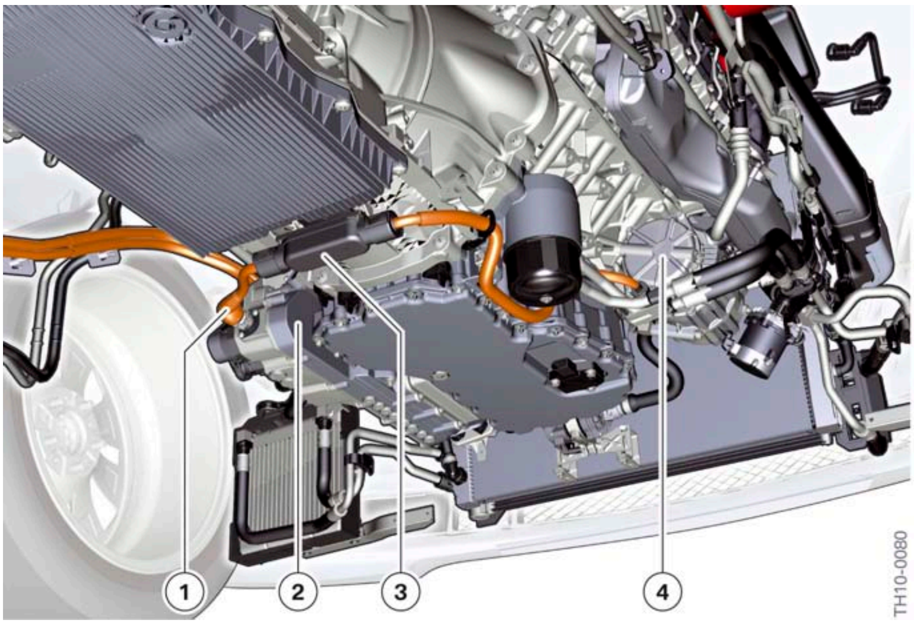


Structure of the electric A/C compressor

Index	Explanation
1	A/C compressor control unit and DC/AC inverter
2	Connection for gaseous refrigerant with low temperature and low pressure (input)
3	Three-phase synchronous machine
4	Drive shaft
5	Discs with spiral profile
6	Oil separator
7	Connection for gaseous refrigerant with high temperature and high pressure (output)
8	High-voltage connector

The structure of the electric A/C compressor is shown in the above graphic. The manufacturer and developer of the electric A/C compressor is the company Visteon.

Power supply, electric A/C compressor



Power supply for electric A/C compressor

Index	Explanation
1	Connection for high-voltage cable to the EME
2	Electric motor electronics (EME)
3	High-voltage fuse for electric A/C compressor
4	Electric A/C compressor

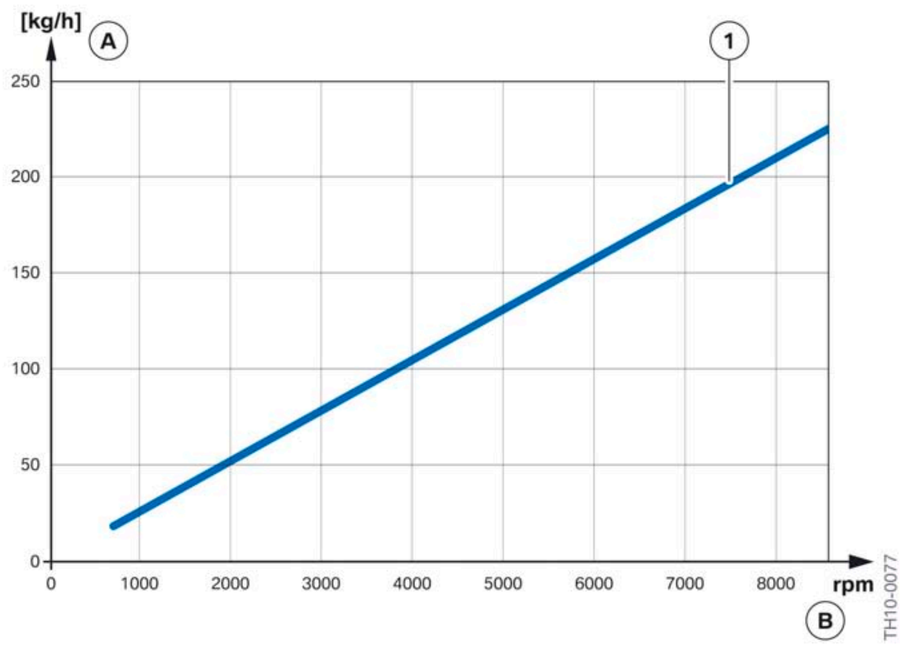
The electric A/C compressor is operated by the electrical energy from the high-voltage battery. The high-voltage cables from the high-voltage battery run first to the EME. The connection of the high-voltage cable for the electric A/C compressor is located on the EME. The high-voltage fuse serves to protect the high-voltage cable between the EME and the electric A/C compressor; this fuse can be replaced in a Service.

Electric A/C compressor control unit and DC/AC inverter

The electric A/C compressor control unit controls the rotational speed of the three-phase motor in the A/C compressor as a function of the requests of the IHKA. The electric A/C compressor communicates with the IHKA via the LIN bus. The IHKA is the master control unit for the electric A/C compressor. The DC/AC inverter converts the direct current voltage into the alternating current that is required to operate the three-phase motor. The electric A/C compressor control unit and the DC/AC inverter are integrated in the aluminum housing of the A/C compressor and are cooled by the gaseous refrigerant flowing past. If the temperature of the DC/AC inverter exceeds 230 °F (110 °C), it is shut off by the electric A/C compressor control unit. Attempts are made through different measures such as e.g. increasing the speed of the compressor, which keep the temperature from rising so high. The temperature is monitored by the electric A/C compressor control unit.

Three-phase motor

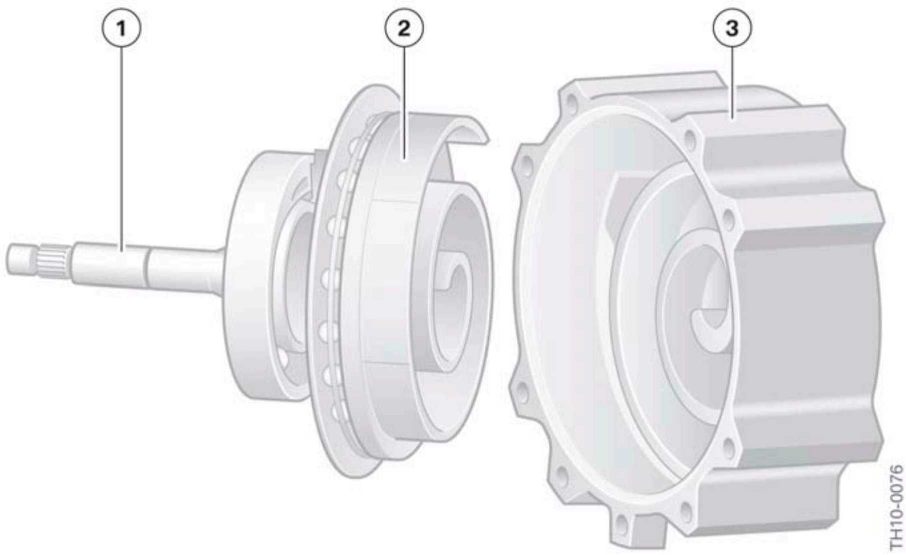
A three-phase AC synchronous motor is used as the drive for the A/C compressor. It is an outer rotor design and the magnetic field of the rotor is generated by ten permanent magnets. The synchronous motor is infinitely variable and operated in the speed range between 2000 and 8600 rpm. The nominal power capacity is 4.5 kW at 6500 rpm.



Index	Explanation
A	Volumetric flow
B	Rotational speed of the three-phase synchronous machine
1	Volumetric flow as a function of the rotational speed of the three-phase synchronous machine

Compression mechanism

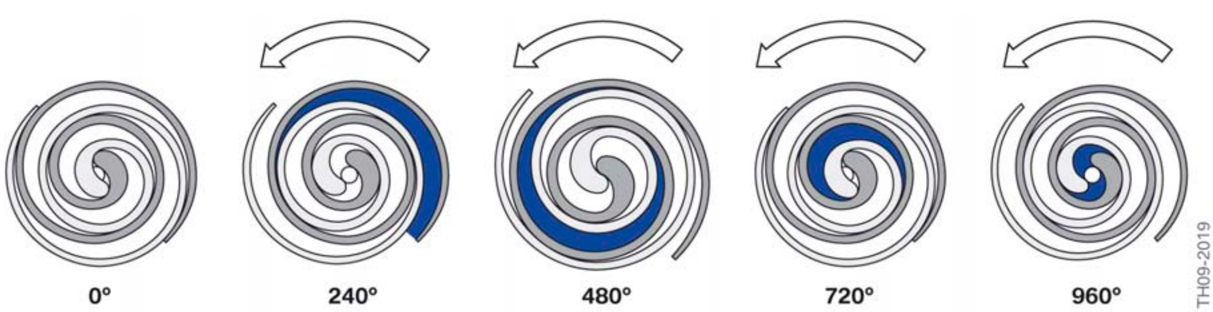
To compress the refrigerant, the spiral compressor (also known as the scroll compressor) is used.



Discs with spiral profile

Index	Explanation
1	Shaft
2	Inner disc with spiral profile
3	Outer disc with spiral profile

The inner disc with spiral profile is driven via a shaft by the synchronous motor and rotates eccentrically. The gaseous refrigerant at low temperature and low pressure is drawn in through two openings in the fixed outer spiral profile disc. There it is compressed and heated by the movement of the two spiral discs.

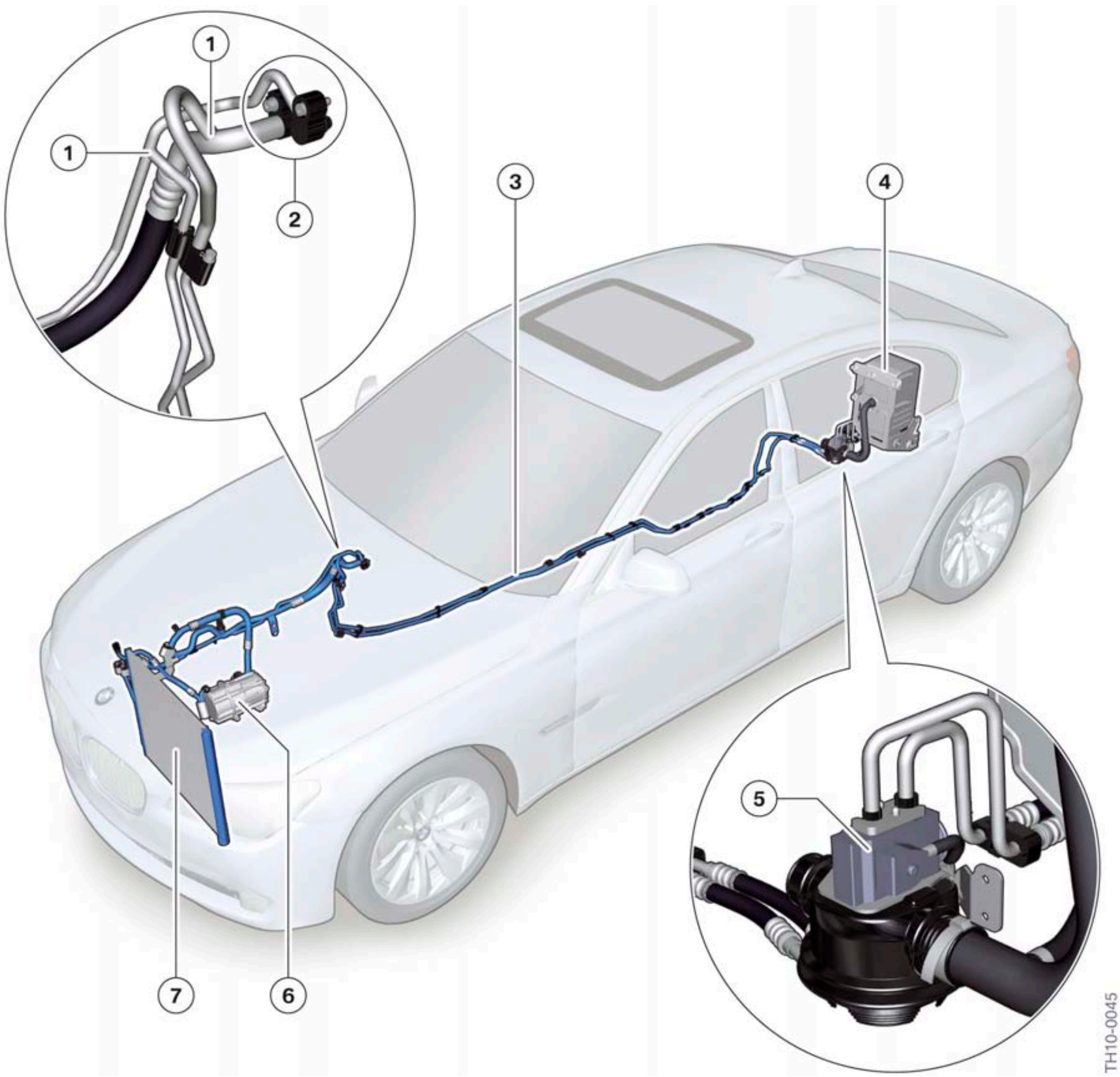


The principle of refrigerant compression

After three revolutions, the refrigerant drawn in is compressed, heated and exits in a gaseous state through an opening in the center of the outer disc. From here, the gaseous refrigerant with high temperature and high pressure is sent via an oil separator (at the connection of the A/C compressor) to the condenser. The maximum operating pressure is 30 bar.

Since the combustion engine on a hybrid vehicle does not run when the vehicle is stopped and thus cannot drown the noise generated by the auxiliary component, these are designed to operate as quiet as possible. For this reason, the sound of electric A/C compressor is muffled with the use of a special silencer installed between the connection of the A/C compressor and the condenser.

9.2. Refrigerant circuit



Refrigerant circuit in the F04

Index	Explanation
1	Branching of refrigerant lines to high-voltage battery
2	Connection to expansion valve for passenger compartment
3	Refrigerant lines to high-voltage battery
4	High-voltage battery
5	Combined shut-off and expansion valve for high-voltage battery
6	Electric A/C compressor
7	Condenser

The refrigerant circuit of the F04 is essentially the same as that used in conventional vehicles. R134a is used as the refrigerant, which circulates in a circuit, absorbing heat at one point in the system and releasing it at another point. The heat absorbed from the passenger compartment and high-voltage battery is released to the ambient air in a heat exchanger (condenser) on the front of the vehicle. When the air conditioning is activated for the passenger compartment or when cooling output is requested for the high-voltage battery, the electrically driven A/C compressor is switched on and the system supplies the corresponding area with refrigerant. The passenger compartment cooling and the cooling of the high-voltage battery can be operated independently of each other. The energy required for this is drawn by the electric A/C compressor from the high-voltage battery. The BMW-approved PAG oil is used as the lubricant for the refrigerant circuit.

So that the battery cooling and the passenger compartment cooling can be operated independently of each other, special solenoid valves are integrated into the refrigerant circuit. These open only the portion of the circuit that is actually required. This ensures high efficiency and proper control characteristics of the system. The following table shows how the valves and the electric A/C compressor are controlled.

Cooling of	Solenoid valve for evaporator (passenger compartment)	Solenoid valve for expansion valve (HV battery)	Electric A/C compressor
High-voltage battery	closed	open	switched on
Passenger compartment	open	closed	switched on
High-voltage battery and passenger compartment	open	open	switched on
No cooling	closed	closed	Switched off

If the customer switches off the A/C compressor, for example, the LED for switching the A/C compressor goes out, even though the electric A/C compressor may in some cases still be switched on for cooling the high-voltage battery.

Depending on the SoC value of the high-voltage battery, when "ready to drive" is activated (terminal 15 is switched on), the electric A/C compressor and thus the passenger compartment cooling can be requested (star LED is illuminated).

9.3. New features

9.3.1. Independent air conditioning

Due to the high energy and power density of the high-voltage battery and the use of an electric AC compressor in the F04, it was possible to implement the **independent air conditioning** function for the first time in a BMW production vehicle.

F04 infrared remote control

Index	Explanation
1	Button for activating independent air conditioning

Here the hot passenger compartment can be cooled immediately prior to the start of driving for about two minutes. The function can be conveniently activated by pressing the fourth button on the vehicle's infrared remote control at outside temperatures > 59 °F (15 °C). If the customer opens a car door shortly before these two minutes have elapsed, the cooling period is extended by about 30 seconds. Independent air conditioning can be activated again only after engine operation. The prerequisite for activating independent air conditioning is a sufficient state of charge of the high-voltage battery (SoC > 42 %). The customer is alerted by a Check Control message if the state of charge of the high-voltage battery is not sufficient.

Independent ventilation can also be activated with the remote control above an outside temperature of 59 °F (15 °C). In this case independent ventilation is activated automatically for a maximum period of 30 minutes after the end of the independent air conditioning function. Both functions, independent air conditioning and independent ventilation are ended when terminal 15 is activated.

The reception-dependent average range of the remote control is about 49 ft/15 m.

9.3.2. Residual Cooling

IHKA control panel

Index	Explanation
1	Button for increasing air volume

F04 Complete Vehicle

9. Climate Control

The **residual cooling** function is an additional climate control function which has been made possible by the use of the electrically operated A/C compressor. The customer can activate this function when he/she leaves the vehicle for a short time and then wishes to resume driving, for example to refuel the car, and would like to retain the pleasant interior temperature. As with residual heating, residual cooling can be activated with the ignition switched off by pressing the button for increasing the air volume. The interior temperature is then maintained for up to 6 minutes. With temperatures above 59 °F the AC will operate and with temperatures below 59 °F the residual heating will take over.

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