Technical training.
Product information.

I01 High-voltage Components

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BMW Group University
Technical Training
ST1403a 3/1/2014

BMW Service

General information

Symbols used

The following symbol is used in this document to facilitate better comprehension or to draw attention to very important information:

⚠

Contains important safety information and information that needs to be observed strictly in order to guarantee the smooth operation of the system.

Information status and national-market versions

BMW Group vehicles meet the requirements of the highest safety and quality standards. Changes in requirements for environmental protection, customer benefits and design render necessary continuous development of systems and components. Consequently, there may be discrepancies between the contents of this document and the vehicles available in the training course.

This document basically relates to the European version of left hand drive vehicles. Some operating elements or components are arranged differently in right-hand drive vehicles than shown in the graphics in this document. Further differences may arise as the result of the equipment specification in specific markets or countries.

Additional sources of information

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

- Owner's Handbook
- Integrated Service Technical Application.

Contact: conceptinfo@bmw.de

The information contained in this document forms an integral part of the technical training of the BMW Group and is intended for the trainer and participants in the seminar. Refer to the latest relevant information systems of the BMW Group for any changes/additions to the technical data.

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BV-72/Technical Training

I01 High-voltage Components

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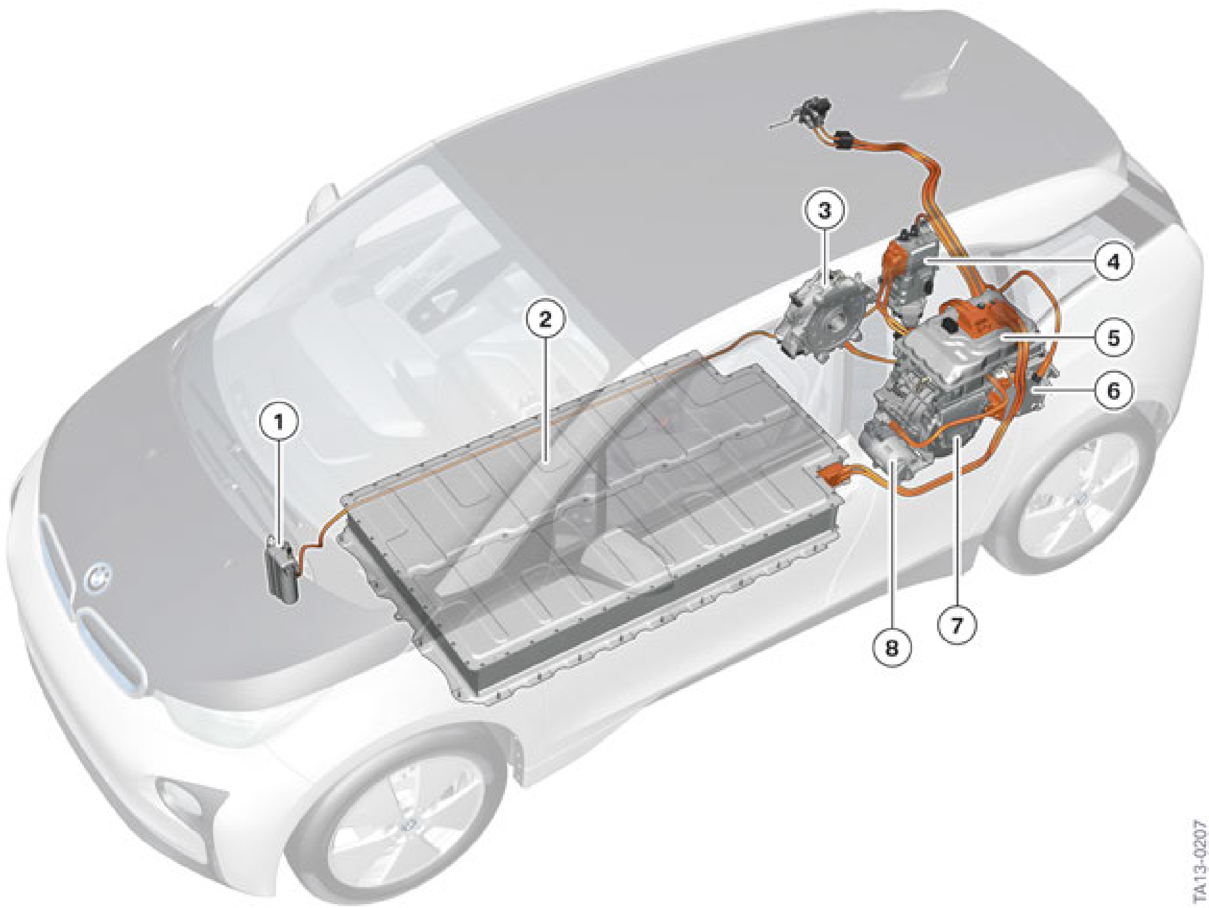
1. Introduction

A huge number of the high-voltage components in the I01 is used, on the one hand, for the electric motor, and, on the other hand, for some convenience functions.



High-voltage components in the I01

Index	Explanation
1	Electric heating
2	High-voltage battery
3	Range extender electrical machine
4	Range Extender Electrical Machine Electronics
5	Electrical machine electronics
6	Convenience charging electronics
7	Electrical machine
8	EKK

These components have one thing in common:

They all work with high voltage!

This is why particular care is needed in the case of a repair.

I01 High-voltage Components

1. Introduction

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Only Service employees who satisfy all the prerequisites are permitted to work on the designated high-voltage components: qualification, compliance with the safety rules, proceed exactly as per repair instructions (see also chapter "Prerequisites").

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

I01 High-voltage Components

2. Important Notes

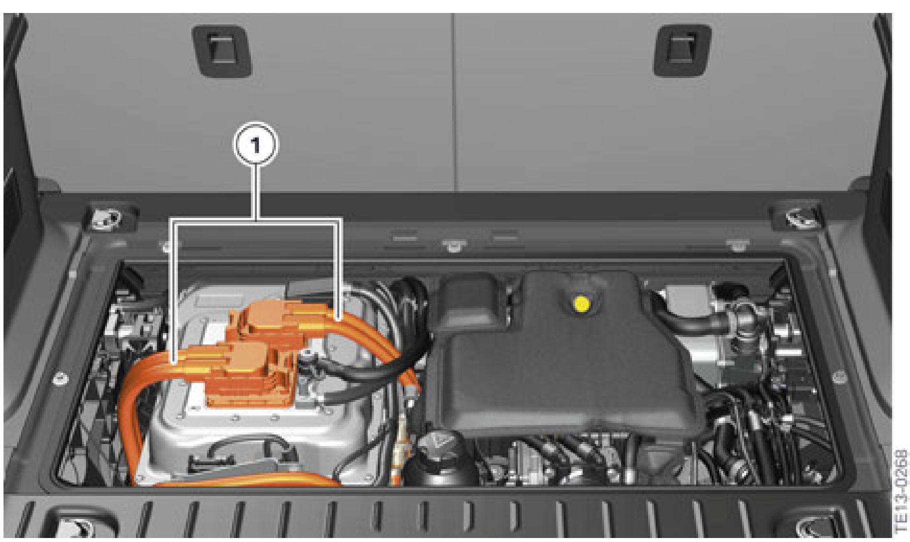
The high-voltage components of the I01 have an intrinsically safe design. This means that faults which could lead to harming the vehicle user are reliably identified.

2.1. Identification of the high-voltage components

Each high-voltage component has on its housing or casing an identifying label that enables Service employees and vehicle users to identify intuitively the possible hazards that can result from the high electric voltages used.

High-voltage component warning sticker

The high-voltage cables are a special case for identification. As they may be a few meterslong, identification with a warning sticker at one or two places would not make sense. The Service employee could easily oversee these stickers. Instead all high-voltage cables are marked in the orange warning color. Also the connectors at high-voltage cables, as well as the high-voltage safety connector, are marked in orange.



Orange color for the high-voltage cables.

Index	Explanation
1	High-voltage cables at EME

2. Important Notes

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

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Before working on high-voltage components of the I01, it is essential to observe and implement the electrical safety rules:

1 The high-voltage system must be disconnected from the 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

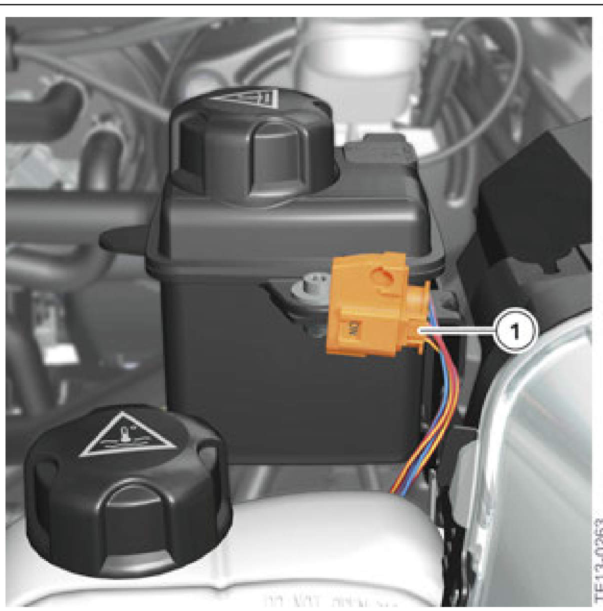
The following chapters provide brief descriptions on how to implement the electrical safety rules in the I01.

2.2.1. Preparations

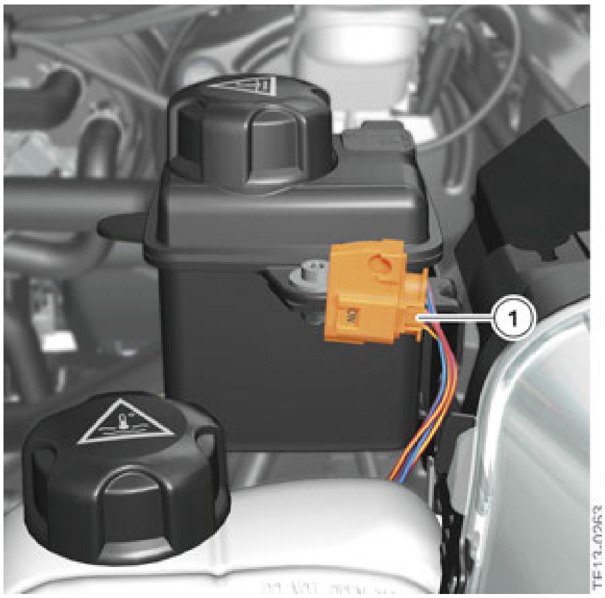
Prior to beginning any work, the vehicle must be secured against rolling away (engage the parking lock of the transmission and activate the parking brake). Terminal 15 and terminal R must be switched off. Disconnect any connected charging cables. The vehicle should be in "rest state".

2.2.2. Disconnect the high-voltage system from the supply

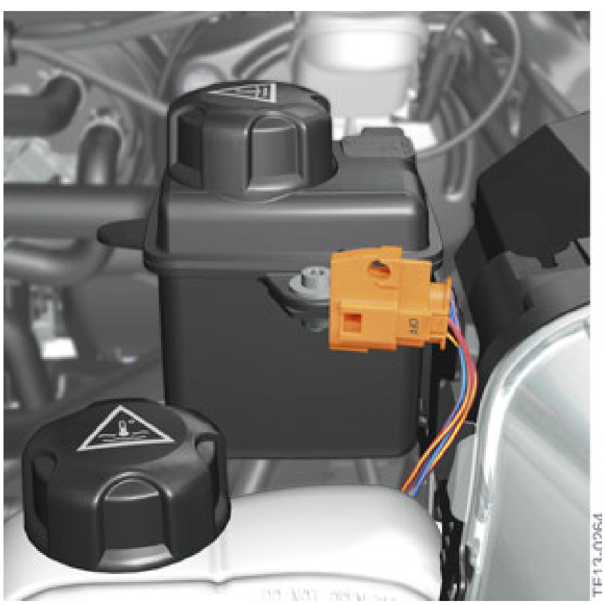
The high-voltage system in the I01 is disconnected from the supply with the high-voltage safety connector. To disconnect from the supply, the connector must be pulled from the relevant socket. This interrupts the circuit of the high-voltage interlock loop.



This image shows the high-voltage safety connector in a connected state. The circuit of the high-voltage interlock loop is not interrupted.
The message "ON" at the high-voltage safety connector indicates an active high-voltage system.



In order to be able to separate the connector, the mechanical lock (1) has to be pressed.



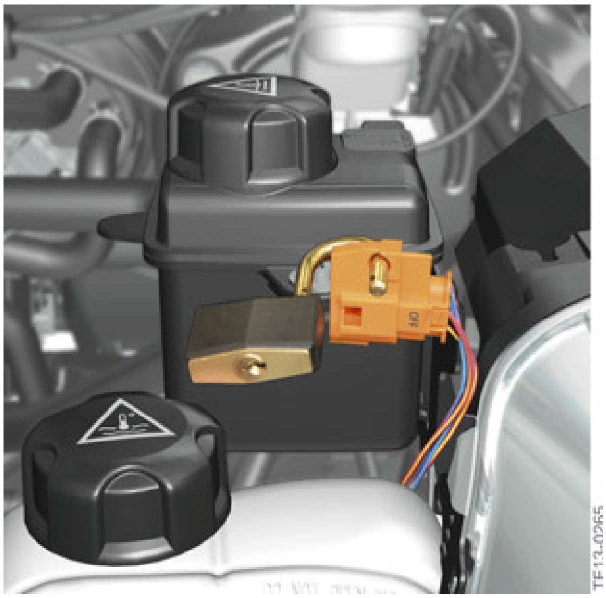
As soon as the mechanical lock has been removed, the connector can be pulled from the socket a few millimeters.

Do not pull any further or harder if resistance can be felt. The high-voltage safety connector cannot be disconnected from each other completely.

When the high-voltage safety connector is pulled out far enough the message "OFF" is visible. The high-voltage system is thus in a de-energized state.

2.2.3. Provide the high-voltage system with a safeguard against unintentional restarting

Securing against restart is also effected at the high-voltage safety connector. A commercially available U-lock (for example, ABUS 45/40) is required for this purpose.



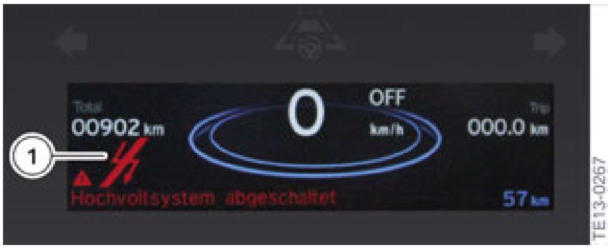
By separating the high-voltage safety connector, a bore hole becomes free through both parts. The loop of a typical U-lock must be inserted in this bore hole.

The U-lock can now be closed. The key must be stored in a safe place during work on the high-voltage system so that an unauthorized person cannot unlock the lock.
The connector can no longer be used by inserting and closing the U-lock at the high-voltage safety connector. 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 employee.

2.2.4. Verifying safe isolation from the supply

In BMW Service the de-energized state is not verified using a measuring device or via the diagnosis 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. This Check Control symbol in red shows a crossed-out flash symbol. The text message "High-voltage system switched off" also appears in the instrument cluster.



Check Control symbol "High-voltage system de-energized"

Index	Explanation
1	Check Control symbol for the display of the de-energized state and text message "High-voltage system switched off"

In order to verify the de-energized state, the Service employee must switch on terminal 15 and wait until he sees the Check Control message with the symbol and text shown above on the instrument cluster. Then, and only then, have you 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.

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

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Refueling the vehicle while the high-voltage battery is charging is not permitted!

When the charging cable is inserted do not initiate a refueling procedure and keep a safe distance from highly flammable materials. Otherwise, in the event of incorrect connection or removal of the charging cable there is a risk of personal injury or material damage by burning fuel for example.

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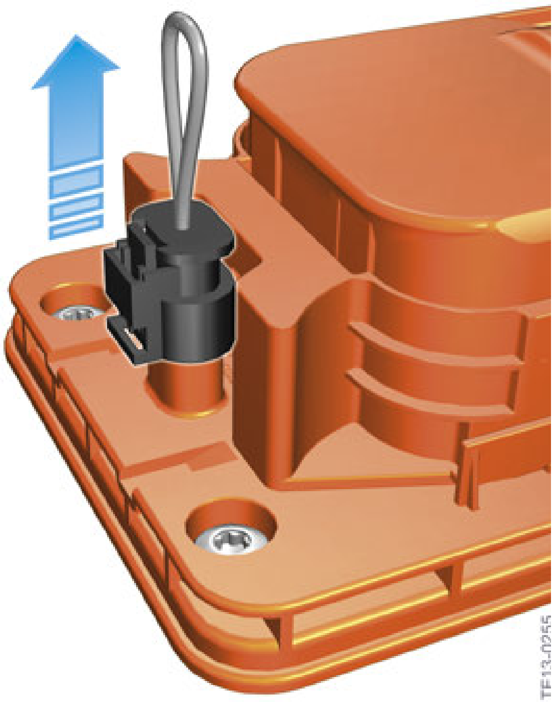
While the I01 is connected to the AC voltage network for charging, no work may be performed at the high-voltage system.

2.3. Removing and connecting the high-voltage connector

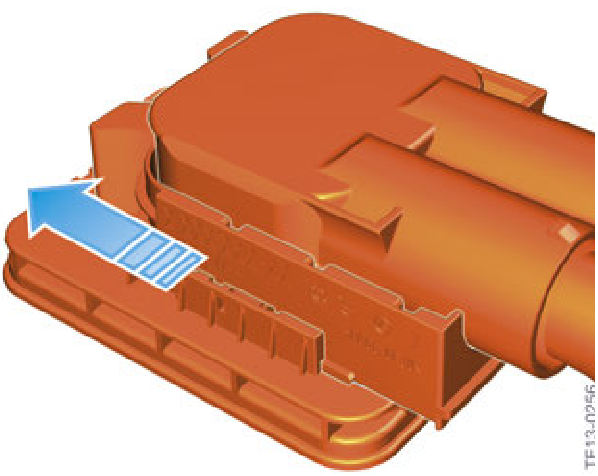
A certain sequence must be observed when breaking or establishing the contact connection both for flat and round high-voltage connectors. The individual steps are described below in the form of graphics and texts.

2. Important Notes

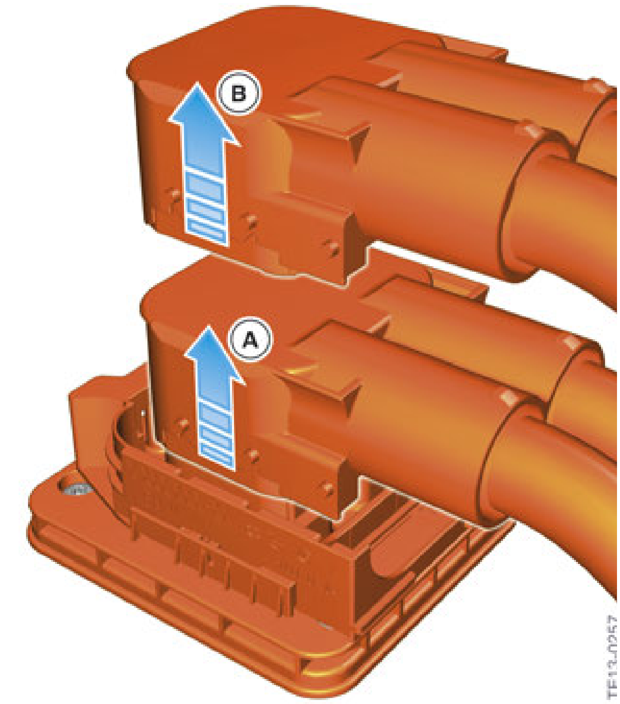
2.3.1. Removing the flat high-voltage connector



Bridge for high-voltage interlock loop
Before the high-voltage connector can be disconnected, the bridge for the high-voltage interlock loop must first be removed. The bridge closes the circuit of the high-voltage interlock loop in a connected state. The high-voltage control units continuously monitor the circuit of the high-voltage interlock loop and only when the circuit is closed is the high-voltage system active.
If the circuit of the high-voltage interlock loop is interrupted by removing the bridge, the high-voltage system shuts down automatically. This is an additional safety precaution as the Service employee has already switched off the high-voltage system before beginning work.



Removing the mechanical locking
Only after the bridge of the high-voltage interlock loop has been removed, can the mechanical locking be moved in the direction of the arrow. The mechanical locking is an element of the high-voltage connector on the high-voltage components (e.g. electrical machine electronics).
By moving the lock in the direction of the arrow the mechanical guide of the high-voltage connector on the high-voltage cable is released which permits the subsequent disconnection.



Removing the connector of the high-voltage cable

The connector of the high-voltage cable must now be removed in the direction of the arrow. After the connector has been pulled out a few millimeters (A), one encounters a higher counterforce. The connector must then be pulled out further in the same direction (B). Under no circumstances must the connector be pressed back into the socket on the high-voltage component after reaching position (A). This may damage the connector on the high-voltage components.

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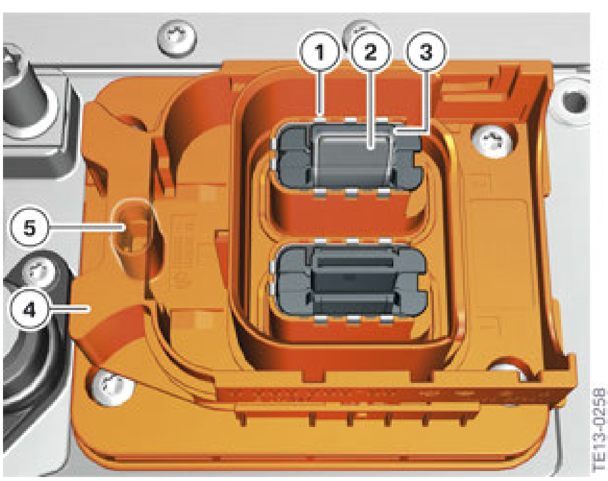
The high-voltage connector of the high-voltage cables must be pulled out at a right angle in two steps and in the same direction. Changing the direction of movement during removal is not permitted.

Proceed in the reverse order when reattaching the high-voltage cable. The following graphic shows the complex design of the high-voltage connector on the high-voltage components and explains why one must proceed with care when removing and inserting high-voltage cables.



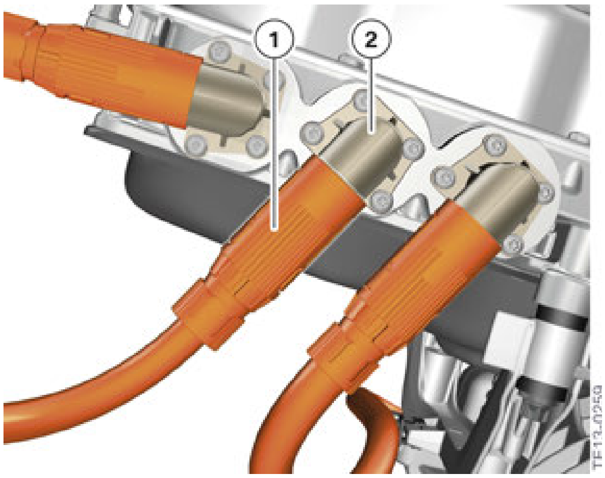
High-voltage connector on the high-voltage component

Index	Explanation
1	Electrical contact for shielding
2	Electrical contact for high-voltage cable
3	Contact protection
4	Mechanical locking
5	High-voltage interlock loop connector/bridge

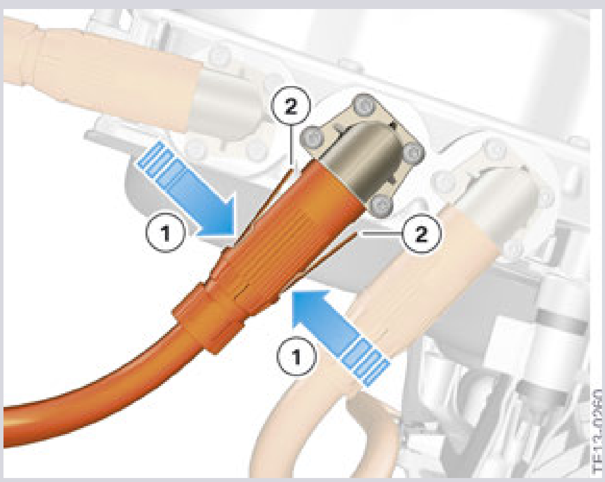
2.3.2. Removing the round high-voltage connector

The procedure described here applies for removing the round high-voltage connector in the I01. The following graphics show the procedure using the example of the high-voltage connection at the electrical machine electronics, at which the high-voltage cable is connected for the electric heating.

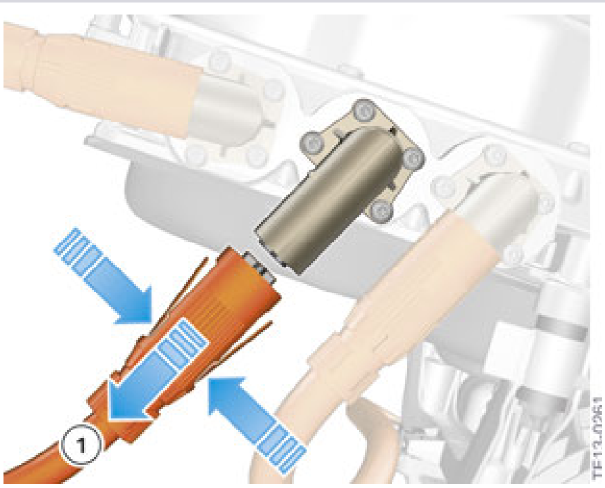
2. Important Notes



The connector of the high-voltage cable (1) is located at the high-voltage connection of the component (2) and is locked.



The two locking elements (2) must be pressed together in the direction of arrow (1). The mechanical lock of the connector at the connection of the high-voltage component is thus removed.

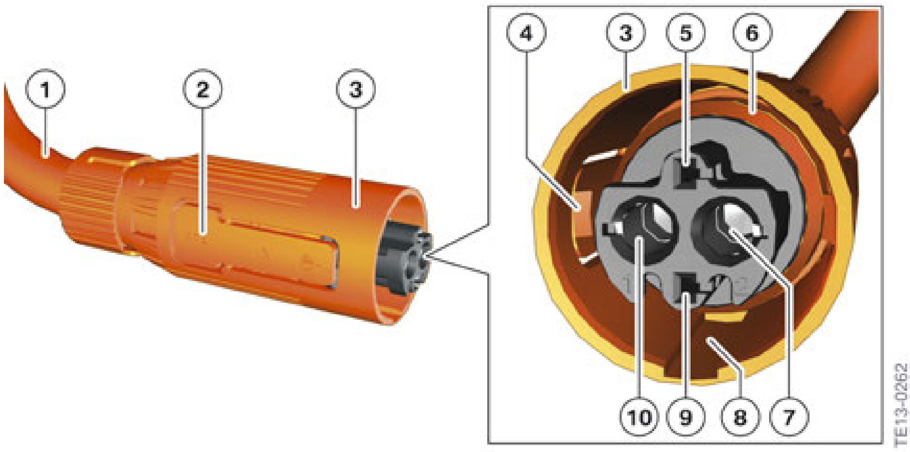


While the locking elements are further pushed together, the connector must be removed lengthways in the direction of arrow (1).

When reconnecting the high-voltage cable the locking elements must not be pushed together. It is sufficient to slide the connector lengthways onto the high-voltage connection of the component. Ensure that the locking elements engage ("clicking" noise). In addition, the engaging of the locking elements should be checked by subsequent pulling on the connector.

2. Important Notes

The following graphic shows the design of the round high-voltage connector on the high-voltage cable.



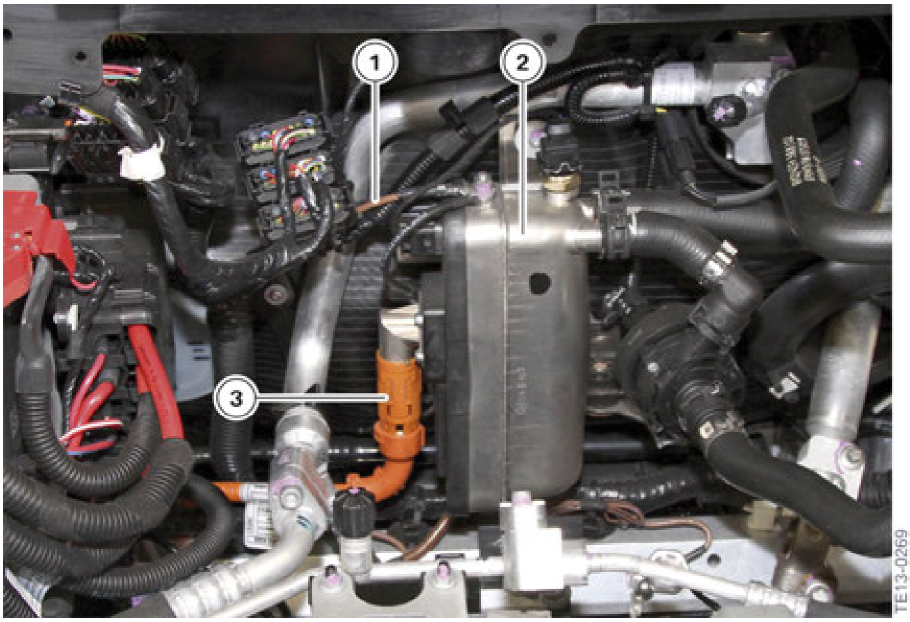
Design of the round high-voltage connector

Index	Explanation
1	High-voltage cable
2	Actuation points on locking elements
3	Housing
4	Locking element
5	Connection 1 for bridge in the connector
6	Connection for shielding
7	High-voltage connection, pin 2 (DC, minus)
8	Mechanical encoding
9	Connection 2 for bridge in the connector
10	High-voltage connection, pin 1 (DC, plus)

The bridge in the high-voltage connector serves for electrical safety. The signal of the high-voltage interlock loop runs over this bridge when the high-voltage cable is connected to the high-voltage component. For the connection of the high-voltage cable to the EKK and to the electric heating the voltage supply of the EKK or transmission control unit runs via the bridge. If one of the circuits is interrupted, this also results in an automatic interruption to the current flow (returns to zero) in the respective high-voltage cable. As the two contacts of the bridge opposite the high-voltage contacts advance, this measure constitutes protection against the formation of an electric arc when removing the high-voltage connector.

2.4. Connections for potential compensation lines

The safety concept of the high-voltage system includes the measurement and monitoring of the isolation resistance of the high-voltage cables to each other and against ground. This safety function is performed in the I01 of the SME control unit, but should identify isolation faults in the entire high-voltage circuit. For this purpose, the housing of all high-voltage components must be connected galvanically to ground.



Electrical connections at the electric heating

Index	Explanation
1	Potential compensation line
2	Housing of the electric heating
3	High-voltage connector

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The high-voltage system must not be operated if the potential compensation cables are not properly connected to the high-voltage components.

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If in the event of a repair the high-voltage components or the potential compensation lines are replaced, the following must be observed during assembly: The galvanic connection between the housing of the high-voltage components and ground must be properly re-established. The repair instructions must be strictly observed (tightening torque, self-cutting screws). In addition, a second Service employee has to check the repair work (correct tightening torque and correct location of bare metal) and record this in writing in the repair order.

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3. Electric Motor

3.1. Electrical machine

The electrical machine in the I01 receives an electric motor identification, as known from combustion engines. This electrical machine identification is **IB1P25B**.

3.1.1. Designation and identification of electrical machines

Designation of electrical machines

The electrical machine designations are used in the technical documentation for clear identification of the electrical machines.

According to GS 90023, the designation of the electrical machine used in the I01 is:

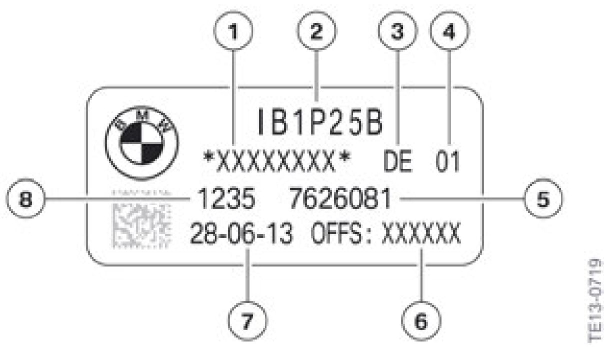
EMP242.130.01.250(300)-A3-X1

In frequent cases, however, only a short designation is used. This short designation is used to assign an electrical machine to an electrical machine family. For instance, the short designation EMP242 is also used.

Position	Meaning	Index	Explanation
1	Abbreviation	**EM**	Electrical machine
2	Machine type	N U O **P** R S T	Asynchronous machine Direct current machine Axial flow machine Permanently excited synchronous machine Switched reluctance machine Electrically excited synchronous machine Transverse flow machine
3	Outer diameter of stacks of sheet of the electrical machine	0 to ... (**242**)	in millimeter [mm]
4	Length of stacks of sheet of the electrical machine	0 to ... (**130**)	in millimeter [mm]
5	Version	**01** 02 ...	Every change to the original version, e.g. housing, sheet cutting, coil changes
6	Peak torque	1 to ... (**250**)	in Newton meter [Nm]
7	Phase current	1 to ... (**300**)	in ampere [A]

8	Model	**A** G H V K M N R	Axially parallel layout Electrical machine integrated in the transmission Rear axle Front axle Crankshaft mounted Coaxial with separation clutch Wheel hub Assigned to the belt drive
9	Number of phases	1 to ... (**3**)	Number of phases of the machine
10	Supplier	**X**	Is defined by the project
11	Serial number of the machine	**1**	-Optional

Identification of the electrical machine i.a.w. GS 90023



Type plate for electrical machine

Index	Explanation
1	Serial number
2	Designation i.a.w. GS 90023
3	Country of manufacture
4	Revision index
5	Part number
6	Adjustment value (angle) for rotor position sensor
7	Production date
8	Unified Parts Group

The electrical machines have an identification to ensure clear identification and classification. This identification is also necessary for approval by government authorities. The identification of the electrical machines is equivalent to the identification of the combustion engines. The number of the electrical machine can be found under the electrical machine identification on the electrical machine. This consecutive number, in conjunction with the identification, permits unambiguous identification of each individual electrical machine.

Position	Meaning	Index	Explanation
1	Engine developer	G I J	Electrical machine in/at the transmission Electrical machine, BMW Electrical machine, external
2	Engine type (outer diameter of stack of sheets)	A B C D E	< 200 mm > 200 mm < 250 mm > 250 mm < 300 mm > 300 mm Outer rotor with small diameter
3	Change to the basic engine concept	0 or 1 2 to 9	Basic engine Changes, e.g. variation of sheet cut (even numbers reserved for motorbikes, odd numbers for passenger cars)
4	Machine type (engine procedure)	N U O P R S T	Asynchronous machine Direct current machine Axial flow machine Permanently excited synchronous machine Switched reluctance machine Electrically excited synchronous machine Transverse flow machine
5 + 6	Torque	0 to ...	e.g. 25 = 250 Nm
7	Type test concerns (changes that require a new type test)	A B to Z	Standard Acc. to requirements, e.g. adaptations to length and coils

For the electrical machine EMP242.130.01.250(300)-A3-X1 the engine identification looks like this: IB1P25B.

3.1.2. Technical data

The electrical machine in the I01 is a synchronous machine. Its general structure and operating principle correspond to those of a permanently excited synchronous machine with internal rotor: The rotor is located inside and is equipped with permanent magnets. The stator is ring-shaped and arranged outside around the rotor. It is formed by the 3-phase coils which are housed in the grooves of the stator. If a 3-phase AC voltage is applied to the stator coils, they generate a rotating magnetic field, which "pulls" the magnets in the rotor (in engine operation).

3. Electric Motor

Principal structure of the synchronous machine

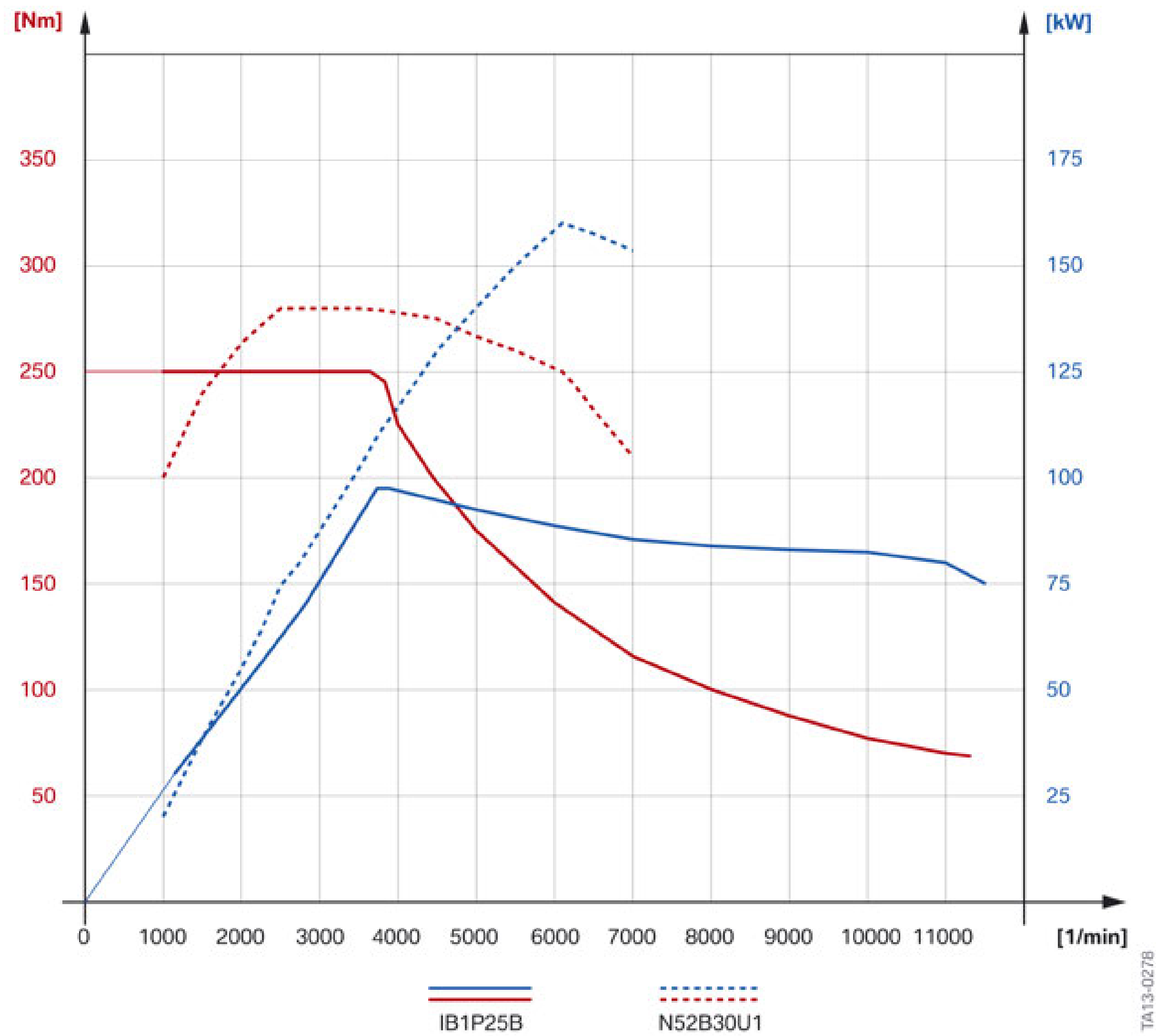
Index	Explanation
A	Conventional synchronous machine
B	Synchronous machine in the I01
1	Stator
2	Stack of sheets, rotor
3	South pole of a permanent magnet
4	North pole of a permanent magnet

To improve the technical data the structure, primarily of the rotor, was modified and optimized. The rotor has a new arrangement of the permanent magnets and a stack of sheets which has a positive influence on the characteristic of the magnetic field lines. On the one hand, this improves the torque. On the other hand, there are lower current levels in the stator coils, whereby the efficiency is increased in comparison to a conventional synchronous machine.

The impressive performance data are summarized in the following table.

Nominal voltage	360 V	
Nominal current	400 A	Actual value
Maximum peak output	125 kW/170 bhp	for a maximum duration of 30 s
Maximum continuous output	about 75 kW	continuous
Maximum torque	250 Nm/184 lb-ft	in the engine speed range 0 – 5,000 rpm.
Maximum engine speed	about 11,400 1 min.	
Weight	about 49 kg	

The maximum power of 125 kW can only be made available for a maximum duration of 30 s. Otherwise, the components of the drive train would be damaged through overheating – this affects not only the electrical machine, but also the high-voltage battery and the electrical machine electronics. The maximum power applies for the motor operation – in theory it could also be used in the alternator operation during brake energy regeneration. However, in practice only a fractional part of this maximum value is used in alternator operation. As a result, the braking torque at the rear axle is restricted so as not to affect the driving stability by the brake energy regeneration.



Power and torque diagram for IB1P25B machine compared to the N52B30U1 engine

The power and torque diagram shown here is not the full load diagram. Instead, the data was recorded at a lower supply voltage, as it occurs, for example, during a partially charged high-voltage battery. Nevertheless, the data of the electrical machine are impressive and do not need to fear comparison with the N52B30U1 engine. The following properties are characteristic of the electrical machine IB1P25B in the I01:

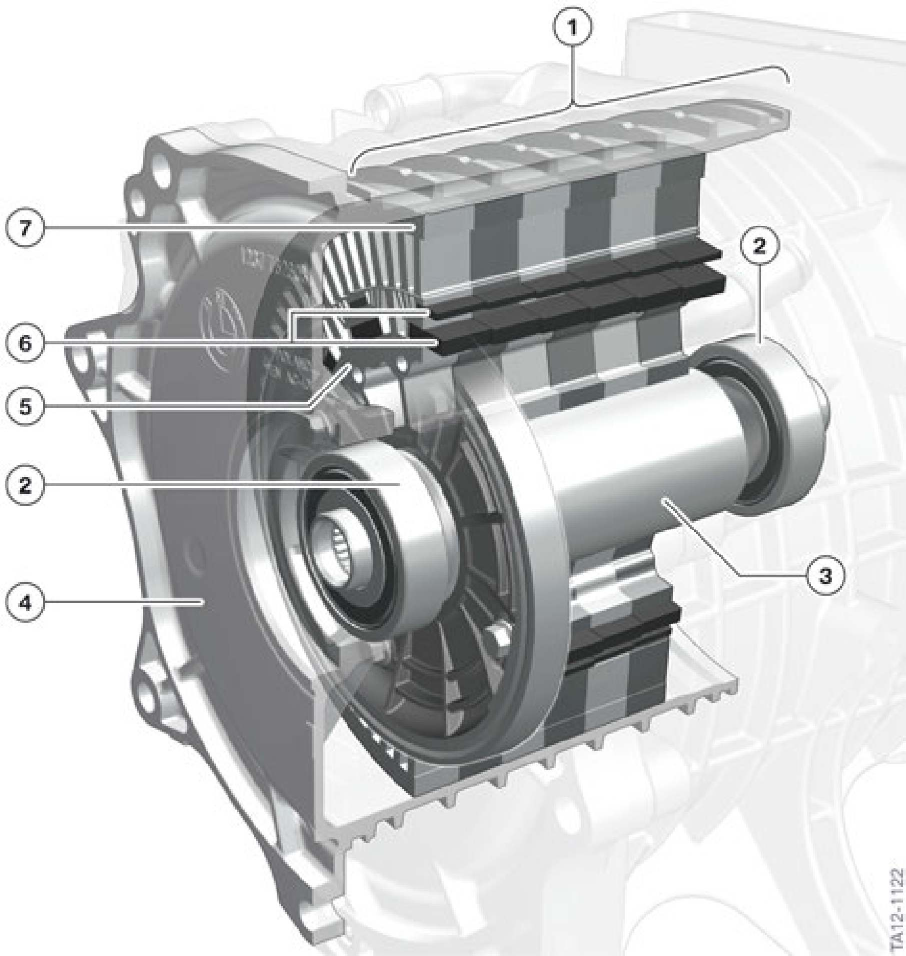
3. Electric Motor

- The maximum torque of 250 Nm is already available from when the machine is at a standstill and is available up to average engine speeds. This is why the drive train of the I01 does not need a clutch. Besides this technical feature, there is also another advantage for the customer: The I01 has an impressive accelerating ability from standstill, which results in The Ultimate Driving Machine typical of BMW, particularly in urban traffic.
- The maximum torque only decreases again at higher engine speeds. However, it is sufficient to be able to dynamically overtake in the speed range on national roads.
- The characteristic of the maximum power can be deduced from the characteristic of the maximum torque: In the engine speed range in which the maximum torque is applied constantly the maximum power increases linear to its maximum. Despite the falling torque at higher engine speeds, the maximum power only decreases slightly to the maximum engine speed.
- The usable engine speed range of the electrical machine is sufficient from 0 to almost 11,400 rpm. Owing to this almost double the engine speed range of a combustion engine, the I01 manages without a manual gearbox and still achieves a remarkable maximum speed of 150 km/h.

3. Electric Motor

3.1.3. Design

Electrical machine



Design of electric motor

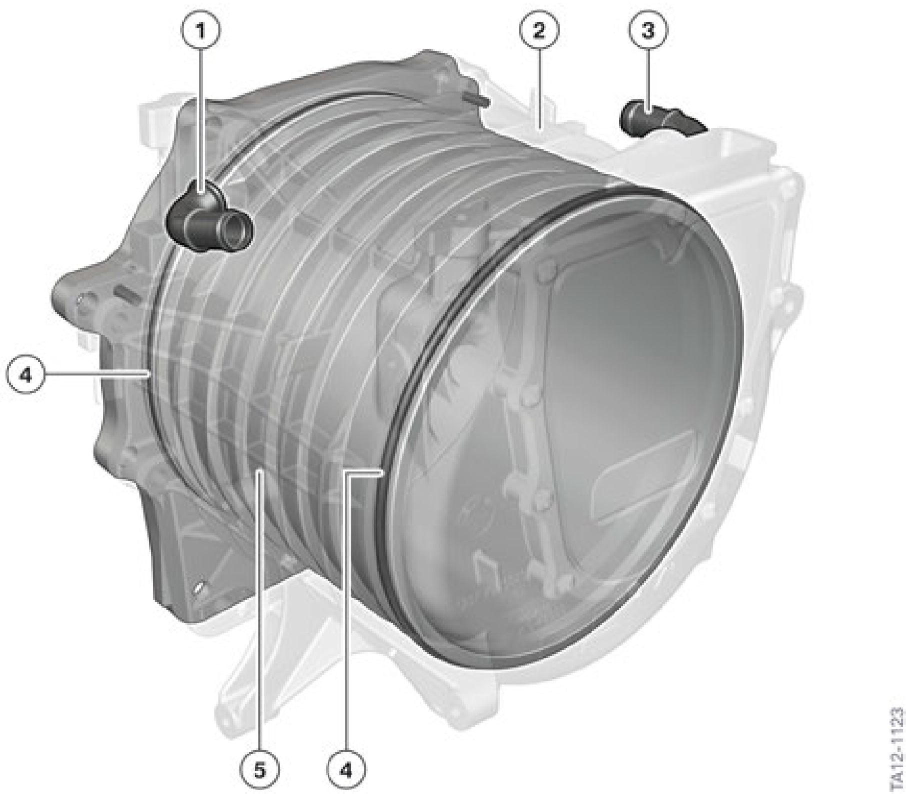
Index	Explanation
1	Coolant ducts
2	Grooved ball bearing
3	Drive shaft
4	Inner housing
5	Stack of sheets in the rotor
6	Permanent magnets in the rotor
7	Stator stack of sheets

3. Electric Motor

In the graphic only the part of the stator without coil is shown. The rotor consists of a weight-optimized support in the inside, a stack of sheets and permanent magnets, which are arranged in two layers. The torque that can be generated by the machine is therefore increased. The rotor is shrink-fitted on the drive shaft.

The number of pole pairs of 6 is a good ratio between the justifiable complexity of the design and represents a constant torque curve for each revolution where possible.

The electrical machine of the I01 does not have an oil filling. Only the two grooved ball bearings which include a grease filling are lubricated. The cooling of the electrical machine is effected using coolant, which is conveyed from the output of the electrical machine electronics to the electrical machine. In the electrical machine the coolant flows through a spiral-shaped coolant duct, which runs at the outer side. Two O-rings at the housing ends seal the coolant duct. The inside of the electrical machine is therefore completely "dry".



Cooling of the electrical machine

Index	Explanation
1	Connection for coolant line (input of electrical machine, coming from the electrical machine electronics)
2	Outer housing
3	Connection for coolant line (output of electrical machine, to the radiator)
4	O-ring
5	Cooling duct

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3. Electric Motor

The electrical machine is designed for a large temperature range. The coolant can reach a temperature of up to 70 °C at the input (supply). And although the electrical machine demonstrates less losses during energy conversion than a combustion engine, its housing can absorb a temperature of up to 100 °C.

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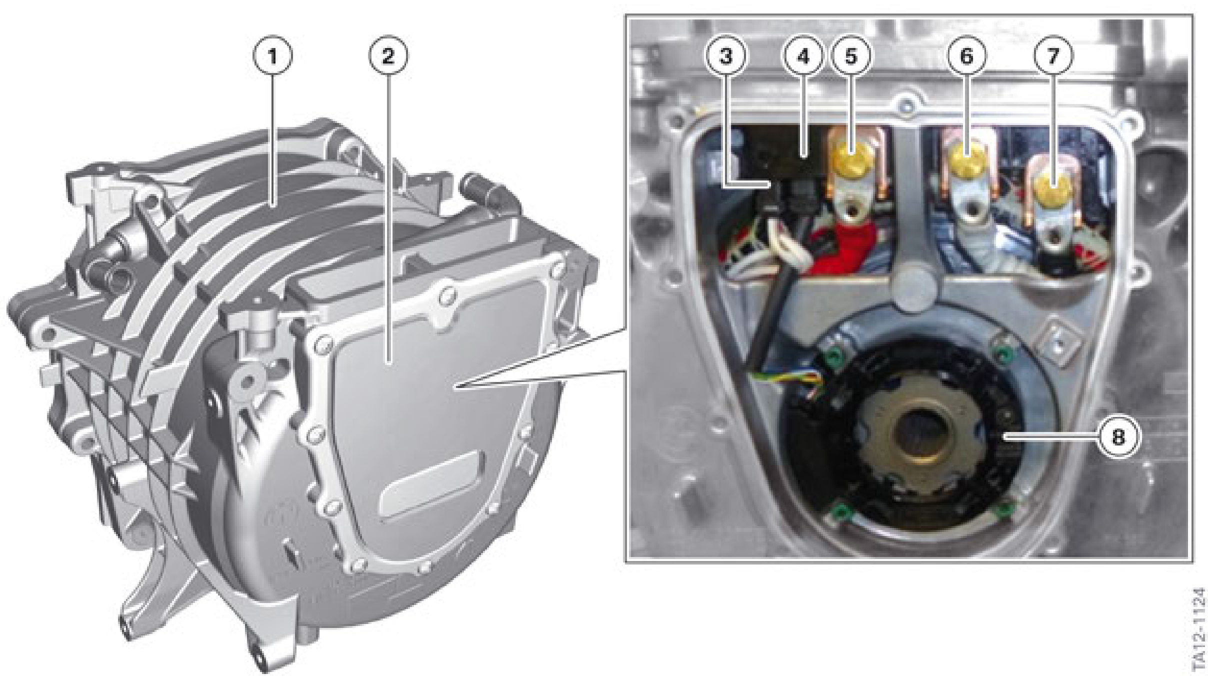
Danger of injury: The housing of the electrical machine can absorb temperatures of up to 100 °C during operation. A sufficiently long time must be waited for cooling if work is to be performed, for example the removal of the drive unit.

Sensors

In order to avoid damage to the components due to the high temperature, there are two temperature sensors in the electrical machine of the I01. Both temperature sensors are located in the coils of the stator. The temperature of the rotor is not measured directly, but can be determined from the measured values of the temperature sensors in the stator. The two temperature sensors are temperature-dependent resistors of type NTC. Their signals are read in and evaluated analogically by the electrical machine electronics.

So that the voltages for the coils in the stator can be correctly calculated and generated by the electrical machine electronics in terms of amplitude and phase layer, the precise angle setting of the rotor must be known. This is why there is a rotor position sensor at the end of the drive shaft, which is turned away from the transmission.



Electrical connections of the electrical machine

3. Electric Motor

Index	Explanation
1	Outer housing
2	Housing cover
3	Connection for rotor position sensor
4	Temperature sensor in the stator
5	High-voltage connection U
6	High-voltage connection V
7	High-voltage connection W
8	Rotor position sensor

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The housing cover must be replaced after disassembly!

⚠

The screws of the high-voltage connections (U, V, W) must be replaced after each disassembly.

The rotor position sensor is secured at the stator of the electrical machine and works according to the tilt sensor principle. There are three coils in the rotor position sensor. A defined AC voltage is fed to one of the coils. The other two coils are each moved 90°. The voltages induced in these coils provide information about the angle setting of the rotor. The rotor position sensor is mounted by the manufacturer of the electrical machine at the corresponding alignment so that it is already correctly adjusted. A precise adjustment of the rotor position sensor is effected during production, after which the electrical machine and electrical machine electronics are joined. The adjustment values are stored in the control unit of the electrical machine electronics.

⚠

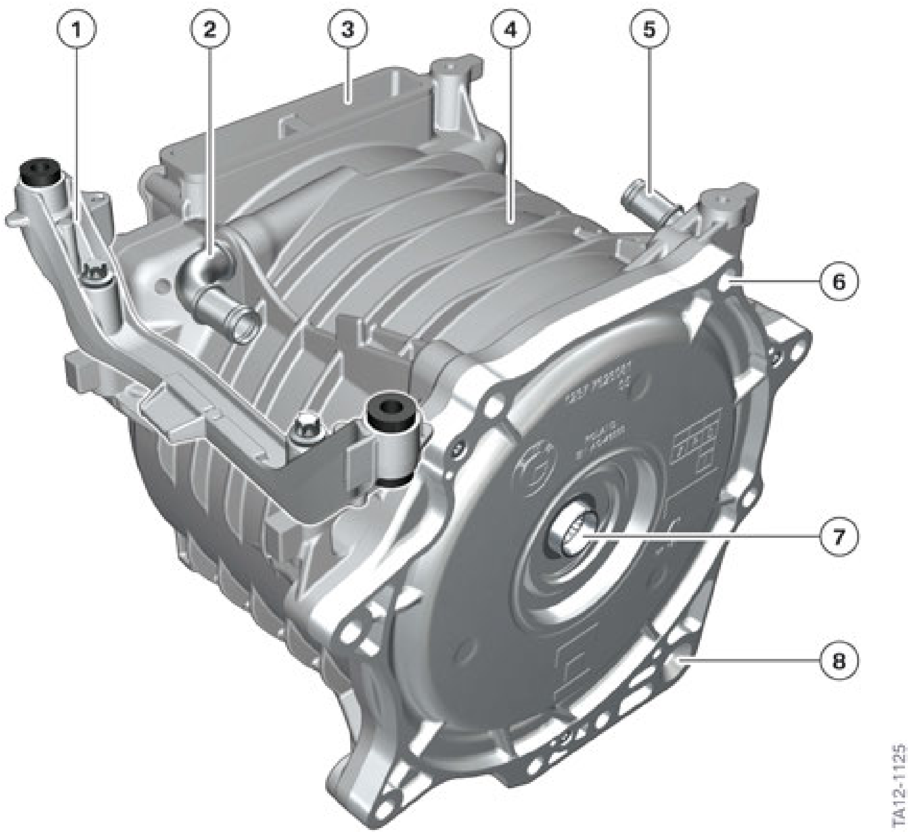
Neither an adjustment nor a replacement of the rotor position sensor can be performed in BMW Service.

⚠

If the electrical machine or the electrical machine electronics are replaced, the code for the angle must be noted via diagnosis in the electrical machine electronics. The code for the angle can be found on the type plate of the electrical machine.

The electrical connection for the sensors of the electrical machine and the electrical machine electronics is shown in a wiring diagram in the chapter "Electrical interfaces".

3.1.4. External features and mechanical interfaces



External features and mechanical interfaces of the electrical machine

Index	Explanation
1	Carrier support for electrical machine electronics
2	Connection for coolant line (output of electrical machine to the radiator)
3	Shaft for electrical connections for the electrical machine electronics
4	Outer housing
5	Connection for coolant line (input of electrical machine, coming from the electrical machine electronics)
6	Bore holes/thread for the mechanical connection with the transmission
7	Drive shaft
8	Anti-roll bar link connection

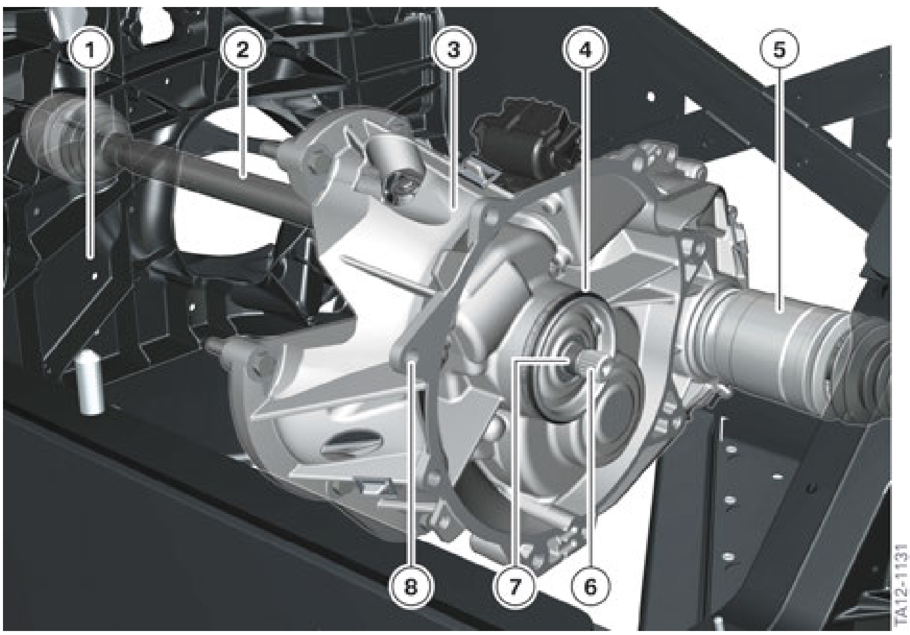
The electrical machine electronics is located above the electrical machine. In order to obtain ample support, the housing of the electrical machine was "extended" with a carrier support at the front in the direction of travel.

The torque is transmitted via a positive connection from the drive shaft of the electrical machine to the transmission input shaft. For this purpose, both shafts have gearing. However, there is no intended centring for the two shafts.

3. Electric Motor

⚠

When joining the transmission and the electrical machine the procedure described in the repair instructions must be followed. Ensure axial alignment of the transmission input shaft and output shaft to avoid distortion during assembly. In addition, the two gearings must be greased before joining. Do not exceed the specified quantity of grease!



Mechanical interfaces of the transmission

Index	Explanation
1	Rear axle module
2	Output shaft, right
3	Transmission housing
4	X-sealing ring
5	Output shaft, left
6	Transmission input shaft with gearing
7	O-sealing ring
8	Bore holes for the mechanical connection with the electrical machine

There is a sealing ring at the joining connection between housings of the electrical machines and the transmission, whose cross-section is shaped like the letter "X". This X-sealing ring must be replaced before joining and is included in the delivery specification of the transmission.

The two connections for the coolant lines integrate the electrical machine in the cooling circuit of the electric motor. This is described in the chapter "Cooling of electric motor components".

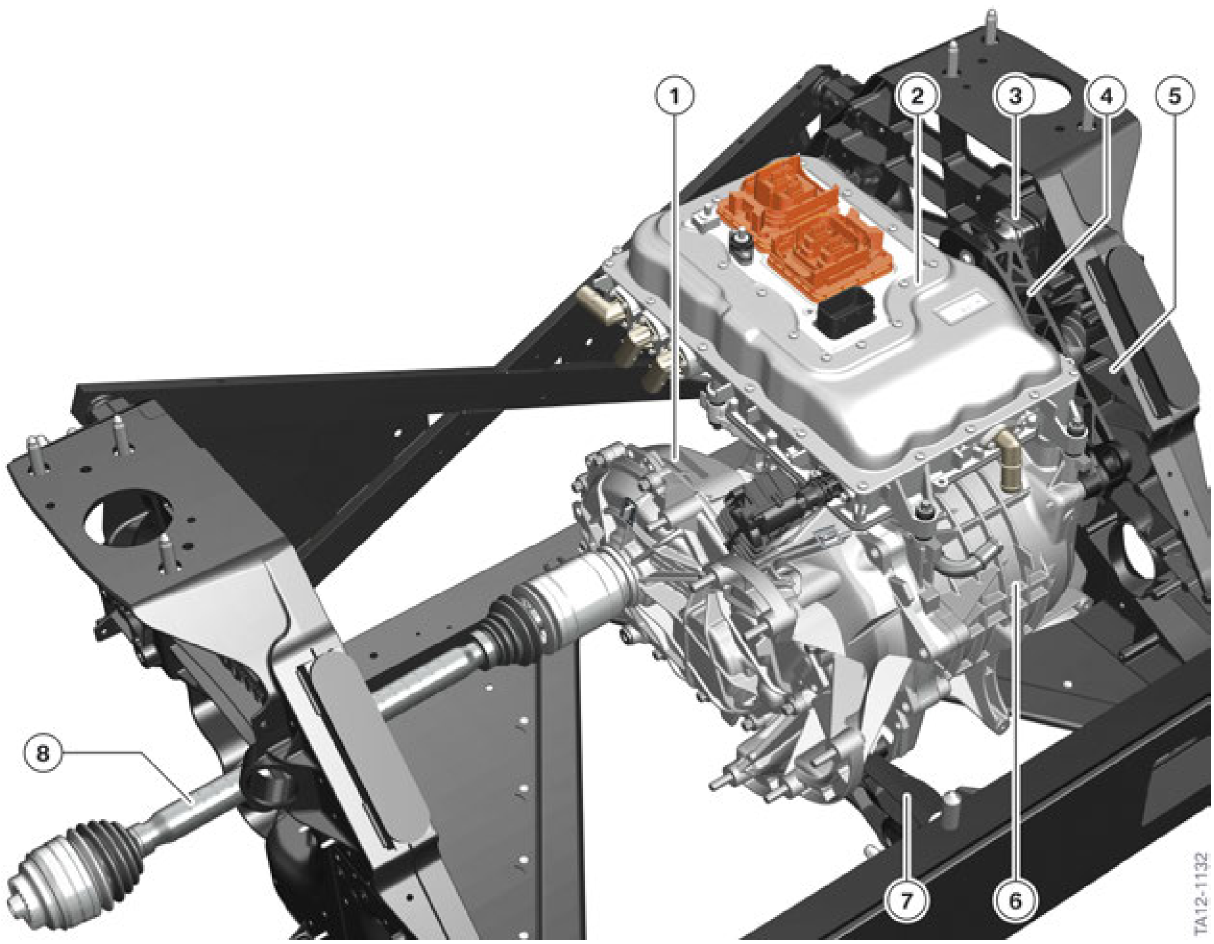
I01 High-voltage Components

3. Electric Motor

The graphics in this document show the electrical machine and the transmission without coating. In the production vehicle sometimes these components are still covered by a foam part. This serves for the acoustic encapsulation of the electric motor and absorbs noises which the customer may find irritating.

The housing of the electrical machine is airtight and waterproof, as the low installation location demands this and to avoid damage by water passing through. However, due to the big temperature differences which may occur during operation there is a need for pressure compensation. This is effected via the shaft used for the electrical connection for the electrical machine electronics.

The mounting and storage is not only related to the electrical machine itself, but also the entire drive unit comprising the electrical machine, transmission and electrical machine electronics.



Mounting and storage of the drive unit (without range extender)

Index	Explanation
1	Transmission
2	Electrical machine electronics
3	Bearing for engine support arm
4	Engine support arm

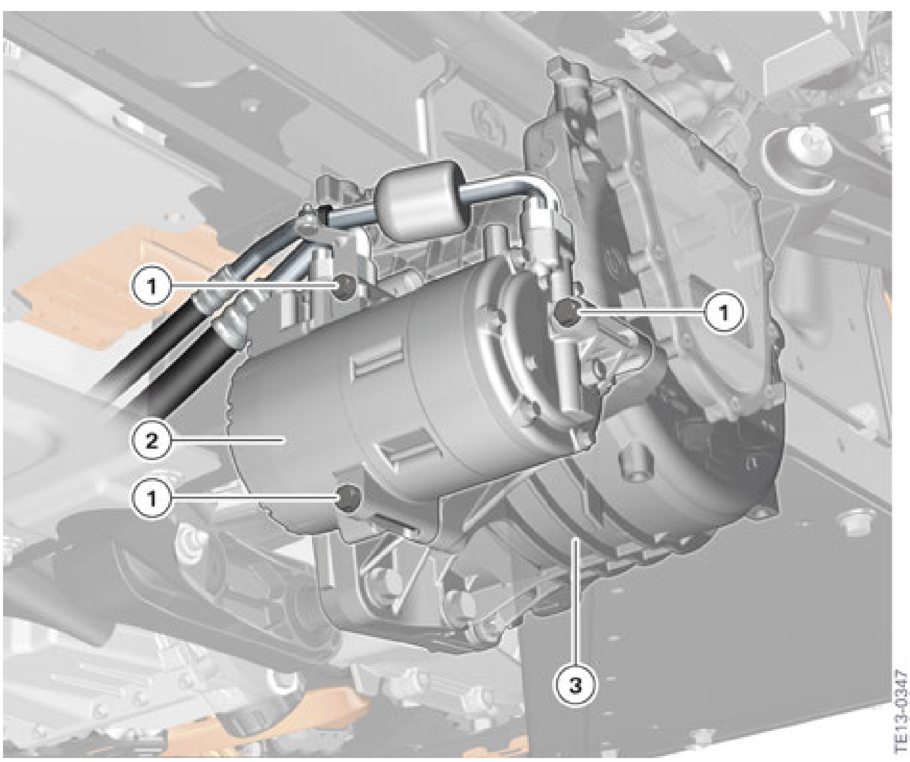
Index	Explanation
5	Rear axle module
6	Electrical machine
7	Anti-roll bar link
8	Output shaft

In the direction of travel on the left an engine support arm connects the housing of the electrical machine to the rear axle module. This engine support arm serves not only to absorb the weight force of the drive unit. Via this engine support arm the drive torque is also transmitted to the rear axle module and ultimately supported at the body. The entire drive unit (electrical machine, electrical machine electronics and transmission) is also connected to the rear axle module via the anti-roll bar link.

⚠

If the electrical machine has to be removed, the entire rear axle must be removed beforehand. This also applies to the removal of the transmission and the electrical machine electronics. Only then can the additional supports be removed from the housings and the individual components also removed.

The EKK is secured to the electrical machine using three screws.



Mounting of the EKK

Index	Explanation
1	EKK
2	Mounting bolts (3x)
3	Electrical machine

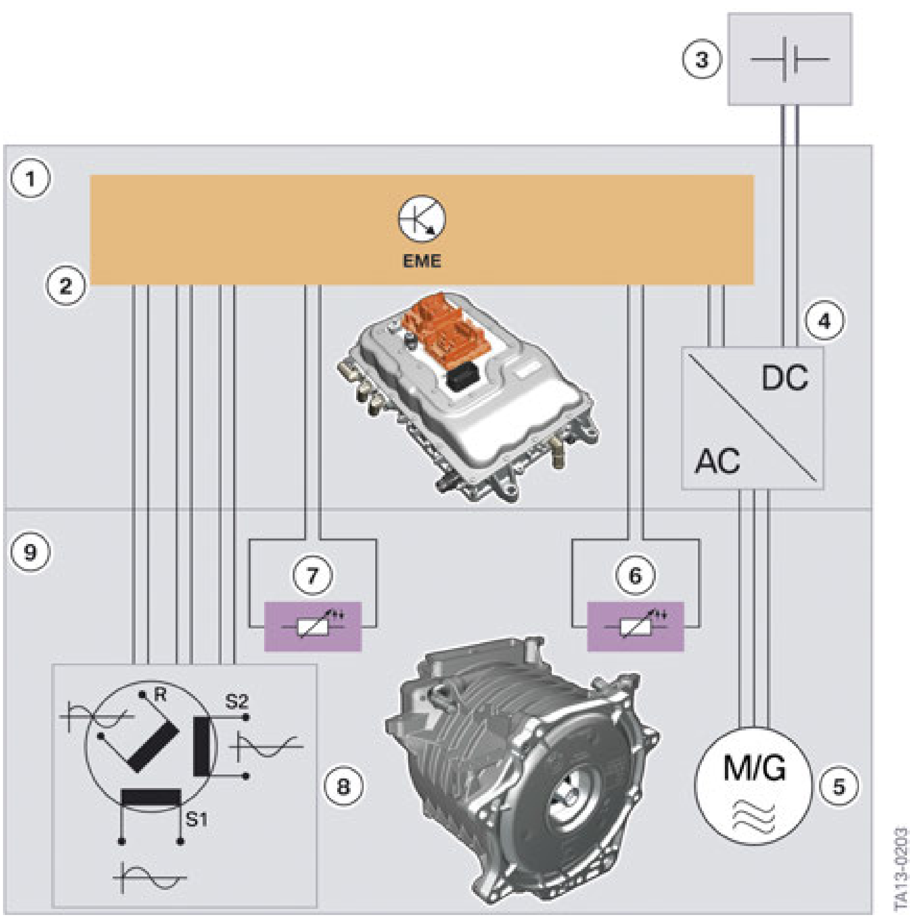
The housing of the electrical machine serves as a mounting and support for the EKK. There are bore holes with threaded inserts at corresponding points on the housing of the electrical machine.

⚠

The threaded inserts for mounting the EKK cannot be replaced!

3.1.5. Electrical interfaces

The electrical machine has electrical interfaces for the electrical machine electronics. The following graphic shows again the electrical interfaces of the electrical machine for the electrical machine electronics.



Electrical interfaces between electrical machine and electrical machine electronics

Index	Explanation
1	Electrical machine electronics (entirety)
2	EME control unit
3	High-voltage battery
4	Bidirectional DC/AC converter
5	Actual electrical machine
6	Temperature sensor in the stator
7	Temperature sensor in the stator
8	Rotor position sensor
9	Electrical machine (entirety)

There is a high-voltage interface and a low-voltage interface. The high-voltage interface is made up of three phases. A bidirectional DC/AC converter in the electrical machine electronics generates three-phase AC voltage, which is transmitted to the coils in the stator of the electrical machine. With this the electrical machine is controlled and its operating mode – as an engine or alternator – is specified. The electrical lines or connections are screwed and concealed under a lid.

The low-voltage interface consists solely of the signal lines of the following sensors:

- Temperature sensors of stator coil (2x)
- Temperature sensor of rotor (at a bearing)
- Rotor position sensor.

The electrical machine electronics measures the electrical resistance of the two temperature sensors, which are designed as negative temperature coefficients, and thus determines the temperatures at the two locations in the electrical machine. In addition, the electrical machine electronics generates AC voltage for the rotor position sensor and evaluates the signals of this sensor (two induced AC voltages). The electrical connection consists of a plug connection, which is concealed under the same lid as the high-voltage connection.

3.2. Transmission

3.2.1. Introduction

The transmission of the I01 must fulfil the following tasks:

- Transmission of engine speed and torque from the electrical machine to the output shafts
- Engine speed adjustment between the two output shafts or sprockets
- Securing the vehicle against rolling away.

To fulfil these tasks the transmission contains the subcomponents listed below:

3. Electric Motor

- Transmission gearing with two spur gear units (central transmission)
- Differential integrated in the transmission housing
- Electromechanically operated parking lock.

As the electrical machine offers a large usable engine speed range, the transmission of the I01 also only has to provide one gear, i.e. a fixed gear ratio. A combustion engine cannot deliver torque when the engine speed is zero. Unlike the electrical machine of the I01: Its high torque is already available when the engine speed is zero meaning a clutch in the transmission of the I01 is not required – not for driving off or for shifting gears.

Gear selector switch I01

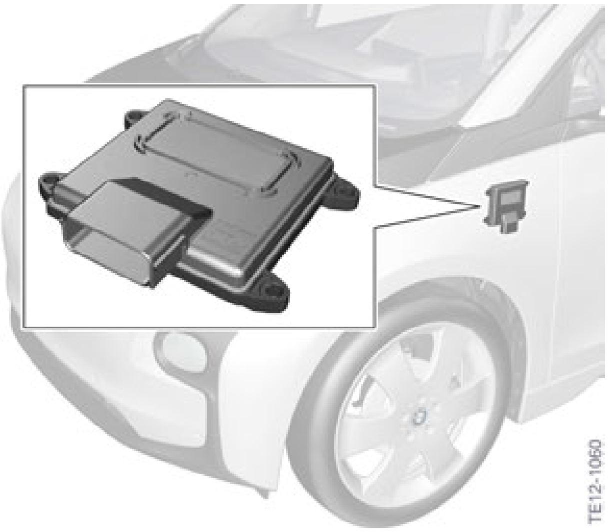
The transmission in the I01 is operated using a mono-stable rotary gear selector switch. The gear selector switch offers the option of selecting the familiar drive positions "P", "N", "R", "D". The drive positions are shown as a shift pattern with auxiliary lines. The current drive position is highlighted.

The following table shows how the individual drive positions are realized.

Drive position	Status of parking lock	Activation of the electrical machine
Parking P	Engaged	De-energized
Neutral N	Disengaged	De-energized
Reverse R	Disengaged	Engine/Alternator with direction of rotation for reversing
Drive D	Disengaged	Engine/Alternator with direction of rotation for forwards travel

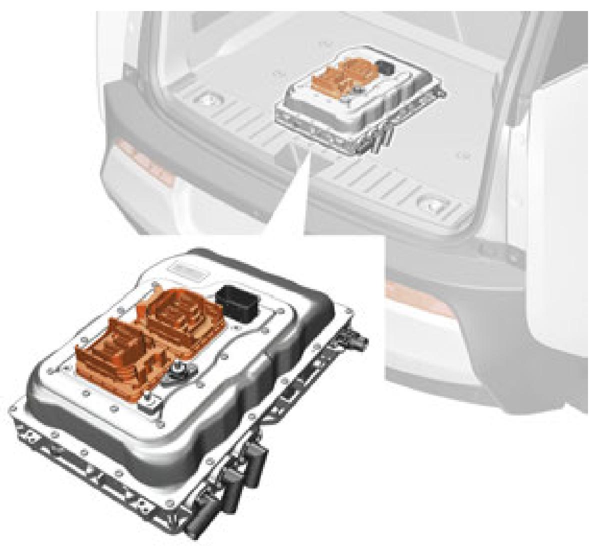
Two control units are responsible for engaging and disengaging the parking lock.

3. Electric Motor



Electrical Digital Motor Electronics EDME

The EDME control unit contains the logics, i.e. the preconditions when the parking lock is to be engaged or disengaged. Via the PT-CAN the EDME control unit sends the corresponding commands to the electrical machine electronics.



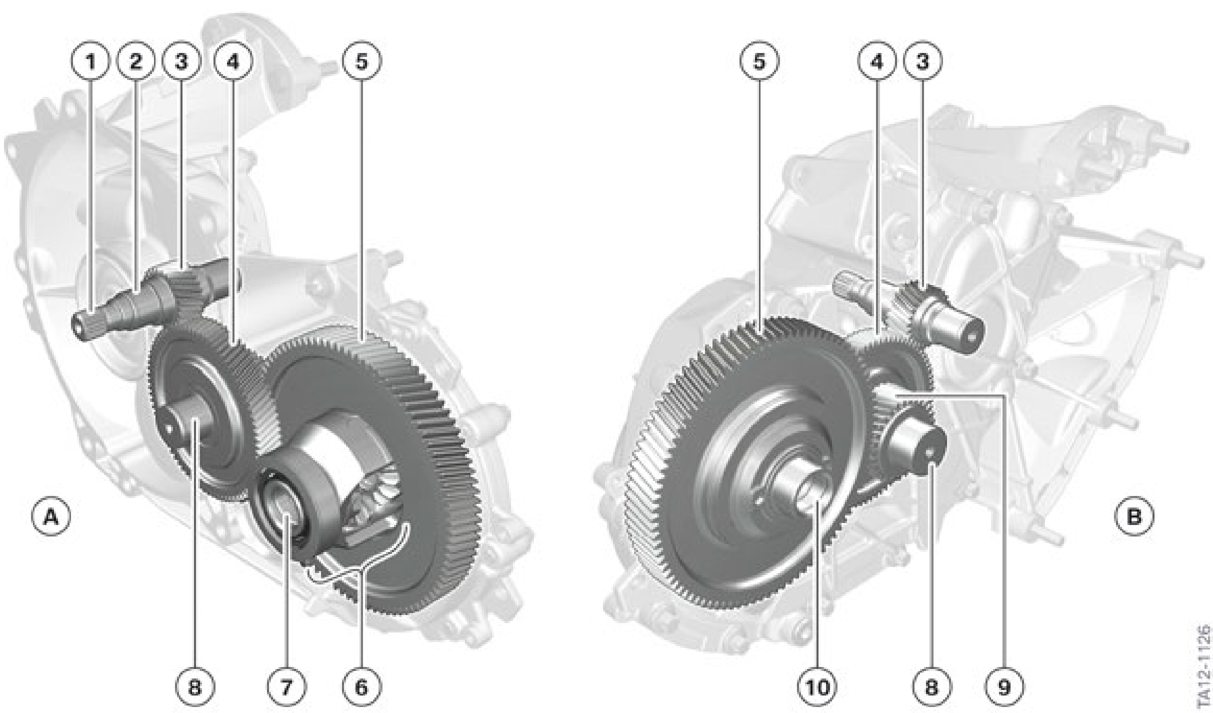
Electrical machine electronics (EME)

The EME control unit activates the parking lock actuator directly. It behaves similarly with the function of the other drive positions "R" and "D". Also here the EDME control unit calculates the logic part. The electrical machine electronics is responsible for the implementation, for example to activate the electrical machine for reversing or forwards travel. Finally, the transmission of the I01 also offers the functions shift lever interlock and interlock, whose logic part is also calculated in the EDME control unit (see section "Shift-by-Wire function").

3.2.2. Transmission

The transmission of the I01 was developed by the BMW Group and its being produced in the BMW plant in Dingolfing.

The transmission has an overall ratio of 9.7:1. The engine speed at the transmission input is 9.7 times greater than at the transmission output. This ratio is realized using two spur gear units. In addition to the input shaft, there is also an intermediate shaft in the transmission. The spur gear unit at the transmission output is fixed to the differential cage and drives the differential. The differential distributes the torque to two outputs and enables the engine speed adjustment between the two outputs. The differential has an almost identical design to that of a front axle differential, as used in BMW vehicles with a four-wheel drive (front axle differential 156). For use in the I01 only surface hardening measures and a high-strength material are used.

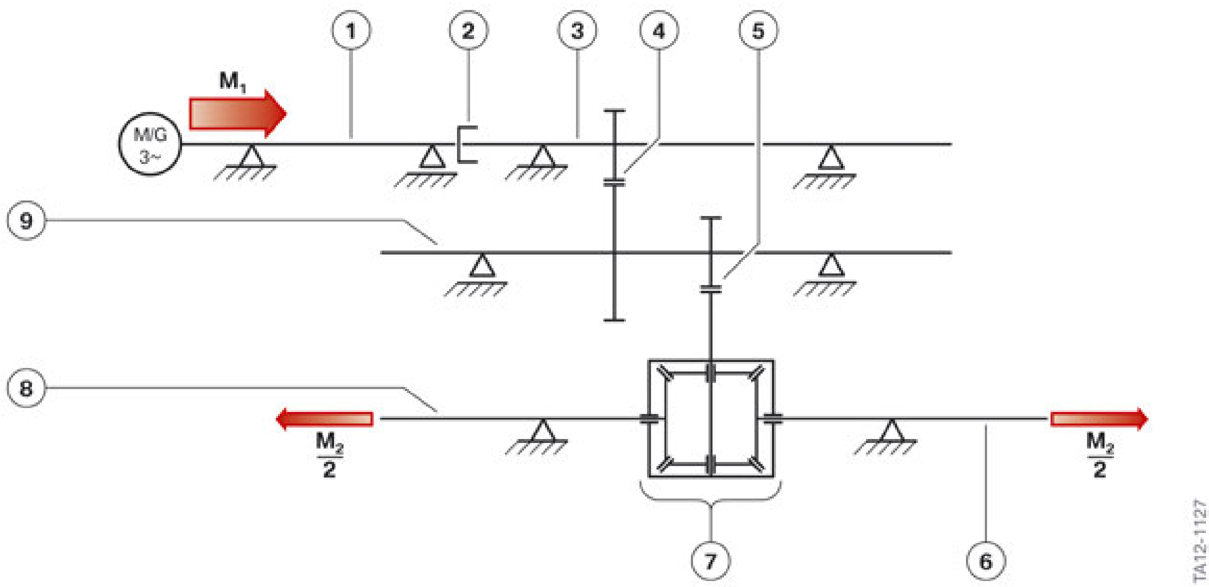


Structure of the transmission

Index	Explanation
A	View from rear left
B	View from rear right
1	Geared shaft as connection for the drive shaft of the electrical machine
2	Transmission input shaft
3	Spur gear unit 1 at input shaft
4	Spur gear unit 2 at intermediate shaft
5	Spur gear unit 4 at transmission output
6	Differential

Index	Explanation
7	Connection for output shaft, left
8	Intermediate shaft
9	Spur gear unit 3 at intermediate shaft
10	Connection for output shaft, right

The following skeleton graphic is a simplified diagram and shows the torque transmission in the transmission.



Skeletal graphic for transmission

Index	Explanation
M1	Torque of the electrical machine = Transmission input torque
M2	Transmission output torque
$M_2/2$	Drive torque at an output shaft
1	Drive shaft of the electrical machine
2	Positive connection between electrical machine and transmission
3	Transmission input shaft
4	Combination of spur gear unit 1 and 2
5	Combination of spur gear unit 3 and 4
6	Output shaft, right
7	Differential
8	Output shaft, left
9	Intermediate shaft

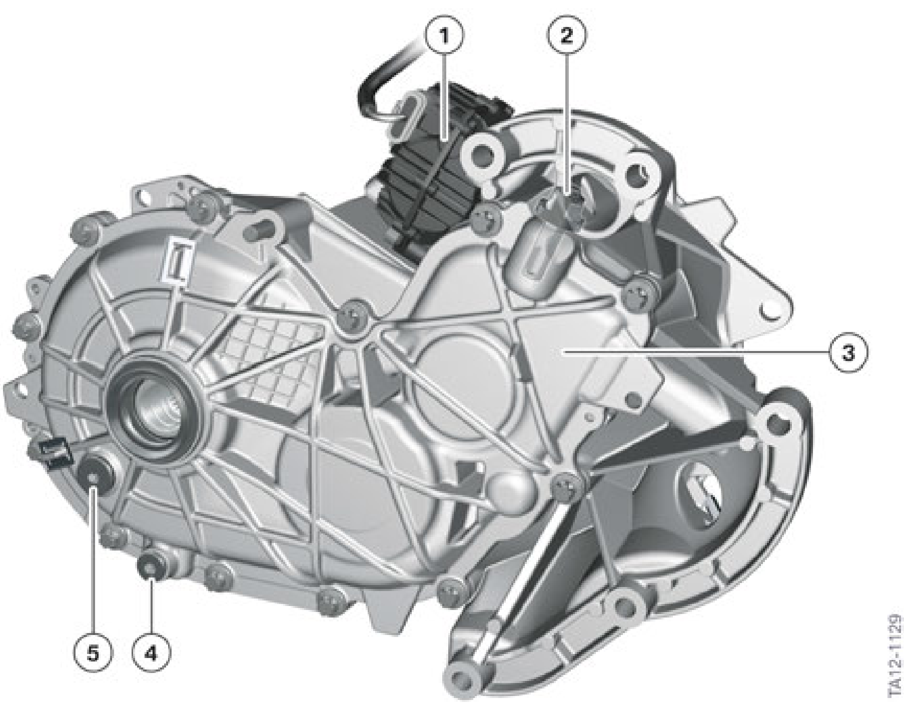
An axle transmission oil known from conventionally driven BMW vehicles is used as transmission oil (manufacturer designation, e.g. Castrol BOT-448). The transmission housing is also used as an oil sump and holds the full capacity of 0.5 l transmission oil. The spur gear units and the differential run in the transmission oil and ensure the entire transmission is lubricated (oil sump lubrication). The transmission oil is designed for the operating life of the I01 meaning there is no need for a replacement of the transmission oil. Nevertheless, there is an oil drain plug, as well as an oil filler plug, with which the oil level can also be checked. These are shown in a graphic in the chapter "Mechanical interfaces".

The transmission is not integrated in the cooling system of the electric motor and therefore has no connections for coolant lines. The heat in the transmission which arises during operation is low. Sufficient heat is discharged via the air flowing by at the transmission housing and the connection for the electrical machine. The temperature in the transmission remains in a range up to a maximum 120 °C, for which the components and the transmission oil are designed. The transmission can, however, also absorb significantly lower temperatures: When driving off after a long immobilization period the components have the ambient temperature. As a result of the large temperature range excess pressure or a vacuum would occur in a completely tight housing. To avoid this there is a bleeding hole above at the transmission housing. It has a cap to protect against dirt contamination. The bleeding hole is also shown in a graphic in the chapter "Mechanical interfaces".

3.2.3. Mechanical interfaces

Mounting and torque support

The mounting and support of the drive torque is not only related to the transmission, but also the entire drive unit comprising the electrical machine, transmission and electrical machine electronics. The weight force and drive torque are transmitted to the rear axle module via engine support arm and anti-roll bar link and from there to the body.



Components of the transmission visible from the outside

3. Electric Motor

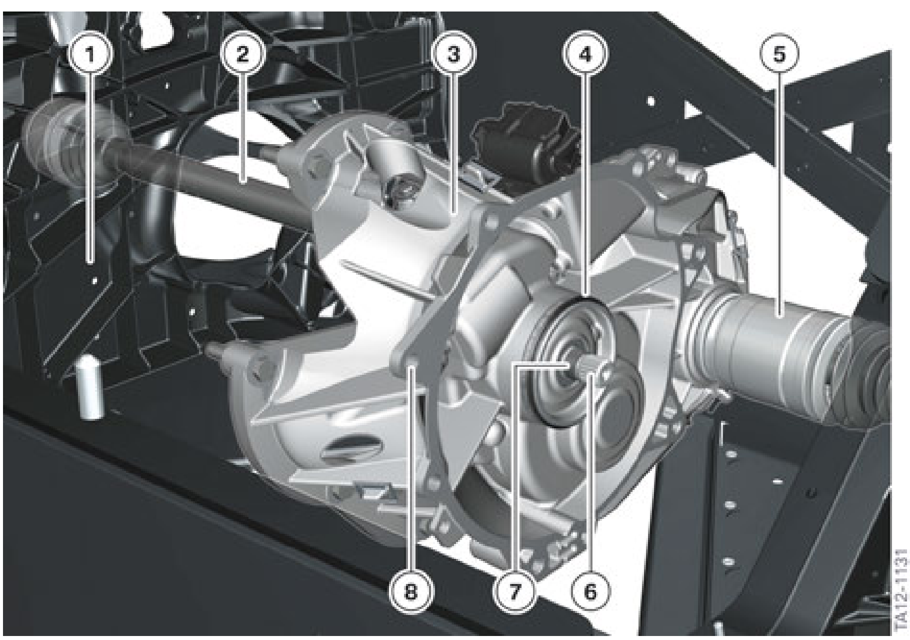
Index	Explanation
1	Parking lock module
2	Ventilation opening
3	Transmission housing
4	Oil drain plug
5	Fluid filler plug

Interface for the electrical machine

The torque is transmitted via a positive connection from the drive shaft of the electrical machine to the transmission input shaft. For this purpose, both shafts have gearing. However, there is no intended centring for the two shafts.

⚠

When joining the transmission and the electrical machine the procedure described in the repair instructions must be followed. Ensure axial alignment of the transmission input shaft and output shaft to avoid distortion during assembly. In addition, the two gearings must be greased before joining. Do not exceed the specified quantity of grease!



Mechanical interfaces of the transmission

Index	Explanation
1	Rear axle module
2	Output shaft, right
3	Transmission housing
4	X-sealing ring

Index	Explanation
5	Output shaft, left
6	Transmission input shaft with gearing
7	O-ring seal
8	Bore holes for the mechanical connection with the electrical machine

⚠

The O-ring seal and the X-sealing ring must be replaced after a disconnection of the transmission from the electrical machine!

Water and dirt may penetrate the cavity within the transmission housing which can be seen in the graphic. This is not a problem for the transmission – however, water and dirt must be prevented from entering the electrical machine from there. For this purpose, the sealing ring marked in the graphic, which has the letter "X" in the cross-section, is used.

There is another sealing ring on the transmission input shaft. It seals the hub space of the electrical machine, which is filled with grease. With the sealing ring the grease filled during installation remains in the hub space and ensures the lubrication during the entire service life of the vehicle.

Ring-shaped through-holes arranged on the transmission housing hold the aluminium screws for connecting the housing of the transmission and the electrical machine.

⚠

The aluminium screws must be replaced after disassembly!

Interface for the output shafts

The output shafts are connected in the outputs of the differential. The torque is transmitted by the positive connection (gearing) between the output shafts and the differential. A radial shaft seal, as known from conventional BMW vehicles, seals the oil chamber of the transmission.

Covers

The graphics in this document show the electrical machine and the transmission without its covers. In the vehicle sometimes these components are still covered by a foam part. This serves for the acoustic encapsulation of the electric motor and absorbs noises.

3.2.4. Parking lock

Introduction

The parking lock is responsible for securing the vehicle against rolling away, just like in a conventional vehicle with automatic transmission. Even on steep inclines/downhill gradients up to 32% the parking lock is able to safely hold the I01 at a standstill. Nevertheless, just like for conventional vehicles it is recommended to also secure the vehicle against rolling away using the parking brake.

3. Electric Motor

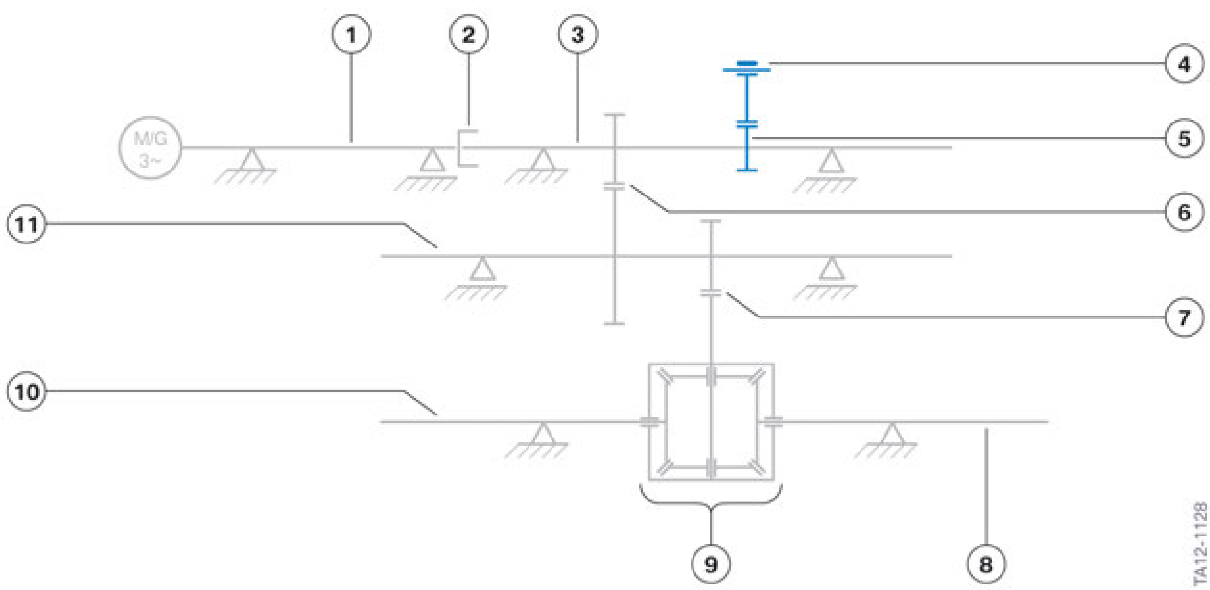
The driver can engage the parking lock in the I01 using the P button at the gear selector switch. It is, however, automatically engaged and under the same conditions known from BMW vehicles with an electronic gear selector switch. For example, the parking lock is automatically engaged when it is detected that the driver has left the vehicle (driver's door open, seat belt open and the pedals not operated). In contrast to conventional vehicles, there is a further precondition, where disengaging the parking lock in the I01 is not possible. This precondition prevents the driver taking off unintentionally as long as a charging cable is connected.

⚠

The parking lock of the I01 cannot be disengaged if a connected charging cable is identified.

Structure and operating principle

The parking lock comprises an electromechanical part (parking lock actuator) and a mechanical part (parking lock pawl and parking lock gear) in the transmission housing. The mechanical part functions at the transmission input shaft, as highlighted from the following transmission skeleton and sectioning.

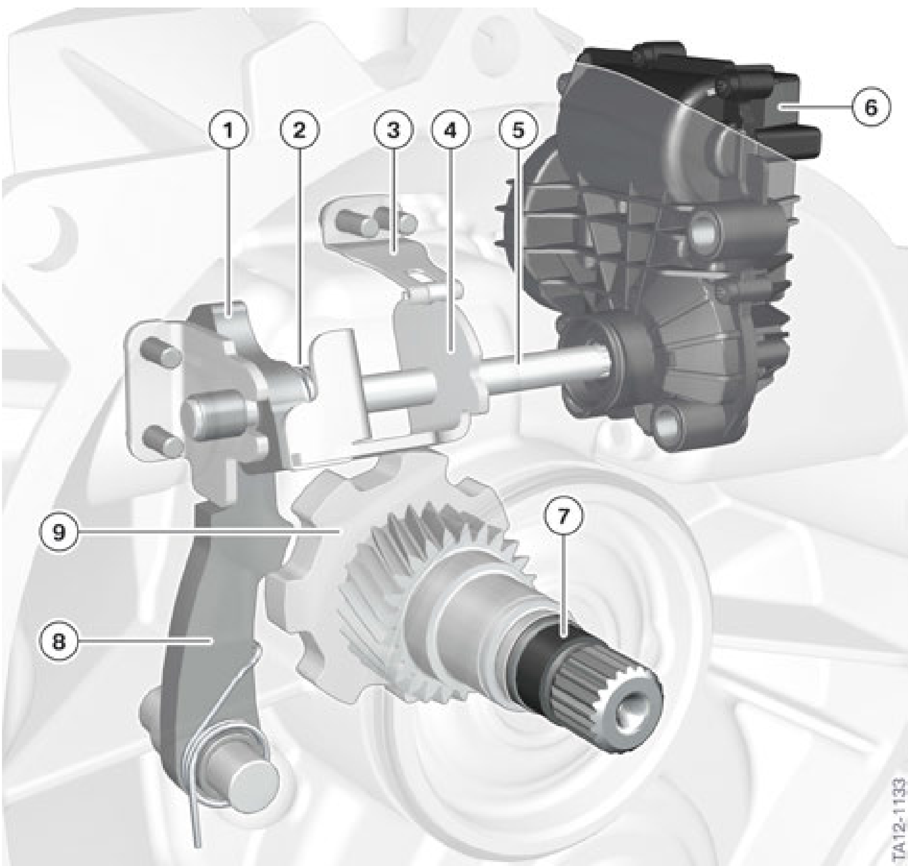


Position of the parking lock in transmission skeleton

Index	Explanation
1	Drive shaft of the electrical machine
2	Positive connection between electrical machine and transmission
3	Transmission input shaft
4	Parking lock pawl
5	Parking lock gear
6	Combination of spur gear unit 1 and 2
7	Combination of spur gear unit 3 and 4

3. Electric Motor

Index	Explanation
8	Output shaft, right
9	Differential
10	Output shaft, left
11	Intermediate shaft



Structure of the mechanical part of the parking lock

Index	Explanation
1	Bar
2	Return spring
3	Fixing element
4	Cam disc with two locking positions
5	Relay shaft
6	Parking lock module
7	Transmission input shaft
8	Parking lock pawl with return spring
9	Parking lock gear

3. Electric Motor

The parking lock module functions at a driving shaft. At the end of the driving shaft there is a bar which is turned about 70 degrees by the revolution of the driving shaft. As a result, the parking lock pawl is inserted into the parking lock gear and the transmission input shaft is blocked. By resetting the bar the parking lock pawl is released again, pulled from the parking lock gear by the return spring and the transmission input shaft is unlocked. The driving shaft is held in the two positions, "engaged" and "disengaged", by a fixing element. The fixing element locks into the respective recesses at the cam disc. The rod cannot be moved from these positions by movements or forces from the transmission. Both positions are stable without the supply of auxiliary power. It is also said:

⚠

The parking lock of the I01 is bi-stable. This means it requires external energy in order to change the condition of the parking lock.

Energy is required for both disengaging and engaging the parking lock. In BMW vehicles with a conventional engine and automatic transmission energy is only required for disengaging the parking lock.

The actuator of the parking lock is a direct current electric motor with gear/worm wheel transmission and two position sensors. All these parts are located in the housing and form one unit. The parking lock module is secured using three raised head Torx screws on the transmission housing and for now is not replaced in BMW Service.

⚠

The parking lock module is connected to the parking lock via a multi-tooth connection of the actuator/driving shaft at the transmission interface. **Attention:** The vehicle must be secured against rolling away by other measures (e.g. by operating the parking brake or positioning a wedge).

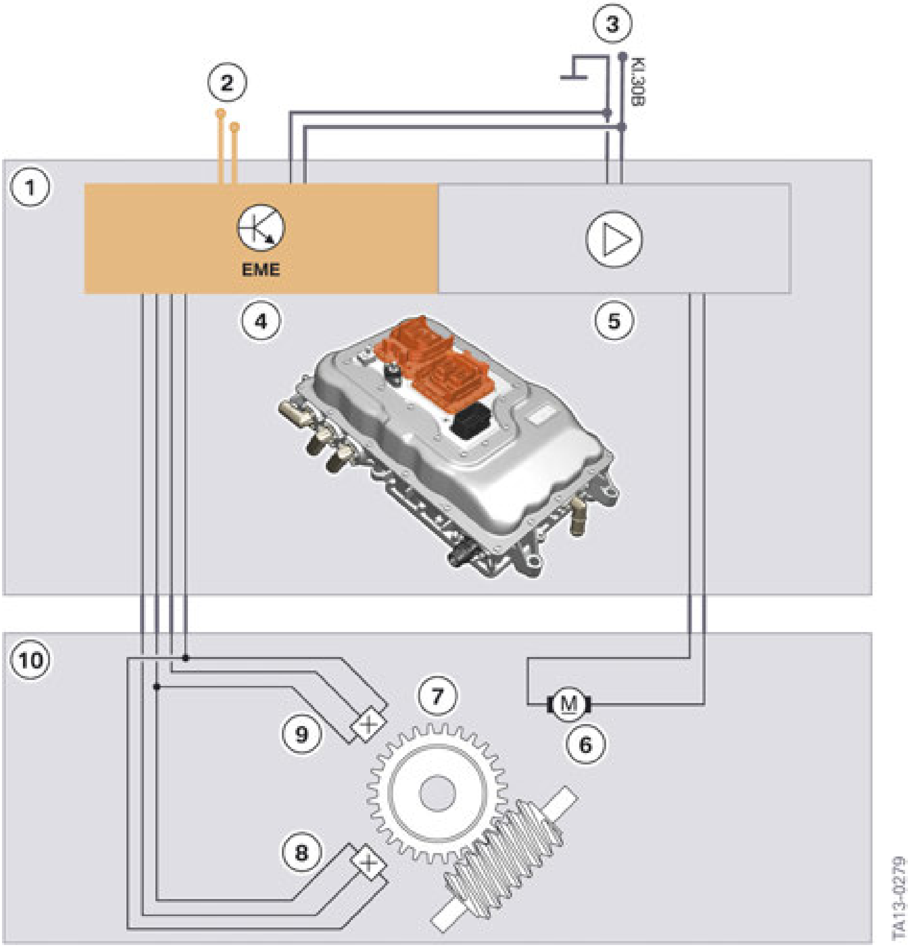
The electric motor in the parking lock module is activated directly by an output stage in the electrical machine electronics. The output stage is current-limited to protect against damage by a short circuit. In order not to overload the electric motor, the power consumption is also measured and a current limitation performed in the software of the electrical machine electronics.

The electric motor is supplied with current until the position sensors display that the parking lock has adopted the desired condition. The position sensors work according to the hall-effect principle and record the movement in the transmission of the parking lock module. As the function of the parking lock is relevant for safety, two redundant position sensors are used to achieve the requested reliability. If a sensor signal fails due to a fault, an active engaging or disengaging procedure can be completed as a result of the redundancy. The position sensors generate signals which are evaluated by the electrical machine electronics.

As the position sensors record the movement of the electric motor in the parking lock module and not the movement of the actual parking lock mechanics, an initialization has to be performed as a one-off so that a conclusion can be drawn about the condition of the parking lock from the sensor signals.

The following graphic shows the electrical structure of the parking lock module and the electrical connection for the electrical machine electronics.

3. Electric Motor



Electrical interfaces between parking lock module and electrical machine electronics

Index	Explanation
1	Electrical machine electronics EME (entirety)
2	PT-CAN connection
3	Voltage supply
4	EME control unit
5	Output stage for parking lock module
6	Electric motor
7	Transmission of the parking lock actuator
8	First position sensor according to the hall-effect principle
9	Second position sensor working in the opposite direction, also according to the hall-effect principle
10	Parking lock module (entirety)

Service information

The EME control unit performs several self-diagnosis functions in order to ensure the proper function of the parking lock module and to protect the components against damage. These self-diagnosis functions are:

- Monitoring of lines for the electric motor, the position sensors and the solenoids for short circuit against ground and supply voltage, as well as for open circuit
- Monitoring of the current level for the electric motor with regards to the maximum value and plausibility for the signals of the position sensors
- Monitoring of the signals of the position sensors (pulse-width modulated signal in the specified range and plausibility of both signals to each other).

If one of the self-diagnosis functions identifies a fault, in the EME control unit an entry is made in the fault memory which can indicate the fault cause. Depending on the severity of the identified fault the parking lock will either work again or remain in the current position. In each case, however, a fault code entry is generated and the customer is requested by a Check Control message to have the vehicle checked by BMW Service.

If the cause for a malfunction cannot be determined using the fault code entry, the Service employee can perform the following checks and thus pinpoint the cause:

- Check the voltage supply of the electric motor at the output of the electrical machine electronics with a measurement
- Check the wiring harness section for open circuit/short circuit.

The diagnosis system not only supports the Service employee during troubleshooting for the parking lock. The diagnosis system also offers Service functions. The most important Service function is used for the initialization of the parking lock. During the initialization the electric motor in the parking lock module approaches its end positions several times. The signals of the position sensors and also the characteristic of the current level, which the electric motor uses, are observed. The force which the electric motor must apply and also the current characteristic change through the locking positions at the cam disc and the force which the fixing element exerts. The EME control unit uses these values to calculate the positions at which the parking lock is correctly engaged or disengaged. The respective signal values of the position sensors are stored permanently in the EME control unit and are available from this time for the control of the operation of the parking lock.

⚠

The initialization of the parking lock in the I01 using the diagnosis system is necessary if

- the transmission was replaced,
- the parking lock module was replaced or
- the electrical machine electronics was replaced.

If the parking lock module is to be replaced, ensure that the new part is supplied in the position which corresponds to the condition "Parking lock disengaged". Proceed as follows to install the new parking lock module:

1 Secure the vehicle against rolling away using the parking brake

2 Move the driving shaft of the parking lock into the locking position for "Parking lock disengaged", if necessary. by moving 70° anti-clockwise.

3 Install the new parking lock module.

⚠

An emergency operation of the parking lock module is not intended! The I01 cannot be towed away. It can only be transported on a loading platform.

3.3. Drive control

The electric motor of the I01 is a distributed system with a variety of components. This is also discernible in the electronic part, the drive control, because several components (control units) are also involved here. The master role for the control of the electric motor in the I01 is assumed by the engine control. It is modelled after vehicles with a gasoline engine with "Electrical Digital Motor Electronics" EDME.

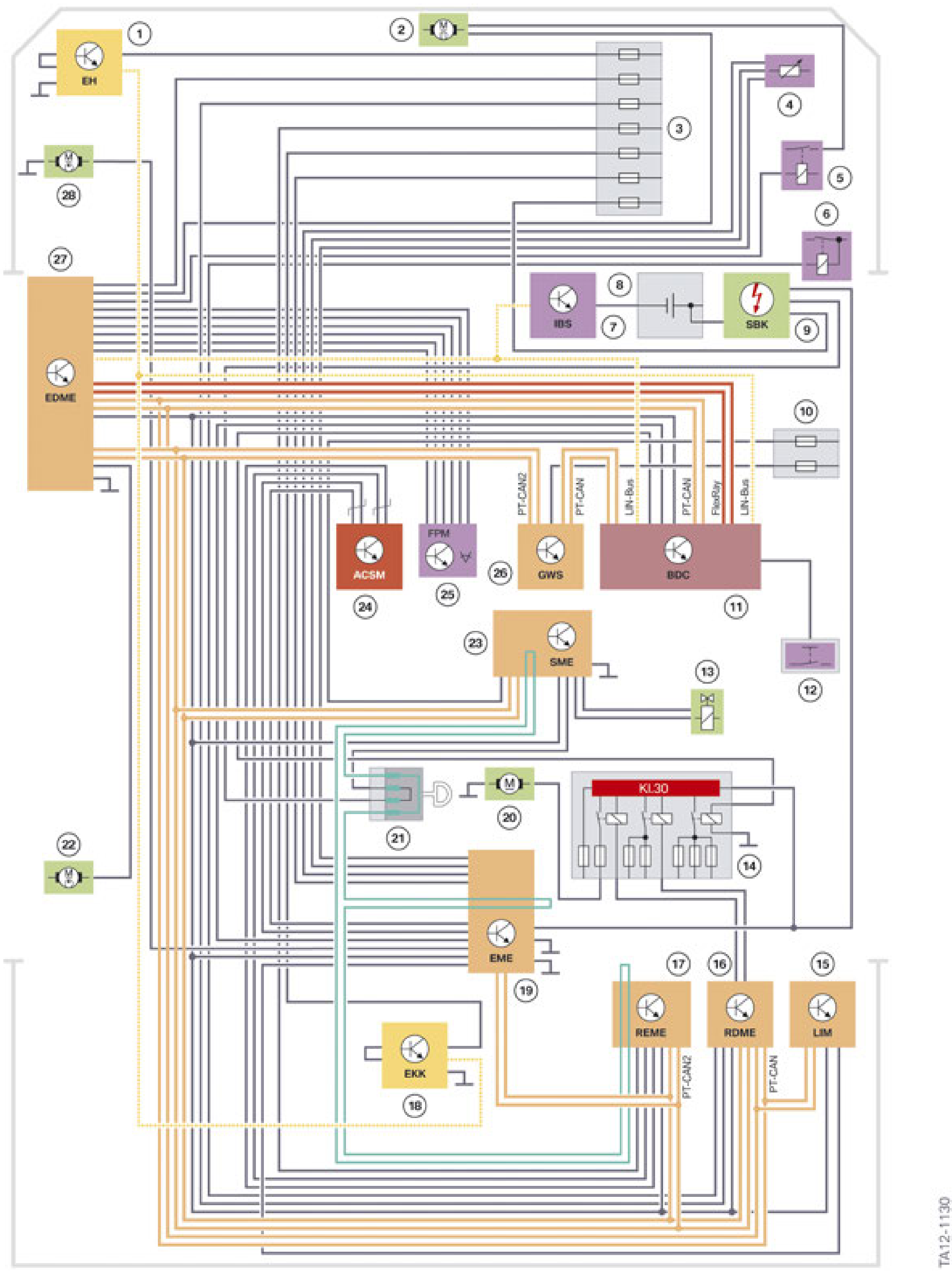
Installation location of the EDME

As the most important partner control unit of the EDME, the electrical machine electronics assumes the activation of the electrical machine and the supply of energy to the low-voltage vehicle electrical system. Other partner control units of the EDME include the battery management electronics SME and the convenience charging electronics KLE.

3.3.1. System overview

The following graphics shows the electrical connection of the key components of the drive control.

3. Electric Motor



System wiring diagram for the drive control

Index	Explanation
1	Electric heating (EH)
2	Electric fan
3	Power distribution box at front in BDC
4	Brake vacuum pressure sensor
5	Relay for switching on the electric fan
6	Fuel pump relay
7	Intelligent battery sensor (IBS)
8	12 V battery
9	Safety battery terminal (SBK)
10	Power distribution box at front in BDC
11	Body Domain Controller (BDC)
12	Driving experience switch
13	Combined expansion and shutoff valve (without heat pump)
14	Integrated supply module
15	Charging interface module (LIM)
16	Range Extender Digital Engine Electronics (RDME)
17	Range Extender Electrical Machine Electronics (REME)
18	EKK
19	Electrical machine electronics (EME)
20	Secondary air pump
21	High-voltage safety connector (Service Disconnect)
22	Electric coolant pump
23	Battery management electronics (SME)
24	Crash Safety Module (ACSM)
25	Accelerator pedal module
26	Electronic gear selector switch (GWS)
27	Electrical Digital Motor Electronics (EDME)
28	Electrical vacuum pump

3.3.2. Functions

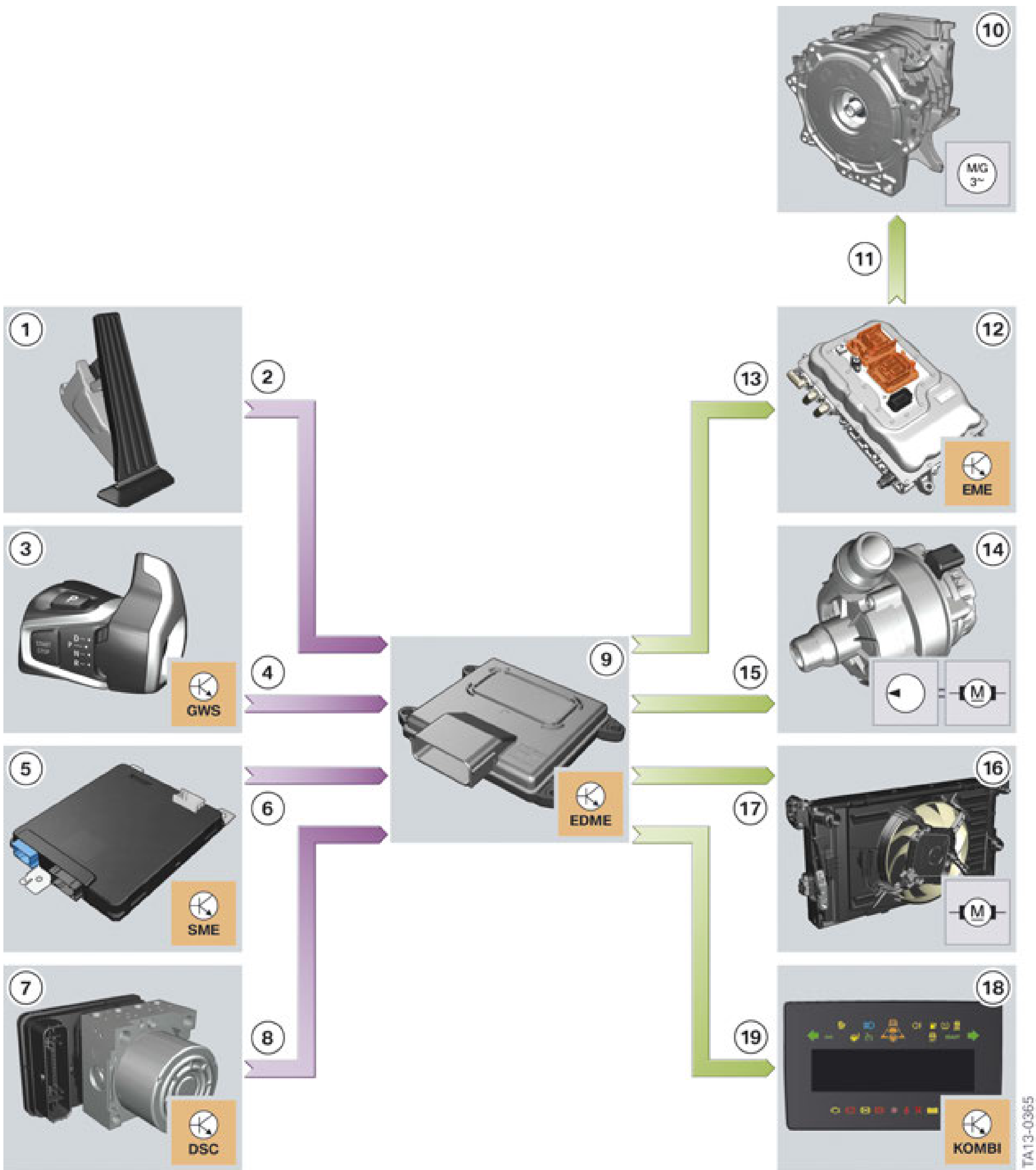
The drive control includes the following primary functions:

- Evaluation of the driver's choice (accelerator pedal)
- Coordination of torque demands
- Operating strategy including behavior in emergency operation

3. Electric Motor

- Activation of the electrical machine
- Heat management
- Evaluation of the electronic gear selector switch (Shift-by-Wire function)
- Power management for the low-voltage vehicle electrical system.

Activation of the electrical machine



Input/Output for the drive control

3. Electric Motor

Index	Explanation
1	Accelerator pedal module
2	Signal, accelerator pedal angle
3	Electronic gear selector switch (GWS)
4	Operating signals of the electronic gear selector switch
5	Battery management electronics (SME)
6	Signals about the state of charge and the available electric power of the high-voltage battery
7	Dynamic Stability Control (DSC)
8	Signals about the dynamic handling characteristics, e.g. the driving speed
9	Electrical Digital Motor Electronics (EDME)
10	Electrical machine
11	Phase voltages for the coils of the electrical machine
12	Electrical machine electronics (EME)
13	Requested drive torque (engine/alternator)
14	Electric coolant pump
15	Power requirement at electric coolant pump
16	Electric fan
17	Power requirement at electric coolant pump
18	Instrument cluster
19	Display information on the condition of the electric motor and Check Control messages in the event of a fault

The upper graphic shows that the EDME control unit acts as a master and coordinator for the primary functions of the drive control.

Before a drive torque is applied, the EDME must check whether the driving readiness is established. The EDME also queries whether all subsystems of the electrical drive train are functioning trouble-free, which is also a prerequisite for the provision of a drive torque. Finally, the EDME still has to consider the available electrical power for the electric motor which is primarily determined by the condition of the high-voltage battery. The SME control unit communicates this condition to the EDME control unit via corresponding bus signals. As a result of these checks the EDME identifies whether and in what scope the drive torque can be provided. In the case of fault statuses or in the event of limited availability, the EDME issues an appropriate Check Control message via the instrument cluster. The functions described here can be summarized under the term "Operating strategy".

An important input signal for the determination of the drive torque is the accelerator pedal angle, which is transmitted via direct wiring from the accelerator pedal module to the EDME. Using this signal the EDME determines the torque request of the driver. The EDME must compare and coordinate this torque request and any other torque requests made at the same time, for example from the cruise control or the DSC. Using this input information the EDME can calculate the actual drive torque required of the electrical machine.

3. Electric Motor

In order to generate the drive torque using the electrical machine, the phase voltages (size, frequency and phase) have to be generated at the coils of the electrical machine. This task is not completed by the EDME itself, but by the electrical machine electronics EME. Via bus signals on the PT-CAN2 the EDME sends the requested drive torque to the EME. The EME control unit then calculates the phase voltages and the power electronics of the EME, which is located in its own housing, generates the phase voltages.

Shift-by-Wire function

Another important function of the drive control is the shift-by-wire function, which evaluates the electronic gear selector switch and other signals, in order to simulate the drive positions of a conventional automatic transmission (P, R, N, D).

The change between the drive positions is achieved in the I01 the same way as in conventional vehicles with automatic transmission and electronic gear selector switch. Some important preconditions and functions are listed below:

- Interlock: Change from P to another drive position only when driving readiness is switched on
- Shift lever interlock: Change from P or N to D or R only when brake pedal is operated at the same time
- Change from P or R to N or D only when selector lever is operated at the same time
- Automatic engaging of P: P is automatically engaged from the other drive positions (at vehicle standstill) if neither the brake pedal or accelerator pedal are operated, the driver's door is open and the driver's seat belt is not inserted in the seat belt buckle. P is also automatically engaged if the driving readiness is switched off
- Car wash function: When the driving readiness is switched on engage drive position N, switch off driving readiness. N remains engaged.

As the transmission of the I01 only has a fixed ratio, there are no gears and thus also no adaptive EGS, no Sport program and also no manual program. The transmission also has no clutch to interrupt or establish the power transmission. There is also no reverse gear in the transmission of the I01. The following table shows how the drive control in the EDME realizes the individual drive positions:

Drive position	Activation of the electrical machine	Actuator for parking lock
Drive D	Direction of rotation forwards, engine or alternator depending on accelerator pedal operation	Disengaged
Reverse R	Direction of rotation reverse, engine or alternator depending on accelerator pedal operation	Disengaged
Neutral N	Direction of rotation is specified by movement direction of vehicle, torque is adjusted to 0 Nm	Disengaged
Parking P	Standstill, torque at 0 Nm	Engaged

The selector level position N is thus not achieved by opening a clutch in the transmission. Instead, the electrical machine is activated so that it neither generates an engine nor alternator torque. One can therefore imagine as if the coils of the stator were open and no voltage is applied from outside. There is in fact voltage, generated by the electrical machine electronics – however, this is adjusted in the amplitude, frequency and phase so that the rotor can rotate without a load (torque 0 Nm).

The difference between the drive positions N and P is solely in the condition of the parking lock module. In N it is disengaged, in P it is engaged.

Power management function

For historical reasons and due to an indirect relation to the drive functions, other functions are integrated in the drive control units, especially in the EDME control unit.

For many years the electrical power management of conventional vehicles has been integrated as a function in the engine control. The evaluation of the 12 V battery state of charge via the IBS and the consumer shutdown are examples for this power management function. This tradition is also continued in the I01: The EDME control unit performs the power management function for the low-voltage vehicle electrical system. The power management in the low-voltage vehicle electrical system includes the following subfunctions:

- Determination of the current energy requirement of the electrical consumers (signals in the form of bus signals, e.g. switch-on status of exterior lights by the Body Domain Controller BDC)
- Determination of state of health, state of charge and charge current/discharge current of the 12 V battery (signals from the IBS)
- Controling the power of the DC/DC converter
- Monitoring of the standby current
- Switch-off of terminals or consumers in order to protect the 12 V battery against heavy discharge.

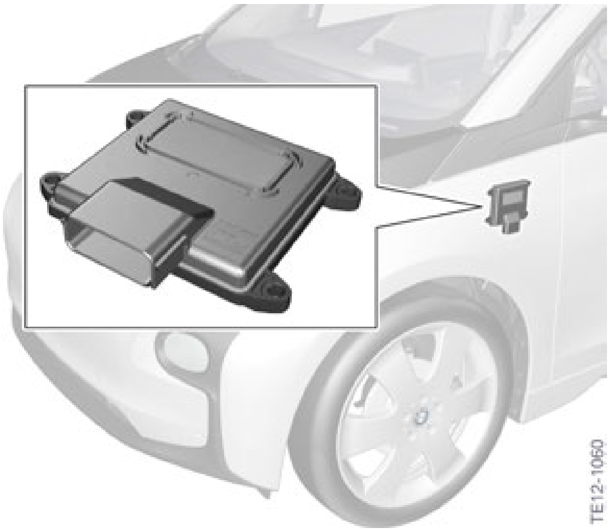
The task of the conventional 12 V alternator is assumed in the I01 by the DC/DC converter in the electrical machine electronics. Depending on the power required, the power management in the EDME requests corresponding power from the electrical machine electronics via bus signals.

3.3.3. Electrical Digital Motor Electronics (EDME)

The designation "Electrical Digital Motor Electronics (EDME)" reflects the electric motor in the I01 (in comparison to the conventional drive with a combustion engine). The manufacturer of the EDME control unit is "Delphi Electronics Group". The manufacturer's internal designation is "DCM 3.8" – this Delphi engine control unit is already used by other vehicle manufacturers and was adapted for the I01 in terms of the electrical interfaces.

The installation location is shown in the following graphic:

3. Electric Motor



Installation location of the EDME

Active cooling of the EDME is not intended as at the installation location there is a significantly lower temperature level as a result of no combustion engine in the I01. The EDME control unit also has considerably fewer output stages in comparison to an engine control for combustion engines and therefore less heat loss occurs in the control unit itself.

The electrical interfaces of the EDME control unit are described in the list below:

- 12 V voltage supply of the EDME control unit (terminal 30B, ground connection)
- Accelerator pedal module with two hall-effect sensors: Supply voltage, ground and sensor output signals with output voltage range of 0 V to 2.5 V and 0 V to 5.0 V
- Brake light switch and brake light test switch: inverse, redundant signals (actuated/not actuated), supply via terminal R
- Local interconnect network bus: Reading of the signals from the IBS and control of the electric coolant pump (cooling circuit between electrical machine/electrical machine electronics and charging electronics)
- Control of the electric fan: The power of the electric fan for cooling the cooling package at the front can be controlled via a pulse-width modulated signal by the EDME. For emergency operation there is a relay with which the electric fan can be switched on at full power by the EDME.
- Body Domain Controller BDC (start enable)
- PT-CAN (no terminating resistor in the EDME)
- PT-CAN2 (no terminating resistor in the EDME)
- FlexRay (terminating resistor in the EDME).

The functions of the drive control are already described in detail in the chapter "Functions". The following list summarizes again the functions which the EDME control unit calculates and performs:

3. Electric Motor

- Torque coordination (driver's choice, assist systems)
- Operating strategy
- Shift-by-Wire
- Low-voltage power management
- Heat management
- Activating the electrical vacuum pump
- Fault management and emergency operation.

4. Electrical Machine Electronics

4.1. Electrical machine electronics (EME)

4.1.1. Introduction

The electrical machine electronics EME serves mainly as control electronics for the electrical machine, which drives the I01. It assumes the task of converting the DC voltage (up to about 400 V DC) from the high-voltage battery into a three-phase AC voltage (up to about 360 V AC) for activating the electrical machine as a motor. Vice versa, when the electrical machine works as an alternator, the electrical machine electronics converts the three-phase AC voltage of the electrical machine to a direct current voltage and can thus charge the high-voltage battery. This takes place during brake energy regeneration. For these two operating modes a bidirectional DC/AC converter is necessary which can work as both an inverter and a rectifier.

The DC/DC converter which is also integrated in the electrical machine electronics ensures the voltage supply to the 12 V vehicle electrical system. The electrical machine electronics has another control unit which bears the same name, "EME" for short.

The entire electrical machine electronics of the I01 is located in an aluminium housing. The control unit of the bidirectional AC/DC converter for the conversion of the AC voltage to direct current voltage for charging the high-voltage battery, as well as conversion of the direct current voltage from the high-voltage battery to 3-phase AC voltage and the DC/DC converter for the voltage supply of the 12 V vehicle electrical system are located in this housing.

⚠

The housing of the electrical machine electronics cannot be opened in Service.

The electrical machine electronics of the I01 is developed and supplied by the relevant departments of BMW AG. The production is carried out in a division of the plant in Dingolfing.

⚠

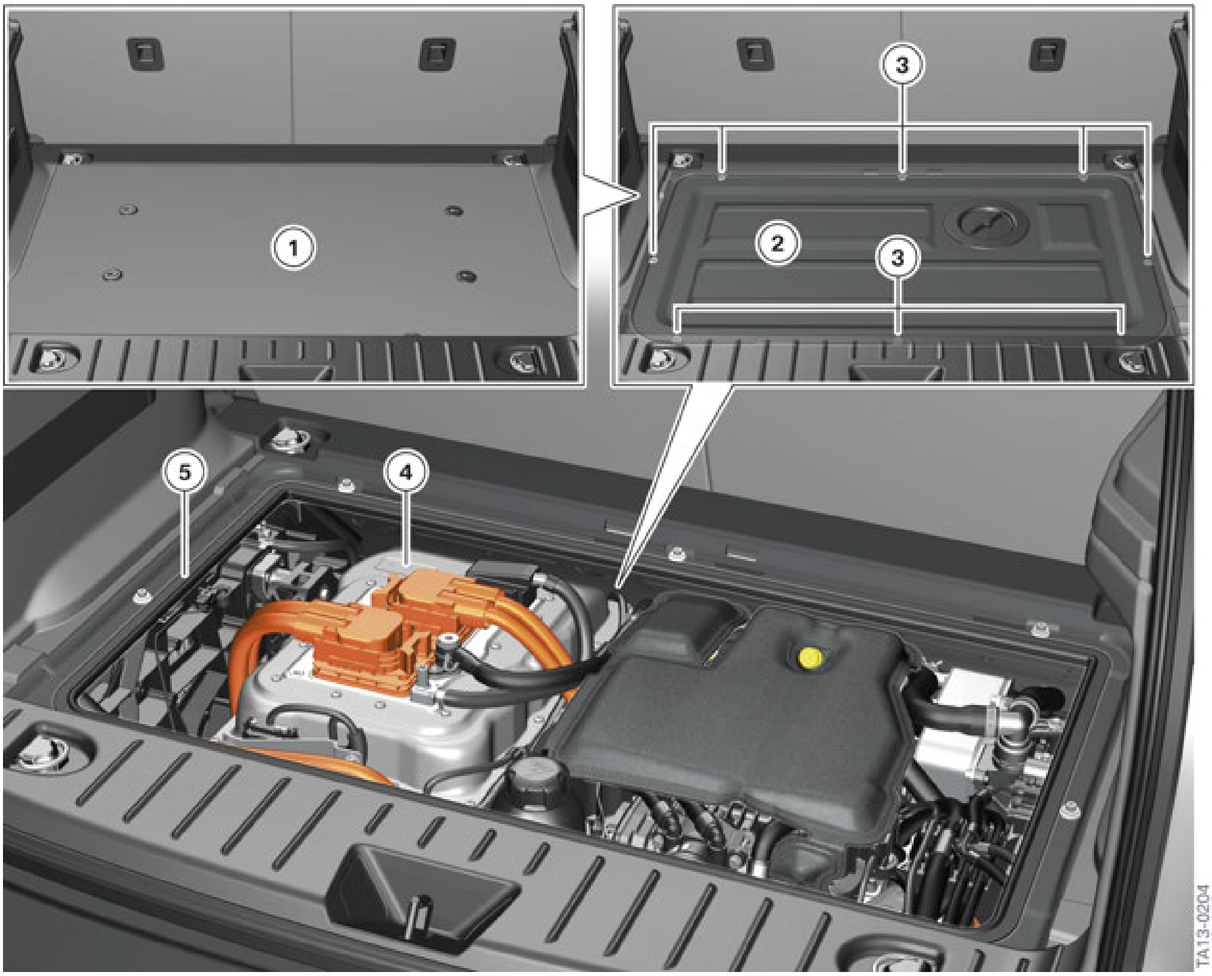
Only Service employees who satisfy all the prerequisites are permitted to work on the designated high-voltage components: suitable qualifications, compliance with the safety rules, procedure following the exact repair instructions.

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

4.1.2. Installation location

The electrical machine electronics is installed in the rear of the I01, in an area separated from the luggage compartment.

4. Electrical Machine Electronics



Access to the electrical machine electronics from the luggage compartment

Index	Explanation
1	Luggage compartment trim panel
2	Cover
3	Mounting bolts of lid
4	Electrical machine electronics
5	Gasket

In order to access the connections of the electrical machine electronics, the part of the luggage compartment panel shown in the graphic must first be removed. A then visible lid must also be removed, thereby creating an opening for Service. The lid is secured to the body using a screw connection and also sealed by a gasket.

The accesses described are not sufficient for the removal and installation of the electrical machine electronics. Instead, the entire drive unit (comprising transmission, electrical machine and electrical machine electronics) must be removed.

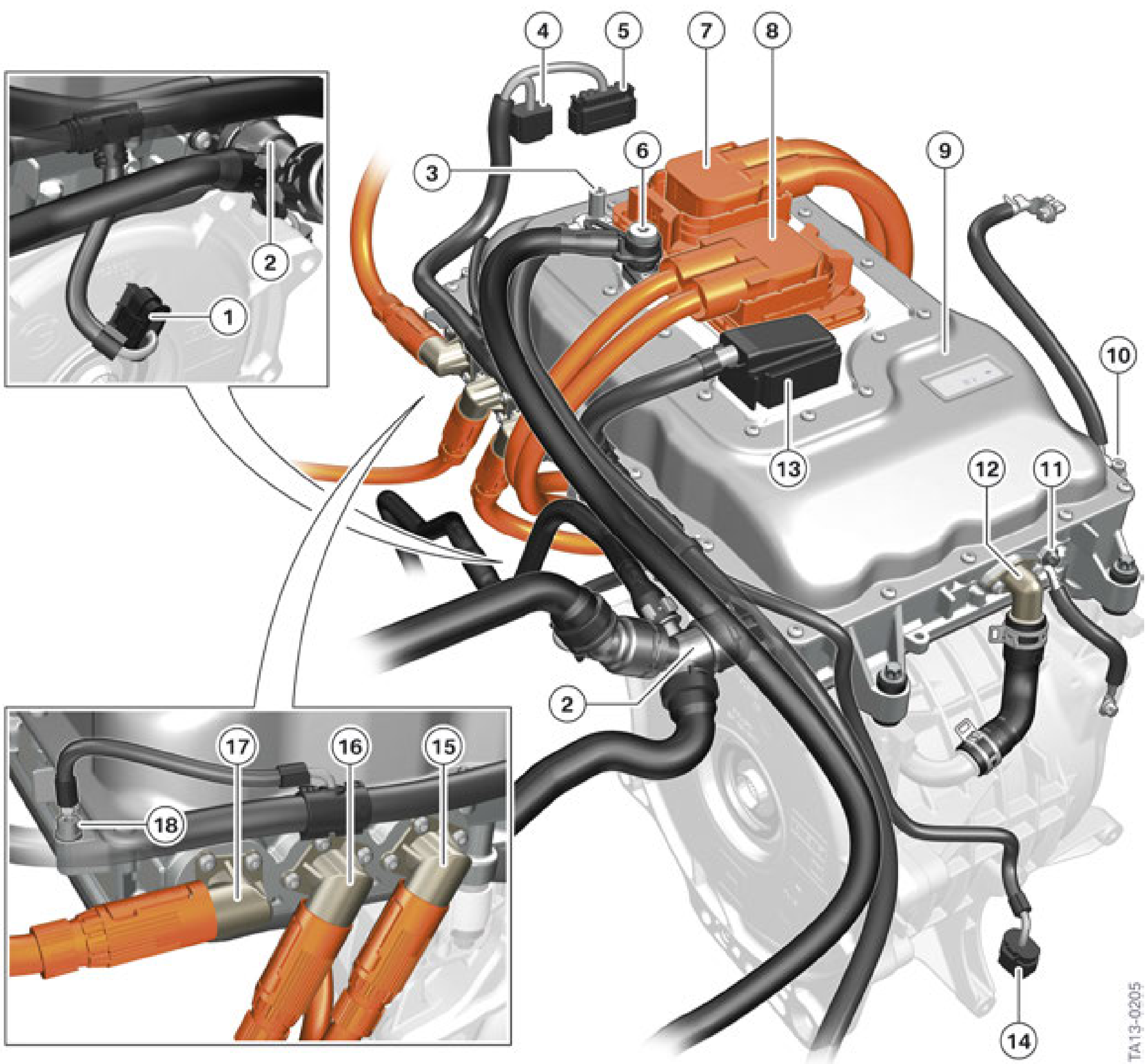
I01 High-voltage Components
4. Electrical Machine Electronics

4.1.3. Connections

The connections at the electrical machine electronics can be divided into four categories:

- Low-voltage connections
- High-voltage connections
- Connections for potential compensation lines
- Connections for coolant lines.

The following graphic shows all connections of the electrical machine electronics. Details of the individual categories are provided in the following chapters.



Connections of the electrical machine electronics with lines

4. Electrical Machine Electronics

Index	Explanation
1	Voltage supply of the electric motor in the parking lock module and signal lines from/to the parking lock module
2	Coolant line (supply, electrical machine electronics)
3	Output, DC/DC converter - 12 V
4	Low-voltage connector
5	Low-voltage connector
6	Output, DC/DC converter +12 V
7	High-voltage cable (DC) for the high-voltage battery
8	High-voltage cable (DC) for the range extender EME
9	Housing of the electrical machine electronics
10	Connection for potential compensation line
11	Connection for potential compensation line
12	Coolant line (return, electrical machine electronics, to electrical machine)
13	Low-voltage connector EME (signal connector)
14	Low-voltage connector EKK
15	High-voltage cable for the EKK
16	High-voltage cable for electric heating
17	High-voltage cable for AC charging
18	Ground connection

Low-voltage connections

In the multipolar low-voltage connector at the electrical machine electronics, which is visible from the outside, the following lines and signals are combined:

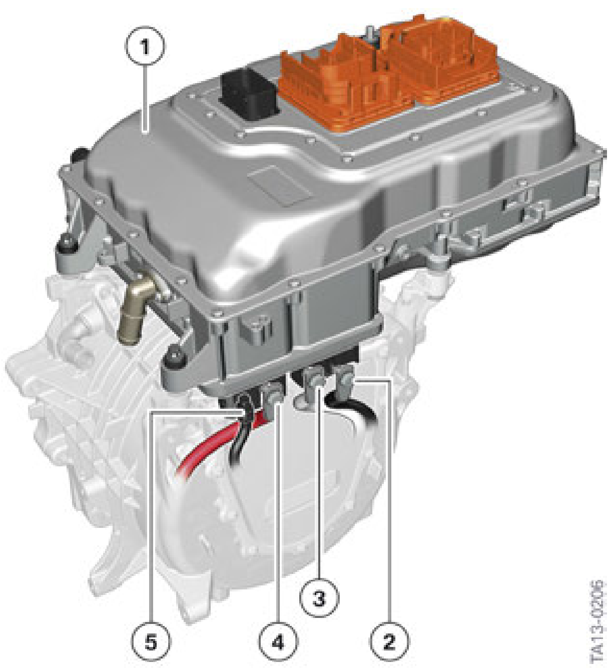
- Voltage supply for the EME control unit (terminal 30B from the power distribution box at the front and ground)
- Terminal 30C from the safety battery terminal (is evaluated by the EME control unit in order to identify an accident)
- Bus system PT-CAN2 (In the EME control unit there is a terminating resistor with 120 Ω for the PT-CAN2)
- Wake-up line
- Control line for the convenience charging electronics to enable the charging procedure
- Input and output of the circuit of the high-voltage interlock loop (EME control unit evaluates the signal and initiates a shutdown of the high-voltage system in the event of an open circuit of the circuit)

4. Electrical Machine Electronics

- Electromechanical parking lock: Voltage supply and signal of the position sensors, voltage supply of the solenoid and the electric motor
- Brake vacuum sensor (supply and evaluation of a pressure-dependent resistance)
- Voltage supply of the electrical vacuum pump.

These lines and signals have relatively low current levels. The electrical machine electronics is connected to the 12 V vehicle electrical system (terminals 30 and 31) via two separate low-voltage connections and lines with large cross-section. Via this connection the DC/DC converter in the electrical machine electronics provides the entire 12 V vehicle electrical system with energy. These two lines are not connected to the electrical machine electronics via a plug connection, but a screw connection.

The connections of the electrical machine electronics to the electrical machine are not visible from the outside. They are located under a lid on the right side of the electrical machine.



Electrical connection of the electrical machine electronics to the electrical machine

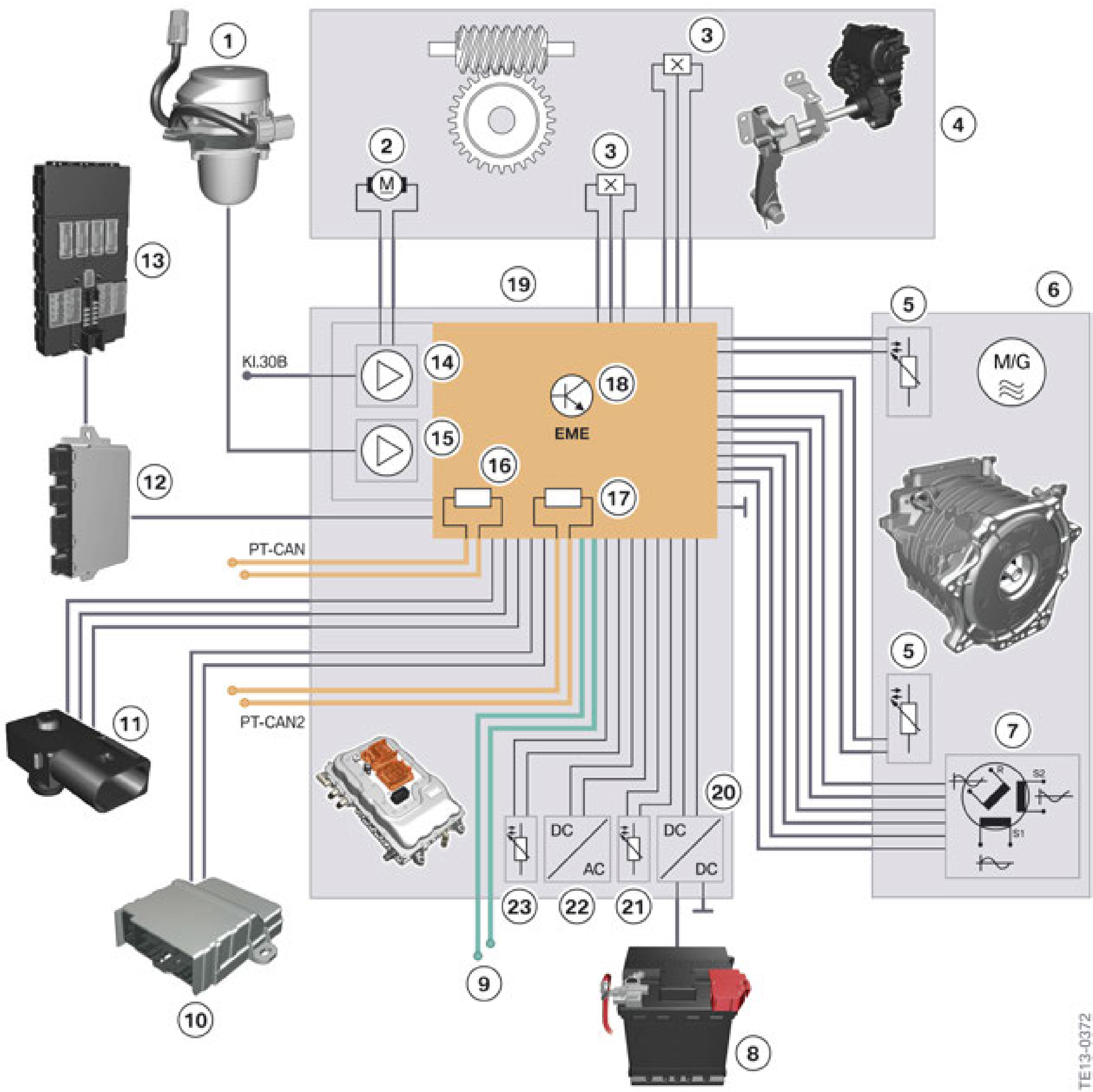
Index	Explanation
1	Electrical machine electronics
2	Screw connection for high-voltage connection, stator coil 1
3	Screw connection for high-voltage connection, stator coil 2
4	Screw connection for high-voltage connection, stator coil 3
5	Low-voltage connector

The screw connections for the supply of the stator coils (high-voltage connections) and a plug connection, via which the following signals are transmitted, are located under the lid:

4. Electrical Machine Electronics

- Rotor position sensor of the electrical machine (supply and sensor signals)
- Signals of the two temperature sensors in the electrical machine.

The following graphic summarizes again the low-voltage connections of the electrical machine electronics in the form of a simplified wiring diagram.



Low-voltage connections of the electrical machine electronics

I01 High-voltage Components
4. Electrical Machine Electronics

Index	Explanation
1	Electrical vacuum pump
2	Electric motor for parking lock
3	Position sensors (hall-effect sensors)
4	Parking lock module
5	Temperature sensors 2 x (negative temperature coefficient)
6	Electrical machine (entirety)
7	Rotor position sensor
8	12 V battery
9	Signal lines of the high-voltage interlock loop
10	Crash Safety Module
11	Brake vacuum pressure sensor
12	LIM
13	Body Domain Controller
14	Output stage for the activation of the parking lock module
15	Output stage for the activation of the electrical vacuum pump
16	Terminating resistor for PT-CAN
17	Terminating resistor for PT-CAN 2
18	EME control unit
19	Electrical machine electronics EME (entirety)
20	DC/DC converter
21	Temperature sensor (negative temperature coefficient) at the DC/DC converter
22	Bidirectional DC/AC converter
23	Temperature sensor (negative temperature coefficient) at the DC/AC converter

High-voltage connections

At the electrical machine electronics there is a total of five high-voltage connections to establish contact between the lines and other high-voltage components:

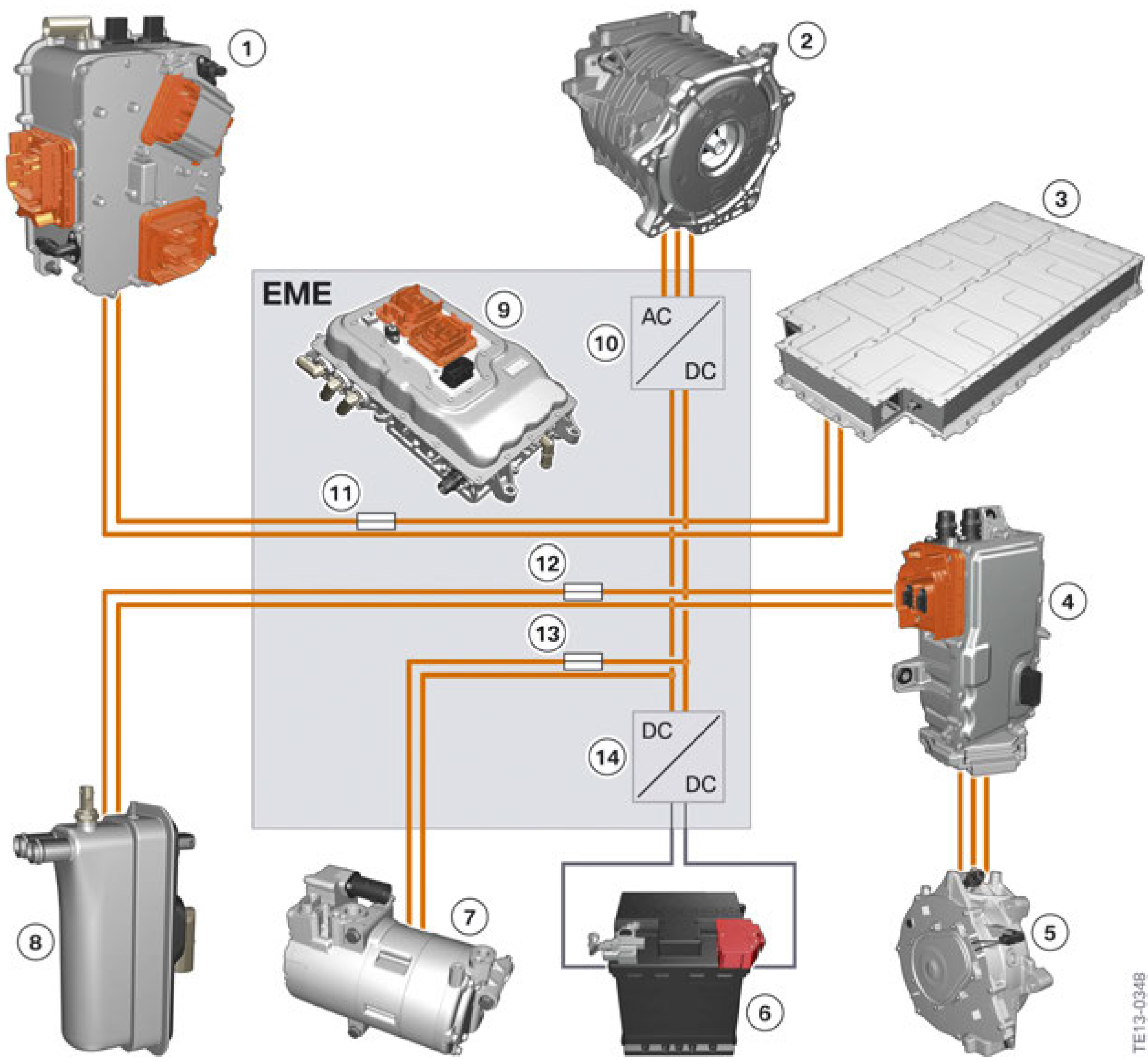
4. Electrical Machine Electronics

Connection to components...	Number of contacts, voltage type, shielding	Type of connection	Contact protection
Electrical machine	- 3-phase - AC voltage - 1 shielding for all 3 lines	Busbars screwed to lines of the electrical machine	Mechanical through lid at electrical machine
High-voltage battery	- Two-pin - Direct current voltage - 1 shielding per line	Flat high-voltage connector with mechanical lock	- Cover over the contact blades - High voltage interlock loop
Convenience charging electronics	- Two-pin - Direct current voltage - 1 shielding per line	Flat high-voltage connector with mechanical lock	- Cover over the contact blades - High voltage interlock loop
EKK	- Two-pin - Direct current voltage - 1 shielding for all both lines	Round high-voltage connector	Cover over the contacts (contact protection)
Electric heating	- Two-pin - Direct current voltage - 1 shielding for all both lines	Round high-voltage connector	Cover over the contacts (contact protection)

The following simplified wiring diagram shows the high-voltage connections between the electrical machine electronics and the other high-voltage components.

I01 High-voltage Components

4. Electrical Machine Electronics



High-voltage connections of the electrical machine electronics

Index	Explanation
1	Convenience charging electronics
2	Electrical machine
3	High-voltage battery
4	Range Extender Electrical Machine Electronics (REME)
5	Range extender electrical machine
6	12 V battery
7	EKK
8	Electric heating
9	Electrical machine electronics (entirety)

Index	Explanation
10	Bidirectional DC/AC converter in the electrical machine electronics
11	Overcurrent fuse in the supply line for the convenience charging electronics
12	Overcurrent fuse in the supply line for the electric heating
13	Overcurrent fuse in the supply line for the EKK
14	DC/DC converter in the EME

4.1.4. Structure and functions

The electrical machine electronics is made up internally of four subcomponents: the bidirectional DC/AC converter, the unidirectional AC/DC converter, the DC/DC converter and the EME control unit. The link capacitors are also an element of the power electronics switching in order to smooth the voltage and filter high-frequency parts.

It performs the following functions with help of the subcomponents mentioned:

- Control of the internal subcomponents by the EME control unit
- Supply of the 12 V electrical system via the DC/DC converter
- Control of the electrical machine (engine speed, torque) using DC/AC converter
- High-voltage power management
- Contacting of the electric motor via busbars
- Contact of the high-voltage battery
- Charging the high-voltage battery when stationary
- Contact of the convenience charging electronics
- Contact of the EKK
- Contact of the electric heating
- Contact of the Range Extender Electrical Machine Electronics
- Communication with other control units, in particular the EDME
- Cooling for electrical machine electronics
- Evaluation of sensors of the electromechanical parking lock
- Activation of the electromechanical parking lock
- Activating the electrical vacuum pump
- Active and passive discharging of the link capacitors to voltages less then 60 V
- Active evaluation of the signal for the high-voltage interlock loop
- Self-test and diagnostic function

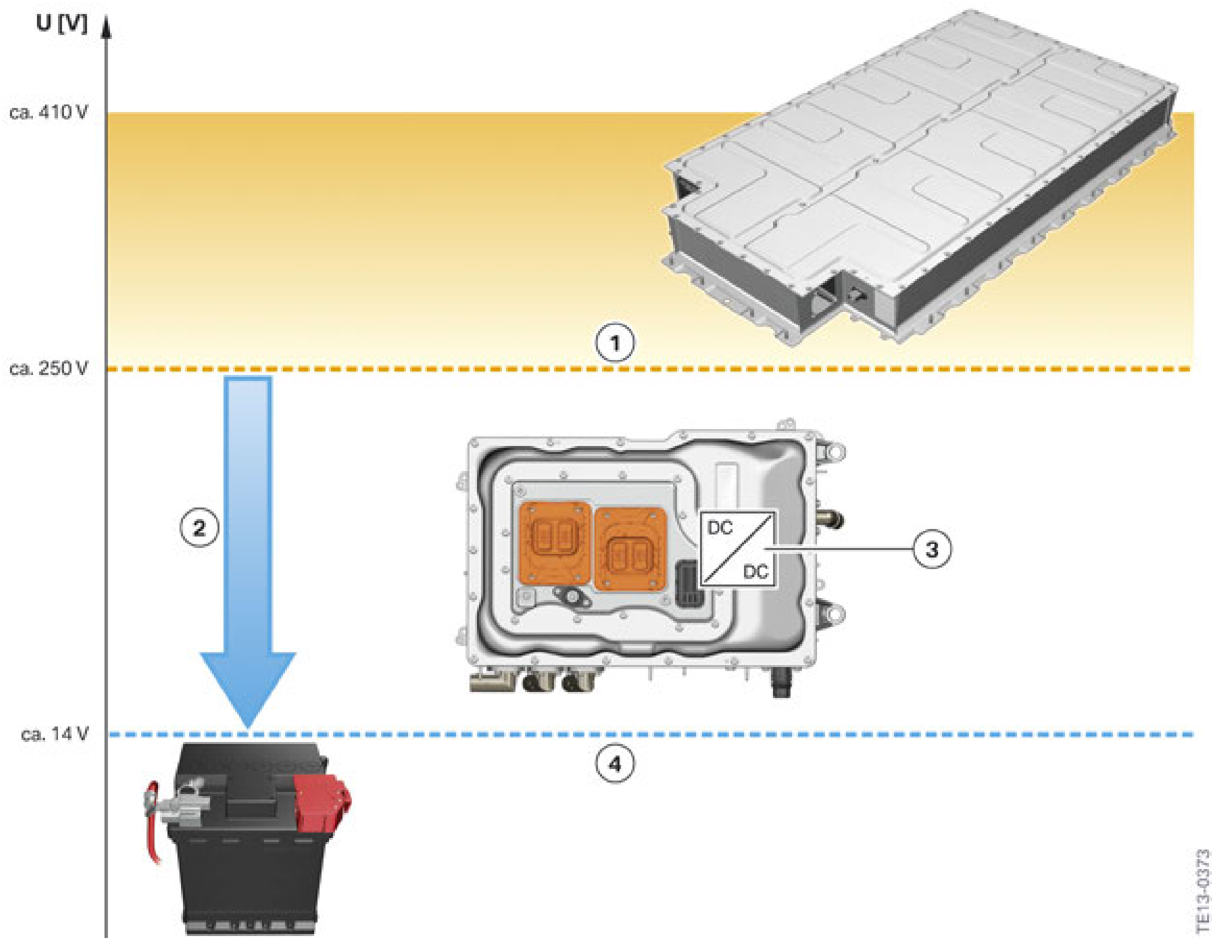
DC/DC converter

The DC/DC converter in the electrical machine electronics of the I01 is also able to adopt the following operating modes:

- Standby (also in the event of a component fault or short circuit, power electronics off)
- Buck mode (Energy flow to the low-voltage side. Converter controls voltage on low-voltage side)
- Discharging the high-voltage link capacitor (interlock fault, accident, request from master).

The DC/DC converter is in "Standby" mode when the electrical machine electronics is not in operation. This is the case when the EME control unit is not supplied with voltage due, for example, to a terminal status. But also if there is a fault the EME control unit prompts the DC/DC converter to assume "Standby" mode. In this operating mode there is no energy transfer between the two vehicle electrical systems and they remain galvanically separated.

Buck mode is the normal operating mode when the high-voltage system is active. The DC/DC converter transfers electrical energy from the high-voltage electrical system to the 12 V vehicle electrical system and assumes the function of the alternator in a conventional vehicle. The DC/DC converter must reduce the varying voltage from the high-voltage electrical system to the voltage in the low-voltage vehicle electrical system. The voltage in the high-voltage electrical system is dependent, for example, on the state of charge of the high-voltage battery (about 260 V to about 390 V). The voltage in the low-voltage vehicle electrical system controls the DC/DC converter so that the 12 V battery is optimally charged and sets a voltage of about 14 V depending on the state of charge and the temperature of the battery. The EME control unit communicates with the EDME control unit, in which the 12 V power management functions are performed. The result is the setpoint value specification for the voltage, which the DC/DC converter should adjust in the low-voltage vehicle electrical system. The continuous output power of the DC/DC converter is 2500 W.

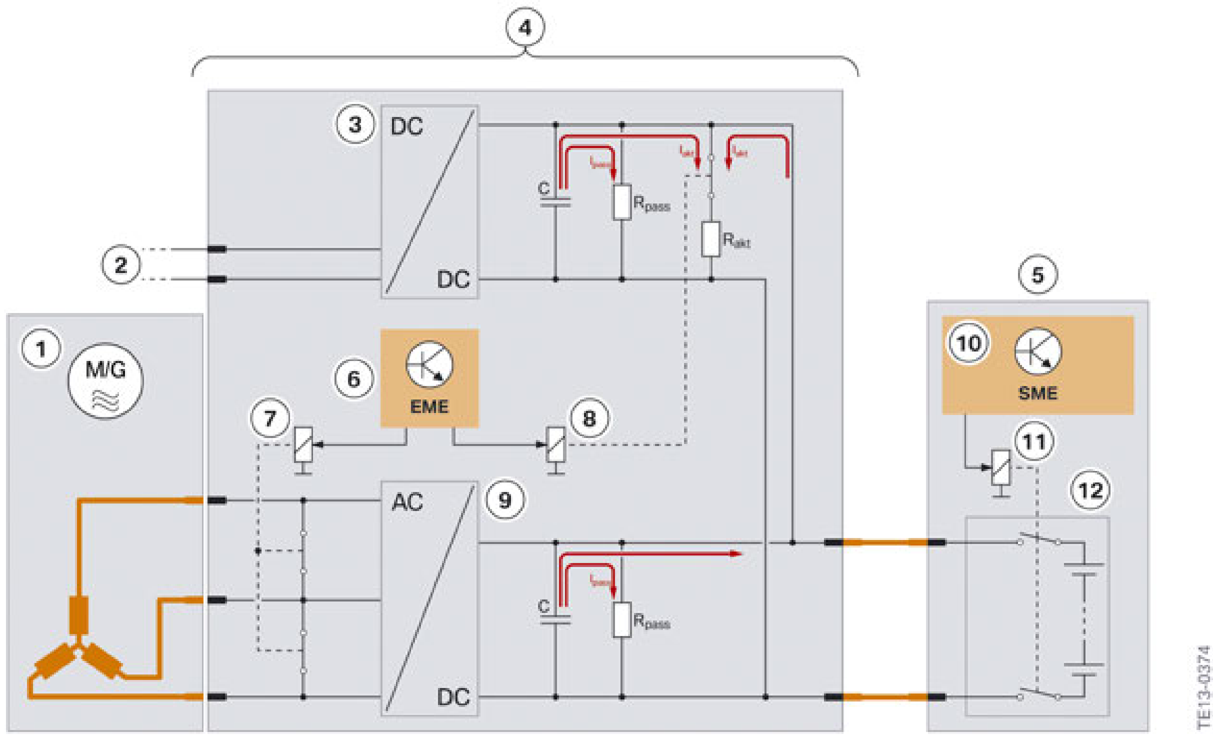


Operating principle of the DC/DC converter

Index	Explanation
1	Voltage of the high-voltage electrical system, about 250 V to about 410 V
2	Down conversion
3	DC/DC converter in the EME
4	Voltage of the low-voltage vehicle electrical system, about 14 V

The technology of the DC/DC converter in the I01 would also enable the operating mode "Boost mode", such as the DC/DC converter in the F04. However, this operating mode is not used in the I01. Charging of the high-voltage battery of the I01 is not possible using energy from the 12 V vehicle electrical system.

The last operating mode of the DC/DC converter is assumed during (regular or quick) shutdown of the high-voltage system. For the shutdown of the high-voltage system the system must be discharged to a safe voltage less than 60 V within a specified time. The DC/DC converter has a discharge circuit for the link capacitors. First of all, these try to transmit the energy stored in the link capacitors to the low-voltage vehicle electrical system. If this does not lead to a sufficiently quick reduction of the voltage, the discharging is effected via an active resistor. This way the high-voltage electrical system is discharged in less than 5 seconds. For safety reasons there is also a so-called passive discharge resistor (switched in parallel). This enables a reliable discharge of the high-voltage electrical system if the first two measures do not work for discharging due to a fault. The period up until the discharge to a voltage below 60 V is longer and is maximum 120 s.



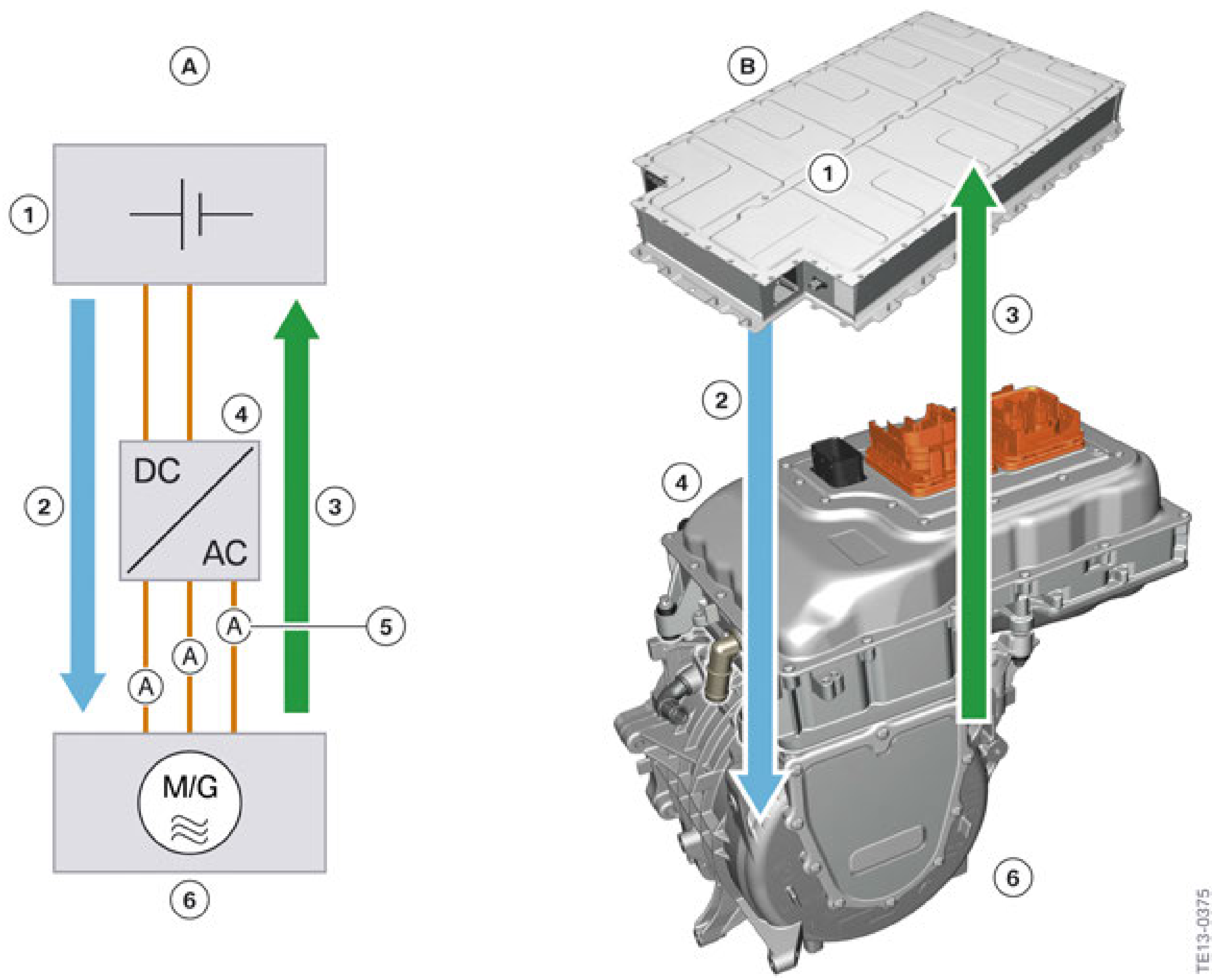
Discharge of the high-voltage link capacitor

Index	Explanation
1	Electrical machine
2	Connection to the 12 V vehicle electrical system
3	DC/DC converter in the EME
4	Electrical machine electronics (entirety)
5	High-voltage battery unit
6	EME control unit
7	Relay for short-circuit of the coils of the electrical machine
8	Relay for active discharging of the capacitors
9	Bidirectional DC/AC converter in the electrical machine electronics
10	SME control unit
11	Electromechanical switch contactor in the high-voltage battery units
12	High-voltage battery
C	Link capacitors
R_{pass}	Passive discharge resistor
R_{act}	Active discharge resistor

The temperature of the DC/DC converter is measured using a temperature sensor and monitored by the EME control unit. If the temperature exceeds the permissible range despite cooling using the coolant, the EME control unit reduces the power of the DC/DC converter to protect the components.

Power electronics for activation of the electrical machine

The power electronics for the activation of the electrical machine are mainly made up of the bidirectional DC/AC converter. It is a pulse converter with a two-pin DC voltage connection and a 3-phase AC voltage connection. This DC/AC converter can work as an inverter and conduct electrical energy from the high-voltage battery to the electrical machine when it should work as an engine. However, it can also work as a rectifier and transfers electrical energy from the electrical machine to the high-voltage battery. This operating mode occurs during brake energy regeneration in which the electrical machine works as an alternator and "generates" electrical energy.



Operating modes of the bidirectional DC/AC converter

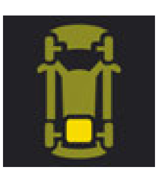
4. Electrical Machine Electronics

Index	Explanation
A	Schematic illustration
B	Schematic diagram with components
1	High-voltage battery
2	Operating mode as inverter, electrical machine works as an engine
3	Operating mode as rectifier, electrical machine works as an alternator
4	DC/AC converter
5	Current sensors
6	Electrical machine

The operating mode of the DC/AC converter is defined by the EME control unit. The EME control unit also receives the setpoint values (essential input variables) from the EDME control unit for which torque (amount and sign) the electrical machine should supply. From this setpoint value and the current operating condition of the electrical machine (engine speed and torque) the EME control unit determines the operating mode of the DC/AC converter, as well as the amplitude and frequency of the phase voltages for the electrical machine. According to these specifications, the power semiconductors of the DC/AC converter are activated in sync.

In addition to the DC/AC converter, the power electronics also contains current sensors in all three phases on the AC voltage side of the DC/AC converter. Using the signals from the current sensor, the EME control unit monitors the electrical power which is used in the power electronics and electrical machine and what torque the electrical machine generates. The control loop of the electrical machine electronics is closed by the signals of the current sensors and the rotor position sensor in the electrical machine.

The performance data of the electrical machine electronics and the electrical machine are coordinated in development. The electrical machine electronics must be able to provide continuous electrical power of 75 kW and supply a maximum power of 125 kW for a short time. In order to avoid overloading the power electronics, there is also another temperature sensor at the DC/AC converter. If an excessive temperature of the power semiconductor is identified using this signal, the EME control unit reduces the power delivered to the electrical machine in order to protect the power electronics. The customer is informed via a Check Control message in the case of a noticeable power reduction. The customer receives the same error response (power reduction) and the same Check Control message if the temperature of the electrical machine exceeds the permissible range.



Check Control symbol for power reduction due to high temperature of electric motor components

High-voltage power management

The power management for the high-voltage electrical system includes two subfunctions: one for driving and one for charging mode. In driving mode the energy flows from the high-voltage battery to the high-voltage consumers are coordinated. The following steps are performed by the EME and repeated constantly:

1 Query of the power available from the high-voltage battery (signal source: SME)

2 Query of the requested power from the electric motor (signal source: EDME)

3 Query of the requested power for climate control (electric heating, EKK, IHKA)

4 Decision on the distribution of the electrical power and communication to the control units of the consumers.

For charging mode the task of the high-voltage power management is different: It controls the energy flow from outside the vehicle via the EME and/or the convenience charging electronics KLE to the high-voltage battery and if required to the electric heating or to the EKK. The procedure constantly repeated in the EME consists of the following individual steps:

1 Query of the available power from outside (signal source: LIM)

2 Query of the power which the high-voltage battery can use (SME)

3 Query of the power which is required for the climate control (IHKA)

4 Requesting the necessary power from the (EME/KLE)

5 Communication of the available partial powers to the receiver of the high-voltage battery (SME control unit) and heating and air-conditioning system (IHKA control unit).

The externally available power cannot be at a high level; it is restricted by the power network and the EME/KLE. Therefore, the available power must be queried first before it can be distributed. The high-voltage battery cannot absorb much power, for example due to its state of charge, which is why this value is also queried first. Depending on the temperature of the high-voltage battery or on a heating or an air-conditioning request by the driver, the heating and air-conditioning system also needs electrical power, whose amount is the third important input signal for the high-voltage power management in the charging mode. Using this information the externally requested power is controlled and distributed to the consumers.

Voltage supply for other high-voltage consumers

The electrical machine electronics supplies voltage not only to the electrical machine. The high-voltage consumers "EKK" and "electric heating" also receive their high-voltage supply from the electrical machine electronics.

However, there is no complex control function in the electrical machine electronics. Instead, the electrical machine electronics serves as a simple distributor of the high-voltage direct current voltage, which is provided by the high-voltage battery. In order to protect the high-voltage cable for the two high-voltage consumers against overloading in the event of a short circuit, the electrical machine electronics contains a high-voltage fuse for the EKK and a high-voltage fuse for the electric heating. Both high-voltage fuses have a nominal current level of 40 A.

The distribution and the electrical connection of the fuses are already shown in the chapter "High-voltage connections".

Activation of the parking lock

The electromechanical parking lock of the I01 including its operating principle and activation is described in detail in the section "Electric motor". Therefore, only the key aspects of the activation are mentioned here. The electrical machine electronics contains the following components required for the parking lock:

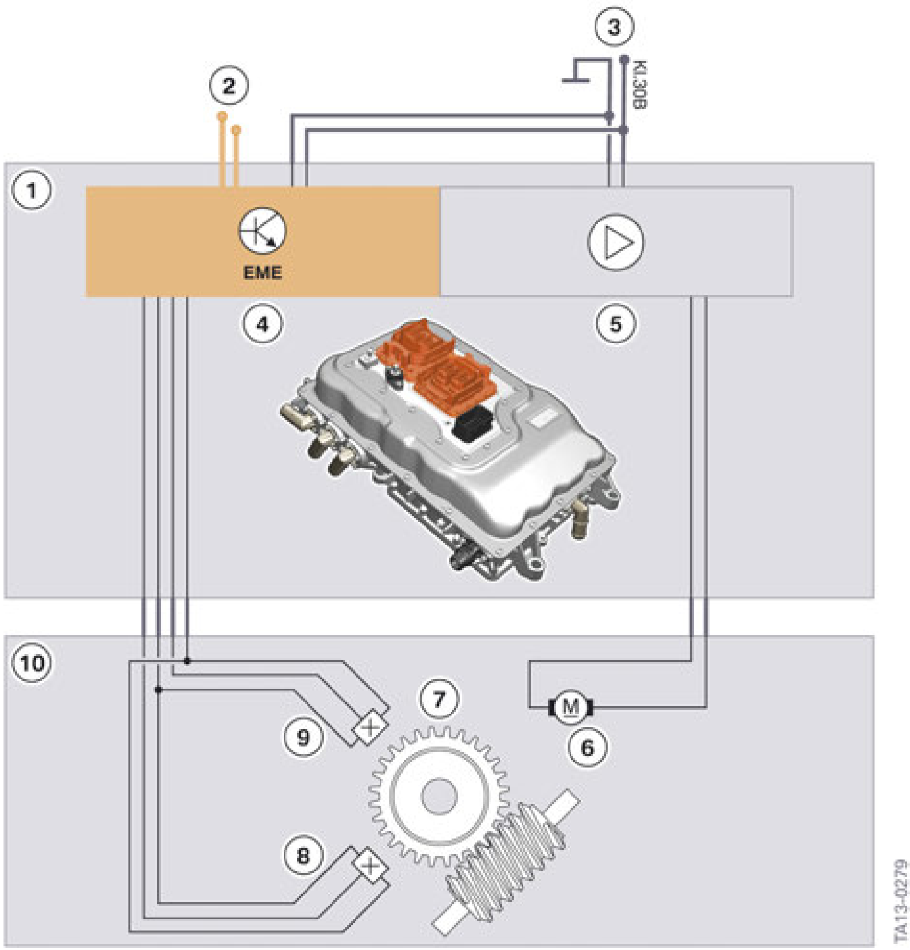
- Output stage for the activation of the electric motor in the parking lock module
- Current sensor for the monitoring of the electric motor
- Evaluation electronics for sensor signals.

The output stage for the activation of the electric motor only comprises one bridge circuit of power transistors. It is able to supply the electric motor with the necessary current of about 3 A to 4 A during the operation, as well as supply the high starting current for the electric motor of up to 10 A. The bridge circuit is designed so that it will not suffer damage in the event of a short circuit at the output (current limitation). In order to protect the electric motor and the line against overloading, the EME control unit monitors the current level of the output stage and also restricts it if required. For this purpose, the output stage contains a current sensor, whose signal is evaluated by the EME control unit.

The two redundant position sensors in the parking lock module are hall-effect sensors. The EME control unit provides the voltage supply for the sensors. It also reads in the signals from the position sensors, validates their plausibility and evaluates them. Using the signals of the position sensors the EME control unit determines the status of the parking lock (engaged/disengaged) and makes the status available as a bus signal. This is read in for example by the EDME control unit where the transmission functions, e.g. engaging the drive positions, are calculated.

The familiar graphic from the chapter "Electric motor > Transmission > Parking lock" shows the electrical interface between the parking lock module and the electrical machine electronics.

4. Electrical Machine Electronics



Electrical interfaces between parking lock module and electrical machine electronics

Index	Explanation
1	Electrical machine electronics (EME)
2	PT-CAN2 connection
3	Voltage supply
4	EME control unit
5	Output stage for parking lock module
6	Electric motor
7	Worm gear
8	First position sensor according to the hall-effect principle
9	Second position sensor working in the opposite direction to the first, also according to the hall-effect principle
10	Parking lock module

4. Electrical Machine Electronics

Activation of the electrical vacuum pump

The electrical machine electronics provides the hardware for the evaluation of the signals of the brake vacuum sensor and for the activation of the electrical vacuum pump. The function logic for the activation of the electrical vacuum pump is located not in the EME control unit, but in the DSC control unit. The EME and DSC control unit exchange sensor signals and the switch-on request for the electrical vacuum pump via bus signals at the PT-CAN and PT-CAN2.

The brake vacuum sensor is mainly known from conventionally driven vehicles with automatic engine start-stop function. Similar to those vehicles, it is also installed in the I01 at the housing of the brake servo.

The sensor is supplied with voltage from the electrical machine electronics and returns a voltage signal depending on the vacuum in the brake servo. This analog sensor signal is converted by the EME control unit to the actual brake vacuum and sent as a bus signal to the DSC control unit.

The DSC control unit evaluates the brake vacuum signal, includes dynamic handling characteristics (e.g. the driving speed) and the accelerator pedal actuation and determines whether the electrical vacuum pump should be switched on. The function logic in the DSC control unit also takes into consideration a hysteresis so that the electrical vacuum pump is not constantly switched on and off. Instead, it remains switched on until a requested minimum level of the brake vacuum is reached. The DSC control unit sends back the switch-on request from the electrical vacuum pump as a bus signal to the EME control unit.

The electrical machine electronics contains an output stage (semiconductor relay), with whose help the voltage supply of the electrical vacuum pump can be switched on and off. Upon request the output voltage of the DC/DC converter can be shifted through directly to the electrical vacuum pump. Switch-on currents of up to 30 A can occur in the process. The current level is restricted electronically to protect the output stage and the line. There is no control of the power or engine speed for the electrical vacuum pump – it is simply switched on and off.

A malfunction of the electrical vacuum pump is identified using a brake vacuum sensor by means of the no longer available vacuum. At least the legally prescribed deceleration (increased brake pedal force) is available. The DSC will realize a type of hydraulic brake-servo assistance, i.e. depending on the driver pressure a hydraulically reinforced circuit pressure is generated.

Advantage: Lower brake pedal force also in this fault scenario

Disadvantage: Modified brake pedal response.

I01 High-voltage Components

5. High-voltage Battery Unit

The high-voltage battery unit is the energy storage device for the electric motor of the I01. It is the equivalent to the fuel tank of a conventional vehicle with a combustion engine. Also in BMW active hybrid vehicles there is already a high-voltage battery unit, which supplies the electric motor with energy. In the BMW active hybrid the high-voltage battery is charged when the electrical machine is operated as an alternator. This happens during brake energy regeneration or by a load point increase of the combustion engine. In the I01 the high-voltage battery can also be partially charged during brake energy regeneration. However, it is mainly charged using energy from an external power network. An optional range extender can also provide electrical energy using a gasoline engine and another electrical machine. However, this is primarily used for maintaining the state of charge when the high-voltage battery is already heavily discharged. The range of the I01 can be increased.

5.1. Overview

The high-voltage battery of a vehicle with an electric motor is the equivalent to the fuel tank in a vehicle with a combustion engine: It is the energy storage device for the electric motor. In order to achieve the desired range of the I01, the amount of energy to be stored is correspondingly high, which is why the volume and weight of the energy storage device are also high. Nevertheless, some vehicle characteristics were positively influenced by the installation of the high-voltage battery unit in the Drive module of the I01:

- Thanks to the low installation location the center of gravity of the vehicle is lowered, which reduces the roll tendency in bends, in particular.
- The passenger compartment is not restricted by the high-voltage battery unit.
- The high-voltage battery unit is well accessible in Service, which reduces the repair costs.

5.1.1. Technical data

The high-voltage battery unit of the I01 is made up of the following fundamental components:

- Cell modules with the actual battery cells
- Cell supervision circuits
- Heat exchanger with coolant ducts and heating
- Control unit, battery management electronics (SME)
- Wiring harnesses
- Safety box
- Connections (electrical, refrigerant, venting)
- Housing and fastening parts.

The battery cells are supplied by Samsung SDI to the BMW plant in Dingolfing. There the cell modules are assembled from the battery cells and mounted into complete high-voltage battery units with the other components. The manufacturer of the SME control unit and the cell supervision circuit is Preh.

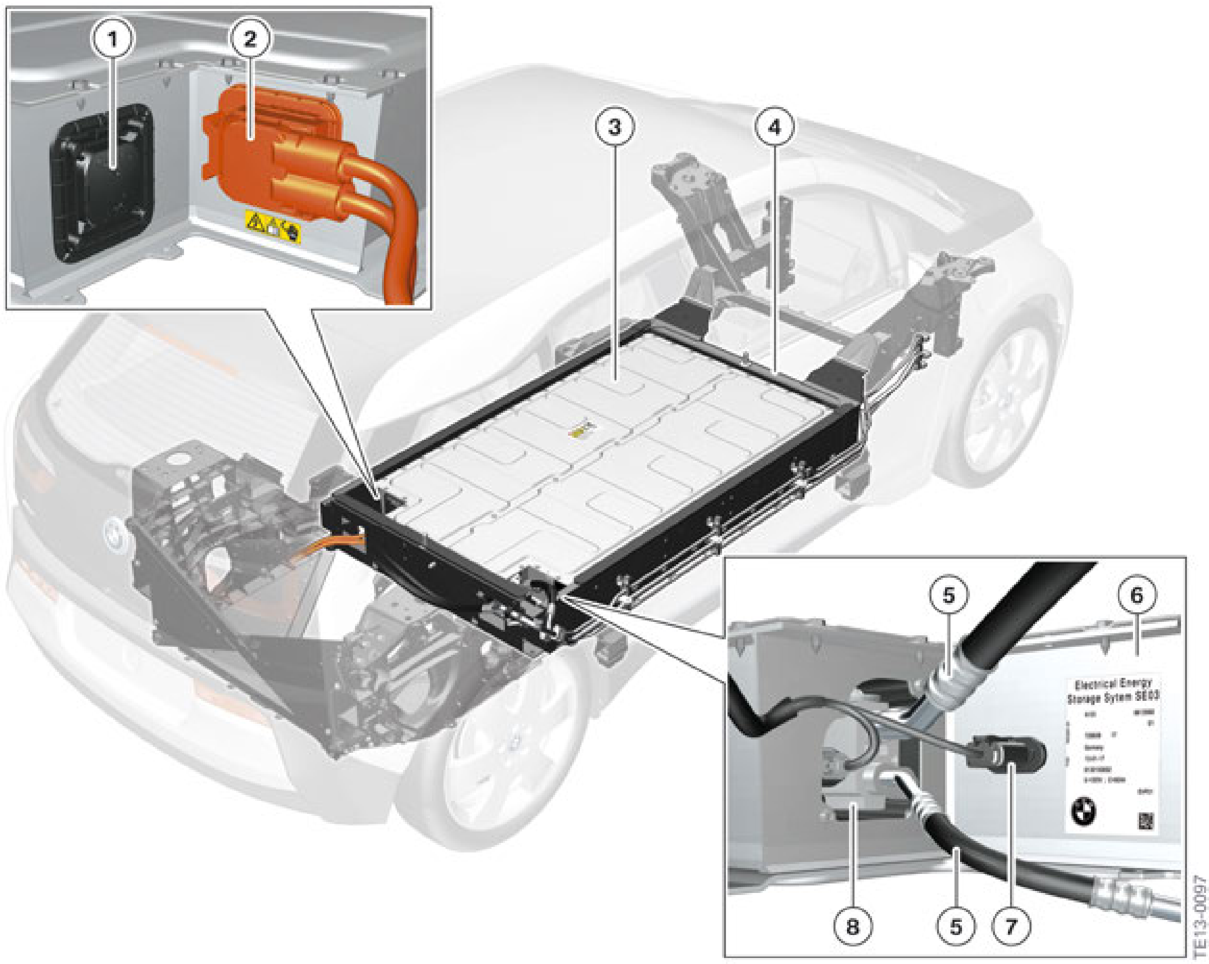
The battery cells used in the high-voltage battery of the I01 are **lithium-ion** cells (cell type NMC/LMO mixture). The anode material of lithium-ion batteries is generally a lithium metal oxide. The designation "NMC/LMO mixture" refers to the metals used for this cell type: It is a mix of nickel, manganese and cobalt on the one hand, and lithium manganese oxide on the other hand. The characteristics of the high-voltage battery for use in an electric vehicle were able to be optimized through the selection of

5. High-voltage Battery Unit

the anode material (high energy density, high cycle number). Graphite is normally used for the cathode. The lithium ions are deposited in the cathode during discharging. As a result of the materials used the total nominal voltage of the battery cells is **3.75 V**. The following table lists the most essential technical data of the high-voltage battery in the I01.

Voltage	360 V (nominal voltage) 259 V – 396 V (voltage range)
Battery cells	96 battery cells in series, each 3.75 V and 60 Ah
Storable amount of energy	21.8 kWh (gross) 18.8 kWh (net, practical use)
Maximum power (discharge)	147 kW (short-term), at least 40 kW (continuous)
Maximum power (charge)	20 kW (rapid charge to 80% SoC), about 3.6 kW (full charge to 100% SoC in 8 hours)
Total weight	233 kg
Dimensions	1584 mm x 892 mm x 171 mm (volume 213 l, incl. housing)
Cooling system	by refrigerant R134a
Heating	Electric, maximum 1000 W (optional equipment)

5.1.2. Installation location



Installation location of the high-voltage battery unit

Index	Explanation
1	Vent hole
2	High-voltage connection
3	High-voltage battery unit
4	Frame (Drive module)
5	Refrigerant lines
6	Label
7	Low-voltage connection
8	Combined expansion and shutoff valve

5. High-voltage Battery Unit

The high-voltage battery unit also has a low-voltage connection, as well as the high-voltage connection. The integrated control units are supplied with voltage, data bus, sensor and monitoring signals via this interface. It is incorporated in the refrigerant circuit for cooling the high-voltage battery. The label on the high-voltage battery unit informs people working with these components about the technology used and possible electrical and chemical dangers.

⚠

The electrical voltage of the high-voltage battery unit is well over 60 V. This is why **before** any work at the high-voltage battery unit the **electrical safety rules** must be observed:

1 Disconnect the system from the power supply

2 Provide a safeguard to prevent unintentional restarting

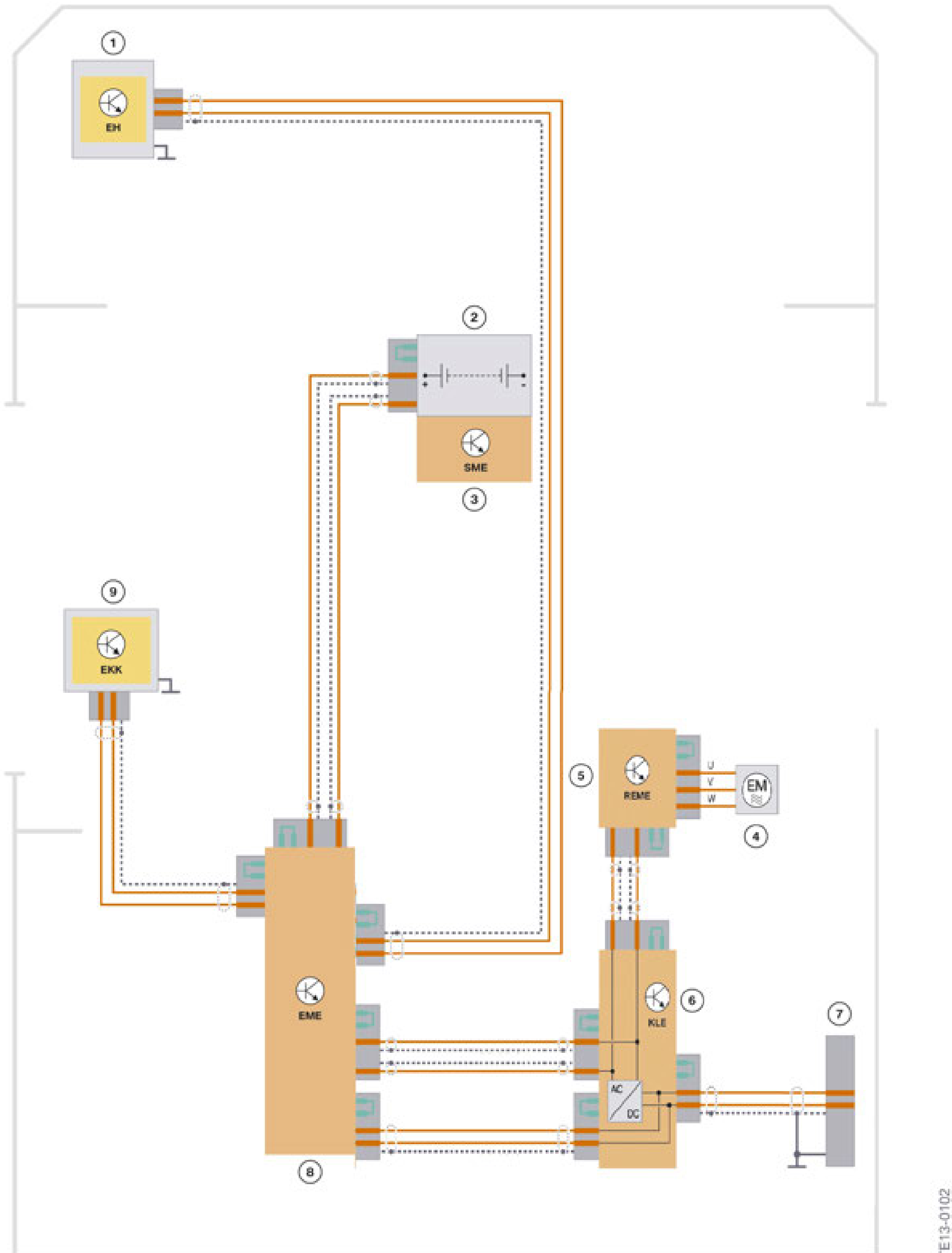
3 Establish that the system is isolated from the power supply.

The electrical lines (high-voltage and low-voltage), as well as the refrigerant lines, can be disconnected without having to remove the high-voltage battery unit.

The high-voltage battery unit is located outside the passenger compartment. If the battery cells generate excess pressure due to a massive fault, the arising gases cannot be transported outwards via a vent pipe. A vent hole at the housing of the high-voltage battery unit is sufficient to allow pressure compensation.

The high-voltage safety connector (Service Disconnect) is not an element of the high-voltage battery unit, just like in current BMW active hybrid vehicles. It is located below the engine compartment lid.

5.1.3. System wiring diagram



System wiring diagram of high-voltage battery unit

Index	Explanation
1	Electric heating (EH)
2	High-voltage battery unit
3	Battery management electronics (SME)
4	Electrical machine
5	Range Extender Electrical Machine Electronics (REME)
6	Convenience charging electronics (KLE)
7	Charging socket at the vehicle
8	Electrical machine electronics (EME)
9	EKK

5.2. External features

5.2.1. Mechanical interfaces

The housing of the high-voltage battery unit is connected mechanically to the Drive module of the I01 using a total of 26 screws. This way the weight and the acceleration forces occurring during the journey are supported at the body. The mounting bolts are accessible directly from below, without having to first disassemble the underbody paneling . For the removal of the high-voltage battery unit firstly all preliminary work specified in the repair instructions (diagnosis, disconnecting from the power supply, etc.) has to be performed. Before the mounting bolts are slackened the special tool for lowering (mobile table lift MHT 1200) must be positioned below the high-voltage battery unit.

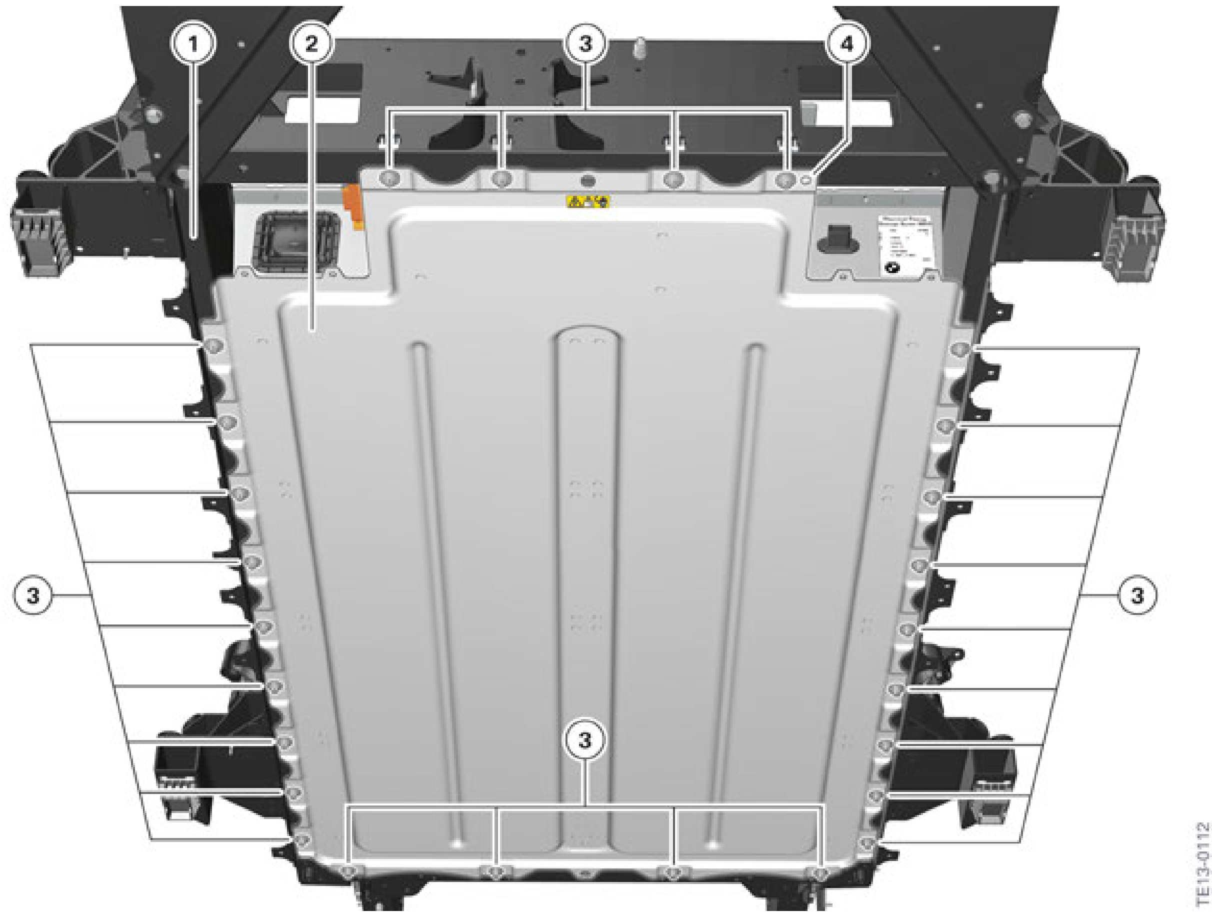
The electrical connection is established between the housing and Drive module by another potential compensation screw.

⚠

The low resistance connection between the housing of the high-voltage battery unit and ground (= Drive module) is a crucial prerequisite for the fault-free function of the automatic isolation monitoring. This is why it is important to ensure the correct tightening torque is applied for this potential compensation screw.

It is also important to ensure that neither the housing of the high-voltage battery unit nor the Drive module at the respective bore holes is painted, corroded or dirty. The bare metal must be exposed if necessary before the potential compensation screw is mounted.

5. High-voltage Battery Unit

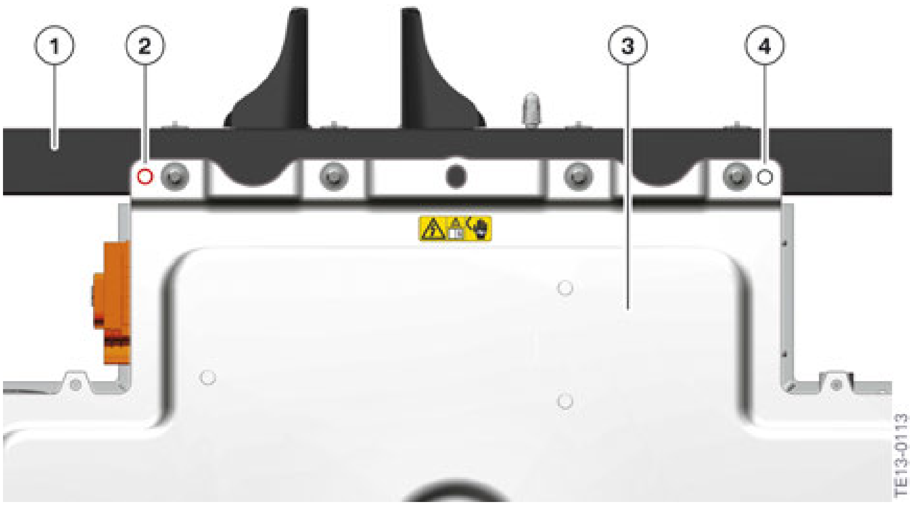


Mounting of the high-voltage battery unit at the Drive module

Index	Explanation
1	Frame (Drive module)
2	High-voltage battery unit
3	Mounting bolts
4	Potential compensation screw

If the potential compensation screw can no longer be tightened to the required torque after a number of removal and installation procedures, a new bore hole for the potential compensation screw must be created. The rough position of the bore hole is shown in the following graphic - the exact position can be found in the repair instructions.

5. High-voltage Battery Unit

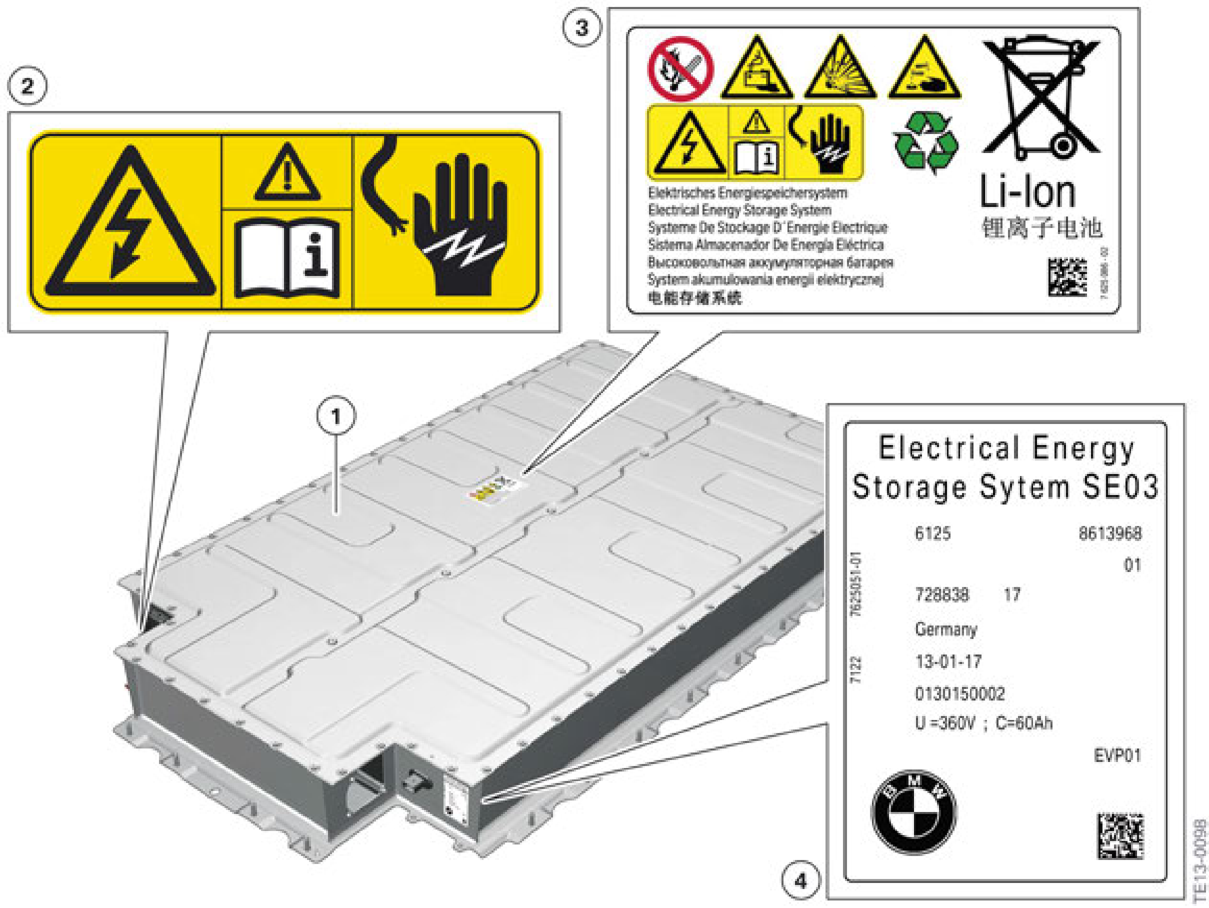


Bore hole for potential compensation screw

Index	Explanation
1	Frame (Drive module)
2	New bore hole for potential compensation screw in the event of a repair
3	Housing of high-voltage battery unit
4	Original bore hole for potential compensation screw ex works

Similar to vehicles with a frame design, the Life-Drive concept is made up of two independent modules separated horizontally. The "Life" module consists mainly of a high-strength and very lightweight passenger cell made of carbon reinforced plastic. The "Drive" module, the chassis, forms the stable base, in which the high-voltage battery unit is integrated. Crash-active structures made from aluminium at the front end and rear end of the Drive module ensure additional safety in the event of a head-on and rear-end collision. The high-voltage battery unit is located in the vehicle underbody for the best possible protection as a vehicle suffers the least amount of deformation in this area in the event of a crash. In the event of a side collision the high-voltage battery unit also benefits from the crash properties of the Life module, as the entire energy is collected here and does not advance as far as the energy storage device. Overall, the high-strength carbon passenger compartment in conjunction with the intelligent force distribution in the LifeDrive module creates the prerequisite for optimal occupant safety.

Three labels are attached at the high-voltage battery unit of the I01: one type plate and two warning stickers. The type plate provides logistical information (e.g. part number) and the key technical data (e.g. nominal voltage). The two warning stickers draw attention to the lithium-ion technology and the high electrical voltage used in the high-voltage battery unit and alert people to associated possible dangers. The following graphic shows where the three labels are located at the high-voltage battery unit.



Labels on the housing of the high-voltage battery unit

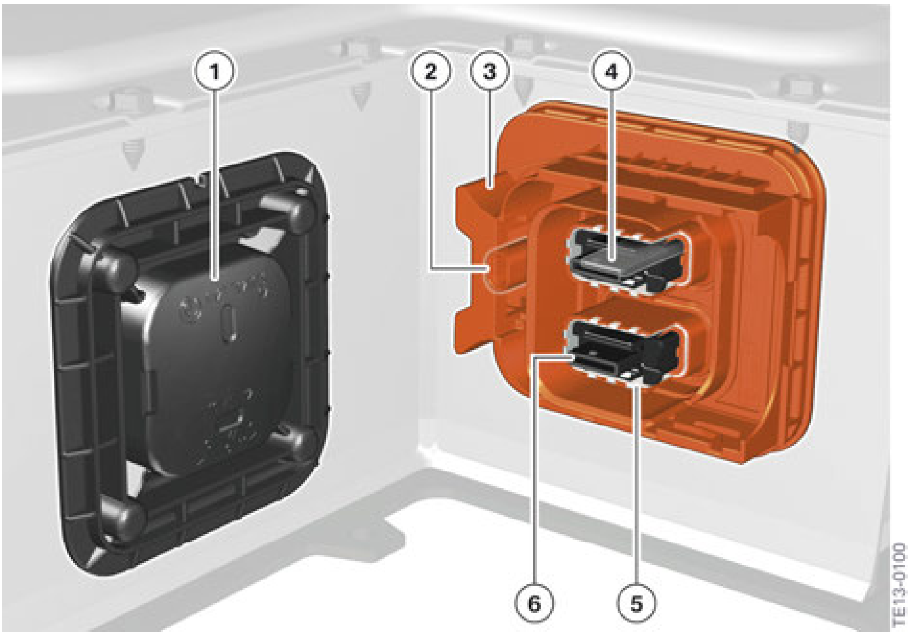
Index	Explanation
1	Housing cover of high-voltage battery unit
2	High-voltage component warning sticker
3	Warning sticker
4	Label with technical data

5.2.2. Electrical interfaces

High-voltage connection

There is a two-pin high-voltage connection at the high-voltage battery unit with which the high-voltage battery unit is connected to the high-voltage electrical system.

5. High-voltage Battery Unit

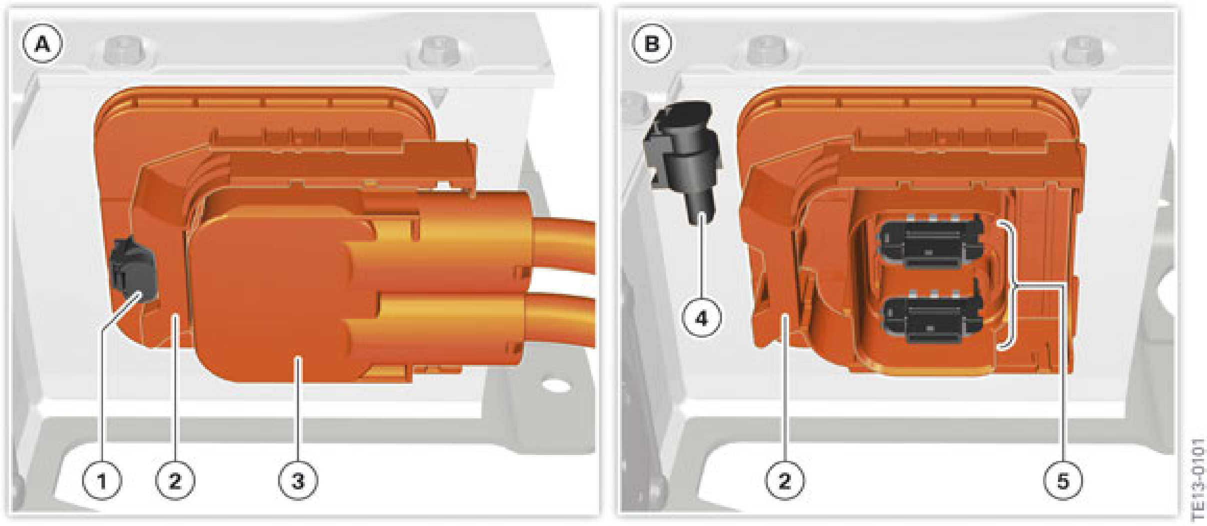


Connections of the high-voltage battery unit, left

Index	Explanation
1	Vent hole
2	High-voltage interlock loop connector/bridge
3	Mechanical slide
4	Separate contact for high-voltage cable
5	Contact for shielding
6	Contact protection

A contact is available for shielding around each of the two electrical contacts for the high-voltage cables. The shielding of the high-voltage cable (shielding for each cable) is continued into the housing of the high-voltage battery unit and thus contributes to the electromagnetic compatibility (EMC).

In addition, the high-voltage connection provides protection against contact with live parts. The actual contacts are coated in plastic so that nobody can touch them directly. Only when the cable is connected is the coating pushed away and the contact established. The plastic slide serves as the mechanical latch mechanism of the connector. In addition, it is also an element of a safety function: If the high-voltage cable is not connected, the slide conceals the connection for the bridge of the high-voltage interlock loop. Only when the high-voltage cable is properly connected and the connector is locked, is this connection accessible and the bridge can be inserted. This guarantees that only when a high-voltage cable is connected is the circuit of the high-voltage interlock loop also closed. This principle applies to all high-voltage connections in the I01, for instance connections at the high-voltage battery unit, at the electrical machine electronics, at the convenience charging electronics and at the range extender electrical machine electronics. The high-voltage system can only be active when all high-voltage cables are connected. This is additional protection against contact with contact surfaces, which otherwise may carry voltage.



High-voltage connection

Index	Explanation
A	High-voltage connection with connected high-voltage cable
B	High-voltage connection with disconnected high-voltage cable
1	Bridge for high-voltage interlock loop (connected)
2	Mechanical slide
3	High-voltage connector of the high-voltage cable
4	Bridge for high-voltage interlock loop (disconnected)
5	High-voltage connection

The high-voltage connection can be replaced as a separate component, just like all other components of the high-voltage battery unit.

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

Low-voltage connections

There are two low-voltage connections at the high-voltage battery unit of the I01:

1 Connection for lines to the SME control unit

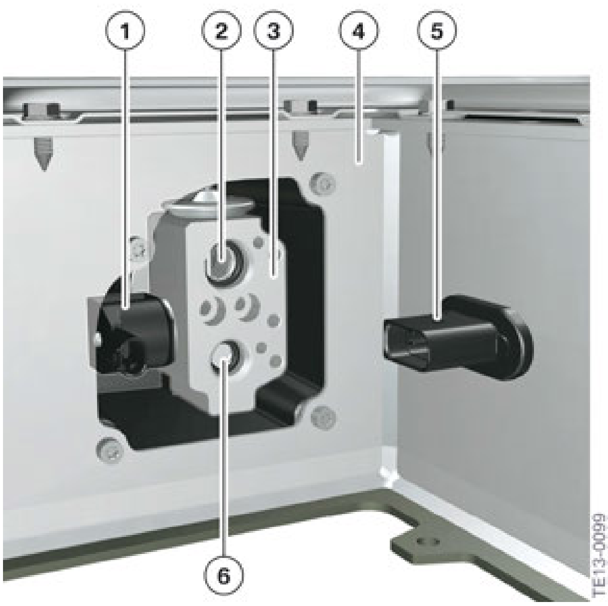
2 Connection for the activation of the combined expansion and shutoff valve

The connection for the SME control unit has the following lines:

- Voltage supply of the SME control unit with terminal 30F and ground connection
- Terminal 30C for the voltage supply of the electromechanical switch contactors
- Wake-up line from the BDC

5. High-voltage Battery Unit

- Input and output of the line for the high-voltage interlock loop
- Output (+12 V and ground) for the activation of the combined shutoff and expansion valve (without heat pump)
- PT-CAN2
- Two unused signals (only for development purposes).



Connections of the high-voltage battery unit, right

Index	Explanation
1	Connection for combined expansion and shutoff valve
2	Connection for refrigerant intake pipe
3	Combined expansion and shutoff valve
4	Housing of high-voltage battery unit
5	Low-voltage connection of the high-voltage battery unit
6	Connection for refrigerant pressure line

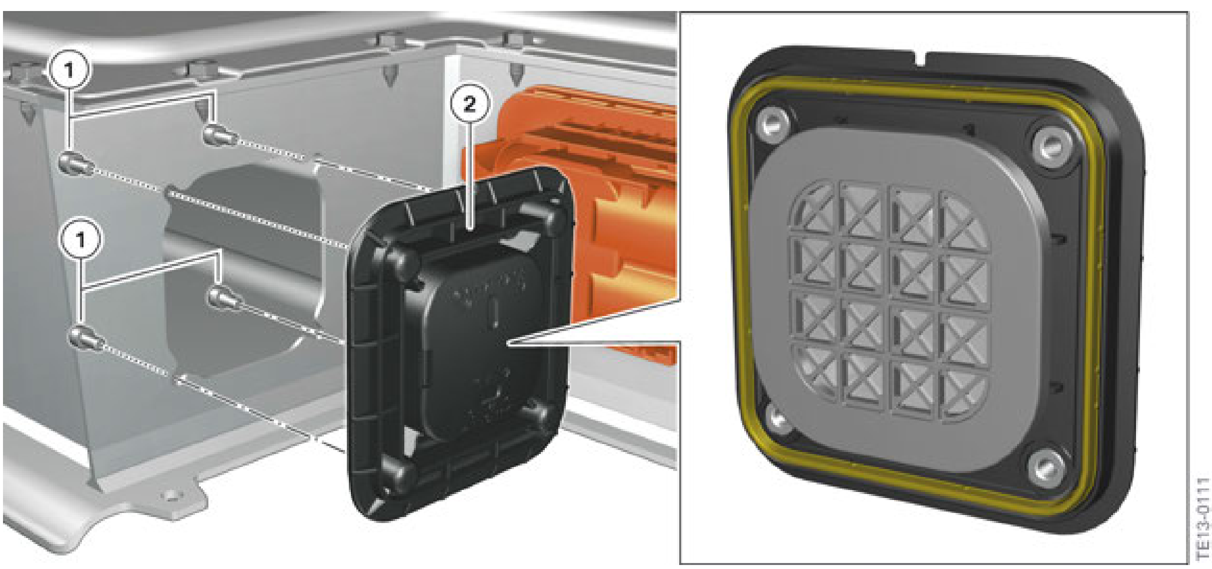
With the optional heat pump the actuating wires coming from the SME control unit for the combined expansion and shutoff valve initially lead into the wiring harness. From there they are guided directly to this valve. There are no other electrical vehicle components involved which may influence this activation signal. With the optional heat pump the activation of the combined expansion and shutoff valve is assumed by the heat pump control unit and not the SME control unit. The SME control unit only communicates the cooling requirement for the high-voltage battery which is performed via the IHKA and the heat pump control unit.

5.2.3. Vent hole

The vent hole has two tasks. The first task of the vent hole is to offset large pressure differences between the inside and outside of the high-voltage battery unit. Such pressure differences can only arise in the event of a damaged battery cell. For safety reasons the housing of the cell module with the damaged battery cell is opened to reduce the pressure. The gases are initially located in the housing of the high-voltage battery unit. From there they can be transported outwards via the vent hole.

The second task of the vent hole is to transport outwards condensate arising in the inside of the high-voltage battery unit. Besides the technical components, there is also air inside the high-voltage battery unit. If the air or the housing is cooled by a lower ambient temperature or by a refrigerant through the activation of the air conditioning function, some of the water vapor from the air condenses. This means small amounts of liquid water can form in the inside of the high-voltage battery unit. This has no affect on the function. During the next heating of the air or the housing the water evaporates again and, at the same time, the pressure in the housing rises slightly. The vent hole permits pressure compensation by allowing the warm air to escape outwards. The water vapor in the air is also transported outwards and also the previously liquid condensate.

To fulfil these tasks the vent hole has a permeable diaphragm for gases (and water vapor) and an impermeable diaphragm for fluids. There is a two-piece cover located above the diaphragm with which the diaphragm is protected against coarse dirt contamination.



Vent hole

Index	Explanation
1	Mounting bolts (x4)
2	Vent hole

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The venting unit can be replaced in Service as an entire unit. A replacement makes sense if the venting unit is heavily contaminated or has suffered mechanical damage.

If the housing of the high-voltage battery unit is also damaged, for example a crack, contact must be established with Technical Support to determine a suitable course of action.

5.2.4. Interface for the refrigerant circuit

It is incorporated in the refrigerant circuit of the heating and air-conditioning system for cooling the high-voltage battery. In order to be able to perform condition-based cooling, there is an electrically activated combined expansion and shutoff valve at the high-voltage battery unit.

There are two versions of this valve. Which version is installed in the I01 depends on the equipment without/with heat pump (option 4T9). Without the optional heat pump the combined shutoff and expansion valve is hard-wired to the SME control unit and is activated directly by this control unit. The valve is closed currentless, i.e. no refrigerant flows into the high-voltage battery unit. The valve only knows two positions, "closed" and "open". The amount of flowing refrigerant is adjusted thermally.

With the optional heat pump the combined expansion and shutoff valve is a constantly activated valve. The precise operating principle is described in the product information bulletin "I01 Heating and Air-Conditioning System".

The exact installation location of this valve is shown in a graphic in the chapter "Low-voltage connections". The operating principle of the cooling system is described in the next chapter.

5.3. Heating and cooling system

5.3.1. Overview

To maximizethe 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 unit is essentially operational in the range of -40 °C to +50 °C. These temperature limits, however, relate to the actual temperature of the cell, not the ambient temperature. In terms of temperature behavior the high-voltage battery unit is a slow-action system, i.e. it takes several hours until the cells assume the 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 already have assumed this temperature.

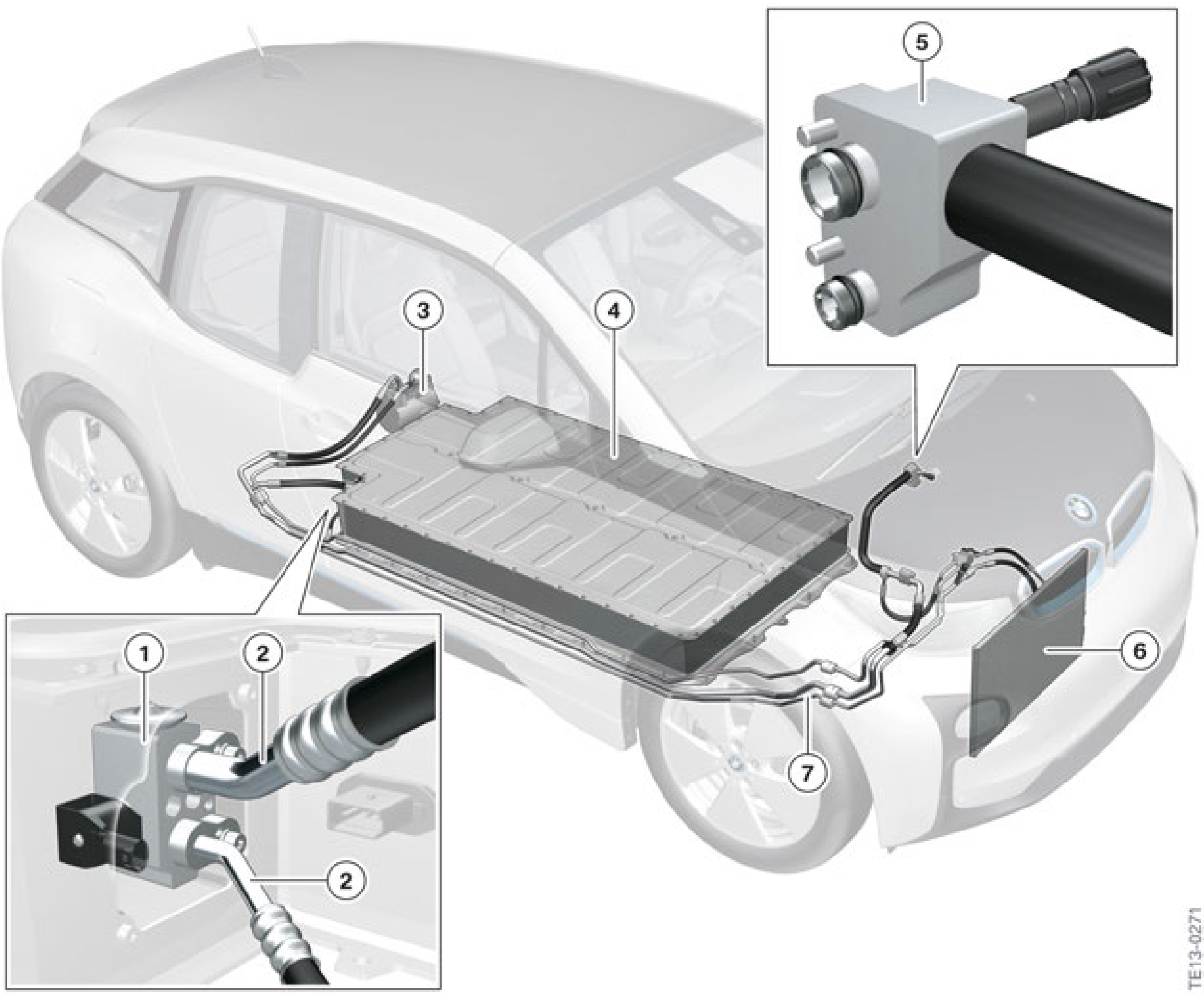
The optimal range of the temperature of the cell with regard to service life and performance is more limited. It is between +25 °C and +40 °C. Mainly if the cell temperature is continuously significantly outside this range and, at the same time, high power is required, this would reduce the service life of the battery cells. To counteract this effect and ensure maximum performance at any ambient temperature, there is automatic heating and cooling for the high-voltage battery unit of the I01.

The I01 is equipped as standard with a cooling system for the high-voltage battery. For this purpose it is incorporated in the refrigerant circuit of the heating and air-conditioning system, similar to current BMW active hybrid vehicles. If the customer orders optional equipment 494 (Seat heating) for driver and front passenger, his I01 also has heating for the high-voltage battery. The heat effect of the electrical current is used for heating up the high-voltage battery. This heating including the control is located inside the high-voltage battery unit. At a very low ambient temperature or cell temperature and with a connected charging cable, the heating is automatically activated if required in order to warm up the battery cells. This way the otherwise restricted performance is improved considerably at very low temperatures and the range can be increased.

I01 High-voltage Components

5. High-voltage Battery Unit

The following graphic provides an overview of the entire system for the heating and cooling of the high-voltage battery unit.



Entire cooling system of the high-voltage battery unit

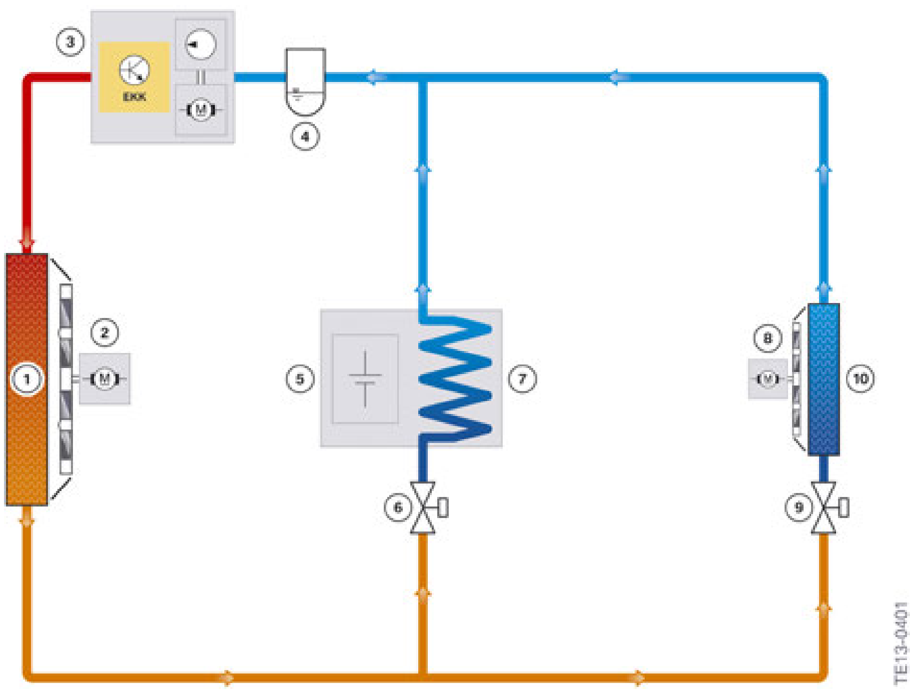
Index	Explanation
1	Combined expansion and shutoff valve
2	Refrigerant lines for cooling of the high-voltage battery unit
3	EKK
4	High-voltage battery unit
5	Expansion valve for passenger compartment cooling
6	Capacitor in the refrigerant circuit
7	Refrigerant lines

The subsystems for heating and cooling are shown individually below.

5. High-voltage Battery Unit

Cooling system of the high-voltage battery

The high-voltage battery unit in the I01 is cooled directly by refrigerant. The refrigerant circuit of the air conditioning system is therefore made up of two parallel branches: One for cooling the passenger compartment and one for cooling the high-voltage battery unit. For each branch there is a combined expansion and shutoff valve in order to be able to control the cooling functions independent of each other. The battery management electronics can activate and open the combined expansion and shutoff valve by applying voltage. In this way refrigerant can flow to the high-voltage battery, expanding, evaporating and cooling in the process. The cooling of the passenger compartment is also effected in a condition-based manner. The combined expansion and shutoff valve upstream from the evaporator can also be activated electrically and by the EDME.



Entire heating/cooling system of the high-voltage battery

Index	Explanation
1	Capacitor in the refrigerant circuit
2	Electric fan, refrigerant circuit for passenger compartment
3	EKK
4	Dryer flask
5	High-voltage battery unit
6	Combined expansion and shut-off valve in the refrigerant circuit (for cooling high-voltage battery)

Index	Explanation
7	Heat exchanger
8	Blower for passenger compartment
9	Combined expansion and shutoff valve in the refrigerant circuit (for cooling the passenger compartment)
10	Evaporator, passenger compartment

During cooling the battery cells emit heat energy to the refrigerant. While the battery cells are cooled down, the refrigerant is heated. The EKK compresses the refrigerant again and in the capacitor it returns to a liquid state. As a result, the refrigerant is once again able to absorb heat energy. This way the maximum cooling power of about 1000 W can be generated. In other words: A heat output of up to 1000 W can be discharged by the high-voltage battery. This maximum cooling power is only required at a very high ambient temperature and, at the same time, a high drive power.

In order to cool battery cells using refrigerant, there is a heat exchanger located below the cell modules which is made from flat aluminium pipes. They are connected to the internal refrigerant lines and refrigerant flows through them during cooling.

Heating

Vice versa, if the I01 was parked outside for example for several days at temperatures below 0 °C, it makes sense to heat the battery cells before departure and/or to their optimal temperature level. They then deliver their full power before the journey commences. The customer can use this option if the vehicle is connected to the power network using the charging cable and the function for the interior air temperature control of the vehicle was selected. In order to warm up the batteries, the high-voltage system is activated and electrical current is sent through a network of heating wires. This network of heating wires is arranged along the coolant ducts. As the coolant ducts and the cell modules touch, the heat generated in the heater coils is transmitted to the cell modules and therefore the battery cells.

5.4. Internal structure of the high-voltage battery unit

The information on the internal structure and other functions of the high-voltage battery unit can be found in the product information bulletin "I01 High-voltage Battery Unit".

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A repair of the high-voltage battery unit is only intended in a dealership with the Service format "BMW i Extended Battery Service" or "BMW i Full Service".

I01 High-voltage Components
6. Charging the High-voltage Battery

6.1. General information on charging

6.1.1. Introduction

The "charging" procedure for an electric vehicle corresponds to "refueling " a conventionally driven vehicle. Accordingly, in this chapter "charging" means:

- Charging the high-voltage battery in the vehicle
- while at standstill (not through brake energy regeneration),
- by supply of electrical energy,
- which is provided by an AC voltage network outside the vehicle
- and is fed to the vehicle via a charging cable.

As a charging cable is used, one also refers to conductive (grid-bound) charging. The inductive charging is not possible at the I01. It is still undergoing research and development.

Components inside and outside the vehicle are required for charging. In the vehicle a charging socket and power electronics are required for the voltage conversion. Outside the vehicle a device which performs the protection and control functions is needed, in addition to the AC voltage network and a charging cable. This device is called an "Electric Vehicle Supply Equipment (EVSE)" in the standards and in development. The following graphic shows the components for the charging of the high-voltage battery inside and outside the electric vehicle and compares them to the components needed for refueling in a conventional vehicle.

Components for refueling the vehicle and charging the high-voltage battery

Index	Refueling the vehicle	Charging the high-voltage battery
1	Filling station	AC voltage network
2	Petrol pump	Electric Vehicle Supply Equipment (e.g. wallbox)
3	Fuel line between fuel pump nozzle and gasoline pump	Charging cable
4	Fuel pump nozzle	Vehicle connector at charging cable

6. Charging the High-voltage Battery

5	Fuel filler neck	Charging socket
6	-	Power electronics
7	Fuel tank	High-voltage battery

The Electric Vehicle Supply Equipment can either be integrated in the charging cable or be an element of a fixed charging station (also called "wallbox"). The EVSE establishes the connection to the AC voltage network and serves for the fulfilment of requirements for electrical safety when charging the vehicle. Communication to the vehicle can also be set up via the pilot line. As a result, it is possible to safely start the charging procedure and exchange the charging parameters (e.g. maximum current level) between vehicle and EVSE. Details on the possible versions, structure and functioning of the EVSE are described in one of the following chapters.

The voltage of the AC voltage network can be in the range of 110 V to 240 V. It is fed to the vehicle via a single-phase supply. From the AC voltage network side, in theory a maximum charging power of $P_{max} = U_{max} \times I_{max} = 240\ V \times 32\ A = 7.7\ kW$ is possible.

Many of the components mentioned for charging the I01 are standardized in terms of their structure and functions. In European countries IEC 61851 is the applicable standard. The components for charging the I01 satisfy charging mode 2 (connection to standard household socket with additional pilot line) and charging mode 3 (connection to fixed wallbox with pilot line).

The standard for America is SAE J1772. Charge Level 1 and 2 are comparable to charging modes 2 and 3. Most components for charging the I01 only satisfy both standards with one technical version. A national-market or standard-specific version is required for Europe and America only by the "Electric Vehicle Supply Equipment".

For the employees in BMW Service the following important safety rules must be observed in relation to charging:

⚠

Refueling the vehicle while the high-voltage battery is charging is not permitted!

When the charging cable is inserted do not initiate a refueling procedure and keep a safe distance from highly flammable materials. Otherwise, in the event of incorrect connection or removal of the charging cable there is a risk of personal injury or material damage by burning fuel for example.

⚠

While the I01 is connected to the AC voltage network for charging, no work may be performed at the high-voltage system.

⚠

During the charging procedure the electric coolant pump and the electric fan can be switched on automatically for cooling the power electronics. This is why no work can be performed at the cooling system of the electric motor and at the electric fan when a charging cable is connected to the I01.

⚠

Work at the charging cable, at the Electric Vehicle Supply Equipment, at household sockets or charging stations can only be performed by qualified electricians, and **not** by BMW Service employees.

6.1.2. Overview of charging options

In general, the high-voltage battery can either be charged using alternating current (AC charging) or direct current (DC charging). The charging options of the high-voltage battery in the I01 are generally specified by the equipment for charging in the vehicle, as well as the national-market charging infrastructure. The following table provides an overview of the different charging options in various countries. The charging powers always relate to the mains power and not the charging power used to charge the high-voltage battery. The charging power is always less than the available mains power.

Markets (LHD)	Charging system	Charging interface	Equipment (basic version, option)
US market (LHD)	AC charging 7.4 kW	Type 1	Standard Equipment Charging (SA4U8 AC Fast Charging)
	Combo (AC charging 7.4 kW and DC charging 50 kW)	Combo 1	Optional Equipment Charging (SA 4U7 DC Fast Charging

6.1.3. Charging modes

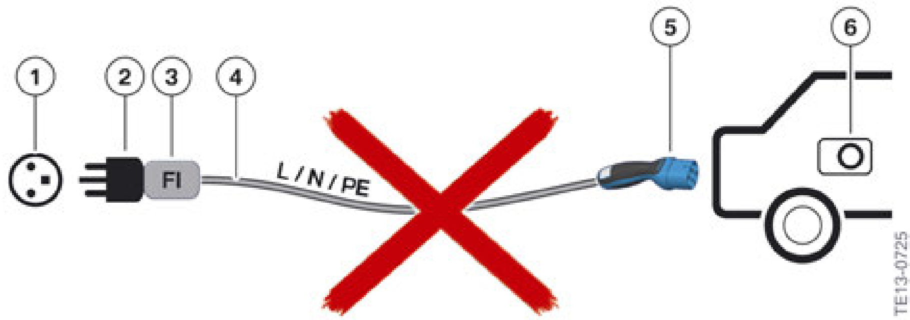
The charging modes are defined in the international standard IEC61851-1 (IEC = International Electrotechnical Commission). The key parameters of the individual charging modes are summarized in the following table:

	Maximum power	Communication with the vehicle	Locking the charging plug
Charging mode 1 **(Not Used for I01)**	3.7 kW (16 A)	none	in the vehicle
Charging mode 2 (Occasional use cable)	8 A to 12 A at 100 V to 230 V	via module in the charging cable	in the vehicle
Charging mode 3 (Wallbox)	14.5 kW (63 A)	via module in the charging station	in the vehicle and in the power socket
Charging mode 4 **(Not Used for I01)**	DC Low 38 kW DC High 170 kW	via module in the charging station	in the vehicle and in the power socket

⚠

Charging mode 1 and charging mode 4 are not used for the I01. A German Industrial Standard DIN is applied for DC charging (charging mode 4) in the I01.

6. Charging the High-voltage Battery

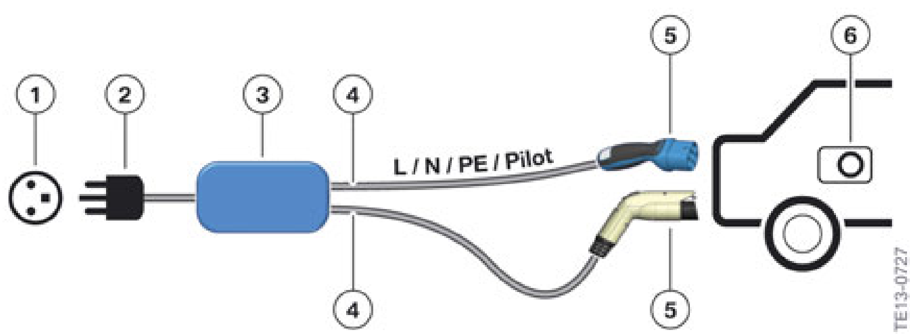


IEC Charging mode 1

Index	Explanation
1	Household power socket
2	Connector for household socket
3	Circuit breaker
4	Charging cable
5	Charging plug
6	Charging socket at the vehicle

⚠

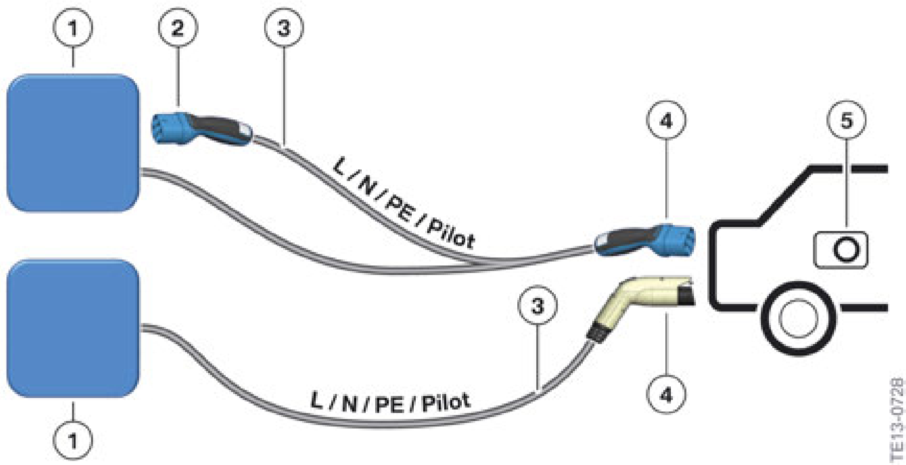
Charging mode 1 i.a.w. IEC61851-1 is NOT USED in the I01 due to a lack of communication between the vehicle and voltage supply.



IEC Charging mode 2 (Occasional use cable)

Index	Explanation
1	Household power socket
2	Connector for household socket
3	In-cable box
4	Charging cable
5	Charging plug (Europe and US version)
6	Charging socket at the vehicle

The communication between vehicle and voltage supply is possible via the In-Cable box.



IEC Charging mode 3 (Wallbox)

Index	Explanation
1	Wallbox or charging station
2	Charging plug for connection at wallbox or charging station (only in Europe)
3	Charging cable
4	Charging plug (Europe and US version) for connection to vehicle
5	Charging socket at the vehicle

In the US market the plug connection between the charging cable and AC charging station is permanently attached to the charging station (wallbox). Therefore the charging cable cannot be separated from the AC charging station by the customer.

6.1.4. Charging plug

The charging plugs used are also standardized (IEC 62196-2). Depending on the vehicle equipment and national-market version different charging sockets are used. The following table provides an overview of the most frequently used connectors:

	US market (Type 1)
AC charging	 SAE J1772 / IEC 62196–2
Combo charging plug (DC charging)	 SAE J1772 / IEC 62196–3 Combo 1

6.1.5. Electric Vehicle Supply Equipment

The EVSE establishes the connection to the AC voltage network and serves for the fulfilment of requirements for electrical safety when charging the vehicle. Communication to the vehicle can also be set up via the so-called pilot line. As a result, it is possible to safely start the charging procedure and exchange the charging parameters (e.g. maximum current level) between vehicle and EVSE. The EVSE can either be integrated in the charging cable (mobile solution) or be an element of a fixed charging station (also called "wallbox").

In both cases the EVSE contains the following subcomponents:

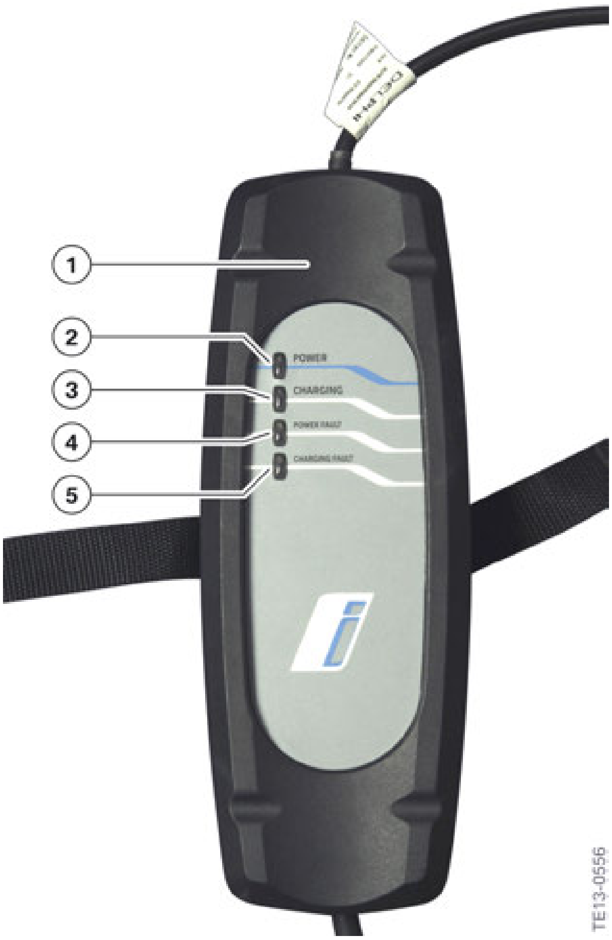
- Earth leakage circuit breaker (FI)
- Display whether the AC voltage network is connected and available
- Electronic disconnect switch for phase (L1) and neutral conductor (N)
- Electronic switching for generating the pilot signal
- Continuous protective earth (PE).

Mobile solution

The version integrated in the charging cable is also called "In-Cable box" and is designed for mobile use. The volume and weight of this solution is low and the charging and EVSE can be easily transported in the vehicle.

I01 High-voltage Components

6. Charging the High-voltage Battery



EVSE for mobile use

Index	Explanation
1	BMW i mobile EVSE
2	Display for the availability of the voltage supply
3	Display for charging
4	Display for fault in the voltage supply
5	Display for fault during charging

As a household power socket is used for the connection of this EVSE to the AV voltage network, the maximum current level is restricted for charging. A product of this kind offered for the AC voltage network in Germany can be used up to a current level of 16 A or up to a charging power of 3.7 kW. The duration until a fully discharged high-voltage battery of the I01 is fully charged up again (18.8 kWh net) would be roughly 7 hours in optimal conditions.

⚠

Please consult the operating instructions of the respective manufacturer for the operation and use of a charging cable with an integrated EVSE.

6. Charging the High-voltage Battery

Employees in BMW Service cannot perform any maintenance or repair work on the charging cable or the EVSE. In the event of a defect with or a malfunction of the charging cable or the EVSE, the manufacturer must be contacted.

Fixed charging station

This version of the Electric Vehicle Supply Equipment must be installed permanently owing to its size and electrical requirements, e.g. at the house or in the customer's garage. Such a charging station can also be built at public places, e.g. car parks.

⚠

The installation, maintenance and repair of fixed charging stations can only be performed by suitably qualified electricians. Employees in BMW Service are not authorized to perform this work as they generally do not have this training.

For the fixed charging stations (also called "wallbox") a distinction is made between AC charging stations and DC charging stations.

AC charging stations

The connection of the AC charging stations to the AC voltage network can be via a two-phase (US market) or three-phase (typical in Germany) supply – the connection to the I01 is, however, always designed as a single-phase supply. In comparison to the mobile solution, a maximum current level of 32 A or a maximum charging power of 7.4 kW is possible. These maximum values are, however, still dependent on the size of the line cross-section, which was used in the electrical installation at the charging site. The electrician configures the charging station during installation according to the line cross-section so that the applicable maximum current level is transmitted to the vehicle using the pilot signal.

AC charging stations from other manufacturers or the versions for other countries may differ from the versions shown up to now.

The following graphic shows an AC charging station for the US market.

AC charging station for the US market, manufactured by AeroVironment

Index	Explanation
1	Display of the operating condition
2	Button for starting and stopping the charging procedure
3	Charging cable with connector for the connection at the vehicle (stored in the AC charging station)

⚠

For more information regarding the charging cable refer to chapter 6.3.2 “Charging Cable“ of this training manual.

In the US market a plug connection between the charging cable and AC charging station is permanently attached to the charging station (wallbox). Therefore the charging cable cannot be separated from the AC charging station by the customer. The connector visible in the graphic is not the connector for the connection to the AC charging station, but for the connection to the vehicle, which is only stored in the AC charging station.

DC charging station

TE13-0708

DC charging station

The DC charging stations form the second group of the fixed charging stations. In comparison to the AC charging station, the AC voltage is already converted to direct current in the DC charging station. Therefore, power electronics for the conversion of the AC voltage to direct current voltage in the electric vehicle are not required.

As the weight of the power electronics in the DC charging station plays a minor role, large transformers and a rectifier can be installed there to use the full network power. For this reason, DC charging stations generally deliver a much higher charging power than AC charging stations. Using a DC charging station the high-voltage battery can thus be charged much quicker.

6.2. AC charging with 3.7 kW (Occasional Use Cable)

Although the high-voltage battery of the I01 can also be partially charged by brake energy regeneration, the "normal" charging procedure takes place when the I01 is connected to the AC voltage network of the power supply company. Energy is taken from the AC voltage network and fed to the direct current voltage high-voltage electrical system of the I01.

6. Charging the High-voltage Battery

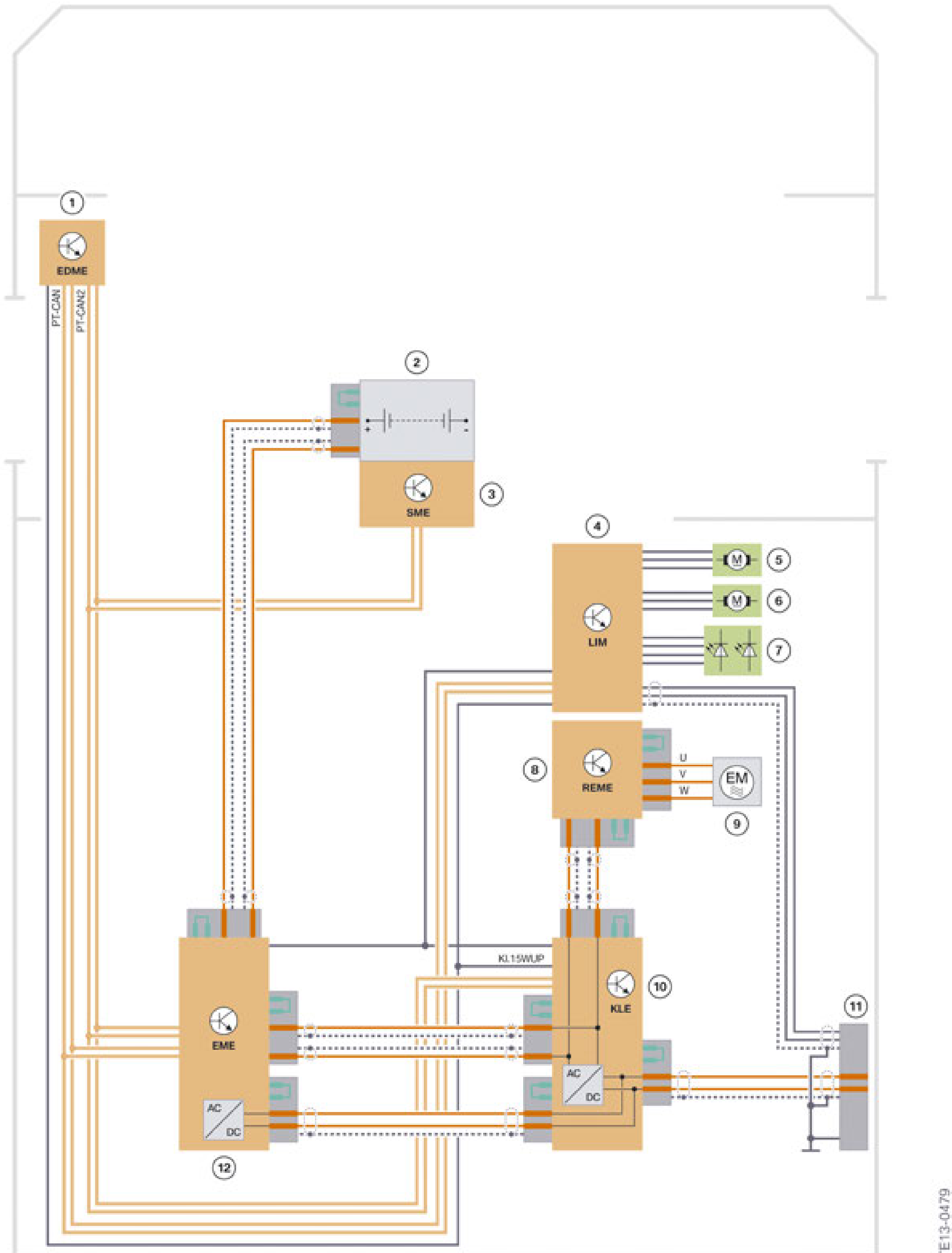
Although AC charging with 3.7 kW is standard equipment in many countries in the US market, it only refers to the charging via the occasional use cable (inserted into a normal 110V socket). The big advantage of this charging option is that for charging the high-voltage battery the charging cable can be connected at any household power socket with protective contact. However, the current level for charging is also restricted to a maximum 16 A. The maximum charging power is, for example for supply at AC voltage network in Germany, 3680 W (P = U x I = 230 V x 16 A). The total time it takes to fully charge a discharged high-voltage battery of the I01 (storable energy: 18.8 kW net) would be about 7 hours. In order to reduce the use of the maximum charging power for houses, a charging procedure is never performed at maximum charge current. Therefore, the actual charging time is longer.

⚠

The EME is designed so it can provide a maximum electrical power of 3.7 kW on the output side. This is charging configuration is used (in the US market) only when charging with the occasional use cable via a household 120 V socket. And it sufficient to fully charge the I01 high-voltage battery under optimal marginal conditions in about 16 hours.

6. Charging the High-voltage Battery

6.2.1. Wiring diagram



Wiring diagram for AC charging at 3.7 kW (US market)

Index	Explanation
1	Electrical Digital Motor Electronics (EDME)
2	High-voltage battery unit
3	Battery management electronics (SME)
4	Charging interface module (LIM)
5	Electric motor for the connector fastener
6	Electric motor for the central locking system of the charging socket cover
7	Locator and status lighting
8	Range Extender Electrical Machine Electronics (REME)
9	Range extender electrical machine
10	Convenience charging electronics (KLE)
11	Charging socket at the vehicle
12	Electrical machine electronics (EME)

6.2.2. Charging cable

Charging cable with integrated mobile version of the Electric Vehicle Supply Equipment (Charging mode 2 i.a.w. IEC 61851)

Index	Explanation
1	Electric Vehicle Supply Equipment (integrated, also called "In-Cable box")
2	Connector for connection at a household power socket
3	Connector for the connection at the vehicle

6. Charging the High-voltage Battery

The charging cable is used to join the following components:

- Specific national-market connection for household power socket with protective contact
- Plug connection between specific national-market connector and "In-Cable box"
- "In-Cable box" (EVSE)
- Plug connection between "In-Cable box" and connector for vehicle connection
- Connector for vehicle connection.

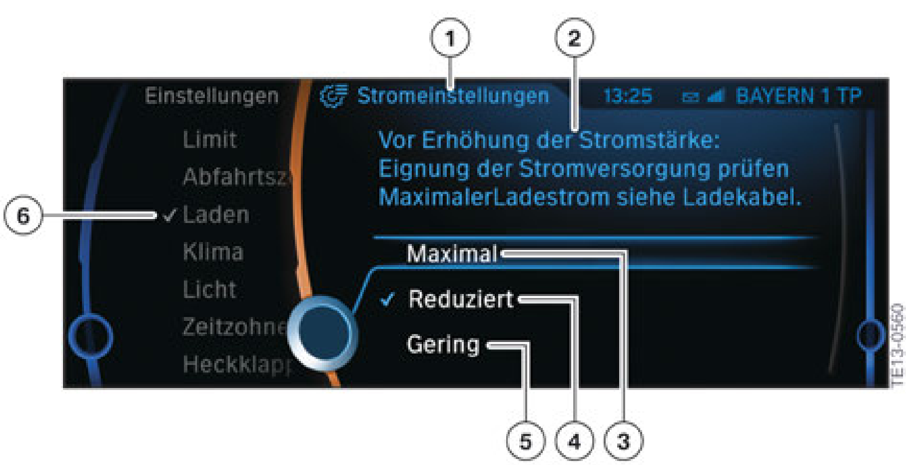
The charging cable is the electrical connection between the AC voltage network and the direct current voltage high-voltage electrical system of the vehicle. The connection to the AC voltage network is effected at a typical household power socket with protective contact, which does not include Electric Vehicle Supply Equipment. In this case the switching and functions of the Electric Vehicle Supply Equipment are integrated in the charging cable. This is called an "In-Cable box". This charging cable for the I01 is always designed for single-phase supply, in line with the charging socket at the vehicle (phase L1 and neutral conductor N) and always includes the protective earth PE, as well as the pilot and proximity line. The connector is designed so that the connection is first made with the protective contact. The ground is grounded via the protective earth.

The charging cable can be housed in the charging cable compartment under the engine compartment lid.

⚠

Please consult the operating instructions of the respective manufacturer for the operation and use of a charging cable with an integrated EVSE.

Employees in BMW Service cannot perform any maintenance or repair work on the charging cable or the EVSE. In the event of a defect with or a malfunction of the charging cable or the EVSE, the manufacturer must be contacted.



Menu for the setting of the current level

Index	Explanation
1	"Current settings" submenu
2	Note "Before increasing the current level: Check suitability of voltage supply. For maximum charge current see charging cable."
3	Charge current "Maximum", 100% of possible current level (information via proximity line)
4	Charge current "Reduced", 75% of possible current level (information via proximity line)
5	Charge current "Low" about 6 A
6	"Settings" menu

The driver has the option to restrict the maximum current level at the power socket via the "Settings" submenu in the vehicle. If the current level at the power socket is insufficient or unknown, it is recommended to adjust the current level to "Reduced" or "Low".

⚠

Charging with Level 1 (occasional use cable) should take about 15 hrs. in the US market but this time varies depending on the on voltage supply and on the vehicle charge settings.

6.2.3. What must be observed when charging the high-voltage battery unit?

⚠

Filling the fuel tank while the high-voltage battery is charging is not permitted!

When the charging cable is connected do not fill the fuel tank and keep a safe distance from highly flammable materials. Otherwise, in the event of an improper connection or if the charging cable is pulled out, there is a risk of personal injury or material damage by burning fuel for example.

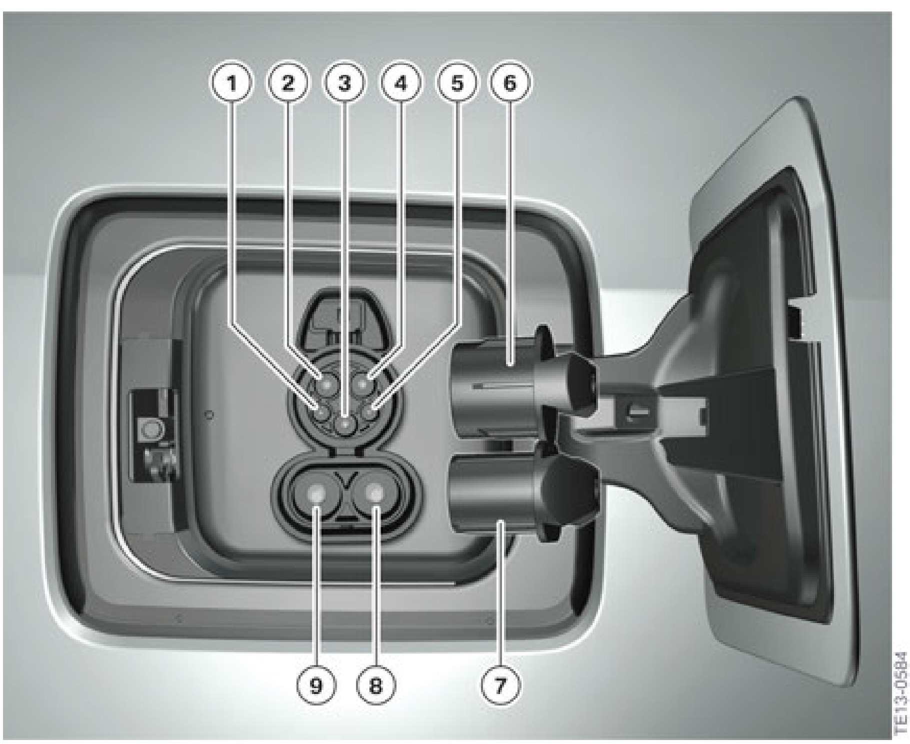
Charging the high-voltage battery using a typical household power socket results in a high continuous load on the power socket, which does not occur with other household appliances. Therefore, the following information must be observed:

- Do not use an adapter or extension cable
- After charging plug the charging plug into the vehicle first and then into the wall
- Avoid tripping hazards and mechanical loads for charging cables and power sockets
- Do not insert the charging plug in damaged power sockets
- Do not use damaged charging cables
- The charging plug and charging cable may be warm when charging the high-voltage battery. If they become too hot, the power socket is not suitable for charging or the charging cable is damaged. Stop charging immediately and have the power socket and charging cable checked by an electrician
- In the event of repeated charging faults or terminations contact a suitably qualified Service employee

- Only use power sockets protected against moisture and weathering
- Do not touch contact areas of power sockets with fingers or objects
- Never repair or modify a charging cable yourself
- Remove cable on both sides before cleaning. Do not immerse in fluids.
- Do not go through a car wash during charging
- Only charge at power sockets checked by an electrician
- Observe special information in the operating instructions for charging at unknown or unfamiliar infrastructure/power sockets. Set the charging current in the vehicle to "low".

6.2.4. Charging socket at the vehicle

The charging socket at the I01 is located precisely where the fuel filler neck is located in a conventional vehicle with a combustion engine. Just like the fuel filler flap has to be opened in a conventional vehicle, the charging socket cover also has to be opened in the I01. Press the charging socket cover to operate the release button and unlock the charging socket cover. The actual charging socket is then protected against moisture and dirt contamination by another lid. The charging socket satisfies the protection class IP5K5. The charging socket cover and the connector assignment are shown in the following graphic.



Charging socket at the vehicle for combo charging, type 1 (US market)

Index	Explanation
1	Connection for proximity line
2	Connection for phase L1
3	Connection for protective earth (PE)
4	Connection for neutral conductor (N)
5	Connection for pilot line
6	Protective cap for AC charging socket
7	Protective cap for DC charging socket
8	Connection for DC ground cable
9	Connection for DC positive wire

The high-voltage cables of the charging socket are connected to the electrical machine electronics (via the KLE in the US market). Phase L1 and neutral conductor N are designed as shielded high-voltage cables and end with a flat high-voltage connector at the alternating current connection of the electrical machine electronics. The pilot line and the proximity line are simple signal lines. These signal lines are also shielded and end at a connector in the charging interface module (LIM). The protective earth is connected electrically to ground in close proximity to the charging socket. This ensures proper grounding.

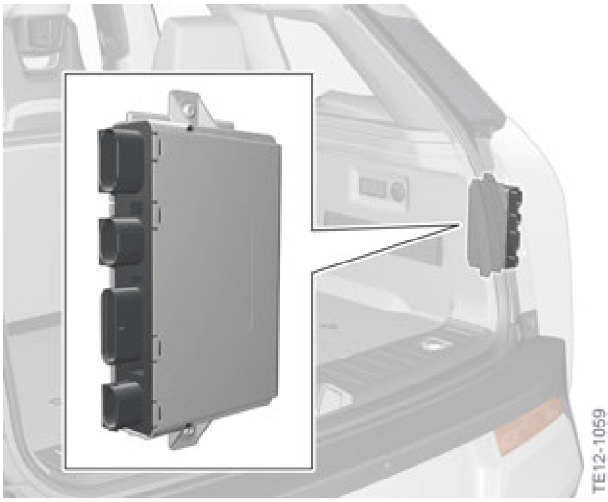
A C-shaped fiber-optic conductor runs around the charging socket at the vehicle. With this C-shaped fiber-optic conductor it is possible to show the status for charging. The lighting of the fiber-optic conductor is effected using two LEDs which are controlled by the LIM.

⚠

The charging socket at the vehicle can only be replaced together with the high-voltage cable as one unit.

6.2.5. Charging interface module (LIM)

The LIM enables communication between the vehicle and charging station. The voltage supply of the LIM control unit is effected by terminal 30F. There is a terminating resistor for the PT-CAN in the LIM. The LIM can also wake up the control units in the vehicle electrical system when the charging cable is connected. There is also a line which runs directly from the LIM control unit to the electrical machine electronics. Only when the LIM control unit enables the charging procedure via a signal on this line, does the electrical machine electronics start the voltage conversion and thus the charging procedure.

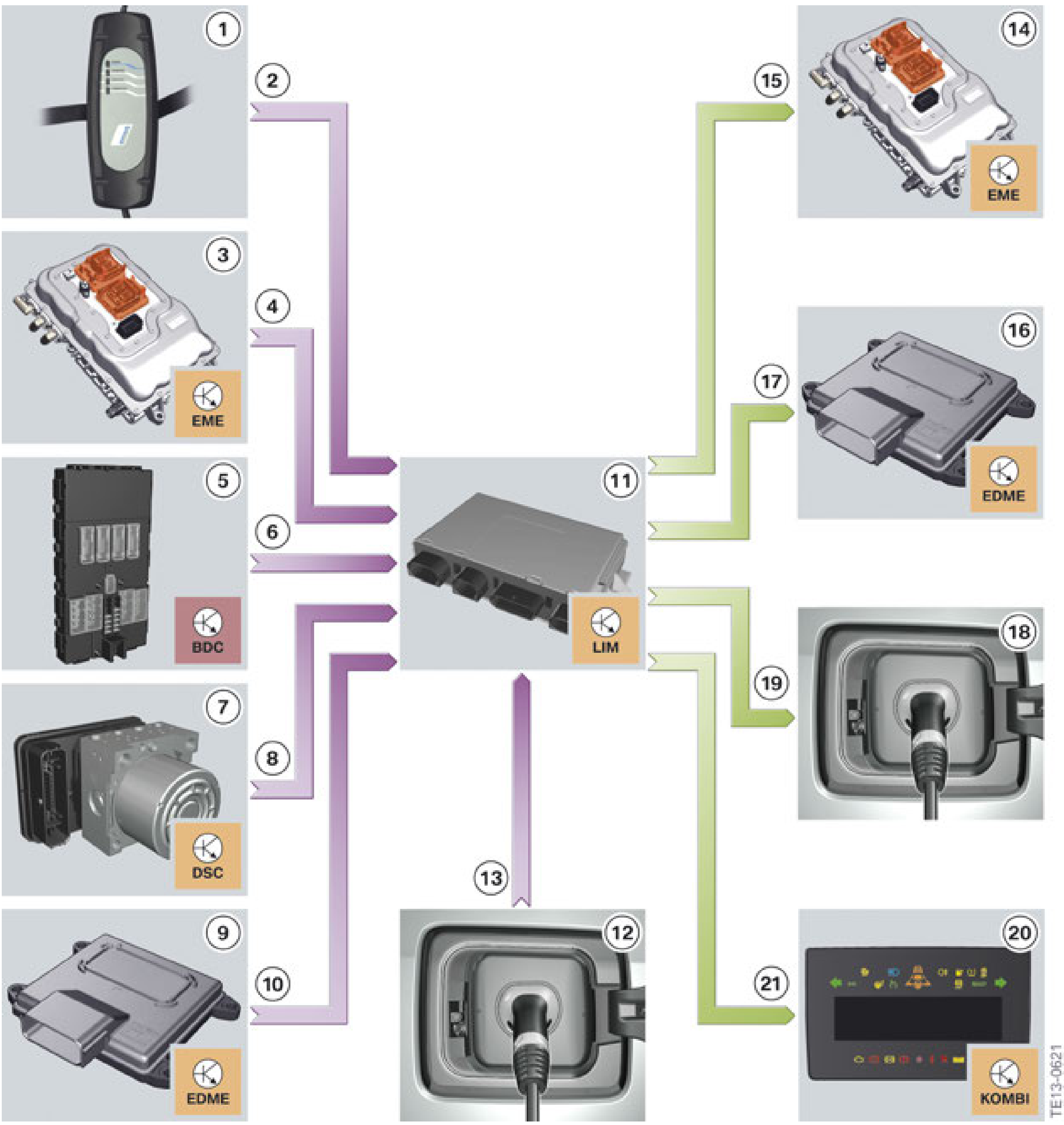


Installation location of LIM

The main tasks of the LIM are:

- Communication with EVSE via pilot and proximity line
- Coordinating the charging procedure
- Activation of the LEDs for displaying the charging status
- Activation of the electric motor for locking the charging socket cover

6. Charging the High-voltage Battery



Input/Output for charging interface module

Index	Explanation
1	Electric Vehicle Supply Equipment
2	Information whether the AC voltage network is available and the charging cable is correctly connected, as well as the maximum available current level
3	Electrical machine electronics (EME)
4	Requested charging power, charging voltage and charging current level (set-point values)

6. Charging the High-voltage Battery

Index	Explanation
5	Body Domain Controller (BDC)
6	Terminal status, driving readiness switched off
7	Dynamic Stability Control (DSC)
8	Vehicle speed
9	Electrical Digital Motor Electronics (EDME)
10	Status of parking lock (engaged/disengaged), power requirement in the high-voltage vehicle electrical system
11	Charging interface module (LIM)
12	Charging socket at the vehicle
13	Status of the charging socket cover and the charging plug
14	Electrical machine electronics (EME)
15	Actual value of the set charging power, charging voltage and charging current level, charging release
16	Electrical Digital Motor Electronics (EDME)
17	Information whether the charging cable is connected and the charging procedure is active
18	Charging socket
19	Activation of LEDs for locator lighting and charging status display, status of the charging socket cover.
20	Instrument cluster
21	Signals for the display of charging information

Communication with EVSE via pilot and proximity line

The pilot line and the proximity line are realized as simple signal lines. These signal lines are shielded and end at a connector in the charging interface module LIM.

Via the proximity line the connection of the charging plug in the charging socket at the vehicle is identified, as well as the maximum current carrying capacity of the charging cable determined. In the connector of the charging cable there is an ohmic resistor between the proximity connection and the protective earth. The LIM applies a measured voltage and calculates which value the resistance in the proximity line has. The resistance value specifies which maximum current level is allowed for the charging cable used (dependent on the line cross-section). The assignment of resistance – current level is specified in the standard IEC 61851.

The pilot line is required for the determination and transmission of the maximum available charging current level. The pilot signal is a bipolar rectangle signal (-12 V to +12 V). The voltage and the duty cycle are used for the communication of different statuses between EVSE and I01:

- Electric vehicle is ready to charge (Yes/No)
- Fault present (Yes/No)
- Maximum charge current which can be provided by the AC voltage network.

Coordinating the charging procedure

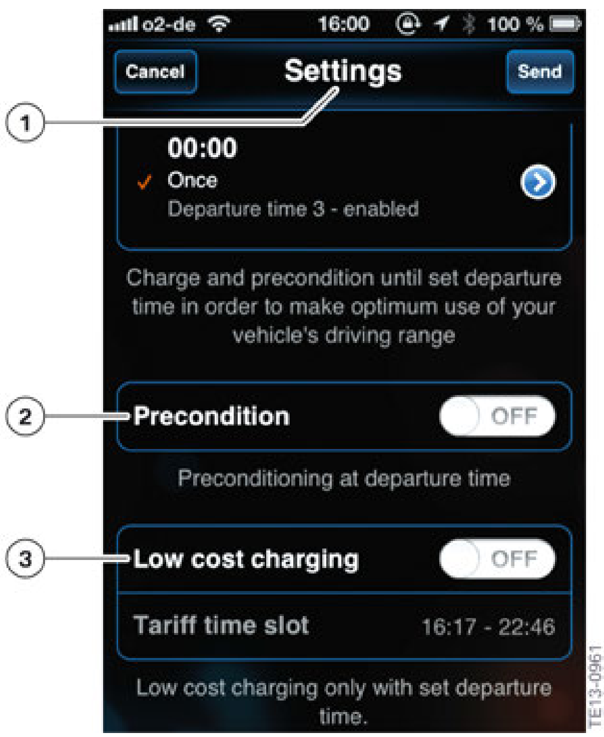
The LIM control unit coordinates the start and finish of the charging procedure.

There are two actions required by the customer at the start of the charging procedure:

1 Set the start time for charging

2 Connect the charging cable.

Using the controller and the menu in the central information display CID the customer can set and adjust the start time for charging in the vehicle. The customer has a second range of adjustment with the "BMW i Remote app" for the iPhone™. The customer can select to start the charging procedure immediately after connecting the charging cable or specify a time at which the charging procedure should start.



BMW i Remote app: Charging the high-voltage battery

Index	Explanation
1	Settings for charging, e.g. departure time
2	Switching climate control on/off at departure time
3	Switching charging on/off at reasonable electricity rate

If the customer connects the charging cable, the LIM control unit wakes up the control units in the vehicle electrical system (if they have not already been woken up by another event). The LIM control unit uses the wake-up line wired directly to the BDC control unit. Then the LIM control unit checks the functional prerequisites for charging and receives information about the conditions relevant for safety via the powertrain CAN.

6. Charging the High-voltage Battery

These checks are summarized in the following list:

- Driving readiness off
- Driving speed zero
- Parking lock engaged
- Charging cable connect (proximity)
- Communication with Electric Vehicle Supply Equipment OK (pilot)
- High-voltage system active and trouble-free.

When all prerequisites for charging are satisfied, the high-voltage power management in the EME requests a charging power from the power electronics in the EME and starts the charging procedure. The EME control unit sends not only setpoint values for the charging power, but also specifies limit values for the maximum charging voltage and the maximum charge current. These values are based on the current condition (e.g. state of charge and temperature) of the high-voltage battery and according to the power requirement of the rest of the vehicle electrical system (e.g. for climate control). The EME control unit cleverly implements these setpoint values, i.e. it takes into consideration not only the setpoint values, but other marginal conditions. These include the actual status of the electrical machine electronics (fault, temperature), as well as the current level restricted by the AC voltage network and the charging cable.

Only when the communication between the vehicle (LIM) and Electric Vehicle Supply Equipment has been started successfully via the pilot line, is the voltage applied to the phase L1. This also gives further protection for customers and Service employees against the dangers of electricity.

Activation of the LEDs for displaying the charging status

A C-shaped fiber-optic conductor runs around the charging socket at the vehicle. With this C-shaped fiber-optic conductor it is possible to show the status for charging. At the same time, this fiber-optic conductor is used as locator lighting for the charging socket. The lighting of the fiber-optic conductor is effected using two LEDs which are controlled by the LIM.

Locator lighting:
The locator lighting of the charging socket is used as an orientation aid by the driver for the connection and disconnection of the charging plug.
The two LEDs light up in white as soon as the charging socket cover has been opened. The locator lighting remains switched on as long as the bus systems are active. As soon as a charging plug has been identified as correctly connected, the locator lighting is switched off and the initialization status is displayed.

6. Charging the High-voltage Battery

Initialization:
The initialization starts immediately after the correct connection of the charging plug. The initialization phase takes up to 10 seconds.
The LEDs flash in an orange color at a frequency of 1 Hz.
After successful initialization the charging of the high-voltage battery can be started.

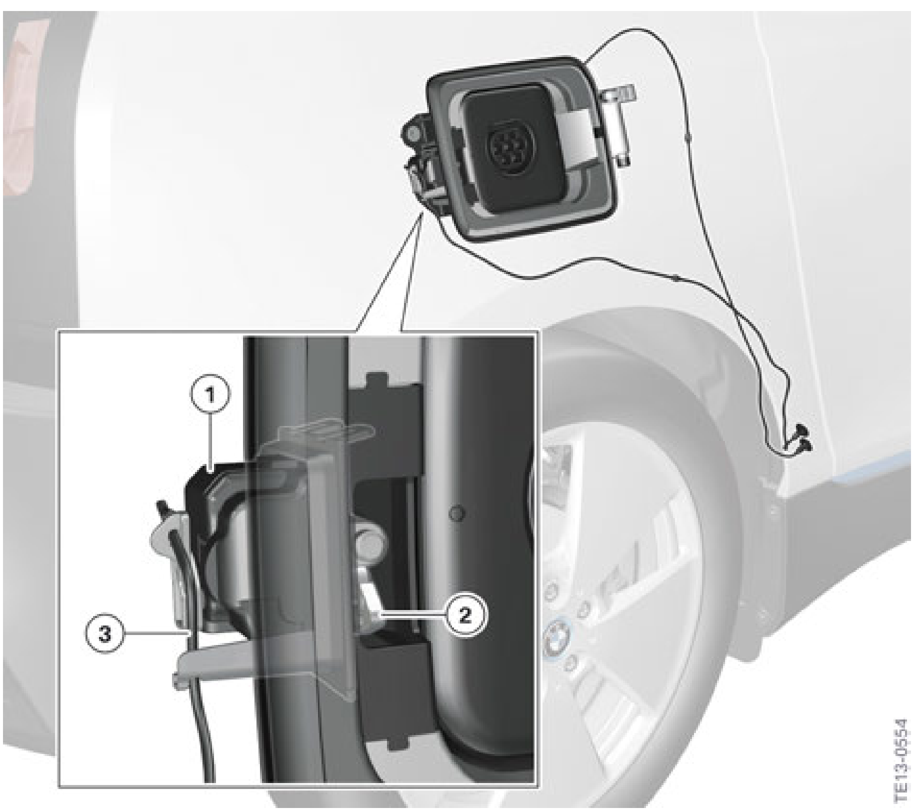
Charging active:
The currently active charging procedure of the high-voltage battery is displayed by flashing blue LEDs. The flashing frequency is about 1.42 Hz.
Charging interval:
Charging interval or charging readiness present when the initialization phase was completed successfully and the charging start is sometime in the future (e.g.: charging at a less expensive time).

Charging complete:
The state of charge of the high-voltage battery "fully charged" is indicated by permanently green LEDs.

Fault during charging:
If faults occur during the charging procedure, then this status is displayed by flashing red LEDs. The LEDs flash three times at a frequency of about 2.0 Hz and an interval of about 0.8 seconds between the three groups.

The LEDs for these displays are activated after the charging plug is connected or after unlocking/locking the vehicle for 12 seconds. If during this time the vehicle is unlocked/locked again, the display lasts for another 12 seconds.

Locking the charging socket cover



Locking the charging socket cover

6. Charging the High-voltage Battery

Index	Explanation
1	Electric motor for locking the charging socket cover
2	Locking hook
3	Bowden cable for the emergency operation of the charging socket cover

The charging socket cover is held closed by a spring-activated locking hook. The locking hook is a part of the central locking drive for the charging socket cover. The unlocking/locking of the charging socket cover is effected using an electric motor. This electric motor is activated by the LIM. The request for unlocking/locking the charging socket cover comes from the BDC.

A microswitch is also installed in the central locking drive. The status of the microswitch (actuated/not actuated) provides information on the status of the charging socket cover (open/closed). In rest position, i.e. when the charging socket cover is closed, the microswitch is not actuated. The microswitch is actuated when the charging socket cover is open. The microswitch is also actuated when the charging socket cover is pressed and held.

In the event of an electrical fault, e.g. failure of both the charging socket cover and the DC charging plug can be unlocked manually.

Emergency release buttons

Index	Explanation
1	Button for the emergency release of the charging socket cover
2	Button for the emergency release of the DC charging plug

The rear door on the side on which the charging socket cover is located must be opened.

When the rear door is open two blue buttons are visible in the lower area. To unlock the charging socket cover the upper blue button must be pulled.

The DC charging plug is unlocked by pulling the lower blue button.

6.2.6. Power electronics in the (EME)

The power electronics for the conversion of the AC voltage coming from the charging socket to direct current voltage required for charging the high-voltage battery is housed in the electrical machine electronics. The AC voltage is fed to the electrical machine electronics via a single-phase supply. The input voltage, which can be processed by the electrical machine electronics, may be in the following range: 100 V to 240 V, 50 Hz or 60 Hz.

The power electronics module is a unidirectional AC/DC converter, i.e. a rectifier.

At the output, which is separated galvanically from the input, the electrical machine electronics supplies an electronically adjustable direct current voltage or an electronically adjustable direct current flows. The specifications for the output voltage and the output current come from the function "High-voltage power management" in the EME control unit. The values are calculated and adjusted by the EME so that the high-voltage battery is optimally charged and the other consumers in the I01 are supplied with sufficient electrical energy.

The EME is designed so it can provide a maximum electrical power of 3.7 kW on the output side. This is charging configuration is used (in the US market) only when charging with the occasional use cable via a household 120V socket. And it sufficient to fully charge the I01 high-voltage battery under optimal marginal conditions in about 16 hours.

6.3. AC charging with 7.4 kW

AC charging with 7.4 kW is standard equipment for the US market (SA 4U8 AC Fast Charging) and it is possible via a permanently installed AC charging station (wallbox). In order to deliver the charging power of 7.4 kW, the AC charging station must provide 32 A at a phase connection. P = U x I = 230 V x 32 A = 7360 W = 7.4 kW.

6. Charging the High-voltage Battery

BMW i charging station

Index	Explanation
1	BMW i charging station
2	ON/OFF button
3	Charging plug

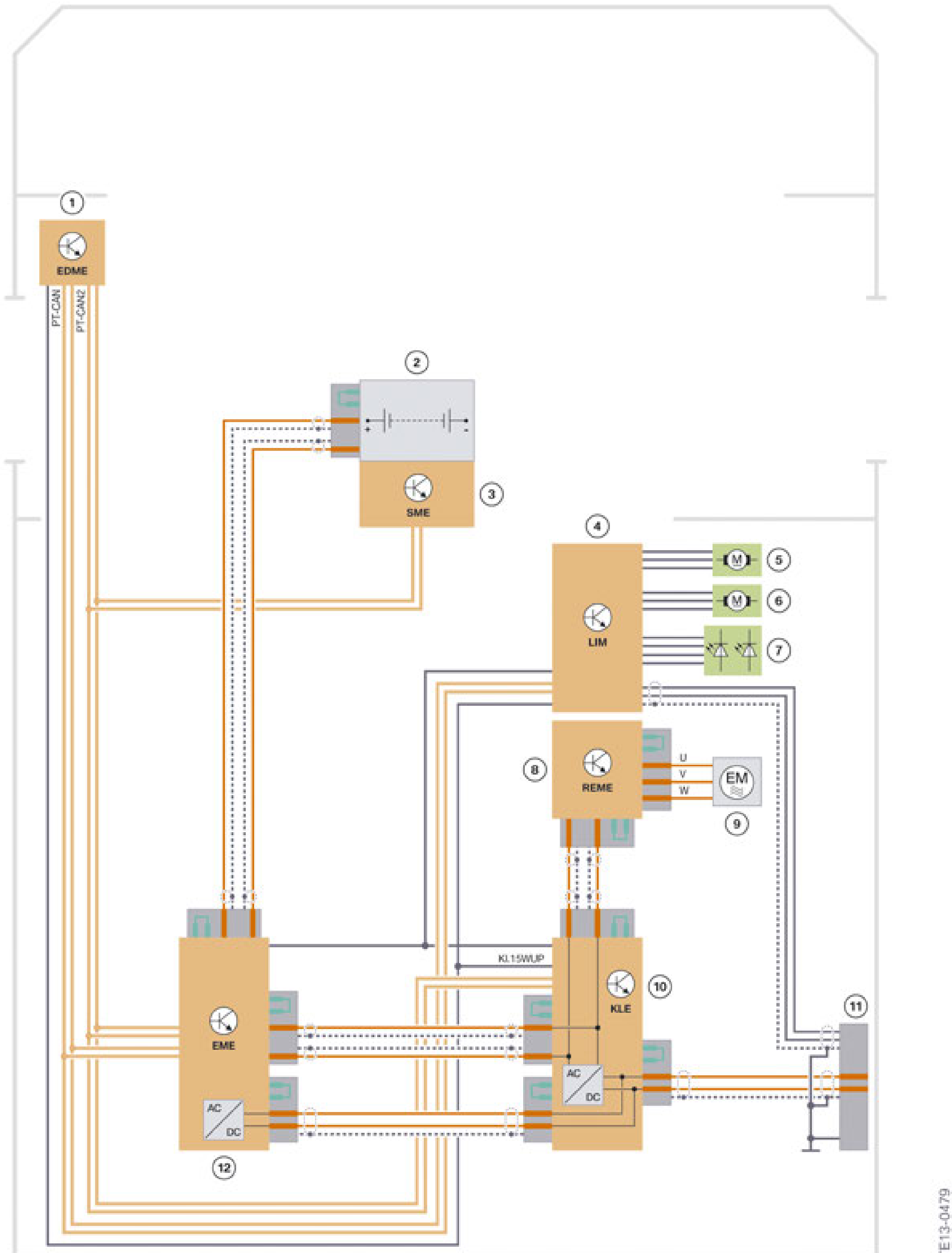
⚠

AC charging with 7.4 kW (SA 4U8 AC Fast Charging) is standard equipment for the US market.

The EVSE is located inside the AC charging station. With this stationary version of the EVSE, the time to fully charge a discharged high-voltage battery in the I01 is cut by half, when compared to AC charging with 3.7 kW (standard equipment in European vehicles).

The same components are required for both the AC charging at 7.4 kW (in the US) and for AC charging at 3.7 kW (in EU). In order to deliver the additional 3.7 kW of charging power, the 7.4 kW system requires a different charging cable and the installation of a convenience charging electronics (KLE). These two components are described here in detail.

6.3.1. Wiring diagram



Wiring diagram for AC charging at 7.4 kW (US market)

Index	Explanation
1	Electrical Digital Motor Electronics (EDME)
2	High-voltage battery unit
3	Battery management electronics (SME)
4	Charging interface module (LIM)
5	Electric motor for the connector fastener
6	Electric motor for the central locking system of the charging socket cover
7	Locator and status lighting
8	Range Extender Electrical Machine Electronics (REME)
9	Range extender electrical machine
10	Convenience charging electronics (KLE)
11	Charging socket at the vehicle
12	Electrical machine electronics (EME)

6.3.2. Charging cable

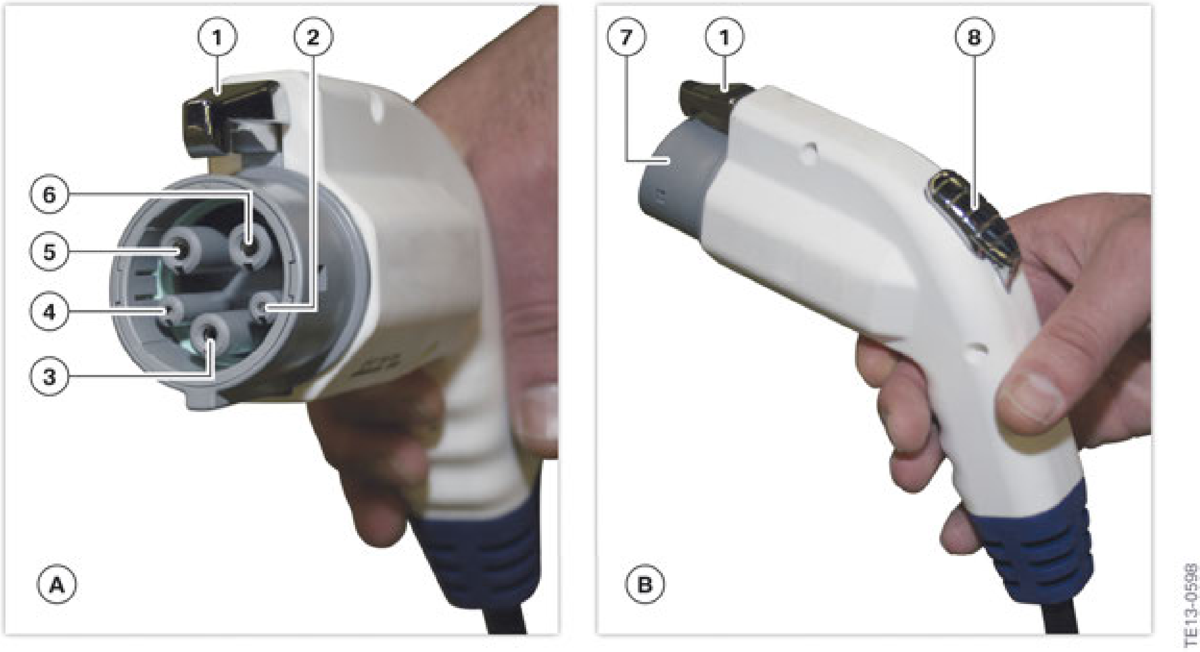
This charging cable for the I01 is always designed for single-phase supply, in line with the charging socket at the vehicle (phase L1 and neutral conductor N) and always includes the protective earth (PE), as well as the pilot line. The ground is grounded via the protective earth. Using the pilot line the correct connection to the AC voltage network and its maximum available charging current level can be identified or transmitted. In the connector an ohmic resistor is also installed between the proximity connection and the protective earth. The resistance value specifies which maximum current level is allowed for the charging cable used (dependent on the line cross-section). The assignment of resistance – current level is specified in the standard IEC 61851. Using the resistance in the proximity line the LIM in the vehicle can identify whether the charging cable is properly connected and which current level is allowed for this charging cable. The convenience charging electronics applies a measured voltage and calculates which value the resistance in the proximity line has.

The connection with the AC voltage network is done via a fixed charging station, which includes the Electric Vehicle Supply Equipment. The appropriate charging cable for this purpose is solely the electrical connection between charging station and charging socket at the vehicle.

The charging cable for AC Charging at 7.4 kW (standard equipment in US) and AC charging at 3.7 kW (Standard equipment in Europe) have the same connector for the connection at the vehicle. The connectors are only distinguished by their differing resistances in the proximity line, appropriate to the current carrying capacity of the charging cable. The following graphic shows the structure and the connections of this connector.

I01 High-voltage Components

6. Charging the High-voltage Battery



Connector of the charging cable for the connection to the vehicle (standardized i.a.w. IEC 62196-2: Type 1)

Index	Explanation
A	View from the side of the electrical connection
B	View from the side of the handle
1	Mechanical locking
2	Connection for pilot line
3	Connection for protective earth
4	Connection for proximity line
5	Connection for phase L1
6	Connection for neutral conductor (N)
7	Mechanical guide/connector housing
8	Button for the mechanical unlocking of the connector before removal

The connector of the charging cable and the charging socket in the vehicle are protected against direct contact. In addition, the geometry of the contacts is designed so that the following sequence results for the connection of the connector with the charging socket:

1 Proximity line

2 Protection earth (PE)

3 Neutral conductor (N), phase L1

4 Pilot line.

I01 High-voltage Components

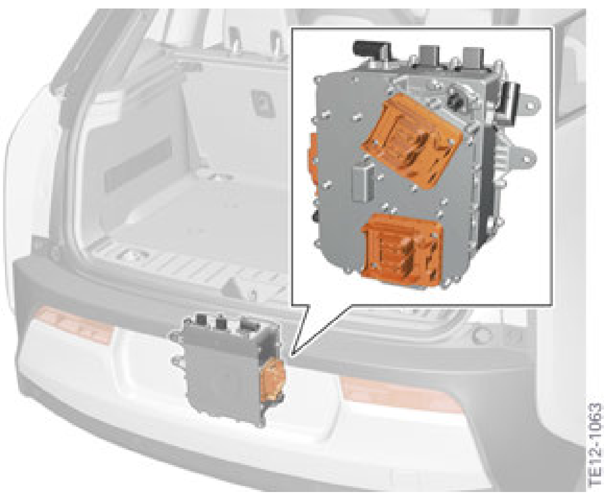
6. Charging the High-voltage Battery

Only when the communication between the vehicle (LIM) and Electric Vehicle Supply Equipment has been started successfully via the pilot line, is the charging voltage applied to the phase L1. This also gives further protection for customers and Service employees against the dangers of electricity.

With this stationary version of the EVSE the lines can transmit up to 7.4 kW. The AC/DC converter in the convenience charging electronics (3.7 kW) and in the electrical machine electronics (3.7 kW) ensure the conversion of the single-phase AC voltage to the direct current voltage required for charging the high-voltage battery. The duration of the full charge of an empty high-voltage battery of the I01 can then be reduced to three to four hours.

6.3.3. Convenience charging electronics

The convenience charging electronics (KLE) is installed in the rear of the I01, in an area separated from the luggage compartment.



Installation location of the convenience charging electronics

The main task of the convenience charging electronics (KLE) during AC charging at 7.4 kW is the conversion of the AC voltage to direct current voltage. A rectifier switching in the KLE comprising two modules completes this task. These power electronics modules are controlled by a control unit, which also bears the same name: Convenience charging electronics (KLE).

The convenience charging electronics is designed so it can provide a maximum electrical power of 3.7 kW on the output side. Together with the 3.7 kW from the standard power electronics of the EME, this is sufficient in the I01 to fully charge the high-voltage battery (at optimal marginal conditions) in three to six hours. This short charging time means enhanced comfort for the customer when using the I01. For this reason, this charging electronics was called "convenience charging electronics".

The AC voltage is fed to the vehicle or the convenience charging electronics via a single-phase supply. The input voltage, which can be processed by the convenience charging electronics, may be in the following range: 100 V – 240 V, 50 Hz or 60 Hz. At the output, which is separated galvanically from the input, the convenience charging electronics supplies an electronically adjustable direct current voltage or an electronically adjustable direct current flows. The specifications for the output voltage and the output current come from the function "High-voltage power management" in the EME control unit. The values are calculated and adjusted by the KLE so that the high-voltage battery is optimally charged and the other consumers in the I01 are supplied with sufficient electrical energy.

Although the convenience charging electronics works at a high degree of efficiency of well over 90%, active cooling is required at full performance. For this reason it is integrated in the cooling circuit of the electric motor.

In addition to the voltage conversion and energy provision, the convenience charging electronics also assumes safety functions which protect the customer and Service employee from the dangers of electricity. Nevertheless, the following applies:

The convenience charging electronics is a high-voltage component!

Only qualified Service employees can work on the convenience charging electronics while observing the repair instructions.

Before working on the convenience charging electronics, it is essential to observe the electrical safety rules.

Similar to all high-voltage components, the convenience charging electronics can only be replaced in Service if required, it cannot be opened or repairs.

The manufacturer of the convenience charging electronics is "Meta System".

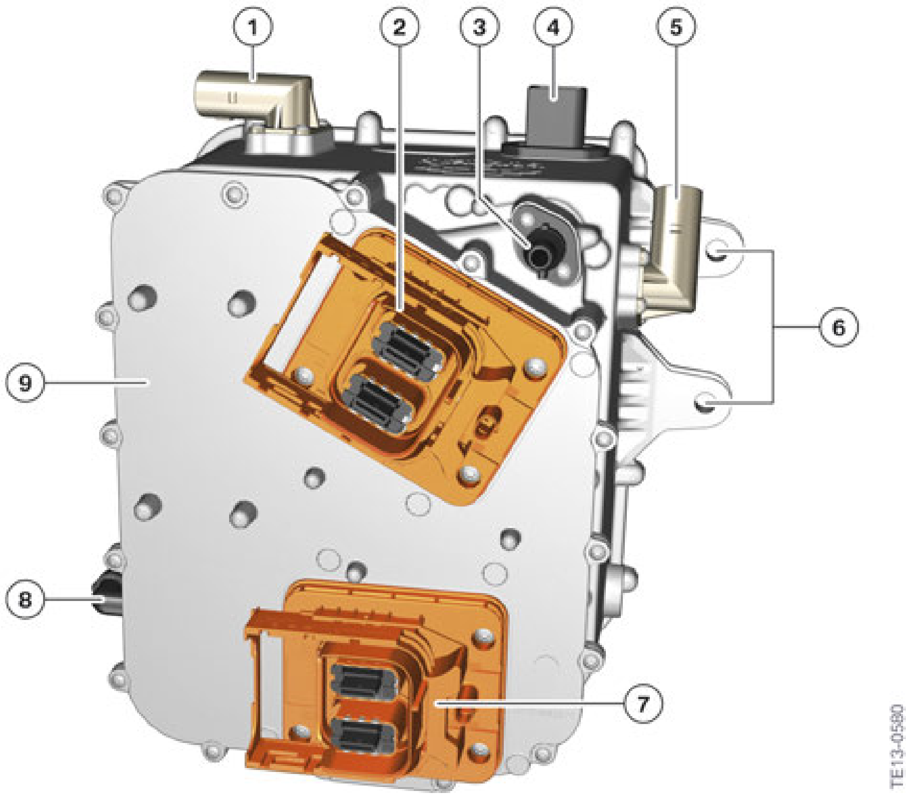
Connections

The connections at the convenience charging electronics can be divided into four categories:

- Low-voltage connections
- High-voltage connections
- Connection for potential compensation line
- Connections for coolant lines.

The following graphic shows all connections of the convenience charging electronics:

6. Charging the High-voltage Battery



Connections of the convenience charging electronics in the version for AC charging at 7.4 kW

Index	Explanation
1	High-voltage cable (AC) from the charging socket
2	High-voltage cable (DC) to the electrical machine electronics
3	Coolant line (supply)
4	Low-voltage cables
5	High-voltage cable (AC) from KLE to EME
6	KLE mounting (potential compensation contact)
7	High-voltage cable (DC) from REME
8	Coolant line (return)
9	Convenience charging electronics (KLE)

Low-voltage connections

The multipolar low-voltage connector at the convenience charging electronics joins the following lines and signals:

- Voltage supply for the KLE control unit (terminal 30B, terminal 30 from the power distribution box at the front and ground)
- Voltage supply via terminal 30C (quick shutdown in the event of an accident)
- Bus system PT-CAN2

6. Charging the High-voltage Battery

- Wake-up lines to the BDC control unit and EDME control unit
- Control line from the LIM, with which the charging procedure is released
- Inputs and outputs of the circuit of the high-voltage interlock loop (KLE control unit evaluates the signal).

The KLE control unit is supplied with voltage via terminal 30 and terminal 30B and has two wake-up line outputs. The convenience charging electronics can also wake up the control units in the vehicle electrical system when the charging cable is connected.

Via the bus system PT-CAN2 the KLE control unit receives the request and the control signals for charging. There is also a line which is wired directly from the LIM to the convenience charging electronics. Only when the LIM enables the charging procedure via a signal on this line, does the convenience charging electronics start the voltage conversion and thus the charging procedure.

The high-voltage connectors of the convenience charging electronics are also integrated in the circuit of the high-voltage interlock loop. Via the low-voltage connection the test signal is forwarded to the high-voltage interlock loop and to the other high-voltage components. The KLE control unit monitors the test signal and interrupts the charging procedure if it is not in the specified range.

High-voltage connections

There are three high-voltage connections at the convenience charging electronics to connect the high-voltage cables to the charging socket (1 x) and to the electrical machine electronics (2 x). If the I01 vehicle is equipped with a range extender, the convenience charging electronics has another high-voltage connection in order to connect the range extender electrical machine electronics REME.

6. Charging the High-voltage Battery

Connection to components...	Number of contacts, voltage type, shielding	Type of connection	Contact protection
Charging socket	• 1-phase (phase L1 and neutral conductor N) • AC voltage • 1 shielding for both lines	Round connector	- HV contacts cannot be touched with fingers - High-voltage interlock loop
Electrical machine electronics	Line from the AC/DC converter of the KLE to the EME • Two-pin • Direct current voltage • 1 shielding per line Line from the KLE to the EME • 1-phase (phase L1 and neutral conductor N) • AC voltage • 1 shielding per line	Flat high-voltage connector with mechanical lock Round connector	- Cover over the contact blades - High-voltage interlock loop - HV contacts cannot be touched with fingers
Range Extender Electrical Machine Electronics	• Two-pin • Direct current voltage • 1 shielding per line	Flat high-voltage connector with mechanical lock	- Cover over the contact blades - High voltage interlock loop

Connection for potential compensation line

Similar to all high-voltage components, the housing of the convenience charging electronics must be connected electrically to ground. Only then can the automatic monitoring of the isolation resistance work properly. Also with the convenience charging electronics, the protective earth of the AC voltage network at the charging socket is also connected to ground. Protective earth (PE) and housing of the convenience charging electronics must have the same potential, so that any isolation fault can be identified on the AV voltage side of the AC/DC converter. The housing of the KLE is connected to the Drive module using four screws for this purpose.

⚠

The charging of the high-voltage battery in the I01 can only be effected if the potential compensation line is properly connected to the convenience charging electronics.

Connections for coolant lines

The convenience charging electronics is integrated in the cooling circuit of the electric motor. This cooling circuit is described in detail in chapter 11 "Cooling the electric motor components".

6.4. Combined Charging System

The "Combined Charging System", or combo charging for short, is a charging system for electric and plug-in hybrid cars i.a.w. IEC 62196 and supports both AC charging (alternating current) and DC charging (direct current). A Phoenix contact was developed in cooperation with the automobile manufacturers and is essentially made up of a charging socket on the vehicle side, the so-called inlet, and a charging plug, in which the two individual charging plugs are integrated for AC and DC charging. Thanks to this universal connector system only one charging socket is required at the vehicle in order to cover the various charging options of AC and DC charging. A distinction is made between connections of type 1 (for the US market) and type 2 (for the European market). The contacts for the DC connection are the same in both versions. Due to the larger DC contacts in comparison to AC charging, currents of up to 200 A are possible, whereby Fast charging, for example during transport, can be possible.

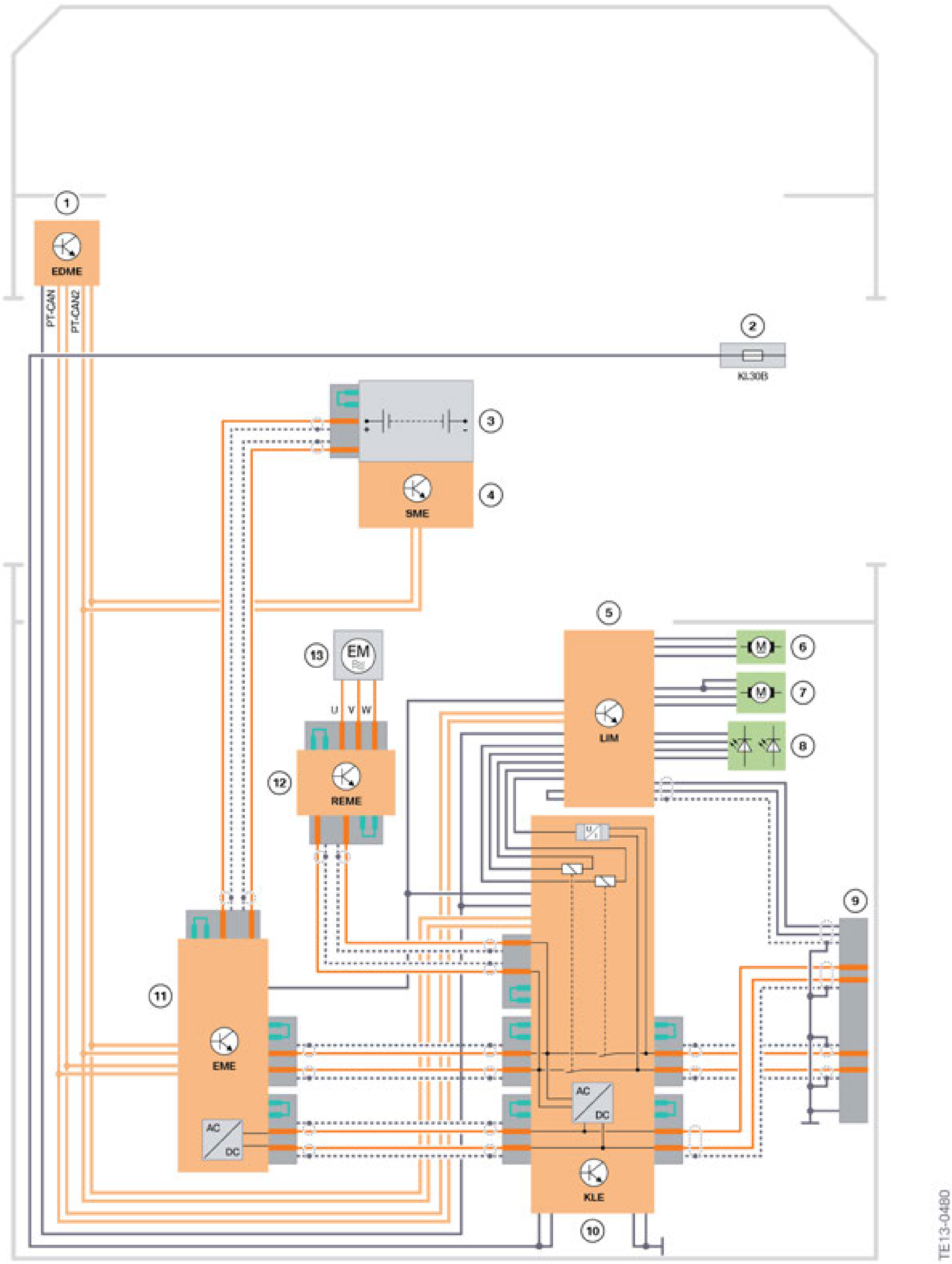
In the I01 two versions of the combo charging are offered, depending on the AC charging power:

- Combo charging at 3.7 kW AC charging power (standard equipment in Europe)
- Combo charging at 7.4 kW AC charging power (standard equipment in USA)

⚠

In US market vehicles option 4U7 DC Fast Charging is offered as optional equipment; this option includes the necessary hardware for the Combo charging at 7.4 kW AC charging or DC charging.

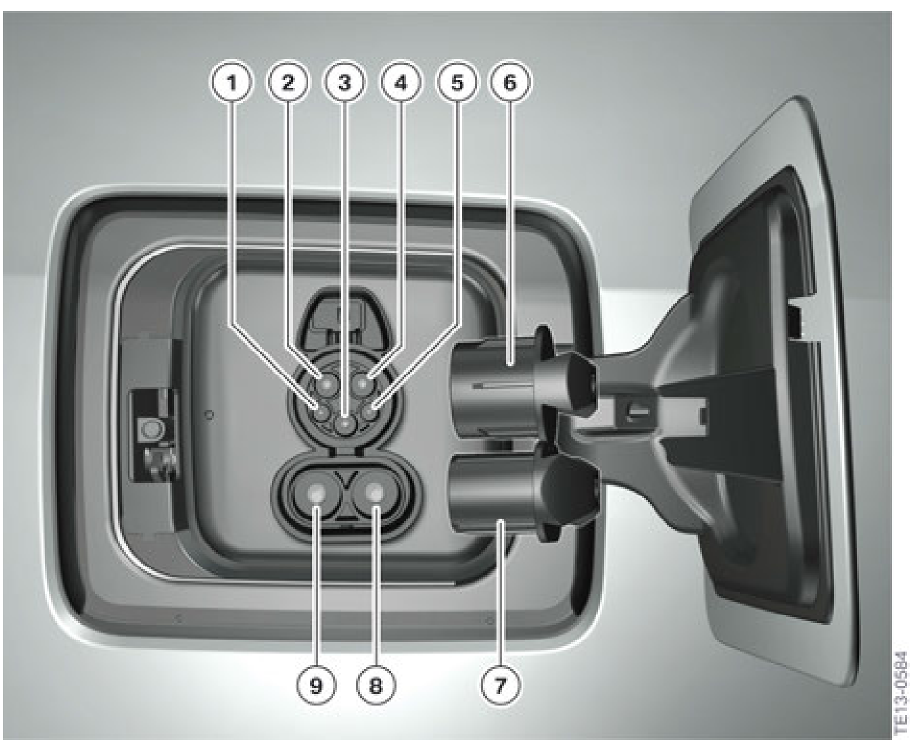
6.4.1. Wiring diagrams



Wiring diagram for combo charging at 7.4 kW (US market)

Index	Explanation
1	Electrical Digital Motor Electronics (EDME)
2	Voltage supply for KLE (terminal 30B)
3	High-voltage battery unit
4	Battery management electronics (SME)
5	Charging interface module (LIM)
6	Electric motor for the connector fastener
7	Electric motor for the central locking system of the charging socket cover
8	Locator and status lighting
9	Charging socket at the vehicle
10	Convenience charging electronics (KLE)
11	Electrical machine electronics (EME)
12	Range Extender Electrical Machine Electronics (REME)
13	Range extender electrical machine

6.4.2. Charging socket at the vehicle



Charging socket at the vehicle for combo charging, type 1 (US market)

Index	Explanation
1	Connection for proximity line
2	Connection for phase L1
3	Connection for protective earth (PE)
4	Connection for neutral conductor (N)
5	Connection for pilot line
6	Protective cap for AC charging socket
7	Protective cap for DC charging socket
8	Connection for DC ground cable
9	Connection for DC positive wire

The charging socket in the vehicle for combo charging includes the sockets for AC charging and the socket for DC charging. The advantage of this charging socket configuration is that the customer can use both AC charging stations and DC charging stations for charging the high-voltage battery.

During DC charging an electric arc may form by disconnecting the charging plug during the charging procedure. To prevent this the charging plug is locked electromechanically during the charging procedure. This way a possible dangerous situation for the user is avoided. An ergonomic handle at the charging plug and low connection and disconnection forces enable comfortable operation of the connector using only one hand.

Simultaneous charging via AC and DC is not possible.

6.4.3. LIM

The main tasks of the LIM are already described previously in this chapter. Only the additional functions and tasks of the LIM for combo charging are described here. A new tasks of the LIM is, for example, the activation of the switch contactors in the KLE for DC charging.

Communication

Also for combo charging the LIM assumes the communication between the vehicle and the charging station. The communication between the vehicle and the charging station is enabled and the charging procedure is controlled via the pilot and proximity line.

Using the proximity line the correct connection of the charging cable at the vehicle is identified and the maximum current carrying capacity of the charging cable is measured by the LIM using the resistor in the charging cable.

The high-voltage power management in the EME sends a request to charge the high-voltage battery to the LIM via the PT-CAN. The LIM then starts the communication with the charging station via the pilot line. The information about charging requirement, charging range and accuracy is exchanged. Only after successful communication start is the charging voltage applied to the phase L1 or to the DC positive wire and ground cable. This also gives further protection for customers and Service employees against the dangers of electricity.

The LIM sends a signal for "Enable charging" for AC charging via the separate line to EME and KLE.

Activation of the switch contactors in the KLE

For DC charging the LIM closes the two switch contactors in the KLE, thus enabling the shift through from the direct current voltage from the DC charging station to the high-voltage battery. The LIM tests after every completed DC charging procedure the DC switch contactors so that a switch contactor label (switch contactor cannot open the contacts) is identified. A switch contactor label (single or double) is identified by the LIM and sent to the EME as a fault code. If during the charging procedure no valid pilot signal is identified by the LIM, the LIM must open the DC switch contactors within 200 ms.

The direct current voltage applied at the charging socket is measured by the KLE. The measured value is then sent to the LIM as an analog signal. The LIM then sends the calculated value via PT-CAN to other control units.

Emergency charging

If both the high-voltage and the 12 V battery are discharged, the emergency charging of the 12 V battery is automatically started when the charging cable is connected. As the two batteries are discharged, there is also no voltage supply of the 12 V vehicle electrical system and the LIM is in this case initially not working. So that the LIM can start communication with the charging station and thus also the charging procedures, a special voltage supply of the LIM is required. The voltage supply for the LIM is effected in this case by the pilot line. The energy used by the pilot line is so low that the voltage evaluation for the EVSE is not affected.

In order to identify emergency charging the voltage value of terminal 30F is evaluated. The evaluation circuit is located in the LIM. If the voltage value of terminal 30F falls below 6 V and the pilot line is correctly connected, the evaluation circuit drags the voltage value on the pilot line to a value of 6 V. This voltage value corresponds to the message at the charging station that the vehicle is ready for charging. The charging station is thus prompted to apply the vehicle voltage.

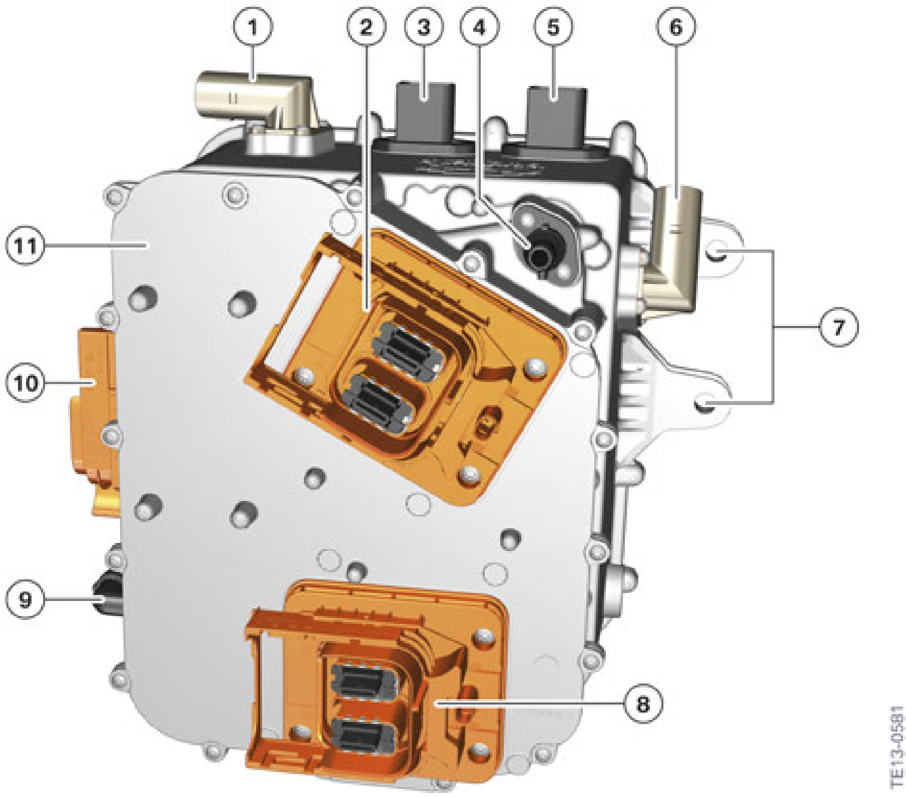
6.4.4. Convenience charging electronics (KLE)

Convenience charging electronics for combo charging at 7.4 kW AC charging power

The KLE version installed for combo charging at 7.4 kW AC charging power is responsible for the contact of all HV connections and the housing of the two DC switch contactors.

In this case the KLE has **no** rectifier switching for the conversion of AC voltage to direct current voltage. The conversion of the AC voltage to direct current voltage takes place in the charging station. The full power of the AC network is used (all three phases). If all prerequisites for charging the high-voltage battery are satisfied, the LIM switches on the two switch contactors in the KLE. The charging station then provides the direct current voltage at the output for charging the high-voltage battery. The direct current voltage reaches the KLE via the charging socket and the high-voltage cables. The direct current voltage is directed via the high-voltage cables to the EME and then finally to the high-voltage battery. The high-voltage cables and the switch contactors are designed for an electrical power of up to 50 kW.

6. Charging the High-voltage Battery



Convenience charging electronics for combo charging at 7.4 kW AC charging power

Index	Explanation
1	High-voltage cable (AC) from the charging socket
2	High-voltage cable (DC) to the electrical machine electronics
3	Low-voltage lines (for switching the switch contactors)
4	Coolant line (supply)
5	Low-voltage lines (signal connector)
6	High-voltage cable (AC) from KLE to EME
7	KLE mounting (potential compensation contact)
8	High-voltage cable (DC) from REME
9	Coolant line (return)
10	High-voltage cable (DC) from the charging socket to the KLE
11	Convenience charging electronics (KLE)

With the combo charging at 7.4 kW AC charging power the convenience charging electronics can convert both the single-phase AC voltage of the AC charging station to direct current voltage, and shift through the direct current voltage of the DC charging station for the electrical machine electronics and high-voltage battery using the DC switch contactors. The conversion of the AC voltage to the direct current voltage required for charging the high-voltage battery is done by the AC/DC converter at a maximum power of 3.7 kW. The properties and function of the AC/DC converter were already described in the previous chapter. Together with the standard AC/DC converter in the EME, which also provides an output power of 3.7 kW, charging the high-voltage battery in the I01 via the single-phase alternating current at 7.4 kW is also possible.

In this version of the convenience charging electronics two further switch contactors are housed which can shift through the direct current voltage of a DC charging station via the EME to the high-voltage battery. The function and activation of the switch contactors are described in the previous subchapter.

At full performance of the AC/DC converter active cooling is required. The convenience charging electronics is therefore integrated in the cooling circuit of the electric motor.

I01 High-voltage Components

7. EKK

Very high requirements are made of the heating and air-conditioning functions in the I01. On the one hand, the passenger compartment must always be at a pleasant temperature for the customer. On the other hand, in order to prolong the service life of the high-voltage battery, the high-voltage battery must be cooled at high temperatures.

An EKK is used in the I01.

The EKK is a high-voltage component!

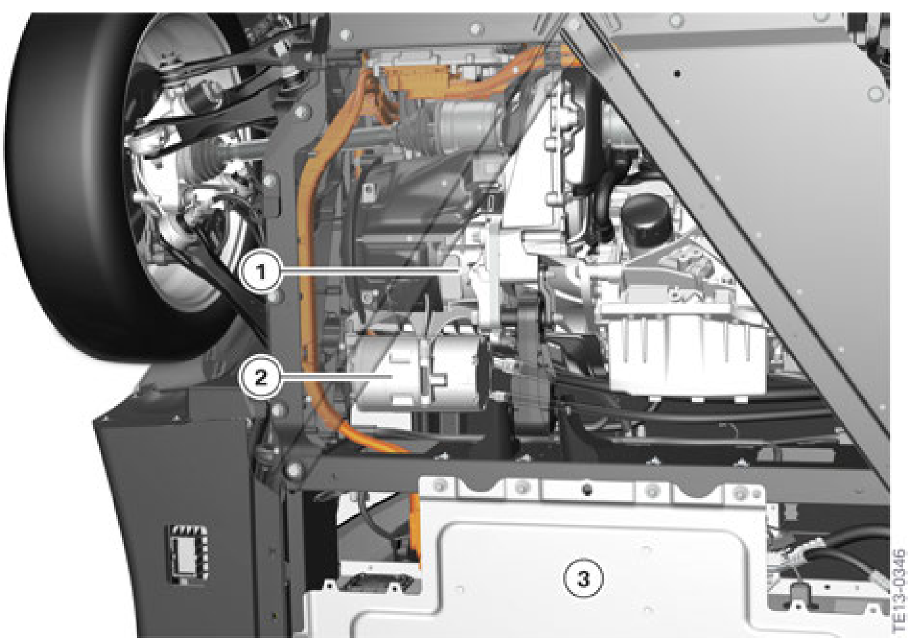
⚠

Only Service employees who satisfy all the prerequisites are permitted to work on the designated high-voltage components: suitable qualifications, compliance with the safety rules, procedure following the repair instructions to the letter.

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

7.1. Location and connections

The EKK is installed at the housing of the electrical machine.

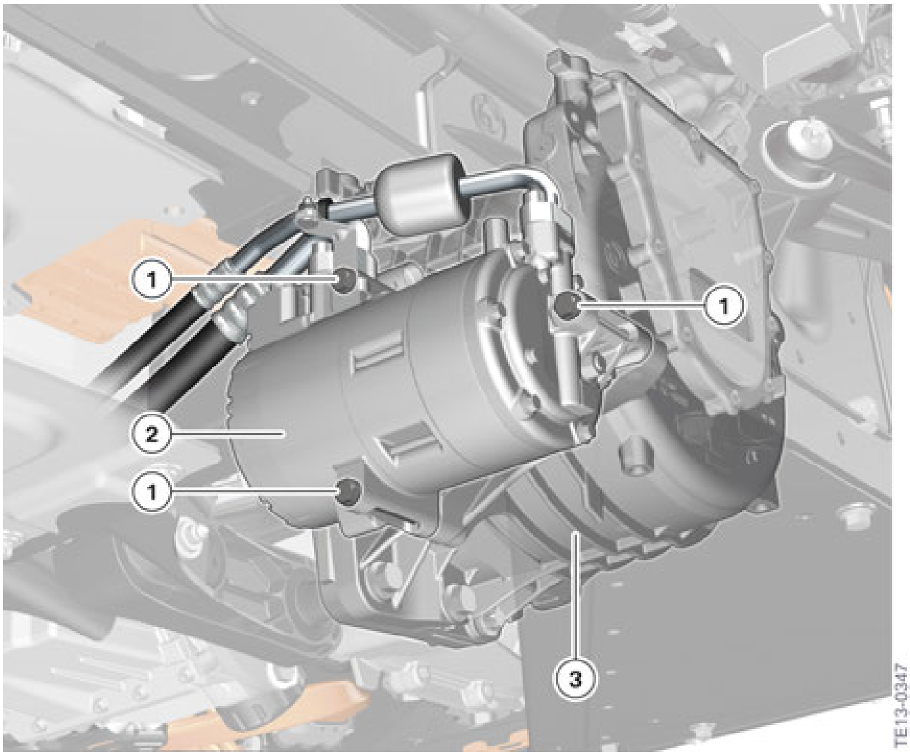


Installation location of EKK in the I01

Index	Explanation
1	Electrical machine
2	EKK
3	High-voltage battery

I01 High-voltage Components

7. EKK

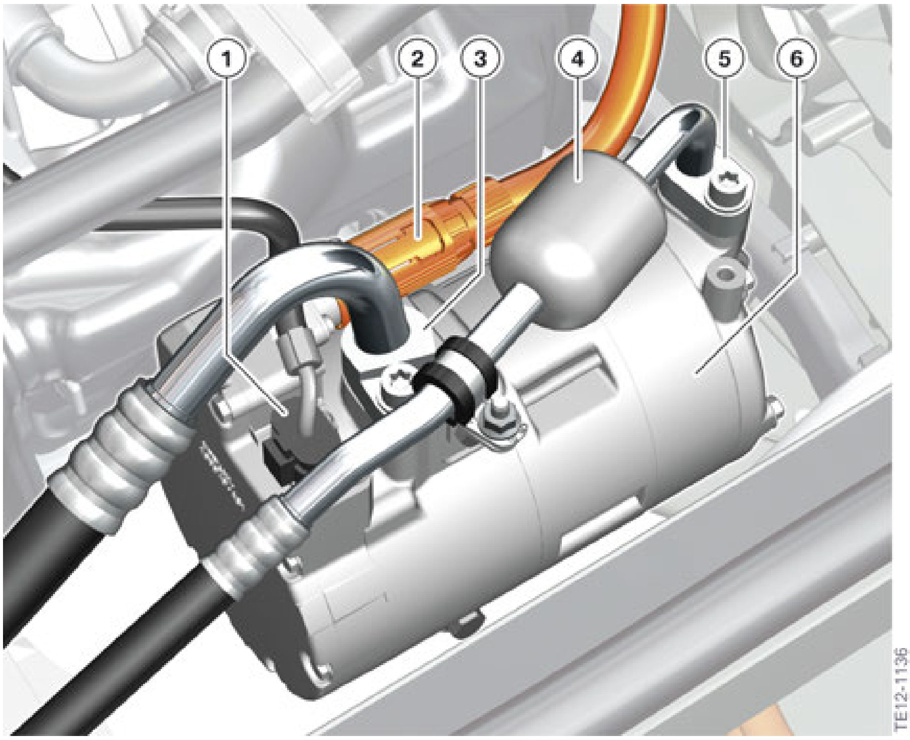


Mounting of the EKK at the electrical machine

Index	Explanation
1	Screws
2	EKK
3	Housing of the electrical machine

The EKK is secured to the housing of the electrical machine using three screws.

The housing of the EKK is mechanically disconnected from the housing of the electrical machine, thus improving the acoustic behavior. As the two housings are not connected, there is a separate potential compensation line of the housing of the EKK for the rear axle module (not shown in the graphic below).



Connections of the EKK in the I01 (view from above)

Index	Explanation
1	Low-voltage connector
2	High-voltage connector
3	Connection for intake pipe
4	Silencer
5	Connection for pressure line
6	EKK

In the eight-pin signal connector the connections for local interconnect network bus, ground and the 12 V voltage supply (terminal 30) are integrated.

Special silencing in the pressure line provides for further acoustic comfort. The heating and air-conditioning is barely audible even when the vehicle is at a standstill. The mechanical disconnection of the EKK from the electrical machine also improves the acoustic behavior.

7.2. Structure of the electric A/C compressor

When one talks about the EKK, the entire component is meant. The EKK comprises the following components:

- Housing
- EKK control unit
- Three-phase current synchronous motor
- AC inverter
- Air conditioning compressor.

These individual components are never replaced separately! The entire EKK is always replaced. At this stage the tasks of some components are explained in order to better explain the function of the EKK.

7.2.1. EKK control unit

The EKK control unit controls the engine speed of the three-phase motor in the EKK based on the requests of the IHKA and reports the operating status back to the IHKA control unit. The EKK control unit communicates with the IHKA via the LIN bus. The IHKA is the master control unit for the EKK.

7.2.2. Three-phase current synchronous motor

A three-phase synchronous motor is used as the drive for the EKK. The energy is taken from the high-voltage battery. The necessary three-phase current is converted in the EKK using an AC inverter (DC/AC converter). The three-phase synchronous motor is operated in the engine speed range between 860 and 8600 rpm and is infinitely variable. It uses an electrical power of up to 4.5 kW. The maximum power is required, for example, at high ambient temperatures, high interior temperatures, high temperatures of the high-voltage battery and low air flow of the cooling module.

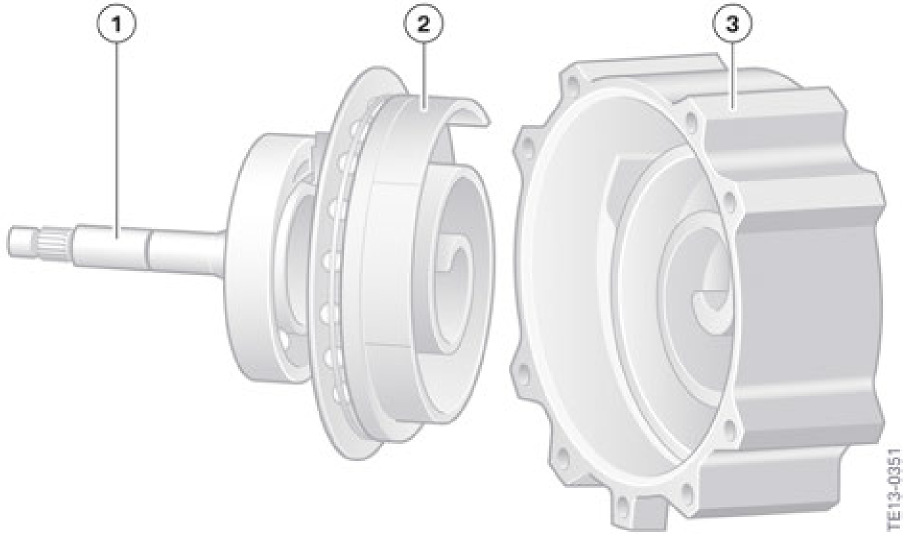
7.2.3. AC inverter

The DC/AC converter converts the direct current voltage into the three-phase alternating current that is required to operate the three-phase synchronous motor. The EKK control unit and the DC/AC converter are integrated in the aluminium housing of the EKK and are cooled by the gaseous refrigerant flowing past. If the temperature of the DC/AC converter exceeds 125 °C, the high-voltage supply is shut off by the EKK control unit. The attempt is made through different measures such as speed increase for cooling initially not to allow the temperature to rise so high. The temperature is monitored by the electric A/C compressor control unit. If the temperature drops below 112 °C, the EKK continues to run.

The supply voltage for EKK has a voltage range of about 200 V to 410 V. The power is reduced above and below this voltage range or the EKK is switched off.

7.2.4. Air conditioning compressor

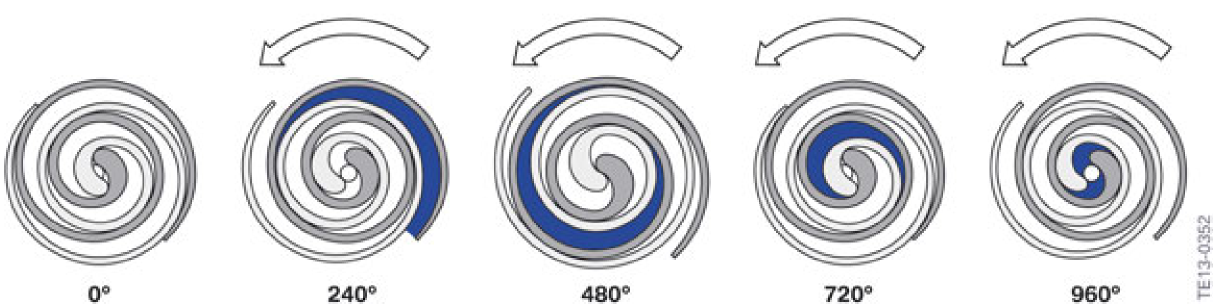
To compress the refrigerant, the spiral compressor (also known as the scroll compressor) is used. R134a refrigerant is used for the US market.



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 three-phase current synchronous motor and rotates eccentrically. The gaseous refrigerant at low temperature and low pressure is drawn in through two openings in the fixed outer disc with spiral profile and compressed and heated by the movement of the two discs with spiral profiles.

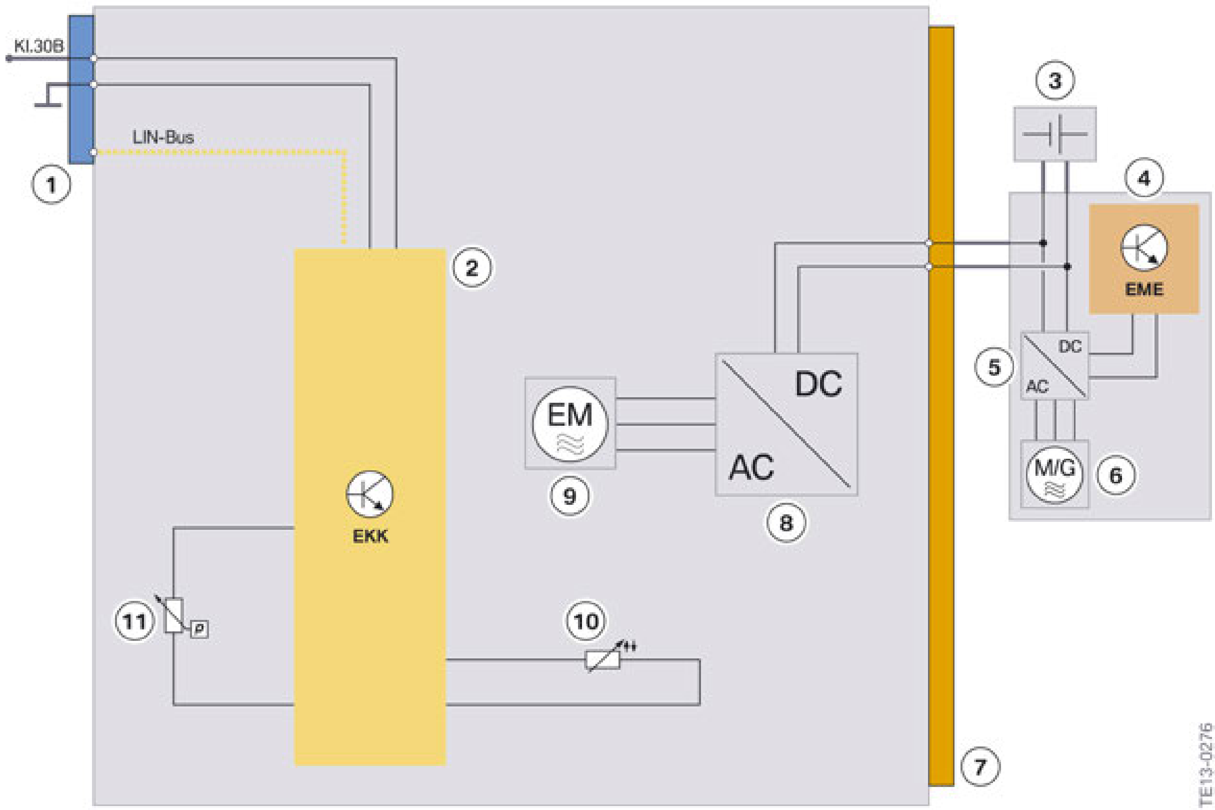


Principle of refrigerant compression

After three revolutions, the refrigerant drawn in is compressed and heated and can escape in a gaseous state through an opening in the center of the outer disc. From here, gaseous refrigerant with high temperature and high pressure escapes via an oil separator at the connection of the A/C compressor towards the condenser. The EKK is operated at maximum 8600 rpm and generates a maximum operating pressure of about 30 bar.

7.3. High-voltage safety

7. EKK



Functional wiring diagram for the EKK

Index	Explanation
1	Low-voltage connector
2	EKK (EKK control unit)
3	High-voltage battery
4	Electrical machine electronics
5	Bidirectional AC/DC converter in the EME
6	Electrical machine
7	High-voltage connector at EKK
8	Unidirectional inverter DC/AC converter in the EKK
9	Three-phase current synchronous motor
10	Temperature sensor
11	Pressure sensor

The high-voltage contacts of the round high-voltage connector for the EKK are protected against contact.

The high-voltage connector of the EKK is **not** part of the circuit of the high-voltage interlock loop.

The electrical capacity in the EKK is less than 100 µF. This capacity is discharged via a passive resistor in the EKK. After the EKK is shut down the voltage falls to below 60 V in less than 5 seconds.

I01 High-voltage Components

8. Electric Heating

Due to the high efficiency considerably less heat is emitted from the electrical machine than from combustion engines. The heat from the electrical machine can therefore not be used for heating. In order to be able to control the interior temperature of the passenger compartment, electric heating is installed in the I01.

The electric heating is a high-voltage component!

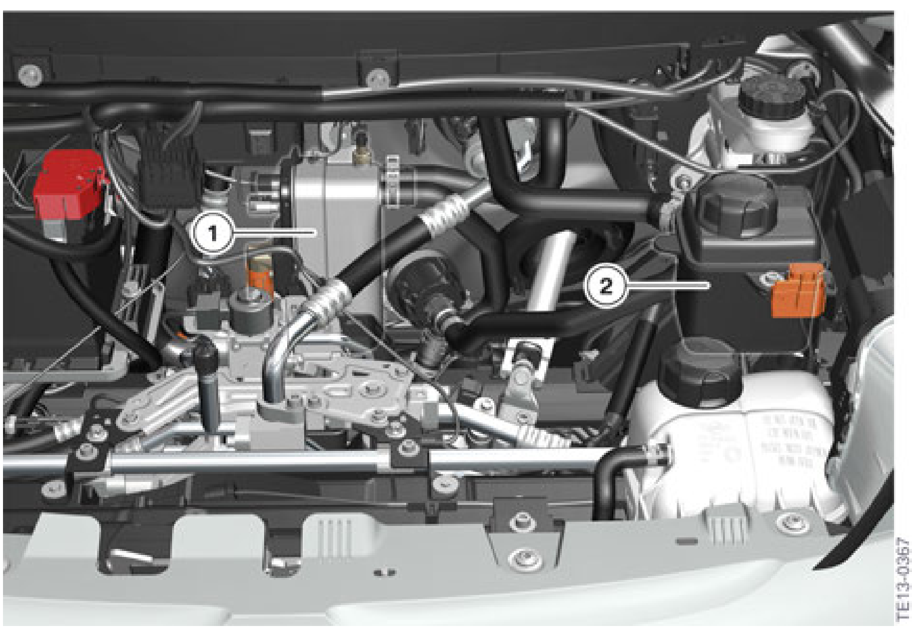
⚠

Only Service employees who satisfy all the prerequisites are permitted to work on the designated high-voltage components: suitable qualifications, compliance with the safety rules, procedure following the repair instructions to the letter.

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

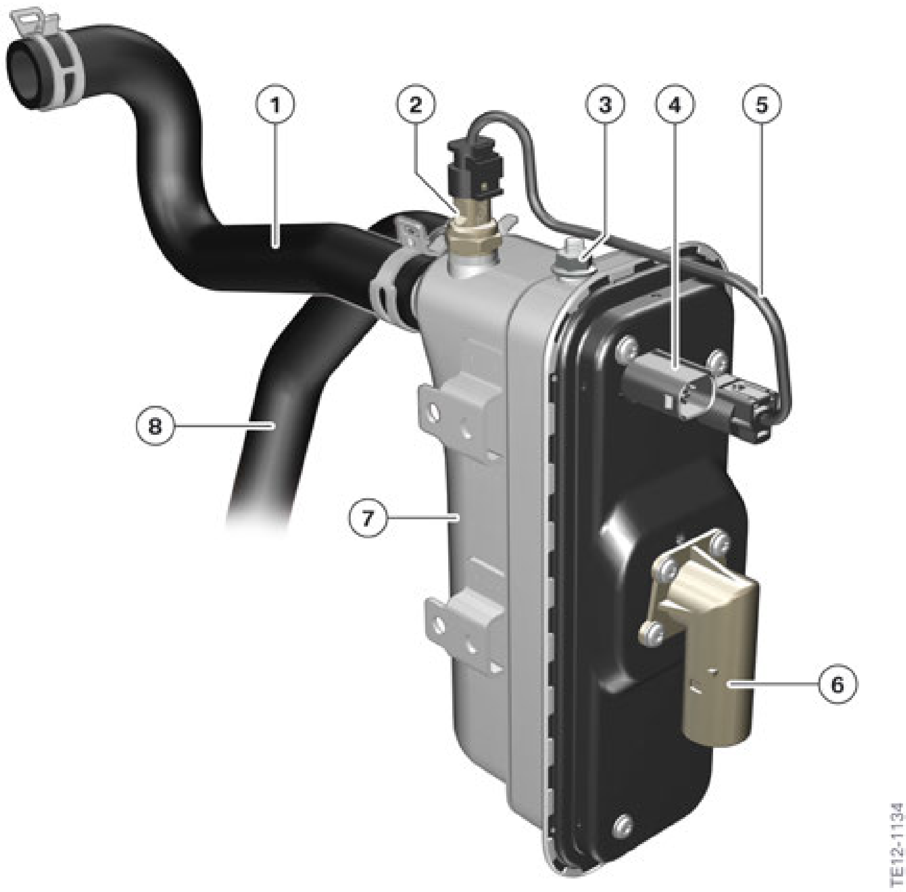
8.1. Location and connections

The installation location of the electric heating is in the space below the engine compartment lid.



Installation location of the electric heating

Index	Explanation
1	Electric heating
2	Coolant expansion tank

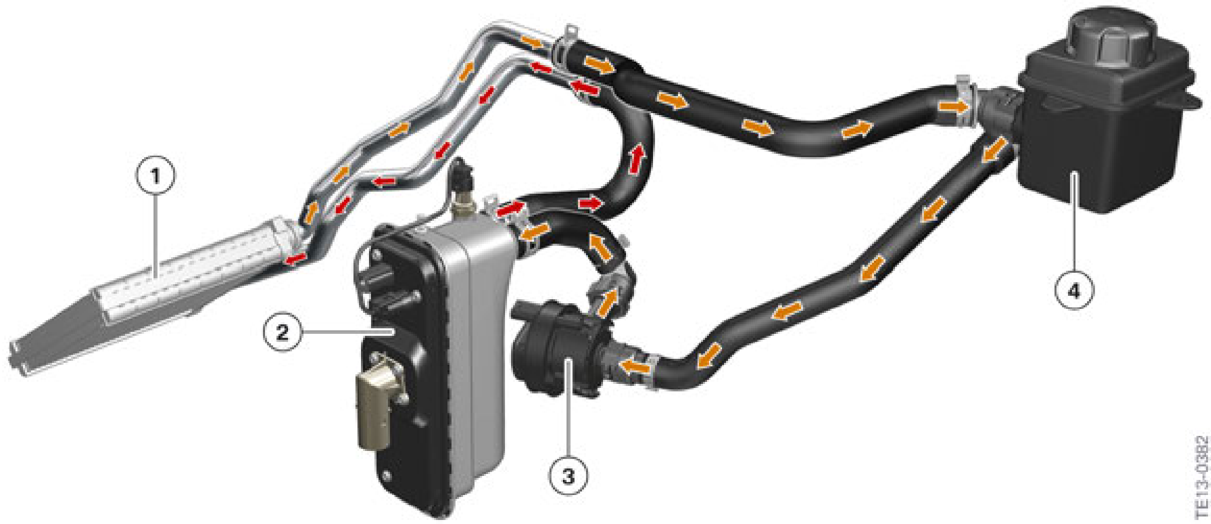


Connections at the electric heating

Index	Explanation
1	Connection for coolant return
2	Sensor for temperature of the coolant at the output of the electric heating
3	Connection for potential compensation line
4	Signal connector (low-voltage connector)
5	Connection for sensor
6	Connection for high-voltage connector
7	Housing of the electric heating
8	Connection for coolant return

8. Electric Heating

8.2. Operating principle



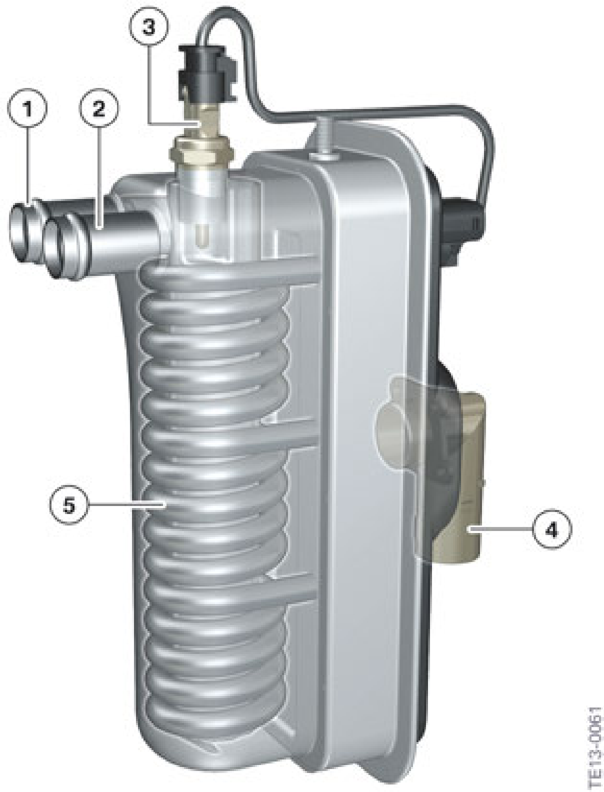
Heating for the passenger compartment in the standard equipment

Index	Explanation
1	Heat exchanger in the passenger compartment
2	Electric heating
3	Electric coolant pump (12 V)
4	Coolant expansion tank

The coolant is heated up in the electric heating and circulated by an electric coolant pump (20 W). The warm coolant flows through the heat exchanger in the passenger compartment and emits the heat. The warm air finally reaches the passenger compartment by means of a blower. The refrigerant is conveyed from the heat exchanger to the coolant expansion tank.

A mixture of water and a new coolant concentrate called "coolant concentrate i3" is used as a coolant. The water and coolant concentrate are mixed in the ratio 50:50.

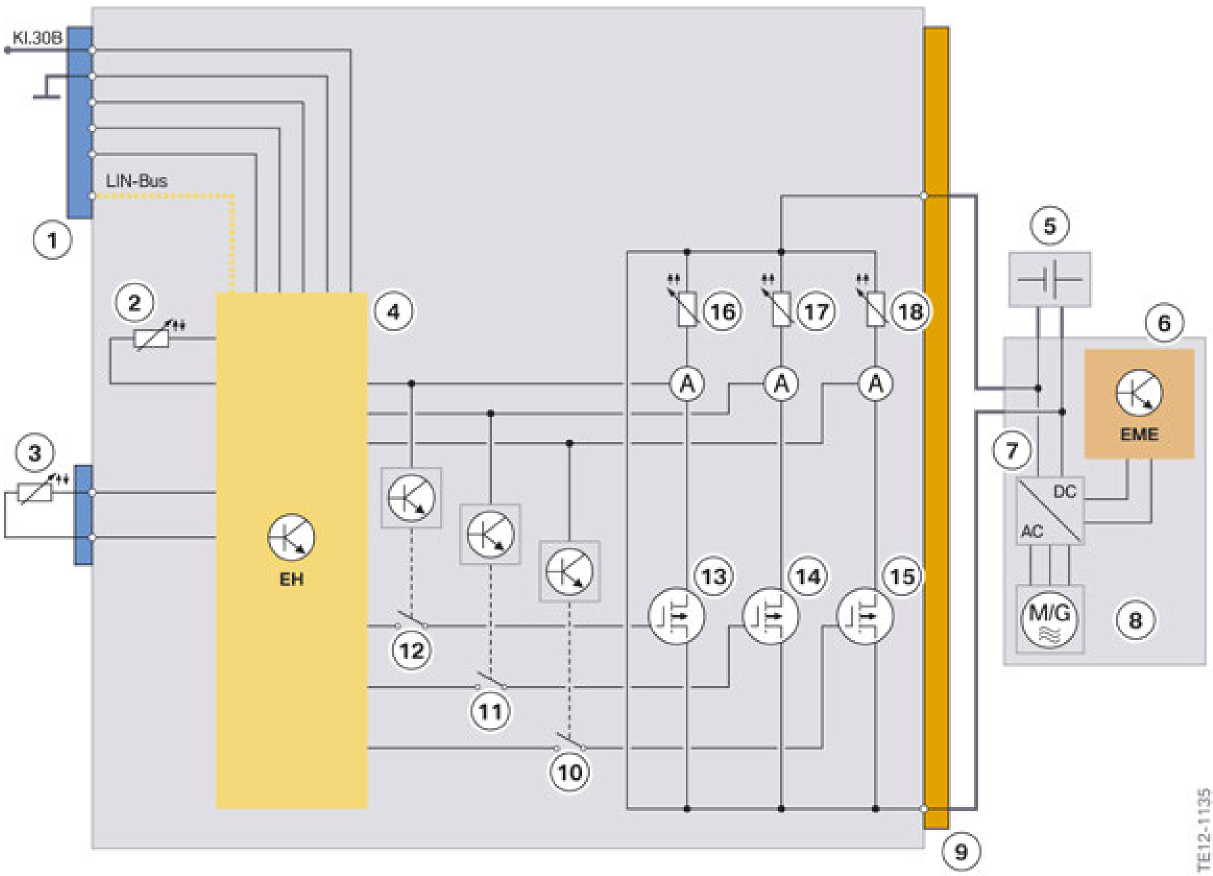
8. Electric Heating



Index	Explanation
1	Connection for coolant supply from the electrical 12 V coolant pump or with corresponding optional equipment from the heat pump capacitor
2	Connection for coolant return (to the heat exchanger for the passenger compartment)
3	Sensor for temperature of the coolant at the output of the electric heating
4	High-voltage connection
5	Three heater coils

The maximum electrical power of the electric heating is 5.5 kW (280 V x 20 A). The electric heating is done by three heater coils, each with a power of about 0.75 kW, 1.5 kW and 2.25 kW. The switching of the heater coils (individually or together) is effected within the electric heating using an electronic switch (Power MOSFET).

8. Electric Heating



Functional wiring diagram for the electric heating

Index	Explanation
1	Low-voltage connector
2	Sensor for temperature of the printed circuit board of the control unit for electric heating
3	Sensor for temperature of the return coolant
4	Electric heating (control unit)
5	High-voltage battery
6	Electrical machine electronics
7	Bidirectional AC/DC converter in the EME
8	Electrical machine
9	High-voltage connector at electric heating
10	Hardware shutdown in the event of excessive current in heater coil 3
11	Hardware shutdown in the event of excessive current in heater coil 2
12	Hardware shutdown in the event of excessive current in heater coil 1
13	Electronic switch (Power MOSFET) for heater coil 1
14	Electronic switch (Power MOSFET) for heater coil 2

Index	Explanation
15	Electronic switch (Power MOSFET) for heater coil 3
16	Heater coil 1
17	Heater coil 2
18	Heater coil 3

The current through the individual strands is measured and controlled by the electric heating control unit. A current of maximum 20 A flows in a voltage range of 250 V to 400 V. The power is reduced above and below this voltage range. At increased power consumption the energy supply by the hardware switching is interrupted. This switching is designed so that even in the event of a fault in the control unit a power cut is effected safely.

The temperature of the coolant is measured using a sensor at the output of the electric heating.

Inside the electric heating a galvanic separation was installed between the high-voltage circuit and the low-voltage circuit.

The connections for local interconnect network bus and voltage supply (terminal 30B) are located at the low-voltage connector.

A bridge is integrated in the high-voltage connector beside the contacts for the high voltage. The contacts of the bridge in the high-voltage connector are designed as leading contacts. This means when removing the high-voltage connector the contacts of the high-voltage bridge are separated first. As a result, the voltage supply of the control unit (EH) is interrupted. This also means the high-voltage supply is interrupted before the high-voltage connector is pulled out fully. No electric arc thus arises on the high-voltage contacts. The high-voltage contacts are protected from contact. The high-voltage connector of the electric heating is **not** part of the circuit of the high-voltage interlock loop.

8.3. Control system

Six heating stages can be set through separate or combined activation of the individual heater coils. The request for switching on the heating comes from the IHKA control unit via local interconnect network bus.

Heater coil	Heating stage
1	1
2	2
3	3
1 + 3	4
2 + 3	5
1 + 2 + 3	6

When the maximum temperature is reached or if the maximum permissible current level is exceeded, the heater output is automatically restricted by the electric heating control unit.

The electric heating is switched off in the event of system faults.

The electric heating is maintenance-free.

9. Range Extender Electrical Machine

9.1. Introduction

The high-voltage components examined up to now pave the way for a pure electric driving of the I01. The electrical machine receives the energy required for the electric motor from the high-voltage battery. The EME converts the direct current voltage from the high-voltage battery into 3-phase AC voltage.

The I01 with a pure electric driving is designed so that a distance of about 150 km / 93 mi (115 mi using efficiency mode) can be covered before the high-voltage battery must be charged up again. The high-voltage battery can also be charged at an earlier stage.

A I01 which is equipped with a range extender can cover a distance of about 300 km / 186 mi (200 mi using efficiency mode) before the high-voltage battery has to be charged or the tank has to be refuelled. This means a I01 with range extender offers double the range in comparison to a I01 with a purely electric motor.

Also in the I01 with range extender the electric motor with energy from the high-voltage battery is used as a primary drive type. The range extender system is only activated when the state of charge of the high-voltage battery falls below a certain value.

The range extender system consists of the following components:

- W20 Combustion engine
- Range extender electrical machine
- Range Extender Electrical Machine Electronics
- Range Extender Digital Engine Electronics.

The W20 combustion engine is a 2-cylinder engine. It is a small, very smooth-running and quiet gasoline engine, which is connected mechanically to the range extender electrical machine via a geared shaft. At a low state of charge of the high-voltage battery the W20 engine is started using the range extender electrical machine. In this case the range extender electrical machine works in engine mode. The electrical energy for starting the W20 engine comes from the high-voltage battery. As soon as the W20 has been started, the range extender electrical machine changes from engine to alternator mode and generates electrical energy which is used for the electric motor of the vehicle via the (main) electrical machine. The W20 engine is not connected mechanically to the sprockets. The mechanical energy of the W20 engine is converted by the range extender electrical machine solely into electrical energy. The (main) electrical machine uses this electrical energy and converts it to mechanical energy to drive the rear wheels. The layout of these components corresponds to a serial hybrid car.

In this chapter the range extender electrical machine is described and in the next chapter details are provided on the range extender electrical machine electronics.

The W20 engine and the engine control of the range extender digital engine electronics are described in the product information bulletin "W20 Engine".

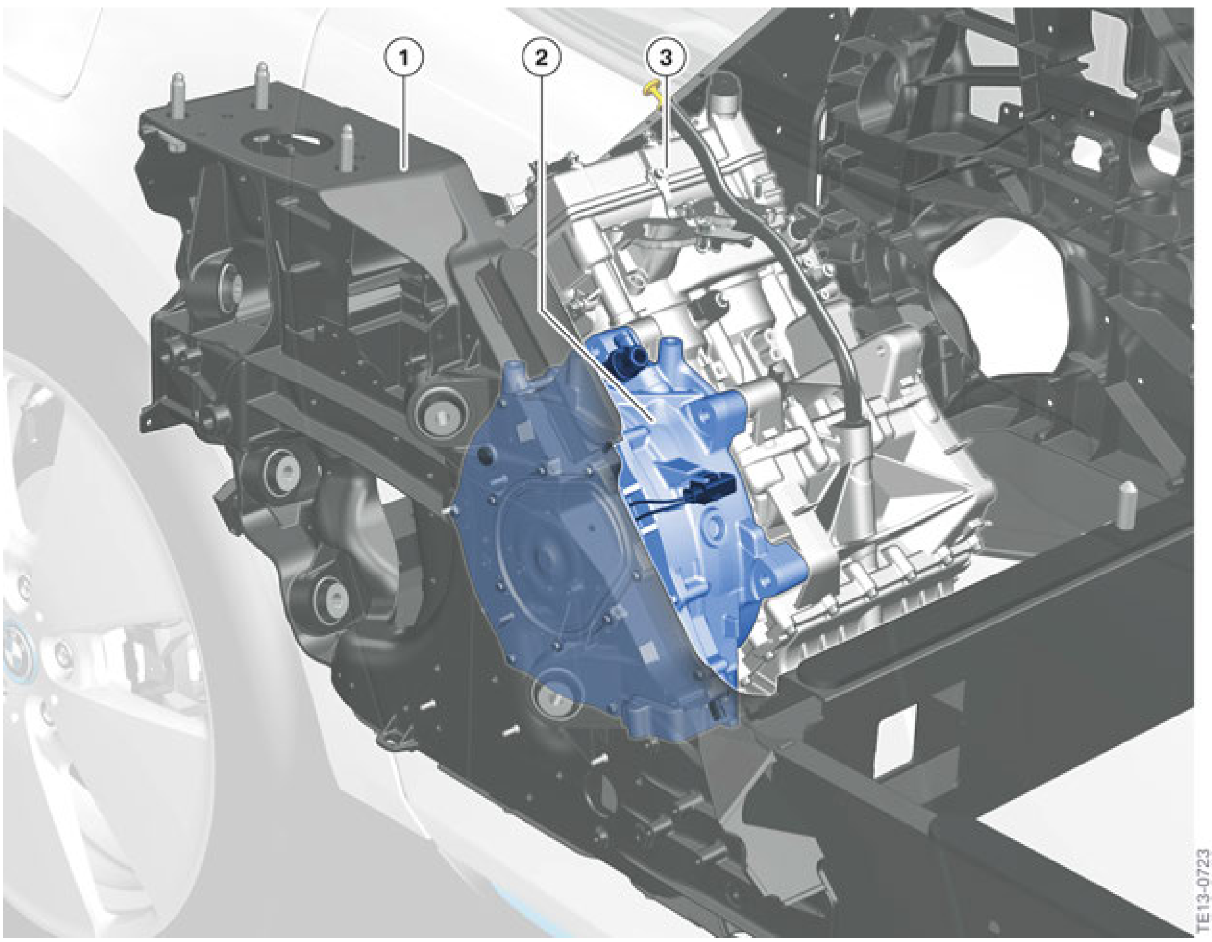
9.2. Technical data

The performance data of the range extender electrical machine is summarized in the following table:

9. Range Extender Electrical Machine

Size	Value
Nominal voltage	250 V
Continuous power, electrical	about 23.3 kW electrical DC power at 4300 rpm and 330 V DC
Efficiency	about 94%
Outer diameter	about 300 mm
Length	about 115 mm
Weight	about 26 kg

The range extender electrical machine is supplied by Valeo.



Installation location of the range extender electrical machine

Index	Explanation
1	Rear axle module
2	Range extender electrical machine
3	Range extender (W20 engine)

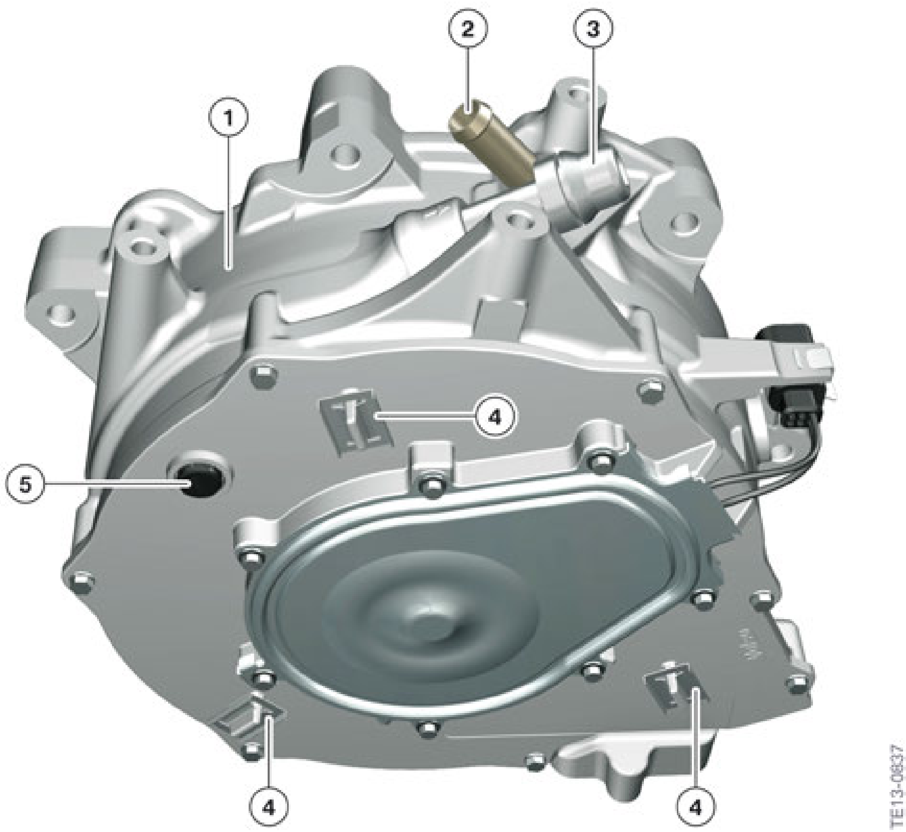
9. Range Extender Electrical Machine

The range extender electrical machine is installed in the rear of the I01.

9.3. Design

The range extender electrical machine in the I01 is a synchronous machine. Its general structure and operating principle correspond to those of a permanently excited synchronous machine with internal rotor: The rotor is located inside and is equipped with permanent magnets. The stator is ring-shaped and located outside around the rotor. It is shaped with iron cores through the 3-phase coils. If a 3-phase AC voltage is applied to the stator coils, they generate a rotating magnetic field, which "pulls" the magnets in the rotor (in engine operation).

9.3.1. Cooling



Connections for coolant lines

Index	Explanation
1	Range extender electrical machine
2	Connection for coolant line (supply)
3	Connection for coolant line (return)
4	Retaining springs for the coating
5	Ventilation

The electrical machine is designed for a large temperature range. The coolant can reach a temperature of up to 70 °C (158 °F) at the input (supply) at a flow of six liters per minute. The temperature at the input is time-restricted and can rise up to 85 °C (185 °F). And although the electrical machine demonstrates less losses during energy conversion than a combustion engine, its housing can absorb a temperature of up to 100 °C (212 °F).

The two connections for the coolant lines integrate the range extender electrical machine in the cooling circuit of the electric motor. This is described in the chapter "Cooling of electric motor components". The graphics in this chapter show the range extender electrical machine and the W20 engine without coating. In the production vehicle sometimes these components are still covered by a foam part. This serves for the acoustic encapsulation of the range extender components and absorbs noises which the customer may find irritating.

The housing of the range extender electrical machine is airtight and waterproof. A vent line is required to prevent water (resulting from temperature changes and thus possible condensation of air humidity) collecting inside the range extender electrical machine.

9.3.2. Sensors

Temperature sensor

In order to avoid damage to the components due to the high temperature, there is a temperature sensor in the range extender electrical machine of the I01. The temperature sensor is a temperature-dependent resistor and is located in the coils of the stator. The temperature of the rotor is not measured directly, but can be determined from the measured values of the temperature sensors in the stator. The signal is read in and evaluated analogously by the range extender electrical machine electronics.

Rotor position sensor

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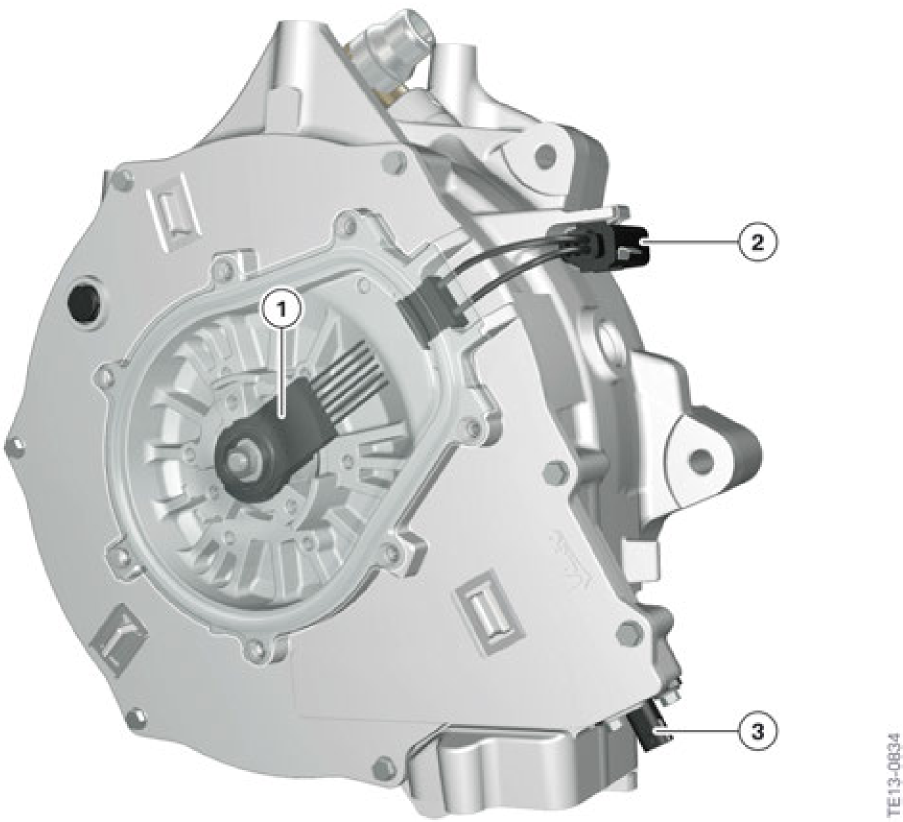
The rotor position sensor cannot be replaced in Service!

9. Range Extender Electrical Machine



Rotor position sensor in range extender electrical machine

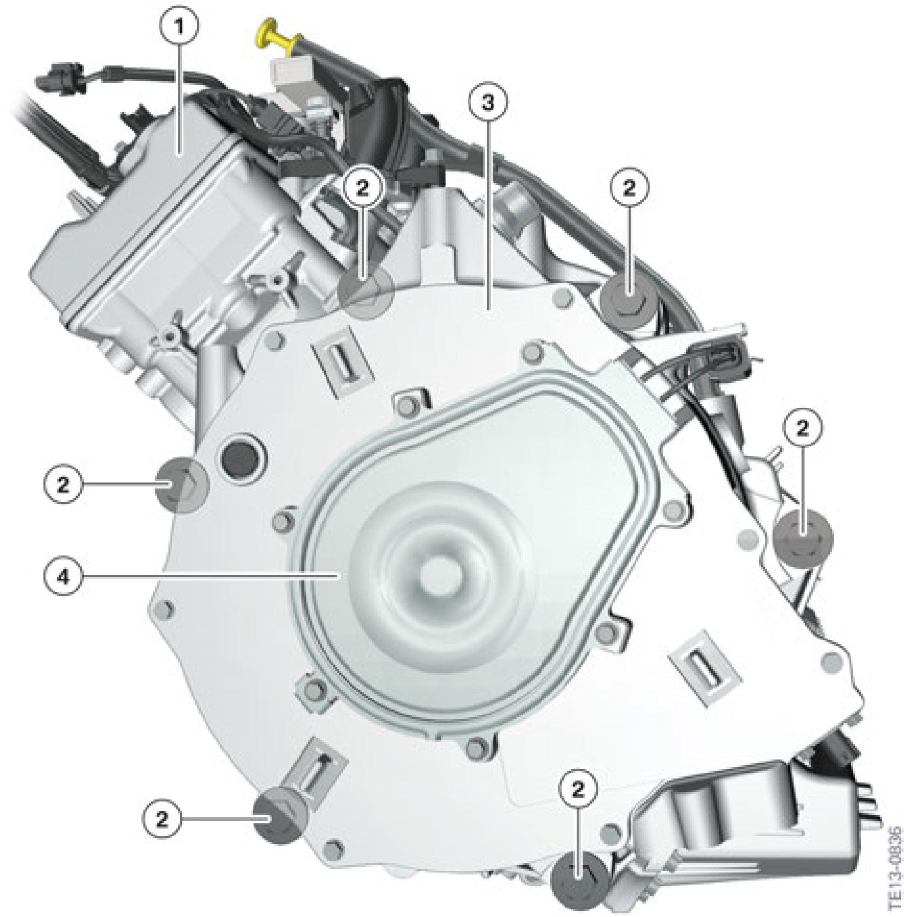
Index	Explanation
1	Rotor position sensor in the range extender electrical machine
2	Connection for rotor position sensor
3	Connection for temperature sensor

So that the voltages for the coils in the stator can be correctly calculated and generated by the range extender electrical machine electronics in terms of amplitude and phase layer, the precise angle setting of the rotor must be known. This is why there is also a rotor position sensor in the range extender electrical machine.

The rotor position sensor is secured at the stator of the range extender electrical machine and works according to the tilt sensor principle. There are three coils in the rotor position sensor. A defined AC voltage is fed to one of the coils. The other two coils are each moved 90°. The voltages induced in these coils provide information about the angle setting of the rotor. The rotor position sensor is mounted by the manufacturer of the range extender electrical machine at the corresponding alignment so that it is already correctly adjusted.

9.4. External characteristics and interfaces

9.4.1. Mechanical interfaces



Mounting of the range extender electrical machine

Index	Explanation
1	W20 Combustion engine
2	Mounting bolts for range extender electrical machine (x6)
3	Range extender electrical machine
4	Cover over the rotor position sensor

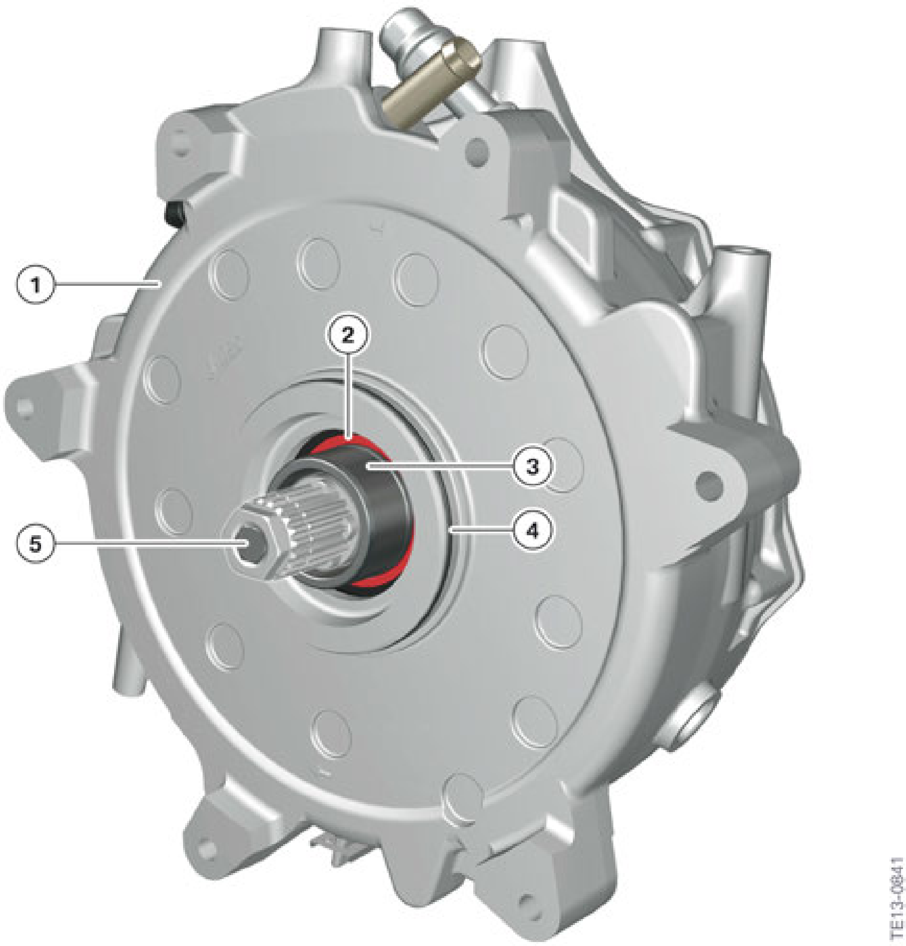
The range extender electrical machine is secured at the crankcase of the W20 engine using six screws.

The power transmission between the crankshaft of the combustion engine and the range extender electrical machine is effected via a geared shaft.

9. Range Extender Electrical Machine

⚠

The cover over the rotor position sensor **cannot** be removed!



Geared shaft for the power transmission

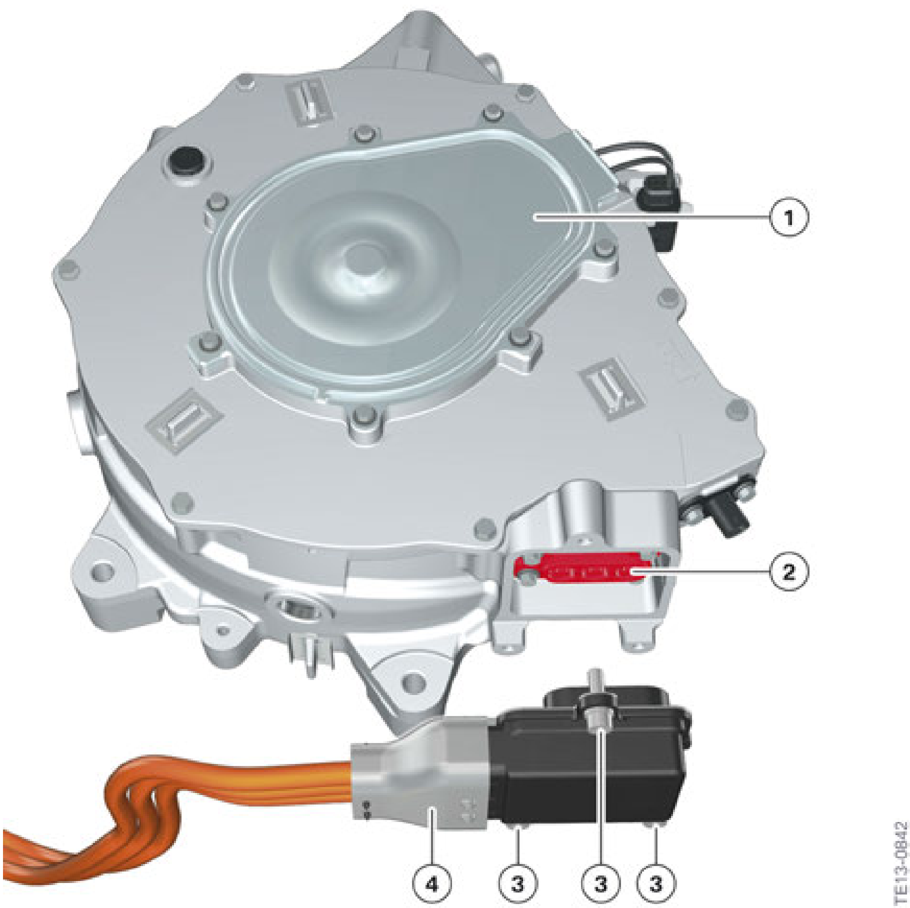
Index	Explanation
1	Range extender electrical machine
2	O-ring seal
3	Grooved ball bearing
4	Sealing ring
5	Geared shaft

The range extender electrical machine can be removed separately from the W20 engine using a separate tool.

Please refer to the repair instructions for the exact procedure.

9.4.2. Electrical interfaces

There are both connections for the two sensors and also a high-voltage connection at the range extender electrical machine. The connections for the temperature sensor and the rotor position sensor were shown and described in the previous section.



High-voltage connection at the range extender electrical machine

Index	Explanation
1	Range extender electrical machine
2	High-voltage connection at the range extender electrical machine
3	Screws for mounting the high-voltage connection
4	High-voltage connector and line to the REME

9.4.3. Coolant connections

The two connections for the coolant lines integrate the range extender electrical machine in the cooling circuit of the electric motor. This is described in the chapter "Cooling of electric motor components".

10. REME

10.1. Introduction

The main task of the range extender electrical machine electronics is to control the range extender electrical machine. It converts the direct current voltage from the high-voltage battery into a three-phase AC voltage (up to about 420 V AC) for the activation of the range extender electrical machine as an engine. Currents of up to 200 A can flow. Vice versa, when the range extender electrical machine works as an alternator, the range extender electrical machine electronics converts the three-phase AC voltage of the range extender electrical machine to a direct current voltage and can thus supply the energy for the electric motor of the I01. The continuous phase currents of about 130 A flow. For these two operating modes a bidirectional DC/AC converter is necessary which can work as both an inverter and a rectifier.

The entire range extender electrical machine electronics of the I01 is located in an aluminium housing. This housing accommodates the control unit and the bidirectional DC/AC.

The range extender electrical machine electronics is a high-voltage component!

⚠

Only Service employees who satisfy all the prerequisites are permitted to work on the designated high-voltage components: suitable qualifications, compliance with the safety rules, procedure following the repair instructions to the letter.

The diagnosis and repair of the high-voltage components is only allowed in a retail service center that has qualified and certified service technicians. These technicians must have completed the ST1403b I01 High Voltage Battery and Maintenance instructor led course and successfully passed the hands on certification.

⚠

The housing of the range extender electrical machine electronics cannot be opened in Service.

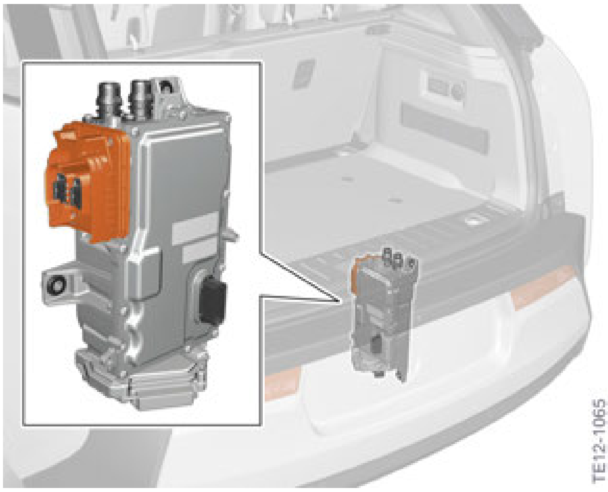
The range extender electrical machine electronics of the I01 was developed and supplied by Bosch. The efficiency of the REME is 96%. The weight of the REME is about 6 kg.

10.2. Installation location and mounting

The range extender electrical machine electronics is installed in the rear of the I01, in an area separated from the luggage compartment.

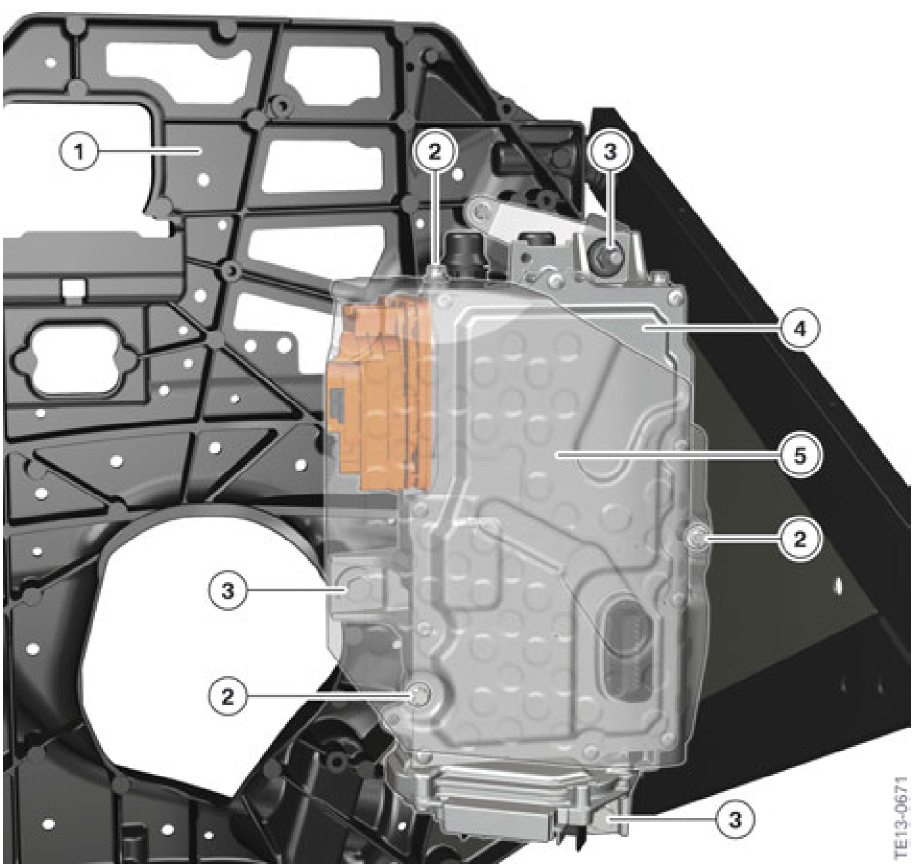
I01 High-voltage Components

10. REME



Installation location of the REME

The REME is secured at the rear axle module on the right using three screws.



REME at rear axle module

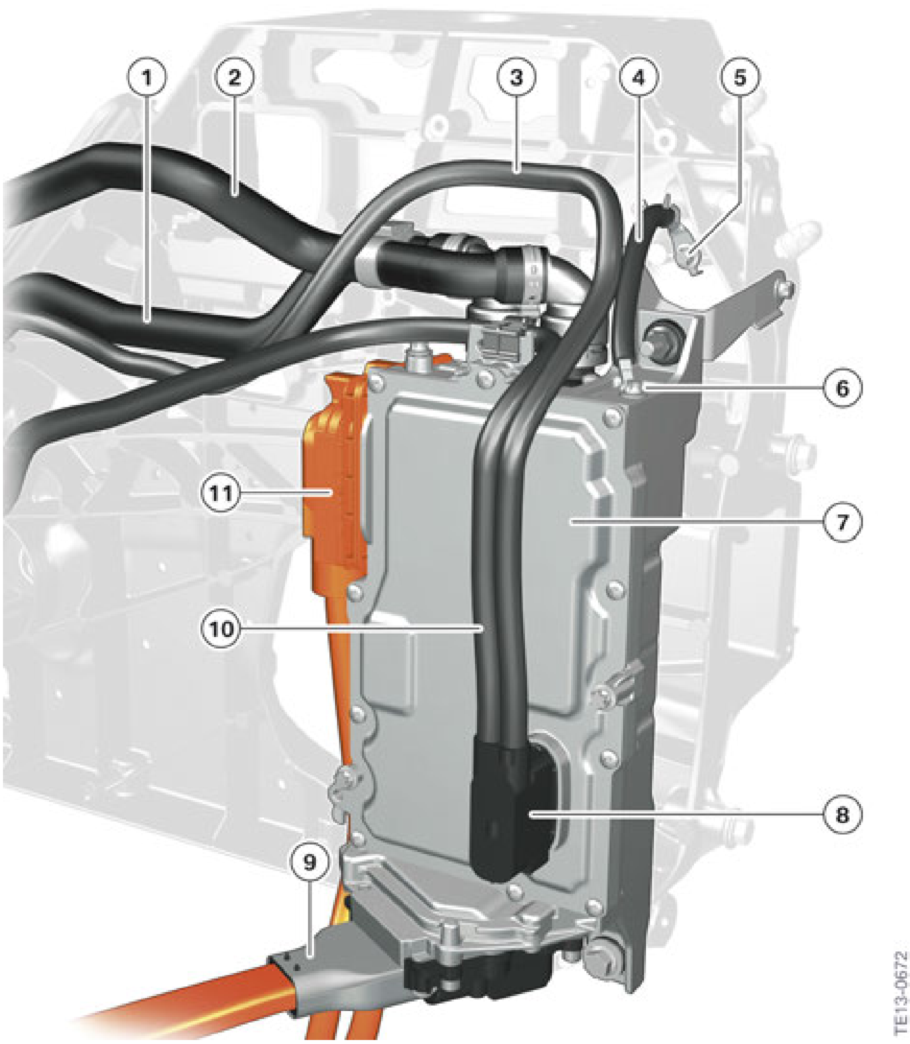
Index	Explanation
1	Rear axle module
2	Screws for mounting the heat shield
3	Screws for mounting the REME at the rear axle module
4	REME
5	Heat shield for REME

The heating of the REME by the combustion engine is reduced by a heat shield. The heat shield is secured to the REME using three screws. In order to remove the flat high-voltage connector and the signal connector from the REME, this heat shield has to be removed.

10.3. Connections at REME

The following graphics show all the connections of the range extender electrical machine electronics. Details of the individual categories are provided in the following chapters.

I01 High-voltage Components
10. REME

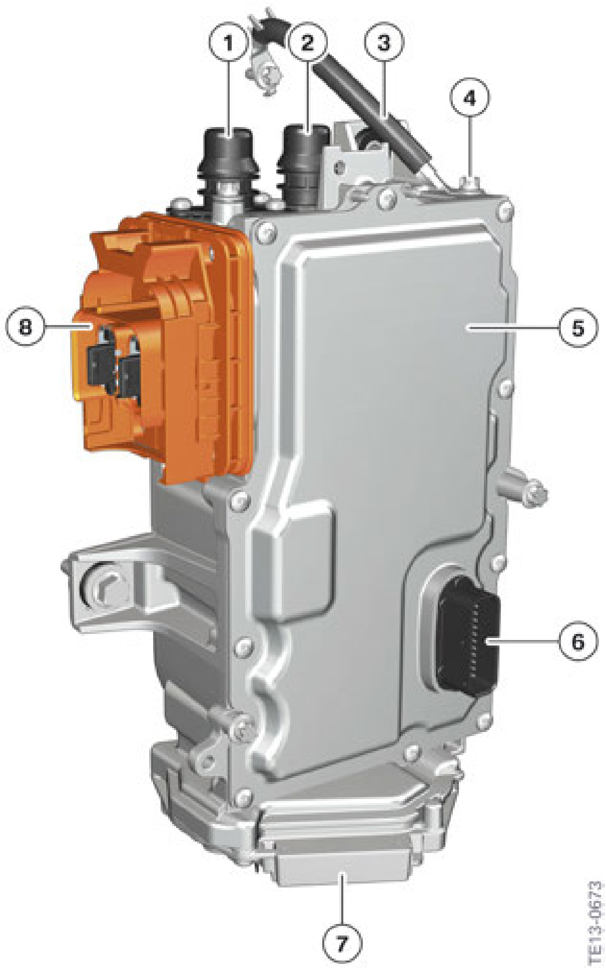


Connections at REME with lines

Index	Explanation
1	Coolant line (return)
2	Coolant line (supply)
3	Signal line from the vehicle electrical system
4	Potential compensation line
5	Screw connection of the potential compensation screw at the rear axle module
6	Screw connection of the potential compensation screw at the REME
7	Range Extender Electrical Machine Electronics
8	Signal connector
9	3-phase high-voltage cable to the range extender electrical machine
10	Signal line from the range extender electrical machine
11	Two-phase high-voltage cable to the EME or KLE

10. REME

For a better overview the connections at the REME are shown without lines.



Connections at the REME without connected lines

Index	Explanation
1	Coolant connection (return)
2	Coolant connection (supply)
3	Potential compensation line
4	Screw connection of the potential compensation screw at the REME
5	Range Extender Electrical Machine Electronics
6	Connection for signal connector
7	Connection for three-phase high-voltage cable from the range extender electrical machine
8	Connection for the two-pin high-voltage cable from the EME or KLE

The connections at the range extender electrical machine electronics can be divided into four categories:

- Low-voltage connections
- High-voltage connections
- Connection for potential compensation line
- Connections for coolant lines.

10.3.1. Low-voltage connections

In the multipolar low-voltage connector at the range extender electrical machine electronics two multi-core lines with the following signals are combined:

- Voltage supply for the REME control unit (terminal 30B and ground connection)
- PT-CAN 2
- Two lines from the ACSM for the signal for the quick shutdown of the high-voltage system in the event of an accident of corresponding severity
- Wake-up line
- Input and output of the circuit of the high-voltage interlock loop (REME control unit does not evaluate the signal)
- Rotor position sensor of the electrical machine (supply and sensor signals)
- Signal of the temperature sensor in the stator coils of the electrical machine.

These lines and signals have relatively low current levels.

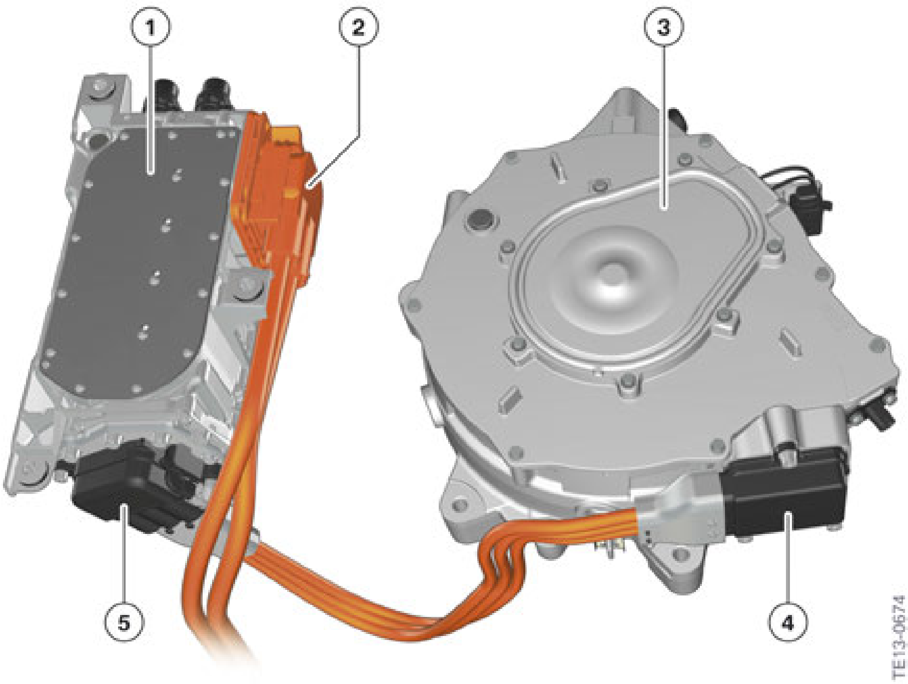
10.3.2. High-voltage connections

Two high-voltage cables are connected at the REME:

- 3-phase high-voltage cable from the range extender electrical machine
- Two-pin high-voltage cable from the KLE.

I01 High-voltage Components

10. REME



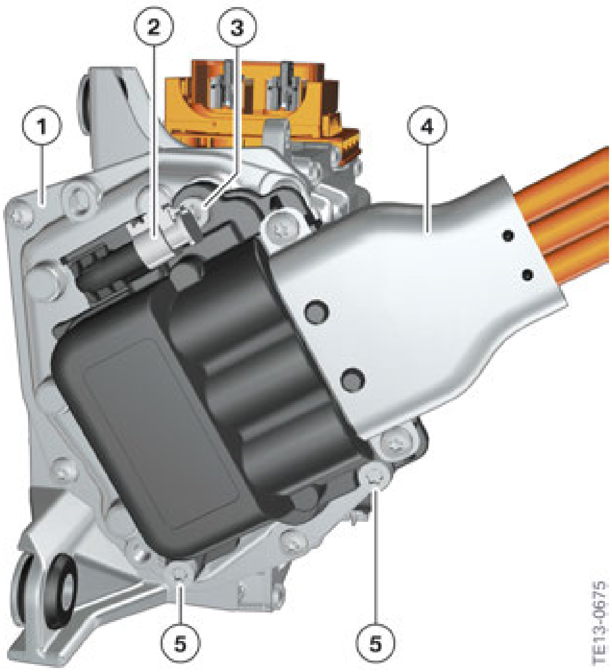
High-voltage cables at the REME

Index	Explanation
1	Range Extender Electrical Machine Electronics
2	Flat two-pin high-voltage connector
3	Range extender electrical machine
4	3-phase high-voltage connector at range extender electrical machine
5	3-phase high-voltage connector at range extender electrical machine electronics

The procedure for removing the flat high-voltage connector was already described in chapter 2 of this product information bulletin.

Three screws must be slackened to remove the 3-phase high-voltage connector at the REME.

10. REME



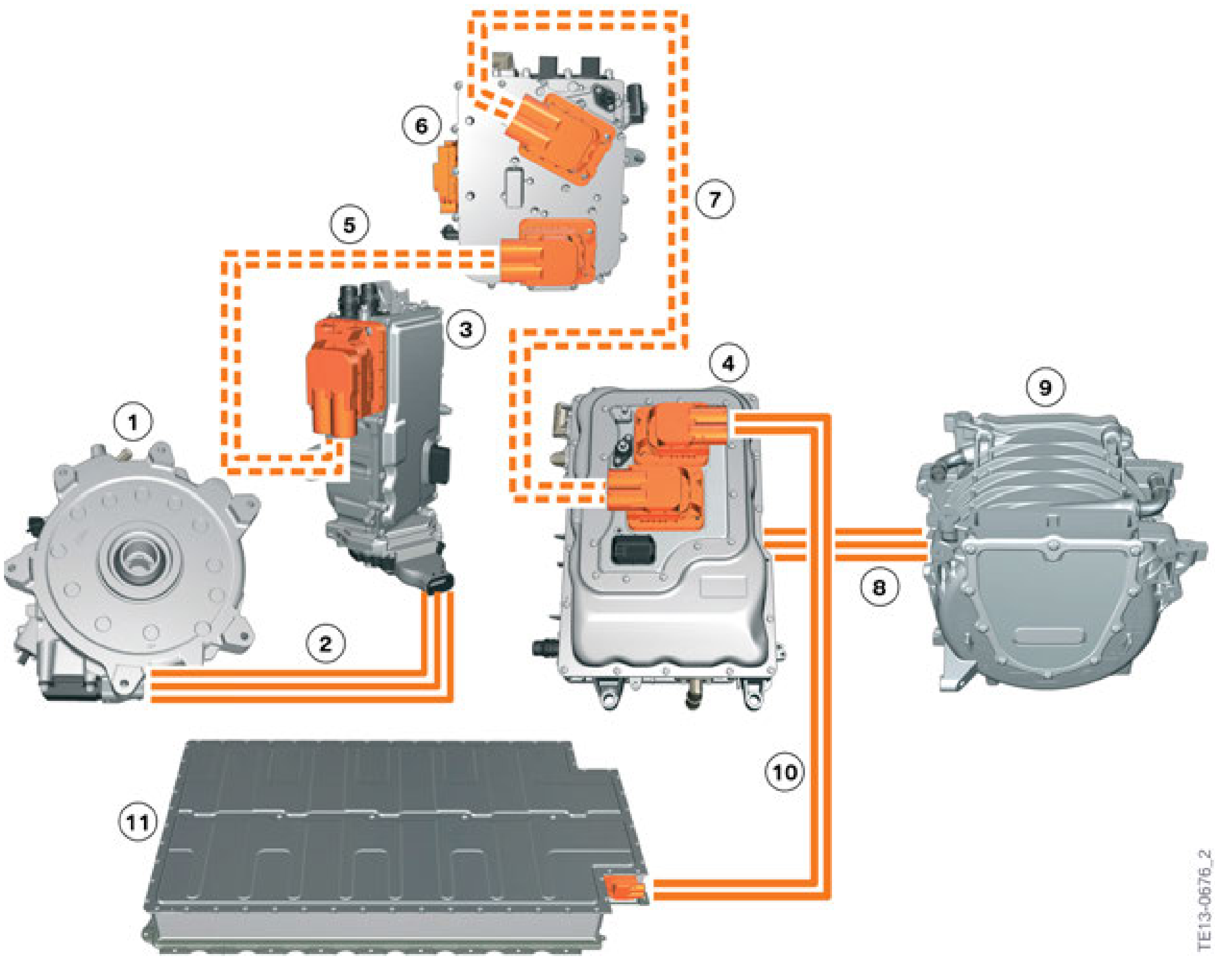
3-phase high-voltage connector at the REME

Index	Explanation
1	Range Extender Electrical Machine Electronics
2	Bridge for high-voltage interlock loop
3	Screw for securing the high-voltage connector at the REME (under the bridge)
4	Three-phase high-voltage connector
5	Screws for securing the high-voltage connector at the REME

Two of the three screws are accessible and can be easily slackened. To slacken the third screw the bridge of the high-voltage interlock loop must be removed first. Only then is the third screw visible and it can be slackened. Separating the bridge of the high-voltage interlock loop causes the high-voltage system to shut down.

The connection of the two-pin line from the REME is dependent on the vehicle equipment.

10. REME



High-voltage connections at the REME

Index	Explanation
1	Range extender electrical machine
2	3-phase high-voltage cables between range extender electrical machine and REME
3	Range Extender Electrical Machine Electronics (REME)
4	Electrical machine electronics (EME)
5	Two-pin high-voltage cable between KLE
6	Convenience charging electronics KLE
7	Two-pin high-voltage cable between KLE and EME
8	Three-phase high-voltage cable between EME and electrical machine
9	Electrical machine
10	Two-pin high-voltage cable between EME and high-voltage battery
11	High-voltage battery

If a convenience charging electronics is installed in the vehicle, the REME is connected via a two-pin HV cable and a flat HV connector to the KLE. The KLE is also connected to the EME via a two-pin high-voltage cable and a flat high-voltage connector. The 3-phase AC voltage generated by the range extender electrical machine is converted by the REME to direct current voltage and fed from the REME via the KLE to the EME via the high-voltage cables. The energy required to start the range extender combustion engine is provided by the high-voltage battery. The direct current voltage is directed via the EME and KLE to the REME by two-pin high-voltage cables. The EME and the KLE do not convert this direct current voltage, it is used solely for the contact. With this type of contact (via KLE) only one version of the EME (irrespective of the equipment) has to be installed in the I01.

10.3.3. Connections for coolant lines

The range extender electrical machine electronics is integrated in the cooling circuit of the electric motor. This cooling circuit is described in detail in chapter 11 "Cooling the electric motor components".

10.3.4. Connection for potential compensation line

The housing of the REME is connected to the rear axle module and thus ground via a potential compensation line. The potential compensation line is secured using a screw connection.

10.4. Structure and functions

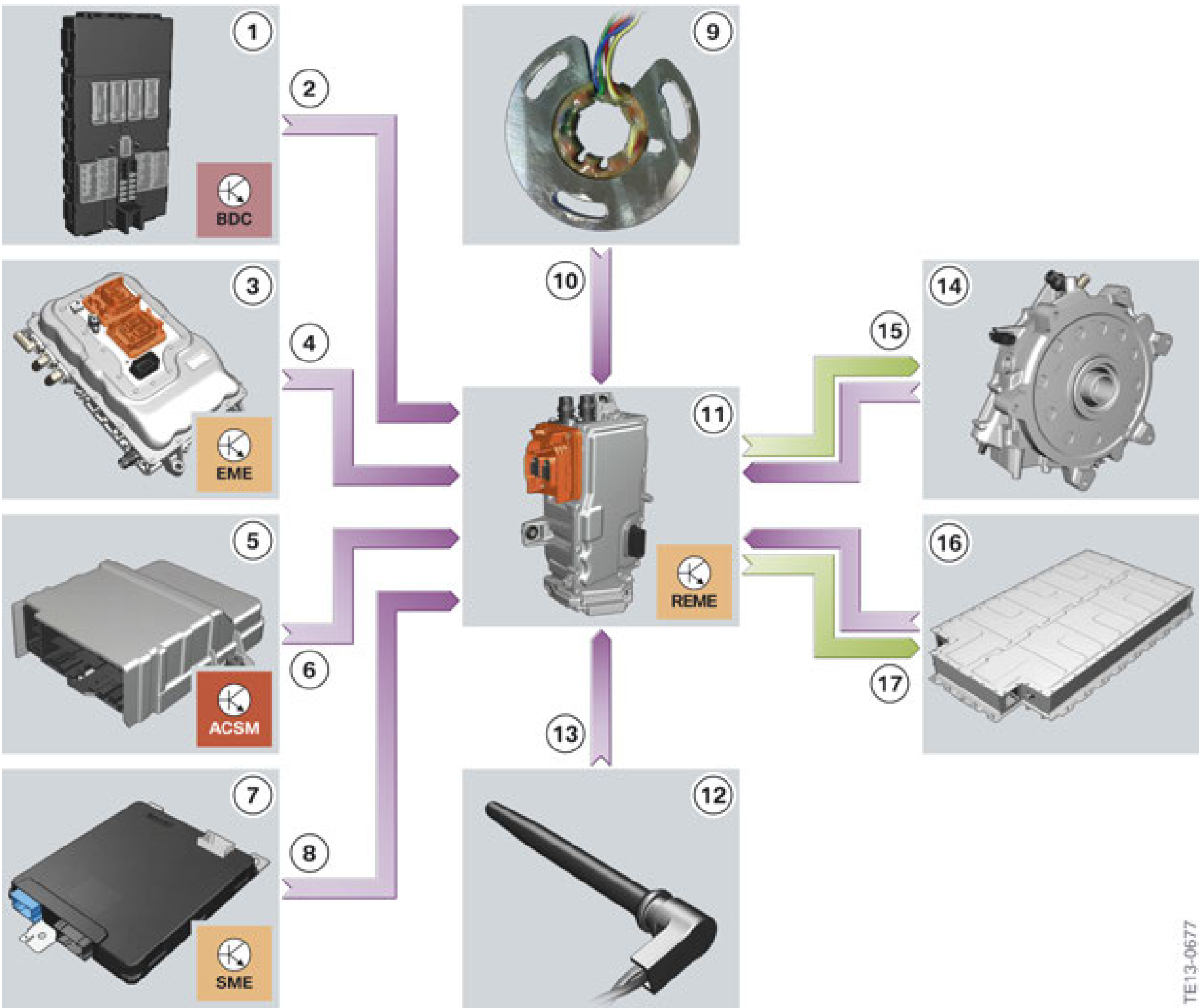
The range extender electrical machine electronics is made up internally of two subcomponents: the bidirectional DC/AC converter and the REME control unit. The link capacitors for smoothing the voltage and filtering high-frequency parts are also an element of the power electronics switching. It performs the following functions with help of the subcomponents mentioned:

- Control of the electrical machine (engine speed, torque) using DC/AC converter
- Reading and evaluation of the temperature sensor of the range extender electrical machine
- Reading and evaluation of the rotor position sensor
- Contact of the range extender electrical machine
- Contact of the electrical machine electronics or the convenience charging electronics
- Communication with other control units
- Active and passive discharging of the link capacitors to voltages less then 60 V
- Self-test and diagnostic function

The power electronics for the activation of the electrical machine are mainly made up of the bidirectional DC/AC converter. It is a pulse converter (also called "inverter") with a two-pin DC voltage connection and a 3-phase AC voltage connection. This DC/AC converter can work as an inverter and conduct electrical energy from the high-voltage battery to the range extender electrical machine when it should work as an engine. However, it can also work as a rectifier and transfers electrical energy from the range extender electrical machine (via EME or KLE) to the electrical machine or high-voltage battery.

I01 High-voltage Components

10. REME



Input/Output of REME

Index	Explanation
1	Body Domain Controller (BDC)
2	Terminal status
3	Electrical machine electronics (EME)
4	Setpoint value, engine speed
5	Crash Safety Module (ACSM)
6	Signal for quick shutdown of the high-voltage system in the event of an accident
7	Battery management electronics (SME)
8	Information about the state of charge of the high-voltage battery
9	Rotor position sensor of the range extender electrical machine
10	Signal from rotor position sensor
11	Range Extender Electrical Machine Electronics (REME)

Index	Explanation
12	Temperature sensor of the range extender electrical machine
13	Signal from temperature sensor
14	Range extender electrical machine
15	Bidirectional energy flow between REME and range extender electrical machine
16	High-voltage battery
17	Bidirectional energy flow between REME and high-voltage battery

The operating mode of the DC/AC converter is defined by the REME control unit. The REME control unit receives the setpoint value as an important input variable from the EME control unit. From this setpoint value and the current operating condition of the range extender electrical machine (engine speed and torque) the REME control unit determines the operating mode of the DC/AC converter, as well as the amplitude and frequency of the phase voltages for the range extender electrical machine. According to these specifications, the power semiconductors of the DC/AC converter are activated in sync.

In addition to the DC/AC converter, the power electronics also contains current sensors in all three phases on the AC voltage side of the DC/AC converter. Using the signals from the current sensors, the REME control unit monitors the electrical power which is used in the power electronics and the range extender electrical machine and what torque the range extender electrical machine generates. The control loop of the range extender electrical machine electronics is closed by the signals of the current sensors and the rotor position sensor in the range extender electrical machine.

The performance data of the range extender electrical machine electronics and the range extender electrical machine are coordinated in development. The range extender electrical machine electronics is thus able to permanently provide an electrical power of about 23.3 kW (DC power at 4300 rpm). In order to avoid overloading the power electronics, there is also another temperature sensor at the DC/AC converter. If an excessive temperature of the power semiconductor is identified using this signal, the REME control unit reduces the power delivered to the range extender electrical machine or used by the range extender electrical machine in order to protect the power electronics. The customer is informed via a Check Control message in the case of a noticeable power reduction. The customer receives the same error response (power reduction) and the same Check Control message if the temperature of the range extender electrical machine exceeds the permissible range.

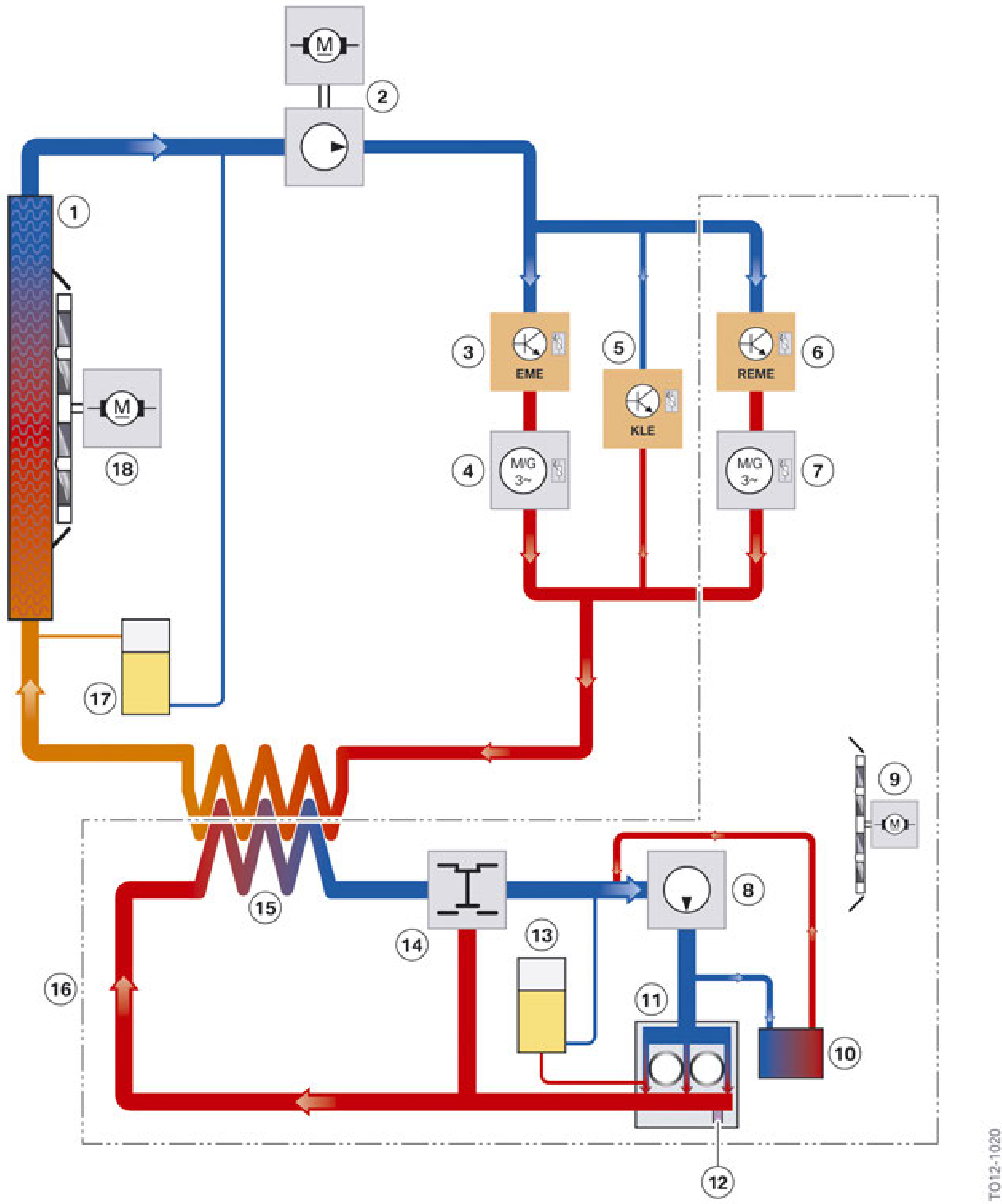
11. Cooling the Electrical Machine Components

Due to the high efficiency considerably less heat is emitted from the electrical machines and the power electronics than from combustion engines. Nevertheless, in order to ensure fault-free operation at all temperature conditions, a cooling system for cooling the electric motor components is necessary in the I01. To provide a complete overview the cooling system is shown below with the maximum equipment. For vehicles with less equipment, e.g. no range extender or no convenience charging electronics, the scope of the components of the cooling system is reduced.

All circuits are colored for better representation. The blue colors should indicate a lower temperature. The red colors indicate a high temperature of the coolant. The different red colors highlight the different high temperatures.

11. Cooling the Electrical Machine Components

11.1. System overview



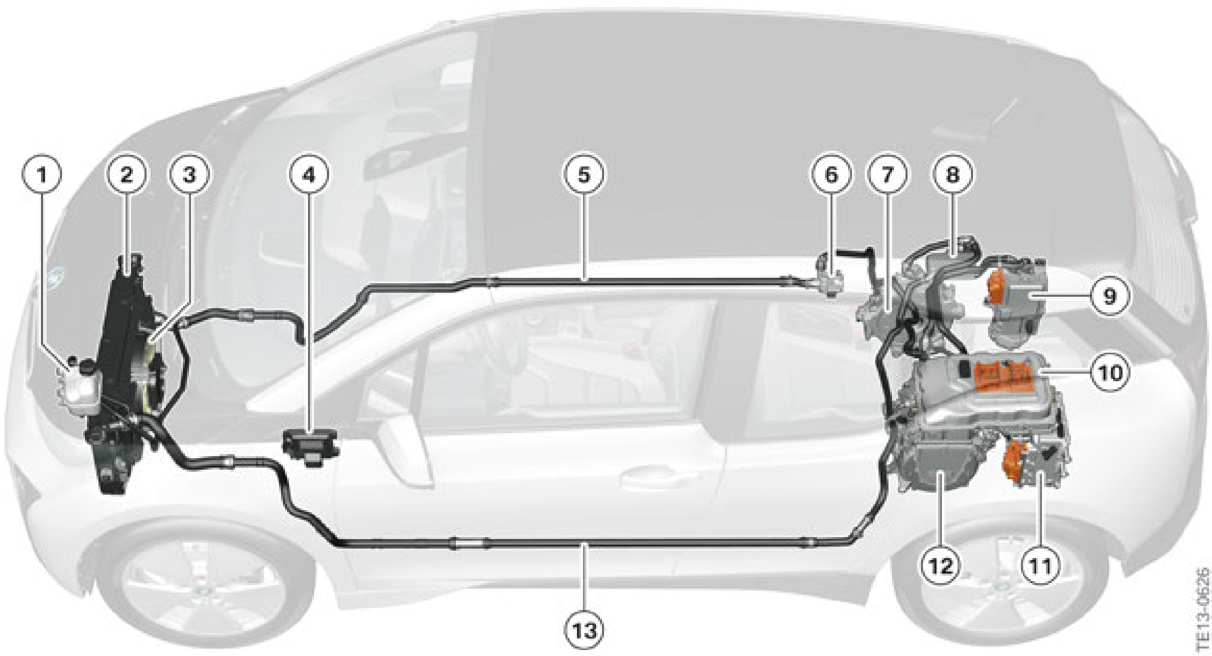
System overview for cooling the drive components in the I01 (maximum equipment)

11. Cooling the Electrical Machine Components

Index	Explanation
1	Radiator
2	Electric coolant pump (80 W)
3	Electrical machine electronics (EME)
4	Electrical machine
5	Convenience charging electronics (KLE)
6	Range Extender Electrical Machine Electronics (REME)
7	Range extender electrical machine
8	Mechanical coolant pump
9	Additional electric fan for range extender cooling unit (coolant-refrigerant heat exchanger)
10	Engine oil-to-coolant heat exchanger
11	Range extender for W20 engine
12	Coolant temperature sensor
13	Expansion tank in the cooling circuit of the combustion engine
14	Thermostat
15	Coolant-refrigerant heat exchanger for range extender
16	Scope is only installed for equipment with range extender
17	Expansion tank in the cooling circuit of the electric motor components
18	Electric fan for the radiator

The components to be cooled are switched in the cooling circuit so that the maximum temperature levels required are observed. A lower temperature is required for the electrical machine electronics than for the electrical machine, which is why the series connection in this sequence was chosen. As the electric motor and the convenience charging electronics are not operated at the same time, the parallel circuit was chosen. The range extender electrical machine and the range extender electrical machine electronics are switched initially in series. As these two components are operated at the same time as the convenience charging electronics and the electrical machine electronics, they were switched in parallel to these. In addition, the cooling system is therefore not designed for the sum of all heat outputs, because in reality heat only has to be discharged in one or two of the parallel branches. If the vehicle is equipped with a range extender, in the cooling circuit there is a coolant-coolant heat exchanger for cooling the W20 engine.

11.2. Components



Cooling of electric motor components — Installation locations

Index	Explanation
1	Expansion tank in the cooling circuit of the electric motor components
2	Radiator
3	Electric fan for the radiator
4	Electrical Digital Motor Electronics
5	Feed line
6	Electric coolant pump (80 W)
7	Range extender electrical machine
8	Expansion tank in the cooling circuit of the combustion engine
9	Range Extender Electrical Machine Electronics (REME)
10	Electrical machine electronics (EME)
11	Convenience charging electronics (KLE)
12	Electrical machine
13	Return line

The cooling module at the front of vehicle is made up of the coolant-air heat exchanger, the electric fan and optional active air cooling flaps.

11. Cooling the Electrical Machine Components

The electric coolant pump has a power of 80 W (Manufacturer: Bosch). The coolant pump is activated by the EDME control unit. For this purpose, the coolant pump and the EDME control unit are connected via a direct line. The electric coolant pump can be activated at varying power by pulse-width modulated signals. The voltage supply of the coolant pump is effected via terminal 30B. The installation location of the coolant pump is at the rear right.

The expansion tank is located in the space below the engine compartment lid on the left. There is no electrical level sensor installed in the expansion tank. But there is the following special feature to be noted for Service: A loss of coolant, for example due to a leak, in the cooling system is not identified directly due to the lack of an electrical level sensor. Instead, in the event of coolant loss the temperature of the cooled components (electrical machine, electrical machine electronics, convenience charging electronics, range extender and the range extender electrical machine electronics) rises above the normal operating range. In this case the power of the electric motor is reduced and a corresponding Check Control message is issued. The Service employee must check the following fault causes during troubleshooting:

- Loss of coolant, e.g. by a leak
- Coolant-air heat exchanger blocked
- Electric fan does not work or is restricted
- Coolant pump does not work
- Coolant lines or connections damaged
- Components to be cooled faulty (electrical machine, electrical machine electronics, convenience charging electronics, range extender electrical machine, range extender electrical machine electronics).

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If excess temperature is displayed in the cooling system of the electric motor, then this may have several causes, including also the loss of coolant. Therefore, during troubleshooting all components of the cooling system must be checked systematically.

The familiar mixture of water and antifreeze and corrosion inhibitors in BMW vehicles is used as a coolant.

⚠

When filling the cooling circuit of the electric motor use the special tool for vacuum filling according to the repair instructions.

Perform a bleeding after filling the cooling circuit, as well as after replacing components in the cooling circuit.

For the bleeding the cooling circuit for the electric motor in the I01 follow the same procedure as for conventional vehicles. There is a Service function in the diagnosis system for the activation of a bleeding procedure. This consists of appropriate activation of the electric coolant pump (varying engine speed, defined duration). This bleeding procedure can also be activated without the diagnosis system. The following procedural steps must be carried out here:

1. Connect the charging plug to the vehicle
2. Switch on terminal 15 (only ignition, no driving readiness)

3 Switch on light
4 Actuate the parking brake
5 Activate the parking lock
6 Adjust heating control to maximum temperature
7 Press and hold down brake pedal at the same time
8 Press the accelerator pedal for less than 10 seconds (fully)
9 The bleeding procedure is started. The bleeding procedure takes about 12 minutes.

⚠

Before the high-voltage battery is charged or the I01 is driven, the cooling system of the electric motor is filled with coolant and bled. Otherwise, damage may occur to the convenience charging electronics, the electrical machine, the electrical machine electronics, the range extender electrical machine or the range extender electrical machine electronics.

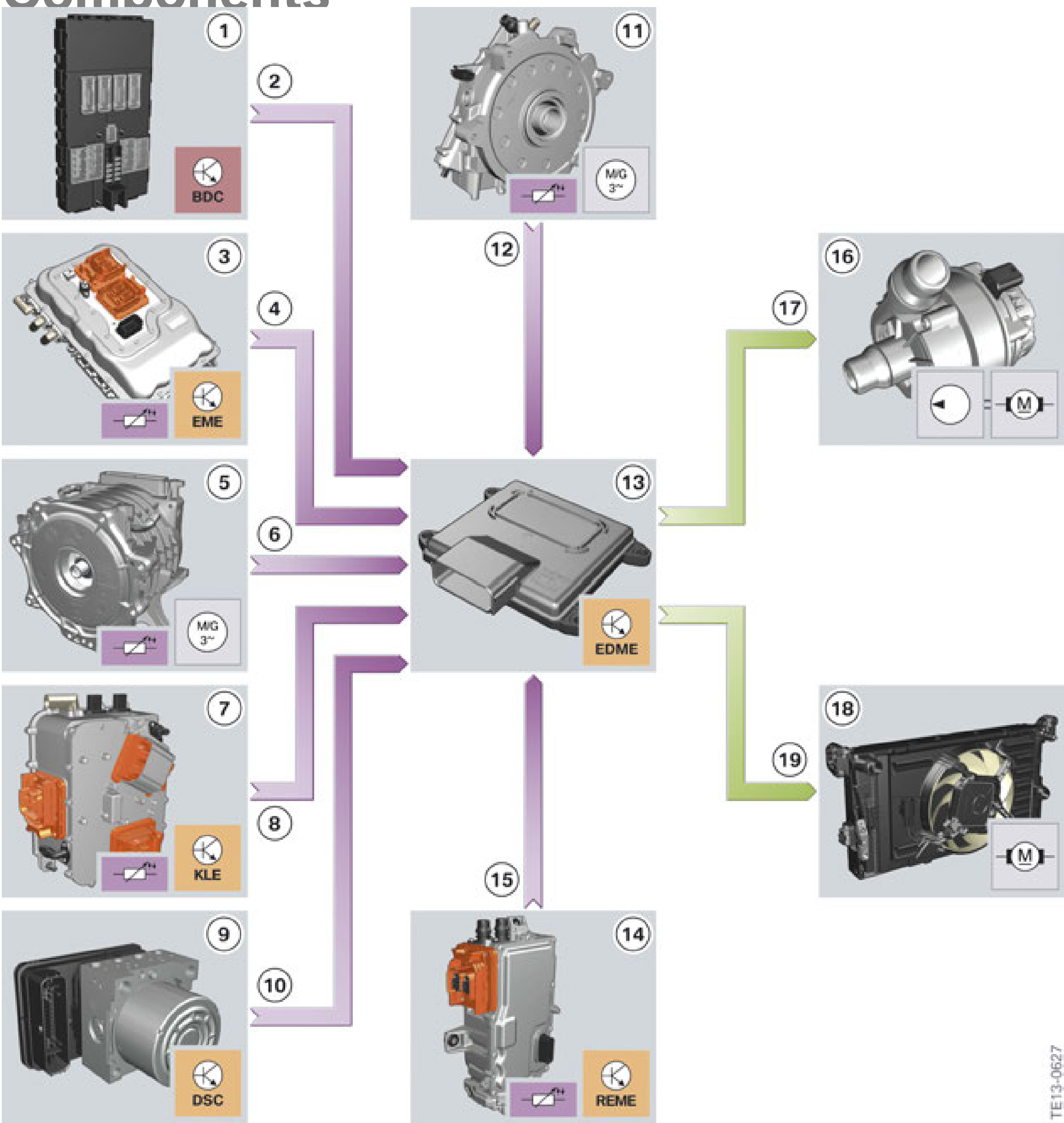
11.3. Function

The coolant in the cooling circuit of the electric motor components is pumped by an electric coolant pump (80 W) through the five electric motor components and if necessary the coolant-coolant heat exchanger.

If the air stream is insufficient for cooling the coolant in the radiator, the electric fan is also switched on by the EDME. The electric fan has a power rating of 400 W.

There is only one version of this cooling system, which is used in both the European and US version of the vehicle. A variant for cold and hot countries is not offered.

11. Cooling the Electrical Machine Components



Input/Output for cooling of electric motor components

Index	Explanation
1	Body Domain Controller (BDC)
2	Signal, terminal status
3	Temperature sensor in the electrical machine electronics
4	Signal, temperature of the power electronics in the electrical machine electronics
5	Temperature sensor in the electrical machine

11. Cooling the Electrical Machine Components

Index	Explanation
6	Signal, temperature in the electrical machine
7	Temperature sensor in the convenience charging electronics
8	Signal, temperature in the convenience charging electronics
9	Dynamic Stability Control
10	Vehicle speed
11	Temperature sensor of the range extender electrical machine
12	Signal, temperature in the range extender electrical machine
13	Electrical Digital Motor Electronics
14	Temperature sensor in the range extender electrical machine electronics
15	Signal, temperature in the range extender electrical machine electronics
16	Electric coolant pump
17	Power requirement at electric coolant pump
18	Electric fan
19	Speed requirement, electric fan

Similar to the cooling systems of current BMW vehicles with combustion engines, the control in the I01 is also effected depending on the cooling power requirement. This control is integrated in the Electrical Digital Motor Electronics (EDME).

The following input signals are used for the control:

- Component temperature of electrical machine
- Component temperature of electrical machine electronics
- Component temperature of convenience charging electronics
- Component temperature of range extender electrical machine electronics
- Component temperature of range extender electrical machine
- Current power used in the electric motor or convenience charging electronics
- Driving speed.

In comparison to the familiar cooling systems of conventional vehicles, the coolant temperature is **not** used as an input variable for the control. Accordingly, there is no coolant temperature sensor in the cooling system for the electric motor of the I01. Instead, the electric coolant pump and the electric fan are activated according to the listed input variables and also the current cooling requirement. The coolant can reach a maximum temperature of about 85 °C/ 185 °F (return from the electrical machine). In comparison to the cooling system for BMW combustion engines, the temperature level is lower. The cooling circuit for the range extender has a higher temperature. Therefore, using the coolant-coolant heat exchanger the temperature of the coolant in the cooling circuit for the range extender can be reduced. Also in the I01 the familiar precautionary measures must be observed before working on the cooling system.

The activation of the coolant pump and electric fan can be effected in the following vehicle conditions:

11. Cooling the Electrical Machine Components

- Terminal 15 switched on, driving readiness
- Terminal 15 switched on, no driving readiness
- High-voltage battery is charged.

The power electronics switching of the electrical machine electronics are already working when terminal 15 is switched on. Both the high-voltage electrical system (EKK and electric heating) and the 12 V vehicle electrical system are supplied with energy by the DC/DC converter. If due to the arising heat a cooling requirement is identified, the coolant pump is switched on, and if required also the electric fan.

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When terminal 15 is switched the coolant pump and electric fan can be switched on automatically. For work with an open engine compartment lid or at the cooling module it is imperative terminal 15 is switched off.

While the high-voltage battery is being charged, the power electronics in the electrical machine electronics and in the convenience charging electronics are working. Due to the high electrical power, which is generated in the electrical machine electronics and the convenience charging electronics, heat also develops. This must be dissipated using the cooling circuit described here. For this reason, the electric coolant pump and the electric fan are also switched on during charging with a correspondingly high temperature in the electrical machine electronics and in the convenience charging electronics.

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The coolant pump and the electric fan can be switched on automatically when charging the high-voltage battery. The high-voltage battery cannot be charged when working with the engine compartment lid open or at the cooling module.

I01 High-voltage Components

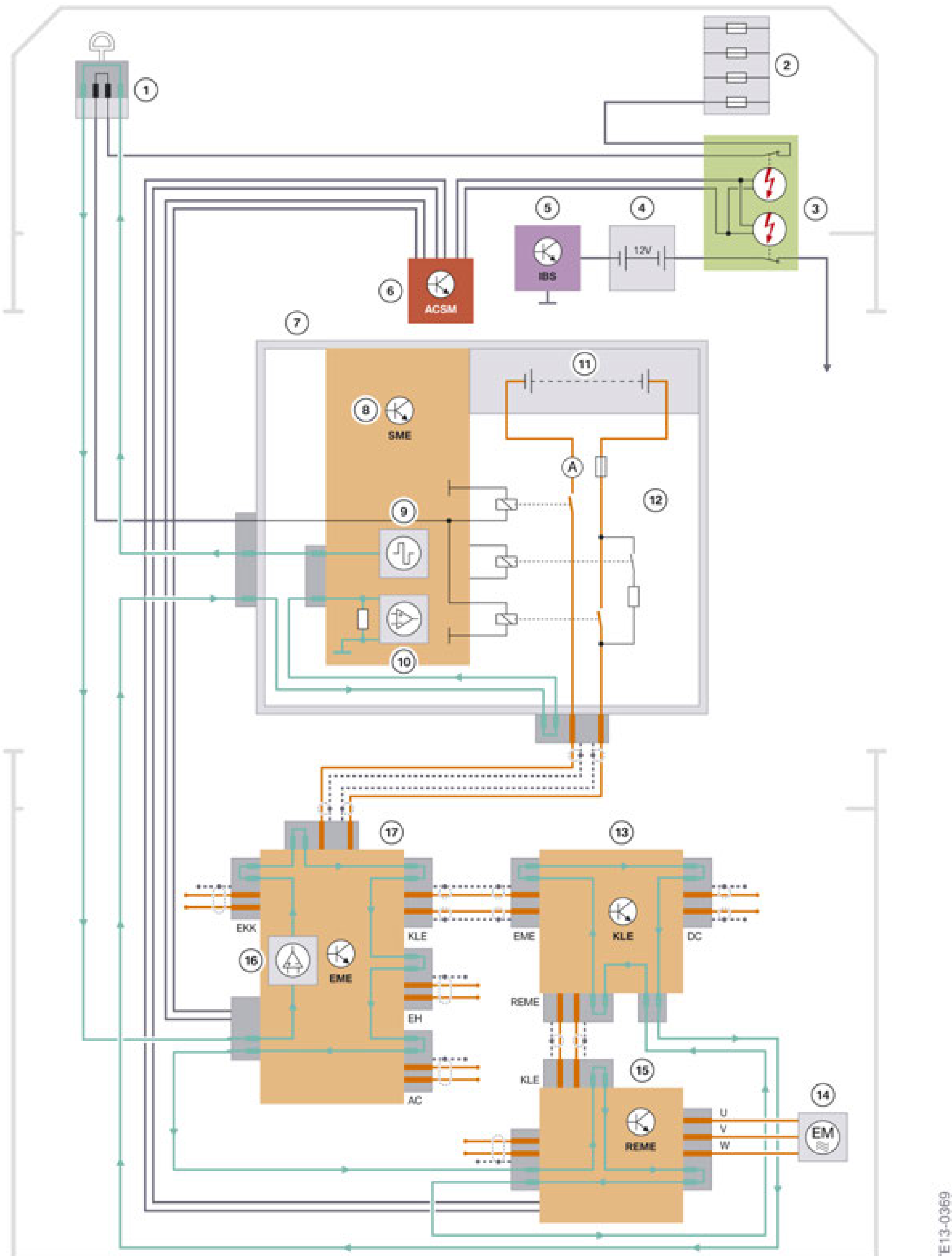
12. Technical Safety Precautions

12.1. High voltage interlock loop

The high-voltage interlock loop is used to protect individuals when working on or at the high-voltage components. Via the high-voltage interlock loop it is identified whether one or several high-voltage plug connections have been disconnected. If a high-voltage plug connection has been disconnected, the entire high-voltage system is shut down automatically. A square wave signal with alternating current direction is sent through the line of the high-voltage interlock loop by the battery management electronics SME. The SME and the electrical machine electronics EME evaluate this signal.

The line of the high-voltage interlock loop runs through each connector/plug of the high-voltage components, which are able to generate high voltage.

12. Technical Safety Precautions



Main wiring diagram for high voltage interlock loop

Index	Explanation
1	High-voltage safety connector ("Service-Disconnect")
2	Fuse block, front
3	Safety battery terminal (SBK)
4	12 V battery
5	Intelligent battery sensor (IBS)
6	Crash Safety Module (ACSM)
7	High-voltage battery unit
8	Battery management electronics (SME)
9	Signal generator for test signal of the high-voltage interlock loop in the battery management electronics
10	Evaluation circuit for test signal of the high-voltage interlock loop in the battery management electronics
11	Cells of the high-voltage battery
12	Switch contactor, fuse and series resistor in the high-voltage battery
13	Convenience charging electronics (KLE)
14	Range extender electrical machine
15	Range Extender Electrical Machine Electronics (REME)
16	Evaluation circuit for test signal of the high-voltage interlock loop in the electrical machine electronics
17	Electrical machine electronics (EME)

12.2. Starting and shutting down the high-voltage system

The master control unit for the control of the high-voltage system is the electrical machine electronics.

12.2.1. Starting

The sequence for starting the high-voltage system is always the same irrespective of which of the following events was the trigger:

- Terminal 15 is switched on or driving readiness is established
- Charging the high-voltage battery should start
- "Preparation" of the vehicle for the journey (climate control of the high-voltage battery or the passenger compartment).

The individual steps for starting the high-voltage system are:

1 EME control unit requests starting via bus signal at the PT-CAN and PT-CAN2

2 The high-voltage electrical system is checked using self-diagnosis functions

3 The voltage in the high-voltage circuit is increased continuously

4 The contacts of the switch contactors are fully closed.

The high-voltage electrical system is mainly checked by the EME control unit and the SME control unit. Criteria relevant for safety, for example the circuit of the high-voltage interlock loop or the isolation resistance, are checked. Functional preconditions such as the operating readiness of all subsystems must also be fulfilled for starting.

As the high-voltage circuit capacitors have high capacity values (link capacitors in the power electronics), the contacts of the electromechanical switch contactors cannot be easily closed. Extremely high current pulses would damage both the high-voltage battery and the link capacitors and the contacts of the switch contactors. First of all, the switch contactor of the ground cable in the high-voltage battery is closed. In order to restrict the switch-on current, there is a current path with resistance in the positive wire (connected parallel to the switch contactor). This is now activated and a switch-on current restricted by the resistance charges the link capacitors. If the voltage of the link capacitors has reached the approximate value of the battery voltage, the last contact of the switch contactor at the positive terminal of the high-voltage battery unit is closed. The high-voltage system is now fully operational.

If there is no fault in the high-voltage system, the entire starting of the high-voltage system is completed in about 0.5 seconds. There is thus no disadvantage for the customer in comparison to vehicles with a conventional engine.

The SME control unit communicates successful starting via the PT-CAN2 to the EME control unit. Fault statuses are also communicated in the same way, if, for example, a contact of a switch contactor was unable to be closed.

12.2.2. 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. The regular shutdown described here protects all respective components on the one hand, and, on the other hand, includes the monitoring of components of the high-voltage system which are relevant for safety.

Regular shutdown

If the following preconditions or criteria are present, the high-voltage system is shutdown in the regular manner:

- Terminal 15 is switched off by the driver and the after-running period is expired (controlled by EME)
- End of the functions "stationary cooling", "auxiliary heater" or "conditioning of the high-voltage battery"
- End of the charging procedure for the high-voltage battery.

The sequence for the regular shutdown is generally the same irrespective of the trigger. The individual steps are:

1 EME orders the shutdown after the after-running period has expired via bus signals at the PT-CAN/PT-CAN2

2 The systems at the high-voltage electrical system (EME, REME, KLE, EKK, EH) reduce the currents in the high-voltage electrical system to zero

3 Opening the switch contactors in the high-voltage battery unit (controlled by SME)

4 Discharging the high-voltage circuit, i.e. active discharging of the link capacitors (EME, REME and KLE), short-circuit of the coils of the electrical machine (EME and REME), short-circuit of the coils of the EKK

5 Checking the high-voltage system, e.g. as to whether the contacts of the electromechanical switch contactors were correctly opened.

Both the after-running period after switching off terminal 15 and the shutdown itself can last a few minutes. The automatic monitoring functions are a reason for this, for example. The regular shutdown is interrupted if in the meantime either a request for a renewed start-up is made or a condition has arisen to request a quick shutdown.

Quick shutdown

The overriding aim here is to shut down the high-voltage system as quickly as possible. This quick shutdown is then always carried out if for safety reasons the voltage in the high-voltage system has to be reduced to a safe value as quickly as possible. The following list describes the triggering conditions and the functional chain leading to the quick shutdown.

- **Accident:**
  ACSM identifies an accident. Depending on the severity of the accident the shutdown of the high-voltage system is requested via bus signals. The SME triggers the separation of the switch contactors in the high-voltage battery. In the case where communication via a data bus is faulty or not possible, the switch-off of the switch contactors is forced (hard opening). The switch contactors are supplied with voltage by terminal 30C. Through the separation of the safety battery terminal from the positive terminal of the 12 V battery, the voltage supply of the switch contactors is also interrupted and their contacts open automatically.
  The EME and the REME also receive bus signals for switching off the high-voltage system. Both control units immediately trigger the active short circuit of the electrical machines (short-circuit of the coils of the corresponding electrical machine via the power semiconductor of the AC/DC converter) and the active link capacitors are discharged. If communication via the data bus is not possible, the shutdown request is sent via the separate lines between ASCM and EME, as well as between ACSM and REME.
- **Overload current monitoring:**
  With help of current sensors in the high-voltage battery unit the current level in the high-voltage electrical system is monitored. If too high a current level is identified, the SME control unit causes a hard opening of the electromechanical switch contactors. Considerable wear occurs to the contacts of the switch contactors as a result of this opening under a high current, which must be accepted to protect the other components from damage.
- **Protection in the event of a short circuit:**
  In the high-voltage battery unit there is an overload current fuse which interrupts the high-voltage circuit in the event of a short circuit.
- **Critical cell state:**

If a cell supervision circuit identifies extreme under-voltage, over-voltage or excess temperature at a battery cell, this also leads to a hard opening of the electromechanical switch contactors - controlled by the SME control unit. Although this may lead again to increased wear at the contacts, this quick shutdown is necessary to prevent destroying the respective battery cells.

- **Malfunction of the 12 V voltage supply of the high-voltage battery unit:** In this case the battery management electronics control unit no longer works and it is no longer possible to monitor the battery cells. For this reason the contacts of the electromechanical switch contactors also open here automatically.

12.2.3. Charging the high-voltage battery

The SME control unit also plays an important role in the charging of the high-voltage battery with energy supply from an external power network. Using the state of charge and the temperature of the battery cells, the SME control unit defines the maximum electrical power which the high-voltage battery can currently use. This value is transmitted in the form of a bus signal via the PT-CAN2 to the EME control unit. The "High-voltage power management" function coordinates the individual power requirements and forwards the total value to the electrical machine electronics (and from there to the convenience charging electronics).

During charging the SME control unit constantly identifies the state of charge already reached and monitors all sensor signals of the high-voltage battery. In order to ensure optimal progress of the charging procedure, the SME control unit constantly calculates current values for the maximum charging power based on these values and communicates these to the EME control unit. The heating/cooling system of the high-voltage battery is also continuously controlled by the SME control unit during the charging procedure which contributes to a quick and efficient charging procedure.

12.3. Pinpointing isolation faults

The SME control unit reliably identifies when the isolation resistance in the high-voltage electrical system drops below the specified values. A fault code entry, a Check Control message and, if required, the shutdown of the high-voltage system, are automatically effected. The isolation monitoring in the SME control unit alone cannot determine the actual location of the fault in the high-voltage electrical system. Instead, an isolation fault must be pinpointed by using a test schedule in the diagnosis system. Several systematic test steps are required in order to determine the components or the high-voltage cable causing the isolation fault.

12.4. Start-up of the high-voltage system

If in the event of a repair high-voltage components are removed or replaced, it is imperative to ensure that

- all high-voltage connectors
- all potential compensation lines and connections for potential compensation
- all signal connectors
- all coolant or refrigerant lines and
- all mechanical connections are properly connected.

12. Technical Safety Precautions

The cooling or refrigerant system must also be filled with coolant or refrigerant.

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If the above-mentioned preconditions are not satisfied, the high-voltage system cannot be operated.

13. Operating Strategy

The operating strategy has the task of maximizing the service life of the high-voltage battery and protecting it against damage during operation. All customer requirements when driving and during charging should also be fulfilled. The behavior of the electric motor in the event of a fault is also an element of the operating strategy. The EDME is the master control unit for the operating strategy.

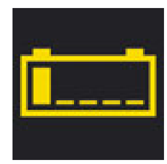
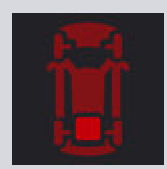
13.1. Operating strategy with pure electric drive

The I01 is designed as a vehicle with a pure electric drive for urban mobility. The high-voltage battery and the electrical machine deliver impressive vehicle performances:

- Range > 160 km (at 20 °C) / 100 mi (at 68 °F)
- Maximum speed 150 km/h/ 93 mph (short-term, 3 minutes) or 120 km/h/74.5 mph (continuous)
- Acceleration from 0-100 km/h in 7.2 s

Before a drive torque is applied, the EDME must check whether the driving readiness is established. The EDME also queries whether all subsystems of the electrical drive train are functioning trouble-free, which is also a prerequisite for the provision of a drive torque. Finally, the EDME still has to consider the available electrical power for the electric motor which is primarily determined by the condition of the high-voltage battery. The SME control unit communicates this condition to the EDME control unit via corresponding bus signals. As a result of these checks the EDME identifies whether and in what scope the drive torque can be provided. In the case of fault statuses or in the event of limited availability, the EDME issues an appropriate Check Control message via the instrument cluster.

The statuses of the operating strategy relevant for the customer and the Service employee are listed below and described briefly.

Status	Features	Reason/ Precondition	Displays
Driving without restrictions	The full power of the electric motor is available for acceleration. Full scope of brake energy regeneration is possible. Full scope of all climate control functions are available.	State of charge of the high-voltage battery in optimal range. Temperature of the high-voltage battery in optimal range	Normal functional displays such as state of charge of the high-voltage battery, drive power during acceleration or deceleration
Driving with restricted driving power	The drive power is reduced to protect components. Full scope of all climate control functions is possibly no longer available.	State of charge of the high-voltage battery very low. Temperature of the high-voltage battery extremely low or extremely high	 
High-voltage system deactivated	Electric motor and climate control functions no longer work because the high-voltage system can no longer supply energy.	High-voltage system disconnected from the supply. High-voltage battery completely discharged or damaged.	 
Climate control while vehicle is stationary	The passenger compartment and/ or the high-voltage battery are heated or cooled.	Customer activates the function at the vehicle or using "My BMW i Remote app". Vehicle is connected at AC voltage network using charging cable.	In the central information display and in the IHKA display.
No brake energy regeneration possible	The vehicle does not decelerate when the vehicle is released using the electric motor.	The high-voltage battery cannot absorb any electrical energy (e.g. because it is fully charged or the cell temperature does not allow it).	

13. Operating Strategy

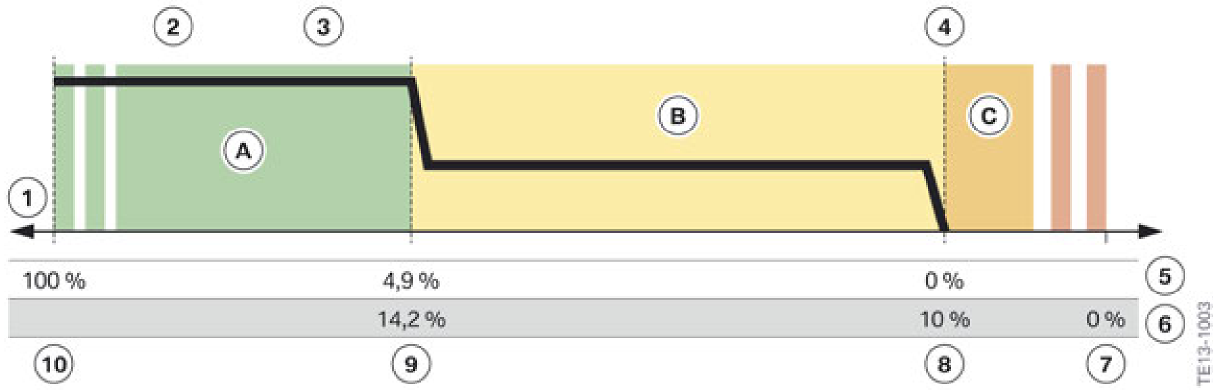


Diagram for the BEV operating strategy

Index	Explanation
A	Range in which driving without restrictions is possible
B	Range in which driving with restricted drive power takes place
C	Range in which driving is not possible
1	Calculated state of charge of the high-voltage battery (State of Charge = SOC)
2	Warning for range of 20 km
3	Warning for range of 10 km
4	Warning for range of less than 1 km
5	Axis for relative SOC values
6	Axis for absolute SOC values
7	SOC of the high-voltage battery 0% absolute
8	SOC of the high-voltage battery 10% absolute, or 0% relative
9	SOC of the high-voltage battery 14.2% absolute, or 4.9% relative
10	SOC of the high-voltage battery 100% relative

In the diagram the relative and the absolute state of charge values (SOC values) of the high-voltage battery are shown. The absolute values correspond to the actual state of charge of the high-voltage battery. The relative SOC values are the values which are displayed to the driver in the instrument cluster or in the central information display. In range "A" driving without power restriction and full functionality of the convenience functions are available. If the SOC value of the high-voltage battery approaches about 5%, the Check Control messages for ranges between 20 km and 10 km are issued.

In range "B" the performance of the drive train is reduced due to the low state of charge of the high-voltage battery. The heating and air-conditioning system is switched off here.

If the absolute SOC value falls below 10%, driving the vehicle is no longer possible. The reserve of 10% is required to give the customer adequate time to charge the high-voltage battery and prevent deep discharge.

The driver has the option to extend the range by activating ECO PRO or ECO PRO + mode. Here the power of some electrical consumers is reduced or the consumers are switched off completely. In ECO PRO mode the maximum speed is 130 km/h (can be adjusted in ECO PRO menu from 80 km/h to 130 km/h). In ECO PRO + mode the maximum driving speed is restricted to 90 km/h.

	Comfort	ECO PRO	ECO PRO +
Range potential		up to 20% more than in Comfort mode	up to 30% more than in Comfort mode
Restriction of the maximum driving speed (can be breached)	none	80 km/h to 130 km/h (adjustable)	90 km/h
Mirror heating	No reduction	- 25%	- 25% and after 10 minutes off, if wiper off
Heated rear window	No reduction	Shorter heating and cycle times	Shorter heating and cycle times
Dim low-beam headlight	No	No	No
Heated seats	No reduction	Maximum Stage 2	Deactivated
Cooling in passenger compartment	Balance comfort/ range	More economical program with reduced consumption	Climate control off, blower output reduced (windows are fog-free)
Heating for passenger compartment	Balance comfort/ range	More economical program with reduced consumption	Heater output is reduced so that only the windows remain fog-free

13.2. Operating strategy for vehicles with range extender

Using the optional range extender it is possible to extend the range of the I01. The W20 combustion engine drives the range extender electrical machine, whereby electrical energy is generated. This electrical energy flows directly to the electric motor/electrical machine or to the high-voltage battery depending on the driving requirement (the EME decides the flow). The aim is to keep the state of charge (SOC) at a constant level.

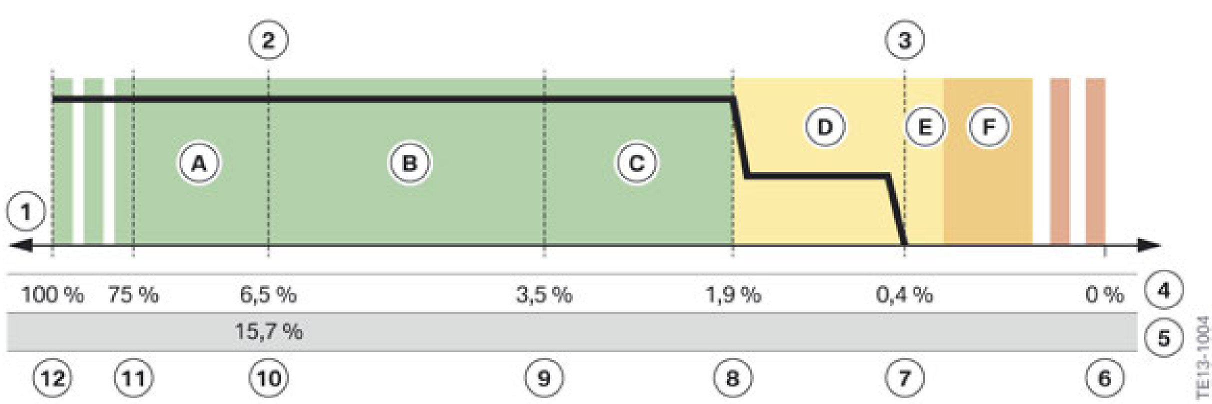


Diagram for the REX operating strategy

13. Operating Strategy

Index	Explanation
A	Range in which driving without restrictions is possible
B	Range in which driving without restrictions is possible and automatic engine start-stop function is active
C	Range in which driving without restrictions is possible and automatic engine start-stop function is not active (REX is permanently on)
D	Range in which driving with restricted drive power takes place
E	Range with safety reserve for REX start
F	Range in which driving is not possible
1	Calculated state of charge of the high-voltage battery (State of Charge = SOC)
2	First automatic REX start
3	Warning for range of less than 1 km
4	Axis for relative SOC values
5	Axis for absolute SOC values
6	SOC of the high-voltage battery 0% absolute
7	SOC of the high-voltage battery 0.4% relative
8	SOC of the high-voltage battery 1.9% relative
9	SOC of the high-voltage battery 3.5% relative
10	SOC of the high-voltage battery 6.5% relative, or 15.7% absolute
11	SOC of the high-voltage battery 75% relative
12	SOC of the high-voltage battery 100% relative

Up to a state of charge of the high-voltage battery of 6.5% relative (displayed SOC) a I01 with REX behaves in exactly the same way as a I01 with a pure electric motor.

If the state of charge of the high-voltage battery drops below 6.5% relative, the REX combustion engine is started automatically. The automatic engine start-stop function is active up to a state of charge of 3.5%. Driving without restrictions is possible for the state of charge between 3.5% and 1.9%, but without automatic engine start-stop function. Only when the state of charge of the high-voltage battery falls below 1.9%, does the driving with restricted drive power takes effect. At a state of charge of 0.4% a warning message with range of one kilometer is issued. Driving is no longer possible below this SOC value. In the high-voltage battery there is an energy reserve so that it is possible to restart the REX combustion engine or so that the high-voltage battery does not discharge fully over an extended period.

After refueling the I01 with REX driving without restrictions is again possible.

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