Electrical safety on charging electric vehicles

The monitoring of the insulation resistance is particularly important for the prevention of damage and injury, and for the reliability of electrical systems. The insulation resistance also serves as an important indicator for the condition of an electrical installation. This statement also applies to the area of e-mobility. By means of the correct selection of the type of system, combined with protective and monitoring devices compliant with the standards, a high degree of safety and reliability is achieved.

Type of system and protective measures

In the e-mobility area there are essentially three types of system to be taken into account. In the case of AC charging these are primarily earthed systems (TN-S systems) while in the case of the DC charging station unearthed power supplies (IT systems) are used. The electric vehicle itself has an insulated high voltage system that is comparable with an IT system in accordance with DIN VDE 0100-100:2009 [1]. A key issue for the electrical safety is the charging process in particular, as here different types of system are connected together to form an overall system. During vehicle operation the vehicle's high voltage system can be considered a “mobile” IT system, during charging this changes to either an earthed (TN system) or an unearthed (IT system) overall system with the important challenge of reconciling the supplying system’s and the HV system’s protective measures.

HV system

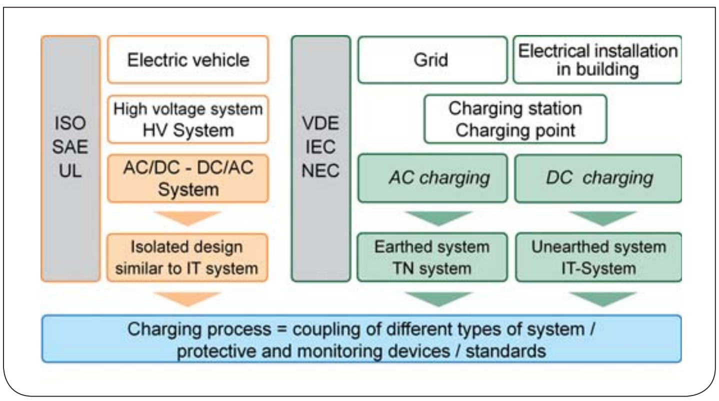
The HV system in the vehicle is monitored by an on-board insulation monitoring device and the occurrence of an insulation fault signalled, as shutdown while driving would be fatal. The message is displayed to the driver, e.g., on a display such that the insulation fault can be rectified by a specialist garage. There is no immediate hazard for the driver, however the insulation fault must be rectified as soon as possible to prevent a second fault on another cable affecting the operation of the vehicle.

Charging process

The protective measures for the electrical installation are described in detail in the standard DIN VDE 0100-410 (VDE 0100-410): 2007-06 [2], while the measures for the electric vehicle are defined in the standard ISO/FDIS 6469-3:2011-05 [5]. Before an electric vehicle can be charged, it should first be ensured that the HV system in the vehicle is free of insulation faults. In this way it is ensured that an insulation fault in the vehicle does not cause the protective and monitoring device in the charging station to trigger and therefore prevent charging. As a rule the vehicle’s own insulation monitoring system checks the insulation resistance and only enables the charging contact in the vehicle if there is adequate insulation resistance. Limits are defined, e.g., in ISO/FDIS 6469-3:2011-05 [5] as 500 V/Ω for AC systems and as 100 Ω/V for DC systems. At the start of the charging process, the vehicle’s insulation monitoring is mostly switched to passive to prevent interaction with the protective and monitoring devices in the charging station. As a result the protective device in the charging station then has the task during the charging to monitor the complete circuit including the charging electronics in the vehicle.

An important prerequisite for a safe charging process is the continuity of the protective conductor. This continuity is checked by the ControlPilot and monitored during the charging process. If there are no problems with the protective conductor the charging process is enabled. From the point of view of the charging station it is also possible to measure the insulation resistance prior to the start; this measurement will then mostly include the charging cable to the vehicle input. This, however, makes it possible to detect, e.g. damage to the charging cable caused by mechanical effects.

FIGURE 1: CO-ORDINATION OF THE MEASURES
[GRAPHIC, BENDER GRUENBERG]



There are various options in the standards for charging an electric vehicle; these options are defined in the DIN IEC 61851-... series of standards [3] as mode 1...4.

AC charging (mode 2 and 3)

For AC charging a residual current device of type A is required per charging socket in accordance with IEC 61581-...[3] mode 3. It is also necessary to take into account the requirements from DIN EN 61140 (VDE 0140-1):2007-3 [7] that the measures taken against protective conductor currents must be compatible with all the frequencies transmitted to and from the equipment. This means that if DC fault currents ≤ 6 mA or fault currents with higher frequencies (e.g. 20 kHz) can occur, protection against electric shock is to be provided using a residual current device of type B or B+, or equivalent alternative switching monitoring devices. If it is not ensured that there is an RCD in the charging socket's circuit, a portable protective device IC-RCD must be used (node 2). The residual current devices or switching monitoring devices ensure that any AC fault current or DC fault current is interrupted within a specified time, i.e. the load is switched off so that individuals cannot be placed at risk.

FIGURE 2: AC CHARGING IN MODE 2 WITH AN IC-RCD OF TYPE A IN THE CHARGING CABLE AND FAULT CURRENT DETECTION FOR DC ≥ 6MA OR HIGHER FREQUENCIES IN THE VEHICLE
[GRAPHIC, BENDER GRUENBERG]

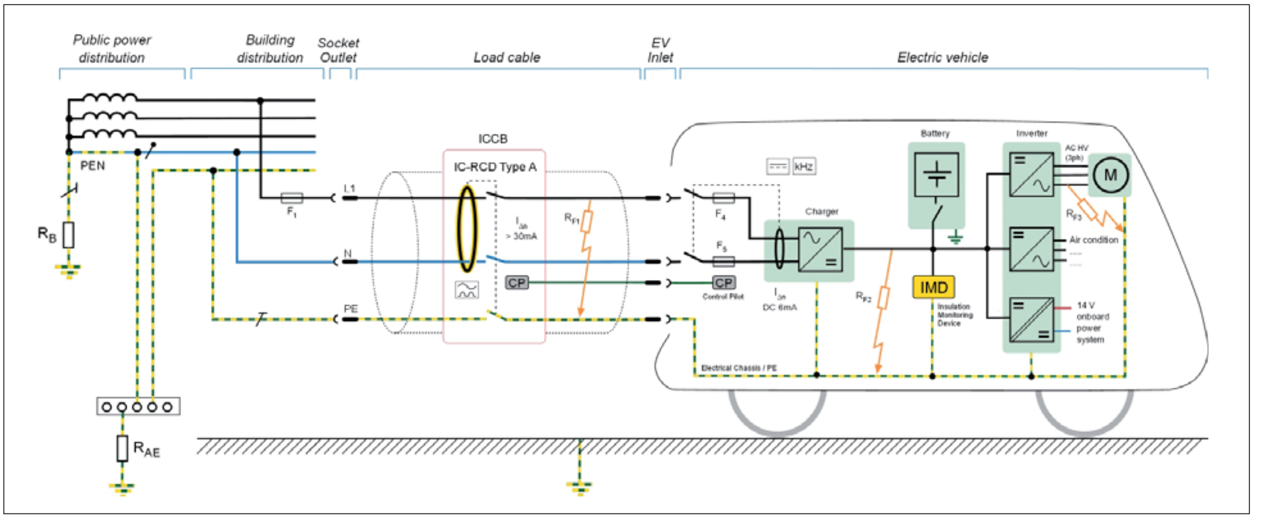
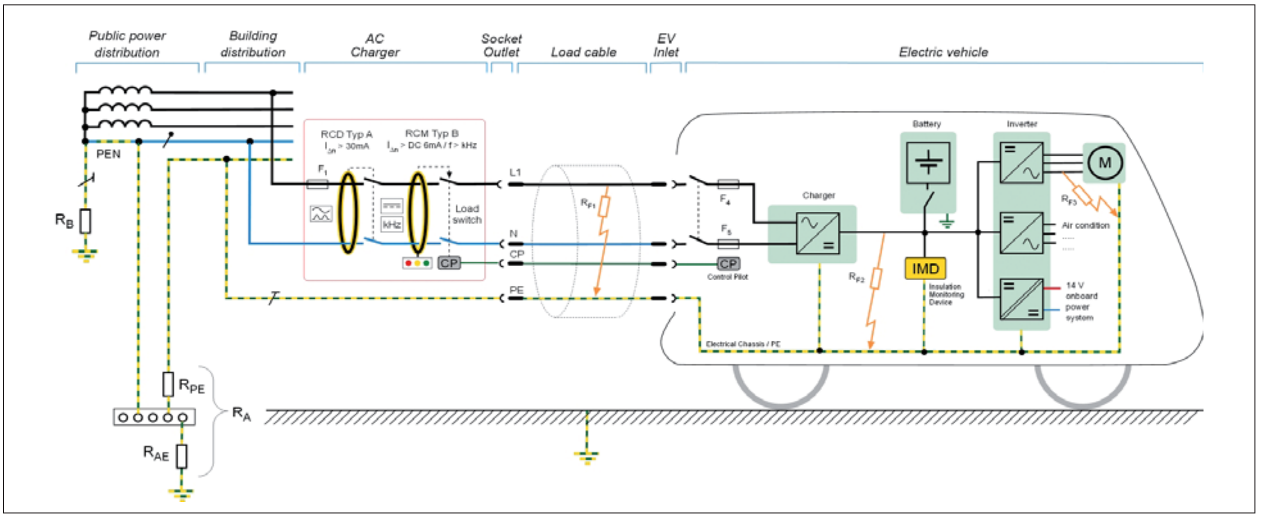


FIGURE 3: AC CHARGING IN MODE 3 WITH AN RCD OF TYPE A AND ADDITIONAL MONITORING FOR FAULT CURRENTS DC ≥ 6MA OR HIGH FREQUENCIES IN THE ELECTRICAL INSTALLATION
[GRAPHIC, BENDER GRUENBERG]



DC charging (mode 4)

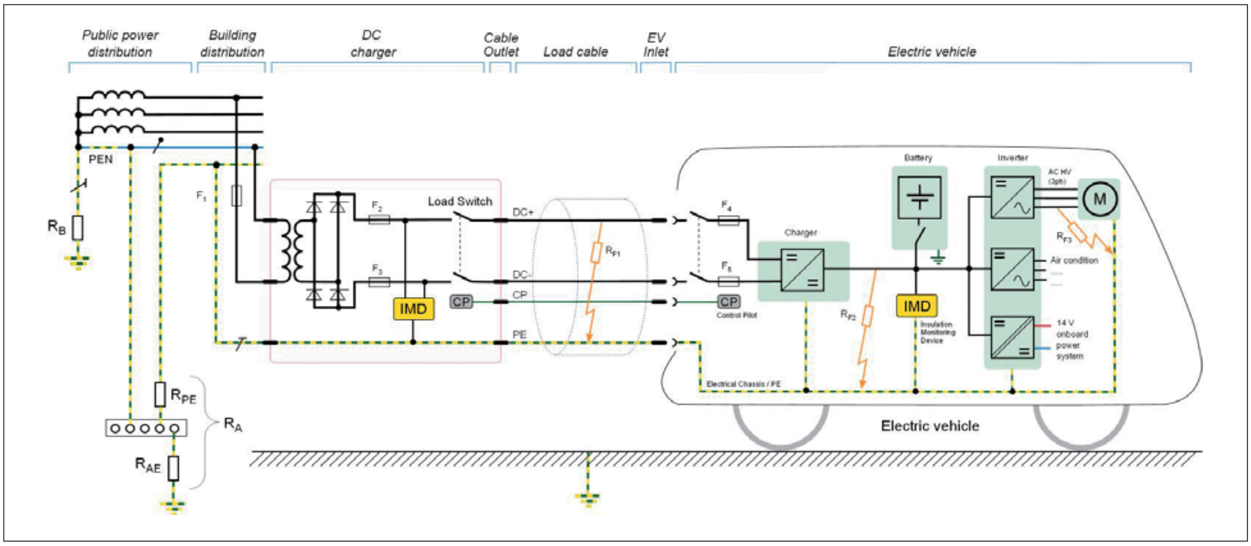
DC charging stations are designed as unearthed systems (IT systems), i.e. an active conductor is not allowed to be connected to earth. This situation is achieved in the DC charging station by the isolated design of the charging electronics or an isolating transformer. In accordance with DIN VDE 0100-410:2007-06[2] an IT system must be permanently monitored using an insulation monitoring device and a signal output if a specified value is exceeded. Such an IT system has two important advantages: a first insulation fault will not result in shutdown but only signalling. This means that the charging process can be continued until it is complete without problems. The second important advantage: the touch voltage in the case of the first fault is approximately 0 V. As a result a potential hazard due to current flowing through the body can be almost excluded. An important aspect, particularly in relation to the usage of charging stations by individuals with no electrical knowledge.

In accordance with DIN VDE 0100-410:2007-06 [2] the insulation monitoring device itself must satisfy the requirements of DIN EN 61557-8:2007-12 [6], i.e. it must detect both symmetrical and unsymmetrical insulation faults. A symmetrical insulation fault can to occur when the insulation resistance of all conductors in a system to be monitored decreases to approximately the same extent. If this fault condition is not detected, there is, e.g., a risk of fire, as a higher current flows due to the two insulation faults on different active conductors; this current can cause increased heating at the faults.

Touch voltages on a 1st fault in a DC IT system

In accordance with DIN VDE 0100-410 (VDE 0100-410): 2007-06 [2] exposed-conductive-parts of electrical equipment in IT systems must be earthed individually, in groups, or collectively, using a protective conductor. The condition $R_A \times I_d \leq 50$ V (AC) or 120 V (DC) must be met. Here R_A is the sum of the resistances of the earth electrode

FIGURE 4: DC CHARGING IN MODE 4
[GRAPHIC, BENDER GRUENBERG]

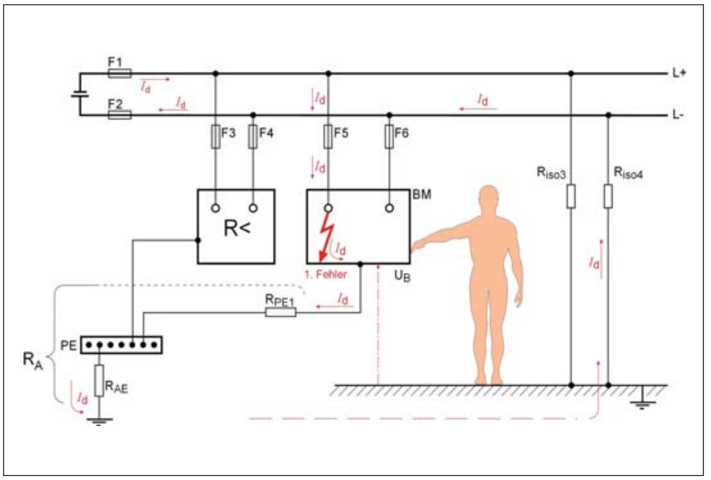


and the protective conductor for the exposed-conductive parts , I_d is the fault current of the first fault of negligible impedance between a line conductor and an exposed-conductive-part. The value I_d takes into account the total insulation resistance of the electrical system in relation to earth.

Figure 5 shows the current path on the occurrence of a first fault (insulation fault) in an IT system. R_{iso3} and R_{iso4} represent the total insulation resistance to earth that form part of the fault current circuit in the event of a fault. The insulation resistances shown in the figure are mostly very high in practice and only have a minimal effect on the touch voltage in the fault situation shown.

Figure 5 makes it clear that the touch voltage depends on the natural insulation resistances R_{iso3}, R_{iso4}, the resistance of the protective conductor R_{PE1} for the equipment touched and the earth resistance. Given the assumption that the protective conductor resistance and the earth resistance R_{AE} are small, the touch voltage is only slightly affected by the connection in parallel of the resistance of the human body (approx. 1 kΩ). In Figure 6 the magnitudes of the possible touch voltages in a DC 400 V IT system on a first fault are shown as curves. Variables plotted here are the natural insulation resistance R_{iso3}, R_{iso4} and the earthing resistance R_A. The equipment's protective conductor resistance is taken into account as 0.2 Ω. During the evaluation of the touch voltage, it has to be considered that the charging station and the electric vehicle have a common earth.

FIGURE 5: TOUCH VOLTAGE IN A DC IT-SYSTEM
[GRAPHIC, BENDER GRUENBERG]



CALCULATED TOUCH VOLTAGES IN A DC IT SYSTEM ON THE OCCURRENCE OF A FIRST FAULT
[GRAPHIC, BENDER GRUENBERG]

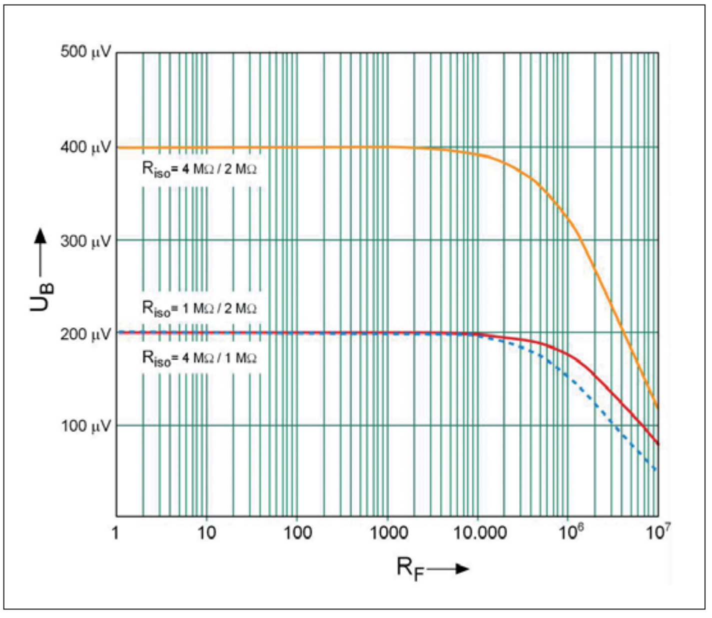


FIGURE 7: EXAMPLE INSULATION MONITORING DEVICE (A-ISOMETER®) FROM THE E-MOBILITY AREA
[FACTORY PHOTO, BENDER GRUENBERG]

Even though on a first fault in IT systems only relatively low touch voltages are to be expected, the mandatory requirement in point 413.1.5.4 of DIN VDE 0100-410:2007-06 [2] on the need for an insulation monitoring device is of elementary importance. With the requirement in note 1 point 413.1.5.4 recommending that "a first fault be eliminated with the shortest practicable delay" , it is clear that in the case of a first fault that has not been eliminated, an additional second fault may cause higher touch voltages. If in such a case both faults are relatively low, impedance and on different active conductors (L+, L-), power may be lost due to the triggering of the upstream protective device. An important reason for the need for insulation monitoring devices to be able to also detect symmetrical insulation faults. ■

Dipl.-Ing. Wolfgang Hofheinz, CTO
Dipl.-Ing. Harald Sellner, S-MAR

SUMMARY

In e-mobility attention has to be paid when AC systems and DC systems meet the high voltage system in the vehicle, particularly during the analysis of protective measures. With the correct selection of the protective and monitoring devices in relation to the related type of system, a high degree of electrical safety and reliability is, however, achieved for the users and operators of electric vehicles.

The IT system has clear advantages particularly with respect to a high degree of safety and high reliability.

BIBLIOGRAPHY

[1] W. Hofheinz "Schutztechnik mit Isolationsüberwachung" VDE series vol. 114 Issue 2011

[2] DIN VDE 0100-410 (VDE 0100-410):2007-06 Low-voltage electrical installations - Part 4-141 Protection against electric shock (IEC 60364-4-41:2005, modified)

[3] DIN IEC 61851-.... series of standards Electric vehicle conductive charging system - ...

[4] DIN VDE 0100-100 (VDE 0100-100):2009-06 Low-voltage electrical installations -Part 1: Fundamental principles, assessment of general characteristics, definitions (IEC 60364-1:2005, modified);

[5] ISO/FDIS 6469-3:2011-05 Electrically propelled road vehicles – Safety specification – Part 3: Protection of persons against electric shock

[6] DIN EN 61557-8 (VDE 0413 part 8):2007-12 Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. - Equipment for testing, measuring or monitoring of protective measures - Part 8: Insulation monitoring devices for IT systems (IEC 61557-8:2007 + Corrigendum 2007-05);

[7] DIN EN 61140 (VDE 0140-1):2007-3 Protection against electric shock. Common aspects for installation and equipment (IEC 61140:2001 + A1:2004, modified); German version EN 61140:2002+ A1:2006

[Standards can be procured from: www.vde-verlag.de, www.beuth.de]