Insights and best practice

EMC COMPLIANCE KNOW-HOW

TECHNICAL NOTE 0110

EMC TESTING ON ELECTRIC VEHICLES
AN INTRODUCTION

The challenge

The introduction of electric vehicles poses many EMC challenges for the Automotive Designer and Test lab Engineer, including the requirements of additional EMC standards that must be met. This Technical Note provides some insights and best practices on this important topic.

The document is designed to accompany a video recording of a live webinar "An Introduction to EMC Testing on Electric Vehicles" presented by Thomas Handschin. Each page of this Technical Note has a time-stamp that corresponds to the relevant section of the video presentation.

Author:
Thomas Handschin
Product Manager
AMETEK CTS

You can view the **recording here**

AMETEK CTS GmbH Sternenhofstrasse 15 4153 Reinach, Switzerland info.cts@ametek.com

AMETEK® COMPLIANCE TEST SOLUTIONS

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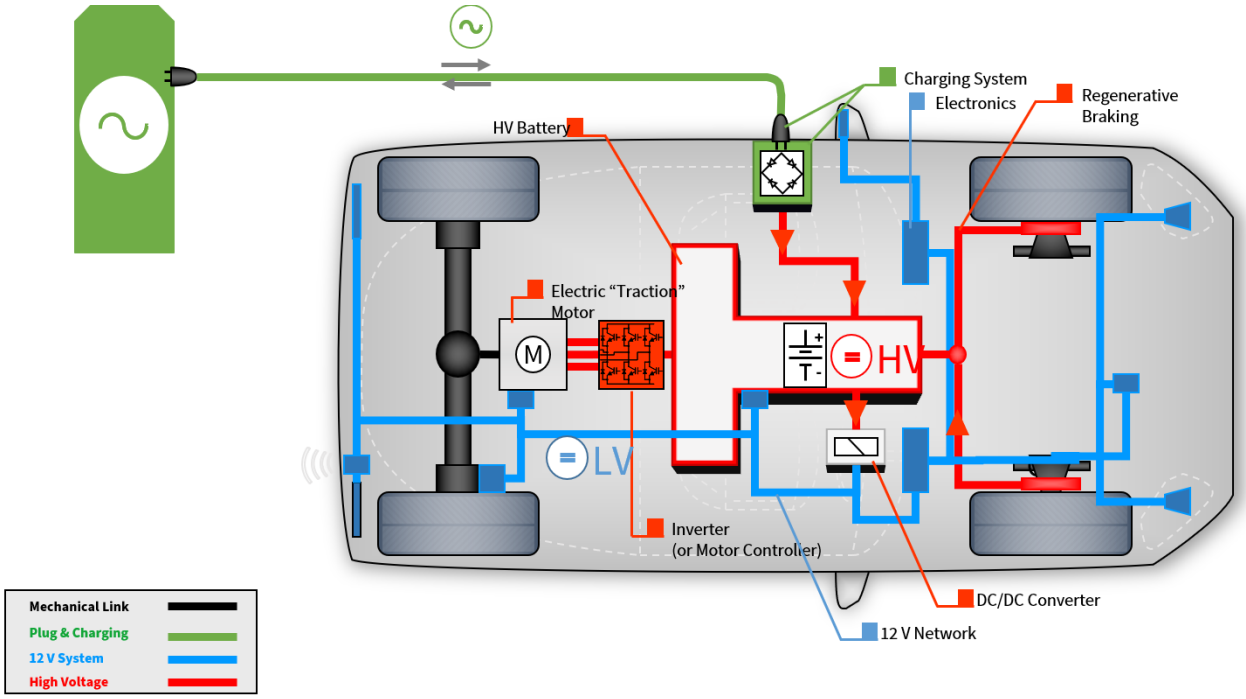
OVERVIEW



An electrical vehicle includes several electrical circuits:

- LV (low voltage) typically 12/24/48VDC - standard electrical circuit, same as with combustion engines
- HV (high voltage) - "where the energy comes from", replaces the combustion engine, traction system (electric motor)
- AC - charging the battery on the car

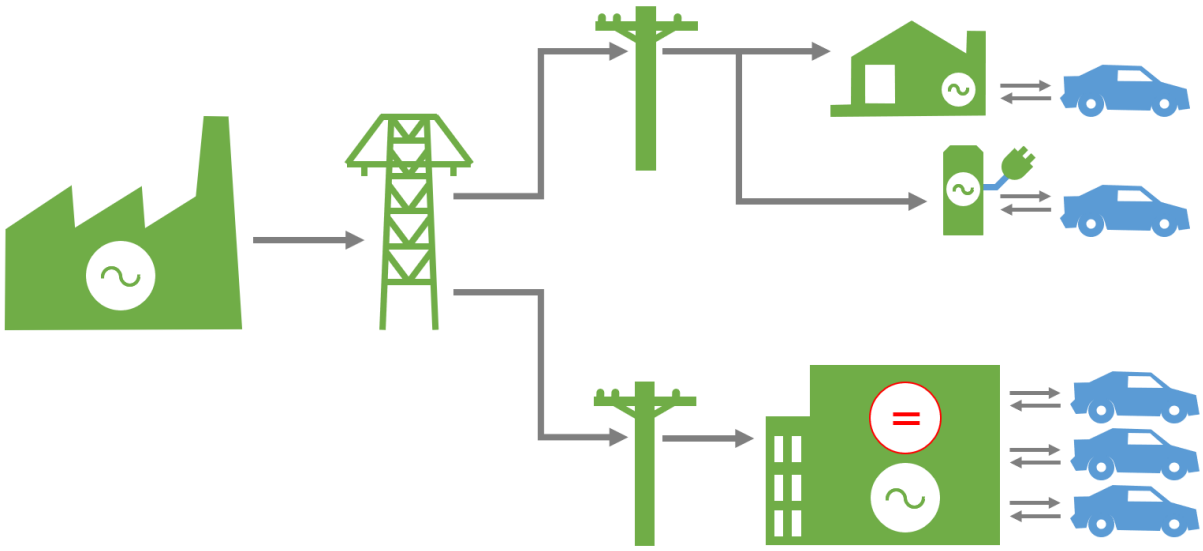
In sum only a small number of components are HV – but for EMC it is the most critical part and the biggest difference from a traditional car.

IMPORTANT CHANGES IN IEC 61000-4-4

Shown is the complete chain of energy generation, energy transmission and energy distribution. This is highly developed and standardized.

The plug of the car makes it now a piece of this system needs to fulfil the standards as any other device

Slow charging at home with on board charger (110/230V, 16A) or with "wall box" charger (typ. 3x400V, 16A)



Fast charging at charging stations, either high current AC (3x400V, 200A) or with DC (up to 1000V); on-board charger is not used

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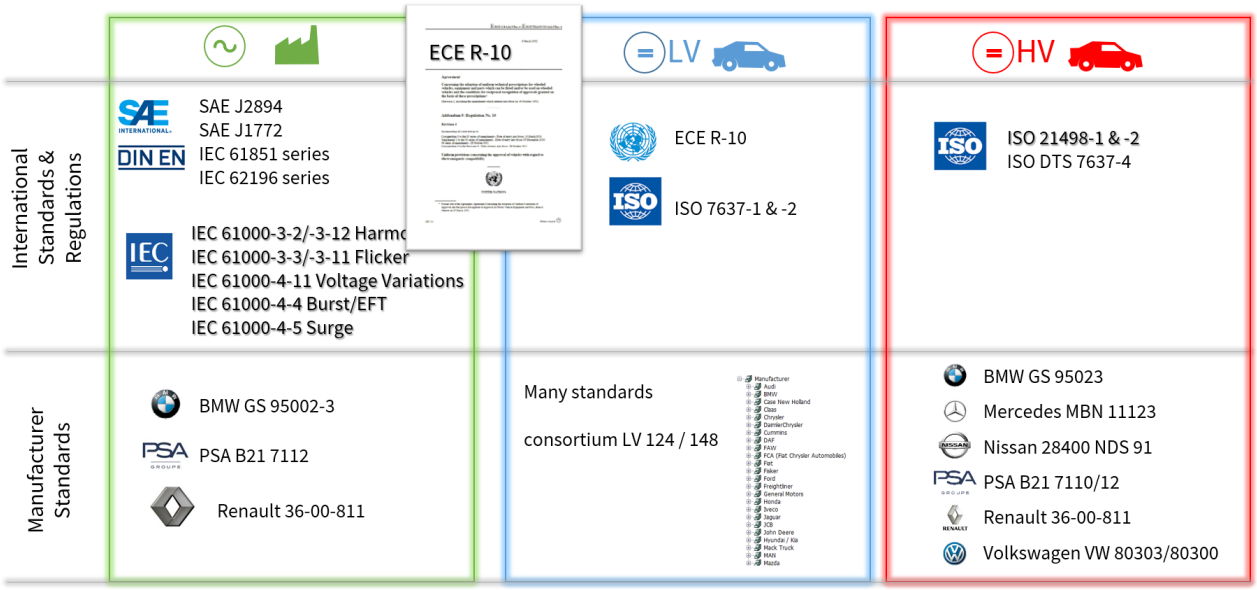
TEST LEVEL SINCE IEC 61000-4-4:2004



Above is a an overview of the relevant EMC laws, regulations and standards for electrical vehicles.

Three areas: LV, HV and AC, divided into international (generally valid) and manufacturer standards

LV:

- Regulation ECE R-10 (“E mark”) and series of ISO standards
- Large variety of manufacturer standards, each OEM defines its own tests. This has led to a vast variety of tests (>10’000)

HV:

- Standardization is at the early stages; started with ISO 7637-4 (technical specification) and now developed into ISO 21498 (released 2021).
- Manufacturer standards already exist and now increasingly applied
- Standards continue to evolve with the development of components, platforms and cars (most common standards are shown in the table)

AC:

- DIN and EN standards for chargers, plugs etc.
- An important document is ECE R-10 which introduced specific requirements for EVs in 2018; it is a legally binding document in most countries, and therefore is the dominant standard
- Manufacturers standards also exist
- American standard SAE defines chargers, modes and plugs
- SAE J2894 Power Quality SAE Chargers

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HV STANDARDS & TESTS

ISO 21498-2 AND ISO 7637-4

ISO 21498 - STANDARD FOR HV COMPONENTS

Electrically propelled road vehicles — Electrical specifications and tests for voltage class B systems and components

- Split in two parts:
  - Part 1 – Voltage sub-classes and characteristics
  - Part 2 - Electrical tests for components
- New standard currently developed – publish planned for 2021
- For class B electric propulsion systems
- Supported by all major car manufacturers
- Similar tests as LV 123

Part 1 of this standard provides definitions of and for voltage sub-classes and characteristics for rechargeable energy storage systems (RESS) and electric propulsion systems. It defines specified values for these sub-classes based on maximum working voltage. Voltage sub-classes listed in this document are used for voltage class B systems of all kinds of current or future electrically propelled road vehicles.

Part 2 of this standard provides electrical tests for electric and electronic components at voltage class B used for electrically propelled road vehicles. All relevant characteristics are covered considering usual driving scenarios as well as deviations from normal operation. The descriptions are generalized and include purpose, setup, procedure and requirements for the tests.

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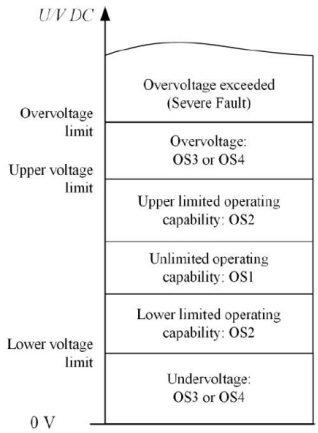
HV STANDARDS & TESTS

ISO 21498-2 AND ISO 7637-4

ISO 21498-1 VOLTAGE CLASSES & OPERATING STATUS

Voltage Class	Upper Voltage Limit
A (LV)	≤ 60 VDC / 30 VAC
B (HV)	> 60 and ≤ 1500 VDC > 30 and ≤ 1000 VAC
B_220	220 VDC
B_420	420 VDC
B_470	470 VDC
B_750	750 VDC
B_850	850 VDC
B_1250	1250 VDC



Source: ISO 21498-2

Operating Status	Description
OS1	The component shall provide the specified full performance (reduction of performance not allowed). The component shall automatically change its operating status depending on the voltage relevant for the operating status.
OS2	The component shall provide the specified reduced performance within its permissible deviations (reduction of performance allowed). The component shall automatically change its operating status depending on the voltage relevant for the operating status.
OS3	The component may de-rate or cut-off its performance for self-protection purpose. The component shall automatically change its operating status depending on the voltage relevant for the operating status.
OS4	The component may cut-off its performance. Triggered by a reset or an external event (e.g. change of ignition status, restart vehicle), the component shall change its operating status depending on the voltage relevant for the operating status.

ISO 21498-2 ELECTRICAL TESTS FOR COMPONENTS

Chapter	Description	Type	Equipment Required
6.2	Direct current supply voltage	Immunity - Voltage variation	DC Source
6.3	Generated voltage slope	Emission	DC Source & Oscilloscope & AN
6.4	Present voltage slope	Immunity - Voltage variation	DC Source
6.5	Generated voltage ripple	Emission	DC Source & Oscilloscope & AN
6.6	Present voltage ripple	Immunity - Ripple on DC	DC Source & Ripple Generator
6.7	Overvoltage	Immunity - Voltage Variation	DC Source
6.8	Undervoltage	Immunity - Battery Test	DC Source
6.9	Voltage offset	Immunity - Voltage variation	DC Source
6.1	Generated load dump voltage	Emission	DC Source & Oscilloscope & AN
6.11	Present load dump	Immunity - Voltage variation	DC Source

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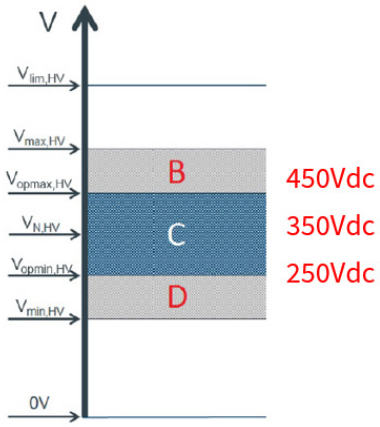
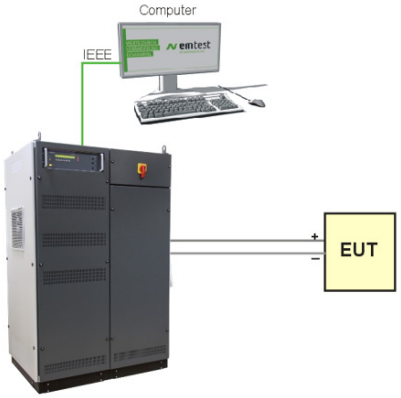
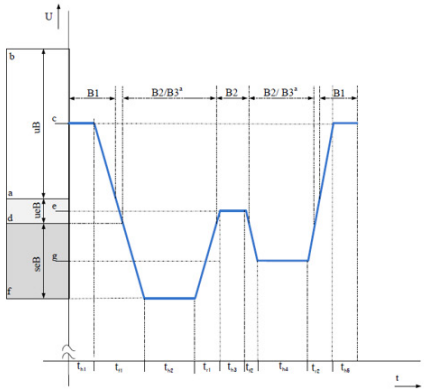
HV STANDARDS & TESTS

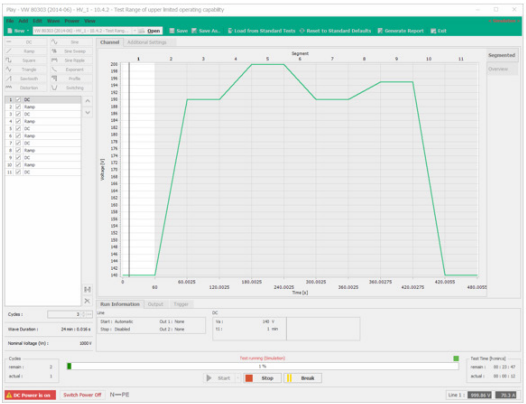
ISO 21498-2 AND ISO 7637-4

VOLTAGE VARIATIONS









Technical Requirements	
Max. voltage	> 1'000V DC
Max. slew rate	> 250 V / us

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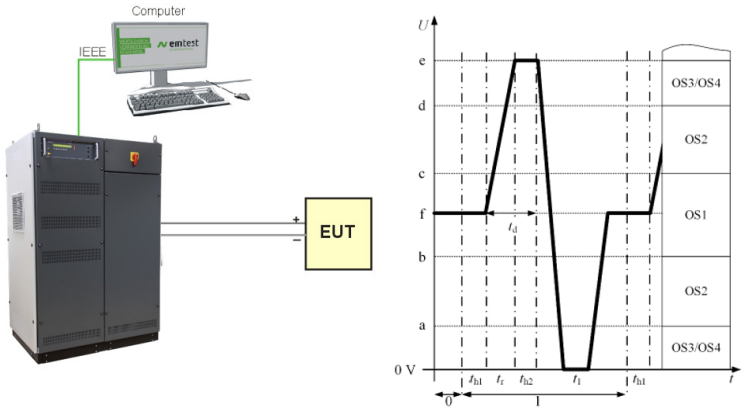
HV STANDARDS & TESTS

ISO 21498-2 AND ISO 7637-4

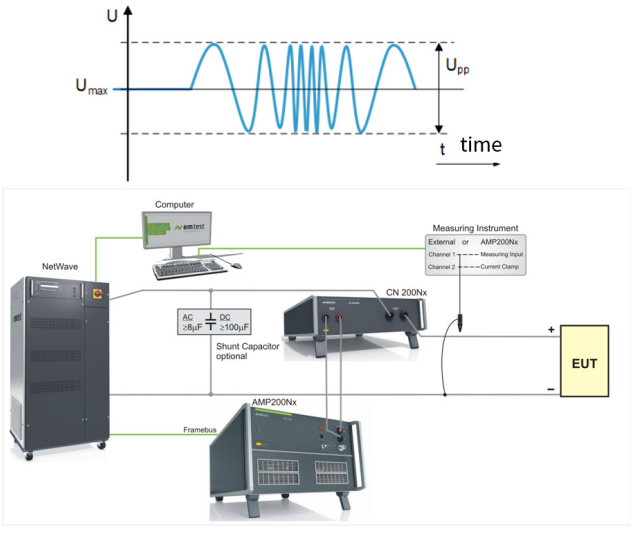
PRESENT LOAD DUMP

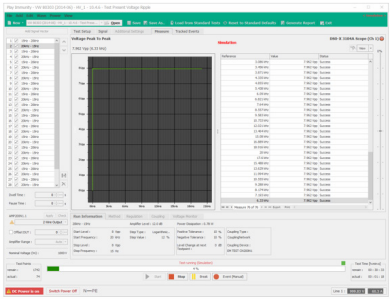


Technical Requirements	
dV/dt	> 250 V / ms
tr	< 200 µs
Max. voltage	450 VDC

Example with 400V rated voltage

PRESENT LOAD DUMP





Technical Requirements	
Max. DC voltage	> 1'000V DC
Max. AC voltage	32 Vp
Frequency range	10 Hz – 250 kHz

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HV STANDARDS & TESTS

ISO 21498-2 AND ISO 7637-4

ISO DTS 7637-4 OVERVIEW

Road Vehicles – Electrical disturbances by conduction and coupling – Part 4: Electrical transient conduction along shielded high voltage supply lines only

- Part of the well-known ISO 7637 series
- Published 2020-05 as Technical Specification
- Already applied by several OEMs and test houses
- Includes also high frequency test

This part of ISO 7637 specifies test methods and procedures to ensure the compatibility to conducted electrical transients along shielded high voltage supply lines. This applies to equipment installed on passenger cars and commercial vehicles. fitted with electrical systems with voltages higher than 60 Vd.c. and lower than 1 500 Vd.c. and a power-supply isolated from the vehicle-body.

It describes bench tests for both, injection and measurement of transients. It is applicable to all types of electrical independent driven, road vehicles (e.g. battery electrical vehicle (BEV) or hybrid electrical vehicle (HEV), plugin hybrid electric vehicle (PHEV)).

No.	Description	Type	Equipment Required
4.5	Voltage transient emissions test along high voltage supply lines	Emission Test	DC Source, Artificial Network, Measurement Receiver
4.6.2 Pulse A	Test set-up for immunity test for pulsed sinusoidal disturbances (1 to 10 MHz)	RF Immunity	DC Source, RF Generator, Artificial Network
4.6.3 Pulse B	Immunity test for pulsed sinusoidal disturbances (3 – 300 kHz)	Ripple on DC	DC Source & Ripple Generator

ISO 7637-4 consists of one emission test and two pulse – one RF immunity and one LF immunity

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HV STANDARDS & TESTS

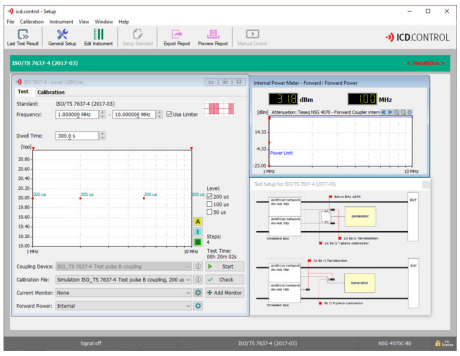
ISO 21498-2 AND ISO 7637-4

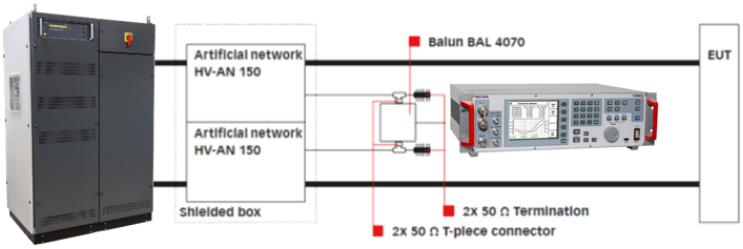
HV DC – TEST SETUP – RF PULSED IMMUNITY

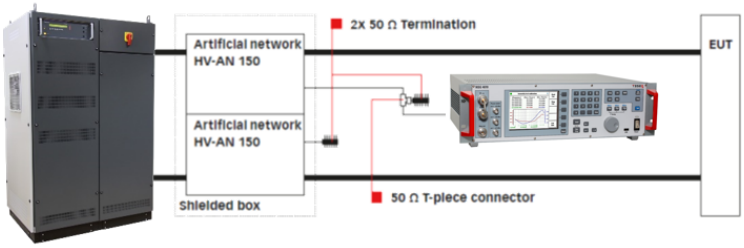
Table A.2 – Parameters for test pulse B, pulsed sinusoidal disturbances

Pulse frequency (MHz)	Test voltage U_{pp} (V) (*) severity level				Oscillations per pulse packet	Repetition time (µs)	Test duration (minutes)	Test coupling
	I	II	III	IV				
1	20	50	100	(**)	10	200 / 100 / 50	5 / 5 / 5	HV+ to HV- HV+ to ground HV- to ground
2								
5								
10								

(*) Test voltage shall be set at 50 Ω load. Details shall be defined in the test plan.
Severity level is related to the HV nominal voltage (e.g. 5 to 10%).
(**) Severity level class for special applications: Details shall be defined in the test plan.







- Pulsed RF signal with 1,2,5 and 10MHz
- Two test setups: common mode and differential mode (with balun)
- NetWave is source
- HV-AN150 are the mandatory artificial networks
- NSG 4070C generates the RF pulsed signal

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AC STANDARDS & TESTS

ECE REG 10

ECE REG 10 REV5

Agreement
Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions

UNITED NATIONS

E1

SUMMARY

- United Nations regulations regarding vehicles
- legally binding document (“law”)
- defines limits and test procedures for vehicles and ESA (electrical sub assembly)
- Revision 5 added requirements for electrical vehicle (RESS charging mode)

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AC STANDARDS & TESTS

ECE REG 10

IMPORTANT CHANGES IN IEC 61000-4-5 ED. 3

Chapter	Description	Standard	Equipment Required
7.2 / 7.10	Broadband electromagnetic radiation	RF Emission Test	AC Source, Antennas, Measurement Receiver, Chamber
7.3 / 7.11	Harmonics on AC power lines	IEC 61000-3-2 IEC 61000-3-12	AC Source, Power Analyzer
7.4 / 7.12	Voltage changes, voltage fluctuations and flicker	IEC 61000-3-3 IEC 61000-3-11	AC Source, Power Analyzer, Flicker Impedance
7.5 / 7.13	Emission of RF conduced disturbances on AC or DC power lines	CISPR 16-2-1 IEC 61000-6-3	AC Source, Artificial Network, Measurement Receiver
7.6 / 7.14	Emission of RF conducted disturbances on network and telecommunication lines	CISPR 22 IEC 61000-6-3	AC Source, Artificial Network, Measurement Receiver
7.7 / 7.15	Immunity to electromagnetic radiation	ISO 11451-2	AC Source, RF Generator and Amplifier
7.8 / 7.16	Immunity to electrical fast transients / burst on AC or DC power lines	IEC 61000-4-4	Pulse Generator, Coupling Network
7.9 / 7.17	Immunity to surge conducted on AC or DC power lines	IEC 61000-4-5	Pulse Generator, Coupling Network
7.18	Specifications concerning immunity of ESAs to electromagnetic radiation	ISO 11452 series	AC Source, Antennas, Measurement Receiver, Chamber
7.19	Specifications concerning the immunity of ESAs to transient disturbances along 12 /24 V supply lines	ISO 7637-2	LV Pulse Generator, LV Source

AC STANDARDS & TESTS

ECE REG 10

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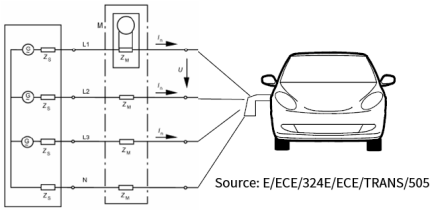
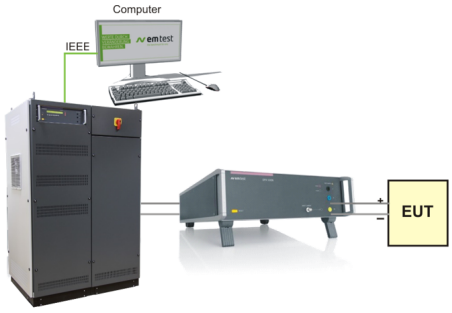
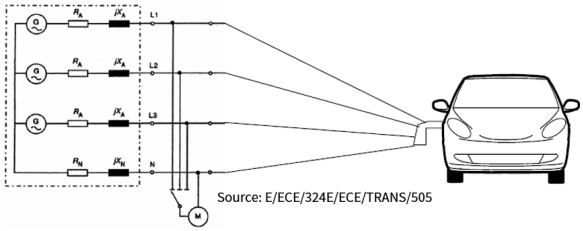
AC – TEST SETUP - HARMONICS – IEC 61000-3-2/-12

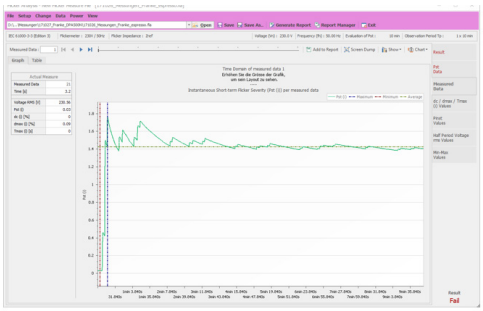


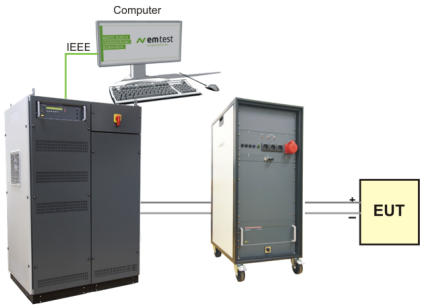


Technical Requirements	
Max. voltage	3 x 480V ACph-ph
THD	< 0.5 %
Analyzer	according IEC 61000-4-7
Frequency range	50 Hz – 2 kHz

AC – TEST SETUP – FLICKER – IEC 61000-3-3/-11







Technical Requirements	
Flickerimpedance	according IEC 60725
Flickermeter	according IEC 61000-4-15
THD	< 3%

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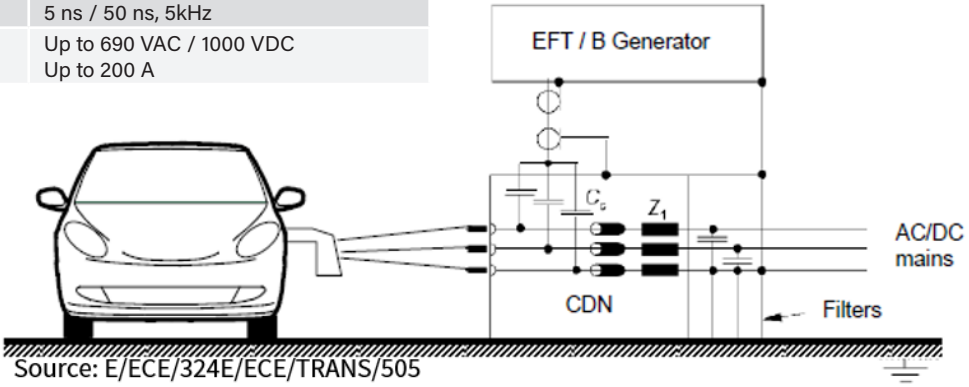
AC STANDARDS & TESTS

ECE REG 10

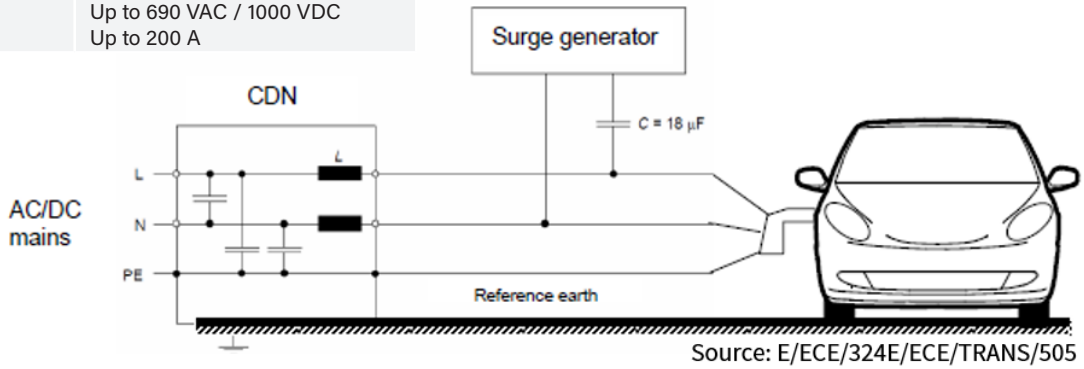
AC – TEST SETUP – SURGE & BURST

Burst / EFT	
Standard	IEC 61000-4-4
Pulse	± 2kV 5 ns / 50 ns, 5kHz
Supply	Up to 690 VAC / 1000 VDC Up to 200 A



Source: E/ECE/324E/ECE/TRANS/505

Surge	
Standard	IEC 61000-4-5
Pulse	AC: ± 2 kV L-PE / ± 1 kV L-L DC: ± 0.5 kV L-PE / ± 0.5 kV L-L 1.2 µs / 50 µs
Supply	Up to 690 VAC / 1000 VDC Up to 200 A



Source: E/ECE/324E/ECE/TRANS/505

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SUMMARY

- Electrical vehicles have three power systems: low voltage, high voltage and AC mains
- Standards for high voltage components exist and are evolving quickly
- Most important standards: High voltage - ISO 21498 & LV123AC Mains - ECE R-10 with IEC 61000-3-x and IEC 61000-4-x series

About Thomas Handschin

Thomas is the Product Manager for EMC conducted products at AMETEK CTS. His product portfolio includes testing solutions for harmonics, flicker, and HV electrical vehicle testing.

Thomas has an engineering degree in microtechnology and business management engineering, and 15 years of test and measurement experience. He is also a member of IEC technical committee 77A working group 1(harmonics) and 2 (flicker).

About AMETEK CTS

AMETEK CTS is a global leader in EMC compliance testing and RF power amplifiers. AMETEK has been designing and manufacturing precision instruments for more than 30 years. Under the brand names of EM Test, Teseq, IFI and Milmega the company produce a wide range of specialist solutions aligned to the individual needs of equipment manufacturers across a variety of industries. These include:

Automotive
Aerospace and Defense
Consumer electronics
Household appliances
Medical devices
Renewable energy

From its design and manufacturing facilities in Switzerland, Germany, the United States and the UK, AMETEK CTS provides customers with innovative solutions to the complex requirements of EMC compliance standards.