White Paper

# Charging station and EV connected through Coupling/Decoupling Network: a signal analysis

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## Contents

# 1 Summary

Testing Electric Vehicles (EVs), Electronic SubAssemblies (ESAs) and charging stations has become a very common topic in recent period. New power supply technologies based on direct current (DC) are providing excellent results in terms of flexibility and efficiency.

Current technical paper expands on the challenges created by the new "DC" technologies when utilized with an IEC 61000-4-5 standard Coupling/Decoupling Network (CDN) to perform burst and surge tests on EVs, ESAs and generally DC-DC converters. The paper also provides hints on why and how to employ different measures for overcoming possible issues related to application of mentioned tests.

# 2 Introduction

The latest edition of IEC61000-4-5 (2014)[1] defines CDNs for currents up to 200 A or higher and acknowledges an issue related to decoupling inductors: a single value of decoupling inductance cannot be used for the entire current domain 0 – 200 A. An EUT supplied directly with 230 V L-PE and 200 A per phase will experience a voltage drop of 61.7 V when supplied through a CDN that uses 1.5 mH decoupling inductor, and its current will drop from 200 A to 146.7 A. Hence, the standard hints lower values for the decoupling inductance when EUT rated current becomes higher.

Reducing the decoupling inductance of CDNs used to test powered EVs and ESAs is an important first step in eliminating issues related to power supply through CDN, but some issues have been still reported in the field after 2014. In order to address them, the IEC introduced in 2017 Amendment 1 to IEC 61000-4-5 Edition 3, indicating two possible methods to prevent oscillations or malfunction in power supply when applying the surge test via CDN:

- Utilizing a CDN model with current rating higher than that of EUT;
- Placing a diode-resistor network between power source, i.e. charging station, and CDN.

The results of implementing such measures in an actual setup will be discussed in the next sections.

[1] https://www.iec.ch/

## 3 A model for voltage and current charging waveforms

DC charging stations apply normally trapezoidal PWM current pulses when charging a battery. In order to generate such waveforms, either trapezoidal voltage waveforms or variations of it are applied. In all cases, both current and voltage waveforms present a rise time and a fall time.

A hypothetical charging station and an EV (called EUT) are considered in fig. 1.

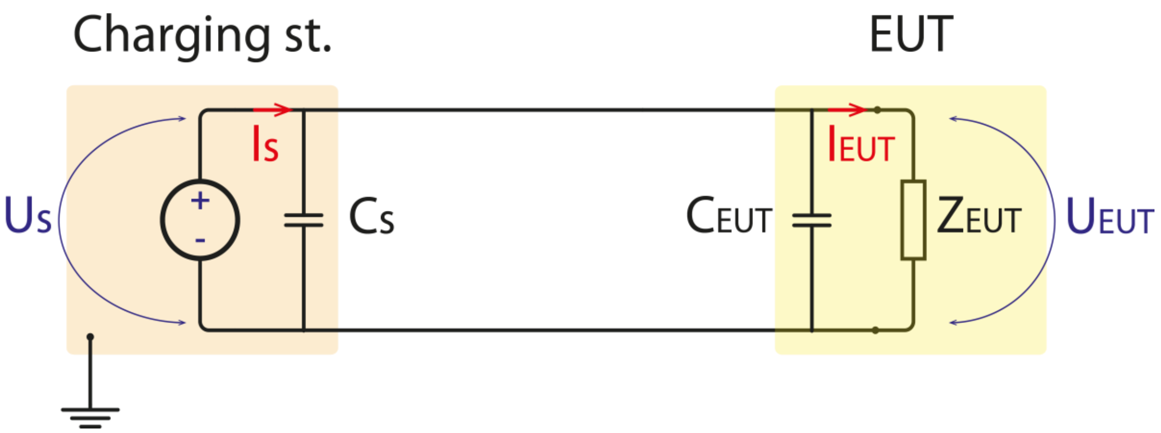



Figure 1. Simplified model for charging station and EV input circuit.

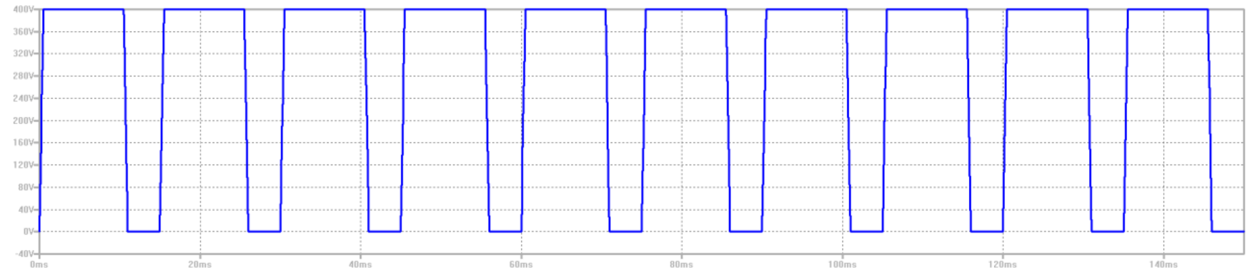
Following theoretical parameters have been considered in fig. 1:

$U_s$ = 400 V DC PWM modulated: $t_{RISE}$ and $t_{FALL}$ = 500 µs, $t_{ON}$= 10 ms ; $t_{PERIOD}$ = 15 ms (rise and fall time allowing a theoretical max. PWM frequency of 1 kHz);

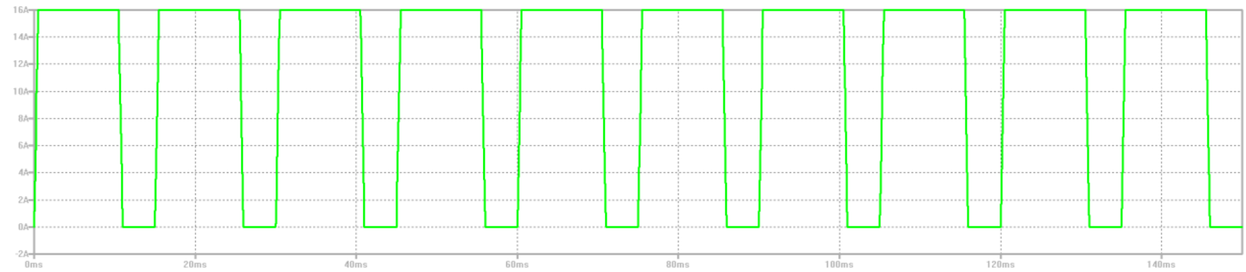
$C_S$= 5 µF;

$C_{EUT}$= 5 µF;

$Z_{EUT}$ = $R_{EUT}$ = 25 Ω (resistive).




a) $U_{EUT}$




b) $I_{EUT}$

Figure 2. a) $V_{EUT}$ without CDN interposed; b) $I_{EUT}$ without CDN inteprosed.

For the circuit from fig. 1, $U_{EUT}$ and $I_{EUT}$ are represented in fig. 2. Voltage applied to the EUT is always positive and current as well. Waveforms do not present any significant distortion and leakage current through each filter capacitor is low.

In figure 3, a CDN with $L_{DEC}$ = 1.5 mH per line is introduced in the circuit from fig. 1. The introduction of decoupling inductors results in distortions of EUT voltage and current as presented in fig. 4.

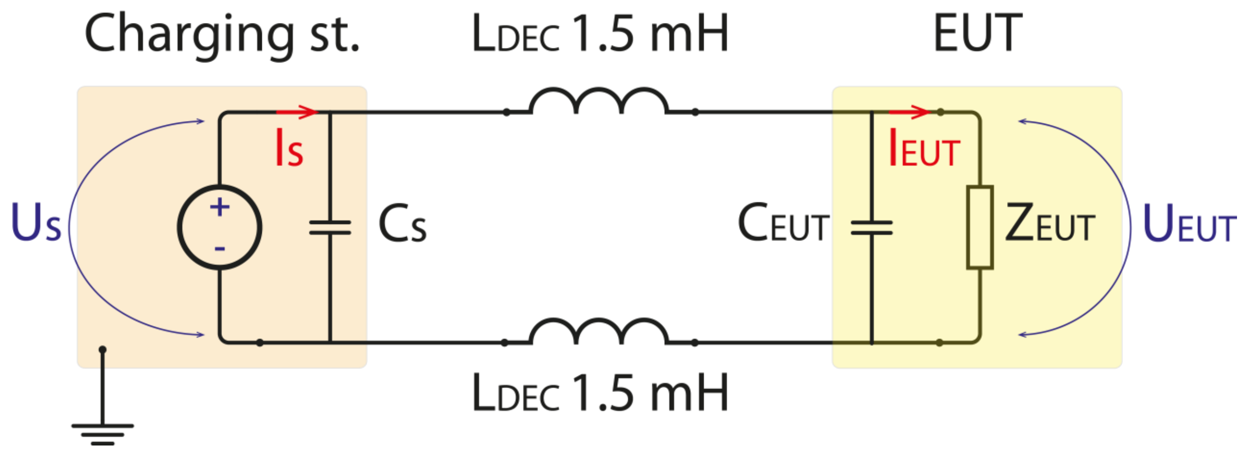
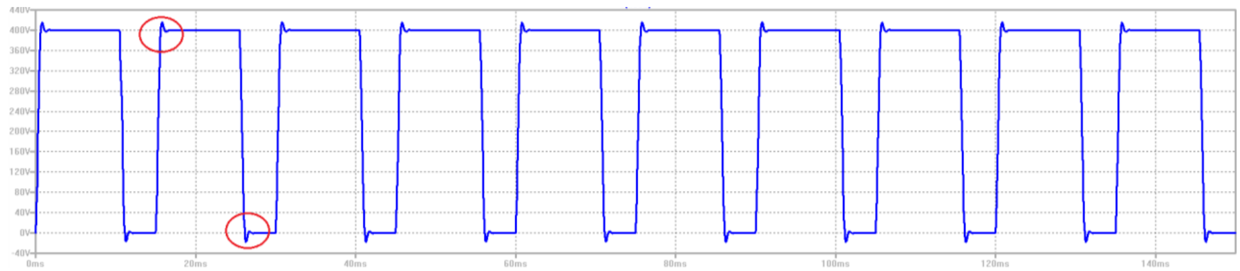
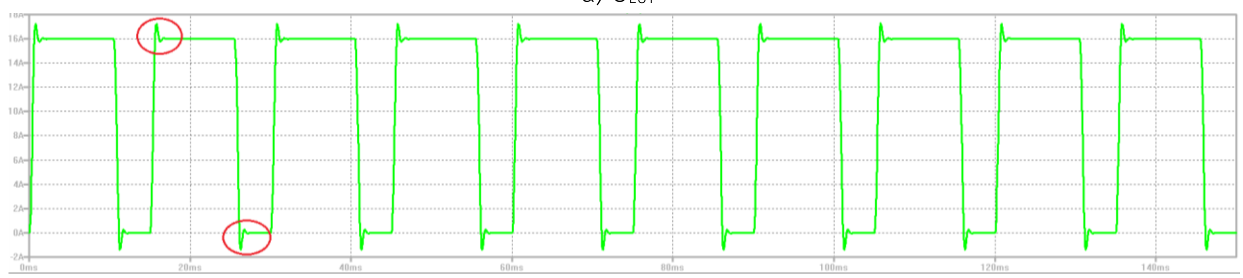



Figure 3. Model for charging station and EV input circuit with CDN decoupling inductors interposed.

In fig. 4 it can be noticed that both voltage and current waveforms start to present distortions. The introduction of decoupling coils in the circuit determine a positive overvoltage of 415 V instead of 400 V and a negative voltage peak of – 17.25 V, the latter having the potential to generate errors and eventually interrupt the charging process.



a) $U_{EUT}$



b) $I_{EUT}$

Figure 4. a) $V_{EUT}$ with CDN decoupling inductance interposed;
b) $I_{EUT}$ with CDN decoupling inductanceinteprosed.

The negative current peak from figure 4b amounts – 1.38 A and, as in the case of voltage, might generate errors and lead to interruption of the charging process.

The amplitude of distortions depends on filter capacitors and decoupling inductors. Simulations indicate that the filter capacitor at EUT input has a more significant impact on EUT input voltage and current than the one at the output of charging station. Furthermore, grounding either minus terminal or plus terminal of the source does not improve the waveform quality when CDN decoupling inductances are included. Amplitude of disturbances is relatively low when considering voltage rise time of 500 µs and hence a maximum theoretical modulation frequency of 1 kHz. Increasing modulation frequency and reducing rise and fall times will increase the amplitude of distortions, as it will be depicted in subsequent chapters.

The two methods suggested in Amendment 1 / 2017 of IEC 61000-4-5 Ed. 3 for tackling the distortions (mainly the negative ones) are the reduction of decoupling inductance value (or better formulated: the usage of a CDN with higher EUT current rating) and introduction of a diode-resistor network in the circuit.

The utilization of a CDN with higher EUT current rating has been simulated. Decreasing each decoupling inductor from 1.5 mH to 0.3 mH has reduced negative distortions, but has not cancelled them completely. So the measure is partially useful and can be employed.

The circuit from fig. 5 is the same as the one from fig. 3, but has an additional diode-resistor network added between charging station and the decoupling inductors of the CDN. The resistor is adjustable from 1 Ω to 220 Ω, exactly as a DC-DC32 diode-resistor network from EMC PARTNER[2].

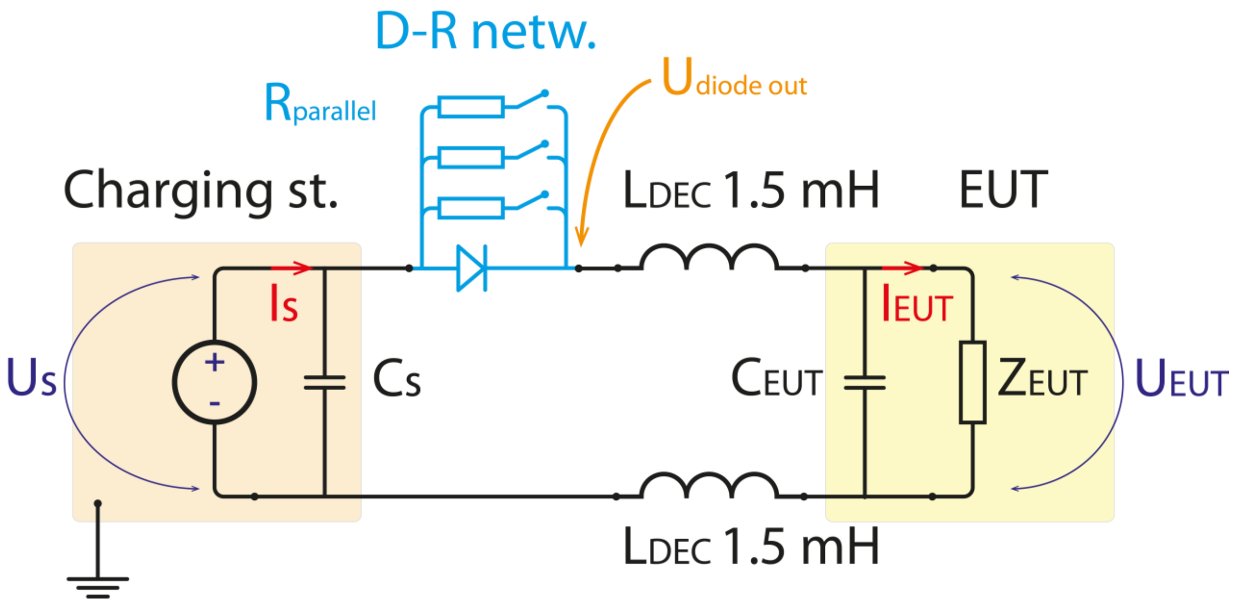



Figure 5. Model for charging station and EV input circuit with CDN decoupling inductors interposed and diode-resistor network.

The diode-resistor network is suitable only for DC-supplied equipment and has the role to prevent the change of current direction (negative voltage and current at EUT terminals) on the falling edge of the PWM DC voltage.

When the energy is blocked completely from returning to the power source (no resistor connected, high impedance in parallel to the diode), the voltage at output of the resistor-diode network tends to increase and might determine overvoltage errors.

When the parallel resistance has a low value, for example 1 Ω, the diode will not be able to properly prevent the energy from returning to the power source on the negative edge of the PWM DC voltage, as the energy will return via the resistor.

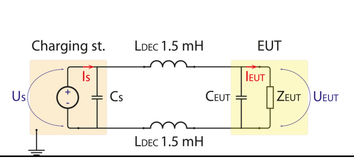
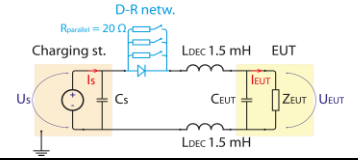
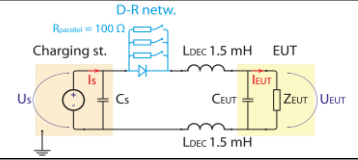
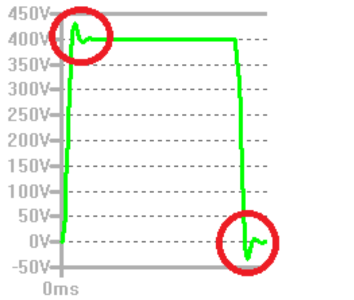
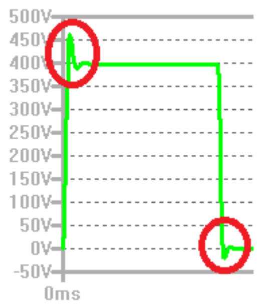
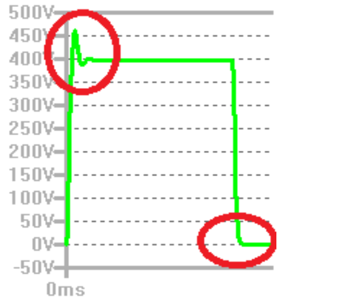
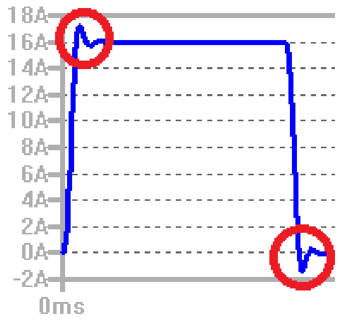
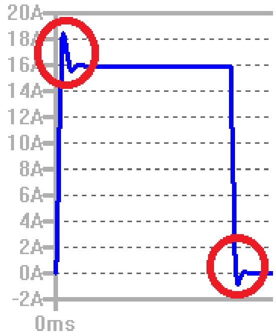
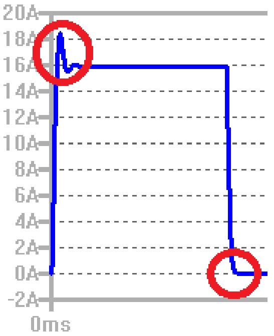
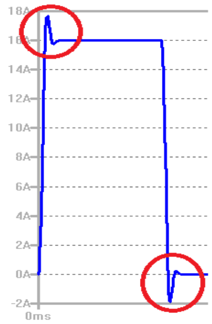
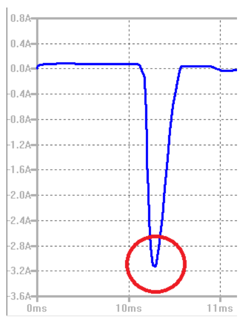
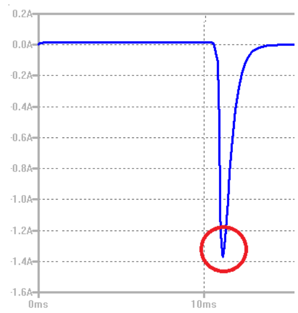
Hence, the parallel resistance must be high enough to prevent the return of energy to the power source and eliminate possible negative voltage at EUT terminals, but low enough to prevent possible overvoltage. When utilized with the diode, a resistor acts like a "valve" balancing too much energy returning to power source and potential high voltages in the circuit.

Three cases will be considered in the table below:

1) Circuit from figure 3 and waveforms from figure 4, for reference;
2) Circuit from figure 5, in which the resistor in parallel to the diode has a value of 20 Ω;
3) Circuit from figure 5, in which the resistor in parallel to the diode has a value of 100 Ω.

[2] https://www.emc-partner.com/company-documents-brochures/brochures/9-immunity-test-brochure/file page 27.

Table 1. Different parameters of the circuits from considered cases.

| Case | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| | Fig. 3, $Z_{EUT}$ = 25 Ω | Fig. 5 $Z_{EUT}$ = 25 Ω | Fig. 5 $Z_{EUT}$ = 25 Ω |
| Circuit |  |  |  |
| $R_{parallel}$ | - | 20 Ω | 100 Ω |
| $U_{EUT}$ |  |  |  |
| $U_{EUT}$ max/min | 431.64 V peak<br>-34.82 V peak | 460.4 V peak<br>- 20.5 V peak | 462.81 V peak<br>0 V ✓ |
| $I_{EUT}$ |  |  |  |
| $I_{EUT}$ max/min | 17.26 A<br>-1.39 A | 18.42 A peak<br>- 0.81 A | 18.51 A peak<br>0 A ✓ |
| Max $U_{diode\ out}$ | - | 400 V (see fig. 5) | 400 V (see fig. 5) |
| I through $R_{parallel}$ | I through shunt R 1mΩ placed in the position of R-D circuit<br> |  |  |
| I through $R_{parallel}$ | Max. 17.69 A peak<br>Min. -1.9 A | Max. 0 A<br>Min. - 3.12 A peak | Max. 0 A peal<br>Min. - 1.37 A peak |

**Discussion of simulation results**

In case 1, a circuit consisting of power source, EUT and CDN decoupling inductors has been simulated. In cases 2 and 3, a diode-resistor network has been added between positive terminal of the power source and decoupling inductor of the CDN as follows: in case 2 a 20 Ω parallel resistor has been selected and in case 3 a 100 Ω parallel resistor has been selected.

In case 1, EUT voltage and current waveforms present both positive and negative distortions when compared to waveforms from fig. 2. Introduction of decoupling inductors between power source and EUT has resulted in distortion of both current and voltage at EUT terminals. Although low energy, voltage distortions at EUT terminals reach 431.64 V (positive peak) and - 34.82 V (negative peak). EUT current reaches 17.26 A (positive peak, in relation to expected 16 A continuous level) and - 1. 39 A (negative peak). This might result in EUT malfunction during the test.

In case 2, a diode-resistor network has been introduced in order to eliminate the distortions. The resistance in parallel to the diode is $R_{parallel}$ = 20 Ω. The introduction of mentioned network has increased positive distortions (positive peak voltage 460.4 V and positive peak current 18.51 A) but decreased the negative distortions (negative peak voltage - 20.5 V and negative peak current - 0.81 A). Negative distortions are still present.

In case 3, a diode-resistor network has been introduced in order to eliminate the distortions. The resistance in parallel to the diode is increased to $R_{parallel}$ = 100 Ω. The increase of parallel resistance from 20 Ω to 100 Ω has further increased the positive disturbances but also eliminated completely the negative disturbances, as described in table 1. The goal of completely eliminating negative disturbances has been achieved by introducing a diode-resistor network with $R_{parallel}$ = 100 Ω.

## 4 Conclusions

This technical paper offers a theoretical explanation to the issues mentioned in Amendment 1 of IEC 61000-4-5 Ed. 3. Some standards require a maximum vehicle charging voltage slew rate of 20 V/ms (e.g. Draft AIS-138 Part 2 / D1 from August 2016)[3], in which case the distortions should be lower than the ones from considered example (slew rate in considered example was 800 V/ms). The higher the slew rate, the higher the probability of issues when interposing a CDN with decoupling inductors between a PWM DC power source and EUT.

For the example considered, the problem of negative EUT voltage and current has been solved by introducing a diode-resistor network between the positive terminal of power source and decoupling inductor. This is achieved by selecting a sufficiently high value of resistance parallel to the diode (100 Ω parallel resistor has completely eliminated the negative voltage and current).

The elements determining possible issues during the test are:

- slew rate of PWM DC supply voltage (the higher the slew rate the higher the probability to generate distortions);
- value of decoupling inductance (the higher the inductance, the higher the probability to generate distortions);
- the value of EUT input capacitor (the higher the input capacitance, the higher the probability to generate distortions).

It has been observed that an increase of power source's output capacitance does not add significantly to distortions at EUT terminals.

[3] ARAI India. *Draft AIS-138 Part 2 / D1*. p. 61. https://araiindia.com/hmr/Control/AIS/922201652239PMAIS-138_Part_2_EVSEDC.pdf 27.02.2019.

Finally, a higher resistance in parallel to the diode might increase the electric potential at diode's output with reference to ground. In the cases considered, this phenomena was not noticed, but for values much higher than 100 Ω, electric potential peaks in excess of 600 V were noticed. This requires a high level of insulation. However, it is recommended to use the lowest value of parallel resistance that fully eliminates negative distortions at EUT terminals.

# 5 Relevant products

a) IMU3000 and IMU4000 generators and accessories:
https://www.emc-partner.com/company-documents-brochures/brochures/9-immunity-test-brochure/file

b) CDN-M- CDN-A- coupling/decoupling networks:
https://www.emc-partner.com/company-documents-brochures/brochures/9-immunity-test-brochure/file

c) DC-DCxxx diode-resistor networks;
https://www.emc-partner.com/company-documents-brochures/brochures/9-immunity-test-brochure/file

# 6 References

[1] IEC Standard IEC 61000-4-5 Edition 3.0: 2014

[2] IEC Standard IEC 61000-4-5 Edition 3.0: 2014 / Amendment 1: 2017

[3] ARAI India Standard Draft AIS-138 Part 2 / D1: 2016