

ED-332

GUIDANCE ON CHARACTERISTICS OF AIRCRAFT PROPULSIVE HIGH VOLTAGE DC ELECTRICAL SYSTEMS

LEGAL NOTICE

This document is the exclusive intellectual and commercial property of EUROCAE. It is presently commercialised by EUROCAE. This electronic copy is delivered to your company/organisation for internal use exclusively. In no case it may be re-sold, hired, lent or exchanged outside your company. It may not be reproduced, in whole or in parts, without prior written permission by EUROCAE.

22 JANUARY 2025

FOREWORD

1. This document was developed by EUROCAE Working Group 116 “High Voltage Systems and Components in Aviation”, and was approved by the Council of EUROCAE on 22 January 2025.
2. EUROCAE, an international non-profit organisation, is the European leader in the development of worldwide recognised standards for aviation. This is achieved by utilising the expertise from our members and stakeholders across the global aviation community.
3. EUROCAE standards are developed following an open, transparent and consensus-based process, governed by process and quality management principles, which are clearly documented and is in line with the World Trade Organisation (WTO) Technical Barriers to Trade (TBT) Agreement, Annex 3 “Code of Good Practice for the Preparation, Adoption and Application of Standards”.
4. EUROCAE standards and other deliverables are recommendations and best industry practices. EUROCAE is not an official body of the European governments. EUROCAE standards are intended to complement and support the regulatory and certification framework.
5. Whilst efforts are made during the standards-development process to avoid the inclusion of proprietary information and material, some of the elements of this document may be the subject of patent, copyright or other proprietary rights. EUROCAE shall not be held responsible for identifying any such rights. Trade names and similar terms used within this document do not constitute an endorsement by EUROCAE thereof.
6. Copies of this document may be obtained from:

EUROCAE

9 – 23 rue Paul Lafargue

93200 Saint-Denis

France

Telephone: +33 1 49 46 19 65

Email: eurocae@eurocae.net

Website: www.eurocae.net

TABLE OF CONTENTS

FOREWORD	i
TABLE OF CONTENTS	ii
TABLE OF FIGURES.....	ii
TABLE OF TABLES.....	iii
CHAPTER 1 GENERAL	1
1.1 Purpose and Scope	1
1.2 General characteristics of the HVDC propulsive network.....	1
1.3 General Test conditions.....	3
1.4 Abbreviations & Acronyms.....	4
1.5 Definitions	4
1.6 Utilisation Equipment Categories	7
CHAPTER 2 ELECTRICAL CHARACTERISTICS OF PROPULSIVE HVDC ELECTRICAL SYSTEM	8
2.1 Differential Mode Steady-state voltage.....	8
2.1.1 Qualification test procedure.....	8
2.2 Differential Mode voltage transients	8
2.2.1 Qualification test procedure.....	9
2.3 Differential mode Voltage ripple	10
2.3.1 Qualification test procedure.....	11
2.4 Differential mode Current ripple	12
2.5 Common Mode voltage.....	12
2.5.1 Example.....	12
2.6 Common mode Voltage ripple.....	13
2.7 Current Inrush	14
2.8 Power regeneration	14
2.9 Reverse polarity	14
2.10 Negative Voltage	14
2.11 System/Network stability	15
2.12 Capacitor discharge	15
2.13 Personal Safety.....	15
2.14 Electrical Bonding.....	15
2.15 Electrical Insulation	16
APPENDIX A SUMMARY OF REQUIREMENTS.....	17
WG-116 MEMBERSHIP.....	21
IMPROVEMENT SUGGESTION FORM.....	25

TABLE OF FIGURES

Figure 1-1: Classification HVDC Propulsive Network	2
Figure 1-2: Scope diagram and POI (Point Of Injection)	3
Figure 1-3: Example Voltage ripple.....	5

Figure 1-4: dV/dt measure.....	6
Figure 2-1: Differential mode normal and abnormal voltage transients	9
Figure 2-2: Differential Mode Voltage Transient Test	10
Figure 2-3: Differential mode voltage ripple spectrum-Normal Condition	11
Figure 2-4: Differential Mode Voltage Ripple Test.....	12
Figure 2-5: Common mode Voltage in Normal Operation.....	12
Figure 2-6: Common Mode Voltage Ripple Spectrum	13
Figure 2-7: Example of direct contact in IT Electrical Network.....	15

TABLE OF TABLES

Table 1-1: Abbreviations & Acronyms.....	4
Table 2-1: Differential Mode steady state voltage	8
Table 2-2: Differential Mode Voltage Transient Test conditions.....	9

CHAPTER 1

GENERAL

1.1 PURPOSE AND SCOPE

This document specifies the minimum performance of a propulsive High-Voltage DC (HVDC) electrical systems. It proposes design requirements and verification means to ensure interoperability within the electrical power system, i.e. compatibility between power sources, distribution equipment and utilisation equipment from power quality and protection standpoints.

A definition of electrical characteristics is provided to demonstrate this minimum performance. This definition shall be adapted and completed according to the specificities of the electrical power system and the aircraft's operating domain, in normal, abnormal and emergency conditions.

Conformity with these electrical characteristics shall be demonstrated through tests at utilisation equipment level (qualification tests) and at system level (integration tests). Test procedures and conditions can be derived from those defined in ED-14/DO-160, sections 16, 17, 18, but the test principles and setups must be adapted according to the specifics of the electrical power system. Some generic test procedures are defined within this document to demonstrate compliance. Any additional tests helpful to an exhaustive validation of utilisation equipment under test shall be proposed by the manufacturer.

Although the aircraft electrical power system may feature different voltage levels, e.g. 28VDC, 540VDC, 800VDC, 1000VDC, 115VAC, this document proposes a set of acceptable requirements for unregulated and regulated propulsive HVDC electrical systems with 800VDC as the nominal voltage. The objective of this document is not to impose these values as mandatory and inhibit further innovation in the industry. The values provided have been discussed among industry stakeholders and are consistent with the current technological state of the art.

For different voltage levels, design requirements and test procedures can be adapted accordingly.

For voltages higher than 1500VDC, additional design requirements and verification tests will need to be considered. As these higher voltage levels are not a current trend in the aircraft industry, they are outside the scope of this document.

1.2 GENERAL CHARACTERISTICS OF THE HVDC PROPULSIVE NETWORK

The aircraft HVDC propulsive network consists of at least the following elements:

- Electrical power sources (e.g. batteries, fuel cells, converters)
- Distribution equipment (including wiring, connectors and protection devices)
- Utilisation equipment supplied from the electrical propulsive network. (e.g. power consumer such as propulsive motor drive). In propulsive applications, the amount of utilisation equipment is expected to be limited about 10 units maximum.

The following diagram ([Figure 1-1](#)) shows different ways to implement a High Voltage DC propulsive network:

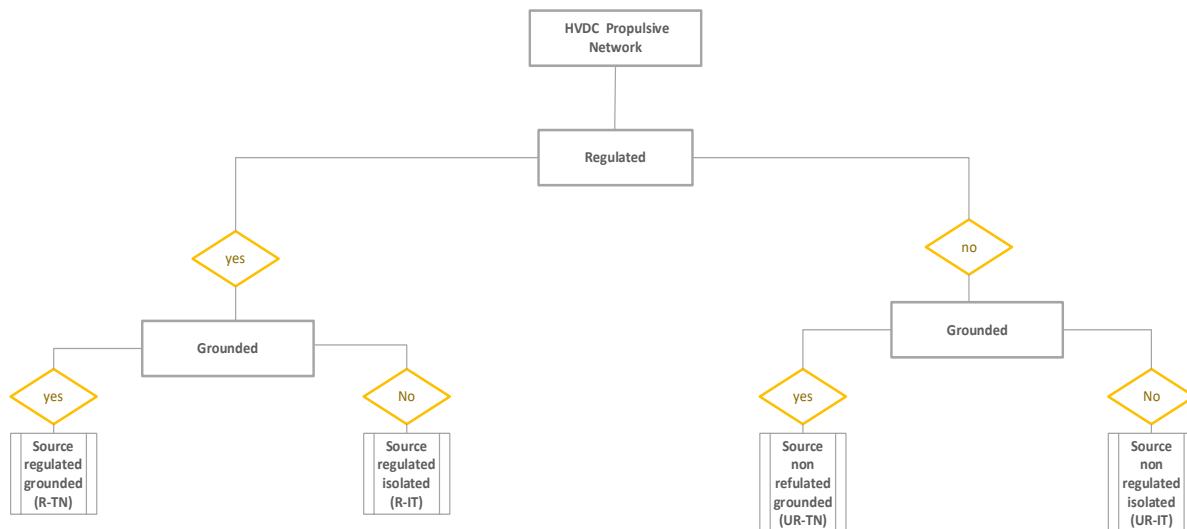


FIGURE 1-1: CLASSIFICATION HVDC PROPULSIVE NETWORK

Unregulated networks allow the use of power sources such as batteries or fuel cells, which can have a wide voltage range depending on their state of charge or discharge. Furthermore, unregulated networks are capable of operating effectively despite significant variations at the input of utilisation equipment.

Regulated networks, on the other hand, offer a tight voltage range. They are particularly well suited for power generators and electrical power systems that feature multiple energy sources, as these systems can provide a relatively constant output voltage. Regulated networks are specifically designed to maintain an accurate output voltage.

High Voltage networks may use an IT earthing scheme to address protection concerns, such as minimizing fault currents or maintaining continuity of service by preventing triggers at the first simple fault. In case of TN earthing scheme, high short circuit currents to the ground need to be adequately managed.

The characteristics of electrical power source, including grounding, fall under the responsibility of the system integrator. These resulting characteristics need to be communicated to utilisation equipment manufacturer.

This document focuses on the requirements for utilisation equipment. The system integrator must define suitable corresponding requirements for power sources and distribution equipment.

The specified impedance characteristics range of the wiring shall be consistent with the network installation. utilisation equipment must be designed and qualified taking into account the installation constrains, including the wiring. Therefore, the requirements defined in this document will be applicable at a specified Point of Injection (POI), as illustrated in Figure 1-2. All the requirements set forth in this document shall be verified over the entire range of impedance characteristics and at least in the worst-case scenario identified for the considered test. The impedance range shall be defined in the load manufacturer's report.

The specified line impedance shall include at least the resistive and inductive overall components such as wiring/harness, busbars, and connectors. It may also include the parasitic capacitance.

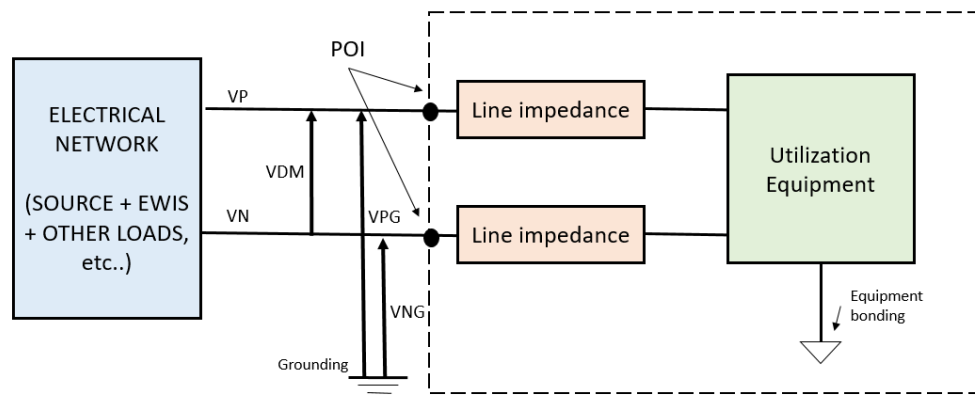


FIGURE 1-2: SCOPE DIAGRAM AND POI (POINT OF INJECTION)

1.3 GENERAL TEST CONDITIONS

The system integrator shall ensure that the HVDC propulsive network complies with the requirements of this standard at POI.

Utilisation Equipment Under Test (EUT) shall be connected to all its real or simulated loads/users and in such a manner that testing accurately represents the actual system characteristics.

The EUT shall be representative of the proposed series production standard. Test procedures shall be applied for several operating points and duty cycles, depending on the utilisation equipment's characteristics and performance requirements. These procedures shall be agreed upon by both the utilisation equipment manufacturer and the system integrator.

Power supply equipment shall feature relevant characteristics to perform the test procedures defined in the present document. Specifically:

- the power supply shall be significantly more powerful than the EUT;
- the power supply impedance should be as close as possible to that of an ideal voltage source (e.g. low impedance over the relevant frequency range, absence of resonance...). Consequently, standard EMC LISNs shall not be used;
- the current limits of the power supply or loading equipment shall not be reached under test conditions.

Unless otherwise specified, all tests shall be conducted under the following ambient conditions:

- Temperature: +15 to +35 degrees Celsius;
- Relative Humidity: Not greater than 85 percent;
- Ambient Pressure: 84 to 107kPa (equivalent to +5000ft to -1500ft) (+1525m to -460m).

1.4

ABBREVIATIONS & ACRONYMS

TABLE 1-1: Abbreviations & Acronyms

A	Ampere
A/C	Aircraft
AC	Alternating Current
CM	Common Mode
DC	Direct Current
DM	Differential Mode
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test
EVSE	Electric Vehicle Supply Equipment
F	Farad
FFT	Fast Fourier Transform
H	Henry
HVDC	High Voltage Direct Current
Hz	Hertz
ICD	Interface Control Document
IT	Isolated-Terre
PE	Protective earthing
POI	Point Of Injection
PTS	Purchaser Technical Specification
RMS	Root-Mean-Square
TVS	Transient Voltage Suppression
V	Volt
W	Watt

1.5

DEFINITIONS

Differential Mode Voltage

Differential mode voltage (e.g. at POI) is the voltage difference measured across the two HVDC utilisation equipment terminals (VDM in [Figure 1-2](#)).

$$VDM = VPG - VNG$$

Common Mode Voltage

Common mode voltage refers to both inputs (VP, VN) relative to the common (ground) see [Figure 1-2](#). The following formula, which gives the mean value of both common-mode voltages, can be used to assess unbalance.

$$VCM = \frac{VPG + VNG}{2}$$

Steady state

The system is considered in steady state when the main parameters (voltages, currents, etc.) which define the behaviour of the system remain mostly constant within the limits defined for a continuous time.

Ripple

Ripple is the cyclic or random variation, or both, about the mean level of the dc current or voltage value during steady state electrical system operation. Since it is not always a symmetrical quantity, the difference between upper and lower peak values is measured instead of the variation about the mean value of voltage or current.

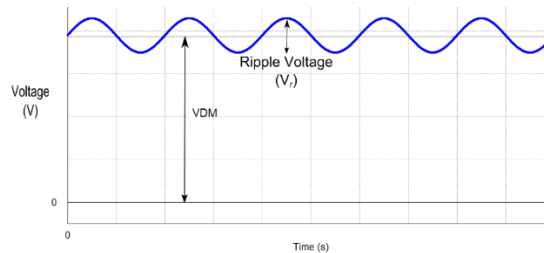


FIGURE 1-3: EXAMPLE VOLTAGE RIPPLE

RMS value (AC or DC waveform signals)

The RMS (Root Mean Square) value X_{RMS} of an AC or DC waveform signal X , where X represents either a voltage or a current, is computed as follows:

$$X_{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T x^2(t) \cdot dt}$$

where: $x(t)$ = instantaneous signal value at time t
 T = waveform time period

dBVrms

Voltages expressed in dBVrms are calculated with the following formula

$$dBV_{rms} = 20 \times \log_{10}(V_{rms})$$

dBArms

Currents expressed in dBVrms are calculated with the following formula

$$dBArms = 20 \times \log_{10}(A_{rms})$$

Transients

A transient is a changing value of a characteristic that occurs as a result of a disturbance such as: electric load change, engine speed change or electric generator speed change.

Normal Transient: Transients that remain within the specified allowable excursion limits.

Abnormal Transient: Transients that exceed specified allowable limits as a result of an abnormal disturbance and eventually return to steady state limits.

dV/dt

It is the voltage change (delta V or ΔV) divided by the time change (delta t or Δt), in other words, it is the rate at which the voltage changes over time. This is measured between 20% and 80% of initial and final steady state values (Figure 1-4).