

ED-296

GUIDANCE ON DESIGN ASSURANCE FOR HIGH VOLTAGE STANDARDS AND POWER QUALITY FOR VTOL APPLICATION

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TABLE OF CONTENTS

FOREWORD	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	iii
LIST OF TABLES	iii
CHAPTER 1 INTRODUCTION	1
1.1 PURPOSE AND SCOPE	1
1.2 APPLICATIONS	1
1.3 DESCRIPTION OF EQUIPMENT/FUNCTION	1
1.4 DEFINITIONS AND ABBREVIATIONS	1
1.5 REFERENCES	3
1.6 RELATIONSHIP TO SC-VTOL	3
1.7 RELATIONSHIP TO OTHER DOCUMENTS	3
CHAPTER 2 GENERAL REQUIREMENTS	5
2.1 GENERAL DESIGN REQUIREMENTS	5
CHAPTER 3 MINIMUM PERFORMANCE REQUIREMENTS	6
3.1 NEW NOMINAL VOLTAGE STANDARD CATEGORIES	6
3.2 POWER QUALITY	7
3.2.1 Verification of the compatibility between EPS and consumers	8
3.2.2 Process proposal to ensure compatibility between EPS and LTU or electric consumers for an application:	8
3.3 POWER CAPACITY	16
APPENDIX A EXAMPLE	18
A.1 EPS DEFINITION	18
A.2 EPS CHARACTERISTICS VERIFICATION	20
A.3 ELECTRICAL LOADS VERIFICATION	23
A.3.1 Normal Operation Steady State Voltage	23
A.3.2 Normal Operation Ripple Voltage	24
A.3.3 Momentary Power Interruption	24
A.3.4 Normal Surge Voltage	24
A.3.5 Abnormal Operation Steady State Voltage	24
A.3.6 Abnormal Operation Ripple Voltage	24
A.3.7 Abnormal Surge Voltage	24
A.3.8 Inrush Current	24
A.3.9 Current Ripple	25
WG-112 MEMBERSHIP	28
IMPROVEMENT SUGGESTION FORM	41

LIST OF FIGURES

FIGURE 3-1 APPLICABILITY LIFT/THRUST UNIT	6
FIGURE 3-2 ELECTRIC PARAMETER RANGE.....	10
FIGURE A-1: OPERATIONAL VOLTAGES	18
FIGURE A-2: SURGE VOLTAGE LIMITS ILLUSTRATION.....	19
FIGURE A-3: VOLTAGE DISTORTION SPECTRUM.....	19
FIGURE A-4: MAXIMUM INRUSH CURRENT ALLOWANCE ILLUSTRATION.....	20
FIGURE A-5: NORMAL OPERATION STEADY STATE VOLTAGE VARIATION.....	20
FIGURE A-6: NORMAL OPERATION RIPPLE VOLTAGE.....	21
FIGURE A-7: NORMAL SURGE VOLTAGE ON THE EPS	21
FIGURE A-8: POWER INTERRUPTION TEST	22
FIGURE A-9: ABNORMAL OPERATION STEADY STATE VOLTAGE VARIATION	22
FIGURE A-10: ABNORMAL OPERATION VOLTAGE RIPPLE.....	22
FIGURE A-11: ABNORMAL SURGE VOLTAGE ON THE EPS	23
FIGURE A-12: EMERGENCY VOLTAGE VARIATION ON EPS.....	23
FIGURE A-13: INRUSH CURRENT TEST FAILED BY PEAK CURRENT.....	24
FIGURE A-14: INRUSH CURRENT TEST FAILED BY DURATION	25
FIGURE A-15: ELECTRICAL LOAD CURRENT RIPPLE TEST	25

LIST OF TABLES

TABLE 3-1: ED-14/DO160 SECTION 16, CHAPTER16.6.....	11
TABLE A-1: OPERATIONAL VOLTAGE LIMITS	18
TABLE A-2: VOLTAGE VARIATION ON EXAMPLE EPS	19
TABLE A-3: INRUSH AND RIPPLE CURRENT DEFINITION	20

CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

This document contains guidance for utilization of *High Voltage Power systems on VTOL*. This standard specifies the minimum performance expected from *High Voltage Power systems*.

Compliance with this standard is recommended as one means of assuring that the High Voltage (HV) system will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operation.

The HV Power system may also have additional functions for which other MOPS or ETSOs may be applicable or, it may contain additional functions not defined by any MOPS or ETSO and, non ETSO function guidance may be applicable.

This document was initially planned to be issued together with ED-290 and was discussed by the same working group. Even though both documents address high voltage application on VTOL, ED-290 is mainly focused on personal safety, whereas ED-296 provides clarification regarding power quality features. Although a decision was made to separate the two documents, some of the definitions, like the voltage levels and minimum insulation, are only presented in ED-290. For personal safety aspects and electrical shock protection, please refer to ED-290; the application is highly recommended together with this document.

Since the intention of this document is to guarantee the compatibility between the electrical power source and the electrical loads, all circuits and equipment associated with it must be considered. This includes multiple sources, like batteries, filters, converters, and different consumers, like LTU, engines, landing gear, etc. In addition, both DC and AC systems shall be considered.

Battery cells degradation, ageing, or different behavior under distinct operation conditions (temperature, pressure, SoC, etc.) are not in scope of this document and shall be assessed using further standards, like DO-311A or ED-289 for instance.

1.2 APPLICATIONS

Compliance with this standard by manufacturers, installers and users is recommended as a means of assuring that the VTOL HV Power system will satisfactorily perform its intended function(s) under all conditions normally encountered in routine aircraft operations.

Any regulatory application of this document in whole or in part is the sole responsibility of appropriate government agencies.

As the measured values of equipment performance characteristics may be a function of the method of measurement, standard test conditions and methods of test are recommended in this document.

1.3 DESCRIPTION OF EQUIPMENT/FUNCTION

High Voltage Electric Power System consists of the electric power generation and distribution subsystems with voltage higher than 60Vdc, 25Vac, including all devices up to the Electric Power Consumers interface such as generators, energy storage devices, cables, switches, protective devices, converters, and regulators.

1.4 DEFINITIONS AND ABBREVIATIONS

AC	Alternate Current
DC	Direct Current
EPC	Electric Power Consumer
ETSO	European Technical Standard Order
HV	High Voltage

IT	Isolé-Terre (isolated ground) grounding system
EPS	Electric Power System
LTS	Lift Thrust System
LTU	Lift Thrust Unit
MOPS	Minimum Operational Performance Standard
MTOW	Maximum Take Off Weight
VTOL	Vertical Take Off and Landing

Abnormal Operation: Abnormal operation occurs when a malfunction or failure in the electrical system has taken place and the protective devices of the system are operating to remove the malfunction or failure. The system components may operate in a degraded mode on a continuous basis.

Crest Factor: Crest factor is the absolute value of the ratio between the peak and the RMS values in an AC voltage waveform.

Distortion: Distortion is defined as unavoidable frequency variation and harmonics on the voltage creating unwanted noise on the power distribution system. In AC systems, distortion is the RMS value of the frequency components on the waveform outside the fundamental frequency. In DC systems, distortion is the RMS value of the AC component of the DC voltage.

Distortion Factor: The distortion factor is defined as the ratio of distortion to the steady state voltage.

Distortion Spectrum: The distortion spectrum quantifies the distortion in terms of the amplitude of each frequency component. The distortion spectrum includes the components resulting from modulation as well as harmonic and nonharmonic components of the waveform.

Electrical Load: Electrical load is defined as the electrical and/or electronic aircraft equipment which requires electrical power. Also referred to as utilization equipment or electrical power consumer.

Emergency Operation: Emergency operation is defined as the condition of the electrical system during flight when the electrical system becomes unable to supply sufficient power, thus limiting the power output capabilities.

Frequency Modulation: Frequency modulation is the difference between the maximum and minimum frequency values that occur during steady state operating conditions. Value is commonly taken for one-minute periods and is a measure of the power system's frequency regulation.

Isolation Resistance: Electrical resistance between conductor or conductive part (intended to be energised in normal use of an electric circuit) and the chassis, as well as other electric circuits which are isolated from this electric circuit.

Inrush Current: Peak electrical current that an electrical load may present on its operation, mainly observed during power on and start-up processes.

Nominal Voltage: Nominal voltage is defined as the voltage value referenced in the power distribution system specification and documentation. It is not necessarily the power supply output voltage.

Normal Operation: Normal operation occurs when the system is operating as intended in the absence of any fault or malfunction that degrades performance beyond established requirements. It includes all system functions required for aircraft operation, including operation from external power sources.

Power Source: Power source is defined as source of electrical power or voltage regulation for delivery to the power distribution system.

Ripple: Ripple is the variation of voltage around the steady state DC voltage during steady state electrical system operation. The amplitude of ripple is measured as the

maximum absolute value of the difference between the steady state and the instantaneous DC voltage.

Steady State Conditions: Steady state conditions may vary slowly with temperature, engine RPM, and load profile but are defined by the absence of step changes in the system (i.e., load profile, faults, transient) throughout an arbitrarily long period of time.

Steady State Voltage: The steady state voltage characteristic is defined as the range from lowest required operating voltage to the highest required operating voltage which exists in the power distribution system during steady state conditions.

Transient: 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.

- a. **Normal Transient:** Transients that remain within the specified allowable excursion limits.
- b. **Abnormal Transient:** Transients that exceed specified allowable limits because of an abnormal disturbance and eventually return to steady state limits.

Voltage Displacement: Also known as voltage fluctuation or common mode voltage, voltage displacement is the oscillation on the potential of the neutral or reference point of a circuit. Voltage displacement is usually caused by impedance unbalance and electrostatic charging of the ground and is more common in IT systems.

Voltage Modulation: Voltage modulation is the variation on the AC voltage during steady state operation. This variation can be caused by changes on the power source or on the utilization equipment.

Voltage Phase Difference: Voltage phase difference is the phase difference (in electrical degrees) between the fundamental components of any two phase voltages taken at consecutive negative to positive zero crossings.

Voltage Unbalance: Voltage unbalance is the maximum difference between RMS phase voltage amplitude in a multi-phase AC system.

Definitions presented above are mostly based on MIL-STD-704F [3].

1.5 REFERENCES

- [1] EASA, Special Condition VTOL, Cologne, Germany, July 2019.
- [2] SAE International, „AS7459 - Bolts and Screws, Steel UNS K14675 Tensile Strength 195 ksi Fatigue and Stress-Rupture Rated Procurement Specification,“ August 2014.
- [3] Department of Defense Interface Standard, MIL-STD-704F AIRCRAFT ELECTRIC POWERCHARACTERISTICS, Lakehurst, March 2004.

1.6 RELATIONSHIP TO SC-VTOL

Whilst this standard was developed with a particular view to the European legal framework, namely the EASA Special Condition VTOL Issue 01, it may be applied to support other regulatory frames.

As regards the EASA SC VTOL, this standard supports the showing of compliance with the following requirements and/or complements the following related Means of Compliance:

- MOC VTOL.2430(a)(3) and (a)(4) Accessible energy in electrical energy storage systems

1.7 RELATIONSHIP TO OTHER DOCUMENTS

- ED-289 Guidance on determination of accessible Energy in Battery Systems for eVTOL Applications

- ED-14G/DO-160G Environmental Conditions and Test Procedures for Airborne Equipment
- ED-234/DO-357 User Guide Supplement to ED-14G/DO-160G
- ED-12C/DO-178C Software considerations in airborne systems and equipment certification
- ED-109A/DO-278A Software Integrity Assurance Considerations for CNS/ATM Systems
- ED-80/DO-254 Design Assurance Guidance for Airborne Electronic Hardware
- ED-79/ARP4754 Certification Considerations for highly-integrated or Complex Aircraft Systems
- ED-201A/DO-391 Aeronautical Information System Security (AISS) Framework Guidance
- ED-202A/DO-326A Airworthiness Security Process Specification
- ED-203A/DO-356A Airworthiness Security Methods and Considerations
- ED-204A/DO-355A Information Security Guidance for Continuing Airworthiness

CHAPTER 2

GENERAL REQUIREMENTS

2.1 GENERAL DESIGN REQUIREMENTS

The following EUROCAE Standards are available as general reference documents:

- Software: ED-12/DO-178 and software documents suite, ED-109A/DO278A
- Hardware: ED-80/DO-254
- System Safety Assessment: ED-79/ARP4754
- Security: ED-201A/DO-391, ED-202A/DO-326A, ED-203A/DO-356A, ED-204A/DO-355A

CHAPTER 3

MINIMUM PERFORMANCE REQUIREMENTS

3.1 NEW NOMINAL VOLTAGE STANDARD CATEGORIES

The aim of this paragraph is to assess the necessity to define new voltage categories. Existing voltage categories defined for on board electrical system are defined in standards such as:

- MIL-STD-704F – Aircraft Electric Power Characteristics
- EN2282 – Characteristics of Aircraft Electrical Supplies
- ISO 1540 – Aerospace – Characteristics of Aircraft Electrical Systems
- STANAG 3456 – Aircraft Electrical Power System Characteristics

Others non aeronautical standards may be considered, for example:

- ISO/PAS 19295 – Electrically Propelled Road Vehicles – Specification of Voltage Sub-Classes for Voltage Class B
- MIL-PRF-GCS600A Performance specification – Characteristics of 600Volt DC Electrical Systems for Military Ground Vehicles

Test procedure and conditions to verify compatibility of equipment to electrical system are defined in ED-14/DO-160 – Section 16.0.

The purpose of the above interface standards is to ensure compatibility between the aircraft Electric Power System, external power, and airborne utilization equipment.

The standards address various voltage levels, including 14Vdc, 28Vdc, 26Vac, 115Vac/400Hz and 60Hz, 270Vdc.

Other voltage levels are considered as potential candidate for standardisation, 42Vdc, 540Vdc.

For new VTOL aircraft including, but not limited to, Lift/Thrust Unit supplied by Electric Power System, the various configurations and architectures may involve various power and voltage solutions with level higher than 270Vdc.

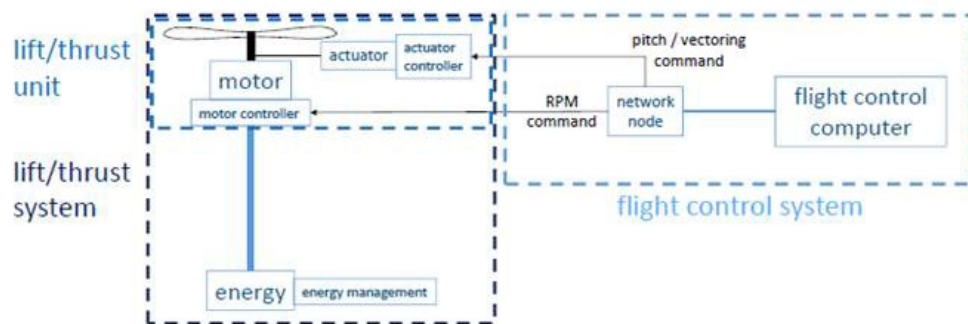


FIGURE 3-1: APPLICABILITY LIFT/THRUST UNIT

These voltage solutions may be identified by categories according to level of safety linked to electrical shocks impacts.

For example:

- Extra low voltage: voltage lower than 60Vdc or 25Vac
- Low voltage: from 60Vdc to 1500Vdc or from 25Vac to 1000Vac
- High voltage: above 1500Vdc or 1000Vac

In the following discussion and for consistency with legacy voltage level existing in the aeronautics domain, the following voltage ranges are proposed:

- LOW VOLTAGE (LV) range: up to 60Vdc and 25Vac nominal voltage. 14Vdc, 28Vdc standards identified in DO-160 or MIL-STD-704 or EN2282 are considered as 'low voltage'.
- HIGH VOLTAGE (HV) range: above 60Vdc and 25Vac and below 1500Vdc and 1000Vac nominal voltage. 115Vac, 270Vdc, 540dc, ... are considered as 'high voltage'.

For HVdc higher than 1500Vdc and HVac higher than 1000Vac, specific considerations need to be proposed. Those higher voltage levels are not intended to be used, for now, in the VTOL industry and is out of scope of this document.

The explanation of LV and HV voltage range proposal and correspondence with electric shock consideration is detailed in ED-290 High Voltage definition and consideration for personal safety.

LTU may be supplied by various types of electric power source, batteries, fuel cells, supercapacitor, DC generators, converters... which may operate by constant voltage and variable voltage with various voltage level.

The voltage level is mainly driven by the amount of power to be managed by the Electric Power System. The power necessary to ensure lift and thrust of the VTOL is directly linked to VTOL MTOW. Number of redundancy of the lift/thrust system also has an impact on the Electrical Power System architecture.

For a given application, with a given MTOW, several EPS architectures are possible to provide the power to LTU.

Considering all above (not exhaustive) parameters, we can state that level of voltage chosen for EPS can vary from one application to another, so it will be difficult to establish voltage level standards.

3.2 POWER QUALITY

Whatever the voltage level, the aim of the standards is to ensure compatibility between the aircraft Electric Power System, external power, and airborne utilization equipment for propulsive system and not propulsive system.

When the voltage level/range is defined for a given VTOL application, the applicant should show by analysis or test that EPS and LTU ensure specified performances in normal and abnormal operation, in all aircraft operating domain.

To show LTS electrical compatibility, the following non-exhaustive operating conditions and life situation shall be considered in the application demonstration:

- Normal operation including Power ON sequence
- Abnormal operation
- Starting operation
- Emergency operation

For each operation condition, steady state and transient operation, including power interruption, shall be considered.

The electrical parameters to be checked should be similar to those defined in above standards:

- DC Voltage:
 - Voltage limits
 - Inrush current
 - Distortion factor

- Distortion spectrum
- Ripple amplitude
- Power interruption
- AC voltage:
 - Voltage limits
 - Inrush current
 - Power factor
 - Voltage unbalance
 - Voltage modulation
 - Voltage phase difference
 - Distortion factor
 - Distortion spectrum
 - Crest factor
 - DC component
 - Frequency limits
 - Frequency modulation

3.2.1 Verification of the compatibility between EPS and consumers

For the verification of the compatibility between Electric Power System and electrical consumer, the applicant shall consider electric parameters operating ranges (in particular the voltage) and consumers operating status.

The operating status of the consumer is introduced to describe the operating behavior and performance of the component that depends on the electric parameters applied at its terminals.

The electric parameters operating ranges is introduced to identify the electric parameters values associated to all operating conditions or life situation of the VTOL.

Threshold associated to normal operation, abnormal operation, emergency, start, etc. shall be defined by the applicant. For each threshold or range, the acceptable behavior of the EPS and associated consumers shall be defined.

The electrical power system shall be tested integrated with all the electrical loads in a representative environment to verify that the power characteristic limits specified are respected. Failure conditions shall be assessed and analysis provided to assure the system behaves as intended.

3.2.2 Process proposal to ensure compatibility between EPS and LTU or electric consumers for an application

The applicant has to follow several steps:

3.2.2.1 Define the EPS characteristics

The applicant shall identify the electrical parameters important to be considered for his application

List of non-exhaustive electrical parameters:

- Voltage
- Current
- Power interruption

For each parameter, standard like MIL-STD-704-F should be used as a guideline to define the operating range and threshold. See MIL-STD-704F chapter 4.1 or general requirements to be adapted to VTOL EPS.

The detailed EPS requirements should be defined by the applicant as defined in MIL-STD-704F Chapter 5:

Chapter 5.1: Transfer operation characteristics to be adapted for the given application

Chapter 5.2: Not applicable in case of DC power source

Chapter 5.3.1: Application to 28Vdc regulated network

Chapter 5.3.2: Applicable for 270Vdc regulated network

The applicant shall identify applicable parameters range for his application in the same way, i.e.:

- Normal operation: Normal operation characteristics shall be in accordance with figures defining:
 - Envelope of normal voltage transients
 - Maximum distortion spectrum
 - Steady state characteristics:
 - Steady state voltage
 - Distortion factor
 - Ripple amplitude
- Abnormal operation: Overvoltage and undervoltage values shall be within the limits of figure defining:
 - Envelope of Abnormal transients
- Emergency operation: The DC steady voltage in emergency operation shall be between specific voltage ranges defined for the application.

According to the operating range defined above, the applicant shall define the applicable operation status for the electric consumers and LTU.

Example of operating status versus voltage operating range:

S1: Normal operation

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.

S2: Abnormal operation

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.

or

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.

S3: Emergency operation

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.

or

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.

S4: Outside of operation range

The component may cut-off its performance triggered by a reset or an external event (e.g., change of ignition status, restart vehicle).

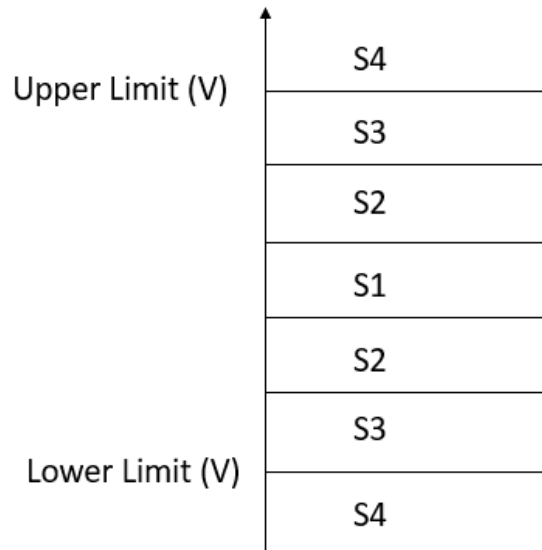


FIGURE 3-2: ELECTRIC PARAMETER RANGE

Figure 3-2 shows an example of allocation of operating status to the voltage operating range.

3.2.2.2 EPS characteristics verification

Once defined, the EPS electric characteristics shall be verified by test at EPS system level.

Dedicated EPS bench set up representative of VTOL installation should be implemented, and test plan and procedure shall be defined for test execution.

See also CS 25/29.1363 for guidance.

3.2.2.3 Electric consumers' verification

To verify that electric consumers and LTU supplied by the EPS operate as specified, electrical compatibility tests should be performed for each electrical consumer.

For legacy electrical network, ED-14/ DO-160 section 16 standard is commonly used to defined tests conditions and procedure.

This standard should be used as guideline to define the tests conditions and procedure for voltage range used for the application but not identified in the standard.

Example of utilization of ED-14/DO-160 as guideline:

Electric consumer or LTU used on VTOL may need main power supply to generate power for propulsion and auxiliary power supply for internal equipment operation.

In general, power supply for propulsion needs HVdc, and auxiliary power supply needs LVdc. LVdc voltage compatibility is commonly demonstrated in line with ED-14/DO-160 standard Chapter 16.

For HV, ED-14/DO-160 Chapter 16 identifies Cat D for 270Vdc regulated voltage. If the HV voltage level is different to Cat D, the applicant may adapt ED-14/DO-160 to demonstrate electrical compatibility.

Table 3-1 shows an example on how to adapt ED-14/DO-160 Section 16 Chapter 16.6 to the application when HV is different from Cat D.