INTERNATIONAL STANDARD

ISO 1540

Third edition
2006-02-15

Aerospace — Characteristics of aircraft electrical systems

Aéronautique — Caractéristiques des systèmes électriques à bord des aéronefs

Reference number
ISO 1540:2006(E)

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Published in Switzerland

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 1540 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 1, *Aerospace electrical requirements*.

This third edition cancels and replaces the second edition (ISO 1540:1984), which has been technically revised.

Introduction

The purpose of this International Standard is to foster compatibility between the providers, distributors and users of aircraft electrical power. This third edition takes into account several recent trends in aircraft electrical system, including that towards increased nonlinear load content on aircraft. It defines design requirements for electrical equipment that will be verified by the test requirements specified in ISO 7137.

Limits defined in this International Standard are based upon historical as well as near term projected equipment characteristics, including recent trends towards increased nonlinear, electronic user equipment. Since these limits are influenced by the overall combination of source, distribution and user equipment, background to their integration sensitivities is also included herein. The intention is to provide system integrator guidance, without restricting flexibility of means by which the specified interface characteristics are achieved. This revision also addresses several power types not at present common on large transport aircraft, such as variable frequency a.c., 230/400 V a.c. and 42 V d.c.

Also fundamental to the basis of these requirements is the assumption that cost-effective utilization equipment needs to be usable on a wide range of new aircraft. This results in some penalties typically only realized on large aircraft, e.g. those associated with longer distribution feeder voltage drops, being accepted for smaller aircraft equipment. The realities of these situations and recent user equipment trends may likely be the reason for differences between this International Standard and other historical standards.

Aerospace — Characteristics of aircraft electrical systems

1 Scope

This International Standard specifies the characteristics of electrical power supplied to the terminals of electrical utilization equipment installed in an aircraft. It is intended to support the interface definition for user equipment designed to accept electrical power on a variety of new civil aircraft applications, such as those certified via the Technical Standard Order (TSO) certification process. It might not be desirable for equipment targeted to a single application or specific military application to follow this International Standard because of the penalties associated with multi-application.

This document also attempts to provide background to the development of these requirements that may be useful to those designing and/or integrating modern aircraft electrical systems. The delivered quality of this electrical power is a result of the combined characteristics of the electrical power source, distribution and user equipment. While only user equipment restrictions are specifically defined, background to key source and distribution equipment interfaces are identified in order to support development of the overall system.

A wide variety of electrical supply types and distribution parameters have been considered, as may be found on both small and large transport aircraft. Sources considered include physically rotating and static types, provided either on-aircraft, or as part of the ground support equipment. Distribution voltages addressed are

— nominal 14 V, 28 V and 42 V d.c.;

— nominal 26 V a.c., 400 Hz, one-phase;

— nominal 115/200 V rms and 230/400 V rms a.c., both one-phase and three-phase, at either a nominal 400 Hz constant frequency (CF), or over a variable frequency (VF) range which includes 400 Hz.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6858, *Aircraft — Ground support electrical supplies — General requirements*

ISO 7137:1995, *Aircraft — Environmental conditions and test procedures for airborne equipment* [1)]

1) Endorsement of EUROCAE ED-14C and RTCA/DO-160C.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
abnormal electrical system operation
aircraft operation where 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 from the rest of the system before the limits for abnormal power quality are exceeded

NOTE Once initiated, abnormal operation may continue for the remainder of a flight with the power quality delivered to users exceeding normal operation limits, but staying within abnormal operation limits.

3.2
abnormal power quality limits
limits provided at user terminals during abnormal operation that take into account the operating tolerances of the system protective devices and any inherently limiting characteristics of the system design

NOTE See also 3.30.

3.3
crest factor
absolute value of the ratio of the peak to the rms value of an a.c. waveform measured under steady-state conditions

NOTE 1 It is unitless and the ratio for a true sine wave is equal to $\sqrt{2}$.

NOTE 2 Written as | V(pk) / V(rms) | .

3.4
current modulation
difference between the maximum and minimum value of electrical current drawn during conditions of cyclic or randomly repeating current variation

NOTE Measurable current modulation by user equipment can impact the quality and/or stability of the provided electrical power.

3.5
distortion (current or voltage)
rms value of the a.c. waveform exclusive of the fundamental component in an a.c. system, or the rms value of the alternating (ripple) component on the d.c. level in a d.c. system

NOTE a.c. system distortion can include harmonic and non-harmonic components. Harmonics are sinusoidal distortion components which occur at integer multiples of the fundamental frequency. Interharmonics are distortion components which occur at non-integer multiples of the fundamental frequency. These and all other elements of waveform distortion are included in this general definition of distortion. (See also 3.23 and 3.25.)

3.6
displacement factor
⟨a.c. user equipment⟩ cosine of the angle (Φ) between the input current (provided at the fundamental frequency) and the input voltage (provided at the fundamental frequency)

NOTE This value does not include the effect of distortion in the input current (and/or voltage) waveform, and it is therefore not applied in this specification in favour of the more general power factor definition. (See also 3.35.)

3.7
distortion factor (current or voltage)
ratio of the distortion in a waveform to the rms value of the fundamental component of the waveform

NOTE 1 The distortion factor is typically expressed as a percentage:

$$df \text{ (per cent)} = 100 \times \frac{\sqrt{(X_{\text{rms}}{}^2 - X_1{}^2)}}{X_1}$$

where

X_{rms} is the rms value of the complete (voltage or current) waveform;

X_1 is the rms value of the fundamental frequency component.

NOTE 2 In a d.c. system, this fundamental component is true d.c. (See also 3.5, 3.43.)

3.8
distortion spectrum
itemization of the amplitude of each frequency component found in the a.c. or d.c. distortion

NOTE 1 Its components may be harmonic or non-harmonic multiples of the fundamental frequency, some of which result from amplitude or frequency modulation.

NOTE 2 Only components up to a frequency of 16 kHz (for 400 Hz, CF equipment) and 32 kHz (for VF equipment) are addressed in this International Standard to clearly separate requirements related to electrical power quality from those related to electromagnetic compatibility (EMC).

3.9
distribution system
collection of interconnection and circuit protection equipment between power sources and user equipment

NOTE See Figure 1.

3.10
drift
extremely slow variation in a random manner of a controlled parameter (such as frequency in a CF system) inside of the specification limits from causes such as ageing of components or self-induced temperature changes

3.11
drift rate
speed of variation due to drift of a controlled parameter

NOTE Drift rate is typically expressed in Hz/min or V/min, depending upon the parameter examined.

3.12
electric engine start operation
special case of normal electrical system operation where an extreme demand of electrical power is required to support the starting of a main engine or the auxiliary power unit

NOTE 1 Normal voltage transient limits may be exceeded during this condition with only selected utilization equipment required to operate throughout the event.

NOTE 2 Typical engine start times are between 15 s and 90 s.

3.13
electric power generating system
EPGS
combination of rotating and static electrical power sources and the devices which provide their control and protection

3.14
electric power system
combination of electrical power sources, conversion equipment, control and protective devices and utilization equipment connected via a distribution network

NOTE Also called simply 'system'.

3.15
emergency electric system operation
electrical system condition during flight when the primary electric power system becomes unable to supply sufficient or proper electrical power, thus requiring the use of independent and potentially limited source(s) to power a reduced complement of distribution and utilization equipment selected to maintain safe flight and personnel safety

3.16
emergency power source
generator, power conversion device (or a combination thereof not involving part of utilization equipment) or battery installed to provide independent electrical power for essential purposes during conditions of electrical emergency in flight

3.17
external power unit
ground power unit
GPU
rotating or static source (or combination thereof) supplied by the maintenance facility to source electrical power demands while the aircraft is not in flight

NOTE It may be either a point-of-use or centrally located ground power electrical supply in land-based facilities, or a shipboard power supply in marine applications.

3.18
frequency
reciprocal of the period of the a.c. waveform

NOTE 1 Frequency is measured in hertz (Hz).

NOTE 2 Steady-state frequency is the time average of the frequency over a period not to exceed one second. Instantaneous frequency is the frequency of a single cycle.

3.19
frequency modulation
cyclic and/or random variation of instantaneous frequency about a mean frequency during steady-state conditions

NOTE Amplitude of the frequency modulation is equal to the difference found between the maximum and minimum frequency measured over a one minute interval.

3.20
frequency modulation rate
rate of change of frequency due to frequency modulation

NOTE Frequency modulation rate is measured in hertz per second (Hz/s).

3.21
fundamental frequency
frequency of the primary power producing component of a periodic waveform supplied by the generation system (component of order 1 of the waveform's Fourier series representation)

3.22
ground
point along a conductive structure or cable which serves as an essentially zero potential reference for a.c. and/or d.c. voltages

3.23
harmonics
sinusoidal voltage or current components (distortion) of a periodic waveform which occur at a frequency that is an integer multiple of the fundamental frequency

NOTE 1 Most nonlinear loads generate odd-numbered harmonics; for example, as a result of full wave rectification of the input power.

NOTE 2 The frequencies at which these 'characteristic harmonics' are produced by a user with a diode-type input rectifier are determined by the following equation:

$$f_H = (k \times q \pm 1) \times f_1$$

where

H is the number of the harmonic;

k is an integer, beginning with 1;

q is an integer, representing the number of rectifier commutations per cycle;

f_1 is the fundamental frequency.

NOTE 3 Half wave rectification produces even-numbered harmonics, which cause very undesirable results (e.g. d.c. content) in the a.c. power system. Full wave rectification at the input of single-phase power users results in 'triplen' harmonics at odd multiples of three times the fundamental frequency. These are also very undesirable given the potential quantity of single-phase users and the fact that these harmonics interact with the distribution system's normally high (zero sequence) impedance to this frequency. User distortion current requirements are therefore intentionally restrictive for even and triplen harmonics. (See also 3.5, 3.39.)

3.24
impedance
complex electrical characteristic of a device or group of devices which relates the ratio of the phasor steady-state voltage to the phasor steady-state current

3.25
individual frequency component of distortion
ratio of the rms value of the waveform distortion at one specific frequency to the rms value of the fundamental component of the waveform

NOTE 1 See also 3.8.

NOTE 2 The individual frequency components of voltage distortion are expressed as

$$D_{vn} = 100 \times (V_n / V_1)$$

where

V_n is the rms value of an individual, non-fundamental frequency component;

V_1 is the rms value of the fundamental frequency component.

3.26
linear load
user of electrical power whose total impedance is constant despite variations in applied voltage and whose current spectrum matches that of the applied voltage

NOTE Conversely, nonlinear loads may have changing impedance with applied voltage and a different spectral content from that of the applied voltage source.

3.27
load unbalance
difference between the highest phase power draw and lowest phase power draw in volt-amperes for a three-phase a.c. power user

3.28
momentary power interruptions
short term power interruptions during which time the supplied voltage will decay at a rate dependent upon bus and load characteristics, as is typical during transfer of power sources

3.29
normal electrical system operation
conditions which include all intended modes of aircraft ground and flight operation during which no electrical system faults or malfunctions occur, except instances of propulsion engine or auxiliary power unit electric starting

NOTE 1 It assumes proper functioning of all equipment within defined operating procedures and limits. Examples of such operation are switching of utilization equipment loads, engine speed changes, source switching and synchronization, and the intended paralleling of power sources.

NOTE 2 Normal operation also includes momentary power interruptions, transients and spikes. (See also 3.1.)

3.30
normal power quality limits
limits which should be maintained during periods of normal electrical system operation

NOTE See also 3.2.

3.31
per unit
PU
standardized quantity in a system where various parameters are quantified with respect to a base value

NOTE 1 The base value is generally the rated value.

NOTE 2 For power systems this is typically applied to the powers, voltages, currents, or impedances where ‘per unit’ numbers equal the actual parameter value divided by the base values.

EXAMPLE In a 115/200 V rms, 3-phase, 120 kVA system: 1 PU power is 120 kVA; 1 PU voltage is equal to 115 V rms; 1 PU phase current is equal to 348 A rms; and 1 PU impedance is equal to 0,33 ohms. A three-phase load on this system that consumes 52 A rms per phase would be considered as drawing 0,15 PU power.

3.32
phase voltage
phase-to-neutral voltages supplied to single-phase or three-phase utilization equipment

NOTE All a.c. voltage values defined in this International Standard are rms, line-to-neutral quantities unless otherwise specified.

3.33
phase voltage displacement
maximum angular separation (about a nominal 120 degrees) between the zero voltage points of any two of the three voltage waveforms in a three-phase a.c. system during steady-state conditions

3.34
phase voltage unbalance
maximum difference between rms phase voltage amplitudes during steady-state conditions

NOTE $V_{\mathrm{UNB}} = \max.\{V_{\mathrm{AN}}, V_{\mathrm{BN}}, V_{\mathrm{CN}}\} - \min.\{V_{\mathrm{AN}}, V_{\mathrm{BN}}, V_{\mathrm{CN}}\}$

where

V_{AN}, V_{BN}, V_{CN} are the phase voltage magnitudes.

3.35
power factor
a.c. user equipment feature determined by the ratio of the real, or active, power consumed in watts to the apparent power drawn in volt-amperes, with

NOTE 1 $PF = P / S$

where

P is the real power in watts;

S is the apparent power, product of rms voltage and current, in volt-amperes.

NOTE 2 This definition of power factor includes the effect of distortion in the input current (and/or voltage) waveform.

NOTE 3 When the fundamental current waveform drawn by a user electrically lags the fundamental voltage waveform (as is typical in inductive loads), it is considered a 'lagging' power factor. Likewise if the current waveform electrically leads the voltage waveform (as expected for capacitive loads), it is considered a 'leading' power factor. When the user only draws real power (no reactive power) and its input current is exactly in phase with the supplied voltage, it is termed a 'unity' power factor load ($PF = 1$). (See also 3.6.)

3.36
primary power source
generator, usually driven by one of the aircraft propulsion engines, and any associated power conditioning equipment (not forming part of the utilization equipment) installed to provide electrical power during all phases of aircraft operation

3.37
ripple
cyclic variation about the mean level of the d.c. current or voltage value during steady-state electrical system operation

NOTE Since it is not always a symmetrical quantity, the difference between upper and lower peak values is measured instead of the mean value of voltage or current.

3.38
rms value (voltage or current)
value of voltage or current based upon the equivalence to the d.c. value that would yield the same power transfer in a d.c. circuit

NOTE The rms voltage value can be computed as

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T v^2(t)\, dt}$$

where

T is the waveform time period;

$v(t)$ is the instantaneous voltage at time t.

3.39
sequence impedances (/harmonics)
positive, negative and zero sequence impedances, determined from a mathematical analysis method termed 'Symmetrical Components' which breaks the quite difficult problem of analysing a three-phase unbalanced system into a study of two balanced three-phase circuits and one zero-phased circuit

NOTE The practical application of these characteristic impedances allows for more complex power system analysis, including the effects of harmonic currents to produce harmonic voltages. Positive and negative sequence impedances are determined by the resistance and reactance of the generating power source and the distribution network. In a.c. electrical systems, therefore, these impedances increase with increasing source (generator) frequency. For passive elements such as distribution feeders, the positive and negative sequence impedances are identical; this is not true for electrical machines.

Zero sequence impedances strongly relate to the impedance of the system to current flow through the power system neutral. Therefore this impedance is heavily influenced by the application of a wired or structure return path, and for the latter case, the exact three-phase wire bundle configuration and its distance from the return path structure. Unbalanced currents and fault currents flow through this impedance.

While positive, negative and zero sequence impedances or currents are traditionally associated with particular harmonic multiples, the harmonics present in a three-phase power system can also be characterized as having positive, negative and zero sequence components. Positive sequence current harmonics consist of three phasors, equal in magnitude and separated from each other by 120° phase displacement, with the same phase sequence as phasors representing the fundamental bus current.

Negative sequence current harmonics also consist of three phasors, equal in magnitude and separated from each other by 120° phase displacement, but with a phase sequence which is opposite to that of phasors representing the fundamental bus current. Whereas positive sequence harmonics provide for positive torque contribution to an a.c. bus fed synchronous motor, negative sequence harmonics negate torque in a.c. bus fed synchronous motors.

Zero sequence harmonics consist of three phasors which are likewise equal in magnitude, but with identical phase angles, and are therefore described as being 'in phase' with each other. Whereas balanced positive and negative sequence harmonics do not result in any neutral conductor current, balanced zero sequence harmonics, such as those from single-phase to neutral nonlinear loads, result in three times the harmonic current in the neutral conductor than is present in any phase. The third harmonics of fundamental phase A, B and C currents, termed 'triplen' harmonics, have identical phase angles and therefore act with a magnitude which is triple that of any one phasor. (See 3.25.)

3.40
spike
variation from the controlled steady state or transient level of a characteristic that occurs for an extremely short duration (microseconds)

NOTE 1 Spikes generally produce a voltage peak and/or wave train, the characteristics of which are dependent on relative impedances of the source, the line, and of the utilization equipment, as well as the manner in which the event occurs.

NOTE 2 Typical voltage spikes result from the switching of inductive or capacitive load elements.

3.41
steady state
operating condition of the system when only negligible changes in electrical parameters appear

3.42
system stability
aspect of system dynamic compatibility associated with certain system performance criteria defined at the power system interfaces

NOTE 1 For aircraft power systems the primary interface is the electrical bus.

NOTE 2 The key performance criteria are therefore associated with the maintenance of voltage and current values, and spectral content thereof, at various points on that bus within the limits defined by this International Standard in the presence of both internal and external stimuli.

3.43
total harmonic distortion (current or voltage)
ratio of the rms value of a waveform's harmonics to the rms value of its fundamental component

NOTE 1 See also 3.7, 3.8.

NOTE 2 The total harmonic distortion may be defined by the following equation:

$$THD_X\text{(per cent)} = 100 \times \frac{\sqrt[2]{\sum_{2}^{n} X_n^{\ 2}}}{X_1}$$

where

X_1 is the fundamental value of current or voltage;

X_n is the nth harmonic value of current or voltage.

3.44
transient
momentary variation of a characteristic from its steady-state limits, and back to its steady-state limits, as a result of a system disturbance

NOTE 1 Rapid load or engine speed changes followed by the conditioned response of the generating system, as well as brief voltage variations or interruptions due to normal source or load switching are considered normal transients.

NOTE 2 Transients which exceed normal transient limits as a result of an abnormal disturbance and eventually return to steady-state limits are defined as abnormal transients.

3.45

uninterruptible power
power (typically d.c.) delivered to essential and/or voltage transient sensitive users in such a manner that normal power interruptions are either eliminated or reduced in severity and probability

3.46
utilization equipment
unit or functional group of units which receives electrical power on the aircraft

NOTE Sometimes referred to as 'load equipment'.

3.47
utilization equipment rating
maximum power a user can be expected to continually consume over a time period which is not less than 200 ms

3.48
voltage modulation
⟨a.c. voltage⟩ cyclic and/or random variation of the a.c. peak voltage around a mean value during steady-state conditions

NOTE 1 Voltage modulation amplitude is the difference between the maximum and minimum peak voltage values that occur in a one second period during steady-state operating conditions. (See 3.27.)

NOTE 2 Frequency characteristics of voltage modulation are the components at individual frequencies that together make up the voltage modulation envelope waveform.

NOTE 3 For d.c. power, see **ripple** (3.37).