DRAFT INTERNATIONAL STANDARD ISO/DIS 1540

ISO/TC **20**/SC **1** Secretariat: **SAC**

Voting begins on
2002-10-03

Voting terminates on
2003-03-03

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Aerospace — Characteristics of aircraft electrical systems

[Revision of second edition (ISO 1540:1984)]

Aéronautique — Caractéristiques des systèmes électriques à bord des aéronefs

ICS 49.060

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

Pour accélérer la distribution, le présent document est distribué tel qu'il est parvenu du secrétariat du comité. Le travail de rédaction et de composition de texte sera effectué au Secrétariat central de l'ISO au stade de publication.

THIS DOCUMENT IS A DRAFT CIRCULATED FOR COMMENT AND APPROVAL. IT IS THEREFORE SUBJECT TO CHANGE AND MAY NOT BE REFERRED TO AS AN INTERNATIONAL STANDARD UNTIL PUBLISHED AS SUCH.

IN ADDITION TO THEIR EVALUATION AS BEING ACCEPTABLE FOR INDUSTRIAL, TECHNOLOGICAL, COMMERCIAL AND USER PURPOSES, DRAFT INTERNATIONAL STANDARDS MAY ON OCCASION HAVE TO BE CONSIDERED IN THE LIGHT OF THEIR POTENTIAL TO BECOME STANDARDS TO WHICH REFERENCE MAY BE MADE IN NATIONAL REGULATIONS.

Copyright notice

Contents

Page

1 Scope 1

2 Technical basis 1

3 Normative references 2

4 Terms and definitions....2

5 Requirements applicable to all systems....9
5.1 General....9
5.2 On-aircraft power sources 10
5.3 External power sources....10
5.4 Source/Distribution system coordination 10
5.5 Utilization equipment....11

6 Constant frequency (CF) a.c. power system characteristics....12
6.1 General characteristics 12
6.2 Steady state characteristics....12
6.3 Transient characteristics....13

7 Variable frequency (VF) a.c.power system characteristics 16
7.1 General characteristics 16
7.2 Consideration of constant frequency power characteristics 16
7.3 Steady state characteristics....16
7.4 Transient characteristics....17

8 D.C. power system characteristics....20
8.1 General characteristics 20
8.2 Steady state characteristics....20
8.3 Transient characteristics....22

9 Requirements allocation 23

10 Utilization equipment restrictions 23
10.1 General....23
10.2 A.C. power utilization....23
10.3 Power factor 23
10.4 Load switching transients....24
10.5 Inrush current....24
10.6 Input current modulation 24
10.7 Input current distortion 25
10.8 Maximum input capacitance 27

11 Power quality associated assumptions and background 27
11.1 General....27
11.2 Background to the document scope....28
11.3 A.C. power system assumptions....28
11.4 A.C. source equipment assumptions....32
11.5 D.C. system assumptions 33
11.6 D.C. engine starting power quality....35
11.7 270 V d.c. input power 35

12 Bibliography 35

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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 ISO 1540:1984 which has been technically revised.

Introduction

The purpose of this standard is to foster compatibility between the providers, distributors and users of aircraft electrical power. This update takes into account several recent trends in aircraft electrical system, including that toward 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.

Any comments regarding this draft may be sent to the Secretariat of ISO TC 20, SC1.

Comment may also be directly supplied to the convenor of ISO/TC 20/SC1/WG13 as follows:

Mario R. Rinaldi, Hamilton Sundstrand, PO Box 7002, M/S 277-6, Rockford, IL 61125-7002

(815) 394-3565 (Voice), (815) 226-2614 (FAX), mario.rinaldi@hs.utc.com (Email)

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. Equipment targeted to a single application or specific military application may not wish to follow this standard due to 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, 28 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 Technical basis

Limits defined in this 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 presently common on large transports, 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 useable 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 and other historical standards.

3 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, the publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7137, *Aircraft — Environmental conditions and test procedures for airborne equipment (Endorsement of EUROCAE ED-14/RTCA DO-160)*

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

4 Terms and definitions

4.1

abnormal electrical system 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 from the rest of the system before the limits for abnormal power quality are exceeded. Once initiated, it 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.

4.2

abnormal power quality limits

Power quality limits provided at user terminals during abnormal operation. These limits take into account the operating tolerances of the system protective devices and any inherently limiting characteristics of the system design. (See also 4.30.)

4.3

crest factor

Crest factor is the absolute value of the ratio of the peak to the rms value of an a.c. waveform measured under steady state conditions. It is unitless and the ratio for a true sine wave is equal to $\sqrt{2}$.

$$cf = | V(\text{pk}) / V(\text{rms}) |$$

4.4

current modulation

Current modulation is the difference between the maximum and minimum value of electrical current drawn during conditions of cyclic or randomly repeating current variation. Measurable current modulation by user equipment may impact the quality and/or stability of the provided electrical power.

4.5

distortion (current or voltage)

In an a.c. system, distortion is the rms value of the a.c. waveform exclusive of the fundamental component. It may include harmonic and non-harmonic components. In a d.c. system, distortion is the rms value of the alternating (ripple) component on the d.c. level.

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 4.23 and 4.25.)

4.6

displacement factor

For a.c. user equipment, the displacement factor is equal to the cosine of the angle (Φ) between the input current (provided at the fundamental frequency) and the input voltage (provided at the fundamental frequency).

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 favor of the more general power factor definition. (See also 4.35.)

4.7

distortion factor (current or voltage)

Distortion factor is the ratio of the distortion in a waveform to the rms value of the fundamental component of the waveform, typically expressed as a percentage. In a d.c. system, this fundamental component is true d.c.. (See also 4.5, 4.43.)

4.8

distortion spectrum

An itemization of the amplitude of each frequency component found in the a.c. or d.c. distortion. Its components may be harmonic or non-harmonic multiples of the fundamental frequency, some of which result from amplitude or frequency modulation. Only components up to a frequency of 16 kHz (for 400 Hz, CF equipment) and 32 kHz (for VF equipment) are addressed in this standard to clearly separate between requirements related to electrical power quality from those related to electromagnetic compatibility (EMC).[1]

4.9

distribution system

Traditionally this includes the generation source bus and related switchgear, the user load bus and all of the interconnection and distribution equipment between these two. For purposes of this document, interconnection, circuit protection and distribution equipment down to the user input terminals, where power quality is defined, is also included (see figure 1).

4.10

drift

The 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.

4.11

drift rate

The speed of variation due to drift of a controlled parameter. It is typically expressed in Hz/min or V/min depending upon the parameter examined.

4.12

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. Normal voltage transients limits may be exceeded during this condition with only selected utilization equipment required to operate throughout the event. Typical engine start times are between 15 and 90 seconds.

4.13

electric power generating system (EPGS)

The combination of rotating and static electrical power sources, devices which provide generating system control and protection, and the feeders which take power from these sources to the source bus (not including, therefore, the distribution switchgear).

4.14

electric power system (also called simply "system")

A combination of electrical power sources, conversion equipment, control and protective devices and utilization equipment connected via a distribution network.

4.15
emergency electric system operation
The condition of the electrical system during flight when the primary electric power system becomes unable to supply sufficient or proper electric 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.

4.16
emergency power source
A generator, a power conversion device (or a combination thereof not involving part of utilization equipment) or a battery installed to provide independent electrical power for essential purposes during conditions of electrical emergency in flight.

4.17
external (or ground) power unit (GPU)
A rotating or static source (or combination thereof) supplied by the maintenance facility to source electrical power demands while the aircraft is not in flight. 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.

4.18
frequency
The reciprocal of the period of the a.c. waveform, in hertz (Hz). 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.

4.19
frequency modulation
The cyclic and/or random variation of instantaneous frequency about a mean frequency during steady state conditions. Amplitude of the frequency modulation is equal to the difference found between the maximum and minimum frequency measured over a one minute interval.

4.20
frequency modulation rate
The rate of change of frequency due to frequency modulation measured in Hz/second.

4.21
fundamental frequency
The 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).

4.22
ground
Any point along a conductive structure or cable which serves as an essentially zero potential reference for a.c. and/or d.c. voltages.

4.23
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. Most nonlinear loads generate odd-numbered harmonics, for example, as a result of full wave rectification of the input power. The frequencies at which these 'characteristic harmonics' are produced by a user with a diode-type input rectifier is determined by the equation:

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

where: H = the number of the harmonic;

k = an integer, beginning with 1;

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

f_1 = the fundamental frequency.

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 intentionally restrictive therefore, for even and triplen harmonics. (See also 4.5, 4.39.)

4.24
impedance

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. It is a complex quantity composed of resistive (real) and reactive (imaginary) elements. In this document, impedance may be encountered from a user (load), distribution network or source impedance perspective.

4.25
individual frequency component of distortion

The ratio of the rms value of the waveform distortion at one specific frequency to the rms value of the fundamental component of the waveform. (See also 4.8.)

The individual frequency components of voltage distortion are expressed as:

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

where: V_n = rms value of an individual, non-fundamental frequency component;

V_1 = rms value of the fundamental frequency component;

4.26
linear load

A user of electrical power whose total impedance is constant despite variations in applied voltage and whose current spectrum matches that of the applied voltage. Conversely, nonlinear loads may have changing impedance with applied voltage and a different spectral content from that of the applied voltage source.

4.27
load unbalance

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

4.28
momentary power interruptions

Transfer of power sources can result in short term power interruptions to user equipment during which time the supplied voltage will decay at a rate dependent upon bus and load characteristics.

4.29
normal electrical system operation

Describes 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. 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. Normal operation also includes momentary power interruptions, transients and spikes. (See also 4.1.)

4.30
normal power quality limits

Those limits which should be maintained during periods of normal electrical system operation. (See also 4.2.)

4.31
per unit (PU)

A method of standardization by which various parameters are quantified with respect to a base value. The base value is generally the rated value . For power systems this is typically applied to the powers, voltages, currents, or impedances. ‘Per unit’ numbers equal the actual parameter value divided by the base values.

For 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.

4.32
phase voltage

The a.c. voltage values stated herein shall be for any of the phase-to-neutral voltages supplied to single-phase or three-phase utilization equipment. All a.c. voltage values defined herein are rms L-N quantities unless otherwise specified.

4.33
phase voltage displacement

Indicates the 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.

4.34
phase voltage unbalance

Indicates the maximum difference between rms phase voltage amplitudes during steady state conditions.

$$V_{UNB} = \mathrm{Max}\ \{ V_{AN}, V_{BN}, V_{CN} \} - \mathrm{Min}\ \{ V_{AN}, V_{BN}, V_{CN} \}$$

where: V_{AN}, V_{BN}, V_{CN} = the phase voltage magnitudes.

4.35
power factor

For a.c. user equipment, power factor is the ratio of the real, or active, power (P) consumed in watts to the apparent power (S) drawn in volt-amperes, with

$$PF = P / S$$

where: P = the real power in watts; and

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

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

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 4.6.)

4.36
primary power source

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

4.37
ripple

Ripple is the cyclic variation about the mean level of the d.c. 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 mean value of voltage or current.

4.38
rms value (voltage or current)

The significance of root-mean-squared (rms) values of voltage and current is based upon the equivalence between these values and the direct current (d.c.) values that would yield the same power transfer in a d.c. circuit. The rms voltage value may be computed as:

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

where: *T* = waveform time period and

v(t) = instantaneous voltage at time t.

4.39
sequence impedances (/harmonics)

Identified as positive, negative and zero sequence, these impedances result from a mathematical analysis method termed ‘Symmetrical Components’. This analysis method breaks the quite difficult problem of analyzing a three-phase unbalanced system into a study of two balanced three-phase circuits and one zero-phased circuit.

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 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 ac 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 3rd 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 4.25.)

4.40

spikes

A variation from the controlled steady state or transient level of a characteristic that occurs for an extremely short duration (microseconds). They generally produce a voltage peak and/or wave train, the characteristics of which are dependent on relative impedances of the source, the line, and that of the utilization equipment, as well as the manner in which the event occurs. Typical voltage spikes result from the switching of inductive or capacitive load elements.

4.41

steady state

Operating condition of the system when only negligible changes in electrical parameters appear.

4.42

system stability

An aspect of system dynamic compatibility associated with certain system performance criteria defined at the power system interfaces. For aircraft power systems the primary interface is the electrical bus. The key performance criteria therefore is 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 standard in presence of both internal as well as external stimuli.

4.43

total harmonic distortion (current or voltage)

The total harmonic distortion of the a.c. waveform is the ratio of the rms value of its harmonics to the rms value of its fundamental component. The formula defining total harmonic distortion (THD) is provided below. The variable ‘X’ may represent voltage or current, and may be expressed as a rms value or a peak value. (See also 4.7, 4.8.)

$$\mathrm{THD}_X = 100 * \frac{\sqrt[2]{\sum_{2}^{n} X_n^{2}}}{X_1}$$

where: X_1 = Fundamental value of current or voltage;

X_n = nth harmonic value of current or voltage.

4.44

transients

Momentary variations of a characteristic from its steady state limits, and back to its steady state limits, as a result of a system disturbance. Examples include rapid load or engine speed changes followed by the conditioned response of the generating system. Brief voltage variations or interruptions due to normal source or load switching are considered normal transients. 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.

4.45

uninterruptible power

Power (typically d.c.) delivered to essential and/or voltage transient sensitive users in such manner that normal power interruptions are either eliminated or reduced in severity and probability. Power quality parameters for these users will be at least equivalent to that specified herein with any application specific parameters specified by the airframer or system integrator.

4.46

utilization equipment

Any unit or functional group of units which receives electrical power on the aircraft. May also be referred to as “load equipment”. Some specifications are only applicable to particular utilization equipment if the unit or grouping of units exceed a minimum power level.