National Aeronautics and Space Administration

International Space Power System Interoperability Standards (ISPSIS)

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Overview

- **Topics:**
  - Background
  - Scope of Rev. A Changes
  - Key Trades and Decisions
  - Document Overview and Requirements
  - Significant Changes and Added Requirements
  - Forward Work
  - References

Background

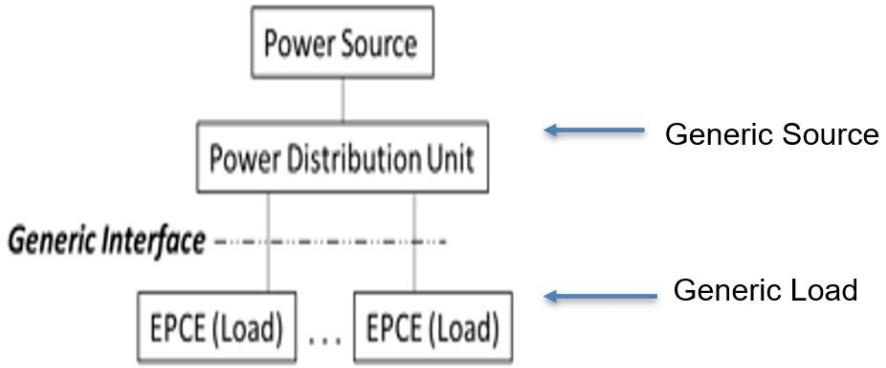
- The ISPSIS, along with 7 other international interoperability standards, Avionics, Communications, ECLSS, Thermal, Rendezvous, External Robotics, and Software are available for international and commercial partnerships.
- The baseline of the ISPSIS was a result of the ISS membership to establish interoperable interfaces, terminology, and techniques, to facilitate collaborative endeavors of space exploration in cislunar and deep space environments. For Revision A, the Gateway membership of International Partners was used.
- Purpose of the standard is to define a bus voltage power quality, and grounding approach to ensure commonality, reliability, safety, interchangeability, and interoperability for load applications between space application power systems such as orbital habitats, crewed or non-crewed space vehicles, ascent/descent vehicles, and surface systems.
  - This Standard is design independent and applies to any space power system that utilizes 120Vdc and/or 28Vdc class power

Background (cont'd)

- **The 120Vdc and 28Vdc performance requirements and verifications of the ISPSIS Power Standard are based on the SAE AS 5698 Space Power Standard, which was first baselined in April 2012**
  - This was a multi-year effort back during the NASA Constellation Program (CxP) that collaborated across all NASA centers and US industry
  - Utilized lessons learned from ISS
  - Defines analyses, verification, and testing methodologies
- **Adopted as a baseline document to define the Gateway Power Quality**
- **Generic Improvements to ISPSIS Revision A have been made based on Gateway Lessons Learned**
  - Most content was already established and enhanced with additional US industry and International comments
- **This standard has <u>BOTH</u> Requirements and Verifications. 'How' you verify is as important as the requirement.**

Background (cont'd)

- **The ISPSIS is a power standard that does not drive a specific EPS design, as it does not define specific vehicle power interfaces. It references generic 120Vdc and 28Vdc class electrical load/distribution source interfaces.**



- **Since the Standard is design neutral by necessity, there remain several items still required by the developer of electrical equipment:**
  - The ratio of Source-to-Load impedance cannot be defined generically. It requires a specific design knowledge.
  - Certain switch gear characteristics are unknown until an actual design is given (current ratings, trip time, etc.)

Scope of Revision A Changes

- **Primary purpose of Revision A was to add 28V to Performance and Verification Sections of the Standard**
- **Key Sections Updated:**
  - Purpose and Scope, Section 1.1 to add 28V
  - New Section 1.3 on Convention and Notation – definitions for the implementation of requirement verbs
  - Section 3.0 which contained the Power Quality Standards and Rationales for 120 VDC – added 28 VDC
  - Section 4.0 Verification and Testing – added 28V EPS and 28V EPCE Characteristics
- **Also included are various editorial updates recommended by the Gateway Power Team to improve readability and understanding.**

Key Trades and Decisions

- **Key decisions were made to broaden the 'operating voltage ranges' of the LOADS to (98-136Vdc, 23-36Vdc)**
  - ISS lessons learned (along with all previous vehicles) taught that designing loads to a very narrow range of voltage creates major compatibility issues as the program matures (as well as incurring additional cost and schedule impacts)
  - This broad voltage range allows the loads to work across multiple vehicles, multiple power sources (includes batteries and fuel cells), and minimizes impacts to the load when the vehicle design undergoes development changes
  - When this operating voltage requirement is made known upfront before the load input filters are designed, impacts are very minimal, if any

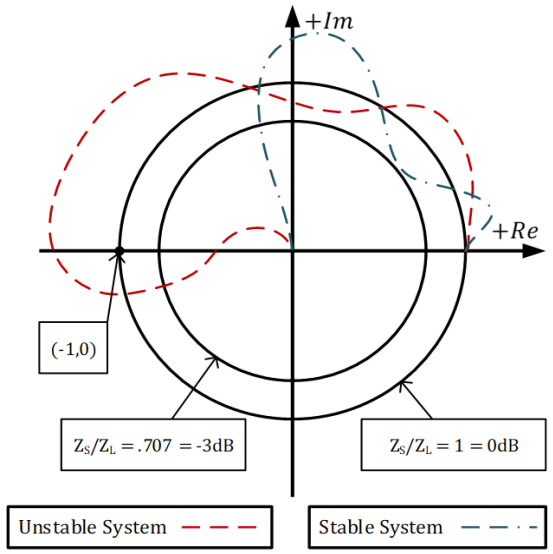
Contributors to the ISPSIS

- Canadian Space Agency (CSA)
- European Space Agency (ESA)
- Japan Aerospace Exploration Agency (JAXA)
- National Aeronautics and Space Administration (NASA)
- Roscosmos, Baseline only*

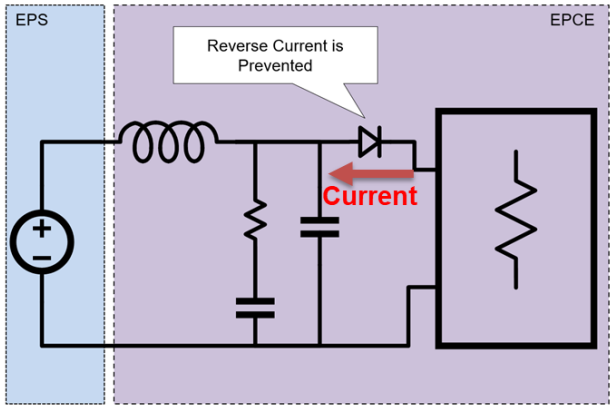
General Requirements

- **General Requirements**
  - Grounding
  - Distribution Wiring
  - Isolation
  - Reverse Current
  - Stability
  - Electromagnetic Compatibility

Stability



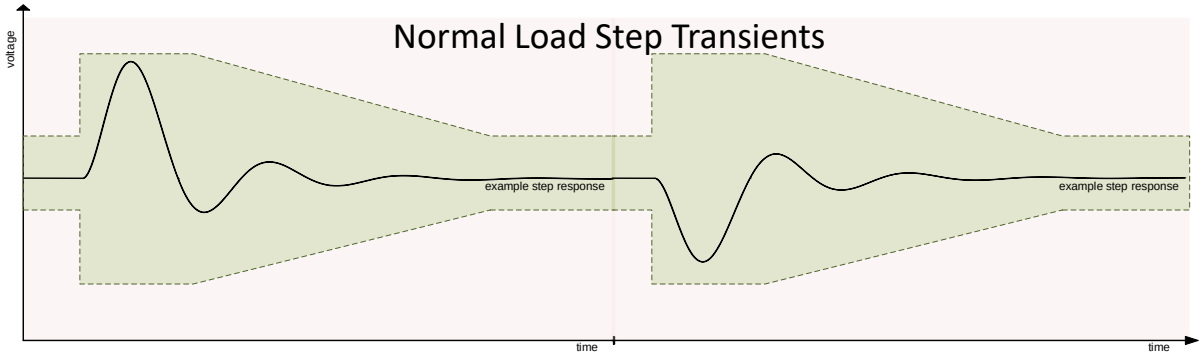
Reverse Current

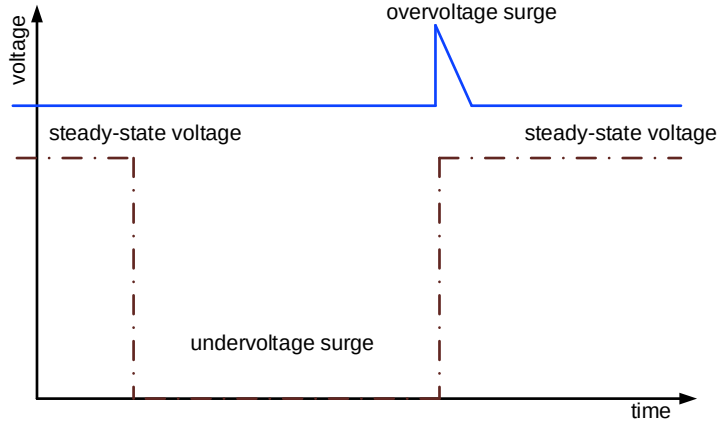


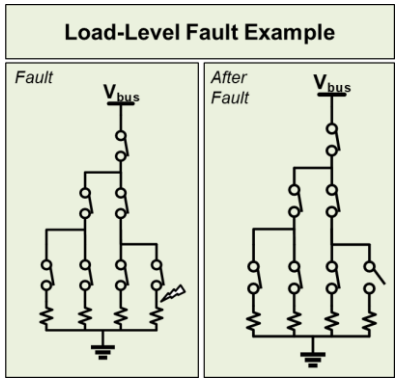
Normal / Abnormal Operating Requirements

- **Normal Requirements**
  - Steady State Voltage
  - Load Step Transient Voltage
  - Pulsed Loads
  - Ripple (Peak, Amplitude, Spectrum)
  - Inrush/Surge
  - External Power

- **Abnormal Requirements**
  - Reverse Current During Voltage Droop
  - Overvoltage/Undervoltage Surge
  - Fault Protection, Coordination, and Clearing
  - Emergency Operation



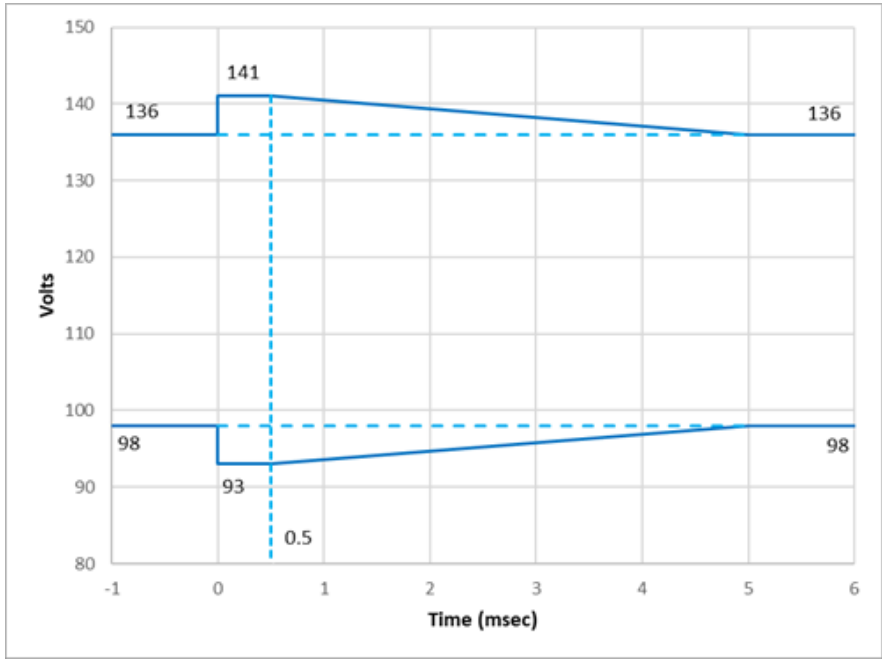




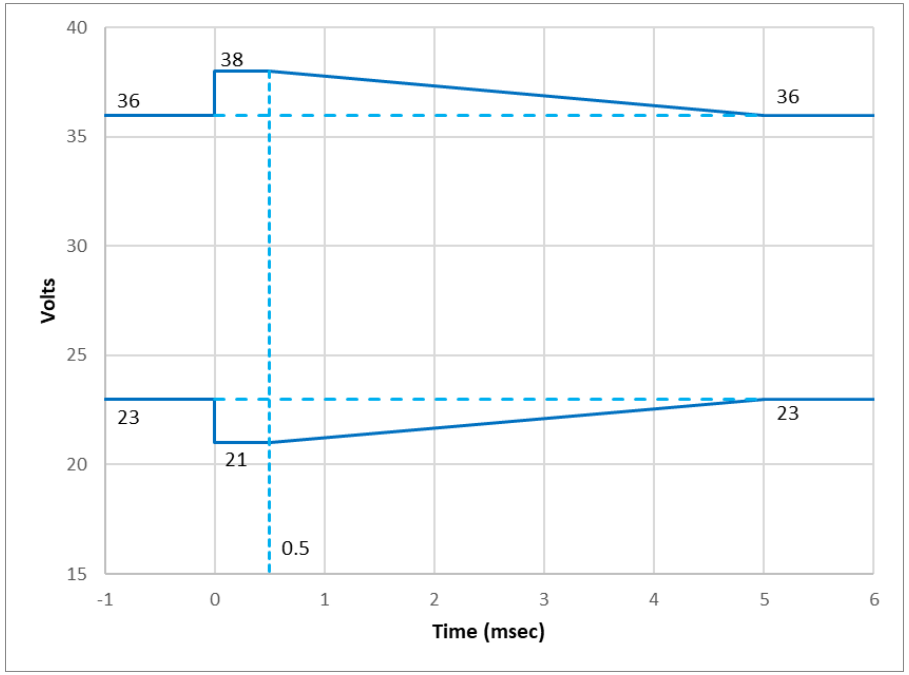
Steady-State and Load Step Transient Voltage

- **Key decisions were made to broaden the 'operating voltage ranges' of the LOADS**

120V Voltage Range and Load Step

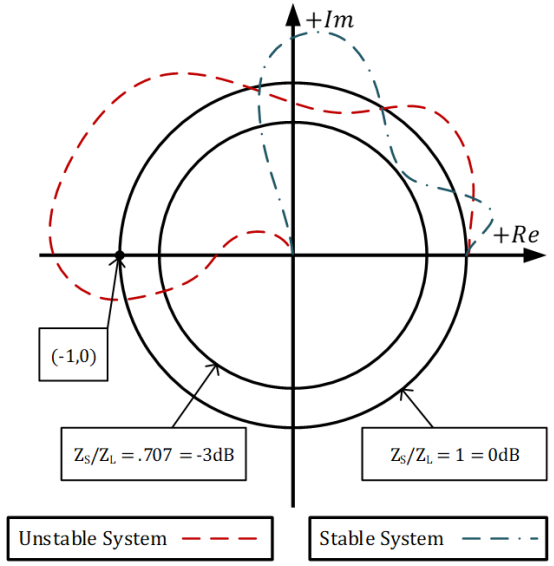


28V Voltage Range and Load Step

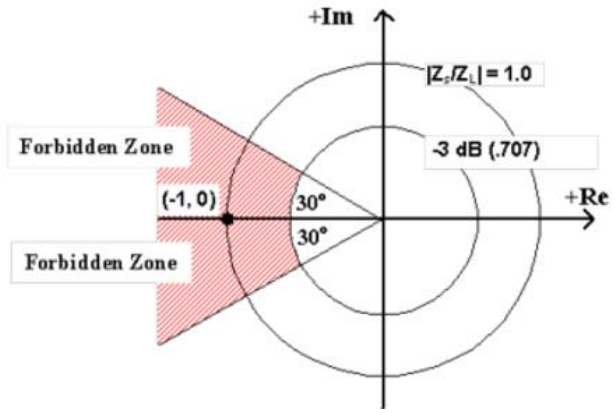


Power System Stability and Impedance

- **A typical cause of system instability is negative load impedance combined with non-ideal source impedance.**
- **Source and load impedances can be measured and characterized for stability independently.**
- **The impedance criterion has a significant advantage over other stability-analysis tools for large-scale systems.**
  - It analyzes the whole system based on the input-output impedance characteristics of each subsystem
    - Instead of on the detailed internal properties of subsystems.



Nyquist Plot of Unstable and Stable System Loop Gains



Forbidden Zone providing gain and phase margin

Source and Load Impedance

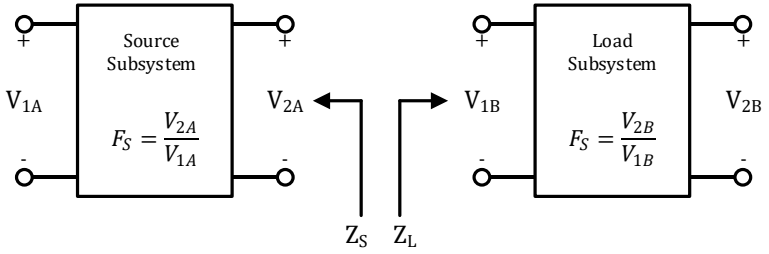
- **Requirements are needed on source impedance and load impedance**
  - To ensure system stability
  - Allow relocation of loads

Source Impedance

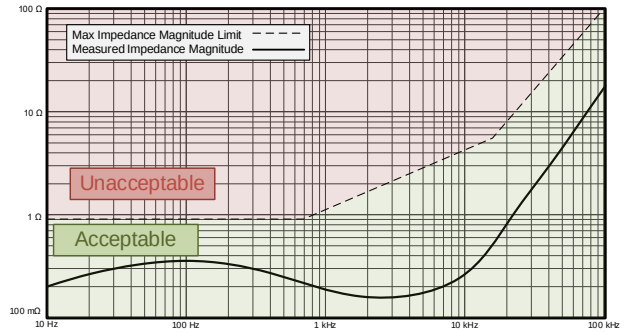
The **EPS** source impedance at the EPCE interface terminals shall be established for the power system.

Load Impedance

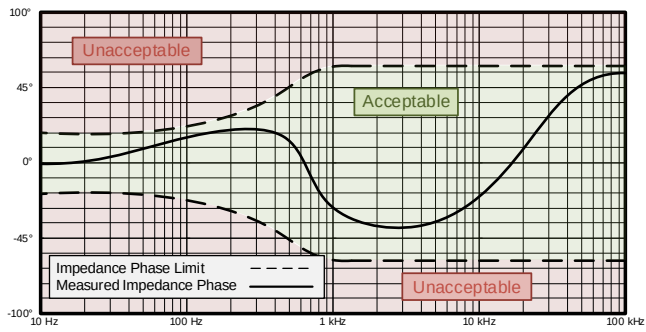
The **EPCE** input load impedance at the EPCE interface terminals shall be measured.

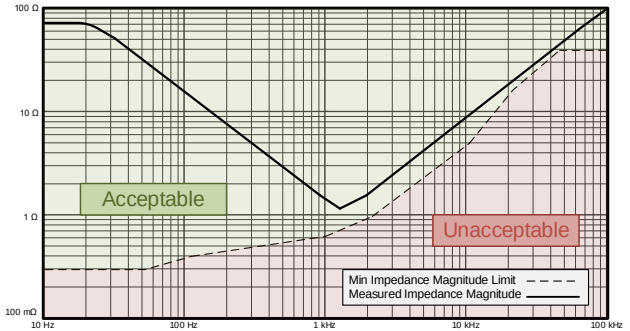


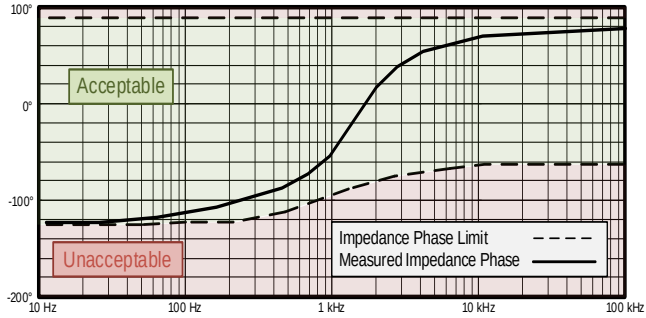
Example Impedance Magnitude Bounds and Measurement



Example Impedance Phase Bounds and Measurement







Ripple Voltages

- **What are ripple voltages?**
  - The total system ripple voltage is comprised of the collective contributions from sources and loads.
  - Voltages are superimposed on the power system.
  - Ripple voltages negatively impact sensitive loads, such as instrumentation.
  - Ripple is defined by three characteristics; peak ripple voltage, ripple voltage amplitude, and ripple voltage spectrum.

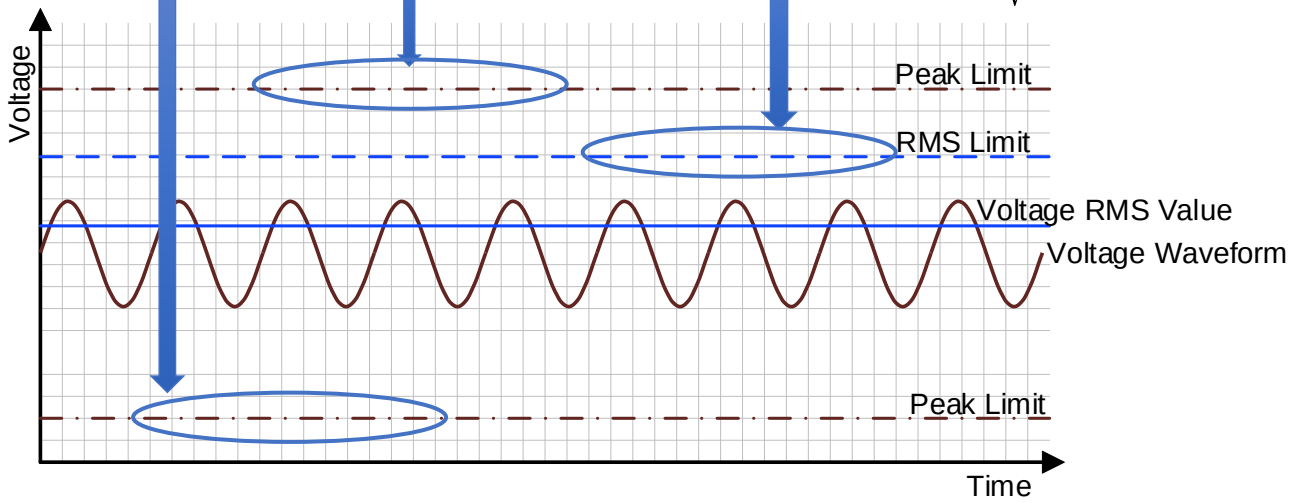
1) **Peak** Ripple Voltage

The peak ripple voltage at the Interface shall be less than X Vp (peak) in a bandwidth of 30Hz to 1 MHz.

2) Ripple Voltage **Amplitude**

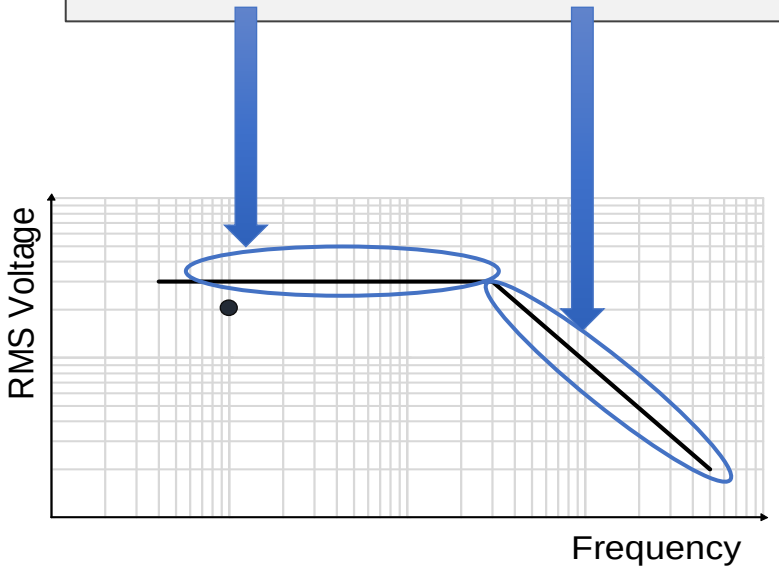
Interface ripple voltage amplitude shall be less than Y Vrms in a bandwidth of 30 Hz to 1 MHz.

$$\mathrm{RMS}_{\mathrm{Total}} = \sqrt{\mathrm{RMS}_1^2 + \mathrm{RMS}_2^2 + \cdots + \mathrm{RMS}_n^2}$$



3) Ripple Voltage **Spectrum**

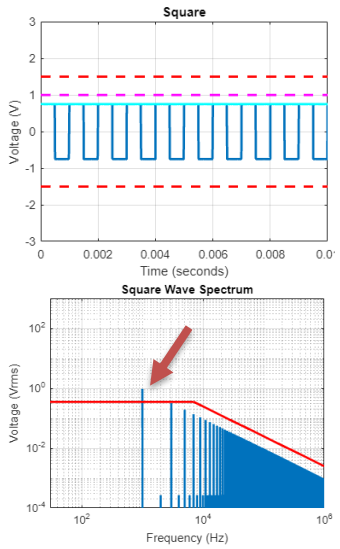
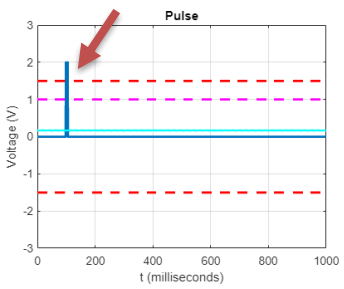
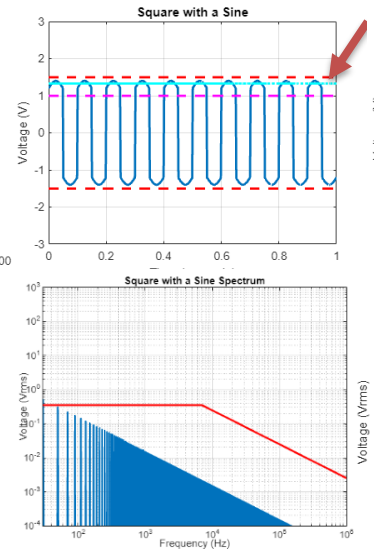
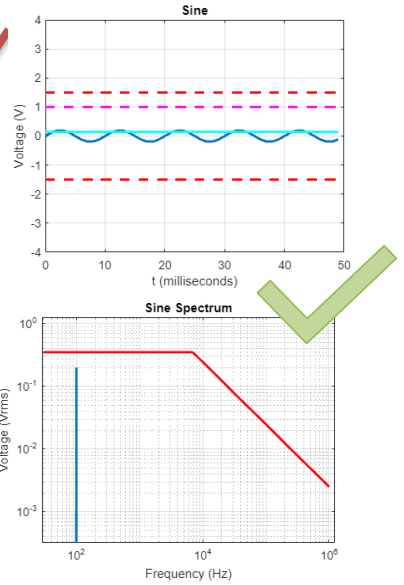
The frequency distribution of the ripple voltage shall remain within the limits shown from the figure.



Why Three Ripple Voltage Requirements

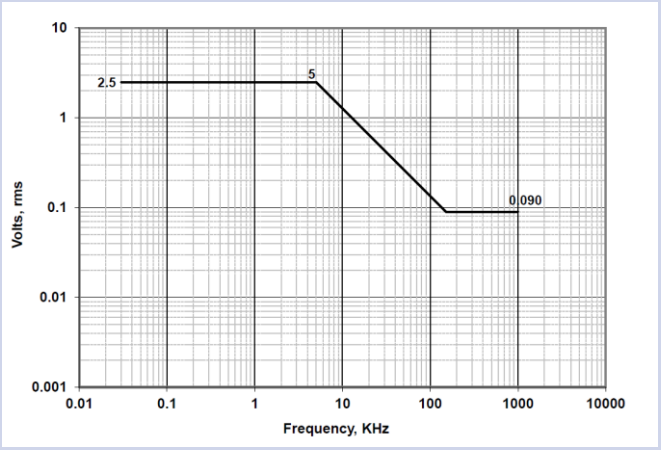
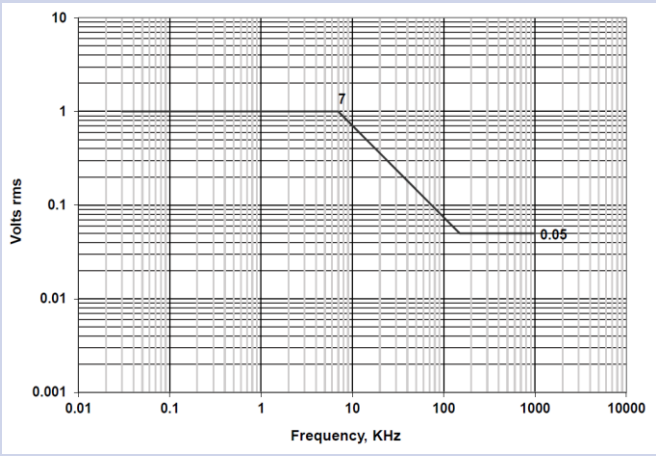
- **Why three ripple voltage requirements?**
  - Different waveforms violate different requirements; see examples

Examples

Violates only **spectrum** requirements	Violates only **peak** requirements	Violates only **amplitude** requirements	All requirements met
			
	N/A		

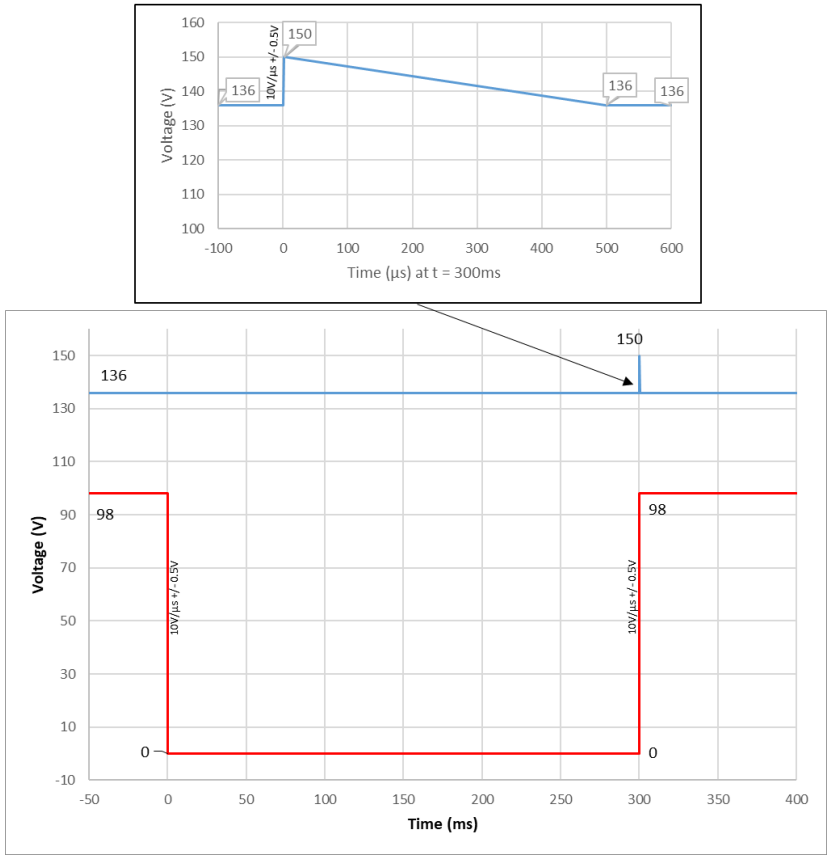
Three distinct ripple requirements are necessary to cover all waveforms

Ripple Limits

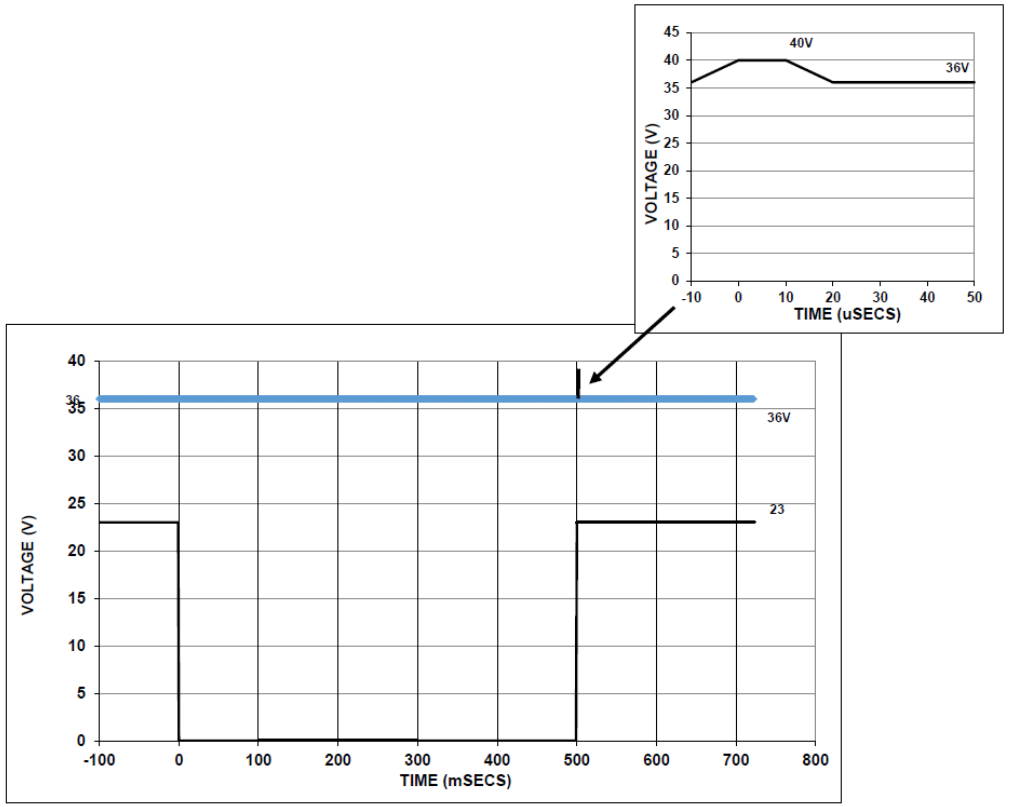
	120V	28V
Peak Ripple Voltage	3.5 Volts Peak	1.5 Volts Peak
Ripple Voltage Amplitude	2.5 Volts RMS	1 Volt RMS
Ripple Voltage Spectrum	120V Ripple Voltage Spectrum 	28V Ripple Voltage Spectrum 

Abnormal Overvoltage/Undervoltage

- **Abnormal Limits apply to system response during a fault event**
- **Not required to ride through**



120V Abnormal Voltage Limits

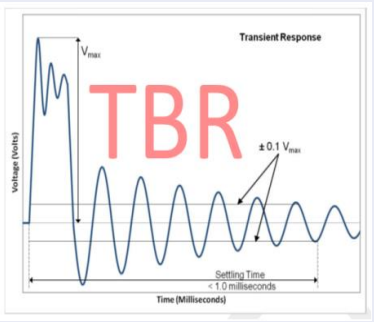
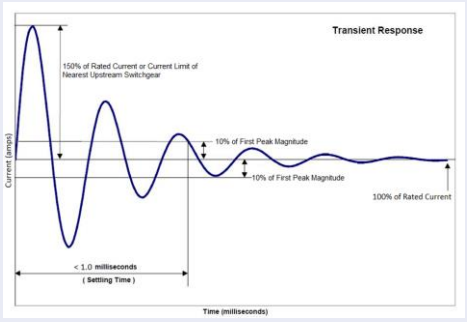
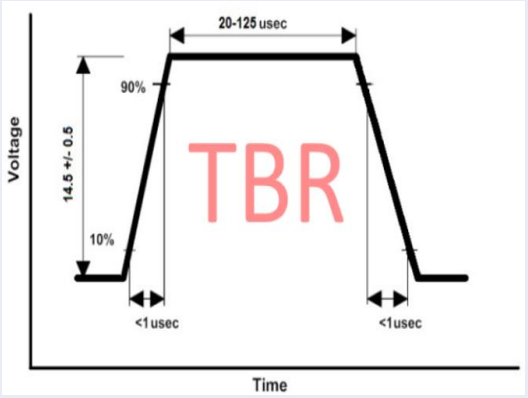
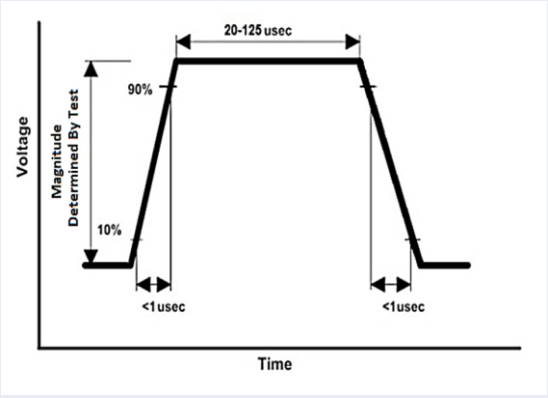


28V Abnormal Voltage Limits

Significant Changes From Revision A

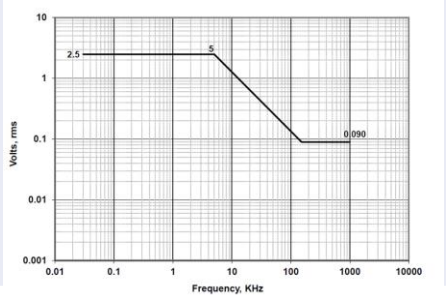
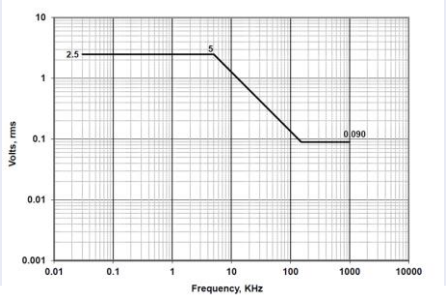
Large Signal Stability PWR120-2005 and PWR28-2005

Changed large signal stability test and verification for 120V and added 28V

FROM	TO	Rationale
PWR120-2005 and PWR28-2005 	**PWR120-2005 and PWR28-2005** 	*Added 28V to Large Signal Stability* *Response requirement changed from a voltage to a current measurement.* *The current is measured to avoid the influences that can potentially be caused by the source power supply and/or the equipment used to inject the pulse.*
PWR120-2005V -Verification Magnitude of the voltage pulses imposed on top of the 120.0 ± 1.0 Vdc input shall be 14.5 ± 0.5 volts, positive. Subsequently, the resulting transient amplitude will remain within the EPS' normal load step transient limits. 	**PWR120-2005V and PWR28-2005V- Verification** 3. Magnitude of the voltage pulses imposed on top of the 120.0 ± 1.0 or 28V ± 1.0 Vdc input shall be selected such that, a. The peak current transient is 50% above full-load current or is at the current limit of the nearest upstream switchgear. b. The resulting voltage magnitude remains within the EPS normal load step transient limits. 	*Added 28V to Large Signal Stability* *Injection changed from a constant voltage of 14.5V +/- 0.5V to a variable voltage that shall be selected that the peak current transient is 50% above full-load current or is at the current limit of the nearest upstream switchgear and the resulting voltage magnitude remains within the EPS normal load step transient limits.* *This change is to maintain a consistent test method and pulse waveform that will not change with the different interfaces. Also, the current is measured to avoid the influences that can potentially be caused by the source power supply and/or the equipment used to inject the pulse.*

120V EPS - Ripple Voltage Requirements

PWR120-1010, PWR120-1011, PWR120-1012

FROM	TO	Rationale
PWR120-1010 – Peak Ripple Voltage The peak ripple voltage shall be less than 5.0 V (peak) in a bandwidth of 30Hz to 1 MHz.	**PWR120-1010** – Peak Ripple Voltage The peak ripple voltage shall be less than 3.5 V (peak) in a bandwidth of 30Hz to 1 MHz. **PWR120-2003 and PWR120-2004** EPCE Requirement and Verification updated accordingly	Updated based on feedback from EMI team and GP 10009 updates
PWR120-1011 – Ripple Voltage Amplitude The ripple voltage amplitude shall be less than 3.0 Vrms in a bandwidth of 30 Hz to 1 MHz.	**PWR120-1011** – Ripple Voltage Amplitude The ripple voltage amplitude shall be less than 2.5 Vrms in a bandwidth of 30 Hz to 1 MHz.	Updated based on feedback from EMI team and GP 10009 updates
PWR120-1012 – Ripple Voltage Spectrum The frequency distribution of the ripple voltage shall remain within the limits shown in Figure 3.3.1.2.3.3-1, 120 V Ripple Voltage Spectral Components.  	**PWR120-1012** – Ripple Voltage Spectrum The frequency distribution of the ripple voltage shall remain within the limits shown in Figure 3.3.2.1.3 1: 120 VDC Ripple Voltage Spectral Components.  	Updated based on feedback from EMI team and GP 10009 updates

28V Added Requirements

Addition of 28V Requirements

FROM	TO	Rationale
No Requirement Defined	**Added 37 Unique Requirements and their Verifications for 28V**	Added 28V Performance and Verification Sections to the ISPSIS document By approved exception, 28 VDC can be utilized and will be primarily utilized for lower power applications such as special purpose sub-bus distributions, portable loads, or low-power independent vehicles.

28V EPS Requirements	28V EPCE Requirements
PWR28-1001	PWR28-2001
PWR28-1002	PWR28-2002
PWR28-1003	PWR28-2003
PWR28-1004	PWR28-2004
PWR28-1005	PWR28-2005
PWR28-1006	PWR28-2006
PWR28-1007	PWR28-2007
PWR28-1008	PWR28-2008
PWR28-1009	PWR28-2009
PWR28-1010	PWR28-2010
PWR28-1011	PWR28-2011
PWR28-1012	PWR28-2012
PWR28-1013	PWR28-2013
PWR28-1014	PWR28-2014
PWR28-1015	PWR28-2015
PWR28-1016	
PWR28-1017	
PWR28-1018	
PWR28-1019	
PWR28-1020	
PWR28-1021	
PWR28-1022	

General EPS Requirements for 120V and 28V

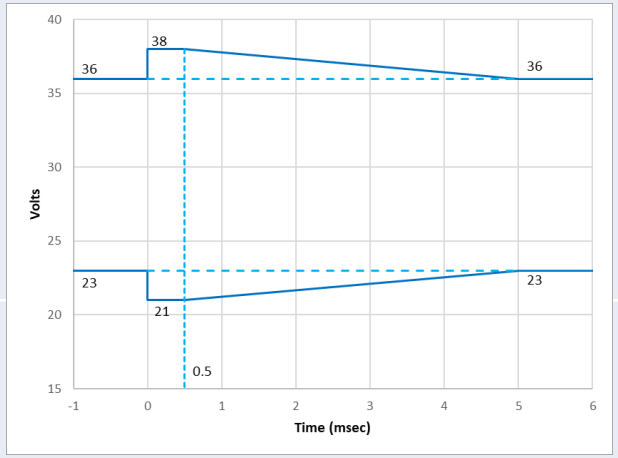
Added Reference to 28V in general requirements alongside 120V

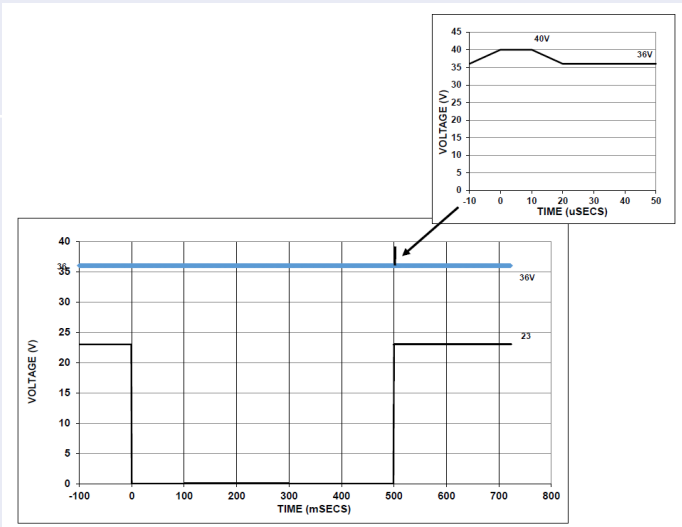
FROM	TO	Rationale
PWR120-1001 PWR120-1002 PWR120-1003 PWR120-1004 PWR120-1005 PWR120-1006 PWR120-1007	PWR120-1001, **PWR28-1001** PWR120-1002, **PWR28-1002** PWR120-1003, **PWR28-1003** PWR120-1004, **PWR28-1004** PWR120-1005, **PWR28-1005** PWR120-1006, **PWR28-1006** PWR120-1007, **PWR28-1007**	*Added 28V requirements to document that share the same text as 120V requirements.* *(ie. Single point ground, Isolation, Stability, etc…)*

28V EPS – Voltage Requirements

Requirements PWR28-1008, 1009, 1017, and 1018

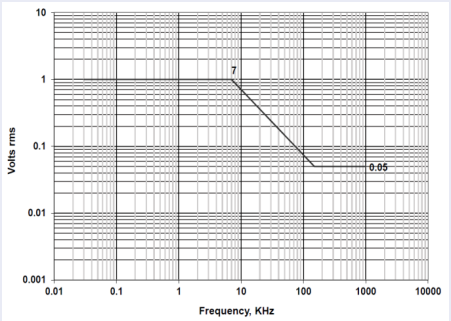
New Requirement	Rationale
PWR28-1008 The EPS shall supply the steady-state voltage at the EPS/EPCE interface within the range of 23 to 36 VDC (28 VDC nominal) for load conditions from no-load to the rated capacity of the system. **PWR28-2001** **EPCE Requirement and Verification updated accordingly**	*Defined steady state voltage range for 28V*
PWR28-1009 **PWR28-2002** **EPCE Requirement** **And Verification** **Updated Accordingly**	*Defined Normal Load Step Transient Voltage for 28V*
PWR28-1017 **PWR28-1018** **PWR28-2013 &** **PWR28-2014** **EPCE Requirement** **And Verification** **Updated Accordingly**	Defined Overvoltage and Undervoltage Surge requirements for 28V





28V EPS - Ripple Voltage Requirements

PWR28-1010, PWR28-1011, PWR28-1012

New Requirement	Rationale
PWR28-1010 – Peak Ripple Voltage The peak ripple voltage shall be less than 1.5 V (peak) in a bandwidth of 30Hz to 1 MHz. **PWR28-2003 and PWR28-2004** EPCE Requirement and Verification updated accordingly	Added requirement for peak ripple voltage for 28V
PWR28-1011 – Ripple Voltage Amplitude The ripple voltage amplitude shall be less than 1.0 Vrms in a bandwidth of 30 Hz to 1 MHz.	Added requirement for ripple voltage amplitude for 28V
PWR28-1012 – Ripple Voltage Spectrum The frequency distribution of the ripple voltage shall remain within the limits shown in Figure 3.3.3.1.3 1: 28 VDC Ripple Voltage Spectral Components.  	Added requirement for ripple voltage spectrum for 28V

28V EPS – External Power source and Emergency Operation

PWR28-1013, PWR28-1019

New Requirement	Rationale
PWR28-1013 – EXTERNAL POWER SOURCE External electric power sources shall supply power having the characteristics as specified within this standard.	External power (any auxiliary or emergency power) must maintain the same ripple, transient, stability, isolation, and fault coordination characteristics that the EPS maintains regardless of whether the external power is operating stand-alone or integrated with the power system.
PWR28-1019 – Emergency Operation The EPS shall be capable of supplying power until all energy sources are depleted. **PWR28-2015** EPCE Requirement and Verification updated accordingly	The EPS should provide for contingency cases where the primary power generation source is disabled or unavailable to allow for 100% power system utilization. The intent is to force the power system to continue operation until it can no longer provide the minimum voltage as specified in this standard.

28V EPS – Inrush/Surge Current and Abnormal Reverse Current

PWR28-1014, PWR28-1015

New Requirement	Rationale
PWR28-1014 – Inrush/Surge Currents The EPS shall support load inrush/surge currents of: • 0.012 A*Sec / A for loads with currents 0A < i < 10A; • 0.00253 A*Sec / A + 0.0947 for loads with currents 10A < i < 200A. **PWR28-2008, PWR28-2009, PWR28-2010** EPCE Requirement and Verification updated accordingly	Establish inrush/surge capability for the power source. EPS designers must allow for inrush/surge conditions while maintaining nominal system voltage. While this inrush/surge requirement does not take into account source / load margin, the EPS designers need to determine sufficient margins to avoid nuisance tripping of source switchgear from protection circuits. Designers should consider minimum values of a margin of 120% of rated output when connecting loads that are not predetermined. The ampere-seconds/ampere are normalized inrush ampere-second current divided by the source current rating of the source.
PWR28-1015 – Abnormal Reverse Current The EPS shall accept reverse currents under abnormal conditions without damage. • 0.012 A*Sec / A for loads with currents 0A < i < 10A • 0.00253 A*Sec / A + 0.0947 for loads with currents 10A < i < 200A **PWR28-2012** EPCE Requirement and Verification updated accordingly	Establish inrush/surge capability for the power source. EPS designers must allow for inrush/surge conditions while maintaining nominal system voltage. While this inrush/surge requirement does not take into account source / load margin, the EPS designers need to determine sufficient margins to avoid nuisance tripping of source switchgear from protection circuits. Designers should consider minimum values of a margin of 120% of rated output when connecting loads that are not predetermined. The ampere-seconds/ampere are normalized inrush ampere-second current divided by the source current rating of the source.
PWR28-1016 – EPS Fault Protection The EPS power distribution system shall provide overcurrent protection to branch circuits that limit fault currents and isolate faults.	The requirement establishes a consistent fault mitigation method for the EPS interface to the EPCE. Faults in any load branch must be cleared and not cause any other load to become disabled. The protection should limit/clear the overcurrent condition to maintain the EPS power quality. The fault and/or overcurrent protection should not trip off due to expected Inrush/Surge transients.

28V EPS – Faults and Fault Containment

PWR28-1020, PWR28-1021, PWR28-1022

New Requirement	Rationale
PWR28-1020 – High Impedance Faults The EPS shall isolate high impedance faults (soft faults) for overcurrent conditions in excess of 150% of rated current of the upstream protective device for a maximum total clearing time less than 4 seconds (from time of detection).	Establish a worst-case clearing time constraint for overcurrent conditions that stress the overall distribution system. The overcurrent conditions must be removed from the EPS. Clearing times for various loads will be based on mission requirements, criticality of the load, and switchgear requirements. The intent of this requirement is to constrain fault current conditions and not directly define the switchgear characteristics. These are upper bounds and projects can implement a protection schema which is faster than this.
PWR28-1021 – High Current Faults The EPS shall isolate high current faults (short circuit) for overcurrent conditions in excess of 400% of the rated current of the upstream protective device with a maximum total clearing time less than or equal to 15 milliseconds (ms) (from time of detection).	Establish a worst-case clearing time for high current faults (short circuit or a load resistance that produces equivalent 400% load current) type conditions that stress the distribution system. Short circuit conditions have to be removed quickly from the EPS before damaging other areas of the system. Faster clearing times under these conditions will be based on mission requirements, criticality of the loads, and switchgear requirements. The intent of this requirement is to constrain fault current conditions and not directly define the switchgear characteristics. The fault and/or overcurrent protection should not trip off due to expected Inrush/Surge Transients.
PWR28-1022 – EPS Fault Coordination The EPS shall provide fault protection coordination so that the protective circuit closest to the fault will contain an electrical short circuit in the electrical distribution system.	Establish fault coordination as fundamental in maintaining the operability of the power system while isolating failures and minimizing the impact of failures to the remaining power system at the EPS. Fault coordination across the interface is necessary to ensure that load branch faults will be cleared without affecting any other load. Coordination must take into account upstream protective equipment, stored energy causing damaging currents, and inrush currents during fault recovery. This coordination will also be implemented downstream from current limiting switchgear to isolate faults occurring in any of the power controller's output lines to contain the fault so the device closest to the fault trips first and power can continue to be provided to the remaining unfaulted outputs. Overcurrent protection should be located at the output of the distribution system. The overcurrent protection will isolate a particular branch feed from the power system. Select overcurrent devices based on the overall protection coordination.

Forward Work

- **Revision B**
  - Add regulated 120Vdc and 28Vdc EPS Performance
  - Survey upcoming technology advancements and assess updates to Ripple Voltage Spectrum Requirements (120Vdc and 28Vdc)
- **External**
  - Work through SAE Aerospace to coordinate ISPSIS Rev. A and Rev. B (future) updates with AS5698

How to Find

The Standard will be posted to the International Deep Space Interoperability Standards Public Website:

https://www.internationaldeepspacestandards.com/

Backup

Applicable and Reference Documents

- **Applicable Documents**
  - The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.
    - None
- **Reference Documents**
  - The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.
    - MIL-STD-461 G — Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
    - SAE AS5698 Rev A — Space Power Standard