

Aircraft DC Power Quality Characteristics of a PCTRU

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ABSTRACT

An overview of aircraft DC power quality specifications reveals that only minor changes have occurred in recent years within industry standards. Current and future advanced electronic aircraft are requiring significant power quality improvements due to increased use of digital and COTS (commercial off the shelf) systems.

Certain electronic systems do not function properly due to various types of electrical disturbances. Some systems shutdown, fault or exhibit operational delays due to power interruptions or "blackout" conditions. Undervoltage or "brownout" conditions also cause this effect. Some electronic systems exhibit critical faults that can affect safety or mission success due to overvoltage conditions. Additional effects of high voltage spikes or overvoltage transients are known to reduce the life of utilization equipment [1], which is directly related to the health of the aircraft's electronic system and creates an economic burden.

These disturbances are described as high voltage transients, low voltage transients or brownouts, power interruptions and voltage modulation. Another type of perceived perturbation on the DC bus is caused by ripple voltage. All of these are fundamental DC power quality characteristics that can induce problems in electronic systems.

These disturbances are caused by various portions of the entire electrical power system consisting of AC generators, transmission lines, power converters, contactors, electrical power distribution controls and AC/DC loads from utilization equipment.

Presented here is a power supply system described as a Passively Controlled Transformer Rectifier Unit (PCTRU) that preserves the desired reliability of a traditional transformer rectifier unit (TRU) while providing stability to the aircraft 28 VDC bus and mitigating risks caused by these various electrical disturbances.

INTRODUCTION

One major AC to DC power conversion topology utilized for aerospace applications is a simple Transformer Rectifier Unit (i.e. TR or TRU) [2]. These designs represent the most reliable power supply topology, which continually meet the first goal of an aerospace DC electrical power system objective-**reliability**. Significant power quality improvements can be achieved with the basic TRU as described in detail here. However, complex solutions with feedback control (i.e. regulated) topologies that forcefully control power also provide power quality improvements, but these benefits are diminished to an extent by additional failure modes, lower reliability, increased electromagnetic interference for emissions and susceptibility and increased cost. If the DC power supply fails resulting in "loss of power", power quality is the least concern. Moreover, if the additional fault is "high steady state output voltage", the more complex solution may cause additional harm to the aircraft electrical system and utilization equipment. These conditions led to the development of a passively controlled power supply that mitigates these risks while preserving reliability.

MAIN SECTION

The typical aircraft DC bus utilizes 28 VDC ranging in current rating for continuous operation from 50 to 400 amperes, with the most common applications requiring 100 to 300 amperes. A common type of power supply is the Transformer Rectifier Unit or TRU, which converts regulated generator power from 115/200 VAC 3 phase 400 Hz to a nominal 28 volts DC for aircraft utilization equipment. Many existing aircraft applications (i.e. fleets) require additional DC power due to increasing loads caused by additional electronic equipment. The range of increased power required for upgraded aircraft programs is typically 20 to 100 percent. Some applications add power supplies incrementally in order to achieve overall system requirements based on a load analysis and testing. Others replace existing power supplies with higher current rated versions due to mounting space limitations.

The DC electrical power quality characteristics discussed here are: voltage regulation (VR), ripple voltage, power interruptions, high voltage transients, low voltage transients and voltage modulation. All of these characteristics are important for new and upgraded aerospace programs for various reasons.

VOLTAGE REGULATION - Voltage regulation or percent voltage regulation, VR, is defined as the ratio of the output voltage change between no load and full load to the full load voltage as a percentage [3]. Voltage regulation of the early traditional TRU was 29 percent at 31-24 VDC. The PCTRU design exhibits an improved voltage regulation of 16 percent at 29-26 VDC, which is nearly 50 percent better than early traditional TRU designs. This improvement eliminates concerns with voltage regulation of the traditional TRU and maintains the same high reliability without involving additional failure modes and overall lower reliability of complex active feedback control topologies (i.e. regulated power supplies).

RIPPLE VOLTAGE - Ripple voltage is defined as the variation of voltage about the steady state DC voltage during steady state electric system operation [4]. This is commonly described as a measure of the power cleanliness for steady state operation. All DC power supplies exhibit ripple voltage caused by the particular conversion process and topology utilized.

Very early TRU designs contained a wye or delta primary and wye secondary resulting in a six-pulse rectification scheme [5]. These devices exhibited a ripple voltage as shown in Figure 1, with this example representing the most severe.



Figure 1: DC Ripple Voltage of Early 6-Pulse TRU

The ripple voltage and harmonic components were greatly improved by use of the wye to delta transformation in the transformer with two six-pulse bridges. This is achieved by a wye or delta primary and

a delta-wye secondary causing a 30 degrees phase shift for twelve pulses per revolution of the generator [5], [6]. The result of this topology is a twelve-pulse rectification scheme with a typical ripple voltage shown in Figure 2.

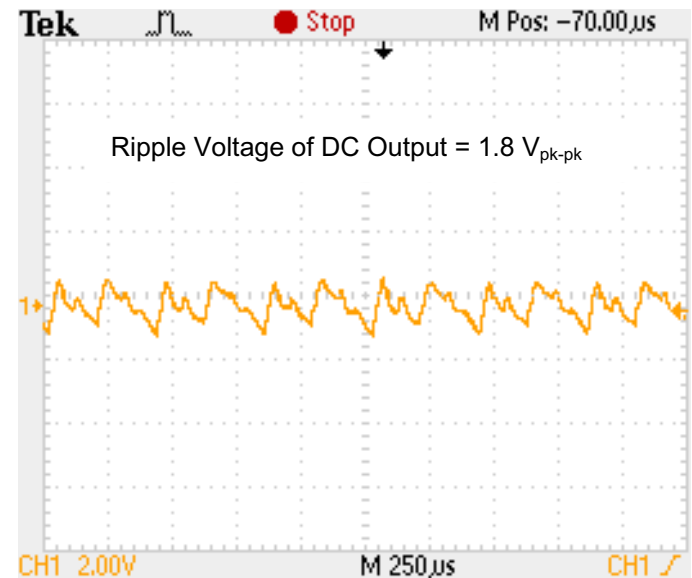


Figure 2: DC Ripple Voltage of a Standard 12-Pulse TRU

This is the foundation of the traditional TRU widely utilized today and exhibits a standard ripple voltage with a balanced input of 1.5-2.0 V_{pk-pk} . Though this complies with ripple specified in MIL-STD-704F of 1.5 V_{pk} maximum amplitude (i.e. 3 V_{pk-pk}), it greatly differs from development and qualification testing conditions of aircraft DC utilization equipment widely used in industry. This difference is due to the common usage of programmable laboratory DC power supplies. Many advanced electronic systems are tested during development and qualification with a programmable DC power supply that exhibits less than 0.2 V_{pk-pk} (i.e. an order of magnitude better than actual aircraft power). This generates significant concerns with the overall system integration with regards to electronic system faults, compatibility and performance degradations in advanced electronic systems. In other words, a system tested for functional performance, EMI and environmental conditions with a laboratory programmable power supply is expected to operate the same when integrated with many other electronic systems that are all ultimately powered with a much higher ripple voltage (i.e. not as clean) DC power source in the aircraft. Problems in this area can arise and may go unsolved due to “no faults found”, while the system does not operate as qualified or desired. Simple passive techniques in the PCTRU provide a typical ripple voltage of 0.20 V_{pk-pk} shown in Figure 3, which is a 90-95 percent improvement beyond other aircraft power supplies.

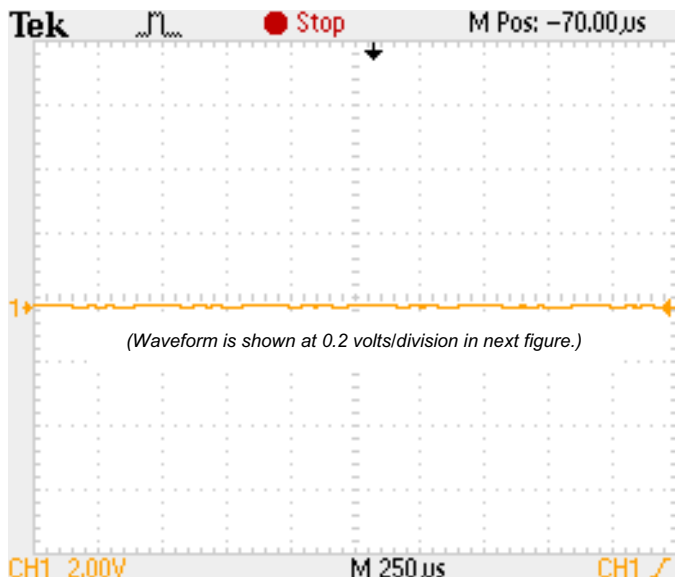


Figure 3: DC Ripple Voltage of a 12-Pulse PCTRU

The ripple voltage of the PCTRU is better viewed with the smaller voltage division as shown in Figure 4 here.

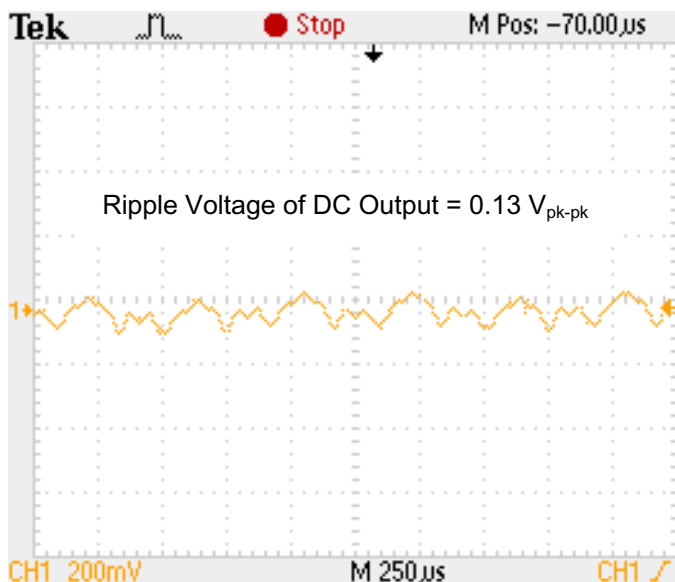


Figure 4: A Closer View of DC Ripple Voltage from the PCTRU

A note to recognize is that “clean” DC power (i.e. low ripple voltage) is independent and unrelated to “voltage regulation” including topologies that contain feedback control; all power supply topologies exhibit ripple voltage, which can be reduced to lower levels with various techniques. This characteristic is mostly dependent on the filter network and power supply topology chosen.

POWER INTERRUPTIONS - A power interruption is defined as a loss of voltage and current from a source to a load for a particular duration of time. Power interruptions are generally unavoidable due to power management and distribution architectures. One of the

fundamental components that partly contributes to the power interruption is the “break before make” function of a common type of electrical contactor. This function is a requirement due to potential power generator conflicts that arise if two or more generators are connected together. There are other contributors to power interruptions associated with controls including those used in power system diagnostics.

The maximum time duration of the interruption is generally required to be less than 50 ms [3]. Some aircraft power systems exhibit greater than 50 ms lasting 500 ms or more as shown in Figure 5.

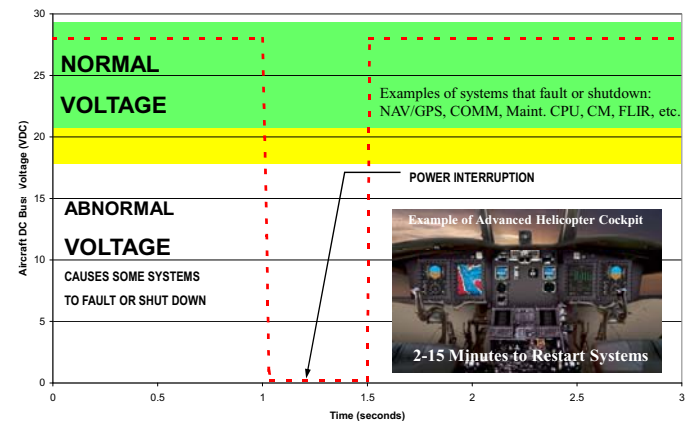


Figure 5: Aircraft DC Bus with Power Interruption

Major computer manufacturers utilize the IEEE Standard 446, “Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications”. It specifies that a momentary undervoltage of 30 percent is acceptable up to 500 ms and a loss of power (i.e. blackout condition) is acceptable for 4-20 ms [2]. This recommended specification is directed towards AC power for computers, but is related to the aircraft electronic system due to “load-based” computer power supplies that reside adjacent to the computer system and initially use aircraft DC power as the source.

The effect of these interruptions cause some utilization equipment to shut down, fault or exhibit operational delays with less than 50 ms of power interruption. Some of the electronic systems that shut down can take as much as 2-15 minutes to restart and provide an operational state, which can be unacceptable for mission requirements. These effects range from nuisance conditions to severe where mission safety is jeopardized. The first of two solutions for this situation is to require each manufacturer of the non-compliant subsystem to incorporate additional internal hold-up power. This, unfortunately, is not usually practical due to additional complexities especially when many systems are COTS or would require a redesign and qualification. The second ideal solution is to provide the entire aircraft DC bus with continuous power (i.e. bridge power) during power interruptions. The **ACR** provides bridge power