
ASSESSMENT OF ELECTRICAL POWER QUALITY ISSUES IN AIRCRAFT DC SYSTEMS: ANALYSIS OF VOLTAGE DROP AND HARMONIC DISTORTION

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ABSTRACT

The transition toward More-Electric Aircraft (MEA), in which hydraulic and pneumatic systems are progressively replaced by electrical alternatives, has intensified reliance on aircraft DC electrical systems, making power quality essential for reliable operation. This study investigates two critical power-quality issues: voltage drop and harmonic distortion and evaluates RC filtering as a mitigation approach. A simulation-based methodology was adopted using MATLAB/Simulink to model a representative aircraft DC distribution network comprising a DC source, distribution-line impedance, variable resistive loads, and a harmonic-injection subsystem emulating non-linear loads such as power converters. Results showed that higher electrical loading increased both voltage drop and harmonic distortion, degrading power quality and voltage regulation. Under high-current (low-resistance) conditions, voltage drop rose from 1.0 V at 25 Ω to 9.7 V at 5 Ω , while total harmonic distortion (THD) rose from 2.7% to 11.8% over the same range, exceeding the commonly adopted 5% threshold at the three lowest resistance cases a level widely flagged as a risk factor for sensitive equipment. A first-order passive RC filter evaluated at the 15 Ω case produced a visibly smoother, more stable load-voltage waveform than the unfiltered case, consistent with the expected attenuation behaviour of a low-pass filter. The study concludes that while load dynamics and non-linear components degrade power quality in aircraft DC systems, properly designed passive filters offer a simple and effective mitigation option. These findings inform the design of more resilient electrical power systems for next-generation More-Electric and All-Electric Aircraft.

Keywords: More-Electric Aircraft; Aircraft DC Distribution; Harmonic Distortion; Voltage Drop; RC Filtering; Avionics

1. INTRODUCTION

Aircraft electrical systems generate, control, and distribute power to flight-deck displays, protection devices, flight controls, and communication and navigation equipment, making power quality central to safe operation (Madonna et al., 2018; Norman et al., 2010). Traditional hydraulic and pneumatic architectures present limitations such as complex piping and difficult leak detection (Aguida et al., 2024), motivating the transition toward More-Electric Aircraft (MEA), in which conventional subsystems are progressively replaced by electrical equivalents (Sarlioglu & Morris, 2015; Verma & Kumar, 2020; Zhao et al., 2014). This transition increases the complexity and capacity of electrical power systems and heightens dependence on reliable power distribution (Rahrovi & Ehsani, 2019).

While MEA improves efficiency, it introduces power-quality challenges: harmonic distortion and voltage drop can cause equipment failure, reduced efficiency and safety risks (Buticchi et al., 2023; Dorn-Gomba et al., 2020). Voltage drop arises from load current interacting with distribution-line impedance, while harmonic distortion results from non-linear loads and power-electronic converters injecting periodic components into the supply waveform (Fernández-Morales et al., 2022; Whaite et al., 2015). Broader DC power-quality studies (Alves et al., 2016; Mariscotti, 2021; Zhao et al., 2014) and passive harmonic-mitigation reviews . Ab Aziz et al., (2021) confirm the relevance of these issues but

do not examine load-dependent voltage-drop and harmonic behaviour in a representative aircraft DC path, nor a simple RC filter's response under such conditions (Chen et al., 2018; Schefer et al., 2020).

This study addresses that gap through a simulation-based assessment of voltage drop and harmonic distortion in an aircraft DC distribution system, evaluating the effectiveness of a passive RC filter as a mitigation approach. The objectives are to:

- (i) Quantify the relationship between load resistance, voltage drop and THD in a representative aircraft DC network.
- (ii) Compare time- and frequency-domain behaviour before and after RC filtering.
- (iii) Relate the findings to established power-quality benchmarks to inform more resilient MEA electrical system design.

2. METHODOLOGY

A simulation-based quantitative approach was used to investigate voltage drop and harmonic distortion in an aircraft DC distribution system. The model was developed in MATLAB/Simulink R2019a, with FFT-based post-processing for frequency-domain analysis. As shown in Figure 1, the simplified network comprises a DC source, distribution-line impedance, variable resistive loading, a harmonic-injection subsystem, a voltage-sag subsystem, and a first-order passive RC filter, rather than a full-fidelity aircraft electrical power system, providing a controlled environment in which the effects of load resistance and injected disturbances can be isolated at the load terminals. The reported values therefore represent this simulated configuration rather than universal aircraft performance, since the model does not reproduce every non-linearity, thermal effect, control interaction and operating variation present in an actual aircraft power system.

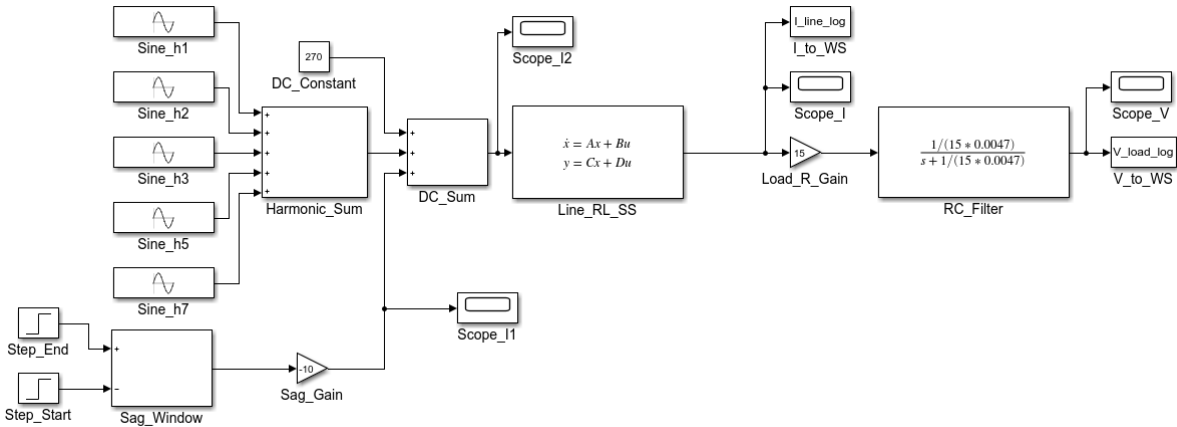


Figure 1: Simulink Model of Aircraft DC Power Quality System for Voltage Drop and Harmonic Distortion Analysis

In Figure 1, the DC source block ($V_{DC} = 270$ V) represents the aircraft's generator output. The harmonic-injection blocks simulate distortion from non-linear loads such as power converters and inverters, combined via a summation block into a composite distorted waveform. The voltage-sag subsystem uses step and gain blocks to model transient disturbances such as motor startup or fault conditions, producing a temporary voltage reduction representative of real sag events, while the distribution-line block represents the voltage drop and phase shift caused by line impedance between source and load.

2.1 DC Source and Distribution-Line Model

The DC source was represented by a constant 270 V supply, representing the aircraft generator output. The distribution line was modelled as a lumped series resistance of 0.5Ω and inductance of 2 mH. Because current flowing through this finite impedance produces a voltage loss, the load voltage is lower than the source voltage. Voltage drop was evaluated as:

$$\Delta V = V_{source} - V_{load} \quad (1)$$

which, for the resistive component of the model, is consistent with:

$$\Delta V \approx I \times R_{line} \quad (2)$$

2.2 Variable Load Conditions

The load was represented by a variable resistance to analyse network response under different loading conditions, using comparison values of 5, 10, 15, 20 and 25 Ω . lower resistance corresponding to higher current demand for the same nominal bus voltage. Voltage and current signals were logged from the Simulink model to the MATLAB workspace for each of the five load cases, each executed as a single simulation run, providing the basis for comparing voltage drop and THD across loading conditions.

2.3 Harmonic Injection and Voltage Sag

Harmonic distortion was introduced by summing multiple sinusoidal components (Sine_h1, Sine_h2, Sine_h3, Sine_h5 and Sine_h7, corresponding to the 1st, 2nd, 3rd, 5th and 7th harmonic orders) with the constant DC source to form a distorted bus waveform. A base harmonic frequency of 400 Hz was adopted, reflecting ripple originating from the aircraft's 400 Hz AC generation system prior to rectification, consistent with typical aircraft power architecture in which DC buses are derived from 400 Hz AC sources. FFT-based frequency-domain analysis was used to evaluate the harmonic content of the simulated waveform, with THD used as the principal comparison metric:

$$THD = \left\{ \frac{\sqrt{V_2^2 + V_3^2 + \dots + V_n^2}}{V_1} \right\} \times 100\% \quad (3)$$

where V_1 is the RMS value of the fundamental component and $V_2, V_3, \dots, V_n$ are the RMS values of the corresponding harmonic components. A voltage-sag subsystem, implemented using step functions and a gain block, reproduced temporary reductions in bus voltage associated with dynamic disturbances such as generator transients or sudden load changes, providing a basis for observing voltage response and recovery in the time domain.

2.3.4 RC Filter Configuration

A first-order passive RC filter ($R = 15 \Omega$, $C = 0.0047 \text{ F}$, giving $RC = 0.0705 \text{ s}$) was connected at the load terminals to attenuate unwanted high-frequency components. These values were selected to place the filter cutoff frequency ($\approx 2.3 \text{ Hz}$) well below the 400 Hz base harmonic frequency, providing strong attenuation of the injected harmonics consistent with standard first-order passive-filter design practice. The filter transfer function is:

$$H(s) = \frac{1}{RC_s + 1} \quad (4)$$

$$H(s) = \frac{1}{14.184s + 14.184} \quad (5)$$

Filtered and unfiltered voltage waveforms and their frequency-domain spectra were compared to assess filter performance.

2.5 Simulation Configuration and Data Analysis

Numerical integration used MATLAB's variable-step ode45 solver; voltage and current signals were logged via workspace blocks, and post-processing comprised time-domain waveform plotting, FFT-based frequency-domain analysis, THD computation, and comparison of filtered/unfiltered conditions (Table 1).

Table 1: Key Simulation Parameters

Parameter	Description	Value
DC Source Voltage	Nominal bus voltage	270 V
Load Resistance	Comparison cases	5,10,15,20 and 25 Ω
Line Resistance	Lumped distribution resistance	0.5 Ω
Line Inductance	Lumped distribution inductance	2 mH
Base harmonic Frequency	harmonic frequency	400 Hz
Simulation Time	Duration of analysis	0.5 s
RC filter capacitance	Passive filter parameter	0.0047F
RC filter resistance	Passive filter parameter	15 Ω
Solver	Numerical Integration	Variable-step ode45

3. RESULTS AND DISCUSSION

The simulation results are examined below in terms of voltage drop, THD, RC-filter response, and their implications, across the five resistive load cases of 5, 10, 15, 20 and 25 Ω .

3.1 Voltage Drop as a Function of Load Resistance

As load resistance decreased, voltage drop increased (Table 2, Figure 2): from 1.0 V at 25 Ω to 9.7 V at 5 Ω . This inverse relationship follows from Ohm's law ($V = I \times R$): lower resistance imposes higher current demand, increasing the voltage loss across the line and moving the load voltage further from the nominal 270 V source. Loading condition is therefore a direct factor in voltage quality at the load terminals, and heavier loading increases susceptibility to voltage sag. An important consideration for MEA architectures, where reducing distribution resistance is beneficial.

Table 2: Relationship between load resistance and voltage drop

Load Resistance (Ω)	Mean V load(V)	Voltage Drop(V)
5.0	260.3	9.7
10.0	264.9	5.1
15.0	266.7	3.3
20.0	268.2	1.8
25.0	269.0	1.0

Relationship between Voltage Drop and Load Resistance

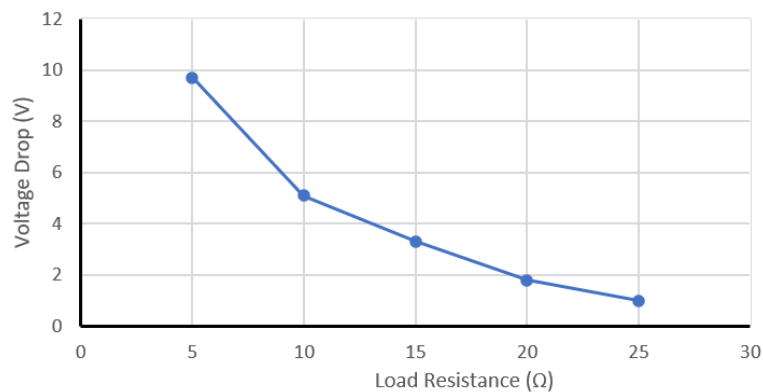


Figure 2: Voltage Drop ($V_{\text{source}} - V_{\text{load}}$) vs. Load Resistance

3.2 Harmonic Distortion as a Function of Load Resistance

THD followed a similar trend, decreasing from 11.8% at 5 Ω to 2.7% at 25 Ω as load resistance increased (Table 3, Figure 3). THD exceeded the 5% threshold recommended by IEEE Std. 519-2014 at the three lowest-resistance cases (5, 10 and 15 Ω), falling within the threshold only at 20 Ω (3.9%) and 25 Ω (2.7%), indicating that nonlinear loading under heavy demand can meaningfully degrade aircraft DC power quality. Aircraft-specific requirements are instead addressed by MIL-STD-704 and RTCA DO-160, which impose voltage and harmonic-related limits distinct from the general IEEE benchmark used here for illustrative comparison; the simulated results indicate relative severity across loading conditions rather than establishing compliance or non-compliance with aircraft certification requirements.

Table 3: Relationship between Load resistance and THD

Load Resistance (Ω)	THD (%)
5.0	11.8
10.0	8.4
15.0	5.2
20.0	3.9
25.0	2.7

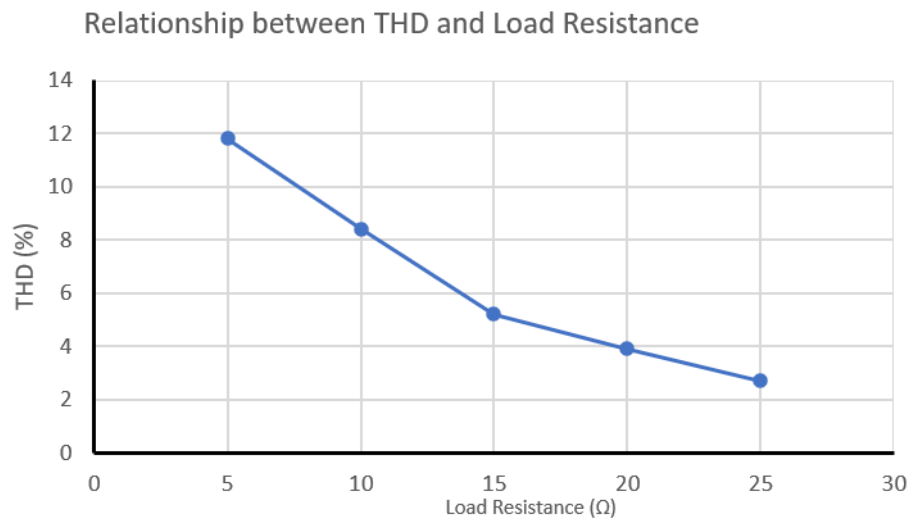


Figure 3: Total Harmonic Distortion (THD) vs. Load Resistance

3.3 Effect of the RC Filter

Representative time- and frequency-domain responses were examined at the 15 Ω load case under unfiltered and filtered conditions. The unfiltered load-voltage waveform showed distortion superimposed on the DC level, with the simulated voltage sag producing a temporary reduction in magnitude followed by oscillatory recovery. With the RC filter engaged, the waveform was visibly smoother, with attenuated transient spikes and high-frequency ripple; the filtered configuration also exhibited faster settling behaviour following the simulated voltage sag, with the oscillatory recovery visible in the unfiltered response notably attenuated in the filtered case. The line-current waveform likewise became smoother and closer to steady-state behaviour. FFT comparison showed a reduction in harmonic content following filtering, consistent with the expected attenuation of a first-order low-pass filter whose cutoff frequency (≈ 2.3 Hz) lies well below the 400 Hz base harmonic frequency. These observations were recorded qualitatively; the precise numeric reduction in THD and the voltage-sag

recovery time at this operating point were not independently logged, and the filter was evaluated only at the single 15 Ω case rather than across the full loading range.

3.4 Implications and Limitations

These results confirm that loading conditions and non-linear components jointly govern the power quality delivered at aircraft DC load terminals, and that a simple passive RC filter can meaningfully improve the simulated waveform. However, the findings rest on a simplified model rather than a full-fidelity aircraft electrical system: source impedance, converter topology, switching behaviour, control interactions, grounding and thermal effects were not represented, so the study does not itself provide a basis for a final aircraft filter design — component ratings, thermal behaviour, mass, volume and transient performance require further analysis before implementation. These findings remain relevant to MEA electrical system design, given the growing number of electrical functions that depend on stable power distribution.

4. CONCLUSION

This study used MATLAB/Simulink to investigate voltage drop and harmonic distortion in a simulated aircraft DC distribution system, modelling a 270 V DC source, distribution-line resistance and inductance, variable resistive loading (5–25 Ω), harmonic injection and voltage-sag conditions and evaluated a first-order passive RC filter as a mitigation approach.

Reducing load resistance increased current demand and produced larger voltage drops, rising from 1.0 V at 25 Ω to 9.7 V at 5 Ω . THD followed the same trend, increasing from 2.7% at 25 Ω to 11.8% at 5 Ω and exceeding the commonly adopted 5% threshold at the three lowest-resistance cases. The RC filter, evaluated at the 15 Ω case, produced a visibly smoother load-voltage waveform with attenuated transient spikes and high-frequency ripple, together with a general reduction in harmonic content; the precise magnitude of this reduction, and its behaviour across the other tested load resistances, was not independently recorded.

These findings confirm that load dynamics and non-linear components degrade power quality in aircraft DC systems, and that properly designed passive filters offer a simple, effective mitigation option. The study is limited to a simplified simulation model, and future work should pursue hardware-in-the-loop or bench validation against measured data, extend harmonic injection to a broader range of profiles, evaluate the RC filter across the full tested load range with paired filtered/unfiltered THD and recovery-time measurements, and assess the thermal and mass feasibility of filter components for aircraft installation.

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