APPLICATION NOTE

Methods for Characterizing DC Inrush Current

KEYSIGHT

Introduction

Inrush current or input surge current refers to the momentarily large surge current that occurs when you turn on the power to a device. Inrush current often occurs in devices with a large amount of parallel capacitance at the input, such as DC-to-DC converters, or devices with extremely low impedance under transient conditions, such as electric motors. Inrush current can be several times larger than the device's steady-state current. For instance, electric motors can have inrush current levels 25 times greater than their steady-state current levels.

When you characterize inrush current, you capture either a high-resolution digitized profile of a device's inrush current or a reliable peak current reading. This application note presents techniques for using a high-resolution oscilloscope and a high-precision digital multimeter to accurately capture inrush current, providing valuable insights into system behavior.

The high-precision digital multimeter (DMM) used for this DC inrush current measurement is part of a set of Keysight Smart Bench Essentials Plus instruments. They come equipped with proven pro-level measurement technologies designed to minimize measurement errors resulting from real-world factors to provide the accuracy and precision required for this application. The instruments also come with large color screen displays and graphical interfaces to visualize, analyze, and share test results quickly.

The high-resolution oscilloscope used in this application is also part of the Smart Bench Essentials Plus instruments. It comes with a custom ASIC and built-in 14-bit analog-to-digital converter to provide very high vertical display resolution and low noise floor to easily catch transient in-rush current spikes for this application.

Why Inrush Current Measurement Is Essential

When an electrical device is powered on, it often draws a surge of current, known as inrush current. This brief but intense current spike can be several times higher than the device's normal operating current. While inrush current is a natural occurrence, uncontrolled surges can lead to various issues, including component damage, power instability, and reduced system efficiency.

To manage these risks, it helps to understand the key benefits of accurately measuring and managing inrush current.

Protecting sensitive components

Electronic devices, such as microcontrollers, sensors, and integrated circuits, are designed to operate within specific current and voltage limits. Excessive inrush current can cause thermal stress, degrade components over time, or even lead to immediate failure. Measuring inrush current enables engineers to design protective circuits, such as inrush current limiters or soft-start circuits, to prevent damage.

Example: In an automotive electronic control unit, repeated exposure to high inrush currents could shorten the lifespan of onboard power regulators and degrade reliability. Proper measurement and tuning of inrush current help maintain system reliability.

Preventing circuit breaker tripping and fuse blowing

Power distribution systems, especially in industrial and commercial applications, rely on circuit breakers and fuses to protect against overcurrent conditions. If the inrush current exceeds the circuit breaker's threshold, the breaker may trip unexpectedly, causing unnecessary downtime or disruptions.

Example: LED lighting systems often experience a high inrush current when switched on. Without proper characterization, an array of LEDs may trip circuit breakers, leading to operational failures in commercial buildings or stadium lighting systems.

Ensuring power supply stability

Sudden inrush currents can create voltage drops or fluctuations in power distribution networks, affecting other connected devices. Characterizing inrush current helps engineers design power supplies and distribution systems that can handle these transients without compromising performance.

Example: In data centers, server power systems must accommodate multiple devices turning on simultaneously. Uncontrolled inrush current could cause voltage sags, leading to unexpected reboots or failures of critical infrastructure.

Optimizing energy efficiency and thermal performance

Higher inrush currents lead to increased energy dissipation, which can generate excess heat and reduce overall system efficiency. Measuring and managing inrush current ensures that devices operate within their optimal thermal and electrical limits.

Example: Industrial motor drives used in manufacturing facilities draw large inrush currents at startup. By measuring and controlling this current, engineers can implement soft-start mechanisms that reduce wear and improve energy efficiency.

Meeting regulatory and safety standards

Many industries have stringent regulations regarding power quality, electromagnetic compatibility, and electrical safety. Accurately characterizing inrush current ensures compliance with industry standards such as IEC, UL, and IEEE guidelines.

Example: Power adapters and battery chargers for consumer electronics must meet regulatory requirements for inrush current limits to prevent electrical hazards and ensure user safety.

Methods for Characterizing Inrush Current

While there are multiple ways to characterize inrush current, this application note focuses on three methods:

- Using a high-vertical-resolution oscilloscope.
- Using a high-precision digital multimeter with a built-in digitizer.
- Using an electronic load with built-in scope view.

Using a high-vertical-resolution oscilloscope

Let’s start with the method that uses an oscilloscope. Measuring current with the Smart Bench Essentials Plus HD302MSO oscilloscope involves more than a simple plug-and-play approach. Oscilloscopes are designed with high input impedance, usually 1 MΩ or more. Because of this high impedance and low voltage, the current draw is minimal when applying Ohm’s law. The high impedance of oscilloscopes minimizes the loading effect, reducing the impact of an oscilloscope on a circuit. As a result, standard oscilloscope probes can measure voltage but not current. There are two ways to mitigate this issue: using a shunt resistor or using a current probe.

The first solution requires the use of a low-resistance shunt resistor, preferably 1 Ω. The shunt resistor is placed in series with the circuit, while the oscilloscope measures the voltage across it. When the power supply is switched on, the oscilloscope measures the voltage drop. Because of the shunt’s low resistance, the voltage waveform closely mirrors the inrush current. However, some calculation is needed because the value recorded by the oscilloscope is in voltage.

Figure 1. Keysight 1146B oscilloscope current probe

The second solution requires a current probe. The clamp-style current probe uses the Hall effect principle. By sensing the magnetic field around a conductor and converting it into a voltage signal, the probe can accurately capture the quick transient of inrush current without introducing any additional resistance into the circuit as a shunt resistor would.

Using a high-precision digital multimeter with built-in digitizer

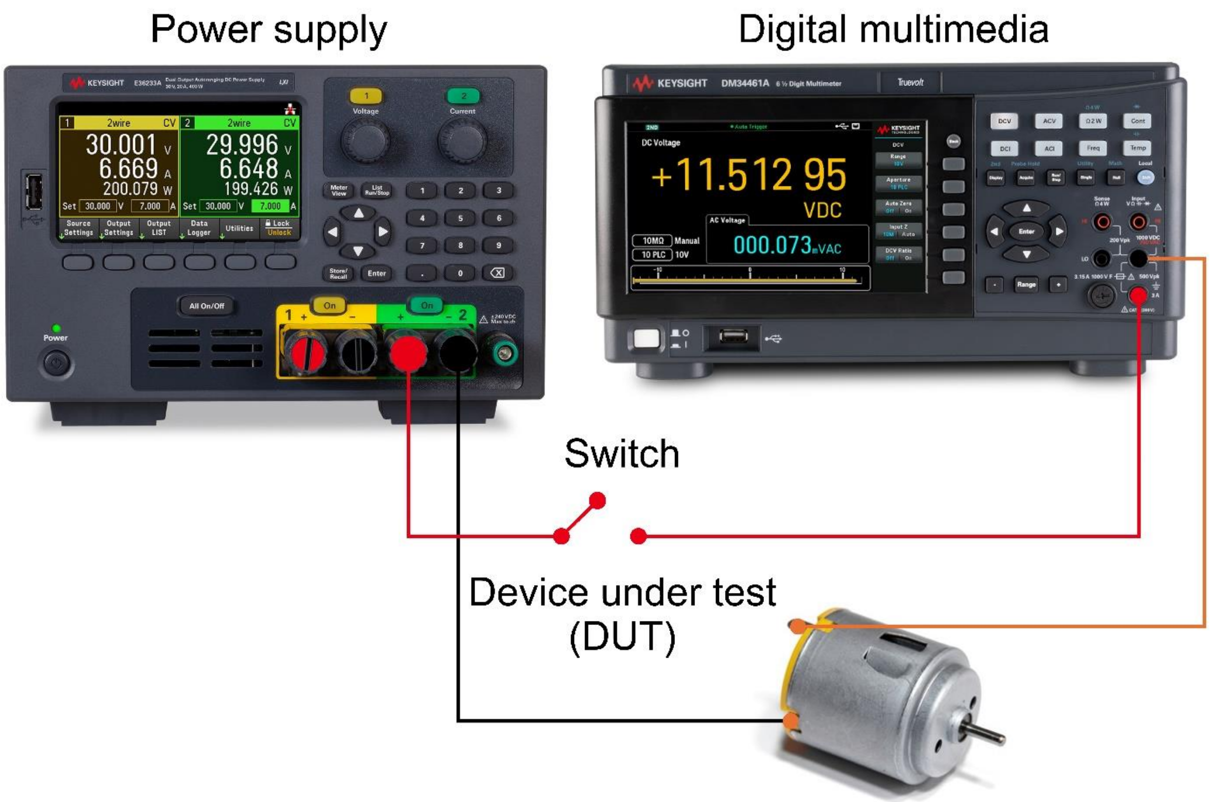

Figure 2. Inrush current characterization test setup with a digital multimeter

Newer models in the Keysight Truevolt DMM line include digitizers with high-speed sampling, making them suitable for measuring inrush current. Unlike standard DMMs, which take discrete readings at slower intervals, a digitizer continuously samples signals at a high rate, storing data for detailed waveform analysis. The Smart Bench Essentials Plus DM34461A digital multimeter features a digitizer with a maximum sampling rate of 50 kHz. It can capture up to 50,000 samples per second, providing a time resolution of 20 microseconds per sample.

According to the Nyquist theorem, the sampling frequency must be double the frequency of the signal captured to avoid aliasing and accurately capture the fast transients. To determine whether the 50 kHz sampling rate is sufficient, we need to consider the frequency of the inrush current.

Research shows that inrush currents generally last 5 to 10 ms. This corresponds to frequencies of approximately 200 Hz (for 5 ms) and 100 Hz (for 10 ms). Since 50 kHz is significantly higher than these frequencies, the DMM is more than capable of capturing the inrush current accurately.

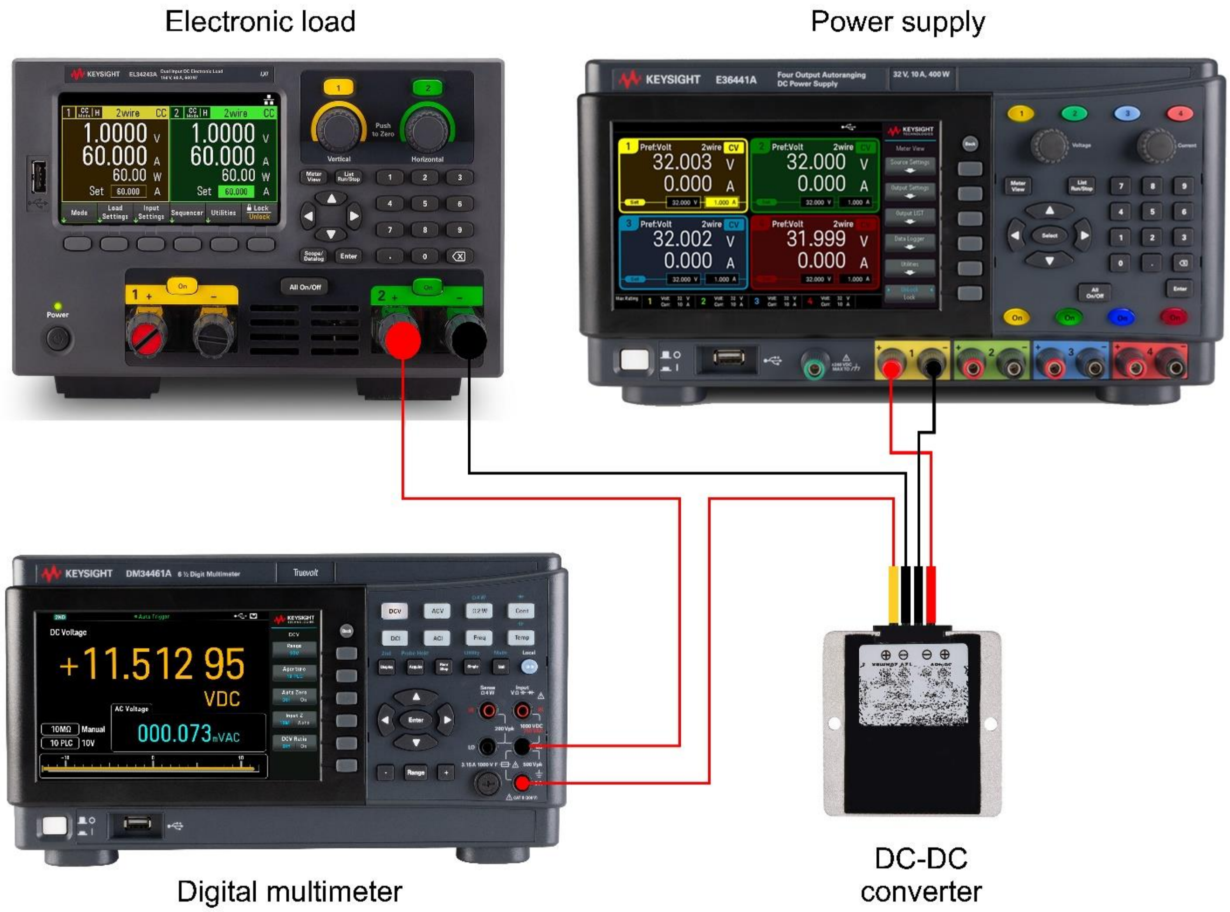

Figure 3. Inrush current characterization test setup with electronic load

To capture the inrush current, connect the DMM in series with the load. In this case, we used an electronic load to replace the device under test (DUT). Figure 3 shows this change. Connect the power supply to the DC-DC converter input and connect the positive terminal of the DC-DC converter output to the DMM positive terminal. Connect the negative terminal of the DC-DC converter output to the negative terminal of the electronic load. Then complete the connection by joining the negative terminal of the DMM to the positive terminal of the electronic load to form a series connection.

Enter the DMM setting to enable the digitizer function. Change the front display to show a trend chart, and ensure that the digitizer sampling is set to 50 kHz. While the digitizer is running, turn on the power supply. When the digitizer stops, use the pan-and-zoom feature to focus on the inrush current.

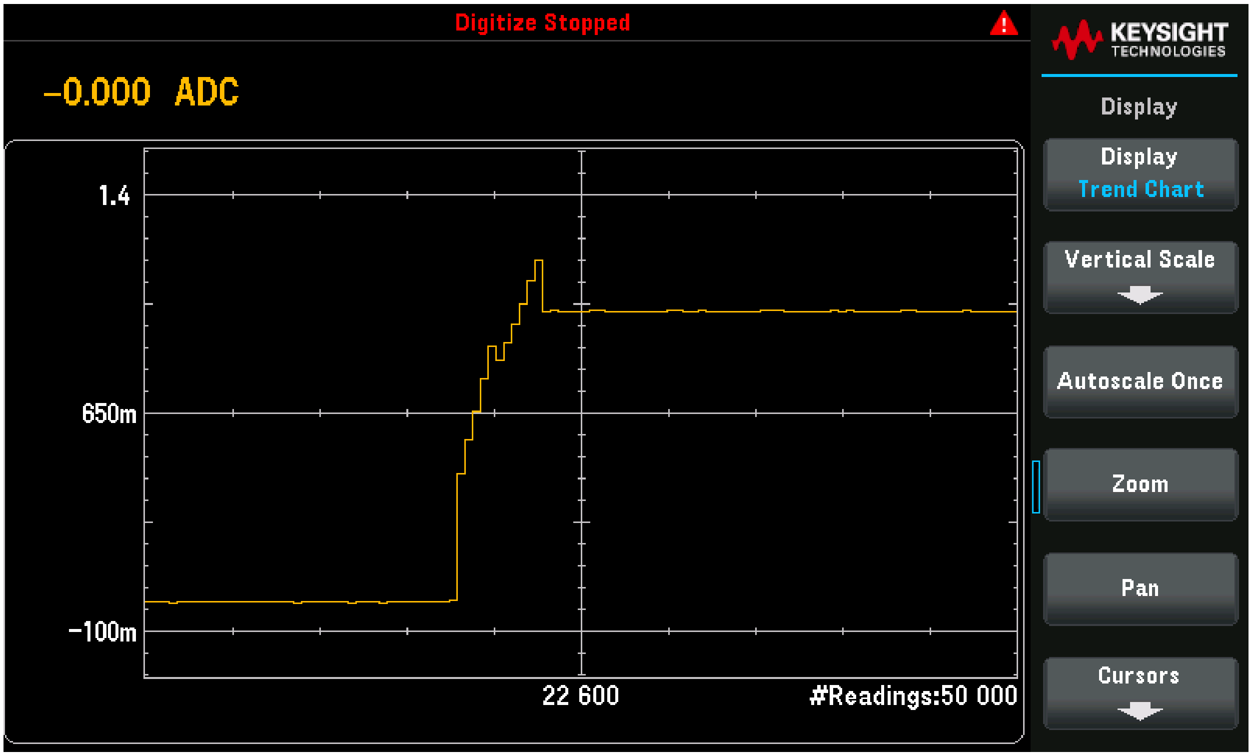

Figure 4. Inrush current characterization using a digitizer

We can observe the inrush current overshooting before settling to the desired value. The DMM digitizer is capable of capturing the characteristics of the inrush current.

Using an electronic load with scope view

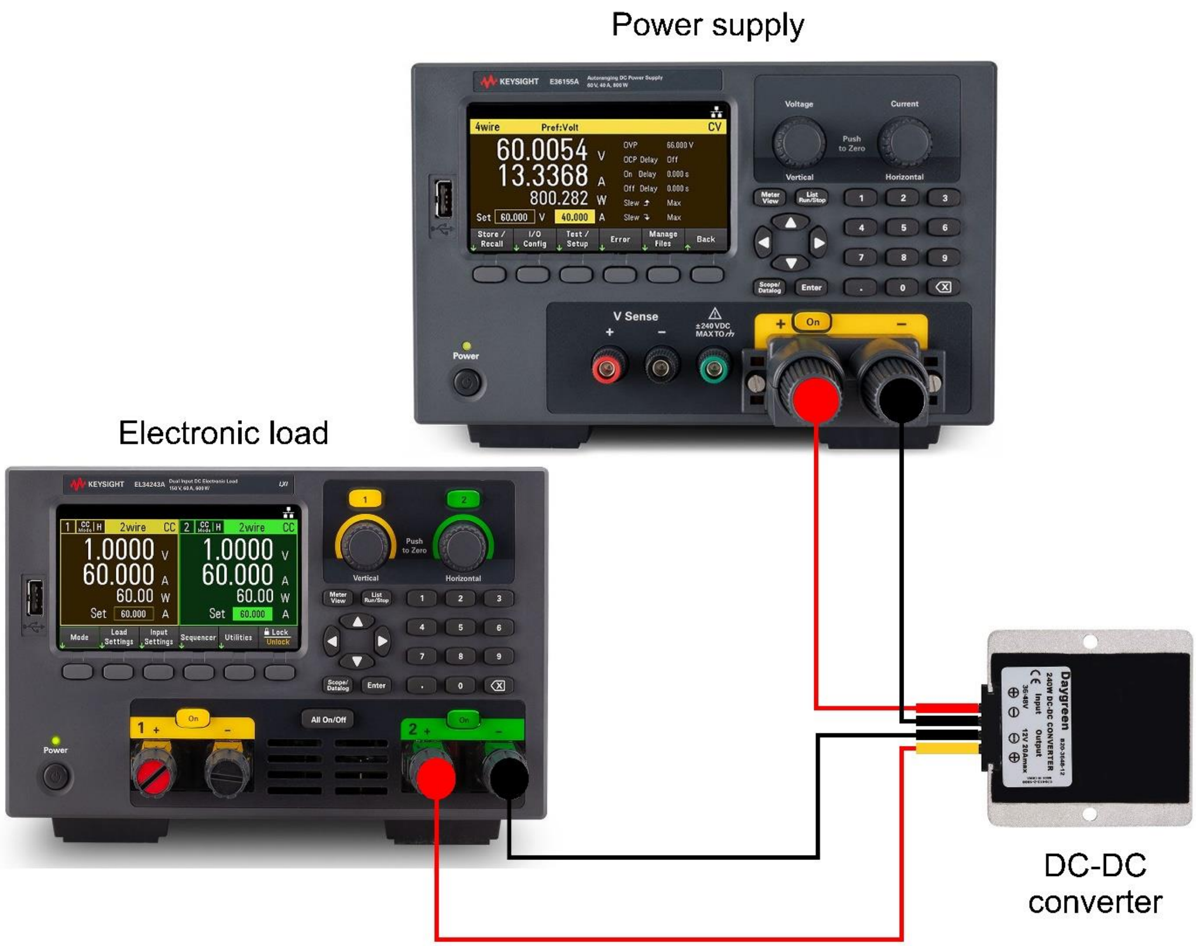

Figure 5. Inrush current characterization test using scope view setup

This approach uses a similar hardware setup as the previous method, but a multimeter is not required. As shown in Figure 5, the power supply connects to the DC-DC converter input while the output connects to the electronic load.

The Keysight EL30000 Series electronic load features a scope view that can capture up to 256k samples. When it is set to record for 1 second, the effective sampling rate is 256 kHz (256k/1s) — more than five times the sampling rate of the digitizer.

In Figure 6, the scope is configured to 256k and 1s. We see that most of the inrush current signal is captured accurately. The high sampling rate ensures that fine details of the inrush current are captured without excessive noise, providing a clear and reliable measurement. With this precise data, engineers can analyze and develop solutions to effectively minimize inrush current and improve system power performance.

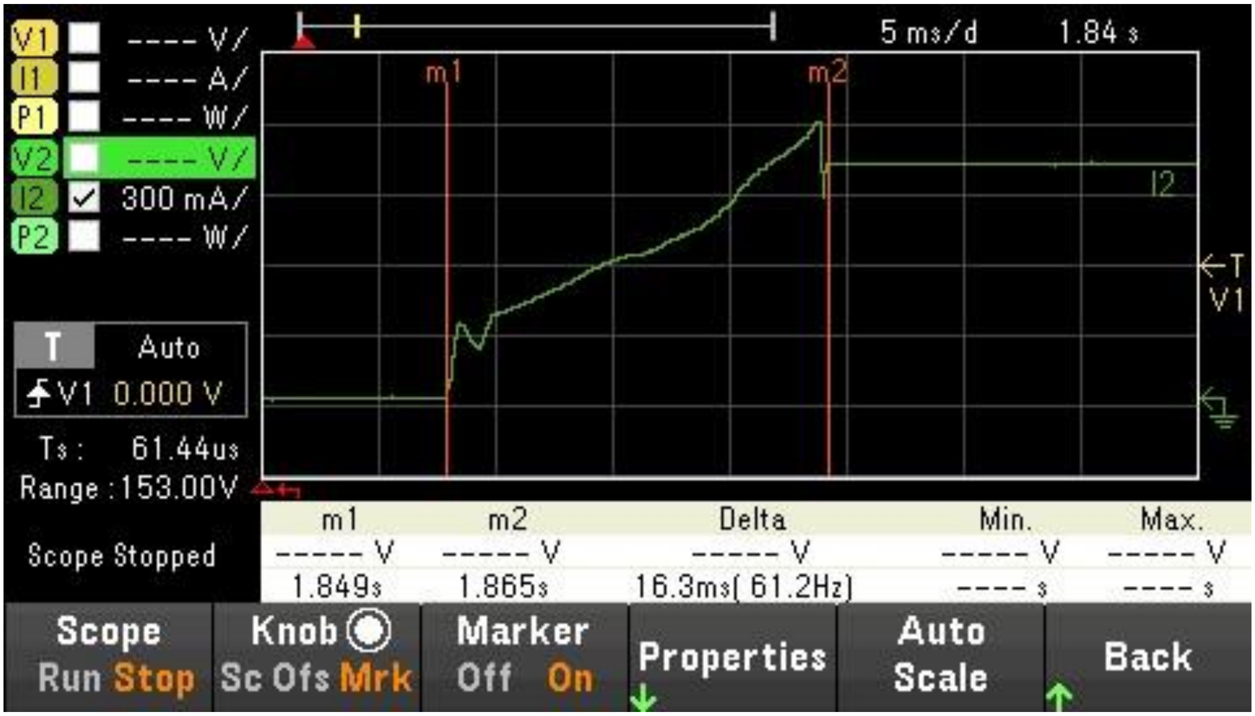

Figure 6. Inrush current characterization (scope view)

Summary

This application note covers three effective methods to measure inrush current. The first method uses the Smart Bench Essentials Plus HD3 oscilloscope. By placing a low-resistance shunt resistor (preferably 1 Ω) in series with the circuit, the oscilloscope can measure the voltage drop across the shunt resistor, which corresponds to the inrush current. Alternatively, a clamp-style current probe can be used. This type of probe senses the magnetic field around a conductor and converts it into a voltage signal, capturing the inrush current without adding resistance to the circuit.

The second method uses the Smart Bench Essentials Plus Truevolt digital multimeter, which features high-speed sampling capabilities. The digitizer's maximum 50 kHz sampling rate provides detailed waveform analysis. Connecting the DMM in series with the load enables the inrush current to be accurately captured.

The third method employs an electronic load scope view, available in instruments such as the EL30000 Series. This feature can capture up to 256k samples, which is equivalent to a 256 kHz sampling rate if the scope runs for 1 second. By connecting the power supply to the DC-DC converter input and the output to the electronic load, the scope view provides a detailed, clear, and reliable measurement of the inrush current.

The choice of method depends on the situation. The oscilloscope method is best suited for inductive loads with fast transients. In cases where fine details are not necessary, the DMM method can be used. For testing resistive loads, the electronic load can substitute for the actual load, making the scope view method appropriate. This approach reduces circuit complexity by omitting an oscilloscope.